Report
of the
Assessment Committee
for the
National Space Weather Program

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PREFACE

The space environment around Earth is becoming of ever-increasing importance for the successful operation of commercial, government, and national security infrastructure essential to the Nation. The U.S. National Space Weather Program (NSWP) is a Federal interagency (seven agencies) initiative whose overall objective to speed improvement of space weather services in order to prepare the country to deal with technological vulnerabilities to variable conditions in the Earth's space environment (space weather). Such vulnerabilities are well documented in numerous reports and research papers and were highlighted in the Space Weather Transition Architecture Plan section of the fiscal year (FY) 2000 National Security Space Architecture Report of the U.S. Department of Defense (DOD 2000).

This assessment report responds to actions in FY 2005 of the Federal Committee for Meteorological Services and Supporting Research (FCMSSR) and the Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR), which directed the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) to conduct a comprehensive review of the NSWP. To perform this review and assessment, the Federal Coordinator for Meteorology convened a committee of six individuals with expertise encompassing the science and applications aspects of space weather. The Assessment Committee's findings and recommendations, stemming from its comprehensive review of the NSWP, are reported here.

The Assessment Committee thanks the personnel of the OFCM for outstanding support of its activities. Especially important has been the dedicated service of U.S. Air Force Lt. Col. Robert J. Rizza, who served as the Executive Secretary of the Committee and provided outstanding professional advice, assistance, and guidance throughout all of the Committee's activities and deliberations. The Committee thanks Jennifer Rumburg of the National Aeronautics and Space Administration for her leadership role in staging and processing the community and user electronic questionnaires. It thanks Science and Technology Corporation, the OFCM support contractor, for superb administrative and logistical support of the Committee's activities. The Assessment Committee also thanks the individuals in the numerous agencies that were visited (see Appendix C) for supporting its visits, for their informative briefings, and for timely responses to subsequent inquiries.

Louis J. Lanzerotti
Signature

Louis J. Lanzerotti
Chair

CRITICAL FINDINGS AND RECOMMENDATIONS

The National Space Weather Program (NSWP) Assessment Committee concluded that, since the program's inception in 1995, it has had a number of noteworthy achievements, most of which likely would not have been attained without the program's existence. The committee also found shortfalls in the program. Based upon the conclusions of the committee as contained in this report, continuation of the NSWP is strongly warranted because of the enormous potential to enhance the Nation's space weather mission over the next 10 years through improved operational capabilities, which capitalize on the transition of innovative research. Moving NOAA's operational space weather prediction center (i.e., the Space Environment Center) from its research organization to the National Weather Service was a positive step to improve operational focus within the NSWP. The committee made specific recommendations to further strengthen the NSWP in four key areas:

To centralize program management, set national funding priorities, and increase the effectiveness of the NSWP—

- Establish a space weather expert as the permanent Executive Secretary to the Committee for Space Weather under the National Space Weather Program Council
- Establish a focal point for the program in OSTP/OMB
- Create a joint, cross-agency, space weather organization, the "Center for Space Weather Research to Operations."

The Committee firmly believes that NSWP leadership and organization must be strengthened. The NSWP should have a permanent executive secretary with the ability to establish funding priorities between and among agencies. Focal points and expertise within the White House Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) are also required.

For continuity of data sources critical to space weather forecasts and operations—

- Develop and execute strategy and funding for L1 sensor continuity
- Maintain critical ground-based assets such as USGS magnetic observatories.

The Federal government must ensure the continuity of critical data sources used in the NSWP. Particularly crucial are space-based sensors at the Earth-Sun L1 Lagrange point, now supported by NASA. The potential for use of new, lower-cost micro-satellite technologies must be examined. National attention must be given to continuity of essential ground-based data sources (including the magnetic observatories of the U.S. Geological Survey) and to arrangements with other countries for sharing of data from ground- and space-based observations.

To strengthen the science-to-user chain—

- Maintain and strengthen both targeted and strategic space weather research
- Enhance emphasis and resources for transition of models to operational users
- Increase the private sector role in supplying products and services.

The NSF has served as the leader in focusing applicable research results toward products for users. A strengthened NSWP leadership must enhance the process of transitioning research to DOD and NOAA operational users. Strategic research resources in the DOD and NOAA must be cultivated and maintained. The NSWP must strive to encourage the emerging private sector in providing products and services.

To emphasize public and user awareness of space weather for critical national needs—

- Quantify the national benefits that arise from the NSWP
- Enhance academic and professional education programs for new space weather professionals.

The NSWP must increase public, congressional, and administration awareness of its value by better quantifying the benefits of NSWP activities. An emphasis on maintaining an academic pipeline of first-rate space weather professionals, begun with the NSF's new faculty development program, must be continued; it can be enhanced by participation of NASA and other agencies.

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EXECUTIVE SUMMARY

National Space Weather Program

The United States National Space Weather Program (NSWP) is a Federal government interagency initiative with the overall objective of speeding improvement of space weather services in the United States in order to prepare the country to deal with technological vulnerabilities that can occur due to the space environment. Agencies currently involved in the NSWP (www.nswp.gov) are the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the Department of Defense (DOD), the Department of Energy (DOE), the Department of the Interior (DOI), and the Department of Transportation (DOT).

The NSWP builds on existing governmental and civil capabilities in order to establish a coordinated process to set national priorities, focus agency efforts, and leverage national resources. The program encourages contributions from the user community, operational forecasters, researchers, modelers, and experts in instruments, communications, and data processing and analysis—across the government, in research universities, and from industry.

The program is implemented and managed by the National Space Weather Program Council (NSWPC), operating within the Office of the Federal Coordinator for Meteorological Services and Supporting Research **(**www.ofcm.gov**)** under guidance of the Federal Committee for Meteorological Services and Supporting Research (FCMSSR)**.** The NSWPC consists of representatives from the seven agencies that participate in the NSWP. The Committee for Space Weather was established by the NSWPC as the principal agent for advancing the goals of the program.

The National Space Weather Program began in 1995; its latest implementation plan is more than 5 years old. In 2005, the FCMSSR and the Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR) directed the OFCM to undertake a comprehensive review of the program. The stated purpose of the review was "to quantify and document the progress toward meeting the NSWP stated goals in observations, research, modeling, transition of research to operations, and education and outreach; to see if the program is still on target and moving in the direction pointed to by the strategic plan; to determine whether the strategic goals should be adjusted at this time based on emerging/evolving requirements; and to suggest a way ahead which will form a basis for a new strategic plan covering the next 10 years." The full charge to the Assessment Committee, which was formed to conduct the review of the NSWP, is contained in Appendix A.

Committee findings are numbered by the chapter in which they are developed, followed by a sequential number. Recommendations are numbered for the finding on which they are based, followed by a sequential number. For example, finding 3.2 is the second finding in chapter 3, and recommendation 3.2.1 is the first recommendation based on finding 3.2.

> ***Finding 2.1. The First Decade.*** Since its inception in 1995, the National Space Weather Program (NSWP) has had a number of noteworthy achievements, most of

which likely would not have been attained without the program's existence. Significant strides have been made toward institutionalizing forecast and protection mechanisms for safeguarding against space weather events that may impact many of the significant technology systems on which the United States depends for security, commerce, and advances in science. Despite many notable advances, significant shortfalls in the program also exist and are outlined in this report.

> ***Recommendation 2.1.1.*** The highly successful National Space Weather Program should continue as an interagency program; however, it should be updated and modified as detailed in the further recommendations of this report.

NSWP Assessment by Plan Activities

The NSWP was assessed against a set of program activities that were specified for it by the 1995 NSWP Strategic Plan (OFCM 1995). The Assessment Committee added an assessment category for private sector participation and international collaboration—issues that cut across the plan-specified set of activities.

Activities: Assess and Document the Impacts of Space Weather; Identify Customer Needs

The NSWP has supported significant efforts to investigate economic and industrial space weather impacts. Such impacts are now discussed in scholarly science journals and in the industrial and popular literature. The program has significantly increased overall awareness of space weather and assisted in the compilation of a variety of assessment documents.

Agencies participating in the NSWP have devoted considerable attention and resources to the identification of customer needs in the period since the 2000 Implementation Plan (OFCM 2000). These needs have continued to change and evolve with time as the technologies and systems that can be impacted by space weather have evolved and shifted in importance for commercial, governmental, and national security interests.

At the same time, the chain of causality for the forecast of a space weather event to its ultimate economic or social benefits remains complex. To date, few in-depth studies have been done of the benefits to society, both economic and social, of space weather forecasts.

> ***Finding 3.1.*** The NSWP lacks a coordinated effort to identify and quantify, where possible, the benefits to society of providing space weather forecasts.
>
> > ***Recommendation 3.1.1.*** The NSWP should institute a coordinated effort to fund a series of space weather benefit studies that would cover the primary topics of concern to operators of space weather–vulnerable systems.

Activity: Determine Agency Roles

The NSWP has been a loose confederation of agencies in which participants coordinate their space weather activities as individual agency funding and statutory directives permit. The seven

NSWP member agencies, of which four (NSF, NASA, NOAA, DOD) act as cochairs of the Committee for Space Weather, cannot always speak and act with one voice. Although each agency has demonstrated considerable interest in, and commitment to, the NSWP, each agency must adhere to its own mission statement and authorizing legislation.

Activities: Coordinate Interagency Efforts and Resources; Set Priorities; Ensure Exchange of Information and Plans

The NSWP has numerous important responsibilities in the areas of agency coordination, priority setting, and information exchange. These are discussed in depth in section 3.4 of the report.

Space weather issues for civil aviation are related to all three areas. When the NSWP began in 1995, space weather needs for civil aviation were rarely noted, although such needs were widely recognized for DOD missions, especially high-altitude reconnaissance missions or those in polar regions. Significant changes have occurred in civilian requirements since the end of the cold war.

> ***Finding 3.2.*** The FAA Air Traffic Organization's advisory *User Needs Analysis* identifies biological radiation exposure as a specification and prediction issue. The FAA Civil Aeromedical Institute has a rudimentary interface for public use available on the internet.
>
> > ***Recommendation 3.2.1.*** The NSWP should encourage and facilitate collection and analysis of real-time background radiation levels at space and aircraft altitudes. As a body, the NSWP should devote interagency resources to incorporate estimated dosage from energetic particle events into cosmic radiation exposure estimates and to make the specifications and results easily accessible, usable, and interpretable by the public via the Internet.

The Assessment Committee received little data comparing performance to the metrics outlined in the NSWP 2000 Implementation Plan. This information was not proffered by individual agencies or in the Committee for Space Weather briefings.

> ***Finding 3.3.*** Little information was available on program performance as related to the metrics given in the latest (2000) NSWP Implementation Plan.

In terms of coordination, the confederation nature of the agency participation in the NSWP often appears to hinder effective assignments of responsibilities and priorities.

> ***Finding 3.4.*** The National Space Weather Program Council does not have the authority to mandate roles, responsibilities, or priorities for space weather infrastructure needs. Nor can it allocate resources.

Activity: Encourage and Focus Research

The agencies in the NSWP have successfully seeded a number of research initiatives that have contributed to the national efforts in space weather. These have taken the form of both targeted research and strategic research.

Many of the targeted research initiatives have been science missions that have finite lifetimes and cannot be expected to contribute to space weather applications into the far future. Two important space missions that fall into this category are the ACE and the SOHO missions, which are located near the L1 Lagrange point.

> ***Finding 3.5.*** Many data sets that are critical for both civilian and national security elements of the NSWP are obtained from science programs of often limited duration (some of these sources are already beyond their design lifetimes) or from sources originally designed for other objectives. Relatively little discussion and contingency planning are underway as to how the NSWP will incorporate possible foreign sources of critical space weather data if some national data sources become unavailable.

Many instruments designed as data sources for operational space weather applications—on the ground or in space—need not have the high precision of measurements usually required for scientific research objectives.

> ***Recommendation 3.5.1***. The cooperating agencies in the NSWP should investigate immediately the feasibility of using micro-satellites with miniaturized sensors to provide cost-effective science and operational data sources for space weather applications.

Measurements of solar and interplanetary phenomena at L1 are essential for many important space weather operational objectives. Arrangements for the continuation of such key measurements are uncertain at the present.

> ***Finding 3.6.*** It is particularly critical to ensure continuity of space weather observations at L1 and continuity in delivery of that data in near real time. Planning for continuity is necessary prior to the failure of current scientific instruments at L1.
>
> > ***Recommendation 3.6.1.*** Micro-satellites and other small missions should be seriously pursued as an option for providing continuity of critical space weather data from observations at L1.

The DOD, NSF, and NASA each have strategic research components in support of their individual agency's goals. Strategic research is closely related to the level of space situational awareness that may—or may not—exist in the relevant agencies at a given time and over major planning cycles.

> ***Finding 3.7.*** The benefits of having space weather strategic research and space situational awareness must be more meaningfully assessed and promulgated.
>
> > ***Recommendation 3.7.1***. The NSWP must enhance its efforts to educate the U.S. Government, wider technical communities, and the public on the importance of strategic research and space situation awareness to national interests, particularly about the possible consequences of space weather events for national interests.

Activity: Facilitate Transition of Research into Operations

Significant advances have occurred in both empirical and physics-based modeling since the inception of the NSWP. The 2000 Implementation Plan identified three primary transition-to-operations objectives: the Community Coordinated Modeling Center (CCMC) and Rapid Prototyping Centers (RPC) at the NOAA SEC and within the DOD, and the radiation belt modeling in the DOE. The CCMC exists and is interacting strongly with the research community. The NOAA RPC is currently understaffed. Because the Air Force Space Weather Center of Excellence is scheduled for realignment and reorganization within the DOD, its future ability to provide prototyping support is unclear.

> ***Finding 3.8.*** There is an absence of suitable connection for "academia-to-operations" knowledge transfer and for the transition of research to operations in general.
>
> > ***Recommendation 3.8.1.*** The agencies involved in the NSWP should continue to support basic research modeling efforts and, if possible, provide increased resources for modeling that has space weather operational potential. New resources should be made available within NSWP agencies for transition of research models to an operational environment, including validation and revision of existing models. Present resources and human capital should be carefully evaluated, strategically invested, and wisely managed.

Improving the transition process will require quantitative assessments of the accuracy of data, models, and products, with overall progress to be measured in terms of improvements in these metrics. Although many models and many data streams exist, still lacking are quantitative estimates of the accuracy of this information that can be effectively communicated to users of space weather services.

> ***Finding 3.9.*** There currently are few overall verification and validation methodologies that can be used to assess the reliability of space weather models and operational products.
>
> > ***Recommendation 3.9.1.*** The NSWP should establish standards for data and model archives and for access to them. The NSWP should establish standards for modeling frameworks in order to facilitate model coupling, flexible execution, and data assimilation.
> >
> > ***Recommendation 3.9.2.*** The NSWP should work towards the establishment (and application) of metrics for space weather capabilities.

Activity: Foster Education of Customers and the Public

The NSWP has had success in many aspects of education: (a) professional education, (b) formal advanced education, (c) formal undergraduate education, and (d) informal public education.

Some of the NSWP agencies show awareness of the need for workforce education and development in support of the national space weather effort. Other agencies are less clearly

committed to workforce development. The NSWP agencies will need to work with the academic community to encourage it to develop new approaches to attract science and engineering students who can become space weather professionals.

> ***Finding 3.10.*** There is a lack of a systematic approach to 'grow' new space weather professionals.
>
> > ***Recommendation 3.10.1.*** The NSWP agencies should make a more unified and concerted effort to educate a new generation of professionals who have the systems view of space weather.

Private Sector Activities

The private sector has demonstrated interest in supplying tailored and unique space weather products and services as supplements to and enhancements of (added value to) the public products available from Government sources such as the NOAA Space Environment Center and the Air Force Weather Agency. Companies are interested in supplying tailored products to both governmental and private-sector entities.

> ***Finding 3.11.*** The role of the private sector in providing space weather products, including potential for investment, is still being defined.
>
> > ***Recommendation 3.11.1.*** The NSWP should work with the growing commercial sector for space weather services and products to enable this sector to flourish as a vital part of the national space weather program.
> >
> > ***Recommendation 3.11.2.*** The NSWP should work with the private sector to understand better the economic and social values of space weather knowledge and of products and services based on that knowledge.

International Activities

Individual agencies within the NSWP have pursued international collaboration for specific projects. International cooperative efforts could assist in gathering and distributing space weather data if there were coordinated plans for encouraging other countries to participate in these collection and distribution efforts.

> ***Finding 3.12.*** The NSWP has made relatively little effort to consider international partnering opportunities for collecting space weather data and distributing space weather information products. The worldwide space weather community would benefit by much more aggressive collection of space weather data by other countries.
>
> > ***Recommendation 3.12.1.*** The NSWP should consider the benefits (and possible drawbacks) of establishing a formal international coordination mechanism for the promotion, collection, and distribution of space weather data, including all forms of space weather data from satellites and ground-based sensors.

National Space Weather Program: Management Issues

The Assessment Committee identified a number of important management issues related to the program as a whole, as well as to individual agencies. Addressing these issues will enhance the effectiveness of the national effort.

National Space Weather Program Structure

The current arrangement of the NSWP as a loose confederation of agencies has made it difficult for the program to achieve the type of operational coordination that is essential to provide the national leadership needed for addressing the key space weather issues in the civil, governmental, and national security arenas.

> ***Finding 4.1. Organizational Matters.*** The NSWP is an outstanding example of a Federal government program in which a significant number of executive branch agencies have important national interests and where the individual agencies have natural areas of experience and expertise. However, the program management organization under the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM)—namely, the National Space Weather Program Council (NSWPC)—needs to be strengthened and needs to take a more active role in the execution of its overarching responsibility to ensure that the NSWP can move forward in achieving its goals. Without further strengthening of the NSWPC as an interagency integrated program, the chances of meeting the challenging national needs in space weather will be greatly diminished.
>
> > ***Recommendation 4.1.1.*** Oversight for the NSWP should be established in the Executive Office of the President, as is currently done for several other critical cross-agency activities of the Federal government. Policy and technical implementation aspects should be coordinated under the aegis of a space-knowledgeable staff member in the Office of Science and Technology Policy (OSTP). Budgetary coordination and review for the NSWP agencies should be carried out under a designated examiner in the Office of Management and Budget (OMB).
> >
> > ***Recommendation 4.1.2.*** The NSWPC Chair should review the council's membership and consider additional membership to increase the visibility of the program's fiscal and other challenges and to increase support for overcoming those challenges. The NSWPC should review and update its now 10-year-old charter to describe clearly its oversight responsibilities. These should include, but not be limited to, the authority to: (1) address and resolve interagency issues, concerns, and questions; (2) reprioritize and leverage existing resources to meet changing needs and requirements; (3) approve priorities and new requirements as appropriate and take coordinated action to obtain the needed resources through each agency's budgetary process; (4) identify resources needed to achieve established objectives; and (5) coordinate and leverage individual organizational efforts and resources and ensure the effective exchange of information.

Recommendation 4.1.3. A joint working group should be established for all cooperating NSWP agencies similar to that described in the NASA/NOAA Congressional Directive (2006 NASA Reauthorization Bill H.R. 3070, Section 306) and with similar reporting requirements.

Recommendation 4.1.4. A full-time space weather expert should be appointed as Executive Secretary to the Committee for Space Weather under the NSWPC.

Recommendation 4.1.5. The NSWPC should direct that a new NSWP Strategic Plan be written that takes into account the successes and the limitations achieved under the current plan, changes that have occurred in technologies susceptible to space weather, and advances made in scientific understanding.

Recommendation 4.1.6. The NSWPC should direct that a new NSWP Implementation Plan be written following a new strategic plan.

Recommendation 4.1.7. The NSWPC should create a joint, cross-agency, space weather organization, the "Center for Space Weather Research to Operations."

National Space Weather Program Agencies

Solar and solar-terrestrial programs in NASA have unified leadership within that agency, whereas the management of the corresponding programs within NSF is currently divided between two directorates.

Finding 4.2. The current management structure of the NSF solar and solar-terrestrial research programs does not always operate optimally to foster basic solar and solar-terrestrial research or the links from this research to space weather.

Recommendation 4.2.1. The solar and solar-terrestrial program elements of the NSF should be managed as one, possibly division-level, program so as to have a unified overview of both the basic research and space weather elements.

The 2002 Decadal Research Strategy in Solar and Space Physics, from the National Research Council, recommended that both NASA and NSF fund bridged faculty positions at universities to bring solar and space physics into the academic curriculum, commensurate with the national resources that are being devoted to these research endeavors (NRC 2002).

Finding 4.3. While the NSF has implemented a program to support bridged positions for academic faculty in solar and space physics, NASA has yet to address this recommendation of the National Research Council's Decadal Research Strategy in Solar and Space Physics.

Recommendation 4.3.1. NASA should institute a bridged faculty program in solar and space physics.

At times in the past, some programs and offices under the DOD and NOAA sponsored extramural research (primarily academic research) in solar and solar-terrestrial research at funding levels considerably above those at present. That level of research support enabled close interactions between in-house laboratories and the outside community of researchers and helped to develop analysis tools and models in support of space weather applications.

> ***Finding 4.4.*** The continuing decline in the resources available to the DOD and NOAA for contracting peer-reviewed research, both targeted and strategic, to the extramural community, especially the academic community, means that the interactions and interchanges between the government and nongovernmental sectors in space weather are far from optimized.
>
> > ***Recommendation 4.4.1***. Resources should be restored to the operational agencies to allow greater extramural research inputs. NOAA and the DOD should thereby provide competitive peer-reviewed funding for contributions from the nongovernmental sector to space weather program research elements.

1 NATIONAL SPACE WEATHER PROGRAM

The United States National Space Weather Program (NSWP) began 10 years ago as a collaborative enterprise among the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD). Other agencies that participate include the Department of Energy (DOE), the Department of the Interior (DOI), and the Department of Transportation (DOT).

The NSWP is a Federal government interagency initiative whose overall objective is to speed improvement of space weather services in the United States in order to prepare the country to deal with technological vulnerabilities that can occur due to the space environment. As stated on the program's web site (www.nswp.gov), "The overarching goal of the NSWP is to achieve an active, synergistic, interagency system to provide timely, accurate, and reliable space weather warnings, observations, specifications, and forecasts." From the beginning, the program was intended to build on existing governmental and civil capabilities and to establish a coordinated process to set national priorities, focus agency efforts, and leverage national resources. Also from the beginning, the program has encouraged and included contributions from the user community, operational forecasters, researchers, modelers, and experts in instruments, communications, and data processing and analysis – across the government, in research universities, and from industry. The program was conceived and structured as a partnership among academia, industry, and government.

At the Federal level, the program is implemented and managed by the National Space Weather Program Council (NSWPC). The council operates within the Office of the Federal Coordinator for Meteorological Services and Supporting Research under guidance of the Federal Committee for Meteorological Services and Supporting Research (FCMSSR).[1] The NSWPC consists of representatives from the seven executive branch agencies, listed above, that have mission-related involvement in space weather. The NSWPC provides oversight and policy guidance to ensure common needs are met and the interests of each agency are addressed. The Committee for Space Weather, which is co-chaired by NSF, NOAA, NASA, and DOD, was established by the NSWPC as the principal agent for advancing the goals of the program.

The National Space Weather Program is based upon several published documents, including a 10-year strategic plan, approved in August 1995 (OFCM 1995), and an implementation plan; the first edition of which was published in January 1997 (OFCM 1997), with a second edition in July 2000 (OFCM 2000).[2]

The NSWP has been in existence for more than a decade, and the latest implementation plan is now more than 5 years old. Policy considerations and research and user understandings related to

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[1] The OFCM homepage on the Internet is www.ofcm.gov.

[2] These NSWP foundational documents are available online as PDF files at http://www.nswp.gov/nswp_docs.htm.

space weather and national interests continue to evolve in important ways. In view of this history, as well as the growing international interest and presence in research and applications related to space weather, the FCMSSR and the Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR) directed that the OFCM undertake a comprehensive review of the NSWP. The stated purposes of this review were "to quantify and document the progress toward meeting the NSWP-stated goals in observations, research, modeling, transition of research to operations, and education and outreach; to see if the program is still on target and moving in the direction pointed to by the strategic plan; to determine whether the strategic goals should be adjusted at this time based on emerging/evolving requirements; and to suggest a way ahead which will form a basis for a new strategic plan covering the next 10 years." The NSWP strategic goals alluded to in this purpose statement (table 1-1) were listed in the Strategic Plan and both editions of the Implementation Plan.

To conduct the review as directed by the FCMSSR and ICMSSR, the Federal Coordinator for Meteorology formed a committee of six individuals from outside the immediate responsibilities of the involved agencies, yet knowledgeable about the program and active in aspects of space weather research and applications. The formal charge to this Assessment Committee is in Appendix A, and the committee membership is listed in Appendix B.

Table 1-1. National Space Weather Program Goals

To advance
• Observing capabilities • Fundamental understanding of processes • Numerical modeling • Data processing and analysis • Transition of research into operational techniques and algorithms • Forecast accuracy and reliability • Space weather products and services • Education on space weather
To prevent or mitigate
• Under- or over-design of technical systems • Regional blackouts of power utilities • Early demise of multi-million dollar satellites • Disruptions of communications via satellite, HF, and VHF radio • Disruption of long-line telecommunications • Errors in navigation systems • Excessive radiation doses dangerous to human health

Source: OFCM 1995, pg. 5; OFCM 2000, pg. 1-10.

These goals of the NSWP were to be achieved through nine specified activities:

- Assess and document the impacts of space weather
- Identify customer needs
- Set priorities
- Determine agency roles

- Coordinate interagency efforts and resources
- Ensure exchange of information and plans
- Encourage and focus research
- Facilitate transition of research results into operations
- Foster education of customers and the public.

The detailed program assessment presented in chapter 3 is organized under these nine previously specified activities, plus an additional category for crosscutting private sector activities and international activities.

To carry out its review and assessment tasks, the Committee used the following means, in addition to the knowledge of the NSWP and space weather issues brought by the individual members:

- Meetings with relevant agency officials, held in the offices of the OFCM
- Visits to key sites and activities related to space weather, around the nation
- Requests for comment about the NSWP from the general research community and the user community.

The requests for comment were advertised widely to obtain, insofar as possible, a cross-section of responses. Appendix C lists the committee's information-gathering meetings, with the meeting agendas. Appendix D contains responses to the requests for comment.

2 SPACE WEATHER

2.1 Space Weather and Human Technologies

Space weather events have been noted to affect, or even disrupt, human technologies since the development and deployment of the first electrical telegraphs in the 1840s. Electrical currents induced in the Earth by ionosphere and magnetosphere processes caused serious disruptions of telegraphy for decades. Indeed, the great solar storm of 1859 disrupted telegraph operations around the world, causing articles to be published in many major newspapers at that time. Degradation and disruption of wireless signals by space weather effects on the ionosphere have been observed ever since Marconi sent his first transmissions across the Atlantic in December 1901.

Military needs for space situational awareness were evident long before the official beginning of the space age. During World War II, radar signals were a primary element of British defense against the Luftwaffe. Solar radio noise would at times fill the airways, prompting investigations of German jamming capabilities. In fact, particularly severe radar jamming during a large solar event in 1942 led to the discovery of solar radio bursts (only reported following the end of the war). The first measurement of high energy solar cosmic rays was also made during this solar event (by ground-based detectors) and was also reported following the war.

The first transatlantic telephone cable (between Newfoundland and Scotland) was disrupted by the geomagnetic storm of 1958. At the same time, the entire Toronto area lost electrical power because of the storm. Radio communications faltered during that storm in several locations. An Air Force plane loaded with passengers and flying from New Zealand to Antarctica made the 2,000-mile journey without radio contact. The first telecommunications satellite, Telstar 1®, which launched on July 10, 1962, was put out of service after 8 months in orbit by a combination of natural and human-induced radiation in the Van Allen belts. (The Starfish nuclear explosion occurred on July 9, 1962.)

The advent of the space age demonstrated conclusively that ever-advancing technologies—for both civilian and national defense purposes—require an evermore sophisticated understanding of the space environment. Reliable forecasts of changes in this environment—space weather—are now essential for ensuring reliable operations of both space- and ground-based systems. The operations of these systems have often encountered surprises because of solar-terrestrial effects (e.g., Barbieri and Mahmot 2004). Further, "older" problems, such as the disturbance of radar by solar radio noise, require revisiting and reanalysis in the context of newer communications technologies that use different frequencies and implementations than in the past (for instance, the Global Positioning System [GPS] and other positioning, navigation, and timing services; wireless telephony and data transmission services). Contemporary examples of space-weather impacts on many modern technical systems are schematically illustrated in figure 2-1. Details of some of these technological impacts are discussed in side-bar boxes in chapter 3 and at relevant points in the report narrative.

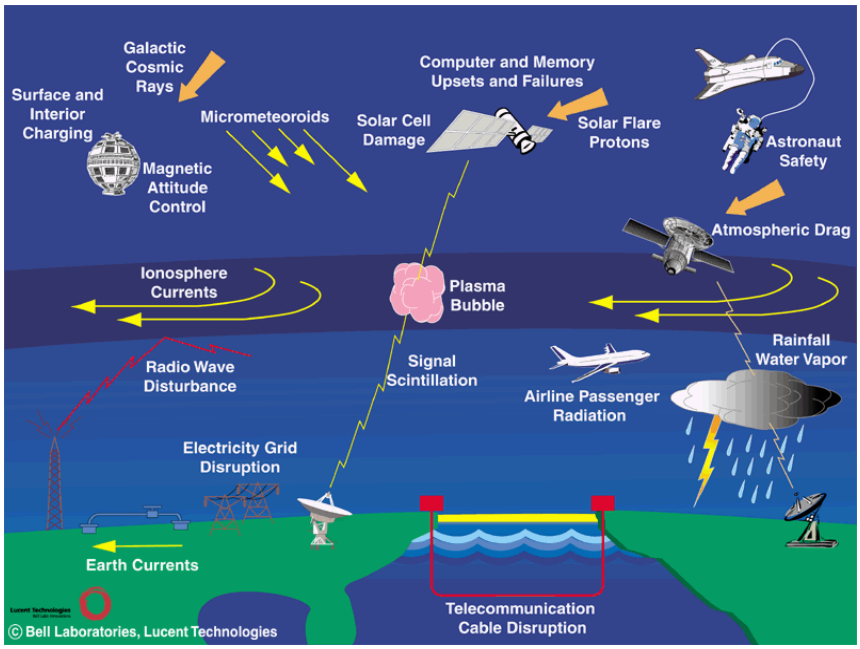


Figure 2-1. Impacts of solar-terrestrial processes on technologies.

2.2 The Emergence of Space Weather Services in the United States

Daily civilian space weather services by the Federal government celebrated their 40th anniversary in 2005, the same year in which the NSWP celebrated its tenth anniversary. The emergence of a coordinated, interagency approach to space weather services and the R&D necessary to support those services began even earlier.

Awareness by civilian agencies of space weather (although not called that at the time) grew considerably at the time of, and following, the International Geophysical Year in 1956-1957. Routine civilian Federal space weather services began a decade later in 1965, the same year that several scientific entities within the Department of Commerce—the Weather Bureau, Central Radio Propagation Laboratory (CRPL), and U.S. Coast and Geodetic Survey—were brought together as the new Environmental Science Services Administration (ESSA), headquartered in Boulder, Colorado. Through several changes in name and organization, a piece of CRPL was transformed into the current Space Environment Center (SEC) within NOAA's National Weather Service (NOAA/NWS). In 2004, the SEC joined the NWS family of prediction centers, known as the National Centers for Environmental Prediction (NCEP).

Space environmental forecasting efforts by NASA and the Air Force began in 1962. DOD's space weather forecasting centers have since migrated from the Air Weather Service to the Air Force Space Command (AFSPC) and then to the Air Force Weather Agency (AFWA). Forecasting research activities began in 1966 at the predecessor to the current Air Force Research Laboratory (AFRL). Currently, the Space Weather Operations Center (SWOC), located at Offutt Air Force Base in Omaha, Nebraska, is a functional element of AFWA.

In the course of assessing successes and achievements during the first 10 years of the NSWP, this report also documents the continued growth in demand for space weather services from both governmental (defense, regulatory, and scientific missions) and civilian interests. Knowledge about the complex system formed by the Sun and the Earth's environment continues to increase, and capabilities for modeling and predicting this dynamic system continue to grow rapidly.

In *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, a survey committee of the National Research Council devoted a chapter to space weather research and its applications (NRC 2002). In discussing the importance of the NSWP, the authoring committee stressed that "*A key function of the National Space Weather Program is to develop processes and policies for monitoring the space weather environment.*" The survey further stated that "technological changes are occurring at a very rapid pace in both large-scale systems and small-scale subsystems that can be affected by solar-terrestrial processes. This is true for both ground- and space-based systems." For example, the electric power grid system in the United State is becoming more interconnected through the use of power-sharing pools and other multi-company arrangements. Due to this interconnectedness, a problem caused by a space weather event in one geographical region of the power grid could potentially cascade to a distant region not directly affected by that event. At the opposite extreme of the size scale, rapid advances continue in microelectronics and in the miniaturization of circuits, Some of these changes can make the components and the systems containing them more vulnerable to effects of space radiation. The increasing use of commercial off-the-shelf components in national security programs (as well as in commercial programs) can also make space subsystems and systems more susceptible to space radiation effects.

Over the past decade, the NSWP has produced a number of very visible and notable achievements. For example, the program has fundamentally changed how researchers approach the study of the Earth's space environment. Today, because of the efforts of the seven agencies in the program, the generation of space weather in the context of its effects on critical technologies is understood as the result of an integrated physical system in which all components from Sun to Earth interact. Hence, researchers increasingly tend to regard space weather and the Sun-Earth system in which it occurs as a whole, rather than as a diverse collection of parts.

This systems understanding, together with the need to be able to predict space weather events, has led to the development of NASA's Community Coordinated Modeling Center (CCMC). This center is a multiagency partnership to provide access to modern space science simulations and to support the transition to space weather operations of modern space research models.

As a second example, the NSWP stimulated the initiation of the technical journal/magazine *Space Weather: The International Journal of Research and Applications*. This Internet-distributed technical magazine (with a hardcopy *Quarterly* edition), published by the American Geophysical Union, contains peer-reviewed technical articles, plus shorter feature articles, news, commentary, and editorials (http://www.agu.org/journals/sw/).

The NSWP has engendered major efforts in the academic community to construct usable models for portions of the solar-terrestrial system, as well as for more inclusive Sun-to-Earth models. All

these models have been designed to address user needs and concerns. The modeling activities are conducted in several major modeling centers supported by the DOD, NASA, and NSF.

The DOD has supported three Multidisciplinary University Research Initiatives (MURIs) that address important space weather modeling problems. The DOD has also supported the development of an undergraduate-level textbook on space weather.

NSF awarded one of its grants for a National Science and Technology Center (NSTC) to a multi-university, multi-institution activity devoted to creating a physics-based numerical simulation model that describes the space environment from the Sun to the Earth. This Center for Integrated Space Weather Modeling (CISM) involves several universities, government laboratories, and industry.

NASA has initiated the Living With a Star (LWS) program, a research program focused on space weather applications (http://lws.gsfc.nasa.gov/). The importance of space weather understanding, monitoring, and prediction has been heightened by the recent U.S. commitment to human exploration of the Moon and Mars. This exploration will expose astronauts and spacecraft to a hazardous space weather environment that will need to be better understood and predicted. The United States has made a good beginning in supporting NASA's ambitious Exploration Initiative, which owes much to the LWS program and the NSWP. However, the work thus far is only a start; much remains to be accomplished in understanding and predicting space weather conditions for human space travel.

Popular interest in the emerging discipline of space weather is on the rise. The NSF cosponsored development of an IMAX© movie production about the recent solar maximum (high point of the solar cycle). Two popular texts, articles in *National Geographic,* and the Internet-based outreach programs funded by NSF and NASA focus on educating the public about space weather and its origins in the Sun-Earth system. Congressional awareness of space weather increased when the Halloween solar storms of 2003 coincided with funding decisions for NOAA/SEC.

The requests for data and service products from the SEC have increased continually since the NSWP began, largely because of the growth in awareness of the SEC's capabilities for space weather forecasts and services. Through the SEC's Space Weather Week, held each spring in Boulder, Colorado, researchers, governmental and nongovernmental users of forecasts and services, and private sector vendors have the opportunity to interact and to develop new concepts for migration of space weather research into useful products and services. The interests of the space weather user community, as expressed at Space Weather Week, continue to expand. For example, a prominent user group with enhanced participation at the most recent Space Weather Week (April 2006) represented the civil space transport and tourism industry.

Despite these notable advances, the NSWP has also experienced some significant shortfalls and difficulties. Some data collection capabilities have declined or will decline in the near future. For example, if current plans hold, the United States will be flying fewer space weather sensors on future NOAA weather satellites than are currently being flown. This outcome will surely cause a sizeable decrease in capabilities to predict space weather events. Further, resources for the creation and implementation of improved operational forecasts (the so-called transition of

research to operations) have declined in the past several years. The SEC has experienced resource instabilities that have hindered provision of national space weather services.

Finding 2.1. The First Decade. Since its inception in 1995, the National Space Weather Program (NSWP) has had a number of noteworthy achievements, most of which likely would not have been attained without the program's existence. Significant strides have been made toward institutionalizing forecast and protection mechanisms for safeguarding against space weather events that may impact many of the significant technology systems on which the United States depends for security, commerce, and advances in science. Despite many notable advances, significant shortfalls in the program also exist and are outlined in this report.

Recommendation 2.1.1. The highly successful National Space Weather Program should continue as an interagency program; however, it should be updated and modified as detailed in the further recommendations of this report.

National Oceanic and Atmospheric Administration

NOAA's Space Weather Program monitors, measures, and specifies the space environment and provides timely and accurate operational space weather forecasts, warnings, alerts, and data to end users in the United States and around the world. The end-to-end program develops space weather observational requirements for NOAA's space-based sensors, ingests and processes their (and others') data, performs research to understand the processes that cause severe space weather, transitions research into operations to improve services, archives data from NOAA and the DOD, and makes the archived data accessible to government and private users.

NOAA's Space Weather Program includes activities within the National Weather Service (NWS) and the National Environmental Satellite, Data, and Information Service (NESDIS). NWS activities are conducted through the Space Environment Center (SEC), which is part of the National Centers for Environmental Prediction (NCEP). NESDIS activities are conducted by the National Geophysical Data Center. These two centers, which are both located in Boulder, Colorado, are direct components of the Space Weather Program. In addition, NOAA's Office of Marine and Aviation Operations provides staff support, and the National Geodetic Survey, within NOAA's National Ocean Service, provides data, as does the Satellite Services Program within NESDIS.

The United States Air Force is an especially strong partner, providing services and data, as well as detailing staff to the SEC. NASA provides key science data from its research satellites and plans to provide science data from future approved missions. The U.S. Geological Survey (USGS) provides key ground-based data. The Space Weather Program also receives data from many countries and their space agencies throughout the world. NOAA is also the lead partner in the International Space Environment Service (ISES), the body responsible under the International Council for Science (ICSU) for coordinating the worldwide provision of space weather services.

National Aeronautics and Space Administration

Science both enables exploration and is enabled by it. A NASA goal in the era of the Vision for Space Exploration is to develop a balanced program of space science within the Science Mission Directorate. The Heliophysics Division in the Science Mission Directorate is organized to address three broad science objectives:

Opening the Frontier to Space Environment Prediction. Investigate and communicate the fundamental physical processes of the space environment—from the Sun to Earth, to other planets, and beyond to the interstellar medium.

Understanding the Nature of Our Home in Space. Discover and document how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields.

Safeguarding the Journey of Exploration. Using new scientific insight, maximize the safety and productivity of human and robotic explorers by developing the capability to predict the extreme and dynamic conditions in space.

To achieve these goals the Heliophysics Division organizes and executes scientific space flight missions to investigate physical conditions and processes found in the solar system. It also conducts programs of theory and research to support these missions through development of new theories and numerical models, creation of national-class databases for conservation of data and scientific results, support for development of new scientific assets such as an extended mission fleet and a guest investigation program, and the training and support of the next generation of explorers.

Where possible, NASA's research and analysis mission is extended to the utilization of new knowledge for societal benefit by forming partnerships with industry, academia, and other governmental agencies that are also engaged in the development of the emerging field of space weather research and predictive capability.

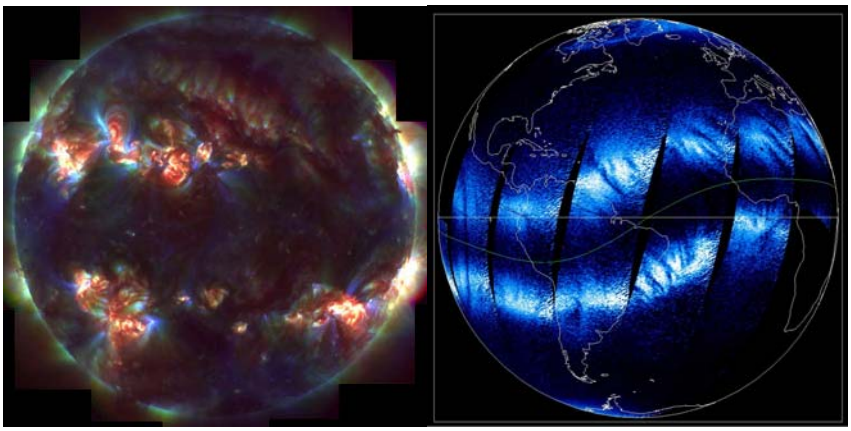


Figure 2-2. The Sun and the Earth observed from space.

Department of Defense

The DOD supports the National Space Weather Program primarily in three areas of strategic priority: forecasting and specification, observation, and technology transition and integration.

The DOD's primary space weather concern is the state of the ionosphere as it impacts communications, navigation, and targeting operations. The U.S. Air Force is responsible for providing space environmental services to all of DOD. The Air Force Weather Agency (AFWA) reports solar activity and conducts forecasting of the ionosphere and magnetosphere, working in close coordination with NOAA/SEC.

The DOD provides reliable, ground-based and on-orbit space environmental observations to the community. DOD solar observatories in Hawaii, New Mexico, Massachusetts, Italy, and Australia detect and report optical flares and their radio signatures on discrete VHF, UHF, and SHF frequencies and from coronal plasma movements. The DOD characterizes the lower portion of the ionosphere by maintaining two dozen ionospheric sounders around the world. It captures the upper portion of the ionosphere with in situ and remote sensing instruments carried on satellites of the Defense Meteorological Satellite Program (DMSP).

Both AFWA and the Air Force Space Command (AFSPC) facilitate technology transition and integration. AFWA implements models for operational use, most notably the Global Assimilation of Ionospheric Measurements (GAIM) model starting in 2006. AFSPC integrates space environmental forecasts directly into joint operations at the Joint Space Operations Center. AFSPC is also developing a system to directly integrate space environmental information into combatant commanders' command and control systems.

Additionally, the DOD conducts research related to space weather and develops sensors and systems through the Air Force Research Laboratory, the Naval Research Laboratory, and the Air Force Office of Scientific Research.

National Science Foundation

Currently, the NSF supports about $2 million annually in focused space weather research grants. It also supports related space physics research programs in aeronomy, magnetospheric physics, and solar-terrestrial physics. Special NSF research programs within these broad space physics programs include: Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR); Geospace Environment Modeling (GEM); Radiative Inputs of the Sun to Earth (RISE); and Solar and Heliospheric Interplanetary Environment (SHINE). The NSF currently supports a number of space weather modeling programs, including the Center for Integrated Space Weather Modeling (CISM), a National Science and Technology Center established in 2002.

In addition to the basic research programs, NSF supports a variety of ground-based observing instruments and major facilities of relevance to the NSWP. Facilities include a chain of incoherent scatter radars located in Jicamarca, Peru; Arecibo, Puerto Rico; Millstone Hill, Massachusetts; and Sondre Stromfjord, Greenland. NSF also supports the U.S. component of the Super Dual Auroral Radar Network (SuperDARN). Also important to space weather is the NSF support of the National Solar Observatory and the National Center for Atmospheric Research (NCAR), including the High Altitude Observatory. NSF also supports relevant space weather research using instrumentation installed in the Antarctic and Arctic regions.

The latest space weather facility, the Advanced Modular Incoherent Scatter Radar (AMISR), is currently under construction in Fairbanks, Alaska. Using state of the art technology, AMISR sets a new world standard in upper atmospheric research facilities, and its unique design features allow the radar to be disassembled and moved as scientific needs dictate.

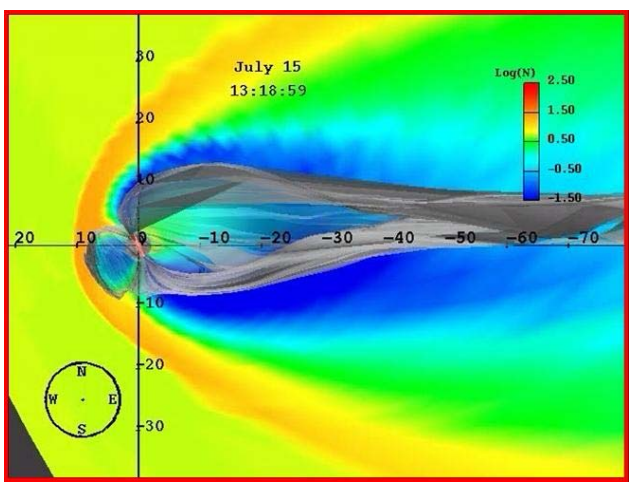


Figure 2-3. Computer simulation of Earth's magnetosphere.
This illustration of an early magnetospheric model developed by CISM is tightly coupled to a realistic model for the polar ionospheres and is driven by solar wind plasma and magnetic field data forward of the calculation domain. Although lacking important physical processes in both the magnetosphere and ionosphere, this is the simplest possible self-consistent model based on first-principle representations.

Department of the Interior Geomagnetism Program

The Geomagnetism Program of the Department of the Interior's U.S. Geological Survey (USGS) serves the NSWP by providing high-quality, ground-based magnetometer data over a wide range of timescales from 14 observatories distributed across the United States and its territories. The Geomagnetism Program collects, transports, and can disseminate these data in near-real time. The Geomagnetism Program also has significant data-processing and data-management capacities. The USGS Geomagnetism Program's data services form the basis of many space-weather diagnostics used by NOAA/SEC, AFWA, other scientific agencies, and the nongovernmental sector.

On an international scale, working through the Intermagnet organization and with other national geomagnetism programs, the USGS Geomagnetism Program assists in coordinated international monitoring of the Earth's magnetic field.

The program has a small research element which concentrates on the analysis of ground-based magnetic observatory data. Additional information can be found at: http://geomag.usgs.gov and http://www.intermagnet.org

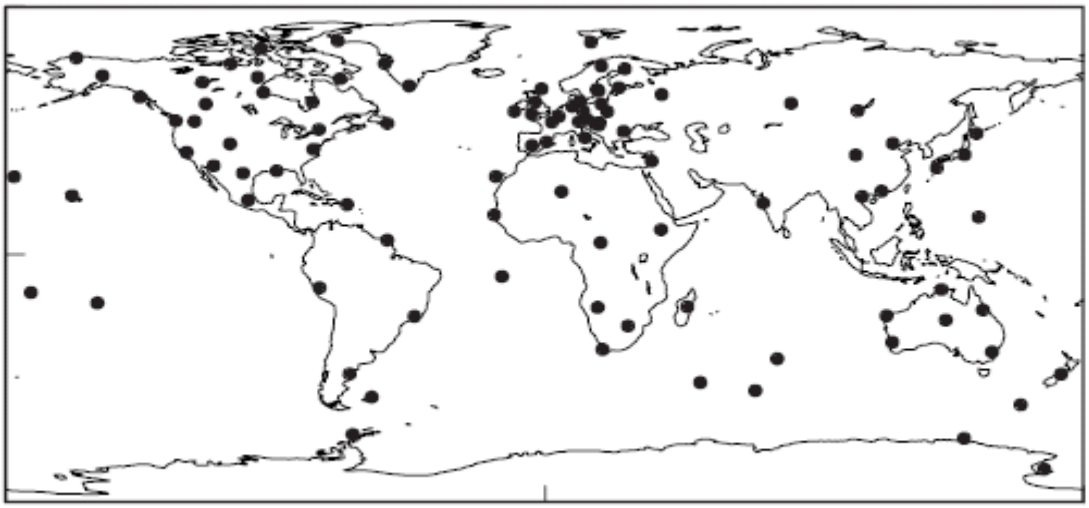


Figure 2-4. World map of locations of Intermagnet observatories.

3 NSWP ASSESSMENT BY PLAN ACTIVITIES

In this chapter, the committee assesses the performance and current status of the NSWP in terms of a set of nine activities called for in the NSWP Strategic Plan and the two editions of the Implementation Plan as the means to achieve program goals. In its assessment, the committee focused on the activity descriptions in the second edition of the Implementation Plan (OFCM 2000) as providing the most recent and most detailed specification of what these activities should achieve. Three of the nine activities have been assessed together because they overlap extensively. The three foundation documents also called for the NSWP to pursue activities to foster enhanced private sector and international coordination. These crosscutting activities are addressed in the final section of the chapter. Table 3-1 lists the resulting set of assessment categories, which correspond to the major headings of the chapter.

Table 3-1. NSWP Assessment Categories

Section	NSWP Activities Assessed
3.1	Assess and document the impacts of space weather
3.2	Identify customer needs
3.3	Determine agency roles
3.4	Coordinate interagency efforts and resources; set priorities; ensure exchange of information and plans
3.5	Encourage and focus research
3.6	Facilitate transition of research results into operations
3.7	Foster education of customers and the public.
3.8	Crosscutting Issues

3.1 Assess and Document the Impacts of Space Weather

The Assessment Committee determined that this NSWP activity should cover, and has covered, two related but distinguishable types of impacts: (1) the impacts of space weather that make it a safety, security, and economic concern for the Nation, and (2) the benefits that can be gained from space weather forecasts.

3.1.1 Impacts of Space Weather

The NSWP has supported significant efforts to investigate economic and industrial space weather impacts. Such impacts are now discussed in scholarly science journals and in industrial and popular literature. The NSWP has significantly increased overall awareness of space weather and assisted in the compilation of a variety of assessment documents. The following are examples of space weather impacts, many of which are cited in the *NOAA Magazine Online*, Story 131 (NOAA 2006):

- The effects of a March 1989 space weather storm cost two large utilities, Hydro Quebec in Canada and PSE&G in New Jersey, an estimated $30 million in direct costs. Hydro-Quebec's solution to the blackout was to install devices that block storm-induced currents from traveling through its transmission lines. Unfortunately, this solution is extremely complex and expensive ($1.2 billion). Comprehensive real-time protective space weather prediction services could have significantly reduced damages and costs (Quinn 2000).
- In research supported by the National Science Foundation, Forbes and St. Cyr (2004) used a multivariate economic analysis of one cross-state transmission system to conclude that space weather produces congestion in that system, which transmits power from the generating site to the distribution site. For the interval studied—June 1, 2000, through December 31, 2001—they concluded that solar-initiated geomagnetic activity increased the wholesale price of electricity by approximately 3.7 percent, or approximately $500 million. The economic conclusions of this analysis have occasioned some controversy, and further discussions and analyses are in progress.
- An aviation insurance underwriter has estimated that $500 million in satellite insurance claims from 1994 to 1999 were the direct or indirect result of space weather (NOAA 2006, cited under "Satellites" subheading).
- The DOD has estimated that disruptions to government satellites from space weather cost about $100 million a year (Rodgers et. al. 2000).
- Solar-initiated geomagnetic storms in 1994 and 1997 appear to have been the cause of the demise of three communications satellites: U.S. Telstar 401 and Canada's Anik-E1 and Anik-E2 satellites. Total replacement costs were estimated to be $600 million (Baker et al. 1994; Chapline 2000). There is not yet agreement in the community on why the Telstar satellite was lost; the loss occurred on the day following a geomagnetic storm. The pager satellite Galaxy IV may also have been rendered inoperable from space weather effects (Baker et al. 1998)
- Interruptions to high frequency radio communications during the Gulf War in 1991 have been attributed to solar storms (NOAA 2003).
- Space weather information is commonly employed as important operational input for determining launch and on-orbit operations of Space Shuttle and International Space Station (ISS) activities.
- Space weather information is crucial for determining time constraints on astronaut operations external to the Shuttle and ISS (space walks) and for re-entering the vehicle.
- During times of high solar activity, polar airline routes are often diverted to lower latitudes to prevent loss of radio communications and avoid human exposure in case of increased radiation from solar energetic particles. Such flight diversions can cost airlines as much as $100,000 per flight for additional fuel, extra flight crews, and additional landings to refuel. This cost does not include economic and unquantifiable losses to passengers, such as missed connections. Space weather considerations will be included in the current Aviation 2025 architecture study by the Federal Aviation Administration (FAA).

- Civil and military search and rescue missions can be, and have been, severely impeded by anomalous radio communication signal propagation under disturbed ionospheric conditions.
- Many elements of commerce and society have become very dependent on global positioning, navigation, and timing (PNT) systems. A one percent gain in continuity and availability of GPS alone is estimated to be worth $180 million per year (Rodgers et. al. 2000).
- In 2004, NOAA/SEC issued the first-ever space weather event assessment (NOAA 2004). This multi-chapter document highlights the physical events and system effects of the large solar and geomagnetic storms of October and November 2003. NASA contributed essential information to this study and followed on with a publication in *Space Weather* (Barbieri and Mahmot 2004), detailing hardware and communications issues addressed by the agency in the storm's aftermath.

The above examples do not include the intangible societal benefits that arise from better knowledge of space weather and from mitigation actions, based upon this knowledge, that have been implemented in various technologies. Just as buildings can be designed with more assurance that they can withstand earthquakes when the Earth's crust and mantle are better understood, so too can space- and ground-based technical systems be designed more reliably when space weather information becomes more accurate and widely available. If systems are better designed to withstand space weather effects, societal costs such as electrical or communications outages can be avoided or at least made less severe. It is difficult, if not impossible, to place monetary figures on technology disruptions that do not occur because some systems were designed to account for space weather effects where they are deployed. Some estimates can be made from knowledge of the systems and the steps necessary to protect them from destructive interruptions. Much more analysis effort in this area is needed in the future.

Despite an increasing awareness of space weather, assessment and documentation of its effects remain difficult because of industrial or governmental proprietary issues, security classification constraints, and misunderstanding or lack of understanding about space weather hazards. Commercial users of space weather products are hesitant to have their concerns with, and vulnerabilities to, space weather effects publicly highlighted for fear of loss of market share or investor confidence.

Even members of the DOD, where operations routinely involve space systems, are uncertain about how best to assess space weather impacts and capabilities. Recently AFWA undertook a review of the overall contribution of weather to the Air Force Concept of Operations. Although the resulting report, *Value of Weather Services to the Combatant Commands*, concentrated on terrestrial weather, it mentioned space weather, concluding that "…There is some uncertainty that what is currently measured is actually important to the expected impact on military systems….Real measures of success for space-weather elements are not currently available in sufficient quantities to be useful in the Air Force Capabilities Review and Risk Assessment process" (AFWA 2005). As a result of this uncertainty, the study recommended additional research and experimentation in the entire area of space weather determine:

(a) What space weather elements should be measured and forecast?

(b) What kinds of sensors (ground- or space-based) produce the most accurate observations?

(c) What are the capabilities (accuracy specifications) of these sensors?

(d) What space elements should AFWA forecast (what are the customer requirements)?

(e) What are the forecast verification statistics for these forecast elements?

Since this report, additional work has been done to identify DOD's space weather needs, as discussed in the following section. Briefings to the Assessment Committee from the AFWA staff, AFSPC, AFRL, and the Office of Naval Research indicate that these concerns are widely recognized, but the resources and authority to address them are lacking.

The *Space Weather Architecture Study* by the National Security Space Architect (NSSA) contains discussions of the importance of space weather for national security (NSSA 1999). Appendix E of this report contains the key summary recommendations from the NSSA study.

3.1.2 Benefits of Space Weather Forecasting

Tracing the complex chain of causality from the forecast of a space weather event to the economic or social benefits gained may require an interdisciplinary team of economists, scientists, engineers, and practitioners within the affected agency or industry. Further, many space weather impacts and the subsequent benefits of space weather forecasts are unquantifiable. Others cannot be detailed publicly because of their national security sensitivity or because they would reveal information that companies (e.g., satellite operators) might wish to keep proprietary for various reasons. As a result, few in-depth studies of the benefits to society, both economic and social, of space weather forecasts have been done. Past studies have tended to focus on a single technology or application. Nevertheless, the national space weather effort would gain from benefit studies, as such studies would help clarify the value of the NSWP to the public, to Congress, and to the executive branch. Such studies would also provide important guidance for future investments in space weather research and operations.

Finding 3.1. The NSWP lacks a coordinated effort to identify and quantify, where possible, the benefits to society of providing space weather forecasts.

Recommendation 3.1.1. The NSWP should institute a coordinated effort to fund a series of space weather benefit studies that would cover the primary topics of concern to operators of space weather–vulnerable systems.

These studies could include, among other systems affected by space weather, geostationary satellites, aircraft, electric power grids, and PNT satellite systems. Among other results, such studies could provide important information for the design and development of new space weather forecast capabilities by helping NSWP participants understand where to expect the highest returns from investments in such capabilities.

Space Weather and Human Space Exploration

Since time immemorial, human beings have explored the Earth—its lands and seas—and have often endured great personal risk and hardship in doing so. Human exploration into space is also a difficult and dangerous endeavor. Such an endeavor requires great ingenuity and optimism, as well as the courage to take measured risks while attempting to optimize safety and success.

In addition to accepting the risks inherent in riding atop millions of pounds of explosives, the human body must successfully adapt to a unique environment, whether in transit to and from the Moon, Mars, or other destinations in deep space. One unavoidable environmental challenge is the radiation environment—solar and galactic cosmic rays—that fills space above Earth's atmosphere. The environment must be studied and understood well enough that solar storm prediction strategies are effective and available mitigation techniques can be employed. All must be accomplished with sufficient accuracy to allow difficult programmatic decisions weighing risks versus rewards to be made by those held accountable for costs to the taxpayer and for the fate of astronauts.

Some considerable experience exists related to astronaut safety during solar events, although most of it currently derives from experience in low Earth orbit (LEO). For example, the Johnson Space Center made the following report for the solar storm events of October-November 2003 (NOAA 2004):

> "Solar flare activity caused flight controllers to issue contingency directives for the ISS Expedition 8 crew to briefly relocate to the aft portion of the station's Zvezda Service Module and the Temporary Sleep Station (TeSS) in the U.S. Lab. The Expedition 8 crew of Commander Mike Foale and Flight Engineer Alexander Kaleri spent brief periods of time in the aft section of the Zvezda Service Module, which is the most shielded location aboard the ISS from higher levels of radiation. During Tuesday (October 28), there were five 20-minute periods during which the crew was asked to remain in the aft end of Zvezda."

Figure 3-1. The ISS.
Courtesy NASA/SRAG.

Astronauts inevitably note that they are willing to take such environmental risks to be part of humanity's exploration away from our planet. They do so with the understanding that not only mission success but their very survival depends on the scientific and operational communities leveraging the best support each has to offer.

3.2 Identify Customer Needs

Agencies participating in the NSWP have devoted considerable attention and resources to the identification of customer needs in the period since the 2000 NSWP Implementation Plan. NOAA/SEC, for example, has a broad government and commercial customer base that continues to grow as the technologies that can be affected by space weather continue to grow both in number and in the demands placed upon many of the customers' operations. During interviews with the Assessment Committee, SEC staff members reported substantial efforts in identifying and supporting customer needs in the industries and agencies shown in figure 3-2. The SEC staff is also actively engaged in working with nongovernmental (commercial) organizations interested in providing value-added products, services, and data for space weather.

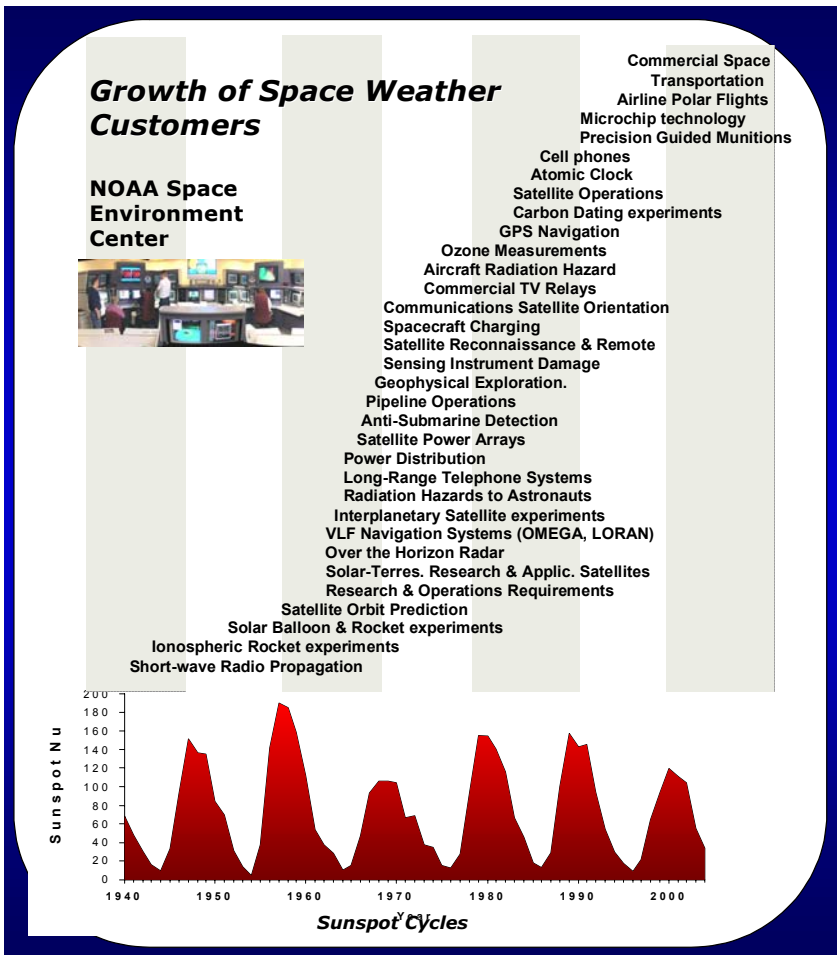


Figure 3-2. Customers of the NOAA Space Environment Center.

Table 3-2 provides a broad overview of space weather hazards as they relate to mission areas within the DOD. One of the primary challenges to DOD space weather service providers (internal DOD, other government, or commercial) is the interface with a changing customer base. Mission area program managers and system or hardware operators may rotate every 2 or 3 years. Thus, in some mission areas, space weather providers may have as much or more knowledge about customer needs as the customers themselves.

When the NSWP began in 1995, space weather needs of civil aviation were rarely mentioned, although such needs were widely recognized for DOD missions, especially high-altitude reconnaissance missions or those in polar regions. Significant changes in civilian requirements have occurred since the end of the cold war, especially in the past five years as an increasing number of flights use routes that cross the northern polar cap between North America and Europe or the Far East. Table 3-3 lists space weather impacts on civilian aviation and the capabilities needed to mitigate them, as identified in the FAA Air Traffic Organization advisory user needs analysis that is currently under consideration.

Table 3-2. DOD Mission Areas Supported by Space Weather Requirements

Space Weather Requirements	DOD Supported Mission Areas
Scintillation	*Communication *Positioning, navigation, and timing Intelligence, surveillance, reconnaissance, ballistic missile defense
Radio frequency interference	*Communication, Intelligence, surveillance, reconnaissance, ballistic missile defense
Radiation and charging	*Spacecraft *High altitude aircraft
Electron density	*Communication *Positioning, navigation, and timing Intelligence, surveillance, reconnaissance. ballistic missile defense
Neutral particle density	*Spacecraft Intelligence, surveillance, reconnaissance, ballistic missile defense
Ground induced currents	*Electric power
Aurora clutter	Intelligence, surveillance, reconnaissance, ballistic missile defense

*Area of commercial/civilian interest in addition to DOD mission relevance.

Table 3-3. Space Weather Impacts on Aviation and the Observation and Forecasting Capabilities Needed to Address Them

Impact on Aviation	Needed Capability
HF communication outage in polar regions	Real-time observation of polar HF radio blackouts. Forecast of polar radio blackouts 12 hours in advance. Graphical depiction of forecasting radio blackouts.
HF communication outage in mid and low latitudes	Real-time observation of mid- and low-latitude HF radio blackouts due to geomagnetic storms, graphical product defining intensity, frequencies affected, and geographical boundaries. Forecast of geomagnetic activity up to 6 hrs in advance.
Navigation disruption or outage	Real-time observation of mid- and low-latitude GPS disruption, graphical product defining intensity and geographical boundaries. Forecast of geomagnetic activity up to 6 hr in advance. Graphical depiction of forecast GPS disruption.
Biological radiation exposure	Provide CAMI access to WMSCR distribution network, with alerts targeted to airlines and FAA Command Center. Incorporate estimated dosage from energetic particle events into cosmic radiation exposure estimates. Longer lead-time and more accurate prediction.

The Space Situational Awareness Information Office, which supports AFSPC in Colorado Springs, has undertaken a study of long-term space-customer needs and likely shortfalls. As communicated to the Assessment Committee, this study emphasizes that even under the most optimistic of scenarios, space-based observing capability will not meet customer needs in the space weather arena.

A similar conclusion was reached by the NSSA in the *Space Weather Architecture Study*. Again based on identified needs, this study concluded that observational capabilities will not meet minimum requirements associated with national security needs (NSSA 1999).

Fostering Collaborations among Academia, Industry, and Government

The Boulder Valley in Colorado has one of the larger concentrations in the world of institutions related to solar physics. Recognizing the potential for collaboration, scientists and administrators at these institutions voluntarily organized the Boulder Solar Alliance in 2005. This organization fosters communications and interactions among solar researchers, identifies joint projects and opportunities of mutual interest, and promotes activities that can contribute to national and international research activities. One such activity is the National Space Weather Program.

Figure 3-3. Participants in the Boulder Solar Alliance.

The technical capabilities and the breadth of intellectual expertise within the Boulder Solar Alliance span the Sun-Earth system. They encompass basic research; numerical modeling; data mining and assimilation; delivery of services; technology transfer; advanced education; practical training; and instrument design, development and fabrication. Member institutions include basic research organizations, such as the Federally-funded High Altitude Observatory of the National Center for Atmospheric Research (NCAR), and academic laboratories, such as the Laboratory for Atmospheric and Space Physics and the Joint Institute for Laboratory Astrophysics of the University of Colorado. The university is currently investigating ways to refine and coordinate its undergraduate and graduate programs in solar and space physics, including avenues for involving scientists from the Boulder Valley in its educational mission. Private not-for-profit groups with complementary research interests include the South West Research Institute's Office of Space Studies and Colorado Research Associates, a division of Northwest Research Associates.

NOAA's Space Environment Center in Boulder builds upon such research to pursue applied and operational research activities, culminating in space weather monitoring, forecasting, and the development of national mitigation strategies. The Boulder Solar Alliance anticipates its members will eventually include local space industry partners such as Ball Aerospace and Technology Company, Raytheon, and Lockheed-Martin.

3.3 Determine Agency Roles

The NSWP is a confederation of agencies (table 3-4) that coordinate their space weather activities as individual agency funding and statutory directives permit. Although each agency has demonstrated considerable interest in, and commitment to, the NSWP, each member organization must adhere to its own mission statement and authorizing legislation.

Nevertheless, progress has been made in interagency efforts and resource coordination, information exchange, and planning. Probably because of the agencies' significant interest in the program, as evidenced by the close interactions of the cochairs of the Committee for Space Weather with each other and with the other three agency representatives on that committee, there has been an extraordinary—and at times novel—leveraging of interagency and intra-agency resources. The attendant planning and information exchanges fuel and sustain these successes.

Table 3-4. NSWP Agency Roles

Department of Commerce/ NOAA	NOAA has the mission of describing and predicting the Earth's environment. The SEC hosts an operational forecast center and research activities. The National Geophysical Data Center is responsible for national sensors (principally those operated by NOAA) and World Data Center archives.
DOD	The DOD develops operational models of the solar terrestrial system and develops and flight-tests new sensors. The Air Force forecast center provides basic and specialized support for military communications, surveillance, and warning systems that operate in or through the upper atmosphere or near-Earth space. The Air Force Research Laboratory and Naval Research Laboratory develop models for DOD operational use and develop or support development of sensors to measure the space environment.
NSF	NSF is responsible for maintaining the health of basic research in all areas of solar and solar-terrestrial science.
NASA	NASA's mission is space exploration and study of the Sun-Earth system. For space weather, the focus areas are causes of solar variability and impacts of variability on Earth and on human exploration of the solar system.
DOI	Within the DOI, the USGS participates in an international network of 98 geomagnetic observatories, several of which contribute data in real time to the Air Force and NOAA/SEC forecast centers.
DOE	Within the DOE are elements that study space weather in the context of nuclear weapons detection and elements concerned with space weather impacts on electrical energy transmission.
DOT	Within the DOT, the FAA is responsible for regulating and promoting the U.S. commercial space transportation industry. The FAA is the licensing and regulatory authority for the nascent space tourism industry. The DOT also fields a GPS-based capability to support en route, terminal, and precision approach operations for airports and heliports.

Among the notable achievements in individual agency and multi-agency activities are the following:

- The annual Space Weather Week meeting of approximately 300 users, government and service providers, and researchers increases in size each year and has been emulated by the European Space Agency (ESA).
- The American Geophysical Union established, with partial support from NSF, the on-line technical journal/magazine *Space Weather, The International Journal of Research and Applications,* with a hard copy *Space Weather Quarterly,* containing selected articles from the on-line edition. This journal facilitates communication across agencies and with the non-Federal communities.
- The NSF's annual competition for space weather grants is partially supported by the DOD and NASA.
- The Community Coordinated Modeling Center (CCMC) at NASA Goddard Space Flight Center operates with NASA, DOD, and NSF support.
- In several cases, DOD, NASA, NSF, and NOAA have coordinated their research and archival efforts in space weather.
- A new NSF Science and Technology Center, the Center for Integrated Space Weather Modeling (CISM) has been funded for a 5-year term, with the possibility of an additional 5-year extension. NOAA participates in CISM.
- New model and forecast products (related to the ionosphere, energetic particles, and the Sun) from NOAA/SEC and AFWA are in the pipeline or in test beds.
- The USGS provides real-time data from five observatories, which allows the Air Force to compute a real-time index of planetary geomagnetic activity called the Kp index.
- The DOD has funded several MURIs to support targeted academic research for DOD and dual DOD-civilian needs.
- The annual meeting of the American Meteorological Society includes sessions focused on space weather.
- The AFSPC has funded improvements to solar irradiance forecasting and neutral thermosphere density modeling for use in satellite drag specification.

Space Weather and Spacecraft Anomalies

Solar storms often produce anomalies in instruments and spacecraft flying in the Earth's space environment, even though these space flight elements are designed using the best current information on the environment. The solar storm events of October–November 2003 produced numerous anomalies on NASA and other spacecraft, many of which were itemized and discussed by Barbieri and Mahmot (2004) in an article in *Space Weather*.

Large numbers of qualitative and quantitative anecdotes exist from the earliest days of space flight related to space-encountered anomalies. A recent one, pointing out the importance of solar event alerts, is from a solar event that interfered with the use of Geostationary Operational Environmental Satellite (GOES) spacecraft for international search and rescue. NOAA GOES satellites form part of the Cospas-Sarsat, a multinational search and rescue effort that uses satellites to detect and locate emergency beacons carried by aircraft, ships, or individuals in distress. The NOAA U.S. Mission Control Center (USMCC) in Suitland, Maryland, encountered a series of GOES anomalies (radio interferences in this case) in early November 2004. One of the interference episodes was identified on the NOAA Office of Satellite Operations Daily News Report on November 3, 2004:

> The GOES-9, GOES-10 and GOES-12 satellites experienced radio noise during November 3 and 4, 2004. The GOES-9 and GOES-12 events occurred on November 3 and the GOES-10 event was during November 4. These satellites have several systems that receive 401 to 406 MHz, including the Satellite Aided Search and Rescue repeater. Of the events, the GOES-12 event was the most severe in both magnitude and duration (about 100 minutes). NOAA/NESDIS would like to receive the solar radio burst alerts. The frequencies of interest are 245 MHz, 410 MHz, and something around 2.0 GHz for our [the NESDIS] telemetry link

The problem was attributed to solar radio burst emissions, particularly in the low 400 MHz range. This event occurred during a 7,200 solar flux unit (sfu) burst on 410 MHz from a solar flare in Active Region 696.

The USMCC staff emphasized the importance of understanding problems that occur with search and rescue (SAR) operations, and the staff requested space weather alert support for this event. The requirement was passed on to AFWA at Offutt Air Force Base in Omaha, Nebraska.

The following excerpt is from the NOAA Office of Satellite Operations Daily News Report on November 3, 2004:

> GOES 12 at 0401Z on November 3: SAR receiver signal strength flagging red high intermittently. Engineers notified. GOES 12 at 0420Z on November 3: SAR receiver signal strength returned to normal for no apparent reason. SAR receiver signal strength will continue to be monitored closely.

3.4 Coordinate Interagency Efforts and Resources; Set Priorities; Ensure Exchange of Information and Plans

The Assessment Committee determined that the same assessment issues were relevant to these three NSWP activities. For the purpose of assessment findings and recommendations, the committee found it more useful to address all three activities together with respect to observing capabilities, forecasting capabilities, and specification capabilities.

3.4.1 Observing Capabilities

The NSWP has as its key data sources a number of important infrastructure elements maintained by the agencies active in space weather pursuits. These infrastructure elements are listed in tables 3-5 and 3-6, which update a similar table compiled in 1995 at the initiation of the NSWP (Tascione and Cliffswallow 1995). To highlight enhancements and deletions in this vital program infrastructure, the tables include the number of operational elements in each program or mission as of 1995 and as of late 2005.

3.4.1.1 Recent Gains in Operational Observing Capabilities

The most important active infrastructure enhancements during the last decade have been the positioning at the L1 Lagrange point of two solar and interplanetary monitors: the Solar and Heliospheric Observatory (SOHO) and the Advanced Composition Explorer (ACE). Data from these science missions are being used operationally and are the key providers of lead-time data in space weather forecasting. SOHO and ACE data, and results derived from these data, permeate current space weather nowcasting and forecasting. These data were identified in the 2000 NSWP Implementation Plan as required sources for four of six NSWP solar-interplanetary metrics. The prediction requirement in that plan cannot be met without an upstream solar wind monitor for comparison (OFCM 2000, pg. 2-24). Similarly, the target architecture level described in the NSSA *Space Weather Architecture Study* cannot be met without an upstream monitor (NSSA 1999, pg. 12; OFCM 2000, pg. C-2).

Among the most important passive infrastructure enhancements has been the development of technologies and algorithms to incorporate ionosphere parameters derived from GPS signals. The widespread use of GPS for space weather monitoring and forecasting was not anticipated in the 1995 Strategic Plan and was mentioned only sparingly in the 2000 Implementation Plan. Future support of these technology and algorithm developments would allow NSWP agencies and participants to take advantage of these new observational capabilities and to support the growing space weather forecast needs in the $20 billion GPS industry.

Another important enhancement of this passive infrastructure has been the effort to recover and predict neutral atmosphere densities from observed drag effects on space debris and inactive orbiting payloads. The DOD recently announced a reduction in density error estimates at 400 km from 16 percent to 10 percent through the use of a Dynamic Calibration Atmosphere to estimate density corrections directly from tracking observations. Most of the improvement has come in the climatological and day-to-day solar EUV forecasts. Geomagnetic storm interval forecasts still

Table 3-5. Space-Based Observation Capabilities for Operations

Program/ Mission	Product	Owner/ Operator	1995 Status[a]	2005 Status	Measurement(s) & Situational Awareness	Comments (*RT*= real time *NRT*=near real time)
Current programs/missions						
	Calibration satellites (inactive)	US DOD		~75	Satellite drag	Daily; input to drag model
POES/	LEO particles	US NOAA	4	4	Particle sensor	*NRT*
DMSP	LEO particles, mag./elec. fields, UV imaging	US DOD/ NOAA	3	3	Particles, plasmas, magnetometer, UV imager	To be replaced by NPOESS
LANL	GEO particles	US	3	2	Geosynchronous particles	Post analysis
GPS	MEO particles	US DOD		> 5	Radiation belt particles	Post analysis
GOES	GEO particles Solar X-rays, fields images	US NOAA	2	2	Solar X-ray and EUV, particles; geomagnetic events	*RT*
ACE	L1 particles & fields	US NASA /NOAA	0	1	Semi Operational Solar Wind Monitor	*RT.* no planned sustainment
SOHO	Solar/coronal images. spectral irradiances	US NASA /ESA	1	1	Science Mission Solar Monitor	*NRT;* no planned sustainment
Future programs/missions						
MetOp	LEO particles	EUMET SAT	2	2	Operational (same as POES)	Launch June 2006
NPOESS	LEO particles, elec. fields, UV imaging	US NOAA /DOD	3	3	Replace POES, DMSP	Launch to be determined; not as capable as DMSP
COSMIC	GPS occultation	Taiwan	4	4	Ionospheric electron density profiles	Launch 2006
STEREO	Solar/coronal images	US NASA	2	2	Solar Science mission	Launch 2006
SDO	Solar images, EUV magnetograms,	US NASA	1	1	Solar science mission	Launch 2008

[a] As reported in Tascione and Cliffswallow 1995.

offer a significant challenge for space weather forecasting and will require multiagency efforts to meet accuracy goals.

3.4.1.2 Near-Term Anticipated Gains in Operational Observing Capabilities

The European MetOp program (first launch in 2006) will improve NOAA/SEC operational products by providing additional polar data obtained with space weather particle sensors of the same design as those now flying on Polar-orbiting Operational Environmental Satellite (POES)

Table 3-6. Ground-Based Observation Capabilities for Operations

Program/ Mission	Product	Owner/ Operator	1995 Status[a]	2005 Status	Measurement(s) & Situational Awareness	Comments (*RT*= real time *NRT*=near real time)
SOON	Solar Optical Network	US DOD	5	3	H-alpha, white light, flares, active regions	*RT;* longitudinal network
	Other telescopes	US	5	> 5	Magnetographs, multi freq, H-alpha,	*RT;* national & internat'l observa-tories via Internet
F10.7	Penticton Radio Observatory	Canada	1	1	Single freq,, 10 cm	*Daily* Single observatory
DISS	Digital ionosondes	US DOD	13	15	Ionosphere parameters	*NRT;* legacy network
	Ionosondes	US, Internat'l		25	Ionosphere parameters	*NRT;* internat'l data exchange
	Ionosondes	Int'l	4	~ 90	Ionosphere parameters	*Post analysis*
IMS	Ionospheric Measuring System	US DOD	0	4	Total electron content and scintillation	Phasing out
SCINDA	Scintillation Network Decision Aid	US DOD		> 12	Equatorial scintillation	*NRT;* operated with internat'l partners
	Polarimeters	US DOD	4	0	Plasma irregularities	Phased out
Riometers	Relative ionosphere opacity meters	US	8	2	Polar cap absorption	*RT;* other internat'l networks available via Internet
GPS	Ground receiver stations	US		50	Total electron content	*NRT;* various net–works and cadence
GPS	Ground receiver stations	US, internat'l		> 125	Total electron content	*NRT;* expanded coverage & cadence; post analysis
USGS	Ground magnetometers	US	13	13	Geomagnetic Indices	*RT n*orthern hemisphere network
Other	Ground magnetometers	US, Internat'l	7	~150	Storm studies, index development	*Some RT, post analysis*

[a] As reported in Tascione and Cliffswallow 1995.

spacecraft. These data will improve the 'refresh rate' for POES products. The planned National Polar-Orbiting Operational Environmental Satellite System (NPOESS) will be a further improvement over POES and is expected to provide good space weather data. The next generation of GOES spacecraft (launch in 2006) will have a solar extreme ultraviolet (EUV) sensor, which will enable enhancement of the ionosphere and thermosphere models, especially those for satellite drag.

New research satellites will include Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC). Its fleet of GPS sensors for occultation observations will provide global electron density profiles. Solar Terrestrial Relations Observatory (STEREO), with its coronagraphs and solar-wind monitors, will provide predictions of coronal mass ejections (CMEs). There is a good chance that COSMIC and STEREO will be used operationally at some

point. Other research satellites include the Solar Dynamics Observatory (SDO), which will provide excellent solar UV images, magnetograms, and EUV spectra.

3.4.1.3 Near-Term Anticipated Losses in Operational Observational Capabilities

The NPOESS program will not provide the same space weather capabilities now available on Defense Meteorological Satellite Program (DMSP) satellites. A DMSP satellite has both a limb-view and nadir-view UV sensor. An NPOESS spacecraft will have only a nadir-viewing UV sensor. This difference will impact two key parameters: the electron density profiles and the neutral density profiles.

The most significant impact to space weather operations would result from the loss of ACE monitoring capabilities. This spacecraft at L1 provides essential advanced warnings and information used in numerous space weather prediction models, as well as in the SEC forecast center. Without ACE, the forecast centers will lose the capability to provide accurate predictions for numerous products. There is currently no plan to replace ACE, although China has announced plans for a similar spacecraft at L1. NOAA is currently supporting studies to evaluate possibilities for a follow-on capability at L1.

The SOHO coronagraph represents a critical solar monitoring capability. If it should eventually fail before a replacement is in place, its absence would materially degrade operational space weather forecasts. SOHO provides a unique view of, and advance warning about, potential space weather storms. STEREO will provide important data for an interval after its launch (summer 2006), but its orbit will inevitably move it from its most useful orbital position for space weather operational use.

3.4.2 Forecasting Capabilities

Table 3-7 illustrates warning, prediction, and analysis capabilities in each space weather regime as they were assessed in the 2000 NSWP Implementation Plan. Red indicates no capability to meet the requirements for the events in the given region, red/yellow (Red Yel) indicates very limited capability, and yellow (Yel) indicates some capability short of meeting operational requirements. No areas are coded green (capable of meeting requirements) because user-specified needs could not be met.

The following paragraphs, quoted from the 2000 Implementation Plan, summarize capabilities at that time in the four product areas of space weather warnings, nowcasts, forecasts, and post analysis.

> *Warnings.* Very little capability exists to warn for space weather events. Causal solar events can be detected in real time, but warnings based on these events lack sufficient reliability for immediate mitigation actions and do not provide useful lead time or information on magnitude and duration of the event.
>
> *Nowcasts.* Limited nowcasting capability based on rudimentary models exists at operational centers. However, the models offer little capability beyond information available from empirical methods and climatology. Capability is best when data to initialize the models are received in a timely manner.

Table 3-7. 2000 Implementation Plan Assessment of Capabilities to Meet Warning, Prediction, and Analysis Requirements[a]

	Warning		Nowcast		Forecast		Post Analysis	
Solar/Interplanetary	Red	Yel	Red	Yel	Red	Yel	Yel	
Magnetosphere	Red		Red	Yel	Red		Red	Yel
Ionosphere	Red		Red	Yel	Red		Yel	
Neutral Atmosphere	Red		Red	Yel	Red		Red	Yel

[a] Source: OFCM 2000, table 2-1, page 2-14.

> *Forecasts.* Forecasting capability suffers from the same weaknesses as warning capability, and, in addition, the challenge is greater because forecasting requires longer lead times. This in turn requires a more complete understanding of both the solar events that drive space weather and the way the space environment reacts to those events.
>
> *Post-Analyses.* Current capabilities are the strongest in support of post-analysis requirements; however, significant deficiencies still exist. The relatively strong capability in this area derives from the fact that some post-analyses are not required in real time. This allows the analyst to gather data that may not have been immediately available to operators and to assimilate it at leisure.
>
> In summary, these limited capabilities come from a basic understanding of space weather combined with a limited observation base and still rudimentary computer models. However, they lack the necessary accuracy and four-dimensional detail to meet operational requirements.
>
> (OFCM 2000, pg. 2-14)

Table 3-8 illustrates the best estimates for the status of capabilities to meet requirements in these same four product areas, using the same color codes as for table 3-7. There have clearly been some improvements in some areas over the past half-decade. There are, however, still no green boxes. The next four paragraphs provide the basis for these assessments.

Table 3-8. Assessment of Warning, Prediction, and Analysis Capabilities in 2005[a]

	Warning		Nowcast		Forecast		Post Analysis	
Solar/Interplanetary	Red	Yel	Red	Yel	Red	Yel	Yellow	
Magnetosphere	Red	Yel	Red	Yel	Red		Red	Yel
Ionosphere	Red	Yel	Red	Yel	Red		Yellow	
Neutral Atmosphere	Red	Yel	Red	Yel	Red	Yel	Yellow	

[a] Estimates by the NSWP Assessment Committee of status as of late 2005, based on 2005 requirements.

Warnings in 2005. Ordinary solar event occurrences can be detected in real time. With the positioning of spacecraft at L1 and advances in modeling capabilities, some space weather warning requirements are being met. ACE data generally provide a 1-hour lead time for the onset

of geomagnetic storms. Data on energetic particles sensed at L1 provide some warning of rising fluxes of such particles due to interplanetary disturbances. Rising energetic particle fluxes are also monitored by NOAA GOES spacecraft and DOE and other satellites in geosynchronous orbit.

Nowcasts in 2005. The SEC introduced the NOAA space weather scales for geomagnetic storms, radiation storms, and radio blackouts from ionospheric storms. In addition, interested parties can view text or graphic displays from five model outputs at http://www.sec.noaa.gov using pull-down menus. Tailored products are becoming available from both SEC and the DOD for specific customer needs. Most models are still empirically based, but some parameterized, partial physics-based models are coming on line. Timely data access often remains a weak link in the nowcasting process.

Forecasts in 2005. Forecasting capability is just beginning to make strides. If transition resources are sufficient, the lag from major model inception to rudimentary forecasting capabilities appears to be roughly 5 years. However, as discussed elsewhere in this report, lack of adequate transition resources has hindered progress in NSWP operational forecasting capability.

Post-Analyses in 2005. National capabilities are strongest for post-analysis products. The dominant work in this area is by the academic community, with contributions from some agency laboratories, such as NASA centers, AFRL, and DOE's Los Alamos National Laboratory (LANL). NSF and NASA have supported a number of specific retrospective studies via various campaign programs and studies including International Solar-Terrestrial Physics Project (ISTP), Geospace Environment Modeling (GEM), Coupling, Energetics and Dynamics of Atmospheric Regions (CEDAR) and Solar and Heliospheric Interplanetary Environment (SHINE). The operational centers also perform assessments of major storms as customer needs and time dictate.

3.4.3 Specification Capabilities

NASA and the DOD have supported space radiation specification tools that are being adapted for use in Earth's atmosphere. The FAA has its own radiation code, CARI-6, that calculates the effective dose of galactic cosmic radiation received by an individual on an aircraft flying a great circle route between any two airports in the world. The program takes into account changes in altitude and geographic location during the course of a flight, as derived from the flight profile entered by the user. Similar model developments are being pursued in Europe and Canada to describe the radiation environment for high altitude flights and long-haul tropospheric flights. Some international airlines monitor radiation dose for specified routes and for flight crew members.

> ***Finding 3.2.*** The FAA Air Traffic Organization's advisory *User Needs Analysis* identifies biological radiation exposure as a specification and prediction issue. The FAA Civil Aeromedical Institute has a rudimentary interface for public use available on the internet.
>
> > ***Recommendation 3.2.1.*** The NSWP should encourage and facilitate collection and analysis of real-time background radiation levels at space and aircraft altitudes. As a body, the NSWP should devote interagency resources to

incorporate estimated dosage from energetic particle events into cosmic radiation exposure estimates and to make the specifications and results easily accessible, usable, and interpretable by the public via the Internet.

3.4.4 Assessing Capabilities with Metrics

The Assessment Committee received little data comparing performance to the metrics outlined in the NSWP 2000 Implementation Plan. Such information was proffered neither by the individual Agencies nor in the Committee on Space Weather briefings of the Assessment Committee.

> ***Finding 3.3.*** Little information was available on program performance as related to the metrics given in the latest (2000) NSWP Implementation Plan.

3.4.5 Agency Versus Interagency Efforts and Resources

The various infrastructure, warning, prediction, and analysis elements listed in tables 3-5 to 3-8 are largely the result of the actions and decisions—and thus priority setting—of individual agencies, although information is provided to the other agencies through the auspices of the Committee on Space Weather. Because of this loose confederation approach to participation in the NSWP, significant and progress-inhibiting gaps often occur in overall NSWP planning, coordination, role-determination, and priority-setting. Such gaps are most apparent in the realms of program metrics and programs that require interagency agreement on major spending. The consequences of these gaps are particularly noticeable for planning and budgeting and for solar and interplanetary monitors.

> ***Finding 3.4.*** The National Space Weather Program Council does not have the authority to mandate roles, responsibilities, or priorities for space weather infrastructure needs. Nor can it allocate resources.

These needs are still largely addressed by individual agencies to the detriment of a truly national program.

Space Weather in Department of Defense Operations

The three anecdotal examples presented here of space weather impacts on DOD operations demonstrate two points: First, the infusion of space weather support to DOD operators can have a positive impact on operations. Second, a great deal of customer education in space weather remains to be done; often the operator is unaware when space weather is the cause of a problem. All three of these problems were encountered within the past 1–5 years.

- High Frequency (HF) radio operations are often impaired during active flare events for regions located on the sunlit side of the Earth, particularly near the subsolar point. Forecasters in the Air Force Space Weather Operations Center (SWOC) produce warning bulletins for these short-wave fade events and then usually contact HF centers near the subsolar point to confirm loss or degradation of HF communications. During one such event, the forecaster contacted the center in Hawaii and requested a communication check with Yokota, Japan. The radio operator returned to the phone reporting Yokota was heard "loud and clear." The stunned forecaster asked what frequency the operator used and was told: "Oh, I couldn't get him on the radio, so I called him on the phone."

- A deployed team was trying to conduct a daily briefing using satellite communications each day at 2100L (9:00 pm local). Due to constant communication issues, the team struggled each day to conduct these briefings. When a weather forecaster (who had a background in space weather) deployed with the team, he quickly determined that the cause of the problem was ionosphere scintillation. With this key piece of information, the deployed team was able to work their briefing times to avoid scintillation effects.

- Radio operators in Thule, Greenland, were having strange multi-day radio outages that were attributed to equipment maintenance issues. Maintainers would spend days pulling radios apart, never being able to determine the cause. The Thule unit then began receiving space weather support and discovered that polar cap absorption events were the cause of the long-term radio outages and had nothing to do with the performance of the radios themselves. Infusion of space weather support saved many hours of fruitless maintenance support.

3.5 Encourage and Focus Research

Research has sustained the NSWP effort during the past 10 years. Agencies under the NSWP umbrella successfully seeded a number of research initiatives. These initiatives have two forms: *targeted* research and *strategic* research. Distinctions between the two types of research are sometimes difficult to draw definitively. "Targeted research" as used here denotes research that is aimed at specific and immediate space weather–related problems. "Strategic research" denotes a planned research effort that addresses broader physical and process issues in space weather. Tackling strategic issues typically requires crossing agency boundaries and coordinating agency funding. New research funding may be necessary.

As discussed below, a burst of targeted research activity arose in the FY 2000 time frame. The sustainability into the future of such targeted research is unclear at the present time. A planned, synergistic approach to research at the multi-agency level will probably be required to sustain future efforts.

3.5.1 Targeted Research

3.5.1.1 National Science Foundation

During the past 10 years, NSF has been an extraordinarily effective catalyst for individual, institutional, and interagency research. A new annual competition for proposals within the Upper Atmosphere Research Section (UARS) created an additional funding opportunity for individuals and teams focusing on observational and predictive research in space weather as a system. Although NSF does not fund transition-to-operations activities, UARS has actively supported verification and metric comparison projects at NASA's Community Coordinated Modeling Center (CCMC). UARS also funds operations at several major ground observatories that contribute to space weather research. Development of the Advanced Modular Incoherent Scatter Radar (AMISR), a major new ground-based facility for studying space weather and characterizing ionosphere-magnetosphere coupling, is the fruit of UARS-supported research facilities. The NSF-funded Synoptic Optical Long-term Investigation of the Sun (SOLIS) is currently providing full-disk and high-resolution line-of-sight magnetograms on a daily basis.

With support and consultation from UARS, NSF invested in a major National Science and Technology Center, the Center for Integrated Space Weather Modeling (CISM). This is a 5-year (with possibility for a 5-year renewal), multimillion dollar effort to understand and model the dynamic Sun-Earth system. The goal is to create a physics-based numerical simulation model that describes the space environment from the Sun to the Earth. CISM's modular approach allows individual researchers to insert promising new empirical or physics-based modules as they are developed.

3.5.1.2 Department of Defense

Funding by the DOD for targeted research has had strong justification from specific users. During the past 5 years, the DOD has invested heavily in modeling and forecasting efforts via a funding tool known as a Multidisciplinary University Research Initiative (MURI).

There have been three DOD-sponsored MURIs in targeted space weather research. The first, a Space Weather MURI awarded to the Center for Space Environmental Modeling (CSEM) at the University of Michigan, was focused on modeling and predicting solar eruptive events and their effects on space weather. Some elements of the CSEM MURI are now undergoing evaluation at the CCMC. This Space Weather MURI is closely coordinated with its sister effort, the Solar MURI, coordinated by the University of California, Berkeley. Utah State University (USU) and University of Southern California (USC) participated in a third MURI for assimilation of ionospheric data. As a result, the USU Global Assimilation of Ionospheric Measurements (GAIM) model is transitioning to operations at AFWA in 2006. Validation has been supported by AFRL. At present, no further MURIs have been identified.

The Office of Naval Research has supported targeted research in:

- Solar coronagraphs and solar wind monitoring
- Improved ionosphere specification and forecast, including initiatives such as GAIM and imaging from geosynchronous orbit
- Ultraviolet remote sensing of the thermosphere and ionosphere
- Low-cost, quick-launch vehicles.

The Large Angle and Spectrometric Coronagraph (LASCO), developed by a consortium led by the Naval Research Laboratory (NRL) as an instrument on the joint NASA-ESA SOHO mission, has been returning images of the Sun's atmosphere from L1 since its launch in December 1995. NRL continues to be active in sensor development. It's contributions to future space weather missions include three different coronagraphs and an EUV imager on two independent spacecraft for the NASA STEREO mission, as well as a high-resolution spectrometer to be flown on the Japanese Solar-B mission.

The Air Force has led the effort to develop operational nowcast and forecast improvements for the neutral atmosphere with a project that incorporates the Dynamic Calibration Atmosphere along with a substantially revised empirical thermospheric density model.

The Space Weather Center of Excellence in the AFRL Space Vehicles Directorate supports both in-house and contracted research in:

- Development of empirical, assimilative, and/or physics-based models to fill gaps in sensor coverage
- Physics-based and quasi-empirical models for high-priority forecast regimes
- Improved design tools and exploration of active techniques to improve and extend the lifetimes of systems subject to space weather damage
- Ground-based and space-based sensors to feed data-starved specification models.

An example of AFRL-sponsored research that has transitioned to operations is the Scintillation Network Decision Aid (SCINDA)—a ground-based sensor and computer model system that specifies and forecasts satellite communication outages caused by ionospheric scintillation.

Recent AFRL initiatives include the Solar Mass Ejection Imager (SMEI) satellite mission, which has been on orbit since 2003. To date, hundreds of CMEs have been catalogued for study. Substantially more analyses and publication of these data would be very worthwhile for basic solar and interplanetary research, as well as for space weather purposes.

AFRL scientists have developed a new application of the satellite magnetometer data from the DMSP system to aid in forecasting extreme upper-atmosphere heating events. Such events are likely to create excess drag on satellites in low Earth orbit (LEO), resulting in loss of precision satellite orientation, as well as a significantly degraded ability to track satellites and other objects in LEO.

The DOD's space weather research effort at AFRL has been compromised at times. Program funding cuts, patchwork-like tasking from multiple user organizations, and customer-funded research have, in essence, created a bimodal distribution of efforts in basic research and advanced technology development at the expense of applied research. As a result, efforts in model transition, ground-based instrument fielding, and space-based instrument development have stretched into decade-long time frames.

Long-term funding for DOD space weather research activities appears to be in decline. Despite recommendations for a "robust space weather research and development program" from the 1999 NSSA *Space Weather Architecture Study* (see Appendix E), there appears to be no coherent plan for long-term space weather research funding and/or prioritization at the DOD executive agent level (NSSA 1999, pg. 10). Further, a significant fraction of the AFRL space weather work force will be eligible for retirement over the next 5 years.

3.5.1.3 Department of Energy

LANL is working on a targeted program to assimilate radiation belt data into a Dynamic Radiation Environment Assimilation Model (DREAM). The effort focuses on understanding natural and artificial processes in the radiation belts. (See the sidebar box "Nuclear Weapon Effects and the Space Environment" at the end of section 3.5.)

3.5.1.4 Department of the Interior

USGS investigators conduct limited research, consistent with budget constraints, on new uses and applications of ground magnetometer data. These data are used for the construction of geomagnetic indexes to assess the space weather state of the ionosphere and magnetosphere. The data provide important backup capability for situational awareness of the geomagnetic environment in the event of a data outage from space assets at L1.

3.5.1.5 Department of Commerce

The NOAA/NWS presentation to the Assessment Committee indicated that the transition of the SEC to operational status within NCEP could reduce SEC targeted research activities—activities that lead to new forecast products and services. In particular, two important research activities appear to be at risk:

- Understand the processes that influence space weather and develop applications for the user community
- Develop new and improved products and transition them into operations to meet evolving users' space weather needs.

It is not clear how NOAA will address this situation.

3.5.1.6 National Aeronautics and Space Administration

NASA space weather research contributions are in two primary areas: (1) Living With a Star (LWS), an initiative focused on space weather and the space environment, and (2) space hardware already on orbit. LWS could also be considered in the strategic research category in that many elements of this program address issues that can affect NASA space systems and future programs, including human exploration.

The primary objective of the LWS program is to perform investigations in space to understand solar variability and its effects at Earth, leading to a capability for reliable prediction of solar variability (i.e., space weather). LWS has three major program elements: Spacecraft, Space Environment Test beds, and Targeted Research and Technology (TR&T) grants.

- The LWS-supported Solar Dynamics Observatory (SDO) is scheduled for launch in 2008. Proposals for the Radiation Belt Storm Probes (RBSP) are under review, and the program may slip somewhat due to decreases in the LWS program budget. The Ionosphere Storm Probes (ISP) are currently delayed for almost a decade, even though the NRC's Decadal Research Strategy in Solar and Space Physics (NRC 2002) envisioned ISP as comprising, with RBSP, a comprehensive system for investigating the Earth's space environment.
- The Space Environment Test beds Project is the element of LWS intended to characterize the space environment and its impact on hardware performance in space.
- NASA has formed focused research teams to tackle problems of pressing concern within the overall TR&T program. The aim of TR&T is to provide a physics-based understanding of the Sun-Earth system. In addition to research topics associated with NSWP activities, LWS research topics include analysis of energetic particles that pose a hazard to astronauts or technology and analysis of the effects of solar variations on Earth's climate.

In 2006, NSF and NASA are jointly administering a basic research grants program focused on high-priority needs in space weather modeling. This joint activity will provide the research community with about $1.5 million of support for focused space weather modeling. Similarly, a joint NSF-NASA program is funding the Global Oscillation Network Group (GONG) to provide real-time line-of-sight solar magnetograms and far-side solar imaging.

Space hardware already on orbit continues to make important and critical contributions to space weather research, as well as to operations. The ACE and SOHO satellites are the most compelling examples of critical contributions to applicable space weather objectives. Many essential space weather forecast products rely on data from these research satellites. Yet, as

shown in table 3-9, more than half of the currently flying research missions of importance for space weather data are scheduled for termination by 2011.

Table 3-9. Operating NASA Science Missions

NASA Mission	Launch	Mission End	Organization	Comments
IMAGE	2000	December 2005[a]	GSFC	
Polar	1996	Mar 2007	GSFC	Fuel Depleting
Ulysses	1990	Mar 2008	JPL	Begin 3rd Pass over Sun
FAST	1996	July 2008	GSFC	
Geotail	1992	July 2008	GSFC	
TRACE	1998	Nov 2008	GSFC	
Cluster	2000	~ 2010	GSFC	
ACE	1997	> 2011	GSFC	
RHESSI	2002	> 2011	GSFC	
SOHO	1995	> 2011	GSFC	
TIMED	2001	> 2011	GSFC	
VOYAGER 1 & 2	1997	> 2011	Cal Tech	V1 - 99 AU, V2 – 80 AU
Wind	1994	> 2011	GSFC	
SAMPEX	1992	TBD	GSFC	Mission extended via multi-agency agreement

[a] IMAGE failed in orbit in mid-December 2005.

3.5.2 Science and Operational Data Sources

From the review in section 3.5.1, it is clear that much of the data essential for observing and predicting space weather for both civil and national security systems are presently obtainable only from scientific research satellites such as ACE and SOHO. Many other in situ space weather data are also obtained from primarily science-driven satellite programs (e.g., TIMED, Polar). Major exceptions to this reliance on research spacecraft are the geosynchronous energetic particle data that are acquired under the auspices of the DOE; the particle, magnetic field, and solar x-ray data from NOAA's GOES and POES spacecraft; and the DOD's DMSP spacecraft. While individuals in relevant agencies recognize the often ad hoc nature of the data sources for space weather applications, the Assessment Committee found no active planning for specific space weather missions that would provide the data required for continuation of many important space environment monitoring and prediction programs.

Even given the recognized ad hoc nature of the critical data sources, there appears to be far too little discussion among the agencies in the NSWP as to the prioritization of the data types and sources that are required for space weather research and for operational applications. This situation leads to too little planning for contingencies in the event that some data (space- or ground-based) become unavailable for whatever reason. In the case of science missions that are at or beyond their design lifetimes (see table 3-9 above), the committee could discern little

interagency strategic planning for replacement data sources when service life finally ends, whether suddenly or gradually over some time interval.

Many ground-based data that are used for determining geomagnetic activity and ionosphere parameters (e.g., magnetometers, ionosondes, GPS receivers) are acquired for other than space weather applications. To obtain the necessary global data coverage, many of the data sources are, of necessity, foreign. The future reliability of such sources, and therefore their supply for their use for national interests, is not sufficiently well understood. While officials express concern about the loss of data from such sources, there does not appear to be any planning for possible back-up alternatives (if indeed any alternative sources are available).

> ***Finding 3.5.*** Many data sets that are critical for both civilian and national security elements of the NSWP are obtained from science programs of often limited duration (some of these sources are already beyond their design lifetimes) or from sources originally designed for other objectives. Relatively little discussion and contingency planning are underway as to how the NSWP will incorporate possible foreign sources of critical space weather data if some national data sources become unavailable.

Many instruments designed as data sources for operational space weather applications need not achieve the high precision of measurements usually required for scientific research objectives. Measuring to within 20 percent (or perhaps with even less precision) is generally good enough. Such loosening of requirements means a significant reduction of costs. Of particular promise for carrying affordable space weather instrumentation is the new class of "micro-satellites." These systems weigh some 50-200 kilograms and cost on the order of $10–$30 million to construct and launch. The Student Nitric Oxide Explorer (SNOE) satellite, built and operated for more than 6 years at the University of Colorado for less than $5 million, produced a large and unique data set that is important for several problems in space weather. Slightly larger mini-satellites weighing about 500 kg have also been built for very low cost. (See the sidebar box "Micro-Satellites and Space Weather" following section 3.6 below.)

Until recently most micro-satellites have been launched into LEO, but this is changing. Moreover, most successful micro-satellites have been European developments. The Space Technology Centre at the University of Surrey (U.K.), a leading European developer of micro-satellites, has been building lightweight, low-cost satellites for more than 20 years. The University of Surrey recently successfully built and launched the prototype for Galileo, the European global positioning system. The cost of this high-orbit satellite was $30-$40 million. Recent progress by the DOD, DOE, and NASA has shown that U.S. capabilities in this low-cost area are growing as well.

> ***Recommendation 3.5.1.*** The cooperating agencies in the NSWP should investigate immediately the feasibility of using micro-satellites with miniaturized sensors to provide cost-effective science and operational data sources for space weather applications.

A major policy decision will face the NSWP if, for example, the only L1 data available at some point in the future were to be those supplied by another country, especially if such data were

critical for applications and predictions, as ACE data are currently. Some other space-faring nations appear to be considering the acquisition of data useful for space weather warnings and prediction. For example, China may be planning an L1 spacecraft that could provide interplanetary data similar to those now acquired by ACE. Similarly, if some of the geomagnetic or ionospheric data that are currently acquired from other nations were suddenly denied to U.S. users, civil and national security monitoring and prediction activities would face a difficult situation.

> ***Finding 3.6.*** It is particularly critical to ensure continuity of space weather observations at L1 and continuity in delivery of that data in near real time. Planning for continuity is necessary prior to the failure of current scientific instruments at L1.
>
> > ***Recommendation 3.6.1.*** Micro-satellites and other small missions should be seriously pursued as an option for providing continuity of critical space weather data from observations at L1.

Retrospective data from data centers can serve as invaluable sources for the examination of past events of space weather importance and for reexamination of solar-terrestrial space weather patterns in the context of new scientific understandings, even years after the observations are made. Important data centers in this regard are the NOAA National Geophysical Data Center and the NASA National Space Science Data Center. Both provide invaluable data archiving and access to past data sets.

The Decadal Research Strategy in Solar and Space Physics stated that engineers are typically interested in space climate, rather than space weather, when designing ground- and space-based systems. The goal of designers is to design a system to be immune to space weather effects as much as is feasible. For design purposes, "the space environment should be removed from the equation; any further space weather issues that might arise can be dealt with separately." To do this, designers need long-term averages of space weather phenomena, the uncertainties in these averages, and values for extreme conditions (NRC 2002, pp. 15, 123).

The NSSA *Space Weather Architecture Study* also stressed the importance of a space weather information archive. It recommended consolidating and expanding the existing archival system to capture space weather environmental data and systems impacts (NSSA 1999, pg. 14).

Data centers can be invaluable in providing retrospective data that can be analyzed and used for space weather climatology studies and model building. However, as the Decadal Research Strategy noted, when climatology models of the space weather environment are developed, extreme conditions tend to be either ignored or not properly represented. The reason for this tendency may be that too few data points exist to justify including them in a statistical database (NRC 2002, pg. 123).

The Decadal Research Strategy concluded that designing for space weather conditions could be considerably enhanced if a centralized database of past extreme space weather conditions existed. The authors recommended that such a database be established. It should cover as many relevant space weather parameters as possible. A possible location for such a database could be

within either NOAA/SEC or NOAA's National Geophysical Data Center (NRC 2002, pp. 15, 123).

3.5.3 Strategic Research

All agencies that participate in the National Space Weather Program Council (NSWPC) have strategic research components in support of their own agency's goals. These strategic components can be the ones most likely to suffer reductions in times of tight budgets. This is a serious concern because strategic research initiatives create the pool of knowledge from which focused applications are developed.

There is a lack of strategic research planning at the NSWPC level. For example, users have identified the lack of in situ thermospheric and ionospheric measurements as a significant data and knowledge gap that inhibits the development of several space weather applications. There currently appear to be no plans for new capabilities in these critical areas until 2015 or beyond. Some space weather data sources may also be lacking in the future because cost overruns in the NPOESS program may necessitate elimination of some instrumentation.

Strategic research is closely related to the level of space situational awareness that may – or may not – exist in the relevant agencies at a given time and over major planning cycles. It is very important that the senior leadership in agencies with space weather–related responsibilities have a good working knowledge of space environmental impacts, as well as the knowledge of the research required to address these impacts. Of particular concern to the Assessment Committee is the status of strategic research in two agencies—the DOD and the DOE.

3.5.3.1 Department of Defense

Strategic research is particularly important for the DOD because the military services anticipate greatly increased reliance on space systems in the decades ahead. Recognizing this importance, the DOD in concert with the National Reconnaissance Office (NRO) initiated a Space Weather Architecture study in 1998. The study was conducted by the NSSA, which had been charged with conducting analyses across the entire range of national security space interests. The key findings and recommendations from the study (NSSA 1999) are summarized in Appendix E. While the national security community has made progress on some of the NSSA recommendations, others have not progressed—particularly the recommendations on strategic research and planning.

The first area of NSSA focus was general space architecture development. The NSSA study recommended emphasis on operational model development. Considerable progress has been made by DOD in the MURIs noted earlier. However, the DOD has been less successful in translating and transferring this understanding into operationally useful prediction and procedures, largely due to insufficient resources and to reductions in the number of professionals trained in space weather.

The NSSA recommended a vigorous effort in space weather importance awareness. In discussions with operational commands, the Assessment Committee found that, while individuals understand the import of space weather, little progress has been made command-

wide in this important area. Relegation of space weather to non-space-oriented organizations appears to have contributed to this problem.

The NSSA recommended the identification of a central cognizant organization within DOD to oversee space weather. It appears that such an organization does not exist, although the NSSA's successor organization, the National Security Space Office, may be the appropriate location for such a function.

The NSSA study made recommendations concerning a central space weather information archive (NSSA 1999, pg. 14). NOAA's National Geophysical Data Center, AFWA, and the AFSPC Space Situation Awareness Information Office each have portions of such an archive. It is not clear, however, that these portions are connected in any meaningful way. This situation hampers the DOD's ability to respond to the NSSA recommendations on central requirements development and user information. The matrix of organizations that currently exists appears disconnected from the top-level coordination functions recommended in the NSSA study.

An area of increasing focus for the DOD was covered in the NSSA recommendations on space weather and man-made effects. The study recommended that the DOD:

- Support the Space Control Protection Mission by providing timely space weather information
- Incorporate the operational specification and forecasting of space environmental effects of man-made (primarily nuclear) events (MME) as a mission into the space weather architecture (NSSA 1999, pg. 18).

Although they recognize that space weather is part of the top-priority space situation mission, the DOD's operational elements do not appear to have connected space weather in a cohesive way to the MME mission area. In contrast, DOD research organizations have embarked on a focused effort to mitigate the damaging and potentially catastrophic effects of a radiation belt pumped up by a nuclear explosion. This research area, Radiation Belt Remediation (RBR), depends critically on accurate space weather understanding and prediction. (See sidebar box "Nuclear Weapon Effects and the Space Environment" at the end of section 3.5.) It does not appear that the DOD has fully made the connection between RBR and space weather. Leadership in such matters can only come from the senior leadership in the relevant agencies.

3.5.3.2 Department of the Interior

Similarly, but in a different realm—on the Earth's surface—the USGS National Geomagnetism Program provides important inputs into many critical NSWP products. Yet it appears that the importance of (and the necessary resources for, including some funding for strategic research) the geomagnetism program is not appreciated even by many within the space weather community, let alone by national and agency leaders.

3.5.3.3 Summary on Strategic Research

While the NSWP must certainly stress the importance of space situational awareness to critical national interests and the impacts and potential consequences of space environmental activity on these interests, it is also important that the program not devolve into sensationalism. Space

weather impacts could be severe in some cases, including the loss of some satellite-provided services, communications, and even power grids. It is unlikely, however, that the average citizen will experience or suffer a space weather event that would have devastating consequences comparable to the recent hurricane or tsunami damage. As noted earlier in this chapter, comprehensive and rigorous strategic research and impact analysis of likely and possible impacts (including cost impacts) do not exist at present for space weather, but they are needed.

Finding 3.7. The benefits of having space weather strategic research and space situational awareness must be more meaningfully assessed and promulgated.

Recommendation 3.7.1. The NSWP must enhance its efforts to educate the U.S. Government, wider technical communities, and the public on the importance of strategic research and space situation awareness to national interests, particularly about the possible consequences of space weather events for national interests.

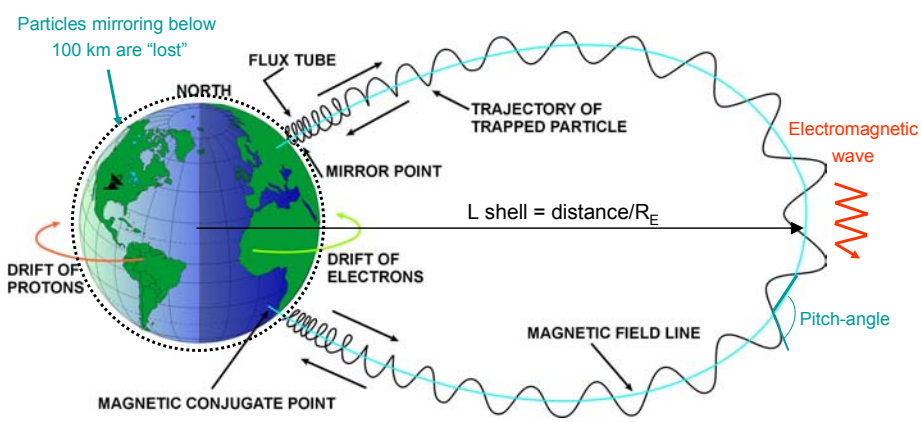
Nuclear Weapon Effects and the Space Environment

On June 19, 1962, the United States detonated its first nuclear explosion in space, code-named Starfish. The 1.4-megaton explosion at an altitude of 400 km produced beta particles (electrons) that were injected into the Earth's magnetic field, where they formed an artificial radiation belt. This artificial electron belt lasted until the early 1970s. The first failure (in one of a redundant pair of command lines) on the Telstar 1® communications satellite, which was launched the day after the Starfish explosion, occurred within about 2 months of launch. The radiation produced by Starfish destroyed seven satellites within 7 months, primarily from damage to their solar cells.

The interaction of nuclear detonations with the space environment is of significant concern for at least two U.S. Government agencies: the DOD and the DOE. The DOD relies on dozens of space systems for critical combat support. A Starfish-type scenario could potentially destroy much national security space infrastructure. The DOE maintains a large constellation of space sensors designed to detect and characterize nuclear explosions. While the DOD seeks to mitigate changes to the space environment, DOE wants to understand the complex interactions of nuclear explosions and the space environment in order to better detect and characterize possible new entrants into the nuclear weapons arena.

The Defense Advanced Research Projects Agency (DARPA) in the DOD has begun, in concert with AFRL, an ambitious program to mitigate the effects of radiation injection into the radiation belts. In essence, the research seeks methods to remove trapped particles. This must begin with a precise and thorough understanding of the radiation belts and their current configuration. Low-frequency radio waves injected into the belts might be able to change the trapped population so as to quickly precipitate out the damaging particles (see figure below).

The DOE also seeks a detailed understanding of the radiation belts and their current configuration. From this understanding, the DOE can use the measurements acquired by its space sensors to pinpoint nuclear weapons activity that occurs in or above the atmosphere. This detection capability is a central element of the Nation's nuclear nonproliferation strategy. LANL is developing a sophisticated, linked model called Dynamic Radiation Environment Assimilation Model (DREAM) as a central tool for this effort.



To remove particles the magnitude of the velocity need not be changed - just the angle between the velocity and B field

Figure 3-4. Mitigating the effects of nuclear explosions on Earth's radiation belts. DOD's Radiation Belt Remediation program seeks to remove high-energy particles from the radiation belts by using low-frequency radio waves to change the pitch angles of the trapped particles. This process lowers the particle mirror points to greatly increase energetic particle losses through their collisions with the atmosphere.

3.6 Facilitate Transition of Research Results Into Operations

Both empirical and physics-based modeling have advanced significantly since the inception of the NSWP. A vision for "technology transfer" of information, data, and models existed when the NSWP began in 1995, and the 2000 Implementation Plan identified three primary transition paths: the Community Coordinated Modeling Center (CCMC) and two Rapid Prototyping Centers (RPCs): one at NOAA/SEC, the other within the DOD (OFCM 2000, pp. ES-4, 2-25 to 2-27).

At the operational level, the "….well-planned and well-executed technology transfer" envisioned in both the 1995 Strategic Plan and the 2000 Implementation Plan (OFCM 2000, pg. 2-25) has yet to materialize. Transition of data, models, and applications into operations has suffered from serious resource deficiencies and appears to follow a tortuous path that wastes resources and slows the expected use of new information and models.

3.6.1 Community Coordinated Modeling Center

Within the transition-to-operations paradigm, the CCMC provides model access and validation leading to comparison with community-designed metrics. As of early 2006, the CCMC is exercising 19 models, including 2 real-time simulations. Experience with and critiques of these models feed back to the model developers. The models being exercised are in the following classes:

- Solar—four models, two of which are physics-based
- Heliosphere—four models, two of which are physics-based; one incorporates data assimilation
- Magnetosphere—six models, four of which are physics-based
- Ionosphere—five models, four or which are physics-based; one is statistical

Five of these models have completed initial metric studies.

3.6.2 National Oceanic and Atmospheric Administration

NOAA/SEC has established a dedicated workspace for transition activities, but the activity is currently resource-constrained. Approximately 5 percent of SEC staffing is currently allocated to transition activities.

Two recent transitions are contributing, or approved for contribution, to the SEC operational baseline:

- SOLAR2000 E10.7 radiation flux model (also under further development for applications at AFSPC)
- Aviation web page.

Six new models are currently running on SEC development computers for test and evaluation to determine their suitability as candidates for transition:

- U.S. TEC Model (Total Electron Content over the United States)
- Solar wind propagation model
- Magnetopause model—predicts location, shape, and variations
- AP forecast model—predicts a geomagnetic index
- Polar cap high-frequency propagation model
- Regional magnetic disturbance model.

The eventual transition to operations of these models, as well as of models that become available in the future, will depend upon the availability of resources.

3.6.3 Department of Defense

DOD model transition activities appear to be divided among AFRL, NRL, elements of AFSPC, AFWA, the DOD-funded MURIs in space weather, and teams within the University Partnering for Operational Support (UPOS) collaboration. Whether a matrixed system such as this can efficiently and rapidly transition models remains to be determined.

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Recent transitions are contributing to the AFWA/SWOC operational baseline:

- Operational Space Environment Network Display (OpSEND) and SCINDA
- Magnetosphere Specification and Forecast model (an inner magnetosphere model)
- Improved Real-Time Kp Estimate and Auroral Boundary Specification and Nowcast
- Relativistic Electron Prediction (produces a 27-day forecast for geostationary satellites)
- Solar wind and interplanetary shock propagation model
- GAIM model (scheduled for operational capability in 2006).

OpSEND is a radio propagation, navigation, and communications tool. The OpSEND team received the Air Force Merewether Award in 2001 for the most significant technical contribution to the air and space weather mission.

A recent transition that is contributing to the AFSPC operational baseline is the High Accuracy Satellite Drag Model. It incorporates near-real-time observations of LEO calibration satellites to estimate thermosphere density.

Both AFWA and SEC lack predictive models for several domains and continue to rely on conditional climatology and global indices as specification and forecast tools. This situation is the result of gaps in basic research understanding, undersampling of domains, and funding shortfalls and instabilities.

In summary, NSWP agencies and participants appear to recognize that major challenges remain in technology transfer, including model validation and how to link the best models together in a suitable framework that will be useful (and usable) by operational agencies. Another major challenge is the validation, and update as necessary, of linked models and their various modules.

3.6.4 Summary on Facilitating Transition to Operations

The Assessment Committee's investigations have shown that modeling capability in the NSWP will continue to improve as the existing relatively static "climate" models of the space environment become more dynamic and responsive to data assimilated in real time. The committee has found overwhelming evidence that space weather users and systems operators require local situational awareness through better data-infused specification ("nowcast") models. Users and operators also require accurate, data-driven models that provide 1–5 day forecasts tailored to their programmatic requirements. DOD-specific requirements are for 72-hour to 120-hour forecasts. The requirements of data assimilation in an operational environment are clearly a very high priority; civilian and military users require operational models that can assimilate real-time data and produce useful, understandable model outputs and forecasts.

Transitioning new knowledge from the research domain to the operations environment is a long, arduous process, replete with impediments. It requires assistance and advice from the researchers; it also requires a sizable, well-funded, and knowledgeable cadre of people in the operational units who can construct fast, efficient, and relatively "bulletproof" research codes. Some operational agencies such as NOAA/SEC and AFWA appear to be understaffed in this area and will likely require staff adjustments and augmentations (and perhaps some partnering) to achieve adequate capability. Efforts at the AFSPC on space weather and sensor requirements appear to be better staffed, but they need more direction and guidance. This area appears to require balancing of resources and the involvement of top-level management.

> ***Finding 3.8.*** There is an absence of suitable connection for "academia-to-operations" knowledge transfer and for the transition of research to operations in general.
>
> > ***Recommendation 3.8.1.*** The agencies involved in the NSWP should continue to support basic research modeling efforts and, if possible, provide increased resources for modeling that has space weather operational potential. New resources should be made available within NSWP agencies for transition of research models to an operational environment, including validation and revision of existing models. Present resources and human capital should be carefully evaluated, strategically invested, and wisely managed.

Improving the transition process will require quantitative assessments of the accuracy of data, models, and products, with overall progress to be measured in terms of improvements in these metrics. Although many models and many data streams exist, still lacking are quantitative estimates of the accuracy of this information that can be effectively communicated to users of space weather services. Effort is required toward the goal of continually refining the understanding of what information is needed operationally and how best to estimate and communicate its limitations to users. The NSWP cannot achieve the progress needed in providing space weather information without first quantifying current capabilities and then setting explicit targets for the future.

> ***Finding 3.9.*** There currently are few overall verification and validation methodologies that can be used to assess the reliability of space weather models and operational products.

Recommendation 3.9.1. The NSWP should establish standards for data and model archives and for access to them. The NSWP should establish standards for modeling frameworks in order to facilitate model coupling, flexible execution, and data assimilation.

Recommendation 3.9.2. The NSWP should work towards the establishment (and application) of metrics for space weather capabilities.

Micro-Satellites and Space Weather

Many important measurements—ground-based as well as space-based—that are needed for space weather applications do not require the precision of data returned by instruments used for scientific research. Thus, new space weather instruments and, in the case of space-based instrumentation, the spacecraft that launch them need not be as costly as the one-of-a-kind, high-precision instruments required for research. The NSWP would benefit from stronger emphases on technologies that miniaturize sensors to the point that some could even become part of the spacecraft skin. With such technologies, every spacecraft would, in essence, have the potential to become a space weather monitoring station. Extending observational coverage and space weather monitoring capabilities through miniature sensor development will ultimately enhance understanding and forecasting of the space environment.

FalconSAT-3 is an example of a student-built micro-satellite (weight typically on the order of 100 kg) that includes miniaturized space environment sensors as part of the payload. This micro-satellite has a mass of approximately 50 kg and will carry two space environment experiments. One experiment is the Flat Plasma Spectrometer for detecting nonthermal properties of plasma distribution functions and their association with growth of plasma density depletions. The second experiment is the Plasma Local Anomalous Noise Experiment for detecting plasma turbulence on different scale sizes. FalconSAT-3, which was designed, built, and tested by Air Force Academy cadets and faculty, is due to be delivered to Cape Canaveral Air Station in the fall of 2006.

Figure 3-5. The payload of a micro-satellite (FalconSAT-2).

In Figure 3-5, Dr. Geoff McHarg, Director of the Air Force Academy Space Physics and Atmospheric Research Center (SPARC), is shown with the payload of the earlier FalconSAT-2 micro-satellite. The payload is inside the rocket faring in this photograph, taken just prior to final checkout of the payload, payload interface, onboard computer, and solar cells. FalconSAT-2 was delivered to the launch site in early November 2005. Unfortunately the launch failed and the payload was lost. Despite the loss, micro-satellites of this type have great potential for space weather monitoring in LEO and medium Earth orbit (MEO).

Slightly larger satellites—the 200-400 kg mini-satellite class—also offer significant potential for space weather observations. Mini-satellites can return space weather measurements from geosynchronous Earth orbit (GEO) and from the L1 Lagrange point, where the ACE and SOHO science satellites currently reside.

3.7 Foster Education of Customers and the Public

The NSWP has shown success in many aspects of education: (a) professional education, (b) formal advanced education, (c) formal undergraduate education, and (d) informal public education.

In the professional realm, NOAA/SEC has played a key role in fostering the education of its customer base. In 2004, SEC published its first service assessment of a severe space weather storm event: the Halloween 2003 solar and geomagnetic storms. (See summary in Appendix F.) NOAA service assessments and NOAA/NWS responses to them are standard tools for internal and external communication of the formal assessment of particularly disruptive and damaging natural events.

On a broader level, SEC introduced Space Weather Storm Categories to provide perspective on space weather event severity in terms of geomagnetic storms, radio blackouts, and space radiation. NOAA has conducted targeted education sessions at Space Weather Week for individuals and for groups of industrial customers. In 2005, SEC added a 1-day pre-meeting education session that addressed many of the lessons learned from the strong storms of Solar Cycle 23. As SEC folds its activities into NWS/NCEP, it has begun providing space weather briefings at the annual American Meteorological Society meeting. These briefings are posted in the same venue as the daily terrestrial weather briefings. Effectively, SEC has begun "mainstreaming" space weather to professionals in allied disciplines.

Professional education activities are also on the rise in other agencies. These include the new NSF-sponsored professional publication, *Space Weather: The International Journal of Research and Applications*, space weather sessions at professional meetings sponsored by the American Geophysical Union, and a Space Weather Symposium at the annual meeting of the American Meteorological Society.

Mainstreaming of space weather within the DOD is also advancing. In late 2005, the AFSPC journal *High Frontier* carried a War Fighter Focus article entitled "Weather Situation Awareness and Joint Space Effects." A June 2005 *Physics Today* article authored by a NRL researcher dealt with relationships between space weather and Earth's climate. In a broader application, all U.S. Air Force pilots now routinely receive preflight briefings on the likelihood of high-frequency communications outages during their missions.

In the arena of formal advanced education, NSF/UARS granted bridge funding during 2005 for eight new tenure-track faculty positions, one each at eight universities. The grant competition received nearly 40 proposals from U.S. universities. Most of the positions have been filled, and new graduate opportunities are being developed with support from these faculty members. In a less-targeted effort, new graduate opportunities are arising in the NSF-funded Space Weather Science and Technology Center, CISM, and in the MURIs supported by DOD. CISM also supports a 2-week summer school aimed at introducing beginning graduate students to the breadth of space weather activities. A more advanced summer school was supported by the NCAR Advanced Studies Program in 2005. Counterbalancing this growth has been a downturn

in NASA-supported research, which has typically provided the bulk of training in space weather instrument development.

The Decadal Research Strategy specifically recommended more support for undergraduate research and development of undergraduate research materials (NRC 2002, pp. 16–17, 136–140; see Appendix G for a list of the study's recommendations). Modest advances are evident in undergraduate space weather education. A new module on auroral physics, developed by a joint NCAR-Cooperative Meteorological Education and Training team, is available on CD or via the Internet. Two space weather–related textbooks are in development. One is targeted at the introductory undergraduate science level and is being tested at the University of California, Los Angeles. The second, whose development is funded by the DOD, is aimed at technical students who are not physics majors. Several universities have NASA or DOD funding for micro-satellite development. These programs are generally operating on small budgets with a handful of faculty. The slim operating margins rarely allow faculty to develop formal coursework in space weather education, although such courses would greatly benefit future spacecraft engineers and satellite operators.

Informal public education continues to strengthen. In the past 5 years, several popular books written for a broader audience have appeared. An IMAX movie, *Solar Max*, has played across the country. NASA has supported significant Internet-based education and public outreach activities aligned with space weather. The NCAR team supporting the Windows–to-the-Universe program reports that about 25 percent of Internet visitors to the site visit pages with space weather content. NASA's *Student Observer Network* provides comparison images, visualizations, and animations that align with national education standards. In the realm of popular content, *National Geographic Magazine* dedicated a substantial portion of the July 2004 edition to space weather storms. Television programs related to space weather have been developed by the Discovery Channel and NBC Universal, for television airing in 2006.

The advances discussed above make space weather materials and educational activities readily available to individuals who choose to seek out intellectual challenge and stimulation. The more difficult business of space weather education is ahead: developing materials for operators and decision makers (industry and governmental) who need to know about system vulnerabilities but are generally inclined to focus on narrower aspects of their own disciplines. In the years ahead, a focus of space weather education must be to make it interdisciplinary.

There is clear evidence that educational programs initiated because of the existence of the NSWP have produced a new awareness in the community (and in the public) of the "end-to-end" nature of the space environment as it affects national assets. This is a significant departure from the past, when space professionals tended to specialize in understanding certain portions of the solar-terrestrial chain but seldom took an overall systems view.

At the present time, some of the NSWP agencies show awareness of the need for workforce education and development in support of the national space weather effort. Other agencies are less clearly committed to workforce development. Nevertheless, all of the NSWP agencies have expressed the desire to maintain efforts to attract, educate, and continue to train a new cadre of space weather professionals.

Among these future professionals will be space scientists to do the basic space weather research and engineers to design and implement data acquisition hardware. It will also be important for a systems view of the Sun-Earth environment to be instilled in space weather forecasters and forecast users in the various operational agencies. The NSWP agencies will need to work with the academic community to encourage it to develop new approaches to attract science and engineering students who can become space weather professionals. Universities will need to provide new courses that educate students broadly by developing courses that demonstrate the highly interconnected character of the Sun-Earth system, especially as it applies to operational and forecast problems. NSWP agencies will also need to offer programs to aid in training students in an interdisciplinary and "cross-disciplinary" sense, as well as continuing education courses for their workforce. Advanced models and modeling frameworks will need to be developed and incorporated into academic courses. Approaches that bridge traditional university departmental boundaries will likely be required in many universities.

> ***Finding 3.10.*** There is a lack of a systematic approach to "grow" new space weather professionals.
>
> > ***Recommendation 3.10.1.*** The NSWP agencies should make a more unified and concerted effort to educate a new generation of professionals who have the systems view of space weather.

Space Weather Effects on Navigation

The Wide Area Augmentation System (WAAS) was designed by FAA and the DOT to become the future primary means of air navigation. WAAS was commissioned for vertical guidance approach (APV) services in July 2003. APV is a service level that guides an aircraft to 250 feet above a runway, even in conditions of poor visibility. The coverage area for the WAAS APV service is currently limited to the contiguous United States (CONUS). Analysis of WAAS performance since commissioning has shown limited availability of the APV service during extreme geomagnetic storm events.

In the WAAS system, the standard GPS service is augmented with corrections for time, the GPS satellite orbits, and the ionosphere. These augmentations enable the WAAS system to meet the very stringent aviation requirements for accuracy, availability and integrity. Quarterly performance reports have shown that the WAAS system generally meets or exceeds these requirements *(http://www.nstb.tc.faa.gov)*.

The performance reports also verify that one of the greatest challenges for WAAS is maintaining continuous APV availability during extreme geomagnetic storm events. Figure 3-6 illustrates this effect by plotting WAAS availability statistics and magnetic activity for an 8-month period surrounding the extreme storm events of October and November 2003. In the top half of the figure, the percent of the CONUS that had APV availability 95 percent of the time is plotted. In the bottom half, the daily minimum Disturbance Storm Time (Dst) is plotted as a proxy for geomagnetic activity. The largest drops in Dst indicate periods of extreme storm activity. Both plots cover the period from 1 July 2003 to 1 March 2004. The figures illustrate that during non-storm days, WAAS generally maintained 95 percent availability over 95 percent of the CONUS. During the extremely disturbed days of October 29-30 and November 20, 2003, however, the APV service was unavailable over the entire CONUS region for periods of approximately 15 and 10 hours, respectively.

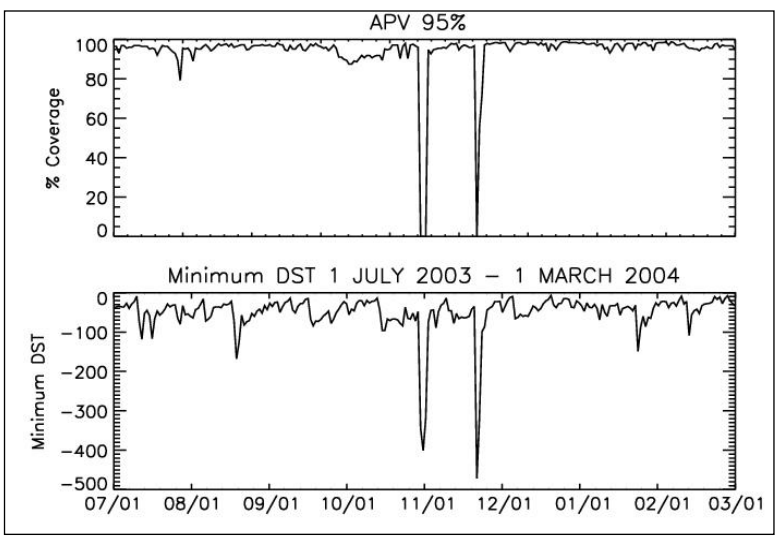

Figure 3-6. WAAS APV response to geomagnetic activity.

Incremental improvements for WAAS are planned with modernization efforts to extend the coverage region and improve availability. This will ultimately enable a greater level of precision approach services. Availability of the system, however, may continue to be challenged by the highly variable and unpredictable effects of extreme geomagnetic storms. Space weather studies that will employ new techniques and data sets to study these events are promising and may lead to a better WAAS system.

3.8 Crosscutting Issues

In the course of its fact-finding, the Assessment Committee identified two areas of concern that cut across several of the NSWP activities as defined in the 1995 Strategic Plan. Both private sector participation and international activities were discussed in previous NSWP documents under the Program Management activity, but their reach is, or should be, broader than just a management issue. The subsection on coordination with international space weather activities was substantially expanded in the 2000 Implementation Plan (OFCM 2000, pp. 7-14 to 7-18).

3.8.1 Private Sector Participation

The private sector has demonstrated interest in supplying tailored and unique space weather products and services as supplements to and enhancements of (added value to) the public products available from Government sources such as NOAA/SEC and AFWA. Companies are interested in supplying tailored products to both governmental and private-sector entities.

The good working relationships, as well as the tensions, between public and private sectors in the supply of space weather products at times mirror those that have existed in the atmospheric weather community for decades. These relationships and tensions can often lead to creative and enhanced responsiveness to user needs and requirements. Aspects of these relationships and related issues as applied to space weather vendors were addressed, with some suggestions for the future, in chapter 5 of the Decadal Research Strategy in Solar and Space Physics (NRC 2002).

When private space weather vendors supply other companies with space weather products, the details of the products often cannot be discussed because of the desire to protect intellectual property and safeguard proprietary information. Some industries are highly reluctant to share data that could be used adversely by a competitor (even if many in an industry might be suffering similar problems). Likewise, in the national security sector, classification of space weather anomaly data does not allow a wide and diverse examination of space weather effects. For these and related reasons, it is often difficult to obtain independent assessments of the cause(s) of some technical anomalies that might have a space weather origin or component.

In addition to supplying space weather products tailored to the needs of specific customer-users, the private sector appears to have some nascent interest in supplying observational data, from both ground- and space-based instruments, of use for both space weather monitoring and tailored products. These interests may even extend to supplying spacecraft specifically targeted to space weather applications. As discussed in Section 3.5, many types of space weather data for monitoring and prediction do not require the degree of precision that is demanded of similar data sets intended for scientific research. Thus, spacecraft and spacecraft instrument requirements (and therefore costs) could be substantially relaxed from those of science missions. With this change, the private sector may be able to formulate a business case for providing data critical to operational space weather monitoring, prediction, and analysis cost-effectively, once science missions are no longer operating.

> ***Finding 3.11*** The role of the private sector in space weather products, including potential for investment, is still being defined.

Recommendation 3.11.1. The NSWP should work with the growing commercial sector for space weather services and products to enable this sector to flourish as a vital part of the national space weather program.

Recommendation 3.11.2. The NSWP should work with the private sector to understand better the economic and social values of space weather knowledge and of products and services based on that knowledge.

In implementing these two recommendations, an industry-by-industry analysis would be highly beneficial.

3.8.2 International Collaboration

Individual agencies within the NSWP have pursued international collaboration for specific projects in both research and operations. For example, many of NASA's solar and solar-terrestrial research projects were developed and funded with international partners: SOHO, Cluster, and Ulysses with ESA; Geotail with Japan. The MetOp polar-orbiting operational environmental satellite, which will be launched and operated by the European Meteorological Satellites organization (EUMETSAT), will carry the Space Environment Monitor (SEM), a space weather senor supplied by NASA on behalf of NOAA. NOAA's National Geophysics Data Center operates the Space Physics Interactive Data Resource, a distributed international network of synchronous databases and middleware servers, containing space physics data accessed via the Internet. Finally, the USGS maintains agreements with international partners around the world for collecting and distributing geomagnetic data through the Intermagnet program of international ground-based observatories located throughout the world.

These efforts to encourage the collection and sharing of data from non-U.S. sources are carried out primarily though the efforts of each individual agency and are not well coordinated within the NSWP partnership. In effect, the NSWP has no international program. Nevertheless, the NSWP faces a potential loss of capability to protect the country's technological resources when several of the research satellites upon which it depends for data finally fail (as discussed in section 3.4). The NSWP needs to make much more extensive use of international cooperative efforts to gather and distribute space weather data by developing a coordinated plan for encouraging other countries to participate in these collection and distribution efforts. The broader the sources of accurate space weather data, the better the forecasts can be. A wider variety of space weather data sources than currently exist would also assist in assuring continuity of data if one or more U.S. sources fail.

Finding 3.12. The NSWP has made relatively little effort to consider international partnering opportunities for collecting space weather data and distributing space weather information products. The worldwide space weather community would benefit by much more aggressive collection of space weather data by other countries.

Recommendation 3.12.1. The NSWP should consider the benefits (and possible drawbacks) of establishing a formal international coordination mechanism for the

> promotion, collection, and distribution of space weather data, including all forms of space weather data from satellites and ground-based sensors.

Such a program could be structured and operated along the lines of the Committee on Earth Observation Satellites (CEOS), which was formed in 1984 to address similar concerns within the Earth observations community. CEOS operates with minimal institutional resources and no central office. Nevertheless, it has been highly effective as the organizational basis for an international system of Earth observation satellites, which service the international needs for such data. The NSWP might even explore the option of establishing a coordinated, international effort under the aegis of CEOS. This option would allow the NSWP to make use of the established CEOS organization and its many members to explore the value of improved provision of space weather data for the world. Additional opportunities for data and research coordination may be possible through the ICSU-chartered International Space Environment Service (ISES).

4 MANAGEMENT ISSUES

Each of the cooperating agencies in the National Space Weather Program (NSWP) has national responsibilities and opportunities that engage with, and are influenced by, the space environment of Earth. By coming together under the umbrella of the National Space Weather Program Council (NSWPC) in OFCM, these agencies expect to leverage their individual expertise, resources, and Federal responsibilities to aid the overall national effort.

The NSWP has accomplished a significant number of important national objectives in the past decade with its current status as a confederation of agencies. Nevertheless, the Assessment Committee has identified a number of important management issues related to the program as a whole, as well as to individual agencies. Addressing these issues will enhance the effectiveness of the national effort. The Assessment Committee recognizes that implementing many of the recommendations in this report will require new resources.

4.1 NSWP Structure

The current arrangement of the NSWP as a loose confederation of agencies has made it difficult for the program to achieve the type of operational coordination that is essential to provide the national leadership needed for addressing the key space weather issues in the civil, governmental, and national security arenas. Although individual agencies' roles and responsibilities may be understood and agreed upon within the NSWPC, execution of those roles and responsibilities is problematic without specific assignments of agency fiscal responsibilities by the Office of Management and Budget (OMB) and Congress. Expenditures within each agency toward NSWP strategic objectives must compete for funding with the myriad of other agency programs and commitments. In an environment of fiscal constraints, NSWP objectives often are underfunded or unfunded. If each agency were required to allocate the funding to fulfill its NSWP role and were required to monitor/report its progress toward successful execution of its role, the NSWP would be much stronger than it is presently and better postured for continued success in meeting the Nation's space weather needs.

> ***Finding 4.1. Organizational Matters.*** The NSWP is an outstanding example of a Federal government program in which a significant number of executive branch agencies have important national interests and where the individual agencies have natural areas of experience and expertise. However, the program management organization under the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM)—namely, the National Space Weather Program Council (NSWPC)—needs to be strengthened and needs to take a more active role in the execution of its overarching responsibility to ensure that the NSWP can move forward in achieving its goals. Without further strengthening of the NSWPC as an interagency integrated program, the chances of meeting the challenging national needs in space weather will be greatly diminished.

The following recommendations (with subsequent discussions) are offered as mechanisms to address what the Assessment Committee considers to be management deficiencies in the NSWP.

> ***Recommendation 4.1.1.*** Oversight for the NSWP should be established in the Executive Office of the President, as is currently done for several other critical cross-agency activities of the Federal government. Policy and technical implementation aspects should be coordinated under the aegis of a space-knowledgeable staff member in the Office of Science and Technology Policy (OSTP). Budgetary coordination and review for the NSWP agencies should be carried out under a designated examiner in the Office of Management and Budget (OMB).

The Earth's space environment is one of the very few issues that affect virtually all aspects of the U.S. Government and American society, yet it is seldom recognized as such a broadly encompassing matter. For this reason, the agencies that are concerned with space weather have been slow to coordinate space weather programs and funding. While the NSWP has been an effective forum for identifying what needs to be done, it has had no power to translate this understanding into U.S. Government policy. Suitable oversight, reporting, review, and fiscal coordination at the presidential level will help assure that agencies work together efficiently and that budgetary allocations are adequate to meet national space weather needs.

> ***Recommendation 4.1.2.*** The NSWPC Chair should review the council's membership and consider additional membership to increase the visibility of the program's fiscal and other challenges and to increase support for overcoming those challenges. The NSWPC should review and update its now 10-year-old charter to describe clearly its oversight responsibilities. These should include, but not be limited to, the authority to: (1) address and resolve interagency issues, concerns, and questions; (2) reprioritize and leverage existing resources to meet changing needs and requirements; (3) approve priorities and new requirements as appropriate and take coordinated action to obtain the needed resources through each agency's budgetary process; (4) identify resources needed to achieve established objectives; and (5) coordinate and leverage individual organizational efforts and resources and ensure the effective exchange of information.

A primary example of the failure to translate needs into government action is the limited remaining operational life (as discussed in chapter 3) of the interplanetary monitoring satellite, the Advanced Composition Explorer (ACE), which is located between Earth and the Sun at the L1 Lagrange point. All agencies acknowledged to the Assessment Committee that continuity of this capability is essential to maintaining critical U.S. monitoring data, as well as to conducting the research needed to develop new, comprehensive models of the space environment. While all participating agencies in the NSWP understand and acknowledge the importance of this capability, none are able to budget a near-term replacement/augmentation of ACE. The Assessment Committee notes that this situation is somewhat analogous to past inability of the Federal Government to provide continuity of multispectral land remote sensing capabilities (LANDSAT). The remedy for the latter situation required top-level Administration coordination and direction.

The Assessment Committee believes that substantially more awareness of the NSWP is needed within the staffs of OMB and OSTP. The Executive Branch must be fully apprised of the national need for improving space weather forecast capabilities. A first agenda item for OSTP/OMB oversight would be to assign responsibilities and funding for the development of a comprehensive ACE L1 follow-on program. The NRC's Decadal Strategy in Solar and Space Physics recommended that NOAA be principally responsible for an L1 follow-on solar monitoring spacecraft (NRC 2002).

Without additional leverage or Executive Office attention, the Assessment Committee believes that it is likely that critical national data collection systems, such as the comprehensive solar monitor at L1, will cease to exist. While the United States might be able to obtain some relevant data from other nations (China is currently planning such a mission), there could be lapses in coverage at times, including times of international tension. Solar event and solar wind warning data are critical to DOD operations, NASA human exploration, and a host of commercial and other space services. To depend on other nations, or simply to do without such data, could have serious negative consequences on many important national programs and activities.

> ***Recommendation 4.1.3.*** A joint working group should be established for all cooperating NSWP agencies similar to that described in the NASA/NOAA Congressional Directive (2006 NASA Reauthorization Bill H.R. 3070, Section 306) and with similar reporting requirements.

Within the 2006 NASA Reauthorization Bill, specific Congressional guidance was given to both NASA and NOAA to form a joint working group and to report annually to the House of Representatives and the Senate on how U.S. Earth science programs will be coordinated in the upcoming year. The Assessment Committee believes that a similar type of oversight could be beneficial for the NSWP. The committee further believes that such "directed coordination," should leverage the existing OFCM and NSWP infrastructure (the NSWPC and the Committee for Space Weather).

> ***Recommendation 4.1.4.*** A full-time space weather expert should be appointed as Executive Secretary to the Committee for Space Weather under the NSWPC.

Implementation of recommendation 4.1.4 will ensure that stakeholder agencies are contributing to the NSWP as specified in the strategic and the implementation plans. It will ensure that NSWPC directions are consistent with the program's strategic and implementation plans. Ensuring that guidance and strategic planning are accomplished across the participating agencies for critical national space weather infrastructure would be an essential responsibility of this position. This person/position would be the primary interface between the NSWPC and the Director of a new Joint Center for Space Weather Research to Operations (see recommendation 4.1.7 below).

Funding of this position could come from contributions from all stakeholder agencies. Currently, all agencies within the NSWPC and the Committee for Space Weather participate on, at most, a "part-time as available" basis.

> ***Recommendation 4.1.5.*** The NSWPC should direct that a new NSWP Strategic Plan be written that takes into account the successes and the limitations achieved under the current plan, changes that have occurred in technologies susceptible to space weather, and advances made in scientific understanding.

The NSWP Strategic Plan is more than a decade old. A new visionary plan should take into account the many developments and changes that have occurred over this time in science and applications, as well as in the management of the NSWP.

> ***Recommendation 4.1.6.*** The NSWPC should direct that a new NSWP Implementation Plan be written following a new strategic plan.

The latest NSWP Implementation Plan is more than 5 years old. A new plan should use the new visionary perspective of the new strategic plan and point the way forward for the program.

> ***Recommendation 4.1.7.*** The NSWPC should create a joint, cross-agency, space weather organization, the "Center for Space Weather Research to Operations."

Currently, seven Federal agency organizations are involved in some aspect of the NSWP objectives as defined in the program's current strategic and implementation plans. However, no single organization has a specific charge to further the NSWP strategic objectives or can ensure that work toward NSWP objectives is progressing and well managed, especially work toward objectives critical to operations. A core of full-time personnel working toward and managing efforts toward the NSWP strategic goal of research to operations (research, modeling, operations, education) would benefit all agencies, and would significantly increase the effectiveness of the NSWP. This would result in an enhanced ability to maintain the Nation's most critical space weather–sensitive operational systems and to keep its citizens safe.

4.2 NSWP Agencies

This section addresses three management-related issues for the agencies in the NSWP. These issues target concerns that primarily affect the research community.

NSF and NASA provide the main funding resources for extramural research (i.e., research that is not conducted within a Federal entity; primarily academic research). While the solar and solar-terrestrial programs in NASA have a unified leadership within that agency, the management of the corresponding programs within NSF is currently divided between two directorates.

> ***Finding 4.2.*** The current management structure of the NSF solar and solar-terrestrial research programs does not always operate optimally to foster basic solar and solar-terrestrial research or the links from this research to space weather.
>
> **Recommendation 4.2.1.** The solar and solar-terrestrial program elements of the NSF should be managed as one, possibly division-level, program so as to have a unified overview of both the basic research and space weather elements.

The Decadal Research Strategy recommended that both NASA and NSF fund bridged faculty positions at universities to bring solar and space physics into the academic curriculum, commensurate with the national resources that are being devoted to these research endeavors. This was to be accomplished through a peer review process (NRC 2002, pp. 35, 148-49).

> ***Finding 4.3.*** While the NSF has implemented a program to support bridged positions for academic faculty in solar and space physics, NASA has yet to address this recommendation of the National Research Council's Decadal Research Strategy in Solar and Space Physics.
>
> > ***Recommendation 4.3.1.*** NASA should institute a bridged faculty program in solar and space physics.

Such a program would be of substantial benefit for NASA's solar and space physics missions, for university education, for transferring knowledge gained from NASA's program to the public, and for the NSWP. Such a program would be a small resource expenditure in comparison to the current levels of NASA programs in this field.

At times in the past, some programs and offices under the DOD and NOAA sponsored extramural research (primarily academic research) in solar and solar-terrestrial physics at funding levels considerably above those at present. That level of research support enabled close interactions between in-house laboratories and the outside community of researchers and helped to develop analysis tools and models in support of space weather applications.

> ***Finding 4.4.*** The continuing decline in the resources available to the DOD and NOAA for contracting peer-reviewed research, both targeted and strategic, to the extramural community, especially the academic community, means that the interactions and interchanges between the government and nongovernmental sectors in space weather are far from optimized.
>
> > ***Recommendation 4.4.1***. Resources should be restored to the operational agencies to allow greater extramural research inputs. NOAA and the DOD should thereby provide competitive peer-reviewed funding for contributions from the nongovernmental sector to space weather program research elements.

The Assessment Committee believes that the NSWP could be significantly strengthened nationally if the participating agencies engaged needed expertise wherever it exists in the Nation's talent pool.

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APPENDICES

APPENDIX A
Charter of the National Space Weather Program Assessment Study Group (NSWPASG)

1. REFERENCES

Reference documents can be viewed and/or downloaded from the OFCM NSWPASG web site at: http://www.ofcm.gov/space_weather_assessment/index.htm.

2. BACKGROUND

The National Space Weather Program Assessment Study Group (NSWPASG) is part of an effort underway within the Office of the Federal Coordinator for Meteorology (OFCM) to respond to the direction of the Federal Committee for Meteorological Services and Supporting Research (FCMSSR) and Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR). Their direction was to undertake a comprehensive review of the National Space Weather Program (NSWP). The purpose is to quantify and document the progress toward meeting the NSWP stated goals in observations, research, modeling, transition of research to operations, and education and outreach; to see if the program is still on target and moving in the direction pointed to by the Strategic Plan; to determine whether the strategic goals should be adjusted at this time based on emerging/evolving requirements; and to suggest a way ahead that will form a basis for a new strategic plan covering the next 10 years.

> ACTION ITEM 2004-2.5 from the November 16, 2004, meeting of the interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR) supported the contention that the time is right to perform an interagency assessment of the National Space Weather Program (NSWP) to quantify our progress toward meeting our goals in observations, research, modeling, transition of research to operations, and education and outreach; to see if we are on target and moving in the direction pointed to by the Strategic Plan; and to determine whether our strategic goals should be adjusted at this time based on emerging/evolving requirements. Further, ICMSSR concurred that OFCM should seek FCMSSR endorsement of this comprehensive review.
>
> ACTION ITEM 2004-1.3 from the December 1, 2004, meeting of the Federal Committee for Meteorological Services and Supporting Research (FCMSSR) concurred and tasked the Committee for Space Weather (CSW) to undertake a comprehensive review of the National Space Weather Program (NSWP) to quantify our progress toward meeting our goals in observations, research, modeling, transition of research to operations, and education and outreach; to see if we are on target and moving in the direction pointed to by the Strategic Plan; and to determine whether our strategic goals should be adjusted at this time based on emerging/evolving requirements. The review methodology will be developed in conjunction with the Committee for Space Weather.

3. PURPOSE

Using all available sources (i.e. industry, academia, Federal agencies...), the NSWPASG will:

a. Review applicable documents/references on the reference web site listed in para. 1.

b. Using the 1995 NSWP Strategic Plan, determine how well have we met the original *Overarching Strategic Goal* "To achieve an active, synergistic, interagency system to provide timely, accurate, and reliable space environment observations, specifications, and forecasts within the next 10 years."

The NSWP overarching goal is further delineated by the following *Supporting Goals*.

To advance

- Observing capabilities (data collection)
- Fundamental understanding of processes
- Numerical modeling
- Data processing and analysis
- Transition of research into operational techniques and algorithms
- Space weather products and services
- Education on space weather

And to prevent or mitigate

- Under- or over-design of technical systems
- Regional blackouts of power utilities
- Early demise of multi-million dollar satellites
- Disruption of communications via satellite, HF, and VHF radio
- Disruption of long-line telecommunications
- Errors in navigation systems
- Excessive radiation doses dangerous to human health

Consider the following questions for each *Supporting Goals*, clearly stating "how" your documented findings support, or contribute to, the NSWP *Overarching Strategic Goal*:

1) Are there notable successes? What elements of the program have contributed most to these? Are there measurable benefits and, if so, will they help justify future research and technology development?

2) What gaps or shortfalls remain? Where are the weaknesses? How can any shortfalls, and weaknesses best be addressed?

3) Are new directions in light of national and agency priorities appropriate in the near and longer term? Do costs/benefits support competition with other priorities?

4) Are new directions in light of evolving customer needs appropriate? (e.g., the President's new emphasis on interplanetary travel)

5) Are new directions/methods of doing research required in the near and longer term?

6) Are new techniques necessary to optimize the transition of research to operations? Are the transition costs reasonable or prohibitive?

7) What is the status of outreach to potential customers, and are changes required? Is education for developers, providers and users keeping pace with research and transition activities?

8) Are new and/or additional methods needed to further NSWP outreach objectives?

9) What have been the roles of the academic and research communities in the NSWP, including its successes and shortcomings? Are these roles appropriate and what changes might be required in the future?

10) Are the participating agencies in the NSWP organized in an effective manner to optimize the outcomes of the Program? Can current/future partnerships (agency to agency, and agency to the outside) be considered as a program benefit multiplier?

11) Are there ways to improve operational efficiency within the NSWP? Are there capabilities that can be leveraged across agencies?

Your report should clearly document the current status of the NSWP. It should provide recommendations that will assist stakeholder Federal agencies with planning for future expenditures of resources to support the NSWP as well as provide a foundation for the creation of a new NSWP strategic plan for the next 10 years.

4. MEMBERSHIP

a. Membership will be drawn from the scientific community outside the *immediate* NSWP community yet having the expertise to perform the task at hand. The NSWPASG will be augmented as needed by Federal and non-Federal personnel to provide subject-matter or other expertise. NSWPASG membership will be coordinated through the Committee for Space Weather and the Office of the Federal Coordinator for Meteorological Services and Supporting Research.

b. The NSWPASG Chairperson will be selected by the CSW co-chairs and with coordination from the Federal Coordinator for Meteorological Services and Supporting Research.

c. The Federal Coordinator will provide the Executive Secretariat.

5. PROCEDURES

a. Meetings shall be called by the study group chair, or his designee, and shall normally be convened in facilities provided by the Federal Coordinator. Typically, the final agenda item for each meeting will be to tentatively establish when, or if, an additional meeting is required. The

meeting agenda, to the greatest extent possible, will normally be finalized as soon as possible prior to meetings. The group will meet, in person, or telephonically, as needed until its business is completed.

b. Group decisions should be by unanimous agreement of all members. Members may reserve their position pending the gathering of additional information or instructions. Decisions may be reached during a face-to-face meeting or through correspondence (including e-mail) circulated to the members by the Chair, his designee, or the Executive Secretary (on the Chair's behalf).

c. If members are unable to reach agreement, the Chair will report the matter, with full documentation, to the Committee for Space Weather for resolution or elevation to the NSWP Council.

d. Previously established action items should be reviewed at the start of each meeting; new action items should be agreed upon and documented prior to the meeting being adjourned. The Executive Secretary will send the draft action items to the study group members to review and comment normally within 5-10 working days after a meeting. The Executive Secretary will document the action items along with other major decisions in brief, informal meeting minutes. Typically, final meeting minutes will be available within 30-45 working days after a meeting. Meeting minutes will generally be distributed by e-mail and available at the referenced web page above. Documentation may also include copies of presentations and/or other material presented at the meetings.

e. Amendments to this charter will be agreed to by all group members and coordinated with the co-chairs of the Committee for Space Weather.

6. REPORTS AND RECORDS

a. The group shall prepare reports and publications identified in this charter and others as requested by the Committee for Space Weather co-chairs.

b. Reports from the group will be considered as guidance documents for use by NSWP Council and Committee for Space Weather. The endorsement of the group's report by the CSW and/or the NSWPC in no way implies a commitment for stakeholder Federal agencies to provide resource support for any suggested initiatives.

c. Records of the group shall be maintained in the Office of the Federal Coordinator for Meteorology.

7. TERMINATION

To facilitate agency consideration during the budgetary planning processes, the group's target is 1 September 2005 for interim assessment results that can be distributed to the FCMSSR members. The target for the final assessment report is 15 January 2006. The NSWPASG shall be terminated by the Committee for Space Weather unless additional tasks are assigned.

Appendix B
Committee Membership

Dr. Louis J. Lanzerotti, Chair

Education
B.S., University of Illinois, 1960
A.M., Harvard University, 1963
Ph.D., Harvard University, 1965

Dr. Lanzerotti is currently a Distinguished Research Professor of Physics in the Center for Solar-Terrestrial Research at the New Jersey Institute of Technology in Newark, New Jersey, and a Consultant to Bell Laboratories, Lucent Technologies, where he spent the first 37 years of his career.

Dr. Lanzerotti's principal research interests have included space plasmas, geophysics, and engineering problems related to the impacts of atmospheric and space processes and the space environment on space and terrestrial technologies. He has co-authored one book, co-edited three books, and is an author of more than 500 refereed engineering and science papers. He is the founding editor of *Space Weather, The International Journal of Research and Applications*, published by the American Geophysical Union. He has seven patents issued or filed.

Dr. Lanzerotti has been elected a member of the National Academy of Engineering and of the International Academy of Astronautics. He is also a Fellow of the Institute of Electrical and Electronics Engineers (IEEE), the American Institute of Aeronautics and Astronautics (AIAA), the American Geophysical Union (AGU), the American Physical Society (APS), and the American Association for the Advancement of Science (AAAS). He is the recipient of two NASA Distinguished Public Service Medals, the NASA Distinguished Scientific Achievement Medal, the COSPAR William Nordberg Medal, and the Antarctic Service Medal of the United States. He was appointed to the National Science Board in 2004.

Dr. Daniel N. Baker

Education
M.S., University of Iowa, 1973
Ph.D., Iowa, 1974

Dr. Baker is Director of the Laboratory for Atmospheric and Space Physics, University of Colorado–Boulder, and is Professor of Astrophysical and Planetary Sciences there. His primary research interest is the study of plasma physical and energetic particle phenomena in planetary magnetospheres and in the Earth's vicinity. He conducts research in space instrument design, space physics data analysis, and magnetospheric modeling.

Dr. Baker is engaged in the analysis of large data sets from numerous NASA and operational spacecraft. His current research involves the study of solar wind-magnetospheric energy coupling and theoretical modeling of magnetotail instabilities. Dr. Baker is also involved in the study of magnetosphere-atmosphere coupling and applying space plasma physics to the study of astrophysical systems. His research is used to understand magnetospheric substorms and geomagnetic storms. Dr. Baker has special interest in the use of computer systems and networks to enhance the acquisition, dissemination, and display of spacecraft data. He is engaged in the teaching of space physics and public policy, as well as public outreach to space technology community and general public.

Following postdoctoral work at the California Institute of Technology, Dr. Baker joined the Physics Division research staff at Los Alamos National Laboratory, where he became Leader of the Space Plasma Physics Group in 1981. From 1987 to 1994, he was the Chief of the Laboratory for Extraterrestrial Physics at NASA Goddard Space Flight Center. In 1994, Dr. Baker went to University of Colorado–Boulder, where he continues his studies of space weather and the effects of the space environment on human technological systems.

Dr. Baker has published over 700 papers in the refereed literature and is a Fellow of the American Geophysical Union and the International Academy of Astronautics. He has won numerous awards for his research efforts and for his management activities. In 2002, Dr. Baker was recognized by the Institute for Scientific Information as being “Highly Cited,” meaning that his work is among the top 100 most-cited researchers in space science. In 2003 he was selected for the Mindlin Foundation Lectureship and Prize at the University of Washington. Dr. Baker recently served as President of the Space Physics and Aeronomy section of the American Geophysical Union (2002-2004). He serves on advisory panels of the National Academy of Sciences, the National Science Foundation, the U.S. Air Force, and NASA. He presently serves on several national and international scientific committees including being Chair of the National Research Council Committee on Solar and Space Physics. Dr. Baker is an investigator on several current NASA space missions including the MESSENGER mission to Mercury, the ESA/NASA Cluster mission, and the NASA Magnetospheric Multi-Scale mission.

Dr. Tammy E. Jernigan

Education
B.S., Stanford University, 1981
M.S., Stanford University, Engineering Science, 1983
M.S., University of California-Berkley, 1985
Ph.D., Rice University, 1988.

Dr. Jernigan completed her B.S. degree in physics (with honors) and M.S. degree in Engineering Science at Stanford University in 1981 and 1983, respectively. She then joined the Astronomy Department at University of California-Berkeley to pursue a Ph.D. degree in theoretical and computational astrophysics. Her research focused on the modeling of high-velocity outflows in regions of star formation, gamma-ray bursters, and the study of radiation produced by interstellar shock waves. In 1985, she was selected as a NASA astronaut and subsequently completed her Ph.D. in space physics and astronomy at Rice University in 1988 while training for the Space Shuttle program.

Dr. Jernigan is a veteran of five Space Shuttle missions, for which she supervised the preflight planning and in-flight execution of critical activities aboard STS-40, 52, 67, 80, and 96. During these flights, Dr. Jernigan served as mission specialist on the first dedicated Life Sciences mission, STS-40, and as payload commander of STS-67. During STS-67, the crew conducted continuous ultraviolet observations of a variety of stars, planets, and distant galaxies. On Dr. Jernigan's last flight, in 1999 on STS-96, the crew performed the first docking to the International Space Station (ISS). Dr. Jernigan also executed a space walk of nearly 8 hours to attach equipment to the exterior of the station.

In October 2001, Dr. Jernigan joined Lawrence Livermore National Laboratory, where she currently serves as Principal Deputy Director of the Physics and Advanced Technologies Directorate (PAT). PAT scientists and engineers execute a broad portfolio of research and development activities ranging from basic science to applied technologies critical to the Nation's homeland security mission. Dr. Jernigan is responsible for day-to-day operations of PAT and plays a lead role in policy development and strategic planning.

In addition to her space flight experience, Dr. Jernigan held numerous management positions as an astronaut. She served as Deputy Chief of the Astronaut Office, assisting with the management of military and civilian astronauts and support personnel. As Deputy for the Space Station program, she developed and advocated Astronaut Office positions on the design and operation of the ISS. She also represented NASA management on the U.S. negotiating team in Moscow during technical interchange meetings designed to resolve crew training, crew rotation, and operational issues. Her numerous awards include the NASA Distinguished Service Medal (2000), Lowell Thomas Award, Explorer's Club (2000), five NASA Space Flight Medals (1991 to 2000), NASA Distinguished Service Medal (1997), NASA Group Achievement Award–EVA Developmental Test Team (1997), Federation Aeronautique Internationale Vladimir Komorov Diploma (1996 and 1997), NASA Outstanding Leadership Medal (1996), NASA Outstanding Performance Award (1993), NASA Exceptional Service Medal (1993), and the Laurels Award from *Aviation Week* (1991). Dr. Jernigan was named 2004 Outstanding Woman of the Year in Science and inducted into the Alameda County Women's Hall of Fame.

Dr. Delores J. Knipp

Education
B.S., University of Missouri, 1976
Ph.D., University of California, Los Angeles, 1989

Dr. Knipp is a Professor of Physics with the U.S. Air Force Academy Department of Physics, where she specializes in solar-terrestrial interactions and space weather effects. She also teaches in the Air Force Academy's interdisciplinary meteorology program. Her recent research interests include satellite drag, upper atmosphere energy budgets, and solar wind-magnetosphere-ionosphere coupling. She has mentored student research projects in satellite drag, energetics of Earth-magnetic cloud interactions, and quantifying the upper atmosphere heat budget. From 1995 to 1998, she led an international space weather storm study that helped launch the NSF-sponsored National Space Weather Program.

Dr. Knipp earned her bachelor's degree in atmospheric science from the University of Missouri in 1976 and entered the Air Force as a weather officer shortly thereafter. She was a NORAD command weather briefer before earning an MS in atmospheric science and joining the physics faculty at the Air Force Academy. In 1986 the Physics Department sponsored her to earn a doctorate in space and atmospheric physics at UCLA. She has been engaged in teaching introductory physics, meteorology, space physics, and astronomy and in researching the effects of solar activity on the near-Earth environment. In 1997 she was a recipient of the Air Force Basic Research Award. That award recognized her significant contribution in leading over 100 scientists in a coordinated study of a major solar terrestrial storm.

Dr Knipp retired in 1999 after 22 years of active duty service. Later that year, she returned to the Physics Department faculty as a Professor of Physics. She is the recipient of NASA, NSF, and AFOSR grants. She has served on the Steering Committee for the Coupling and Energetics of Atmospheric Regions (CEDAR) program, the Geospace Environmental Modeling Program (GEM), and the NSF Upper Atmospheric Research Section (UARS) Committee of Visitors. Dr. Knipp is a principal scientist in the Academy's Space Physics and Atmospheric Research Center (SPARC). This center, which she helped originate, focuses on DOD research needs in space weather, small-satellite payloads, applied physics, astronomy, and meteorology. Dr Knipp is presently writing an undergraduate text on space weather and space environment.

Dr. Ray Williamson

Education
B.A. in Physics, Johns Hopkins University, 1961
Ph.D. in Astronomy and Physics, University of Maryland, 1968

Research Professor of Space Policy and International Affairs

Expertise: Environmental security, Earth observation satellite policy, dual-purpose space technologies, and the commercialization of space-related technologies.

Dr. Williamson is Research Professor of Space Policy and International Affairs in the Space Policy Institute, The Elliott School of International Affairs, George Washington University. He has conducted numerous in-depth studies of space technology and policy.

Before joining the Institute in 1995, Dr. Williamson was Senior Associate and Project Director in the Office of Technology Assessment (OTA) of the U.S. Congress. From 1979 to 1995, he directed most of OTA's space-related studies, including U.S.-Russian Cooperation in Space (1995), Civilian Satellite Remote Sensing (1994), and Global Change Research and NASA's Earth Observing System (1994).

Dr. Williamson is a member of the International Editorial Board of the journal *Space Policy*. He is the editor of *Commercial Observation Satellites: At the Leading Edge of Global Transparency*, with John C. Baker and Kevin O'Connell (RAND and ASPRS, 2001); *Dual-Purpose Space Technologies: Opportunities and Challenges for U.S. Policymaking* (Space Policy Institute, 2001); and *Space and Military Power in East Asia: The Challenge and Opportunity of Dual-Purpose Space Technologies*, with Rebecca Jimerson (Space Policy Institute, 2001). He is also the author or editor of seven books on archeology, historic preservation, and American Indian astronomy and culture, including *Living the Sky: The Cosmos of the American Indian*.

Dr. Williamson received his B.A. in physics from Johns Hopkins University and his Ph.D. in astronomy from the University of Maryland. For 10 years, he taught philosophy, literature, mathematics, physics, and astronomy at St. John's College in Annapolis, where he also served as Assistant Dean for 5 years.

Dr. Simon P. ("Pete") Worden

Education
B.S. in physics and astronomy, University of Michigan, 1971
Ph.D., University of Arizona, 1975

Brig. Gen. Simon P. Worden (USAF, ret.) is currently a Research Professor of Astronomy, Optical Sciences, and Planetary Sciences at the University of Arizona where his primary research direction is the development of large space optics for national security and scientific purposes and near-earth asteroids. In addition, he is working on topics related to space exploration and solar-type activity in nearby stars. He is a recognized expert on space issues—both civil and military. General Worden has authored or coauthored more than 150 scientific and technical papers in astrophysics, space sciences, and strategic studies. Moreover, he served as a scientific co-investigator for two NASA space science missions.

General Worden also serves as a consultant to the Defense Advanced Research Projects Agency on space-related issues. During the 2004 Congressional session, General Worden worked as a Congressional Fellow with the Office of Senator Sam Brownback (R-KS), where he served as Senator Brownback's chief advisor on NASA and space issues.

General Worden retired in 2004 after 29 years of active service in the United States Air Force. His final position was Director of Development and Transformation, Space and Missile Systems Center, Air Force Space Command, Los Angeles Air Force Base, Calif. In this position, he was responsible for developing new directions for Air Force Space Command programs and was instrumental in initiating a major Responsive Space Program designed to produce space systems and launchers capable of tailored military effects on timescales of hours.

General Worden was commissioned in 1971 after receiving a B.S. degree from the University of Michigan. He entered the Air Force in 1975 after graduating from the University of Arizona with a doctorate in astronomy. Throughout the 1980s and early 1990s, General Worden served in every phase of development, international negotiations, and implementation of the Strategic Defense Initiative, a primary component in ending the Cold War. He twice served in the Executive Office of the President. As the staff officer for initiatives in the George Bush administration's National Space Council, General Worden spearheaded efforts to revitalize U.S. civil space-exploration and earth-monitoring programs.

General Worden commanded the 50th Space Wing, which is responsible for more than 60 DOD satellites and more than 6,000 people at 23 worldwide locations. He then served as Deputy Director for Requirements at Headquarters, Air Force Space Command, as well as the Deputy Director for Command and Control with the Office of the Deputy Chief of Staff for Air and Space Operations at Air Force headquarters.

Appendix C
Committee Meeting Agendas

National Space Weather Program Assessment Committee
7– 8 July 2005
Office of the Federal Coordinator for Meteorology
Silver Spring, Maryland

Thursday, July 7, 2005

9:00 am	Welcome from the Federal Coordinator (Mr. Sam Williamson)
9:05 am	Welcome and Introductions by Group Chair (Dr. Lou Lanzerotti)
9:15 am	Administrative comments (Lt Col Rob Rizza)
9:20 am	Charter Discussion – Finalizing the Task Definition (All)
10:00 am	Break
10:15 am	Space Weather Community Presentations Dr. Ernie Hildner (Director, NOAA Space Environment Center; Manager, NOAA Space Weather Program) Dr. Rich Behnke (National Science Foundation)
1:30 pm	Space Weather Community Presentations Dr. Dick Fisher (National Aeronautics and Space Administration) Col. Harold Elkins (Department of Defense)
3:30 pm	Break
4:00 pm	Discussion of presentations; questions to presenters
5:30 pm	Adjourn

Friday, July 8, 2005

9:00 am	Strategy Session (Closed) – Revisit the Task Definition following what we have heard and learned. Discuss who we need to visit, when, how, objective of each visit. Timelines (schedule), etc.
11:00 am	Document any Action Items (Closed)

Noon Adjourn

National Space Weather Program Assessment Committee
15–16 September 2005 Itinerary

Thursday Sep 15, 2005

8:00 - 9:00	NPOESS Briefing/Discussion	Lt Col Mike Bonadonna
9:00 – 11:00	NASA	
(30 min)	CCMC	Dr. Mike Hesse
(20 min)	Research to Ops Challenges	Dr. Ron Birk
(25 min)	Status of Present Assets, Future Plans	Dr. Chuck Holmes
11:30 – 1:00	Lunch	
1:00 – 1:30	OFCM	Mr. Sam Williamson
1:30 – 2:30	NWS Interview	
2:30 – 3:30	NSF Interview	Dr Rich Behnke
3:30 – 4:30	Navy Interview	Dr. Bob McCoy, Dr. Herb Gursky
4:30 – 5:30	Assessment Team Meeting	

Friday Sep 16, 2005

0730	Meet at Pentagon	
8:00 – 9:00	National Security Space Office (4C1000)	Mr. Jay Parness
9:00 – 10:00	Director of Weather (4A1084)	Brig Gen Stickford
10:00 – 12:00	Transit to NRO and Lunch	
12:00 – 1:00	NRO	Dr. Pete Rustan

National Space Weather Program Assessment Committee
12–14 December 2005
Colorado/Omaha Itinerary

Monday Dec 12, 2005

Travel to SEC

9:00 – 10:00am Sun-to-Earth Modeling 2C406 David Skaggs Bldg, SEC
Tom Bogdan
Emily CoBabe-Ammann

10:15 – 11:00am Meet with USGS 2C406 David Skaggs Bldg, SEC
Dr. Jeff Love

11:00am – 1:00pm Lunch

1:00 – 4:00pm Visit the Space Environment Center 2C406 Davis Skaggs Bldg, SEC
Dr. Ron Zwickl

1:00pm	Introductions and agenda confirmation	Dr. Zwickl
1:05pm	Committee introductions and status	Dr. Lanzerotti
1:15pm	NOAA's Space Weather Program and contributions to NSWP	Dr. Zwickl
2:15pm	NGDC Stewardship of space weather data	Dr. Kihn
2:30pm	Break	
2:40pm	Tour of forecast center and test bed	Drs. Kunches and Doggett
3:00pm	Recommendations of future directions	Drs. Singer and Onsager
4:00pm	Adjourn	

4:00 – 6:00pm Travel to Colorado Springs, Check into the Radisson Inn

Tuesday Dec 13, 2005

7:00am Breakfast/Travel to SSAIO office in General Dynamics Bldg

8:00 – 9:00am Meet with USAF Space Command
Col Ron Grundman
Maj Kelly Hand

9:00 – 10:30am Meet w/ Space Situational Awareness Information Officer
POC: Lt Col Bruce Cessna
Lt Col Ken Philippart

11:00am – 12:00pm Small Space Environment Sensors
Dr. M. Geoff McHarg

National Space Weather Program Assessment Committee
12–14 December 2005
Colorado/Omaha Itinerary—Continued

Wednesday Dec 14, 2005

8:00 – 11:00am	Offut Air Force Base, Air Force Weather Agency Col Ray Clark Maj Tim Nobis
8:00am	Mission Briefs with manager-level discussions
9:30am	AFWA/CV
10:00am	Space WOC tour and discussions with personnel
11:00 – 11:45am	Team meeting
11:45am – 12:45pm	Lunch O-Club with LCDR Mike Rocheleau
1:00 – 2:00pm	Meet with U.S. Strategic Command Leadership Mr. John Gipson Associate Dir, Capability & Resource Integration Mr. Chip Coy: Deputy Chief, ISR and Space Division LCDR Mike Rocheleau

National Space Weather Program Assessment Committee
19-20 December 2005
NCR Itinerary

Monday Dec 19, 2005

AM	Travel to Silver Spring	
2:30 – 3:30pm	Meet with FAA	Ms. Lisa Bee Mr. Steve Albersheim
3:30 – 4:15pm	Discuss ongoing NSF funded Space Weather impacts on aviation study	Dr. Genene Fisher (AMS)

Tuesday Dec 20, 2005

8:00 – 8:30am	Conference call with Kathie Olsen	
9:00 – 10:00am	Meet with NWS Leadership	Brig Gen (R) D.L. Johnson Mr. David Caldwell
10:00 – 10:15am	Break	
10:15 – 11:15am	Meet with GOES-R Personnel	Mr. Ben Diedrich
11:15 – 1:00pm	Lunch	
1:00 – 3:00pm	Assessment team working meeting	

Depart

National Space Weather Assessment Committee
6 January 2006
Air Force Research Laboratory Itinerary

Friday Jan 6, 2006

8:30am NSWP Overview (Dr. Lanzerotti)

9:00am AFRL Center of Excellence Overview (Mozer)

9:40am Long-term goal: 72-120-hour space weather forecasting, SEEMs (Cooke)

10:00am Break

10:10am Space Weather Products Overview (led by Ginet)
- GeoSpace (Ginet)
- SCINDA/OPSEND (Groves)
- SEEFS (Hilmer)
- NASCAP-2K (Cooke)
- SMEI/SRBL/SpaN (Mozer)
- Satellite Drag (Huang)

11:10am Projects/Programs (led by Cooke)
- C/NOFS (Odile)
- DSX (Ginet)
- AFRL/CISM collaborations (Arge)

11:55am Issues (Odile)

12:30 – 2:30pm Assessment team working lunch and meeting

Adjourn

Appendix D
Questionnaires

NSWP Community Input Questionnaire

The United States National Space Weather Program (NSWP) began ten years ago as a collaborative enterprise between the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD). The NSWP has operated under the auspices of the Office of the Federal Coordinator for Meteorology (OFCM) and is based upon a Strategic Plan and an Implementation Plan which can be found at the following Web site: http://www.nswp.gov/nswp_docs.htm.

The OFCM, in conjunction with its Committee for Space Weather is now supporting a decadal review of the NSWP. This review is to quantify and document the progress toward meeting program goals. An **Assessment Committee***, comprised of researchers with meteorological, space physics, astrophysics, and policy backgrounds is gathering input from the broad communities in the United States involved in space weather research and applications, including operations. The assessment committee will perform a comprehensive review, which it can best achieve with very strong community participation. All those interested in the NSWP are strongly encouraged to comment on successes, shortfalls, and possible future directions of the program. Brief or extended comments are most welcome for the following questions:

---

0) Is your primary space weather activity research (military, civil), design, civil operations, military operations, commercial, or other? (Please specify).

1) What have you seen as the roles of the academic and research communities in the NSWP, including its successes and shortcomings? Are these roles appropriate and what changes might be required in the future?

2) As seen from your perspective, are there notable successes of the NSWP? What elements of the program have contributed most to these successes? Are there measurable benefits to your research program, commercial efforts, or civil/military operational program and, if so, will they help justify future research and/or technology development?

3) Where are the present weaknesses in the NSWP as you see them? How would you suggest addressing any shortfalls and/or weaknesses in the program?

4) Are new directions in the program in light of national priorities or recent research breakthroughs needed in the near and longer term?

5a) For those respondents with primarily commercial or governmental operational interests, are new directions in light of evolving customer needs appropriate?

5b) For those respondents with primarily research interests, are new directions/methods of doing research required in the near and longer term (e.g., because of the President's new emphasis on interplanetary travel)?

6) What new techniques, if any, are necessary to optimize the transition of your research to operations?

7) Is education about the NSWP for developers, providers and users keeping pace with research and transition activities? What new educational priorities would most serve the needs of the space weather research, governmental, or commercial community?

8) What new and/or additional methods are needed to further NSWP outreach objectives?

9) Any general comments on NSWP successes, shortfalls, and possible future directions of the program?

10) Please include any special instructions you may have for the disposition of your submitted comments (i.e. are your comments confidential, etc.)

Name (optional):
Email Address (optional):

NSWP User Input Questionnaire

The United States National Space Weather Program (NSWP) began ten years ago as a collaborative enterprise between the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD). The NSWP has operated under the auspices of the Office of the Federal Coordinator for Meteorology (OFCM) and is based upon a Strategic Plan and an Implementation Plan which can be found at the following website: http://www.nswp.gov/nswp_docs.htm.

The OFCM, in conjunction with its Committee for Space Weather is now supporting a decadal review of the NSWP. This review is to quantify and document the progress toward meeting program goals. An **Assessment Committee***, comprised of researchers with meteorological, space physics, astrophysics, and policy backgrounds is gathering input from the broad communities in the United States involved in space weather research and applications, including operations. The assessment committee will perform a comprehensive review, which it can best achieve with very strong community participation. All those interested in the NSWP are strongly encouraged to comment on successes, shortfalls, and possible future directions of the program. Brief or extended comments are most welcome for the following questions:

---

1. What is your primary professional activity or interest as they relate to space weather?

- ☐ Electric Power Industry
- ☐ Spacecraft and Space Operations
- ☐ Aviation
- ☐ GPS, Navigation, Surveying, Drilling
- ☐ DOD Operations
- ☐ Land-line Communications
- ☐ Other
- ☐ Radar
- ☐ Oil or Gas Pipeline
- ☐ Media
- ☐ Aurora Viewing
- ☐ Ham Operator
- ☐ HF, UHF Communications

2. What source do you prefer to use in acquiring space weather information?
NOAA/SEC
Other Government Agency
Private Vendor
Educational Facilities
Foreign Source (e.g., IPS, Kyoto, ESA, etc.)
Other (Please Specify)

3. How would you rate your understanding of space weather and its potential impact on your area of interest?

4. What can the space weather community do to improve your understanding of space weather?

5. Which space weather products or data are used by you or your organization?

6. How would you rate the accuracy of the forecast products provided by space weather service providers?

7. What other products and services could the space weather service providers offer in order to serve you better?

8. In your opinion, what is the greatest shortfall in today's operational space weather service industry?

9. What would be the impact(s) on your operations if upstream solar wind and charged particle data such as that currently provided by the Advanced Composition Explorer (ACE) Satellite would not be available at some time in the future?

10) Please include any special instructions you may have for the disposition of your submitted comments (i.e. are your comments confidential, etc.)

Name:
Email Address:

Appendix E

NATIONAL SECURITY SPACE ARCHITECT (NSSA)

SPACE WEATHER ARCHITECTURE STUDY

Final Report

22 March 1999

Key Study Recommendations

To guide future investment, development and acquisition of space and space-related capabilities, the NSSA recommends:

Space Weather Architecture Vector

- Increase emphasis on Operational Model development
- Ensure improved Operational Capabilities based on User Needs
  - National Security priorities include Ionospheric and Radiation Environment Specifications and Forecasts
  - Civil priorities also include Geomagnetic Warnings and Forecasts
- Evolve to improved Forecast Capabilities, as phenomenology is better understood, models mature, and user needs are better defined

Space Weather Importance Awareness

- Integrate Space Weather information (system impacts and space weather environment data) into User Systems through inclusion in:
  - User Education
  - Simulations
  - Wargaming and Training
  - Concept of Operations (CONOPS)
  - Contingency Planning
  - System Anomaly Resolution
  - Damage Assessment and Reporting

Space Weather Requirements

- Develop a set of Approved Validated Space Weather Requirements focused on User Needs
- Update Requirements as User Needs and Technology evolve

Coordinated Space Weather Architecture Acquisition

- Identify a cognizant organization in DOD to:
  - Manage the Acquisition of DOD Operational Space Weather Architecture and focus DOD Space Weather Research and Development
- Ensure Validated Models are developed in conjunction with Sensors and User Needs
- Ensure effective transitioning of R&D into Operations
  - Coordinate Acquisition and Integration of Space Weather Resources across Civil agencies and National Security Interest

Space Weather Information Archive

- Consolidate and Expand the Existing Archival System
  - Capture Space Weather Environmental Data and System Impacts
- The Archival System should be:
  - Centrally Managed
  - User Focused
  - Incorporate Standard Formats
  - Accommodate Multi-level Security

Integrated User Information

- Provide Space Weather Information:
  - In User Impact Terms
  - Routinely Available through Common Dissemination Channels
  - Integrated with Other User Information as required

Integrated Space Weather Center

- Evolve to an Integrated Space Weather Center capability to include:
  - Space Weather Expertise available for User Consultation and Support
  - A National Security Support Cell to produce Tailored Products
  - Back-up capability to provide support in the event of Natural Emergencies or Catastrophic Equipment Failures

Space Weather Research and Development

- Provide a Robust space weather Research and Development Program to:
  - Develop and Implement the Improved Models
  - Provide options for further growth
- Continue to Leverage Research and Development Missions
  - Enhance Operational Products until Operational Systems are ready
- Develop and Implement Standardized Processes to rapidly and efficiently Transition R&D into needed Operational Products

Space Weather and Man-Made Effects Information Coordination

- Support the Space Control Protection Mission by providing timely Space Weather Information
- Incorporate the Operational Specification and Forecasting of Space Environmental Effects of Man-made (Primarily Nuclear) Events (MMEs) as a Mission into the Space Weather Architecture

Appendix F
Recommendations from
U.S. Department of Commerce Service Assessment, April 2004

Intense Space Weather Storms October 19–November 07, 2003

Observations

Recommendation: NOAA should make the coronagraph a baseline instrument on future GOES spacecraft or other space-based platform. If the coronagraph is not deployed as an operational instrument, NOAA will suffer degradation in its current capability to provide space weather alerts and warnings.
Recommendation: NOAA should either procure, launch, operate, and acquire data from a series of real-time solar wind monitors placed near the Sun-Earth line, or NOAA should buy such data from a commercial supplier.

Internal and External Coordination

Recommendation 1a: Develop a website for the airline user community. Pending developments in the private sector, post the applicable services and explanations that apply to airline operational needs.
Recommendation 2a: Provide training for airline staff and management. Best options are for SEC staff to visit airline companies and/or facilitate a workshop for all interested parties (airline personnel, FAA, DOT, medical, etc).
Recommendation: Improve the SEC web page to better facilitate the needs of media and the NOAA Public Affairs Office. Make plain language forecasts, Space Weather Bulletins, Alerts, Watches, and Warnings readily available and easily accessible. This would help alleviate the distraction during high solar activity.

Models and Guidance

Recommendation: Pending developments in the private sector, improve the D-Region Absorption Plot to include impacts of radiation storms and geomagnetic storms on communications, or develop a product for airlines that would depict high latitude HF and VHF communication effects.
Recommendation: Complete Major Event database and interactive software and install in the Forecast Center.
Recommendation: NOAA and SEC must assist in and support modeling efforts such as the Center for Integrated Space weather Modeling (CISM) and the Community Coordinated Modeling Center (CCMC) as well as other research and commercial institution modeling capabilities. Fully functional Rapid Prototyping Centers (RPCs), operations testbeds, or commercially outsourced engineering implementation contracts must be in place for rapid, focused development and transition of required models into Space Weather operations. The recent activity highlighted the need for the following models:

- Coronal Mass Ejection Propagation - CME characterization (mass, speed, direction, and magnetic structure) for predicting time of CME arrival and onset and intensity of geomagnetic storming.
- Solar Energetic Particles (SEP) - SEP spectra for airlines, satellite anomaly, and manned space flight hazard prediction. Airline companies and satellite operators requested more detailed SEP onset time and duration predictions.

- Radiation Belt Particle distribution (>100 keV) for satellite upset prediction. Precipitating particle characterization (location, energy, timing) for polar ionosphere prediction. Requested by both government and commercial satellite companies.
- Ionosphere - Global EDP for radar and communications signal path bending prediction. Global TEC for radar and communications signal path delay prediction. Global ionospheric currents for ionospheric event propagation prediction - A three-dimensional Global Assimilative Ionospheric Model (GAIM)**.** This would help meet the communication needs identified by HF users including airlines.
- Polar Scintillation - Arctic spatial and frequency distribution for communications, radar, and navigation signal corruption and outage prediction. Both DOD and commercial high latitude interests identified this need.
- Neutral Environment - Global neutral density and composition (>90 km) for accurate satellite, space debris, and missile orbit prediction. Global neutral winds (>90 km) for accurate communications, radar, and navigation signal corruption and outage prediction. Global neutral temperature (>90 km) for accurate communications, radar, and navigation signal corruption and outage prediction.

Warnings and Forecasts

Recommendation: Utilize developments in modeling efforts, including those in the academic and vendor community, to provide improved radiation storm warnings to include maximum flux expected.
Recommendation: Establish requirements for amending the (daily) forecast or develop a new web-based dynamic forecast product.

Dissemination

Recommendation: Establish a permanent networking agreement with the NOAA Network Operations Center (NOC) to continue this expanding (Web site) service.

Appendix G
Recommendations from
The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics

Source: NRC 2002.

Space Weather Commentary and Recommendations from chapter 5

- **The National Space Weather Program**

A key function of the National Space Weather Program is to develop processes and policies for monitoring the space weather environment.

Finding: The federal agencies that have important research and/or mission interests in the solar-terrestrial environment are undertaking strong initiatives to establish, nurture, and evolve an effective national program in space weather. There is growing interest in the private sector in the provision of space weather products to both the private and the public sectors. As a result of all of these activities, numerous research and research policy issues have arisen that demand new attention from all parties interested in space weather.

- **Monitoring the solar-terrestrial environment**

Effective monitoring of the space environment requires identification of those research instruments and observations that are needed to provide the basis for modeling interactions of the solar-terrestrial environment with technical systems and for making sound technical design decisions.

Recommendation: NOAA and DOD, in consultation with the research community, should lead in an effort by all involved agencies to jointly assess instrument facilities that contribute key data to public and private space weather models and to operational programs. They should then determine a strategy to maintain the needed facilities and/ or work to establish new facilities. The results of this effort should be available for public dissemination.

Recommendation: NOAA should assume responsibility for the continuance of space-based measurements such as solar wind data from the L1 location as well as near Earth and for distribution of the data for operational use.

Recommendation: NASA and NOAA should initiate the necessary planning to transition solar and geospace imaging instrumentation into operational programs for the public and private sectors.

• The transition from research to operations

An important task facing the space weather community during the coming decade will be to establish, maintain, and evolve mechanisms for the efficient transfer of new models of the solar-terrestrial environment into the user community.

Recommendation: The relevant federal agencies should establish an overall verification and validation program for all publicly funded models and system-impact products before they become operational.

Recommendation: The operational federal agencies, NOAA and DOD, should establish procedures to identify and prioritize operational needs, and these needs should determine which model types are selected for transitioning by the Community Coordinated Modeling Center and the Rapid Prototyping Centers. After the needs have been prioritized, procedures should be established to determine which of the competing models, public or private, is best suited for a particular operational requirement.

• Data acquisition and availability

Developing successful space weather mitigation strategies involves the ability to predict space weather effects on specific technological systems as well as to predict space weather in general; it also requires knowledge of extreme space environmental conditions.

Recommendation: DOD and NOAA should be the lead agencies in acquiring all the data sets needed for accurate specification and forecast modeling, including data from the international community. Because it is extremely important to have real-time data, both space- and ground-based, for predictive purposes, NOAA and DOD should invest in new ways to acquire real-time data from all of the ground- and space-based sources available to them. All data acquired should contain error estimates, which are required by data assimilation models.

Recommendation: A new, centralized database of extreme space weather conditions should be created that covers as many of the relevant space weather parameters as possible.

• The public and private sectors in space weather applications

Both the government and private industry are involved in acquiring, assessing, and disseminating information and models related to the solar-terrestrial environment in the context of its relevance for technological systems. Therefore, it is important to determine the appropriate roles for each sector in space-weather–related activities.

Recommendation: Clear policies should be developed that describe government and industry roles, rights, and responsibilities in space weather activities. Such policies are necessary to optimize the benefits of the national investments, public and private, that are being made.

Education and Public Outreach, Chapter 6

• University faculty and curricula

Augmentation of university faculty in solar and space physics is essential for the support of a strong national solar and space physics research program in the coming decade.

Recommendation: The NSF and NASA should jointly establish a program of "bridged positions" that provides (through a competitive process) partial salary, start-up funding, and research support for four new faculty members every year for 5 years.

Appendix H
Acronyms

ACE	Advanced Composition Explorer
AFRL	Air Force Research Laboratory
AFWA	Air Force Weather Agency
AFSPC	Air Force Space Command
AMISR	Advanced Modular Incoherent Scatter Radar
APV	vertical guidance approach
CAMI	Civil Aerospace Medical Institute
CCMC	Community Coordinated Modeling Center
CEDAR	Coupling, Energetics and Dynamics of Atmospheric Regions [NSF program]
CEOS	Committee on Earth Observation Satellites
CISM	Center for Integrated Space Weather Modeling
CME	coronal mass ejection
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
CONUS	contiguous United States
CRPL	Central Radio Propagation Laboratory
CSEM	Center for Space Environmental Modeling
CSW	Committee for Space Weather
DARPA	Defense Advanced Research Projects Agency
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
DISS	Digital Ionospheric Sounding System
DMSP	Defense Meteorological Satellites Program
DREAM	Dynamic Radiation Environment Assimilation Model
Dst	Disturbance Storm Time [Index]
ESA	European Space Agency
ESSA	Environmental Science Services Administration
EUMETSAT	European Meteorological Satellites
EUV	extreme ultraviolet
FAA	Federal Aviation Administration
FAST	Fast Auroral Snapshot Explorer
FCMSSR	Federal Committee for Meteorological Services and Supporting Research
GAIM	Global Assimilation of Ionospheric Measurements
GEM	Geospace Environment Modeling [NSF program]

GEO	geosynchronous Earth orbit
GOES	Geostationary Operational Environmental Satellite system
GONG	Global Oscillation Network Group
GPS	Global Positioning System
HF	high frequency [region of the radio wave spectrum]
ICMSSR	Interdepartmental Committee for Meteorological Services and Supporting Research
ICSU	International Council for Science
IMAGE	Imager for Magnetopause-to-Aurora Global Exploration
IMS	Ionospheric Measuring System
ISES	International Space Environment Service
ISP	Ionosphere Storm Probes
ISS	International Space Station
ISTP	International Solar-Terrestrial Physics Project
LANDSAT	Land Remote-Sensing Satellite [System]
LANL	Los Alamos National Laboratory
LASCO	Large Angle and Spectrometric Coronagraph
LEO	low Earth orbit
LWS	Living With a Star
MEO	medium Earth orbit
MESSENGER	Mercury Surface, Space Environment, Geochemistry and Ranging [NASA Mission]
MetOp	Meteorological satellites in the EUMETSAT Polar System
MME	man-made events
MURI	Multidisciplinary University Research Initiative
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NRL	Naval Research Laboratory
NRO	National Reconnaissance Office
NSF	National Science Foundation
NSSA	National Security Space Architect
NSTC	National Science and Technology Center
NSWP	National Space Weather Program
NSWPASG	National Space Weather Program Assessment Study Group
NSWPC	National Space Weather Program Council
NWS	National Weather Service

OFCM	Office of the Federal Coordinator for Meteorological Services and Supporting Research
OMB	Office of Management and Budget
OpSEND	Operational Space Environment Network Display
OSTP	Office of Science and Technology Policy
OTA	Office of Technology Assessment
PNT	positioning, navigation, and timing
POES	Polar-orbiting Operational Environmental Satellite [Program in ESE]
RBR	Radiation Belt Remediation
RBSP	Radiation Belt Storm Probes
RHESSI	Ramaty High Energy Solar Spectroscopic Imager
RISE	Radiative Inputs of the Sun to Earth [NSF program]
RPC	Rapid Prototyping Center
SAMPEX	Solar Anomalous and Magnetospheric Particle Explorer
SAR	search and rescue
SCINDA	Scintillation Network Decision Aid
SDO	Solar Dynamics Observatory
SEC	Space Environmental Center [of NOAA/NCEP]
SEM	Space Environment Monitor
sfu	solar flux unit
SHF	superhigh frequency [region of the radio wave spectrum]
SHINE	Solar and Heliospheric Interplanetary Environment [NSF program]
SPARC	Space Physics and Atmospheric Research Center [U.S. Air Force Academy]
SOHO	Solar and Heliospheric Observatory
SOLIS	Synoptic Optical Long-term Investigation of the Sun
SOON	Solar Optical Network
SMEI	Solar Mass Ejection Imager
SNOE	Student Nitric Oxide Explorer
STEREO	Solar Terrestrial Relations Observatory
SWOC	Space Weather Operations Center
SuperDARN	Super Dual Auroral Radar Network
TEC	Total Electron Content [model]
TIMED	Thermosphere * Ionosphere * Mesosphere * Energetics and Dynamics
TR&T	Targeted Research and Technology
TRACE	Transition Region and Coronal Explorer
UARS	Upper Atmosphere Research Section (of NSF)
UHF	ultrahigh frequency [region of the radio wave spectrum]
UPOS	University Partnering for Operational Support
USGS	U.S. Geological Survey
USMCC	U.S. Mission Control Center [NOAA entity]

USU	Utah State University
USC	University of Southern California
UV	ultraviolet
VHF	very high frequency [region of the radio wave spectrum]
WAAS	Wide Area Augmentation System
WMSCR	Weather Message Switching Center Replacement