EXECUTIVE SUMMARY

In the six years since the inception of the National Space Weather Program (NSWP), space weather has virtually become a household word. Space weather refers to conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health. The growing awareness within the general public is largely the result of a conscious effort by all space weather stakeholders to educate the nation on the effects of solar storms and their potential impacts on the modern technology so important to daily life. In addition to increased awareness, solid advances have been made in our knowledge of the space weather system and in our ability to forecast potentially disruptive space weather events.

The NSWP *Strategic Plan*, released in 1995, put forth a strategy for achieving space weather goals. The program elements outlined in this strategy are shown in the figure below. The *Strategic Plan* was followed in 1997 by the NSWP *Implementation Plan*, which identified specific objectives and recommended activities necessary for improving space weather predictive capabilities. In the last six years, significant progress has been made in all programmatic areas. The NSWP's success is a result of the concerted efforts by the government agencies actively involved in space weather, as well as by all

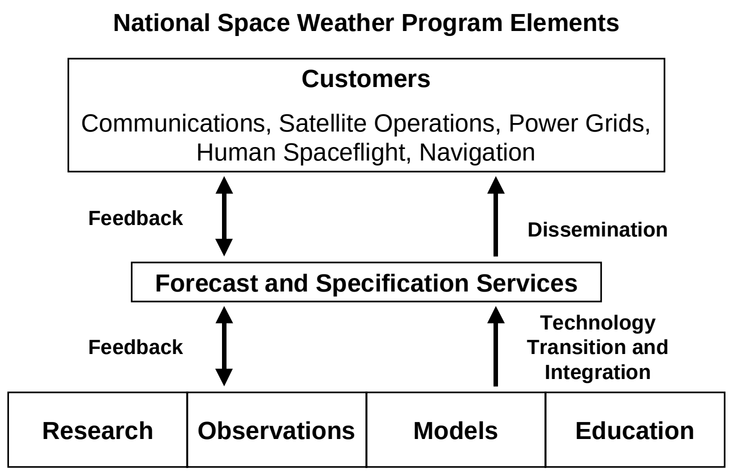

Figure ES-1. National Space Weather Program Elements

stakeholders in government, academia, and industry. The NSWP has provided a context for joint programs, improved communication, and effective sharing of information and results.

The National Oceanic and Atmospheric Administration's Space Environment Center and the U.S. Air Force's 55th Space Weather Squadron constitute the operational arms of the nation's space weather support capabilities. By making use of space-based and ground-based sensors and state-of-the-art computer models, the operations centers provide support for civilian and military customers and systems. Despite the progress made in the last six years, current capabilities still fall short of requirements for warning, nowcasting, forecasting, and post-analysis, although post-analysis capabilities are the most robust. In many areas, significant shortfalls remain and much work remains to be done.

NSWP agencies partnered to create a convenient set of metrics to better quantify the progress being made. Because of the many scientific and technical disciplines involved in the NSWP, developing such metrics is a difficult task. For this reason, a panel of scientists convened to formulate metrics in the three space weather domains. The domains are the ionosphere/thermosphere, the magnetosphere, and solar/solar wind. These research metrics are designed to assess the fundamental understanding of space weather processes. They will be adopted by the space science community and tracked over the next decade as an indicator of scientific progress as well as to identify the most serious gaps in capability.

The National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), and the Department of Defense are supporting aggressive research programs striving to achieve space weather goals. In addition to research efforts aimed at specific goals, many areas of research in space and plasma physics indirectly support program objectives by advancing knowledge in fundamental scientific areas. However, participants recognized early in the program that rapid progress could be made only by implementing a more targeted research program. Toward this end, NSF, with contributions from the Air Force Office of Scientific Research and the Office of Naval Research, began funding competitively-selected research proposals in key areas. They held these competitions in 1996, 1997, 1999, and 2000. The program announcements included a description of the areas of scientific emphasis to fill gaps in our existing knowledge and predictive capabilities. Panels of experts selected proposals based on the merit of the research and their potential to contribute to space weather goals. Results from grants awarded under these programs have included many innovative approaches to space weather model development and predictive capabilities, as well as more basic research aimed at improving our understanding of space weather phenomena. Overall, more than 70 targeted space weather proposals have been funded.

In recent years, models supporting space weather research have improved tremendously. Model development has emphasized physics-based approaches that are more likely to lead to improved predictive capabilities. Adaptive grids and data assimilation techniques

> **One interagency success story…**
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> The success of solar storm readiness is dependent on collaboration across the members of the National Space Weather Program. This was evident during the major geomagnetic storm that occurred from May 4-8, 1998. During the previous week forecasters and scientists mobilized into a high state of readiness as active regions on the sun produced a series of intense solar flares. NOAA forecasters monitoring the activity received numerous calls from the SOHO science team confirming that several large coronal mass ejections directed towards Earth had also occurred. NOAA forecasters used this information to estimate when they should expect to see the disturbances pass ACE. The storms passed ACE as projected and forecasters were able to alert customers with approximately 40 minutes of lead time. In response to the forecast and their own data, electric utilities cut power import from Canada by half and increased safety margins on other parts of the grid.
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> The storm was estimated to be about one quarter of the magnitude of the March 13, 1989 storm, but was still serious enough to cause great concern and stress on power and other systems affected by geomagnetic activity. The cooperation between NOAA, NASA, USAF, NSF and other NSWP partners was critical to preventing major system damage and failures. If one link in the NSWP chain had broken, the outcome may have been vastly different.

have been incorporated into some of the larger and more complex magnetohydrodynamic models describing solar processes and solar wind-magnetosphere interactions. Emphasis has also been placed on combining models to create a more seamless description of the entire space weather system from the Sun to Earth's atmosphere.

The use of research observations to support space weather priorities has also blossomed during the last six years. Many ongoing and planned space-based missions have been developed with space weather requirements in mind, making it easier to adapt the data flow for operational purposes. The explosion of the World Wide Web has also facilitated the faster and broader sharing of space- and ground-based measurements for space weather purposes. Enabled by the NSWP, the excellent coordination between the producers of these research observations and the operational community has produced new opportunities for collaboration. Of particular note is NASA's Living with a Star initiative which will provide observational capabilities, theory, and modeling to enhance knowledge of the space weather system.

Working together, the stakeholding agencies of the federal government have developed new timelines for both operational and research-level models and sensors. These timelines include critical milestones in model development and sensor deployment to guarantee improved space weather forecasting capabilities. Near-term emphasis in NSWP research includes the study of the origins of coronal mass ejections, the triggering of magnetospheric substorms, and the evolution of ionospheric irregularities. For space weather modeling, validation and testing of existing models along with the application of data assimilation techniques are high priorities. The emphasis for observing is to maintain the existing suite of ground- and space-based observatories, take advantage of real-time data when possible, and plan for future missions and facilities, such as NSF's planned Relocatable Atmospheric Observatory, to address gaps in knowledge and observational coverage.

The transfer of research knowledge into operations, commonly known as technology transition, is an area that has long impeded progress in applying scientific research results to operational needs within the space weather forecasting communities. As a result, NSWP agencies initiated a multi-faceted approach to address this issue. Both NOAA and the DOD implemented plans to develop Rapid Prototyping Centers (RPCs) whose function is to adapt space weather models for use in the operational centers. To aid researchers in the development of models, the DOD, NASA, NSF, and NOAA have worked together to create the Community Coordinated Modeling Center (CCMC). A parallel-processing supercomputer at Air Force Weather Agency in Omaha, Nebraska, is linked to front-end workstations at Goddard Space Flight Center, Maryland. The facility provides researchers with a means to exercise models that may eventually be used at the operational centers. The CCMC is intended to provide the critical link between the scientific research community and the Rapid Prototyping Centers as well as establishing data management standards and procedures early in development (see Figure ES-2).

Educational activities play an important role in space weather by elevating awareness of potential impacts, both among space weather customers and the general public. NSWP participants have used both formal and informal venues for educational and outreach efforts in space weather. Educational materials on space weather are being made web-accessible to schools at the K-12 level, while NOAA is producing a curriculum guide on "Solar Physics and Terrestrial Effects" for teachers of grades 7 through 12. Awareness in the general public has been enhanced through the proliferation of space weather web sites and the extensive media coverage in the past several years. Space scientists have made a concerted effort to publicize space weather events and their effects on technical systems. They have participated in the design and development of web sites through which the development of events can be observed in real time. The net result of these efforts has been an unprecedented level of attention to space weather by the general public. Specific

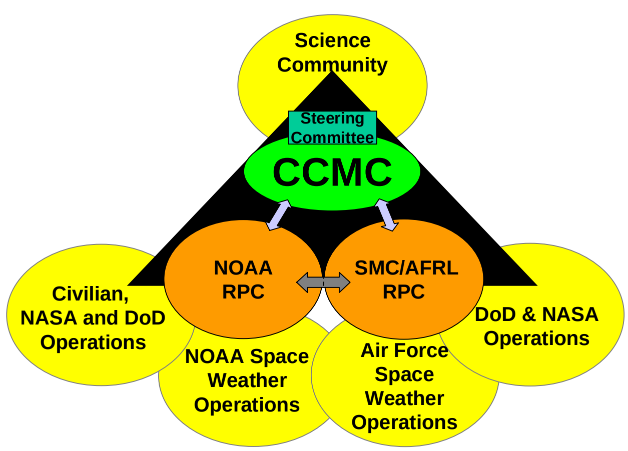

Figure ES-2. Linking the Science Community with Operational Centers

examples include a television program on space weather on the Discovery Channel™, and an IMAX™ film on solar maximum. Press coverage, inspired by carefully planned press releases, has increased tremendously as indicated by the number of articles appearing in newspapers and magazines.

Equally important for effective progress in space weather goals is to establish and strengthen relationships with space weather customers. Interaction between space weather customers and operational forecasters had previously taken place at the Space Environment Center in Boulder during the Space Weather User Conferences held every three years. In 1998, meeting attendees favored meeting annually, at least during the solar maximum period, and also endorsed merging the meeting with the Space Weather Research to Operations Workshops previously held in January in Boulder. The two meetings were held consecutively for the first time in April 1999 in an event referred to as Space Weather Week. This successful format for encouraging feedback between the scientific community and space weather customers will continue on an annual basis for the next several years.

In addition to the Users Conference, program participants conducted two other more specialized workshops. The first was a workshop on Geomagnetically Induced Currents held at the Electric Power Research Institute (EPRI) headquarters in Washington, DC, in October 1996. The second was a workshop on Space Weather Effects on Navigation and Communication Systems held at COMSAT headquarters in Bethesda, MD, in 1997.

Customer education will continue to have a high priority in the NSWP and is expected to help in collecting and analyzing space weather impacts on operations. It is also expected to improve the identification of customer requirements.

SOHO recovered…

On June 25, 1998 NASA radio contact with SOHO was suddenly lost, disrupting a tremendously successful science mission and terminating a valuable source of data on Coronal Mass Ejections for NOAA's Space Environment Center. The effort to find SOHO and recover the spacecraft brought experts from various NSWP agencies together in a common mission. With the encouragement of a NOAA/SEC scientist, staff at NSF's National Astronomy and Ionospheric Center used the Arecibo radio telescope to transmit a signal toward SOHO's last known location on July 23, 1998. Using radar techniques NASA's DSN groundstation at Goldstone received the signal containing SOHO's echo and tracked the spacecraft for more than an hour. The radar data indicated that SOHO was still in its proper orbit, but its solar panels were pointing away from the sun and it had begun slowly turning.

Thanks to the team effort of National Space Weather Program partners and their colleagues SOHO was gradually brought back into service. SOHO first responded to radio transmissions on August 3, and telemetry from SOHO was received August 8, telling controllers the condition of the spacecraft and its instruments. The spacecraft's frozen hydrazine fuel was gradually thawed, and on September 16, SOHO's thrusters were fired to stop its spin and to place it in the correct orientation towards the Sun. Over the next few weeks SOHO's instruments were gradually turned on and tested culminating in mid-October with the release of the first images.

Identifying the requirements of the satellite industry has been difficult due to the highly competitive nature of the industry and the complexities associated with insurance coverage and the legal aspects of satellite communications. To initiate discussions with satellite industry representatives, NSF made an award for the purpose of interviewing top aerospace industry executives. This study underscored the difficulties in addressing commercial space weather needs. The DOD has also initiated efforts with each of its services to improve and expand the documentation of space weather impacts on military operations.

Program management for the NSWP continues to be administered through the Office of the Federal Coordinator for Meteorology (OFCM). The National Space Weather Program Council provides top-level direction, while day to day oversight of the program is entrusted to the Committee for Space Weather aligned under the Council. Parallel efforts in management and coordination of space weather activities have been launched by the DOD through the office of the National Security Space Architect and by NASA through its Living with a Star initiative. The National Security Space Architect has concluded a detailed space weather architecture study and developed a transition plan to meet the nation's space weather needs through the year 2025. Within the framework of the NSWP, the architecture and transition plan provide detailed guidance for DOD agencies to use in planning, funding, developing, acquiring, and operating its portion of the overall architecture. Because of the interagency nature of the NSWP and the nation's space weather operations, many of the NSWP agencies participated in the project and the results have been incorporated in NSWP planning. Similarly, mission planning for Living with a Star is proceeding with close coordination between NASA and other NSWP agencies.

International efforts in space weather have also been greatly expanded as a result of the increasing U. S. activities. The importance of international participation has been continually stressed within the NSWP because it provides a means to blend the unique resources of other nations into the space weather planning process. The effects of space weather are global; experimental campaigns in support of research, as well as environmental monitoring, include the assets that foreign scientists and observing capabilities can contribute. Among the other nations with dedicated space weather programs are Sweden, Australia, Japan, Canada, France, Taiwan, and China. The past few years have seen a tremendous improvement in international coordinating activities, particularly through the Scientific Committee for Solar Terrestrial Research. Among its accomplishments, the S-RAMP Steering Committee under SCOSTEP identified a period of high solar activity as a “Special Study Interval” for space weather, and organized a dedicated campaign in September of 1999.

In conclusion, the past six years have seen significant progress made in all programmatic areas demanded by space weather goals. The success of these endeavors is directly attributed to the excellent cooperation among government agencies and space weather stakeholders. With this spirit of cooperation, optimism for future success remains high.