NATIONAL SPACE WEATHER STRATEGY

PRODUCT OF THE

National Science and Technology Council

October 2015

About the National Science and Technology Council

The National Science and Technology Council (NSTC) is the principal means by which the Executive Branch coordinates science and technology policy across the diverse entities that make up the Federal research and development enterprise. One of the NSTC's primary objectives is establishing clear national goals for Federal science and technology investments. The NSTC prepares R&D packages aimed at accomplishing multiple national goals. The NSTC's work is organized under five committees: Environment, Natural Resources, and Sustainability (CENRS); Homeland and National Security; Science, Technology, Engineering, and Mathematics (STEM) Education; Science; and Technology. Each of these committees oversees subcommittees and working groups that are focused on different aspects of science and technology. More information is available at www.whitehouse.gov/ostp/nstc.

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on questions in which science and technology are important elements; articulating the President's science and technology policy and programs; and fostering strong partnerships among Federal, State, and local governments, and the scientific communities in industry and academia. The Director of OSTP also serves as Assistant to the President for Science and Technology and manages the NSTC. More information is available at www.whitehouse.gov/ostp.

About the Space Weather Operations, Research, and Mitigation (SWORM) Task Force

The Space Weather Operations, Research, and Mitigation (SWORM) task force, an interagency group organized under the NSTC, CENRS, Subcommittee on Disaster Reduction (SDR), was chartered in November 2014 to develop a national strategy and a national action plan to enhance national preparedness for space-weather events.

About this Document

This document was developed by the SWORM Task Force. It was released in draft for public comment on the Federal Register (80 FR 24296), was reviewed by SDR and CENRS, and was finalized and published by OSTP.

Acknowledgements

The SWORM Task Force acknowledges the contributions from the IDA Science and Technology Policy Institute for providing subject-matter expertise, constructive review, and other contributions to the development of this strategy.

Printed in the United States of America, 2015

Space Weather Operations, Research, and Mitigation Task Force

Co-Chairs

Department of Commerce, National Oceanic and Atmospheric Administration
Department of Homeland Security
Office of Science and Technology Policy

Members

Departments
Department of Commerce
Department of Defense
Department of Energy
Department of Homeland Security
Department of the Interior
Department of State
Department of Transportation

Agencies and Service Branches
Federal Aviation Administration
Federal Communications Commission
Federal Emergency Management Agency
Federal Energy Regulatory Commission
National Aeronautics and Space Administration
National Oceanic and Atmospheric Administration
National Science Foundation
Nuclear Regulatory Commission
Office of the Director of National Intelligence
United States Air Force
United States Geological Survey
United States Navy
United States Postal Service

Executive Office of the President
National Security Council
Office of Management and Budget
Office of Science and Technology Policy
White House Military Office

EXECUTIVE OFFICE OF THE PRESIDENT
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
WASHINGTON, D.C. 20502

October 29, 2015

Dear Colleagues,

Space weather is a naturally occurring phenomenon that has the potential to cause substantial detrimental effects on the Nation's economic and social well-being. Preparing for and predicting space-weather events and their potential effects on Earth is a significant challenge. Recent efforts led by the United States and its international partners have resulted in significant progress toward improving the understanding, monitoring, prediction, and mitigation of this hazard, but much more needs to be done.

Over the past 5 years, OSTP has coordinated interagency efforts to improve the Nation's ability to prepare, avoid, mitigate, respond to, and recover from the potentially devastating impacts of space-weather events. These efforts included the establishment of the interagency Space Weather Operations, Research, and Mitigation (SWORM) Task Force in November 2014. The goal of the SWORM Task Force was to unite the national- and homeland-security enterprise with the science and technology enterprise to formulate a cohesive vision to enhance national preparedness for space weather.

This *National Space Weather Strategy* and accompanying *National Space Weather Action Plan* are the result of the SWORM Task Force's efforts. These documents transcend agency-mission and sector boundaries to describe how the Federal Government will coordinate its efforts on space weather and how the Federal Government plans to engage academia, the private and public sectors, and other governments on space weather. The Strategy and associated Action Plan aim to enhance the preparedness of the Nation by interweaving and building upon existing policy efforts to identify overarching goals that underpin and drive the activities necessary to improve the security and resilience of critical technologies and infrastructures.

These documents represent only a next step to improving national preparedness for space weather. The Strategy sets overall goals for Federal action, while the Action Plan establishes Federal actions and timelines for implementation. Many of these activities will require long time horizons, which will necessitate sustained engagement among government agencies and the private sector. This challenge requires the Nation to work together to continually improve understanding, prediction, and preparedness to enhance the Nation's resilience against severe space-weather events.

Sincerely,

John P. Holdren

John P. Holdren
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy

Table of Contents

Executive Summary

Space weather refers to variations in the space environment between the sun and Earth (and throughout the solar system) that can affect technologies in space and on Earth. Space weather can disrupt the technology that forms the backbone of this country's economic vitality and national security, including satellite and airline operations, communications networks, navigation systems, and the electric power grid. As the Nation becomes ever more dependent on these technologies, space weather poses an increasing risk to infrastructure and the economy. Further, the Strategic National Risk Assessment[1] has identified space weather as a hazard that poses significant risk to the security of the Nation. Clearly, reducing vulnerability to space weather needs to be a national priority.

The *National Space Weather Strategy* (Strategy) and the accompanying *National Space Weather Action Plan* (Action Plan) together seek to enhance the integration of existing national efforts and to add important capabilities to help meet growing demands for space-weather information. The Strategy and Action Plan build on recent efforts to reduce risks associated with natural hazards and improve resilience of essential facilities and systems,[2] aiming to foster a collaborative environment in which government, industry, and the American people can better understand and prepare for the effects of space weather. The Nation must continue to leverage existing public and private networks of expertise and capabilities and pursue targeted enhancements to improve the ability to manage risks associated with space weather.

Six strategic goals underpin the effort to reduce the Nation's vulnerability to space weather:

1. **Establish Benchmarks for Space-Weather Events:** Effective and appropriate actions for space-weather events require an understanding of the magnitude and frequency of such events. Benchmarks will help government and industry assess the vulnerability of critical infrastructure, establish decision points and thresholds for action, understand risk, and provide points of reference to enable mitigation procedures and practices and to enhance response and recovery planning.

2. **Enhance Response and Recovery Capabilities:** There is a need to develop comprehensive guidance to support and improve response and recovery capabilities to manage space-weather events, including the capabilities of Federal, State, and local governments[3] and of the private sector.

3. **Improve Protection and Mitigation Efforts:** Improvements to national preparedness for space-weather events will require enhancing approaches to protection and mitigation. Protection focuses on developing capabilities and actions to secure the Nation from the effects of space weather, including vulnerability reduction. Mitigation focuses on minimizing risks, addressing cascading effects, and enhancing disaster resilience.[4] Implementation of these preparedness missions requires joint action from public and private stakeholders whose shared expertise and responsibilities are embedded in the Nation's infrastructure systems.

---

[1] Department of Homeland Security, *The Strategic National Risk Assessment (SNRA) in Support of PPD 8: A Comprehensive Risk-Based Approach toward a Secure and Resilient Nation*, December 2011.

[2] See References section for a list of recent relevant policy documents.

[3] Local governments include tribal, territorial, and insular area governments.

[4] *Disaster resilience* refers to the capability to prevent, or protect infrastructure from, significant multi-hazard threats and incidents and to expeditiously recover and reconstitute critical services with minimum damage to public safety and health, the economy, and national security.

4. **Improve Assessment, Modeling, and Prediction of Impacts on Critical Infrastructure:** Timely, reliable, actionable, and relevant decision-support services during space-weather events are essential to improving national preparedness. Societal effects must be understood to better inform the actions necessary during extreme events and to encourage appropriate mitigation and protection measures before an incident.

5. **Improve Space-Weather Services through Advancing Understanding and Forecasting:** Opportunity exists to improve the fundamental understanding of space weather and increase the accuracy, reliability, and timeliness of space-weather observations and forecasts (and related products and services). The underpinning science and observations will help drive advances in modeling capability and improve the quality of space-weather products and services. There is also a need to improve capacity to develop and transition the latest scientific and technological advances into space-weather operations centers.

6. **Increase International Cooperation:** In a world of complex interdependencies, global engagement and a coordinated international response to space weather is needed. The United States must not only be an integral part of the global effort to prepare for space-weather impacts, but must also help mobilize broad, global support for this effort by using existing agreements and building international support and policies.

The Strategy identifies goals and establishes the guiding principles that will underpin the Nation's efforts to secure the infrastructures vital to national security and economy of the United States. It identifies specific initiatives to drive both near- and long-term national protection priorities. It also provides protocols for preparing and responding to space-weather events and for ensuring that information is available to inform decision-making. This information will be used to enhance national resilience and prepare an appropriate response during space-weather storms.

This Strategy and the associated Action Plan will facilitate the integration of space-weather information into Federal risk-management plans to achieve preparedness levels consistent with national policies. Accomplishing the strategic elements in the Strategy will require a whole-community approach to coordinating domestic and international public and private resources.[5] Government, industry, and the American people must work together to enhance the resilience of critical infrastructure to the adverse effects of space weather on the people, economy, and security of the Nation.

[5] Whole-community planning for resilience is an approach to emergency management that reinforces the ideas that the Federal Emergency Management Agency (FEMA) is only one part of the Nation's emergency management team; that collective resources must be leveraged in preparing for, protecting against, responding to, recovering from, and mitigating against all hazards; and a collective effort is required to meet the needs of the entire community in each of these areas (FEMA, *A Whole Community Approach to Emergency Management: Principles, Themes, and Pathways for Action*, FDOC 104-008-1, December 2011).

Introduction

Space-weather events are naturally occurring phenomena that have the potential to negatively affect technology and energy infrastructure, which are essential contributors to national security and economic vitality. The term "space weather" refers to the dynamic conditions of the space environment that arise from emissions from the sun, which include solar flares, solar energetic particles, and coronal mass ejections (CME).[6] These emissions can interact with Earth and its surrounding space, including the Earth's magnetic field, potentially disrupting electric power systems; satellite, aircraft, and spacecraft operations; telecommunications; position, navigation, and timing services; and other technologies and infrastructures.[7] The Nation's critical infrastructures make up a diverse, complex, interdependent system of systems in which the failure of one could cascade to another. Given the importance of reliable electric power and space-based assets for security and economic well-being, it is essential that the United States establish a strategy to improve the Nation's ability to protect, mitigate, respond to, and recover from the potentially devastating effects of space-weather events.

Space-weather events occur regularly and have measurable effects on critical infrastructure systems and technologies. The *National Space Weather Strategy* (Strategy) and *National Space Weather Action Plan* (Action Plan) establish goals and actions to enhance the understanding of risk from, and national preparedness for, extreme space-weather events. Many of the goals and activities outlined in the Strategy and Action Plan can be scaled to address space-weather events that are smaller in magnitude. Such events occur more frequently than extreme events and can have significant effects.

Space weather is a global issue. Unlike terrestrial weather events (e.g., a hurricane), space weather has the potential to simultaneously affect the whole of North America or reach even wider geographic regions of the planet. Even though the United States is a global leader in observing and forecasting space-weather events, these capabilities depend on international cooperation and coordination.

This Strategy outlines objectives for enhancing the Nation's space-weather readiness in three key areas: national preparedness, forecasting, and understanding. Federal departments and agencies have taken significant steps in these key areas. The challenges posed by global vulnerability to space-weather events require continuing research and development to improve observation and forecasting capabilities, which are linked directly to preparedness. The goals outlined in this Strategy will leverage these efforts and existing policies, while promoting enhanced coordination and cooperation across the public and private sectors in the United States and abroad.

Implementation of the National Space Weather Strategy

The Action Plan, released concurrently with this Strategy, details the Federal activities that will be undertaken to implement the Strategy and achieve the six high-level goals, and includes deliverables and timelines. This Strategy acknowledges the challenges associated with planning and preparing for extreme events that do not currently have well-defined recurrence rates; identified activities in the Action Plan should therefore be prioritized accordingly. The Executive Office of the President will coordinate the execution of the Action Plan and will reevaluate and update the Strategy and Action Plan within 3 years of the date of publication, or as needed.

Full implementation of this Strategy will require the action of a nationwide network of governments, agencies, emergency managers, academia, the media, the insurance industry, nonprofit organizations,

[6] Not all effects of space weather are damaging. The aurora borealis is a striking visual manifestation of space weather.

[7] For a more detailed description of space weather and its drivers, please refer to the Appendix.

and the private sector. Strong public-private collaborations must be established between the Federal Government, industry, and academia to enhance observing networks, conduct research, develop prediction models, and supply the services necessary to protect life and property and to promote economic prosperity. These partnerships will form the backbone of a space-weather-ready Nation.

Enhancing National Preparedness and Critical Infrastructure Resilience

This Strategy ensures that space weather is fully integrated into the frameworks of two Presidential Policy Directives (PPDs): PPD-8, "National Preparedness" (March 30, 2011); and PPD-21, "Critical Infrastructure Security and Resilience" (February 12, 2013).

PPD-8 calls for an integrated, all-of-Nation, capabilities-based approach to preparedness for all hazards. It also calls for the creation of a series of National Planning Frameworks. Accordingly, the Department of Homeland Security (DHS) coordinated the development of the Strategic National Risk Assessment (SNRA).[8] The SNRA identified space weather as one of nine natural hazards with the potential to significantly affect homeland security.

PPD-21 identifies three strategic imperatives to drive the Federal approach to strengthening critical infrastructure security and resilience at the core of this Strategy.[9] The Directive identifies energy and communications systems as vital due to the enabling functions they provide across all critical infrastructure sectors. The Directive also instructs the Federal Government to engage with industry and international partners to strengthen the security and resilience of domestic and international critical infrastructures on which the Nation depends.

Strategic Goals

This Strategy defines six strategic goals to prepare the Nation for near- and long-term space-weather impacts. The goals aim to improve the Nation's preparedness for, forecasting of, and understanding of space-weather events, encompassing efforts related both to the phenomena that cause space weather and the effects of these phenomena. (See the Appendix for background on the phenomena that cause space weather.)

The six high-level goals for Federal research, development, deployment, operations, coordination, and engagement are:

1. Establish Benchmarks for Space-Weather Events
2. Enhance Response and Recovery Capabilities
3. Improve Protection and Mitigation Efforts
4. Improve Assessment, Modeling, and Prediction of Impacts on Critical Infrastructure
5. Improve Space-Weather Services through Advancing Understanding and Forecasting
6. Increase International Cooperation

---

[8] DHS, *The Strategic National Risk Assessment in Support of PPD 8*.

[9] (1) Refine and clarify functional relationships across the Federal Government to advance the national unity of effort to strengthen critical infrastructure security and resilience; (2) Enable effective information exchange by identifying baseline data and systems requirements for the Federal Government; and (3) Implement an integration and analysis function to inform planning and operations decisions regarding critical infrastructure.

1. Establish Benchmarks for Space-Weather Events

Benchmarks are a set of characteristics and conditions against which a space-weather event can be measured. They provide a point of reference from which to improve the understanding of space-weather effects, develop more effective mitigation procedures, enhance response and recovery planning, and understand risk.

Benchmarks should provide clear and consistent descriptions of the relevant physical parameters of space-weather phenomena based on current scientific understanding and the historical record. For example, benchmarks may serve as input to vulnerability assessments to help establish decision points and thresholds for action and to inform practices (e.g., device development, operational planning, and mitigation efforts). These benchmarks will not seek to categorize or classify the degree of impact from a space-weather event on a technology or infrastructure system.

To be effective, the benchmarks must be developed in a timely manner using transparent methodology with a clear statement of assumptions and uncertainties and publicly available data (where possible). Because of relatively limited data and gaps in understanding space-weather phenomena, benchmarks should be reevaluated as significant new data and research become available. The following objectives should be pursued in the development of these benchmarks:

- **Define scope, purpose, and approach for developing benchmarks:** The benchmarks will use multiple physical parameters to describe a space-weather event. The parameters should include characteristics of an event and its interactions with Earth and near-Earth environments (e.g., geomagnetic and ionospheric disturbances).
- **Create multiple benchmarks to address different circumstances:** The benchmarks should cover:
    - Different types of space-weather events (e.g., ionospheric disturbances induced by solar flares, and geomagnetic disturbances induced by CMEs);
    - Multiple physical parameters that will ensure the functionality of the benchmarks (e.g., magnitude and duration); and
    - A range of event magnitudes and associated recurrence intervals (e.g., multiple event scenarios may inform different vulnerability thresholds, and an understanding of the worst-case scenario may be instructive).

2. Enhance Response and Recovery Capabilities

Extreme space-weather events are potentially high-impact events that will require a coordinated national response and recovery effort. Leveraging the National Planning Frameworks,[10] the Nation will develop comprehensive guidance to support existing response and recovery capabilities to manage extreme events with government (Federal, State, and local), industry, and other partners. Improved vulnerability assessments and systems modeling will enhance planning for the effects of extreme events

[10] The National Planning Frameworks describe how the Whole Community works together to achieve the national preparedness goal of "a secure and resilient nation with the capabilities required across the whole community to prevent, protect against, mitigate, respond to, and recover from the threats and hazards that pose the greatest risk." This goal is the cornerstone for the implementation of PPD-8 (FEMA website, "National Planning Frameworks," www.fema.gov/national-planning-frameworks).

on critical infrastructure systems and the Whole Community,[11] as well as inform estimates of duration and costs of response and recovery measures. Likewise, improved forecasting capabilities will enable the development of time-sensitive procedures before significant impacts can occur. Enhancing the Nation's response and recovery capabilities will require continued investments, unique solutions, and strong public-private partnerships. The following objectives should be pursued to enhance response and recovery capabilities:

- **Complete an all-hazards power outage response and recovery plan:** The primary risk from an extreme space-weather event is the potential for the long-term loss of electric power and the cascading effects that it would have on other critical infrastructure sectors. Other high-impact events are also capable of causing long-term regional or national power outages. It is essential to have a comprehensive and executable plan (with key decision points) to address regional or national power outages. The plan must include the Whole Community and prioritize core capabilities.[12]
- **Support government and private-sector planning for and management of extreme space-weather events:** The incorporation of space-weather event information into all-hazards planning is limited for Federal, State, and local governments. Credible information and guidance on how to obtain that knowledge and incorporate it into government all-hazards planning should be developed and disseminated.
- **Provide guidance on contingency planning for the effects of extreme space weather for essential government and industry services:** Preservation of government services, personnel movement, and maintenance of infrastructure systems are essential before, during, and after an extreme space-weather event. Government, the private sector, and critical infrastructure entities need guidance on how to respond in a manner that increases the likelihood of maintaining essential operational elements for a prolonged period of time.
- **Ensure the capability and interoperability of communications systems during extreme space-weather events:** Effective communications systems are essential to gaining and maintaining situational awareness and ensuring unity of effort in response and recovery operations. The effects of space weather on communications systems occur at different timescales and at varying degrees within a single event, depending on the system and the characteristics and duration of the event. Government and private-sector stakeholders need guidance that allows them to maintain communications capabilities (including interoperability) during an extreme space-weather event.
- **Encourage owners and operators of infrastructure and technology assets to coordinate development of realistic power-restoration priorities and expectations:** Electrical power providers should develop protocols for restoring electrical power before disruptions, in coordination with State and local governments. Critical-asset owners and operators must work with their providers to ensure that their power needs are understood. The owners and operators should consider plans and capabilities for temporary power in the event of an electrical power disruption caused by an extreme space-weather event.

[11] Whole Community partners refer to the Nation's larger collective emergency management team and include not only DHS and its partners at the Federal level, but also State, local, tribal, and territorial (SLTT) partners, non-governmental organizations such as faith-based and nonprofit groups and private sector industry, and individuals, families and communities. See FEMA website, "Whole Community," last updated April 16, 2015, www.fema.gov/whole-community.

[12] The FEMA National Response Framework (May 2013) defines 14 response-centric core capabilities.

- **Develop and conduct exercises to improve and test government and industry-related space-weather response and recovery plans:** Evaluating the effectiveness of plans includes developing and executing a combination of training events and exercises to determine whether the goals, objectives, decisions, actions, and timing outlined in the plans support successful response and recovery. Exercising plans and capturing lessons learned enables ongoing improvement in event response and recovery capabilities.

3. Improve Protection and Mitigation Efforts

Growing interdependencies of critical infrastructure systems have increased potential vulnerabilities to space-weather events. Protection and mitigation efforts to eliminate or reduce space-weather vulnerabilities are essential components of national preparedness. Protection focuses on capabilities and actions to eliminate vulnerabilities to space weather, and mitigation focuses on long-term vulnerability reduction and enhancing resilience to disasters.[13] Together, these preparedness missions frame a national effort to reduce vulnerabilities and manage risks associated with space-weather events. Implementing these preparedness missions requires joint action from both public and private stakeholders, due to the shared expertise and responsibilities embedded in the Nation's infrastructure systems. The following objectives should be pursued to improve protection and mitigation efforts with respect to space-weather events:

- **Encourage development of hazard-mitigation plans that reduce vulnerabilities to, manage risks from, and assist with response to the effects of space weather:** In support of Whole Community planning for resilience, information about space-weather hazards should be integrated, as appropriate, into existing mechanisms for information sharing, including Information Sharing Analysis Organizations, and into national preparedness mechanisms that promote strategic alignment between public and private sectors.
- **Work with industry to achieve long-term reduction of vulnerability to space-weather events by implementing measures at locations most susceptible to space weather:** Adopting standards, business practices, and operational procedures that improve protection and resilience is essential to addressing system vulnerabilities to space weather. The benchmark space-weather events described in the first strategic goal (Establish Benchmarks for Space-Weather Events) should be used to support the adoption of design standards for enhanced resilience; evaluate strategies for, priorities for, and feasibility of protecting critical assets; and foster mechanisms for sharing best practices that promote mitigation and protection of systems affected by space weather.
- **Strengthen public-private collaborations that support action to reduce vulnerability to space weather:** Private industries are essential to the Nation's resilience. They are the owners and operators of the majority of the Nation's critical infrastructure, and they play a vital role in research and development to enhance understanding and improve mitigation. Space-weather events do not respect national, jurisdictional, or corporate boundaries. Incorporating resilience measures into U.S. infrastructure systems requires public-private collaboration, support of existing coordinating mechanisms for information sharing and access, and identification of incentives and disincentives for investing in resilience measures.

---

[13] Disaster resilience refers to the capability to prevent, or protect infrastructure from, significant multi-hazard threats and incidents and to expeditiously recover and reconstitute critical services with minimum damage to public safety and health, the economy, and national security (Blanchard, "Guide to Emergency Management and Related Terms").

4. Improve Assessment, Modeling, and Prediction of Impacts on Critical Infrastructure

A key component of improving national preparedness for a space-weather event is the ability to observe and predict associated effects. Providing timely, actionable, and relevant decision-support services during a space-weather event requires improvements in abilities to observe, assess, model, and ultimately predict the effects of space-weather events on critical national infrastructures such as electric power systems; transportation systems (e.g., aviation, rail, and maritime); communications; and position, navigation, and timing systems. The societal and health effects of space-weather events must also be understood to inform the urgency of action during such events and to encourage appropriate mitigation and protection measures before an incident. Improving situational awareness and prediction of the effects on infrastructure during a space-weather event requires better observations and better modeling of system-response characteristics. The following objectives should be pursued to enhance observation, modeling, and prediction capabilities:

- **Assess the vulnerability of critical infrastructure systems to space weather:** To prepare for and enhance the security and resilience of critical infrastructure systems to space-weather events, a thorough and systematic understanding of the effects and vulnerabilities is necessary. This understanding will inform preparedness approaches and planning and enable validation of system-specific impact models.
- **Develop a real-time infrastructure assessment and reporting capability:** Situational awareness of the state of various critical infrastructure systems is crucial to providing actionable event response. This capability will require continued investments in, and assessments of, the real-time monitoring requirements for reporting the state of infrastructures, as well as situational awareness of space weather.
- **Develop or refine operational models that forecast the effects of space weather on critical infrastructure:** To ensure an appropriate and effective response to space-weather events, it is not enough to only forecast the magnitude of such events. It is also necessary to predict the effects of such events on infrastructure and other systems on a regional basis. (Hurricane storm-surge prediction is a terrestrial weather example of this objective.) Effective prediction of the effects of space weather requires reliable, accurate, and fast models that take into account effects on both isolated and interdependent infrastructure systems. There is also a need to define and develop comprehensive requirements for operational impact models, identify deficiencies in current modeling capabilities, and develop new and improved tools.
- **Improve operational impact forecasting and communications:** Based on the assessment and modeling elements outlined above, a national capability to forecast extreme space-weather effects before the onset of an event would enable timely warnings to system operators and emergency managers. This capability should always be available, with rapid computation and dissemination mechanisms.
- **Conduct research on the effects of space weather on industries, operational environments, and infrastructure sectors:** Improving existing models and developing new capabilities in impact forecasting must be based on a better understanding of the fundamental physical processes of the effects of space weather on critical infrastructure systems. Doing so requires identifying gaps in understanding of impacts on these systems; developing strategies to address these gaps; identifying impact-related interdependencies through vulnerability and failure mode-assessments across and between sectors; and supporting research for understanding the cost to mitigate, respond to, and recover from extreme space-weather events.

5. Improve Space-Weather Services through Advancing Understanding and Forecasting

Space-weather services can enhance national preparedness by providing timely, accurate, and relevant forecasting products. Identifying and sustaining a baseline of fundamental measurements from observing platforms is key to providing operational services that inform preparedness. This baseline can also serve as a reference point from which to identify coverage and measurement gaps, as well as opportunities for improvement. Services can be improved through basic research and applied research that focus on the needs of an increasingly diverse user community. To facilitate the transition of these enhancements from the research domain to operations, the responsible agencies will: (1) periodically revalidate user requirements for improved space-weather services; and (2) strengthen and encourage partnerships to accelerate the research-to-operations transition process, with a goal to support key preparedness decisions. The following objectives should be pursued to meet these goals:

- **Improve understanding of user needs for space-weather forecasting to establish lead-time and accuracy goals:** Effective transfer of space-weather knowledge requires a better understanding of the effects of space weather on technology and on industry and government customers, including the associated economic and political impacts on the Nation's critical infrastructures.

- **Ensure space-weather products are intelligible and actionable to inform decision-making:** Decision-relevant information must be communicated in ways that stakeholders can fully understand and use. Models and forecasts will be most useful when they enable swift decision-making with a reasonable assumption of risk.

- **Establish and sustain a baseline observational capability for space-weather operations:** The Nation lacks a comprehensive operational space-weather observation strategy. Opportunities exist to improve the Nation's space-weather-prediction capabilities, which rely on an ad hoc mixture of weather satellites, research satellites, and ground systems to provide data to forecast centers. To ensure adequate and sustained real-time observations for space-weather analysis, forecasting, and decision-support services, a baseline, or minimally adequate, operational observation capability should be defined. The observation baseline should also specify the optimal mix of ground-based and satellite observations to enable continuous and timely space-weather watch, warning, and alert products and services. The associated data reception, relay, processing, assimilation, and archiving infrastructure required to utilize space-weather observations must also be included in the baseline.

- **Improve forecasting lead-time and accuracy:** Society is increasingly at risk from extreme space-weather events. With improved predictions, the Nation can enhance mitigation, response, and recovery actions to safeguard assets and maintain continuity of operations during high-impact space-weather activity.

- **Enhance fundamental understanding of space weather and its drivers to develop and continually improve predictive models:** Forecasting space weather depends on a fundamental understanding of the space-environment processes that give rise to hazardous events. It is particularly important to understand the processes that link the sun to Earth. An improved understanding of space weather and access to better data will help drive the necessary advances in modeling capabilities and validation to support user needs.

- **Improve effectiveness and timeliness of the process that transitions research to operations:** Although the Nation has invested in the development of research infrastructure and predictive models to meet the demands of a growing space-weather user community, existing modeling capabilities still fall short of providing what is needed to meet these demands. Until better research models targeted to operational needs are developed and ultimately incorporated into operational forecasts, the Nation will not fully realize the benefits of its research investments.

6. Increase International Cooperation

In a world increasingly dependent on interconnected and interdependent infrastructure, any disruption to these critical technologies could have regional and even international consequences. Therefore, space weather should be regarded as a global challenge requiring a coordinated global response.

Many countries are becoming increasingly aware of the need to monitor and manage space-weather risks. The United States and other nations are sharing observations and research, disseminating products and services, and collaborating on real-time predictions to mitigate impacts on critical technology and infrastructure. Countries around the world must work together to foster global collaboration, taking advantage of mutual interests and capabilities to improve situational awareness, predictions, and preparedness for extreme space weather. The following objectives should be pursued to increase international cooperation:

- **Build international support and policies for acknowledging space weather as a global challenge:** A prerequisite to enhanced international cooperation is high-level support across partner countries to raise awareness of space weather as a global challenge.
- **Increase engagement with the international community on observation infrastructure, data sharing, numerical modeling, and scientific research:** The Federal Government should explore opportunities to work with the international community to enhance research, observations, models, and forecasting tools that are responsive to the needs of the global scientific community and the providers and users of space-weather information services.
- **Strengthen international coordination and cooperation on space-weather products and services:** Providing high-quality space-weather products and services worldwide requires international consensus and cooperation. Toward this end, the United States should seek international agreement on common terminology, measurements, and scales of magnitude; promote and coordinate sharing and dissemination of space-weather observations, model outputs, and forecasts; and establish coordination procedures across space-weather operations centers during events.
- **Promote a collaborative international approach to preparedness for extreme space-weather events:** The world's interconnected and interdependent systems are vulnerable to extreme space-weather events; this vulnerability could possibly lead to a cascade of impacts across borders and sectors. To mitigate these risks, the United States should work with the international community to facilitate the exchange of information and best practices to strengthen global preparedness capacity for extreme space-weather events. The United States should also foster the development of global mutual-aid arrangements to facilitate response and recovery efforts, and should coordinate international partnership activities to support space-weather preparedness and response exercises.

Conclusion

Space-weather events pose a significant and complex risk to the Nation's infrastructure and have the potential to cause substantial economic and human harm. This Strategy is the first step in addressing the myriad challenges presented when managing and mitigating the risks posed by both extreme and ordinary space weather. The six high-level goals and associated objectives outlined in this Strategy support a collaborative and Federally-coordinated approach to developing effective policies, practices, and procedures for decreasing the Nation's vulnerabilities associated with space weather. By establishing goals for improvements in forecasting, research, preparedness, planning, and domestic and international engagement, this Strategy will help ensure the Nation's resilience to the effects of extreme space-weather events.

Appendix: Background on Solar Phenomena that Drive Space Weather

Space weather is primarily driven by solar storm phenomena that include coronal mass ejections (CMEs), solar flares, solar particle events, and solar wind. These phenomena can occur in various regions on the sun's surface, but only Earth-directed solar storms are the potential drivers of space-weather events on Earth. An understanding of solar storm phenomena is an important component to developing accurate space-weather forecasts (event onset, location, duration, and magnitude).

CMEs are explosions of plasma (charged particles) from the sun's corona. They generally take 2–3 days to arrive at Earth, but in the most extreme cases they have been observed to arrive in as little as 15 hours. When CMEs collide with Earth's magnetic field, they can cause a space-weather event called a geomagnetic storm, which often includes enhanced auroral displays. Geomagnetic storms of varying magnitudes can cause significant long- and short-term impacts to the Nation's critical infrastructure, including the electric power grid, aviation systems, Global Positioning System (GPS) applications, and satellites.

A solar flare is a brief eruption of intense high-energy electromagnetic radiation from the sun's surface, typically associated with sunspots. Solar flares can affect Earth's upper atmosphere, potentially causing disruption, degradation, or blackout of satellite communications, radar, and high-frequency radio communications. The electromagnetic radiation from the flare takes approximately eight minutes to reach Earth, and the effects usually last for one to three hours on the daylight side of Earth.

Solar particle events are bursts of energetic electrons, protons, alpha particles, and other heavier particles into interplanetary space. Following an event on the sun, the fastest moving particles can reach Earth within tens of minutes and temporarily enhance the radiation level in interplanetary and near-Earth space. When energetic protons collide with satellites or humans in space, they can penetrate deep into the object that they collide with and cause damage to electronic circuits or biological DNA. Solar particle events can also pose a risk to passengers and crew in aircraft at high latitudes near the geomagnetic poles and can make radio communications difficult or nearly impossible.

Solar wind, consisting of plasma, continuously flows from the sun. Different regions of the sun produce winds of different speeds and densities. Solar wind speed and density play an important role in space weather. High-speed winds tend to produce geomagnetic disturbances, and slow-speed winds can bring calm space weather. Space-weather effects on Earth are highly dependent on solar wind speed, solar wind density, and direction of the magnetic field embedded in the solar wind. When high-speed solar wind overtakes slow-speed wind or when the magnetic field of solar wind switches polarity, geomagnetic disturbances can result.

References

Blanchard, B. Wayne. "Guide to Emergency Management and Related Terms, Definitions, Concepts, Acronyms, Organizations, Programs, Guidance, Executive Orders & Legislation: A Tutorial on Emergency Management, Broadly Defined, Past and Present." October 22, 2008.

Department of Homeland Security (DHS). *The Strategic National Risk Assessment in Support of PPD 8: A Comprehensive Risk-Based Approach toward a Secure and Resilient Nation*. December 2011.

Federal Emergency Management Agency (FEMA). "National Planning Frameworks." www.fema.gov/national-planning-frameworks.

————."A Whole Community Approach to Emergency Management: Principles, Themes, and Pathways for Action." FDOC 104-008-1. December 2011, www.fema.gov/media-library-data/20130726-1813-25045-0649/whole_community_dec2011__2_.pdf.

Federal Energy Regulatory Commission (FERC). "Reliability Standards for Geomagnetic Disturbances." Order No. 779, 143 FERC ¶ 61,147. May 23, 2013.

————. "Reliability Standard for Geomagnetic Disturbance Operations." Order No. 797, 147 FERC ¶ 61,209. June 25, 2014.

————. "Reliability Standard for Transmission System Planned Performance for Geomagnetic Disturbance Events." 151 FERC ¶ 61,134 May 14, 2015.

National Research Council. *Severe Space Weather Events—Understanding Societal and Economic Impacts, A Workshop Report*. Committee on the Societal and Economic Impacts of Severe Space Weather Events: A Workshop. 2008.

————. *Solar and Space Physics: A Science for a Technological Society*. 2013–2022 Decadal Survey in Solar and Space Physics. 2013.

National Science and Technology Council. *National Strategy for Civil Earth Observations.* April 2013.

National Space Policy of the United States of America. June 28, 2010.

National Space Weather Program Council. *National Space Weather Program: Strategic Plan*. FCM-P30-2010, 2010.

Office of the Federal Coordinator for Meteorological Services and Supporting Research. *Report of the Assessment Committee for the National Space Weather Program*. FCM-R24-2006, June 2006.

Presidential Policy Directive/PPD-8. "National Preparedness." March 30, 2011.

Presidential Policy Directive/PPD-21. "Critical Infrastructure Security and Resilience." February 12, 2013.

Public Law 111-267. *The National Aeronautics and Space Administration Authorization Act of 20*10. October 11, 2010.

Schrijver, Carolus J., Kirsti Kauristie, Alan D. Aylward, Clezio M. Denardini,Sarah E. Gibson, Alexi Glover, Nat Gopalswamy, Manuel Grande, Mike Hapgood, Daniel Heynderickx, Norbert Jakowski, Vladimir V. Kalegaev,Giovanni Lapenta, Jon A. Linker, Siqing Liu, Cristina H. Mandrini, Ian R. Mann,Tsutomu Nagatsuma, Dibyendu Nandi, Takahiro Obara, T. Paul O'Brien,Terrance Onsager, Hermann J. Opgenoorth, Michael Terkildsen, Cesar E. Valladares, and Nicole Vilmer. "Understanding Space Weather to Shield Society: A Global Road Map for 2015–2025 Commissioned by COSPAR and ILWS" *Advances in Space Research* 55 (2015): 2745–2807.

U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability Infrastructure Security and Energy Restoration. *Insurance as a Risk Management Instrument for Energy Infrastructure Security and Resilience*. 2013.