# NATIONAL SPACE WEATHER STRATEGY

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# Executive Summary

Reducing the Nation's vulnerability to space weather is a national priority. Space weather describes the variations in the space environment between the sun and Earth that can affect infrastructure systems and technologies in space and on Earth. It can disrupt the technology that forms the backbone of our economic vitality and national security, including satellite and airline operations, communications networks, navigation systems, and the electric power grid. These key components of our Nation's infrastructure and economy are increasingly at risk from space weather storms. The Strategic National Risk Assessment[1] identifies space weather as a hazard that poses significant risk to the security of the Nation.

This Strategy builds on recent significant efforts to reduce risks associated with natural hazards and improve the resilience of critical facilities and systems.[2] It aims to foster a collaborative environment in which government, industry, and private citizens can better understand and prepare for the effects of space weather. As a Nation, we must continue to leverage our existing national network of expertise and capabilities and pursue targeted enhancements to improve our ability to manage risks associated with space weather.

With this Strategy, we seek to enhance the integration of existing national efforts and add important capabilities to help meet growing demands for space weather information. Six strategic goals underpin our efforts to reduce the Nation's vulnerability to space weather:

- **Establish Benchmarks for Space Weather Events:** Effective and appropriate actions for space weather events require an understanding of the magnitude and frequency of storms. Benchmarks will help us assess the vulnerability of critical infrastructure and will provide critical points of reference to enable mitigation procedures and practices, as well as enhance response and recovery planning.
- **Enhance Response and Recovery Capabilities:** We must develop comprehensive guidance to support existing response and recovery constructs to manage space weather events with Federal, State, local, tribal, and territorial governments and the private sector.
- **Improve Protection and Mitigation Efforts:** To build national preparedness we must improve our protection and mitigation efforts. Protection focuses on capabilities and actions to eliminate critical infrastructure vulnerabilities to space weather, and mitigation focuses on long-term vulnerability reduction and enhancing resilience to disasters. Together, these preparedness missions constitute our national effort to reduce the vulnerabilities and manage the risks associated with space weather events.



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

[2] See reference section for listing of recent relevant policy documents.

- **Improve Assessment, Modeling, and Prediction of Impacts on Critical Infrastructure:** We must provide timely, actionable, and relevant decision-support services during space weather storms. Societal impacts must also be understood to better inform the urgency of action during extreme events and to encourage appropriate mitigation and protection measures before an incident.
- **Improve Space Weather Services through Advancing Understanding and Forecasting:** We must take action to improve the fundamental understanding of space weather. Accurate, reliable, and timely space weather observations and forecasts (and related products and services) are essential elements in enabling national preparedness. The underpinning science and observations that will help drive the necessary advances in modeling capability that supports user needs are the key to the quality of space weather products and services. We must also improve our capacity to develop and transition the latest scientific and technological advances into space weather operations centers.
- **Increase International Cooperation:** Because we live in a world of complex interdependencies, we need global engagement and a coordinated international response to space weather. We must not only be an integral part of the global effort, but must mobilize broad, global support. We will do so by utilizing existing agreements and by building international support at the policy level.

The National Strategy for Space Weather identifies national goals and establishes the guiding principles that will underpin our efforts to secure the critical technology infrastructures vital to our national security and economy. 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, ensuring that critical information is available to national leaders for informed decision-making. This critical information will be used to enhance national resilience and prepare an appropriate response during space weather storms. This Strategy will facilitate the integration of space weather information into Federal Government risk-management plans to achieve desired levels of preparedness consistent with existing national policies. Accomplishing the strategic elements in the Strategy will require a whole-of-government approach to coordinate and apply Federal resources. It will also require us to strengthen public-private and international partnerships, using a Whole Community approach.[3] As a Nation, we must work together to enhance the resilience of critical infrastructure to the potentially debilitating effects of space weather, and we must ensure mechanisms are in place to help protect the people, economy, and national security of the United States.



[3] FEMA, "A Whole Community Approach to Emergency Management: Principles, Themes, and Pathways for Action," FDOC 104-008-1, Department of Homeland Security, December 2011

# Introduction

Space weather is a naturally occurring phenomenon that has the potential to negatively affect energy infrastructure, technology, and human health, 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 interactions with emissions from the sun, including solar flares, solar energetic particles, and coronal mass ejections (CME). These emissions can affect Earth and its surrounding space, potentially causing disruption to electric power systems; satellite, aircraft, and spacecraft operations; telecommunications; position, navigation, timing (PNT) services; and other technology and infrastructure. Given the growing importance of reliable electric power and space-based assets for security and economic well-being, it is critical that we 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 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 even wider geographic regions of the planet. The United States is currently a global leader in observing and forecasting space weather events, but our capability and situational awareness depend on international cooperation and coordination.

This Strategy outlines the objectives for enhancing the Nation's space weather readiness in three key areas: understanding, forecasting, and national preparedness. Federal departments and agencies have taken significant steps in these key areas. The challenges posed by the increasing vulnerability to space weather events require continuing research and development efforts to improve observation and forecast capabilities, which are linked directly to preparedness. 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.

## Structure of the Strategy

This Strategy articulates six high-level goals for Federal research, development, deployment, operations, coordination, and engagement:

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

## Implementation of the Strategy

The implementation of this strategy will be overseen by the NSTC.

## Enhancing National Preparedness and Critical Infrastructure Resilience

This Strategy ensures that space weather is fully integrated into the Presidential Policy Directive (PPD)-8, *National Preparedness* (March 30, 2011) and PPD-21, *Critical Infrastructure Security and Resilience* (February 12, 2013) frameworks.

PPD-8 calls for an integrated, all-of-Nation, capabilities-based approach to preparedness for all hazards. The Directive also calls for the creation of a national planning framework. In support of this, the Department of Homeland Security coordinated the development of the Strategic National Risk Assessment (SNRA).[4] 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 strengthen critical infrastructure security and resilience that are at the core of this Strategy.[5] The Directive identifies energy and communications systems as uniquely critical due to the enabling functions they provide across all critical infrastructure sectors. The Directive also instructs the Federal Government to engage with international partners to strengthen the security and resilience of domestic critical infrastructure and international critical infrastructure on which the Nation depends.

## Strategic Goals

To meet the challenges presented by the negative effects of space weather events, this Strategy defines six strategic goals to prepare the Nation for near- and long-term space weather impacts. The objectives of these goals are to improve our understanding of, forecasting of, and preparedness for space weather events (phenomena and effects).

### 1. Establish Benchmarks for Space Weather Events

Developing benchmarks for space weather events is an important component to addressing the effects of space weather. 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, and enhance response and recovery planning.

The objective of the benchmarks is to 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, the benchmarks may serve as inputs to vulnerability assessments or defining points of action. But these benchmarks do not assign a category, classification, level, or significance of impact to an event.

To be effective, the benchmarks must be developed in a timely manner using transparent methodology with a clear statement of assumptions and uncertainties. Because of relatively limited data and gaps in understanding space weather phenomena, benchmarks should be reevaluated as significant new data and research become available.

- **Define scope, purpose, and approach for developing benchmarks:** Space weather benchmarks will be used to develop scenarios, inform practices (e.g., device, operational, and mitigation), and serve as reference points from which to develop impact and vulnerability assessments. The benchmarks will use multiple parameters to describe the space weather event. The parameters should include

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

[5] (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.

characteristics of the space weather event and the characteristics of its interactions with Earth and near-Earth environments (e.g., radio blackout and geomagnetic disturbance).

Multiple benchmarks will be created to address:

- The different types of space weather events; for example, radio blackouts induced by solar flares and geomagnetic disturbances induced by CMEs;
- Multiple physical parameters that will ensure the functionality of the benchmarks; for example, magnitude and duration; and
- A range of event magnitudes and associated recurrence intervals; for example, 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 low-frequency, potentially high-impact events that will require a coordinated national response and recovery effort. Leveraging the National Planning Frameworks,[6] the Nation will develop comprehensive guidance to support existing response and recovery constructs to manage extreme events with Federal, State, local, tribal, territorial (SLTT), and other Whole Community partners.[7] Improving impact assessments and systems modeling will allow for greater planning fidelity for the effects of extreme events on critical infrastructure systems and the Whole Community. Likewise, improved forecasting capabilities enable development of time-sensitive procedures before any impacts. Building the Nation's restoration capability will require continued investments, unique solutions, and strong public-private partnerships. The following objectives will be met to enhance response and recovery capabilities:

- **Complete an all-hazards power outage response and recovery plan:** The primary risk of an extreme space weather event is the potential for the long-term loss of electric power and the cascading affects that it would have on other critical infrastructure sectors; however, other low-frequency, high-impact events are also capable of causing long-term power outages on a regional or national scale. It is essential to have a comprehensive and executable plan (with key decision points) for regional or national power outages. The plan must include the Whole Community and enable the prioritization of core capabilities.
- **Support Federal, SLTT government, and private sector planning for and managing of an extreme space weather event:** Information on the effects of an extreme space weather hazard on SLTT all-hazards planning is limited. Credible information and guidance on how to incorporate that knowledge into SLTT all-hazards planning will be developed and disseminated.

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[6] The National Planning Framework 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 great risk." This Goal is the cornerstone for the implementation of PPD-8 (https://www.fema.gov/national-planning-frameworks).

[7] Whole Community planning for resilience is an approach to emergency management that reinforces the ideas that FEMA is only one part of our Nation's emergency management team; that we must leverage all the resources of our collective team in preparing for, protecting against, responding to, recovering from, and mitigating against all hazards; and that collectively we must meet the needs of the entire community in each of these areas (https://www.fema.gov/whole-community).

- **Provide guidance on contingency planning for extreme space weather impacts on the continuation of critical government and industry services:** A functional government, movement of personnel, preservation of services, and maintenance of critical infrastructure systems are essential before, during, and after an extreme space weather event. All levels of government, the private sector, and critical infrastructure entities will have guidance to respond in a manner that allows them to maintain the essential elements of their operations for a prolonged period of time.
- **Ensure communications systems capability and interoperability 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. While space weather affects communications systems, these effects can occur at different time scales within a single event and with varying impacts depending on the specific communications system, the characteristics of the event, and its duration. Government and private sector stakeholders must have guidance that allows them to maintain communication systems capabilities (including interoperability) during an extreme event.
- **Encourage the owners and operators of critical assets to coordinate the 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.
- **Develop and conduct exercises to improve and test Federal, State, regional, local, 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 plan support successful response and recovery. Exercising plans and capturing lessons learned enables ongoing improvement in event response and recovery capabilities.
- **Increase the Nation's restoration capability through continued investments, unique solutions, and strong public-private partnerships:** The Nation has not experienced the full consequences of an extreme space weather event in modern history. Improving the Nation's capability to respond to and recover from such an event will require continued investments and innovative solutions. Without strong public and private partnerships developed before such an event, however, an effective recovery will remain impractical.

## 3. Improve Protection and Mitigation Efforts

Growing interdependencies of critical infrastructure systems have increased the potential vulnerabilities to space weather events. Protection and mitigation efforts to eliminate or reduce space weather risks are essential missions of national preparedness. Protection focuses on capabilities and actions to eliminate critical infrastructure vulnerabilities to space weather, and mitigation focuses on long-term vulnerability reduction and enhancing the resilience to disasters.[8] Together, these preparedness

[8] 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 (https://training.fema.gov/hiedu/docs/terms%20and%20definitions/terms%20and%20definitions.pdf).

missions constitute our national effort to reduce the vulnerabilities and manage the risks associated with space weather events. Four objectives are outlined for improving protection and mitigation efforts:

- **Assess the relevant legal mechanisms, authorities, and incentives that can be used to protect critical systems:** Statutory and regulatory authorities related to the protection of critical infrastructure already exist as do incentives for encouraging actions by critical infrastructure owners and operators. These will be identified along with the corresponding authorities, gaps, issues, and associated approaches to governance.
- **Encourage the development of hazard-mitigation plans that reduce vulnerabilities to, manage risks from, and assist with response to impacts associated with space weather:** In support of Whole Community planning for resilience, information about space weather hazards will 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.
- **In concert with industry partners, achieve long-term vulnerability reduction to space weather events by implementing appropriate measures at critical locations most susceptible to space weather:** Adopting standards, business practices, and operational procedures that improve protection and resilience is essential to addressing space weather system vulnerabilities. The space weather benchmark events described in the first strategic goal (Establish Benchmarks for Space Weather Events) will 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 of damage from, and protection of, systems affected by space weather.
- **Strengthen public/private partnerships that support private action to reduce public vulnerability to space weather:** Private sector entities, as the owners and operators of the majority of the Nation's critical infrastructure, are essential to improving resilience. Space weather events do not respect national, jurisdictional, or corporate boundaries. Incorporating resilience measures into U.S. infrastructure systems requires collaboration, the support of existing coordinating mechanisms for information sharing and access, and identifying incentives and disincentives for investing in resilience measures.

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

A key component to 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 the ability to observe, assess, model, and ultimately predict the effects on critical national infrastructures such as the electric power systems, transportation systems, communications, and PNT systems. Societal impacts must also be understood to inform the urgency of action during events and to encourage appropriate mitigation and protection measures before an incident. Improving situational awareness and prediction of effects on infrastructure during an event requires better observations and better modeling of system-response characteristics. The following objectives will be met to enhance observation, modeling, and prediction capabilities:

- **Develop a national capability for real-time assessment of space weather impacts on critical systems:** Situational awareness of the state of various critical infrastructure systems is crucial to providing actionable event response. In addition, better and more thorough measurements of infrastructure responses to space weather events will inform and validate system-specific impact models that will ultimately improve 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 space weather situational awareness.

- **Develop or refine operational space weather impact/systems models:** It is not enough to forecast the magnitude of an impending geomagnetic disturbance for appropriate and effective response: it is also necessary to predict the effects of an event on infrastructure and other systems on a regional basis. Hurricane storm surge prediction is a terrestrial weather example of this objective. To do this effectively requires reliable, accurate, and fast models that take into account effects on both isolated and interdependent infrastructure systems. We must also define and develop comprehensive requirements for operational impact models, identifying deficiencies in current modeling capabilities to develop new and improved tools to achieve these objectives.
- **Improve operational impact forecasting and communications protocols:** 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.
- **Support basic and applied research into space weather impact 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 space weather impacts to critical infrastructure systems. Doing so requires identifying gaps in our understanding of impacts on critical national infrastructures; 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 required to mitigate, respond to, and recover from an extreme space weather event.

## 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 critical 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 and applied research that focuses 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.

Seven objectives are outlined to meet these goals:

- **Define a baseline operational space weather observation capability:** Our Nation currently lacks a comprehensive operational space weather observation strategy. Although operational systems are robust, resilient, and ensure the data continuity necessary for a national space weather prediction capability exists, currently, an ad hoc mixture of weather and research satellites and ground systems is being used to provide critical 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 will 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.

- **Improve understanding of user needs for space weather forecasting and use these data 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 products are intelligible and actionable to inform critical decision-making:** Decision-relevant information must be communicated in ways that stakeholders can fully understand and use. Models and forecasts must enable swift decision-making with a reasonable assumption of risk.
- **Improve forecasting accuracy and lead-time:** Society is increasingly at risk to extreme space weather events. With improved predictions, our Nation can enhance mitigation, response, and recovery actions to safeguard our 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. Particularly important is understanding the processes that link the sun to Earth. An improved understanding will help drive the necessary advances in modeling capability to support user needs.
- **Improve effectiveness and timeliness of research to operations transition process:** 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 critical demands. Until better research models are incorporated into operational forecasts, the Nation will not fully realize the benefits of its research investments.
- **Assess and develop observational strategies for the study and prediction of space weather events:** Fundamental research, modeling, product development, and space weather hazard assessments require observations taken from space and on the ground. Development of advanced technologies has the potential to improve the quality and affordability of new observing systems and optimize the path from research to operational use. Coordination between the space weather research and operations communities to identify critical observational data products required to advance predictive modeling capability is necessary to sustain critical space weather observing capabilities. It is also important to explore the needs for improved coverage, timeliness, and data quality through partnerships with academia, the private sector, and international collaborators.

## 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 have begun sharing observations and research, disseminating products and services, and collaborating on real-time predictions to mitigate impacts on critical technology and infrastructure. We 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 will be met to increase international cooperation:

- **Build international support at the policy level for 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.
- **Promote a collaborative international approach to protect against, mitigate the effects of, respond to, and recover from 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, we will work with the international community to facilitate the exchange of information and best practice to strengthen global preparedness capacity for extreme space weather events. We will also foster the development of global mutual aid agreements to facilitate response and recovery efforts and coordinate international partnership activities to support space weather preparedness and response exercises.
- **Increase engagement with the international community on scientific research, observation infrastructure, and modeling:** Gaps in research, observations, models, and forecasting tools need to be identified and filled to meet the needs of the global scientific community and the providers and users of space weather information services.
- **Improve international data sharing:** Increased access to government, civilian, and commercial space weather data across the globe is of mutual benefit to the United States and partner nations.
- **Strengthen international coordination and cooperation on space weather products and services:** Providing high-quality space weather products and services worldwide requires international coordination and cooperation. Toward this end, we will seek agreement on common terminology, measurements, and scales of magnitude; promote and coordinate the sharing and dissemination of space weather observations, model outputs, and forecasts; and establish coordination procedures across space weather operations centers during extreme events.
- **Develop coherent international communication strategies:** The global hazards of space weather must be clearly communicated to policymakers, the public, and the technical community. A process is needed to (1) issue forecasts, alerts, and warnings using consistent nomenclature and nontechnical terminology where appropriate and (2) promote and support public outreach and space weather education globally.

## 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 severe and ordinary space weather. As outlined above, the six high-level goals and their associated objectives support a collaborative and federally coordinated approach to developing effective policies, practices, and procedures for decreasing our Nation's vulnerabilities. By establishing goals for improvements in forecasting, research, preparedness, planning, and domestic and international engagement, this Strategy will help ensure our Nation's ability to withstand and quickly recover from effects of extreme space weather events.

# References

National Space Policy (June 28, 2010)

National Strategy for Civil Earth Observations (April 2013)

Presidential Policy Directive 8 (PPD-8): National Preparedness (Mar. 30, 2011)

Presidential Policy Directive 21 (PPD-21): Critical Infrastructure Security and Resilience (Feb. 12, 2013)

The Strategic National Risk Assessment in Support of PPD 8: A Comprehensive Risk-Based Approach toward a Secure and Resilient Nation (Dec. 2011)

The National Aeronautics and Space Administration Authorization Act of 2010 (Oct.  11, 2010)

# Abbreviations

| | |
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| CME | coronal mass ejection |
| NSTC | National Science and Technology Council |
| OSTP | Office of Science and Technology Policy |
| PNT | position, navigation, timing |
| PPD | Presidential Policy Directive |
| R&D | research and development |
| SLTT | State, local, tribal, territorial |
| SNRA | Strategic National Risk Assessment |

# Appendix: Background on Solar Phenomena that Drive Space Weather

Space weather is commonly driven by solar storm phenomena that include coronal mass ejections (CMEs), solar flares, solar particle events, and solar wind. These phenomena can occur anywhere on the sun's surface, but only solar storms that are Earth directed 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, 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, have been observed to arrive in as little as 17 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, 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 operations, radar, and high-frequency radio communications. The electromagnetic radiation from the flare takes approximately 8 minutes to reach Earth, and the effects usually last for 1–3 hours on the daylight side of Earth.

Solar particle events are injections 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 while 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.