NATIONAL SPACE WEATHER ACTION PLAN

PRODUCT OF THE

National Science and Technology Council

October 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

Table of Contents

Introduction

Space-weather events are naturally occurring phenomena that have the potential to disrupt electric power systems; satellite, aircraft, and spacecraft operations; telecommunications; position, navigation, and timing services; and other technologies and infrastructures that contribute to the Nation's security and economic vitality. These critical infrastructures make up a diverse, complex, interdependent system of systems in which a failure of one could cascade to another. Given the importance of reliable electric power and space-based assets, it is essential that the United States has the ability to protect, mitigate, respond to, and recover from the potentially devastating effects of space weather.

The *National Space Weather Strategy* (Strategy), released concurrently with this *National Space Weather Action Plan* (Action Plan), details national goals for leveraging existing policies and ongoing research and development efforts regarding space weather while promoting enhanced domestic and international coordination and cooperation across public and private sectors. The implementation of the Strategy will require the action of a nationwide network of governments, agencies, emergency managers, academia, the media, the insurance industry, nonprofit organizations, and the private sector. Strong public-private partnerships must be established 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. This Action Plan details the activities, outcomes, and timelines that will be undertaken by Federal departments and agencies for the Nation to make progress toward the Strategy's goals.

Structure of the Action Plan

With the objectives of improving understanding of, forecasting of, and preparedness for space-weather events (both the phenomena and their effects), the *National Space Weather Strategy* defines six strategic goals to prepare the Nation for near- and long-term space-weather effects. This Action Plan is organized around the same six strategic goals:

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 National Space Weather Strategy

The Action Plan outlines the Federal implementation approach for the *National Space Weather Strategy*. Each action has an associated deliverable and timeline. An interagency body coordinated by the Executive Office of the President will help oversee these actions, including the deliverables and timelines. This Action Plan aligns with investments proposed in the President's Budget for Fiscal Year 2016. The interagency body will also reevaluate and update the Strategy and Action Plan within 3 years of the date of publication, or as needed. Successful progress in achieving these objectives depends on a national commitment of resources, both public and private.

Each action indicates the lead Federal Executive Branch department for completing the action, but does not prescribe a specific approach. For example, a department might engage academia or the private sector to complete a study or procure data. This Action Plan acknowledges the challenges associated with planning and preparing for extreme events that do not currently have well-defined recurrence rates; identified activities should therefore be prioritized accordingly, consistent with existing authorities.

Note: The actions specified in the *National Space Weather Action Plan* are intended to inform the policy development process and are not intended as a budget document. The commitment of Federal resources to support these activities will be determined through the budget process. Additional resources may be needed to fully implement many of the actions in this report; such resources could come from new Federal appropriations, redirection from lower priority Federal Agency activities, and/or from State, local, and/or other resources.

Goal 1: Establish Benchmarks for Space-Weather Events

Introduction

Benchmarks are a set of physical characteristics and conditions against which a space-weather event can be measured. They describe the nature and intensity of extreme space-weather events, providing a point of reference from which to improve understanding of space-weather effects. Benchmarks can serve as input for creating engineering standards, developing vulnerability assessments, establishing decision points and thresholds for action, understanding risk, developing more-effective mitigation procedures and practices, and enhancing response and recovery planning.

Space-weather benchmarks should provide clear and consistent descriptions of space-weather events based on current scientific understanding and the historical record. These benchmarks will not seek to categorize or classify a space-weather event's degree of impact on a technology system.

A two-phase approach with different timelines will be used to balance immediate needs with requirements for scientifically and statistically rigorous benchmarks. Phase 1, a quick-turnaround analysis, will seek to develop each benchmark using existing data sets and studies, where available. For those benchmarks where a quick-turnaround analysis will not yield results of sufficient quality, more rigorous analyses (Phase 2) will be conducted. Benchmarks that are successful in Phase 1 may benefit from further refinement in Phase 2. All benchmarks will be reexamined at least every 5 years or when significant new data or models become available.

The objectives of Goal 1 are to develop the following benchmarks:

- Induced geo-electric fields
- Ionizing radiation
- Ionospheric disturbances
- Solar radio bursts
- Upper atmospheric expansion

1.1 Develop Benchmarks for Induced Geo-Electric Fields

Geomagnetic storms can induce geo-electric fields in the Earth's crust, driving electric currents in long conductors on or near the Earth's surface. These induced geo-electric fields present a risk to the reliable operation of electric power systems and may affect gas and oil pipelines, railways, and other infrastructures that have long conductive paths. For example, a geo-electric field induced by a space-weather event can produce electric currents (i.e., geomagnetically induced currents [GICs]) that could affect electric-grid system stability, with the potential to damage or cause the failure of essential electric power transmission components. Depending on the severity of the geomagnetic storm, cascading system failure or damage could lead to regional interruptions of electrical power distribution and result in complications with recovery and restoration efforts. To be useful, geo-electric field benchmarks should characterize the induced geo-electric field at the Earth's surface (E-field). This parameter can feed directly into vulnerability studies conducted by industry and the private sector.

At a minimum, the E-field benchmarks and associated confidence levels will define the following:

- Amplitude of the induced E-field; and
- Time dependence of the induced E-field.

At a minimum, these benchmarks will be developed for the following event occurrence rate and intensity level:

- An occurrence frequency of 1 in 100 years; and
- An intensity level at the theoretical maximum for the event.

All benchmarks will state the assumptions made and the associated uncertainties and provide sufficient means to account for regional differences across the United States.

The following actions will be taken to develop induced geo-electric field benchmarks:

1.1.1 The Department of the Interior (DOI), the Department of Commerce (DOC), and the National Aeronautics and Space Administration (NASA), in coordination with the Department of Homeland Security (DHS), the Department of Energy (DOE), and the National Science Foundation (NSF), will: (1) assess the feasibility of establishing functional benchmarks using currently available storm data sets, existing models, and published literature; and (2) use the existing body of work to produce benchmarks for specific regions of the United States.

Deliverable: Develop Phase 1 benchmarks

Timeline: Within 180 days of the publication of this Action Plan

1.1.2 DOI, DOC, NASA, and NSF, in coordination with DHS and DOE, will assess the suitability of current data sets and methods to develop a more-refined (compared to Phase 1) set of benchmarks. The assessment will also identify gaps in methods and available data, project the cost of filling these gaps, and project the potential improvement to the benchmarks based on filling each gap.

Deliverable: Complete assessment report

Timeline: Within 1 year of the publication of this Action Plan

1.1.3 DOI, DOC, NASA, and NSF, in coordination with DHS and DOE, will improve on the induced geo-electric field benchmarks for the continental United States.

Deliverable: Develop (Phase 2) improved induced geo-electric field benchmarks

Timeline: Within 2 years of the publication of this Action Plan

1.2 Develop Benchmarks for Ionizing Radiation

Changes in the near-Earth radiation environment can affect satellite operations, astronauts in space, commercial space activities, and the radiation environment on aircraft at relevant latitudes or altitudes. Understanding the diverse effects of increased radiation is challenging, but the ionizing radiation benchmarks will help address these effects.

The following areas should be considered in addressing the near-Earth radiation environment:[1] the Earth's trapped radiation belts, the galactic cosmic ray background, and solar energetic-particle events. The radiation benchmarks should account for any change in the near-Earth radiation environment, which, under extreme cases, could present a significant risk to critical infrastructure operations or human health.

At a minimum, the ionizing radiation benchmarks and associated confidence levels will define at least the radiation intensity as a function of time, particle type, and energy for the following event-occurrence rate and intensity level:

- An occurrence frequency of 1 in 100 years; and
- An intensity level at the theoretical maximum for the event.

The benchmarks will address radiation levels at all applicable altitudes and latitudes in the near-Earth environment, and all benchmarks will state the assumptions made and the associated uncertainties.

The following actions will be taken to develop ionizing radiation benchmarks:

1.2.1 NASA and DOC, in coordination with NSF, the Department of Transportation (DOT), the Department of Defense (DOD), and the Federal Communications Commission (FCC), will: (1) assess the feasibility and utility of establishing functional benchmarks for ionizing radiation using the existing models and body of literature for this phenomenon; and (2) use the existing body of work to produce benchmarks.

Deliverable: Develop Phase 1 benchmarks

Timeline: Within 180 days of the publication of this Action Plan

1.2.2 NASA and DOC, in coordination with NSF, DOT, DOD, and FCC, will assess the suitability of current data sets and methods to develop a more-refined (compared to Phase 1) set of benchmarks. The assessment will identify gaps in methods and available data, project the cost of filling the gaps, and project the improvement to the benchmarks based on filling each gap.

Deliverable: Complete assessment report

Timeline: Within 1 year of the publication of this Action Plan

---

[1] The effects of space weather on technology can extend beyond the near-Earth environment, but this issue is considered outside of the scope of this Action Plan.

1.2.3 NASA and DOC, in coordination with NSF, DOT, DOD, and FCC, will develop enhanced benchmarks.

Deliverable: Develop (Phase 2) improved ionizing radiation benchmarks

Timeline: Within 2 years of the publication of this Action Plan

1.3 Develop Benchmarks for Ionospheric Disturbances

Ionospheric disturbances can adversely affect radio signals that propagate through the upper atmosphere, disrupting communication, navigation, and surveillance capabilities over wide areas on timescales ranging from minutes to hours.[2] These disturbances can be caused directly by solar flares or indirectly by interactions between the solar wind and the Earth's magnetic field. Solar flares primarily affect the dayside of the Earth, while solar wind can affect both the dayside and nightside.

High-frequency radio signals, which are used for airline, maritime, and emergency communications, are particularly susceptible to ionospheric disturbances.[3] Effects of ionospheric disturbances can limit or restrict polar-route flights by commercial and military aircraft for several days and block amateur radio communications that are often used as a backup in disaster situations. Ionospheric disturbances induced by space-weather events can also produce signal errors in position, navigation, and timing (PNT) systems such as the Global Positioning System (GPS).

At a minimum, the ionospheric disturbance benchmarks and associated confidence levels will define at least the following:

- Ionospheric radio absorption and duration as a function of frequency;
- Total electron content (slant, vertical, and rate of change);
- Ionospheric refractive index; and
- Peak ionospheric densities and the height of the peak.

At a minimum, these benchmarks will be developed for at least the following event-occurrence rate and intensity level:

- An occurrence frequency of 1 in 100 years; and
- An intensity level at the theoretical maximum for the event.

All benchmarks will state the assumptions made and the associated uncertainties.

The following actions will be taken to develop ionospheric disturbance benchmarks:

1.3.1 DOC and DOD, in coordination with NASA, DOI, NSF, and FCC, will: (1) assess the feasibility and utility of establishing functional benchmarks using the existing models and body of literature for this phenomenon; and (2) use the existing body of work to produce benchmarks.

Deliverable: Develop Phase 1 benchmarks

Timeline: Within 180 days of the publication of this Action Plan

---

[2] The ionosphere is a portion of the upper atmosphere 50 to 600 miles above the Earth's surface that can be affected by solar flares, coronal mass ejections, and the solar wind.

[3] Radio signals between 3 and 30 MHz are defined as high frequency.

1.3.2 DOC and DOD, in coordination with NASA, DOI, NSF, and FCC, will assess the suitability of current data sets and methods to develop a more-refined (compared to Phase 1) set of benchmarks. The assessment will identify gaps in methods and available data, project the cost of filling the gaps, and project the improvement to the benchmarks based on filling each gap.

Deliverable: Complete assessment report

Timeline: Within 1 year of the publication of this Action Plan

1.3.3 DOC and DOD, in coordination with NASA, DOI, NSF, and FCC, will develop enhanced benchmarks.

Deliverable: Develop (Phase 2) improved ionospheric disturbance benchmarks

Timeline: Within 2 years of the publication of this Action Plan

1.4 Develop Benchmarks for Solar Radio Bursts (SRBs)

SRBs are radio wave emissions from the sun that can interfere with radar, communication, and tracking signals. In severe cases, SRBs can inhibit the successful use of radio communications and disrupt a wide range of systems that are reliant on PNT services on timescales ranging from minutes to hours across wide areas on the dayside of Earth.

Solar flares are the primary drivers of SRBs. Intense SRBs interfere with radar systems, satellite communications, and PNT by increasing the noise level at frequencies of operation and overloading the signal, thus making it difficult for ground facilities to operate. Different types of radio bursts affect different frequency ranges.

At a minimum, the SRB benchmarks and associated confidence levels will define at least the following:

- Wavelength or frequency bands of the relevant SRBs; and
- Flux (photon energy per unit area) in these bands (solar flux unit).

At a minimum, these benchmarks will be developed for at least the following event-occurrence rate and intensity level:

- An occurrence frequency of 1 in 100 years; and
- An intensity level at the theoretical maximum for the event.

All benchmarks will state the assumptions made and the associated uncertainties.

The following actions will be taken to develop SRB benchmarks:

1.4.1 DOC, DOD, and NASA, in coordination with DOI and FCC, will: (1) assess the feasibility and utility of establishing functional benchmarks using the existing models and body of literature for this phenomenon; and (2) use the existing body of work to produce benchmarks.

Deliverable: Develop Phase 1 benchmarks

Timeline: Within 180 days of the publication of this Action Plan

1.4.2 DOC, DOD, and NASA, in coordination with DOI and FCC, will assess the suitability of current data sets and methods to develop a more-refined (compared to Phase 1) set of benchmarks. The assessment will identify gaps in methods and available data, project the cost of filling the gaps, and project the improvement to the benchmarks based on filling each gap.

Deliverable: Complete assessment report

Timeline: Within 1 year of the publication of this Action Plan

1.4.3 DOC, DOD, and NASA, in coordination with DOI and FCC, will develop enhanced benchmarks.

Deliverable: Develop (Phase 2) improved SRB benchmarks

Timeline: Within 2 years of the publication of this Action Plan

1.5 Develop Benchmarks for Upper Atmospheric Expansion

Space-based systems support many different critical infrastructure sectors necessary to ensure the Nation's homeland and economic security. Many of these systems are located in low-Earth orbit (LEO). Upper-atmospheric expansion describes an increase in the temperature and density of the Earth's upper atmosphere. This change is driven by solar activity and can have a direct impact on LEO spacecraft that are susceptible to the effects of atmospheric drag.[4] Increased drag can pull satellites closer to Earth, changing their orbit, decreasing the lifespan of space assets, and making satellite tracking difficult. Understanding this phenomenon and its relationship to atmospheric drag is essential to maintain safe and effective operations of space-based assets through collision avoidance, accurate satellite tracking, object custody, and reentry prediction. At a minimum, the upper-atmospheric expansion benchmarks and associated confidence levels will define neutral density, winds, composition, and temperature of the thermosphere for the following event-occurrence rate and intensity level:

- An occurrence frequency of 1 in 100 years; and
- An intensity level at the theoretical maximum for effects.

All benchmarks will state the assumptions made and the associated uncertainties.

The following actions will be taken to develop upper-atmospheric expansion benchmarks:

1.5.1 DOC, DOD, NSF, and NASA, in coordination with DOI and FCC, will: (1) assess the feasibility and utility of establishing functional benchmarks using the existing models and body of literature for this phenomenon; and (2) use the existing body of work to produce benchmarks.

Deliverable: Develop and complete Phase 1 benchmarks

Timeline: Within 180 days of the publication of this Action Plan

[4] Atmospheric drag refers to the air resistance in the regions where satellites orbit.

1.5.2 DOC, DOD, NSF, and NASA, in coordination with DOI and FCC, will assess the suitability of current data sets and methods to develop a more-refined (compared to Phase 1) set of benchmarks. The assessment will identify gaps in methods and available data, project the cost of filling the gaps, and project the improvement to the benchmarks based on filling each gap.

Deliverable: Complete assessment report

Timeline: Within 1 year of the publication of this Action Plan

1.5.3 DOC, DOD, NSF, and NASA, in coordination with DOI and FCC, will develop enhanced benchmarks.

Deliverable: Develop (Phase 2) improved upper atmospheric expansion benchmarks

Timeline: Within 2 years of the publication of this Action Plan

Goal 2: Enhance Response and Recovery Capabilities

Introduction

The effects of space-weather events on critical infrastructure systems and economic sectors depend on the severity of the event. The effects of an extreme space-weather event may require a coordinated national response and recovery. The Nation can leverage the plans and frameworks in the National Planning Frameworks[5] to help manage response and recovery. From these frameworks, the Nation will develop comprehensive guidance to support and improve existing response and recovery capabilities with Federal, State, and local government,[6] and other Whole Community[7] partners.

An improved ability to forecast and understand the effects and magnitude of a space-weather event is key to enhancing response and recovery planning. Actions that seek to enhance forecasting, impact assessment, and benchmarking of events are outlined in Goals 5, 4, and 1 (respectively) of this Action Plan. Building the Nation's restoration capability will require continued investments, unique solutions, and strong public-private collaborations.

The objectives for Goal 2 are:

- Complete an all-hazards power outage response and recovery plan
- Support government and private-sector planning for and management of extreme space-weather events
- Provide guidance on contingency planning for the effects of extreme space weather for essential government and industry services
- Ensure the capability and interoperability of communications systems during extreme space-weather events
- Encourage owners and operators of infrastructure and technology assets to coordinate development of realistic power-restoration priorities and expectations
- Develop and conduct exercises to improve and test government and industry-related space-weather response and recovery plans

---

5 Refer to PPD-8 and the Federal Emergency Management Agency (FEMA) website. "National Planning Frameworks," last updated March 19, 2015, www.fema.gov/national-planning-frameworkswww.fema.gov/national-planning-frameworks.

6 Local governments include tribal, territorial, and insular area governments.

7 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.

2.1 Complete an All-Hazards Power Outage Response and Recovery Plan

2.1.1 DHS, in partnership with DOE, will develop an all-hazard Power Outage Incident Annex (POIA) to the Federal Interagency Operations Plans (FIOPs)[8] for response and recovery that includes the response to and recovery from an extreme space-weather event.

Deliverable: Complete POIA

Timeline: Within 120 days of the publication of this Action Plan

2.2 Support Government and Private-Sector Planning for and Management of Extreme Space-Weather Events

2.2.1 DHS, in coordination with NASA and DOC, will incorporate the latest data on the threats and vulnerabilities from extreme space weather into the next Strategic National Risk Assessment (SNRA).

Deliverable: Complete update to SNRA

Timeline: Within 2 years of the publication of this Action Plan and update every 3 years thereafter

2.2.2 DHS, in coordination with DOC, DOD, and NASA, will ensure a consistent, joint message concerning the research, prediction, and preparedness for extreme space-weather events across the Federal Government.

Deliverable: Complete development of linkages between agency websites and ensure consistency in messaging

Timeline: Within 120 days of the publication of this Action Plan

2.2.3 DHS, in coordination with the National Preparedness Goal activity,[9] will set forth procedures for accessing and using available space-weather forecast and impact assessment modeling tools to inform response and recovery operational decision-making.

Deliverable: Available tools are identified and socialized with the Emergency Support Function Leadership Group (ESFLG)/Recovery Support Function Leadership Group (RSFLG); and referenced in the FEMA National Watch Center procedures

Timeline: Within 210 days of the completion of Phase 1 benchmarks and Action 4.1.1 initial assessments

---

8 The FIOPs, one for each preparedness mission area, describe how the Federal Government aligns resources and delivers core capabilities.

9 See FEMA website, "National Preparedness Goal," last updated September 2015, www.fema.gov/national-preparedness-goal.

2.2.5 DOC and DHS will ensure that space-weather products are integrated into established national preparedness plans (e.g., FEMA Recovery FIOP[10]), to including a background on space-weather phenomena, and products and services.

Deliverable: Complete integration of space-weather products and develop a process to integrate future products into established response and recovery plans

Timeline: To be commensurate with national preparedness frameworks and FIOPs update cycle

2.2.6 DHS, through Emergency Support Function (ESF) 15[11] and in coordination with DOC, will develop a template for issuing a public information alert and a template for warning messaging for an impending and ongoing threat of extreme space weather to critical infrastructure, the private sector, State, local, tribal, and territorial (SLTT) governments, communities, and individuals and families.[12]

Deliverable: Complete update to the ESF 15 standard operating procedures

Timeline: Within 1 year of the publication of this Action Plan

2.3 Provide Guidance on Contingency Planning for the Effects of Extreme Space Weather for Essential Government and Industry Services

2.3.1 DHS, in coordination with Sector-Specific Agencies (SSAs),[13] will determine the immediate and cascading impacts of a benchmarked space-weather event on essential government and industry services, and provide guidelines on the inclusion of these impacts for continuity and contingency for all-hazards planning and exercises. Guidance will include the application of established benchmarks (as described in Goal 1), making operational the available forecast and impact assessment models or tools (as described in Goals 4 and 5), integration with protection and mitigation efforts (as described in Goal 3), and collaboration with space-weather-community partners. Specific attention to pre-event warning and protective measures will be included in continuity planning guidance.

Deliverable: Complete a National Risk Estimate for Space Weather[14] and integrate comprehensive space-weather preparedness into existing all-hazard preparedness guidance

Timeline: Within 1 year of the completion of Phase 1 benchmarks and Action 4.1.1 initial assessments

---

[10] See FEMA website, "Recovery Federal Interagency Operation Plan (FIOP)," last updated July 2014, www.fema.gov/media-library/assets/documents/97360.

[11] See FEMA website, "Emergency Support Function 15: Standard Operating Procedures," last updated August 21, 2014, www.fema.gov/media-library/assets/documents/34369.

[12] External Affairs ensures that sufficient Federal assets are deployed to the field during incidents requiring a coordinated Federal response to provide accurate, coordinated, timely, and accessible information to affected audiences (e.g., governments, media, the private sector, and the local populace, including the special-needs population).

[13] SSAs are defined by PPD-21 for each of 16 critical infrastructure sectors. See DHS website, "Sector-Specific Agencies," last updated March 2, 2015, www.dhs.gov/sector-specific-agencies.

[14] The Homeland Infrastructure Threat and Risk Analysis Center developed the National Risk Estimate product line in 2010 to provide authoritative, coordinated, risk-informed assessments of key national security issues in the Nation's infrastructure protection community.

2.4 Ensure the Capability and Interoperability of Communications Systems during Extreme Space-Weather Events

2.4.1 DHS will assess the dependencies and vulnerabilities of the various communications systems used by government and industry to support response and recovery operations in the wake of an extreme space-weather event.

Deliverable: Complete white paper on space-weather communications assessment

Timeline: Within 120 days of the completion of Action 2.3.1

2.4.2 DHS will develop guidance, including planning factors, on operating communications systems during and after a benchmarked space-weather event.

Deliverable: Complete comprehensive communications systems operations guidance

Timeline: Within 120 days of the completion of Action 2.4.1

2.5 Encourage Owners and Operators of Infrastructure and Technology Assets to Coordinate Development of Realistic Power-Restoration Priorities and Expectations

2.5.1 DHS, in coordination with DOD, will identify which essential facilities have sufficient back-up power capability to survive an extreme space-weather event and which have the ability to quickly deploy or accept temporary power.

Deliverable: Enter temporary power data into Emergency Power Facility Assessment Tool (EPFAT) database

Timeline: Ongoing

2.6 Develop and Conduct Exercises to Improve and Test Government and Industry-Related Space-Weather Response and Recovery Plans

2.6.1 DHS, in coordination with DOC, DOD, NASA, and DOT, will develop training materials to familiarize scientific, national security, and emergency management professionals with the role and execution of emergency management protocols during the response to extreme space-weather events.

Deliverable: Produce training materials and conduct an annual training seminar through an existing coordination forum

Timeline: Within 1 year of the completion of Phase 1 benchmarks and Action 5.2.2

2.6.2 DHS will incorporate exercise objectives tailored to testing and evaluating the Nation's capabilities to respond to and recover from the potential impacts of a benchmarked space-weather event within relevant exercises.

Deliverable: Incorporate exercise objectives appropriate to space weather in exercise plans

Timeline: Within 180 days of the completion of Action 2.1.1

Goal 3: Improve Protection and Mitigation Efforts

Introduction

Growing interdependencies among critical infrastructure systems and increasing reliance on electronic technologies have increased the Nation's vulnerability to space-weather events. Protection and mitigation efforts to eliminate or reduce space-weather vulnerabilities are essential missions of national preparedness. 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 the resilience to disasters.[15] Together, these preparedness missions frame a national effort to reduce the vulnerabilities and manage the risks associated with space-weather events. Implementation of these missions requires joint action from public and private stakeholders, due to the shared expertise and responsibilities embedded in the Nation's infrastructure systems.

The objectives for Goal 3 are:

- Encourage development of hazard-mitigation plans that reduce vulnerabilities to, manage risks from, and assist with response to the effects of space weather
- Work with industry to achieve long-term reduction of vulnerability to space-weather events by implementing measures at locations most susceptible to space weather
- Strengthen public-private collaborations that support action to reduce vulnerability to space weather

[15] 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.

3.1 Encourage Development of Hazard-Mitigation Plans that Reduce Vulnerabilities to, Manage Risks from, and Assist with Response to the Effects of Space Weather

3.1.1 DHS, in support of Whole Community planning for resilience, will integrate information about space-weather hazards into existing mechanisms for information sharing, including Sector Coordinating Councils (SCCs), and into national preparedness mechanisms that promote strategic alignment between public and private sectors.

Deliverable: Complete update to relevant planning documents

Timeline: Within 1 year of the publication of this Action Plan

3.1.2 DHS will develop a guidance document for integrating space-weather mitigation into existing coordinating mechanisms for mitigation and protection, including Federal leadership groups and SCCs, as outlined in the National Infrastructure Protection Plan.[16]

Deliverable: Complete guidance document

Timeline: Within 1 year of the publication of this Action Plan

3.1.3 DHS, in coordination with other agencies as appropriate, will provide protection and mitigation guidance to enhance resilience across multiple sectors vulnerable to a range of space-weather events, including events less intense than those specified in the benchmarks (Goal 1). Guidance should be applicable to governments and private-sector owners and operators.

Deliverable: Complete guidance development

Timeline: Within 1 year of the completion of Action 4.1.1 initial assessments

3.2 Work with Industry to Achieve Long-Term Reduction of Vulnerability to Space-Weather Events by Implementing Measures at Locations Most Susceptible to Space Weather

3.2.1 DHS will enhance current and forthcoming strategic national risk assessments, analytic projects, national risk estimates, and other relevant activities that provide vulnerability assessments and prioritization guidance for infrastructure sectors at risk from space weather.

Deliverable: Complete necessary modification of assessments and other relevant activities

Timeline: Within 1 year of the publication of this Action Plan

3.2.2 DHS, in coordination with relevant Federal agencies, will develop Federal resilience guidance for space weather, including tools for assessing the value of backup, redundant, and replacement systems. Based on benchmark development and vulnerability analysis, this guidance will identify which facilities and systems need protection.

Deliverable: Complete resilience guidance

Timeline: Within 2 years of the completion of the Phase 1 benchmarks and Action 4.1.1 initial assessments

---

[16] See DHS website, "National Infrastructure Protection Plan," last updated June 16, 2015, www.dhs.gov/national-infrastructure-protection-plan.

3.3 Strengthen Public-Private Collaborations that Support Action to Reduce Vulnerability to Space Weather

3.3.1 DHS, in coordination with relevant Federal agencies, will develop a cross-sector engagement strategy and assess the landscape and feasibility of incentives.

Deliverable: Complete strategy and assessment report

Timeline: Within 1 year of the publication of this Action Plan

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

Introduction

Many of the fundamental physical characteristics of how space weather affects critical infrastructure systems, such as the electric power system, are not fully understood. To enhance preparedness and inform mitigation, protection, response, and recovery activities, the United States must address these gaps in scientific and engineering understanding. Understanding the effects of space weather and associated infrastructure vulnerabilities will support the creation of an operational forecasting capability[17] of space-weather effects. These capabilities will help enable timely warnings to system operators, policy makers, and emergency managers.

Goal 4 seeks to understand vulnerabilities, increase situational awareness, and develop the capability to predict impacts on all affected critical infrastructure systems. Three infrastructures and technologies of particular concern are the electric power grid, conventional aviation and space travel,[18] and position, navigation, and timing (PNT) systems. Real-time monitoring of effects on critical infrastructure is essential for situational awareness, enhanced preparedness, and model validation. Identifying necessary measurements and ways to enhance data sharing are important activities in enabling the creation of a successful monitoring initiative.

The objectives for Goal 4 are:

- Assess the vulnerability of critical infrastructure systems to space weather
- Develop a real-time infrastructure assessment and reporting capability
- Develop or refine operational models that forecast the effects of space weather on critical infrastructure
- Improve operational impact forecasting and communications
- Conduct research on the effects of space weather on industries, operational environments, and infrastructure sectors

---

[17] An operational forecasting capability is one that is available at any time, is resistant to all failure modes, and has rapid computation and dissemination mechanisms.

[18] The focus of support for aviation has been limited to conventional aviation altitudes, but commercial space travel is expected to expand in the coming decades and must be considered. The safety requirements for conventional aviation and space travel have different magnitudes of exposure to extreme space-weather events.

4.1 Assess the Vulnerability of Critical Infrastructure Systems to Space Weather

To enable and increase situational awareness during an extreme space-weather event, Federal agencies will coordinate with academia and the private sector to accomplish the following action:

4.1.1 DHS, in collaboration with Sector Specific Agencies (SSAs), will assess the vulnerability of critical infrastructure to space-weather events (as described in Goal 1). The assessment will include interdependencies and failure modes among sectors that can lead to cascading failures and will identify gaps where scientific or engineering research is required to understand or mitigate risks to critical infrastructure. The assessments will use the Phase 1 benchmarks as an initial input and will be reevaluated upon the completion of Phase 2 benchmarks.

Deliverable: Complete assessment reports

Timeline: The initial assessments will be completed within 18 months of the development of Phase 1 benchmarks. Reevaluations based on the Phase 2 benchmarks will be completed within 1 year of the development of Phase 2 benchmarks

4.2 Develop a Real-Time Infrastructure Assessment and Reporting Capability

The following actions will enable and increase capacity for real-time monitoring of the electric power system during space-weather events:

4.2.1 DOE, in coordination with DHS, DOC, and stakeholders in the energy sector, will develop plans to provide monitoring and data collection systems. The plans will inform a system-wide, real-time view of geomagnetically induced currents (GICs) at the regional level and, to the extent possible, display the status of power generation, transmission, and distribution systems during geomagnetic storms.

Deliverable: Complete plan for national GIC and grid monitoring system and delineate responsibilities for deployment

Timeline: Within 1 year of the publication of this Action Plan

4.2.2 DOE, in coordination with regulatory agencies and the electric power industry, will define data requirements that facilitate a centralized reporting system to collect real-time information on the status of the electric power transmission and distribution system during geomagnetic storms.

Deliverable: Define data requirements

Timeline: Within 1 year of the publication of this Action Plan

The following actions will define requirements for real-time assessment and reporting of radiation impacts to aviation safety:

4.2.3 DOC, in coordination with NASA, DOD, and DOT, will work with the commercial aviation industry, space operations and services, and international groups to define the requirements for real-time monitoring of the charged particle radiation environment to protect the health and safety of crew and passengers during space-weather events.

Deliverable: Complete document on radiation monitoring requirements

Timeline: Within 1 year of the publication of this Action Plan

4.2.4 DOT, in coordination with DOC, the Department of State (DOS), NASA; and in collaboration with commercial aviation, space, and international stakeholders; will define the scope and requirements for a real-time reporting system that conveys situational awareness of the radiation environment to orbital, suborbital, and commercial aviation users during space-weather events.

Deliverable: Develop and implement the mechanism for communicating real-time radiation awareness to aviation operators

Timeline: Within 2 years of the publication of this Action Plan

4.2.5 DOC and DOT, in coordination with NASA, academia, the private sector, and international partners, will develop or improve models for the real-time assessment of radiation levels at commercial flight altitudes.

Deliverable: Develop commercial aviation radiation-environment models ready for operational transition

Timeline: Within 2 years of the publication of this Action Plan

The following actions define requirements for real-time assessment and reporting of impacts to radio and satellite communications and space-based PNT systems:

4.2.6 DOC, in coordination with NSF and DOI, and commercial communication and PNT system stakeholders, will define requirements for real-time monitoring systems to assess atmospheric conditions that could affect these systems during ionospheric disturbances and geomagnetic storms.

Deliverable: Define requirements for a national operational network of real-time ionospheric monitoring stations

Timeline: Within 1 year of the publication of this Action Plan

4.2.7 DOC, DOD, and DHS, in coordination with government and commercial communications and PNT system users, will define the scope and observational requirements for a system that provides near-real-time situational awareness of the space environment for communication and PNT systems.

Deliverable: Complete report with scope and observational requirements

Timeline: Within 1 year of the publication of this Action Plan

4.2.8 DOC and DOD will create and support a satellite-anomaly database to enable secure collection and analysis of satellite-anomaly data related to space weather.

Deliverable: Complete development of a satellite-anomaly database in a secure format at DOC

Timeline: Within 1 year of the publication of this Action Plan

4.3 Develop or Refine Operational Models that Forecast the Effects of Space Weather on Critical Infrastructure

Accurate forecasts of the effects of a space-weather event on critical infrastructure require numerical models that can inform forecasters, decision-makers, and emergency managers prior to and during an event. The following actions are essential to achieving this objective:

4.3.1 DHS, in coordination with SSAs, will work with forecasting centers, emergency managers, governments, and academic and commercial stakeholders to define and develop comprehensive requirements for operational models to forecast the effects of space weather on critical infrastructures.

Deliverable: Define sector-specific requirements for developing operational models for the effects of space weather on critical infrastructures

Timeline: Within 2 years of the publication of this Action Plan

4.3.2 DHS and DOC, in coordination with SSAs and stakeholders, will identify gaps in current modeling capabilities and work with the research community to develop new and improved impact models and decision support tools. This will include a survey of current infrastructure impact models to determine if these models adequately account for the effects of space-weather events.

Deliverable: Complete survey of existing impact models

Timeline: Within 1 year of the completion of Action 4.3.1

4.3.3 Taking into account the results of the survey of existing models called for in Action 4.3.2, DHS and DOC, in coordination with SSAs, and in collaboration with the research community and stakeholders, will test and validate the existing suite of infrastructure impact models (developed by government, private-sector, and academic stakeholders) that enable forecasting of the full range of interconnected effects during an extreme space-weather event. New models will be developed if gaps are identified.

Deliverable: Complete testing and validation of existing models and provide a plan to address any identified gaps

Timeline: Within 1 year of the completion of Action 4.3.2

4.3.4 DHS, in coordination with DOC and SSAs, will incorporate infrastructure impact models into existing and future exercises to develop realistic space-weather scenarios for response and recovery, including societal impacts.

Deliverable: Complete extreme space-weather simulations on a national scale and complete an analysis of results for full system performance (including event forecasting, communications, impacts forecasting, mitigation, and response)

Timeline: Within 1 year of the completion of Phase 1 benchmarks

4.3.5 DHS and DOC, in coordination with government, private sector, and academic stakeholders, will recommend a policy for standardizing communication and data formatting from infrastructure monitoring systems and model outputs.

Deliverable: Complete recommended policy on data access

Timeline: Within 1 year of the publication of this Action Plan

4.3.6 DHS and DOC will develop data stewardship, archiving, and access-provision capabilities for space-weather infrastructure impact data and model output.

Deliverable: Develop policies on stewardship, archiving, and access of data

Timeline: Within 1 year of the completion of 4.3.5

4.4 Improve Operational Impact Forecasting and Communications

An operational capability that can forecast the effects of space weather is required to enable timely warnings to policy makers, system operators, and emergency managers. The following actions will be taken to establish this capability:

4.4.1 DOC and DHS, in coordination with other relevant agencies and stakeholders, will conduct a survey of commercial systems operators, government operators, and emergency managers to identify and assess the requirements for developing functional forecasting capabilities and alert products, including specifications for lead time, accuracy, and uncertainty.

Deliverable: Complete documentation of forecast content and lead-time requirements for relevant critical infrastructure sectors

Timeline: Within 1 year of the publication of this Action Plan

4.4.2 DHS and DOC, in coordination with NASA, NSF, private sector, academia, and other stakeholders, will develop a national capability for operational forecasting of space-weather impacts. The process will seek the development of new or improved forecasting models and the development of relevant tools and products that ensure the operational execution and dissemination of forecasts.

Measure of performance: Complete the development of new or improved operational forecasting models for at least two critical infrastructure sectors: energy and communications

Timeline: Within 3 years of the publication of this Action Plan

4.5 Conduct Research on the Effects of Space Weather on Industries, Operational Environments, and Infrastructure Sectors

The fundamental physical characteristics of space-weather effects on critical infrastructure, such as the electric power system, are not fully understood. The following actions are intended to address gaps in scientific, engineering, social, and economic understanding of these characteristics:

4.5.1 DHS, in coordination with SSAs, will support scientific and engineering research by governments, academia, and private-sector stakeholders to increase understanding of space-weather effects on critical infrastructure systems and to develop measurement systems and tools that enhance the forecasting and mitigation of effects.

Deliverable: Complete review of the extent to which grant programs at various agencies support research on the effects of space weather on critical infrastructure, and identify opportunities to introduce new programs or enhance existing processes

Timeline: Within 1 year of the publication of this Action Plan

4.5.2 DOC, in coordination with DHS, will support research into the social and economic impacts of space-weather effects, including costs of addressing irregularities in the electric power distribution system, addressing airline radiation, and lost productivity due to Global Navigation Satellite System signal impacts. Agencies will develop quantitative estimates of the potential costs of a space-weather event at the most severe level of estimated impact.

Deliverable: Initiate studies on the economic impact of space-weather events

Timeline: Within 2 years of the publication of this Action Plan

Goal 5: Improve Space-Weather Services through Advancing Understanding and Forecasting

Introduction

Space-weather information products are distributed to users worldwide and are vital for protecting life and property and for promoting economic productivity. Accurate, understandable, and timely space-weather information enables actions that reduce the vulnerability of interdependent national critical infrastructure. Building hazard-resilient communities requires an underlying network of interconnected resilient technologies and critical infrastructures. Understanding, predicting, and managing the effects of space weather—extreme events in particular—presents many challenges and requires continued investment in observations, modeling, and forecasting.

Observations are the backbone of forecast and warning capabilities. To achieve a robust operational program for space-weather observations, the United States must: (1) establish and sustain a foundational set of observations; (2) when feasible and cost effective, use data from multiple sources, including international, Federal, State, and local governments, as well as from the academic and industry sectors; (3) ensure the continuity of critical data sources; (4) continue to support sensors for solar and space physics research; (5) ensure data-assimilation techniques are in place; and (6) maintain archives for ground- and space-based data, which are essential for model development and benchmarking.

Both applied and basic research are necessary to improve space-weather services. Applied research must have near-term goals and focus on needed services and technologies. Basic research activities can advance the understanding of the dynamic processes of the sun and the sun-Earth connection. Enhanced understanding of these processes will lead to improved space-weather forecasts, warnings, and mitigation efforts. Federal and non-Federal partners must ensure that research is effectively transitioned to operational forecasting centers (e.g., the National Oceanic and Atmospheric Administration's Space Weather Prediction Center), meeting the needs of these centers and other users.

Timely and accurate space-weather information products will ensure that emergency managers, first responders, government officials, businesses, and the public will be empowered to make fast, smart decisions in response to space-weather events.

These efforts must be closely coordinated and mutually supportive to efficiently and effectively meet the growing need for the delivery of space-weather information and services through collaborations among the Federal, private-sector, academic, and international communities. These collaborations can enhance the Nation's research, effectively transition research to operations, and provide the services needed to protect critical infrastructure.

The objectives for Goal 5 are:

- Improve understanding of user needs for space-weather forecasting to establish lead-time and accuracy goals
- Ensure that space-weather products are intelligible and actionable to inform decision-making
- Establish and sustain a baseline observational capability for space-weather operations
- Improve forecasting lead-time and accuracy
- Enhance fundamental understanding of space weather and its drivers to develop and continually improve predictive models
- Improve effectiveness and timeliness of the process that transitions research to operations

5.1 Improve Understanding of User Needs for Space-Weather Forecasting to Establish Lead-Time and Accuracy Goals

5.1.1 DOC will conduct a comprehensive survey of space-weather data and product requirements needed by user communities to help improve services.

Deliverable: Complete survey and associated analysis of user requirements

Timeline: Within 1 year of the publication of this Action Plan

5.2 Ensure Space-Weather Products Are Intelligible and Actionable to Inform Decision-Making

5.2.1 DOC and DOD, in coordination with DHS, will assess best practices across the Federal Government to identify and document the most effective means to produce and deliver space-weather alerts, warnings, and notifications.

Deliverable: Complete report on best practices with recommendations for implementation

Timeline: Within 6 months of the publication of this Action Plan

5.2.2 DHS, in coordination with DOC, will develop space-weather event-specific protocols that define the chain of command, control, and communication of space-weather-impact information during an extreme space-weather event.

Deliverable: Determine space-weather event-specific protocols

Timeline: Within 1 year of the publication of this Action Plan

5.3 Establish and Sustain a Baseline Observational Capability for Space-Weather Operations

To ensure that an extreme space-weather event is detected before it affects Earth, and to enable future improvements while maintaining current levels of products and services, the United States must establish and sustain a set of baseline space- and ground-based observations. These platforms must meet reliability standards to ensure the observing systems reliably deliver the data and data-derived products. The associated data reception, relay, processing, assimilation, and archiving infrastructure required to utilize space-weather observations must also be included in the baseline.

The following two actions are priorities to sustain current operational observing capabilities:

5.3.1 DOC, NASA, and NSF will develop a strategy for: (1) the continuous operation of the Solar and Heliospheric Observatory/Large Angle and Spectrometric Coronagraph (SOHO/LASCO) for as long as the satellite continues to deliver quality observations; and (2) prioritizing the reception of LASCO data in anticipation of extreme space-weather events.

Deliverable: Complete strategy to sustain SOHO/LASCO operations

Timeline: Within 1 year of the publication of this Action Plan

5.3.2 DOC, in coordination with NASA and DOD, will develop options to deploy an operational satellite mission to a position at least 1 million miles upstream on the sun-Earth line (e.g., the L1 Lagrangian point). The primary instrument on this mission will be a solar coronagraph to replace the SOHO/LASCO coronagraph capability. This mission will also provide solar wind measurements and other measurements essential to space-weather forecasting.

Deliverable: Complete an analysis of alternatives to achieve operational status in time to ensure continuity of coronagraph and solar wind data from the L1 Lagrangian point. This analysis will also consider commercial solutions and international partnerships.

Timeline: By the end of 2017

The following actions will be taken to establish and sustain baseline operational observing capabilities:

5.3.3 DOC will sustain or enhance solar imaging and measurements of solar X-ray irradiance, energetic particles, and *in situ* magnetic field vectors from geostationary orbit.

Deliverable: Achieve sustained measurement and data continuity

Timeline: Continuous

5.3.4 DOC and DOD, in coordination with NSF, will sustain or enhance ground-based solar imaging, including solar magnetic field and H-alpha data for operational forecasting.

Deliverable: Achieve sustained measurement and data continuity for at least 10 years

Timeline: Continuous

5.3.5 DOD, in coordination with DOC, will sustain or enhance ground-based solar radio capabilities that provide continuous observations of solar radio emission to operational forecasting centers.

Deliverable: Achieve sustained measurements from ground-based solar radio capabilities for at least 10 years

Timeline: Continuous

5.3.6 DOI, in coordination with DOC, will sustain the existing ground-based geomagnetic monitoring network and enhance the network through the installation of new observatories that will deliver data to operational centers in real time.

Deliverable: Achieve sustained measurement and data continuity, complete installation of new observatories, develop a real-time data delivery system, and develop enhanced visualization and analysis tools for geomagnetic activity

Timeline: Continuous for sustained measurement; enhancements completed within 5 years of the publication of this Action Plan and sustained thereafter

5.3.7 DOC and DOD will enable and sustain the acquisition and delivery of satellite-based Global Navigation Satellite System radio occultation data with sufficient geographical coverage, data-rate, and latency to satisfy operational ionospheric-forecasting requirements. DOC will also ensure that such data are assimilated into operational models of Earth's thermosphere and ionosphere.

Deliverable: Achieve sustained acquisition, delivery, and assimilation of data for operational models

Timeline: Data acquired and assimilated by 2018

5.3.8 DOC, DOD, and NSF, in collaboration with academia, the private sector, and international partners, will develop options to sustain or enhance the worldwide ground-based neutron-monitoring network to include real-time reporting of ground-level events to operational space-weather-forecasting centers.

Deliverable: Complete plan to ensure a sufficient number of neutron detectors are deployed, worldwide, to adequately characterize the radiation environment and support a real-time alert and warning system

Timeline: Within 6 months of the publication of this Action Plan

The following actions will be taken to prioritize and plan the establishment of the baseline operational observing system:

5.3.9 DOC, in coordination with NASA, DOD, and NSF, will produce a plan for deployment of new operational space-weather-observing assets to provide the baseline measurements outlined above. The plan will prioritize and define the required fidelity, cadence, and latency of ground-based and space-based measurements.

Deliverable: Complete prioritized plan to provide baseline space-weather observations

Timeline: Within 2 years of the publication of this Action Plan

5.3.10 DOC, NASA, NSF, DOD, and DOI will develop a plan to sustain the availability of facilities for the calibration of space-weather-observing assets to ensure that measurements are accurate and comparable through traceability to international standards.

Deliverable: Complete plan to sustain the availability of facilities for the calibration of space-weather-observing assets

Timeline: Within 1 year of the publication of this Action Plan

5.4 Improve Forecasting Lead-Time and Accuracy

Space-weather forecasters analyze near-real-time ground- and space-based observations to assess the current-state space environment. Forecasts are based on a mixture of observations and model calculations, with models relying on observations as inputs. Actions identified to improve both the accuracy and lead-time of space-weather forecasts include:

5.4.1 NASA and DOC will assess space-weather-observation platforms with deep-space orbital positions (including candidate propulsion technology), which allow for additional warning time of incoming space-weather events.

Deliverable: Complete assessment report

Timeline: Within 1 year of the publication of this Action Plan

5.4.2 NASA, DOC, DOD, and NSF will support the development of novel sensor technologies and instrumentation to improve forecasting lead-time and accuracy.

Deliverable: Complete assessment of technology needs

Timeline: Within 1 year of the publication of this Action Plan

5.4.3 NASA, DOC, DOD, and NSF will prioritize and identify needs for improved coverage, timeliness, data rate, and data quality for space-weather observations, and opportunities to address these needs through collaborations with academia, the private sector, and international community.

Deliverable: Develop a report with priorities and recommendations

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter, as necessary

5.5 Enhance Fundamental Understanding of Space Weather and Its Drivers to Develop and Continually Improve Predictive Models

Accurate space-weather forecasts depend largely on understanding the complex interactions between the sun and the Earth. Limited understanding of these interactions hinders accurate forecasting of space-weather events. Additional effort is needed to improve the understanding of these sun-Earth interactions that produce space weather. Actions identified to advance these efforts include:

5.5.1 NSF and NASA, in collaboration with DOC and DOD, will lead an annual effort to prioritize and identify opportunities for research and development (R&D) to enhance the understanding of space weather and its sources. These activities will be coordinated with existing National-level and scientific studies. This effort will include modeling, developing, and testing models of the coupled sun-Earth system and quantifying the long- and short-term variability of space weather.

Deliverable: Document R&D priorities

Timeline: Within 1 year of the release of this Action Plan and every year thereafter, as necessary

5.5.2 NASA, NSF, and DOD will identify and support basic research opportunities that seek to advance understanding of solar processes and how the sun's activity connects to and drives changes on Earth and its near-space environment.

Deliverable: Announce and provide financial awards that enhance basic research in this area

Timeline: Within 1 year and sustained thereafter

5.5.3 NASA, DOC, and DOD will identify and support research opportunities that seek to address targeted operational space-weather needs.

Deliverable: Announce and provide awards that enhance research in focused areas

Timeline: Within 1 year and sustained thereafter

5.5.4 DOI will assess and pilot a geo-electric monitoring capability through the installation of sensors at existing observatories. Data from these observatories will enhance the validation of electric field models.

Deliverable: Complete and begin geo-electric monitoring pilot program

Timeline: Within 1 year of the publication of this Action Plan

5.5.5 DOI will identify and fill gaps in magnetotelluric (MT) surveys[19] of the United States, beginning with the northeastern United States and concentrating on geographic regions judged to have the highest induction hazards.

Deliverable: Complete improvements to localized estimates of geo-electric fields and in lithospheric conductivity models

Timeline: Within 1 year of the publication of this Action Plan, surveys of the northeastern United States will be completed; the remaining components of this action are a long-term effort

5.5.6 DOI will map geomagnetic and geo-electric hazards using observatory and MT data.

Deliverable: Complete map of geomagnetic and geo-electric hazards for targeted geographic regions

Timeline: Within 1 year of the publication of this Action Plan, complete real-time geomagnetic mapping project for DOC, perform scenario storm analysis of induction hazards at sites where MT surveys have been made, develop a report on the feasibility of providing DOC with a real-time service for geo-electric field maps. Within 2 years, using conductivity models derived from MT surveys, perform scenario storm analysis of induction hazards across specific, geographically continuous regions of the United States

5.6 Improve Effectiveness and Timeliness of the Process that Transitions Research to Operations

The ability to effectively transition research to sustained operations is a critical element for improving space-weather products and services. The following actions will facilitate the transition of needed space-weather information and prediction capabilities to the Nation's space-weather service providers:

5.6.1 NASA and NSF, in collaboration with DOC and DOD, will develop a formal process to enhance coordination between research modeling centers and forecasting centers. This process will seek to identify roles and responsibilities in testing, verification, and validation for transitioning space-weather research models to space-weather-forecasting centers and for sustaining and improving models that transition into operations.

Deliverable: Signed memorandum of understanding between modeling and forecasting centers

Timeline: Within 6 months of the publication of this Action Plan

5.6.2 DOC and DOD, in collaboration with NASA and NSF, will develop a plan (which may include a center) that will ensure the improvement, testing, and maintenance of operational forecasting models. This action will leverage existing capabilities in academia and the private sector and enable feedback from operations to research to improve operational space-weather forecasting.

Deliverable: Complete plan for improving, testing, and maintaining operational forecasting models and enabling operations-to-research feedback

Timeline: Within 6 months of the publication of this Action Plan

[19] A method to measure the subsurface electrical conductivity of Earth's crust.

Goal 6: Increase International Cooperation

Introduction

Space weather is a worldwide threat and a concern shared by many nations. The technologies that have revolutionized the global economy and transformed lives are the same technologies that are vulnerable to space weather. This phenomenon is not constrained by national boundaries and has potential to affect many parts of the globe simultaneously. No one nation can meet this global challenge alone.

The United States must partner with other nations in developing and strengthening standards and protocols for the protection of key infrastructure. The actions in this chapter define an approach that unifies U.S. engagement with the international community. The Action Plan identifies the bilateral and multilateral cooperation necessary to promote safety, security, and economic stability before and after space-weather events.

This Action Plan recognizes that many important international initiatives are already underway. Goal 6 actions seek to support these efforts and encourage increased cooperation. The United States must consider complementary approaches to include internationally-negotiated top-down initiatives to further understanding and approaches to space-weather events.

The Nation must manage engagements with international partners under the authority of existing Presidential Directives and international agreements. National efforts will, where possible, advance regulatory coherence and enhance efforts of international organizations.

Common solutions to regional challenges associated with space weather and exchange of best practices between the United States and international partners will strengthen global capacity to respond to extreme space-weather events. These actions pursue an international collaboration that will empower the United States and its international collaborators to be prepared to withstand the effects from space weather.

The objectives for Goal 6 are:

- Build international support and policies for acknowledging space weather as a global challenge
- Increase engagement with the international community on observation infrastructure, data sharing, numerical modeling, and scientific research
- Strengthen international coordination and cooperation on space-weather products and services
- Promote a collaborative international approach to preparedness for extreme space-weather events

6.1 Build International Support at the Policy Level for Acknowledging Space Weather as a Global Challenge

A prerequisite to enhanced international cooperation is high-level support across partner nations to raise awareness of space weather as a global challenge. The following actions will build international support at the policy level:

6.1.1 DOS, in coordination with other agencies, will ensure that policy makers and leaders of partner nations are informed of the need for a comprehensive and coordinated approach to preparing for an extreme space-weather event.

Deliverable: Organize and host a high-level international meeting on economic and societal effects of an extreme space-weather event

Timeline: Within 18 months of the publication of this Action Plan

6.1.2 DOS will coordinate sustained U.S. participation in relevant international space-weather initiatives. This effort will include participation in United Nations activities and incorporation of space-weather-related elements into work plans, programs, and projects by supporting the following activities:

- Develop a 4-year plan for United Nations (UN) World Meteorological Organization (WMO) space-weather activities
- Continue including space weather as a regular agenda item of the Scientific and Technical Subcommittee of the UN Committee on the Peaceful Uses of Outer Space (COPUOS)
- Provide global space-weather information and services for international aviation with the UN International Civil Aviation Organization (ICAO)
- Provide guidance on ionospheric disturbances monitoring and forecasting with the International Telecommunications Union (ITU)

Deliverable: Complete report on progress and international engagement

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter

6.2 Increase Engagement with the International Community on Observation Infrastructure, Data Sharing, Numerical Modeling, and Scientific Research

Increased access to government, civilian, and commercial space-weather observational infrastructure and data across the globe is of mutual benefit to the United States and its partners. Consistent with the U.S. Open Data Action Plan,[20] Federal agencies will facilitate full and open access to data to advance international cooperation in the characterization, prediction, and mitigation of space-weather effects. These same agencies should encourage international science and service partners to adopt policies that promote full and open access to data, consistent with the G8 Open Data Charter,[21] the international Group on Earth Observation (GEO) Data Sharing Principles,[22] and WMO Resolution 40 principles,[23] with

[20] See White House, *U.S. Open Data Action Plan,* May 9, 2014.

[21] See G8, "Open Data Charter," 18 June 2013.

[22] See GEO website, "GEO Data Sharing Principles Implementation," www.earthobservations.org/geoss_dsp.shtml.

[23] See World Meteorological Organization (WMO), "Resolution 40 (Cg-XII)," www.wmo.int/pages/about/Resolution40_en.html.

an emphasis on real-time data access. The following actions will increase engagement with the international community on observation infrastructure, data sharing, numerical modeling, and scientific research:

6.2.1 DOI will lead development of a plan for expansion of the real-time ground-based magnetometer network to improve global geophysical monitoring.

Deliverable: Complete strategy for expanding the magnetometer network

Timeline: Within 1 year of the publication of this Action Plan

6.2.2 DOC and DOI, in coordination with NASA and NSF, will explore opportunities to leverage international partnerships to sustain baseline operational space-weather-observing capabilities.

Deliverable: Complete report on international partnerships

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter

6.2.3 DOC and NASA will collaborate with academia, the private sector, and the international community to explore the potential benefits and costs of space-weather missions in orbits complementary to the sustained missions at the L1 Lagrangian point, which may include missions at the L5 Lagrangian point. Such missions may improve monitoring of CME properties and trajectories relative to Earth.

Deliverable: Complete analysis of space-weather missions in orbits complementary to sustained missions.

Timeline: Within 1 year of the publication of this Action Plan

6.2.4 DOC, in collaboration with DOS, will sustain and enhance international partnerships for the acquisition of data from solar-imaging and solar-wind deep-space missions, building on the ongoing operational Real-Time Solar Wind (RTSW) network. [24]

Deliverable: Complete report on the status of operational deep-space mission data acquisition and needs for additional antenna resources

Timeline: Within 1 year of the release of this Action Plan

6.2.5 DOC, in coordination with DOI, will maintain U.S. input to the WMO Observing System Capability Analysis and Review (OSCAR) database and encourage contributions of international partners to ensure comprehensive knowledge of international space-weather observational systems and their data products currently in use and planned for operational forecasting. This action will include information on ground- and space-based systems.

Deliverable: Complete documentation of international observational systems

Timeline: Within 1 year of the publication of this Action Plan, with annual updates

[24] For a list of international and domestic partners, see the Space Weather Prediction Center website, www.swpc.noaa.gov/products/ace-ground-station-tracking-plots.

6.2.6 DOC and DOI, in coordination with NSF and NASA, will promote the improved exchange of data and information using the WMO Information System and other means, and organize international data comparison activities to promote the availability, intercalibration, and interoperability of space- and ground-based data.

Deliverable: Complete report on the use of the WMO Information System and other data-sharing means and on international data comparison activities

Timeline: Within 2 years of the publication of this Action Plan

6.2.7 DOC and DOI, in coordination with NSF and NASA, will provide input to the WMO operational space-weather-observing requirements and Statement of Guidance and will report to relevant international organizations, including the COPUOS, the Coordination Group for Meteorological Satellites (CGMS), and the International Real-time Magnetic Observatory Network (INTERMAGNET),[25] on priorities for coordinated action.

Deliverable: Submit report to each of the noted international organizations at their respective primary annual meetings

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter

6.2.8 NASA will promote and support the continuation of space weather as a regular topic in the international efforts of the International Council for Science's Committee on Space Research (COSPAR) and within the International Living with a Star (ILWS) program.

Deliverable: Complete progress report

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter

6.3 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. To achieve this, the following actions are necessary: international agreement on common terminology, measurements, and scales of magnitude; promotion, coordination, and dissemination of space-weather observations, model outputs, and forecasts; and establishment of coordination procedures across space-weather operations centers during extreme events. The following actions will strengthen international cooperation on space-weather products and services:

6.3.1 DOC will lead U.S. efforts to engage international partners to ensure that communicated products and services are globally consistent during extreme events.

Deliverable: Complete report on actions taken to sustain, improve, and develop international coordination mechanisms

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter

[25] The INTERMAGNET program exists to establish a global network of cooperating digital magnetic observatories. See INTERMAGNET website, www.intermagnet.org/.

6.3.2 DOT, in coordination with DOC and DOD, will lead U.S. efforts to develop international standards for the provision of space-weather information for international air navigation.

Deliverable: Develop proposal for ICAO

Timeline: Within 1 year of the publication of this Action Plan

6.3.3 DOC and NASA will continue efforts within CGMS to promote an ongoing agenda item on space-weather activities.[26]

Deliverable: Complete progress report

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter

6.3.4 DOC will sustain engagement with the International Space Environment Service (ISES) and foster participation of additional nations in the network of space-weather service providers.

Deliverable: Complete progress report

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter

6.4 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, which could possibly lead to a cascade of effects across borders and sectors. To mitigate these risks, the United States will 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 will also foster development of global mutual-aid arrangements to facilitate response and recovery efforts, and will coordinate international partnership activities to support space-weather preparedness and response exercises. The following actions will promote a collaborative international approach to preparedness for extreme space-weather events:

6.4.1 DOS, DOC, and DHS, in coordination with and other Federal agencies, will provide outreach and education to assist nations in understanding space-weather effects and integrating space weather into national hazard and risk registries.

Deliverable: Complete progress report

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter

6.4.2 DOS, DHS, NSF, DOE, and DOC will work with relevant international organizations[27] and key partners on assessing global economic impact of an extreme space-weather event.

Deliverable: Develop proposal for international assessment

Timeline: Within 1 year of the publication of this Action Plan

---

[26] CGMS identified space weather coordination as the highest priority for the period 2014–18. See CGMS website, "Coordination Group for Meteorological Satellites (CGMS)," http://www.eumetsat.int/website/home/AboutUs/InternationalCooperation/CoordinationGroupforMeteorologicalSatellites CGMS/index.html. .

[27] For example, see *OECD Futures Project on 'Future Global Shocks': Geomagnetic Storms*, 14 January 2011.

6.4.3 The United States Postal Service (USPS), DOT, and DHS will participate in the Civil Emergency Planning Committee (CEPC) of the North Atlantic Treaty Organization (NATO) to advise NATO planners on possible implications of space weather for NATO operations; to promote consistency in communications and operations among NATO members and partner nations; and to assist in and, as appropriate, lead development of training and exercise events.

Deliverable: Complete progress report

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter

6.4.4 DOS, in coordination with DHS, DOD, and DOC, will develop space-weather event-specific protocols that define the communication of U.S. space-weather-impact information to other nations and international organizations during an extreme space-weather event.

Deliverable: Complete development of communications protocols

Timeline: Within 2 years of the publication of this Action Plan

6.4.5 DOS, in coordination with DHS, DOC, and DOT, will inform U.S. Embassies and Missions worldwide of the effects from an extreme space-weather event.

Deliverable: Complete outreach strategy

Timeline: Within 6 months of the publication of this Action Plan

6.4.6 DOS, in coordination with relevant agencies, and consistent with Office of Management and Budget (OMB) Circular A-119[28] and Executive Office of the President (EOP) Memo M-12-08,[29] will support the development and use of international standards for improved resilience of equipment to extreme space-weather events by participating in the development of relevant open, consensus-based international standards.

Deliverable: Complete progress report

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter

6.4.7 DOS, in coordination with DHS, DOC, and other Federal agencies, will address extreme space-weather events in accordance with supply-chain issues and as part of the U.S. government's overall and ongoing efforts to implement the 2012 National Strategy for Global Supply Chain Security.

Deliverable: Complete progress report

Timeline: Within 1 year of the publication of this Action Plan and every year thereafter

[28] OMB, "Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities," OMB Circular A-119, February 10, 1998.

[29] EOP, "Principles for Federal Engagement in Standards Activities to Address National Priorities," EOP Memo M-12-08, January 17, 2012.

Conclusion

The activities outlined in this Action Plan represent a merging of national and homeland security concerns with scientific interests. This effort is only the first step. The Federal Government alone cannot effectively prepare the Nation for space weather; significant effort must go into engaging the broader community. Space weather poses a significant and complex risk to critical technology and infrastructure, and has the potential to cause substantial economic harm. This Action Plan provides a road map for a collaborative and Federally-coordinated approach to developing effective policies, practices, and procedures for decreasing the Nation's vulnerabilities. By specifying tasks that will lead to improvements in forecasting, research, preparedness, planning, and domestic and international engagement, and identifying the responsible agencies, this Action Plan will help ensure that the Federal Government and its domestic and international partners are able to withstand and quickly recover from effects of extreme space-weather events.

References

Coordination Group for Meteorological Satellites (CGMS). "CGMS High Level Priority Plan (HLPP), 2015–2019.

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). "National Infrastructure Protection Plan." Last updated June 16, 2015.

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

————."Sector-Specific Agencies." March 2, 2015.

Executive Office of the President (EOP). "Principles for Federal Engagement in Standards Activities to Address National Priorities." EOP Memo M-12-08. January 17, 2012.

Federal Emergency Management Agency (FEMA). "Emergency Support Function 15: Standard Operating Procedures." Last updated August 21, 2014.

————."National Planning Frameworks." Last updated March 19, 2015. www.fema.gov/national-planning-frameworks.

————. "National Preparedness Goal." Last updated March 19, 2015. www.fema.gov/national-preparedness-goal.

————. "Recovery Federal Interagency Operation Plan (FIOP)." Last updated July 30, 2014.

————. "Whole Community." Last updated April 16, 2015.

————. "A Whole Community Approach to Emergency Management: Principles, Themes, and Pathways for Action," FDOC 104-008-1. December 2011.

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.

G8. "Open Data Charter." Policy Paper. June 18, 2013.

Group on Earth Observations (GEO). "GEO Data Sharing Principles Implementation."

International Real-time Magnetic Observatory network (INTERMAGNET). "Welcome to INTERMAGNET."

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 Weather Program Council. *Report on Space Weather Observing Systems: Current Capabilities and Requirements for the Next Decade.* Office of the Federal Coordinator for Meteorological Services and Supporting Research. 2013.

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,

Office of Management and Budget. "Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities." OMB Circular A-119. Washington, DC: OMB, February 10, 1998.

Organisation for Economic Co-operation and Development (OECD). *OECD Futures Project on 'Future Global Shocks': Geomagnetic Storms*. Paris, France, 11 January 2011.

————. *OECD Reviews of Risk Management Policies: Future Global Shocks–Improving Risk Governance.* Preliminary Version. Paris, France, n.d.

————. "International Futures Program."

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 2010*. 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.

World Meteorological Organization (WMO). "Resolution 40 (Cg-XII)."

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.

White House. *U.S. Open Data Action Plan*. May 9, 2014.

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

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

Abbreviations

CEPC	Civil Emergency Planning Committee
CGMS	Coordination Group for Meteorological Satellites
CME	coronal mass ejection
COPUOS	Committee on the Peaceful Uses of Outer Space
COSPAR	Committee on Space Research
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOS	Department of State
DOT	Department of Transportation
E-field	induced geo-electric field at Earth's surface
EOP	Executive Office of the President
EPFAT	Emergency Power Facility Assessment Tool
ESA	European Space Agency
ESFLG	Emergency Support Function Leadership Group
EUV	extreme ultraviolet
FCC	Federal Communications Commission
FIOP	Federal Interagency Operations Plan
GEO	Group on Earth Observation
GIC	geomagnetically induced current
GPS	Global Positioning System
HHS	Department of Health and Human Services
ICAO	International Civil Aviation Organization
ILWS	International Living with a Star
INTERMAGNET	International Real-time Magnetic Observatory Network
ISES	International Space Environment Service
ITU	International Telecommunications Union
LASCO	Large Angle Spectrometric Coronagraph
LEO	low-Earth orbit

MT	magnetotelluric
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
NSTC	National Science and Technology Council
OECD	Organisation for Economic Co-operation and Development
OMB	Office of Management and Budget
OSCAR	Observing System Capability Analysis and Review
PNT	position, navigation, and timing
POIA	Power Outage Incident Annex
PPD	Presidential Policy Directive
R&D	research and development
RTSW	Real-Time Solar Wind
RSFLG	Recovery Support Function Leadership Group
SCC	Sector Coordinating Council
SLTT	State, local, tribal, territorial
SNRA	Strategic National Risk Assessment
SOHO	Solar and Heliospheric Observatory
SRB	solar radio burst
SSA	Sector-Specific Agency
UN	United Nations
USPS	United States Postal Service
UV	ultraviolet
WMO	World Meteorological Organization