White Paper on the Implementation Status of the National Space Weather Strategy and Action Plan

PRODUCT OF THE

Space Weather Operations, Research, and Mitigation Subcommittee

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About the Space Weather Operations, Research, and Mitigation Subcommittee

The Space Weather Operations, Research, and Mitigation (SWORM) Subcommittee is organized under the National Science and Technology Council Committee on Homeland and National Security under the auspices of the White House Office of Science and Technology Policy. The SWORM Subcommittee seeks to coordinate Federal Government departments and agencies to enhance national capabilities in promoting resilience to the effects of space weather.

About the National Space Weather Strategy and Action Plan

The National Space Weather Strategy and Action Plan was developed by the SWORM Subcommittee. Public input into the development of this document was received through a Federal Register (83 FR 17526) request for information solicitation. Responses to the request for information, along with input from National Security Council and National Space Council staff, informed the development of the National Space Weather Strategy and Action Plan. This document was reviewed by the Committee on Homeland and National Security, and was finalized and published by the Office of Science and Technology Policy.

Introduction

Space weather comprises a set of naturally occurring phenomena that have the potential to adversely affect critical functions, assets, and operations in space and on Earth. Extreme space weather events can degrade or damage critical infrastructures, which may result in direct or cascading failures across key services such as electric power, communications, water supply, healthcare, satellite operations, and transportation. Preparing for space weather events will help protect infrastructure and activities vital to national security and the economy of the United States.

The 2019 update to the National Space Weather Strategy and Action Plan (hereafter referred to as the Strategy and Action Plan) identified key objectives and activities. It leveraged existing national efforts and sought to align ongoing and future space weather activities to increase associated Federal Government efficiency and to enhance American innovation. The Strategy and Action Plan sought to achieve three objectives, each supported by a set of high-level actions, to enhance the Nation's preparedness for space weather events:

1. Enhance the Protection of National Security, Homeland Security, and Commercial Assets and Operations against the Effects of Space Weather;
2. Develop and Disseminate Accurate and Timely Space Weather Characterization and Forecasts; and
3. Establish Plans and Procedures for Responding to and Recovering from Space Weather Events.

Efforts to achieve these objectives and link outcomes among the three objectives will help safeguard national security assets and critical infrastructure, crewed and uncrewed space operations, and foster growth in U.S. commercial space- and ground-based activities.

As the SWORM undergoes a review of the Strategy and Action Plan and an Implementation Plan rewrite in 2023, this white paper provides a status summary of the efforts made to achieve these objectives as of December 2022.

Objective I: Enhance the Protection of National Security, Homeland Security, and Commercial Assets and Operations against the Effects of Space Weather

Space weather poses a risk to civilian critical infrastructure, defense and intelligence systems, and military operations. Strengthening critical infrastructure security and resilience to space weather events requires an understanding of and a reduction in critical infrastructure vulnerabilities to the effects of space weather. Space weather can damage or disrupt space-based assets, jeopardize or impair crewed and uncrewed space activities, and adversely affect the ability to track objects in space. Understanding vulnerabilities to and protecting against the effects of space weather should inform satellite and spacecraft owners' and operators' design and engineering plans, mitigation strategies, and operational decision-making in the space environment. Space weather effects on ground systems, such as radars, or space-, air-, and ground-based communication links, pose a risk to national and homeland security. Developing and refining strategies to protect against and mitigate the potential disruptive effects of space weather, such as hardening critical assets, can minimize space weather risks and enhance resilience.

1.1 Refine space weather benchmarks that provide quantitative baselines to assess the intensity of space weather events.

- Progress:
  The SWORM tracking the progress towards the development of updated space weather benchmarks and scales being conducted by the Office of Science and Technology Policy. Updating the space weather scales will require engagement with NOAA's Space Weather Prediction Center (SWPC), the international user community, and international coordinating bodies to identify the optimal changes needed to improve the space weather scales. The Science and Technology Policy Institute (STPI) has prepared reports detailing the current issues and potential challenges to revise and update both the scales and the benchmarks.

- Gaps:
  Based on STPI's analysis, the primary gaps identified by the SWORM for refining the space weather benchmarks are 1) coordinating activities and identifying funding mechanisms to support research efforts that will inform the benchmarks, 2) additional communication and collaboration with stakeholders in industry and end users who are impacted by space weather phenomena, and 3) raising awareness for the importance of investments in space weather observation and monitoring capabilities needed for sustained, long-term improvement of the space weather benchmarks.

1.2 Assess the vulnerability of priority critical infrastructure systems and national security assets to the effects of space weather and use the results to inform risk management.

NOTE: The progress and gaps identified here are focused on the power grid only. Activities focused on other sectors will be made available at a later date.

- Progress:
  DHS Cybersecurity and Infrastructure Security Agency (CISA), through the National Risk Management Center (NRMC), identified 55 National Critical Functions (NCF) that are vital to the United States. Their disruption, corruption, or dysfunction would have a debilitating effect on security, national economic security, national public health and/or safety. The SWORM is using the NCF methodology to identify and prioritize functions with the greatest dependencies on space

and those that are most susceptible to a disruption caused by a space weather event. The SWORM will use the prioritization and analysis to inform risk management and mitigation recommendations related to the four designated lifeline functions: transportation, water, energy, and communications. The SWORM transitioned from a vulnerabilities-based approach to a risk based approach. Not all space weather events have the same capacity to severely damage infrastructure. The working group focused efforts on CME which has the greatest potential to create catastrophic damage to US infrastructure. Through this process the group identified that current forecasting capabilities do not provide information needed by senior leaders in the government or the private sector to initiate preemptive actions.

In addition to the NCF work, the Department of Energy (DOE), Federal Energy Regulatory Commission (FERC), US Geological Survey (USGS), and CISA are collaborating on identifying electricity infrastructure with increased threat potential that, if disrupted by a geomagnetic disturbance (GMD) event, could result in significant impacts to the delivery of key NCFs. FERC and DOE will assess whether identified transformer archetypes are designed and manufactured to withstand the impacts of a geomagnetically induced current (GIC) caused by a GMD event. The assessment will also consider empirical geoelectric hazard maps for the contiguous United States (CONUS) produced by the USGS to identify geographic areas that are capable of inducing larger threats from a GMD event due to location and geology of the ground on which they are situated. Initial assessments will review the impacts using a 100-year GMD event scenario, as outlined in North American Electric Reliability Corporation (NERC) Reliability Standard TPL-007-4, though additional work is ongoing to determine whether the threshold established in the NERC standard should be adjusted to reflect new understanding of the strength of 100-year events.

- Gaps:
  Two primary gaps were identified:
  - Space weather vulnerability assessments should highlight interdependencies between sectors to better predict potential secondary impacts and cascading failures (e.g., impacts to power transmission may result in impacts to other sectors with power dependencies)
  - Previous power grid vulnerability assessments may not have considered the full 3D effects of Earth conductivity structures and USGS's recent efforts are likely the first attempts to appropriately leverage Magnetotelluric (MT) data and associated research to inform vulnerability

1.3 Model the effects of space weather on space-, air-, and ground-based national critical functions and associated priority critical infrastructure and national security systems, assets, and networks.

NOTE: The progress and gaps identified here are focused on the power grid only. Activities focused on other sectors will be made available at a later date.

- Progress:
  The effects on ground based NCFs are reasonably understood and there are already existing models in place that are being used to assess and mitigate the risk from space weather. One way that SWORM has worked to build on this is to coordinate with working group members from USGS to review magnetotelluric survey data to determine areas of the US that are most susceptible to GMD impacts, based on the conductivity of the ground on which infrastructure is

situated. The magnetotelluric (MT) survey of the contiguousUnited States (CONUS) is nearly complete, and is currently scheduled to be finalized during FY 2024 through a cooperative agreement with USGS and Oregon State University When magnetotelluric impedance tensors are combined with historical geomagnetic observatory time series from USGS geomagnetic observatories, magnetotelluric Earth-surface impedance tensors derived from this survey data allow for retrospective estimation of geoelectric hazards across CONUS. In turn,extreme-value voltages on the national power grid such as would be experienced during a 100-year magnetic storm can be inferred. This analysis identifies regions where geoelectric hazards are higher than those anticipated in the NERC 100-year benchmark storm scenario. These analyses motivate the need for higher density MT surveys in regions with major conductivity contrasts, as indicated by abrupt changes in extreme electric field amplitude that lie close to major population centers. Geoelectric hazards also show significant uncertainty, predominantly the result of the sparsity of geomagnetic monitoring across CONUS. This work can be used to inform future standards for geomagnetic hazard analysis and can be utilized by utility companies to identify the portions of their grid most susceptible to geomagnetic hazards. This information will also help inform decisions on where to prioritize resources for the hardening of equipment, such as large power transformers. DOE is engaged in a multi-year effort to increase the capabilities of modeling tools relevant to GMDs to ensure that once additional data is available, updated Geomagnetically-induced current (GIC) threat calculations can be conducted.

- Gaps:
  Needs identified:
  - Denser-geographic and broad-band (higher-frequency) magnetotelluric surveys in high-risk areas, especially in the Eastern United States and the upper Midwest.
  - Expansion of the USGS ground-based magnetometer observatory network, to reduce uncertainties in geoelectric hazard maps.
  - Magnetotelluric surveying in areas of Canada where there are significant interdependencies between US and Canadian electric infrastructure.
  - Develop one or more standardized time related geomagnetic field waveforms that will provide a consistent means for evaluating the impacts of geomagnetic storms. This is important when considering the unpredictable timing, magnitude and duration of the storms that can exceed the current criteria under NERC's TPL-007-4.
  - Increase the capabilities of modeling tools relevant to GMDs to ensure Geomagnetically-induced current (GIC) threat calculations can be conducted.

1.4 Identify and assess the effects of frequent and extreme space weather events on operations and missions

NOTE: The progress and gaps identified here are focused on the power grid only. Activities focused on other sectors will be made available at a later date.

- Progress:
  The NERC's TPL-007-04 GMD Reliability Standard requires private industry stakeholders to conduct vulnerability assessments and develop corrective actions and plans to mitigate risk from GICs.

- Gaps:
  The data is owned by industry and would not be available to the research community unless it is voluntarily given. Additional gaps will be assessed upon completion of action 1.2 and 1.3.

1.5 Assess the cost of space weather effects on the operations and implementation of critical missions.

- Progress:
  The SWORM assessed the feasibility of estimating the costs associated with space weather effects on the operations and implementation of critical missions. However, it was determined that, due to the ambiguities and uncertainties associated with forecasting the impacts of space weather to critical infrastructure, estimating the granular costs associated with a potential space weather disruption was not a task that could be undertaken with any definitive level of certainty or accuracy for most critical infrastructure[1]. Based on this assessment, the SWORM recommended that task 1.5 be rescoped to examine the costs associated with mitigating critical infrastructure against a GMD event. The "extreme" estimates outlined in the NOAA report on the Social and Economic Impacts of Space Weather in the United States report do not necessarily reflect a Carrington-like event or the theoretical maximum level event; therefore, the SWORM recommends refreshing this report to focus on a space weather event based on recent assessments of maximum geoelectric fields.

- Gaps:
  Space weather events range in intensity and duration and impacts between sectors vary. Such inconsistencies are not necessarily problematic but it should be further quantified with future efforts.

1.6 Identify and prioritize R&D necessary to enhance the security and resilience of critical functions and national security assets to the effects of space weather.

NOTE: The progress and gaps identified here are focused on the power grid only. Activities focused on other sectors will be made available at a later date.

- Progress:
  The White House Subcommittee for Resilience Science and Technology developed the "Research and Development Needs for Improving Resilience to Electromagnetic Pulses" in 2020 to address key considerations regarding research and development (R&D) needs. The report identified departments' and agencies' R&D needs in support of core agency missions and the roles and responsibilities outlined in the Executive Order (E.O.) 13865, Coordinating National Resilience to Electromagnetic Pulses (March 26, 2019). Subsequent to its release, the EMP R&D Interagency Working Group (EMPRAD IWG) reconvened to develop the first annual refresh of the inaugural report. The annual review considers the following broad research categories identified in the original Plan: Environment, System Impact, and Remedies. It enumerates areas where progress has been made and identifies gaps and emerging concerns since the 2020 EMPRAD Plan. EMPRAD IWG members identified numerous areas of progress and efforts underway to advance modeling, both to improve the accuracy and timeliness of space weather forecasts and to improve models for coupling to infrastructure elements and better assess the impacts to infrastructure.

[1] There are cases where the costs of preventative measures may be available, such as the cost of entering conservative operations based on the GMD forecast provided to the electric utilities. It may be difficult however, to project these costs across the entire electric sector as preventative measures may vary from utility-to-utility.

- Gaps:
  Gaps remain around testbed activities, including information sharing and the need to keep pace with the rapid turnover in commercial infrastructure. As an example, DOE has substantial limits currently in their capability to conduct representative testing of GMD events on live transformers due to not being set up for equipment beyond 128 kV. The USGS has identified a need for a geographically dense broad-band (higher-frequency) magnetotelluric survey across the Eastern United States and the upper Midwest to support detailed GMD and EMP scenario analyses.

1.7 Test, evaluate, and deploy technologies and devices to mitigate the effects of space weather on critical functions and assets.

NOTE: The progress and gaps identified here are focused on the power grid only. Activities focused on other sectors will be made available at a later date.

- Progress:
  FERC issued Order No. 779, directing NERC to develop standards that address risks to reliability caused by geomagnetic disturbances and requires owners and operators to develop and implement plans to protect against damages from a 100-year benchmark GMD event. Standards will need to be updated to ensure that reasonable mitigation efforts are taken by the electric grid owners and operators to include, when completed, any relevant adjustments to space weather benchmarks and scales. DOE has recently deployed 1 pilot GIC blocker and is in progress on deploying a second with industry partners to test the ability to successfully operate with these new technologies, evaluate the effects on nearby substations to optimize costs/benefits, and evaluate efficacy of the new technology.

- Gaps:
  Other relevant sectors should be added to the work DOE has done to help mitigate risk to the Energy Sector.

1.8 Support the development and use of standards for improved resilience of equipment to space-weather events.

NOTE: The progress and gaps identified here are focused on the power grid only. Activities focused on other sectors will be made available at a later date.

- Progress:
  The NERC’s TPL-007 GMD Reliability Standard is the primary standard related to mitigating the effects of GMD on the electric grid. NERC, with Federal assistance, as appropriate, should update the existing standards or develop new standards that account for impacts of a space weather event greater in magnitude than the existing 100-year benchmark GMD event.

  To support this effort, FERC, DOE, and Sandia National Laboratory completed a study of the vulnerabilities of transformers to GIC (both from space weather events and deliberate attacks) that identified particular vulnerabilities of Bulk Power System transformers. In addition, DHS Science & Technology (S&T) is undertaking an effort to review the existing NERC standard to determine the susceptibility of energy sector equipment to GMD events and the shielding effectiveness of Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI) standards, based on modeling and testing. This information will be used to identify specific standards that can be updated to help protect energy sector partners from GMD events.

- Gaps:
  While the existing standards improve the resilience of the energy sector to GMD impacts, the standards are only effective if they are adopted. Future efforts may need to focus on facilitating mitigation efforts and driving standards adoption

Objective II: Develop and Disseminate Accurate and Timely Space Weather Characterization and Forecasts

Timely and accurate space weather characterization and forecasts are critical to inform the planning, execution, and decision-making of operations for a diverse set of stakeholders including critical infrastructure owners and operators, the military, and private sector satellite owners and operators. Improved understanding, observations, forecasts, and models for space weather events can lead to better quality and more timely space weather products and services as well as contribute to supporting safe, stable, and sustainable space activities.

2.1 Identify baseline ground-based, sea-based, air-based, and space-based operational observation capabilities.

- Progress:
  The SWORM produced a baseline report of the space- and ground-based observations necessary to satisfy space weather forecasting requirements. This report also provides a prioritization for new operational space-weather-observing assets or improvements to existing assets to provide the required observational capabilities specified in the baseline. The report benefited from both the NASA report, "Space Weather Science and Observation Gap Analysis for the National Aeronautics and Space Administration (NASA)" that was led by the Johns Hopkins University Applied Physics Laboratory and from the National Academies of Sciences (NAS) workshop for the research, operations, and user communities to consider options for continuity and future enhancements of the U.S. space weather operational infrastructure.

  The SWORM also provides input to the World Meteorological Organization (WMO) Observing System Capability Analysis and Review database through the Coordination Group for Meteorological Satellites and the WMO Inter-Programme Coordination Team on Space Weather. This encourages contributions of international partners to ensure comprehensive knowledge of international space-weather observational systems and data products currently in use and planned for operational forecasting. This action includes information on both ground- and space-based systems.

- Gaps:
  Need to obtain more quantitative and objective assessments of observational coverage and identification of gaps. NOAA is in the process of conducting Observing System Simulation Experiments (OSSEs). As new information is obtained, the priorities identified in this report must be reassessed.

2.2 Ensure baseline operational space weather observation platforms, capabilities, and Networks.

- Progress:
  As required by the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act, a number of actions are underway to sustain observations, both ground- and space-based, to meet the observing requirements to deliver real-time data to operational space weather forecast centers.

To provide L1 continuity, NOAA will launch the Space Weather Follow-On L1 mission in 2025 as a rideshare with NASA's IMAP. NOAA will also integrate a coronagraph on GOES-U scheduled for launch in 2024. The SWORM is working in partnership with the European Space Agency (ESA) to provide L5 coverage. The ESA L5 mission, Vigil, received strong support at the 2022 ESA Council at Ministerial level. COSMIC-2 radio occultation results of ionospheric and atmospheric conditions are operational for both NOAA and DoD

The SWORM has also developed a number of plans for ground-based observations including: 1) a collaborative global operational ground-based solar observing network that meets operational observing requirements; 2) sustaining and enhancing the existing ground-based geomagnetic monitoring network; and, 3) the implementation of a global network of ground-based neutron monitors that includes delivery of real-time data to operational space weather forecast centers.

- Gaps:
  Policies need to be developed to facilitate the transition of research and academic data collection platforms to agencies responsible for long-term operational monitoring.

2.3 Support and coordinate opportunities for fundamental research in heliophysics and geospace sciences.

- Progress:
  The SWORM is leading a biennial 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 such as the reports and workshop proceedings mentioned in Action 2.1 and the NAS workshop co-funded by NASA and NSF – "Space Weather Operations and Research Infrastructure Workshop, Phase II"), and future recommendations from the Space Weather Advisory Group's PROSWIFT Act mandated Space Weather User Survey.

- Gaps:
  Space-based monitoring projects and exploratory missions need to be coordinated with agencies responsible for ground-based monitoring.

2.4 Identify, develop, and test innovative approaches to enable enhanced, more informative, robust, and cost-effective measurements.

- Progress:
  This action calls for receiving commercial sector and academic sector input of what ground-based and space-based observation techniques can be improved and/or developed to advance space weather measurements. To address this action, the NAS workshops mentioned in Action 2.1 and 2.3 considers options for continuity and future enhancements of the U.S. space weather operational infrastructure and the research and observations needed to improve scientific understanding of the Sun–Earth interactions that cause space weather.

- Gaps:
  A summary of gaps can be found in the NAS workshop proceedings identified in Actions 2.1 and 2.3.

2.5 Enhance current space weather models and develop improved modeling techniques for space weather.

- Progress:
  Testing and validation of forecasts and models is critical to ensuring their relevance and accuracy. Key tasks for completing this action include enhancing data integration and utilization, developing metrics to measure and evaluate the performance and capabilities of operational and scientific models, supporting R&D to improve models, and identifying computational resource requirements for openly running and testing operational models.

  A number of SWORM activities are underway to implement this action. These include: NASA Community Coordinated Modeling Center's (CCMC) community-wide scoreboards for pre-event forecast validations such as Solar energetic particle events at the NASA Space Radiation Analysis Group. A shared computing environment at CCMC and SWPC, known as the Architecture for Collaborative Evaluation, provides operational evaluation of models; both NASA's Research Opportunities in Space and Earth Sciences (ROSES) R2O2R grant solicitation and Space Weather Centers of Excellence programs, and NSF's solicitation, "Grand Challenges in Integrative Geospace Sciences: Advancing National Space Weather Expertise and Research toward Societal Resilience (ANSWERS). NOAA SWPC and the USGS are collaborating on further development of real-time mapping of storm-induced geoelectric fields across CONUS.

- Gaps:
  The space weather community has requested access to observational and operational data streams as the simulation output will contribute to the identification, preparation, maintenance and augmentation of high-quality datasets for assimilation, model validation, and to optimize utilization. The model output is critical to baseline current model capabilities and will allow for model developers and researchers to identify and demonstrate improvements.

2.6 Identify and release, as appropriate, new or previously underutilized data sets.

- Progress:
  Greater access to existing datasets could improve the development, validation, and testing of models used for characterizing and forecasting space weather events. Examples of underutilized data sets include historical space weather relevant data from satellites, U.S. Government funded ground-based observatories and networks, and in situ measurements throughout the electric power grid. The SWORM completed a public data call of historical datasets of interest in April 2020. Another data call will be conducted and a list of data will be developed and prioritized for public release in early 2023.

- Gaps:
  None identified.

2.7 Identify mechanisms for sustaining and transitioning models and observational capabilities from research to operations.

- Progress:
  Also mandated in the PROSWIFT Act, transitioning models from research to operations and leveraging operations to identify gaps in research (R2O2R) is critical to improving operational space weather forecasts and services. A formal framework was developed by the SWORM to

enhance and accelerate the transition of R2O2R, including academic, private sector, and international partnerships and was published in March 2022.

With the R2O2R formal framework completed, the SWORM is now finalizing a report that will recommend R2O2R best practices. Identifying lessons learned and limitations of previous models transitioned from research to operations at SWPC will accelerate the R2O2R process.

- Gaps:
  A space weather prediction testbed at SWPC is critical for a successful R2O2R process and the transition of models into operations and to get operational needs back to the research community. The testbed received initial funding in FY23 but will need continued, sustainable resources.

2.8 Enhance accessibility and sharing of observational data across the stakeholder Community.

NOTE: The SWORM has combined efforts to implement actions 2.8 and 2.10 together in the Implementation Plan.

- Progress:
  Representatives from various Federal agencies continue to work through international fora such as the United Nations Committee on the Peaceful Uses of Outer Space, the World Meteorological Organization, the International Civil Aviation Organization, the Coordination Group for Meteorological Satellites, the International Space Environment Service, the International Real-Time Magnetic Observatory Network, and the International Space Weather Initiative to coordinate the consistent messaging and communication of space weather events, ways to increase access to government, civilian, and commercial space-weather observational infrastructure and data, and, the observation and characterization of space weather events to enhance global preparedness.

- Gaps:
  The broad scientific and engineering communities within the space-weather enterprise would benefit from the free and open exchange of data related to the impacts of space weather on technological systems operated by the commercial, academic, and governmental sectors. Such data would facilitate collaborations between providers and users of space-weather services.

2.9 Improve the effectiveness of space weather event notifications.

- Progress:
  Improving the overall effectiveness of space weather notifications requires strengthening mechanisms for their communication, dissemination, and coordination as well as educating the public and other recipients of these notifications. The SWORM completed the Customer Needs and Requirements for Space Weather Products and Services Survey (https://www.swpc.noaa.gov/news/customer-needs-requirements-space-weather) and looks forward to future recommendations from the Space Weather Advisory Group's PROSWIFT Act mandated User Survey. Once the SWORM receives the User Survey results, SWPC will work to develop new and improved products to support user requirements as well as best determine the appropriate dissemination methods.

- Gaps:
  The space weather forecasts need to be provided with sufficient lead time and fidelity to be useful by many owners of Critical Infrastructure. Specifically, the forecasts need to provide sufficient information for critical infrastructure owners to take action.

2.10 Engage international partners to ensure space weather products and services are globally coordinated and consistent, as appropriate, during extreme events.

NOTE: The SWORM has combined efforts to implement actions 2.8 and 2.10 together in the Implementation Plan.

- Progress:
  The SWORM continues to work through international fora such as the United Nations Committee on the Peaceful Uses of Outer Space, the World Meteorological Organization, the International Civil Aviation Organization, the Coordination Group for Meteorological Satellites, the International Space Environment Service, the International Real-Time Magnetic Observatory Network (INTERMAGNET), and the International Space Weather Initiative to coordinate the consistent messaging and communication of space weather events, ways to increase access to government, civilian, and commercial space-weather observational infrastructure and data, and, the observation and characterization of space weather events to enhance global preparedness.

- Gaps:
  Meaningful collaborations, and (possibly) the exchange of modest amounts of financial support, with foreign geophysical agencies could facilitate acquisition of real-time global monitoring data of interest to the U.S. domestic space weather community.

2.11 Develop and refine situational awareness capabilities.

- Progress:
  This action includes addressing the effective execution of missions, and the rapid detection, warning, characterization, and attribution of natural versus man-made disturbances to technologies and infrastructure systems critical to national and homeland security. To implement this action a number of reports are underway and near completion to: 1) address requirements and models for radiation monitoring at and above commercial flight levels; 2) assess and develop assimilation models of the ionosphere; 3) address requirements for electric power grid monitoring and reporting; and, 4) develop real-time monitoring of the space environment. The SWORM has worked closely with the larger space weather enterprise to complete these reports.

- Gaps:
  None identified.

Objective III: Establish Plans and Procedures for Responding to and Recovering from Space Weather Events

The ability to rapidly respond to and recover from extreme space weather events requires coordinated efforts and established plans and procedures. Conducting exercises to test and validate these plans and strategies can allow relevant stakeholders to practice and refine them. An improved understanding of critical system and asset vulnerabilities to the effects of space weather (Objective I), and a robust forecasting capability that can enable more timely and accurate services and products (Objective II) are important to inform Federal, State, local governments', private sector and others' efforts, capabilities, and investments in managing space weather events.

3.1 Develop, review, and update Federal response plans, programs, and procedures to address the effects of space weather.

- Progress:
  Executive Order (EO) 13744 requires the creation of the *Federal Operating Concept for Impending Space Weather Events* (CONOPS) which is designed to coordinate Federal assets and activities to respond to notification of, and protect against, impending space weather events. EO 13865 directs the Department of Homeland Security (DHS) to review and update Federal response plans, programs, and procedures to account for the effects of an electromagnetic pulse. EO 13865 also orders agencies that support National Essential Functions to update operational plans documenting their procedures and responsibilities to prepare for, protect against, and mitigate the effects of space weather.

  The CONOPS was released in May 2019. The CONOPS outlines the necessary actions departments and agencies should take to prepare for, and respond to, a notification of an impending space weather event. It provides guidance to departments and agencies to be used in the development of their operational plans to prepare for, protect against, and mitigate the effects of impending space weather events. In July 2019, the Federal Emergency Management Agency (FEMA) released the National Threat and Hazard Identification and Risk Assessment. Space weather was included as one of the threats and hazards of concern with the potential for nationwide effects. Many Federal departments and agencies have integrated space weather products into their preparedness strategies and procedures to enable a coordinated response to space weather events. Going forward, it is expected that Federal hazard preparedness plans and programs will include space weather events and their potential effects.

  This objective also includes developing a space-weather event-specific protocol for the notification and situational awareness reports of space weather information during an extreme space-weather event. A communications plan is being developed that will incorporate roles of the various Federal agencies during a major space weather event.

- Gaps:
  None identified.

3.2 Develop and disseminate products and information on the effects of space weather that support coordinated response and recovery efforts.

- Progress:
  This action focuses largely on two areas: development of training materials to familiarize scientific, national security, and emergency management professionals with the role and execution of emergency management protocols for space-weather events, and sustaining U.S. participation in relevant international space-weather initiatives, including participation in United Nations (UN) activities.

  In September 2022, the FEMA Emergency Management Institute introduced the *Preparing the Nation for Space Weather Events Independent Study* course. This course is designed for emergency managers and provides an introduction to space weather events, the potential consequences from those events, and the roles of the Federal Government as well as the local and jurisdictional Emergency Manager in preparing for and mitigating risks. Space Weather tutorials have also been included in emergency management conferences such as the International Association of Emergency Managers Conference. NOAA and DHS representatives have partnered to provide presentations on space weather to the emergency response community at several levels, e.g. Regional Emergency Communications Coordination Working Groups, County Offices of Emergency Management, and NWS Warning Coordination Meteorologist meetings.

  Representatives from various Federal agencies are engaged in multiple international space-weather initiatives including the UN International Civil Aviation Organization, the UN World Meteorological Organization, the UN Committee on the Peaceful Uses of Outer Space, and North Atlantic Treaty Organization. There are no apparent gaps in U.S Federal government representation and leadership at these intergovernmental organizations.

- Gaps:
  None identified.

3.3 Facilitate information sharing to inform and enhance the operation and restoration of critical infrastructure at greatest risk to the effects of space weather.

- Progress:
  This action largely focuses on procedures for accessing and using space-weather forecast and impact assessment modeling tools (directed in action 1.3), to inform response and recovery operational decision-making.

  In general, risk assessment modeling tools that characterize and quantify space weather impacts on critical infrastructure (CI) are limited in scope and availability. Risk models designed to improve grid resilience are perhaps the most advanced models in support of CI, with a number of innovative modeling tools that help electric utilities determine the effect a geomagnetic storm may have on the grid. Effects modeling is still needed for many other areas, e.g. the potential effects to airspace caused by space weather, and the likely effects of an extreme geomagnetic storm and its consequence to satellites in lower Earth orbit. In addition, modeling and simulation of interdependencies across CI systems during space weather storms is still needed.

- Gaps:
  Efforts to create a satellite-anomaly attribution information system also fall under this action. A space weather satellite anomaly database would enable the space weather community to analyze the effects of space weather on satellite systems, to improve tools for modeling space weather effects, spacecraft design robustness and improve the support of the spacecraft operations community with space weather warnings and better post-event anomaly analysis. Minimal progress was made in this area largely because of the concerns of proprietary information from satellite owners. An international effort is still underway in the Coordination Group for Meteorological Satellites (an international group of government entities that coordinates meteorological satellite systems globally).

3.4 Assess executive and statutory authority regarding the ability to direct, suspend, or control critical infrastructure operations, functions, and services before, during, and after space weather events.

- Progress:
  Also required by EO 13744, Section 5(b). Appendix D: *Executive and Statutory Authority*, in the FEMA *Federal Operating Concept for Impending Space Weather Events* provides a summary of executive and statutory authority and limits of that authority to direct, suspend, or control Critical Infrastructure operations; functions and services before, during, and after a space weather event.

- Gaps:
  None identified.

3.5 Exercise Federal response, recovery, and operations plans and procedures for space weather events.

- Progress:
  Exercises test, assess and improve the nation's preparedness for and resiliency to space weather events. Exercises focused on space weather effects are being held at Federal, state and local levels. The National Security Council conducted Senior Officials Exercises (SOE) at the White House in April 2018 (SOE 18-4) and March 2022 (SOE 22-1). The exercises focused on determination of a grid security emergency (SOE 18-4), the FEMA CONOPS (SOE 22-1), and actions that the US government would take in preparation for and during a major space weather event. Exercises were also conducted at regional level, e.g., FEMA Region 8 (MT, ND, SD, WY, UT, CO) in Nov 2019. State-wide tabletop exercises on space weather were conducted by State Departments of Homeland Security in Florida and Indiana. Locally, space weather exercises were conducted in cities and counties in Texas, Maryland, California, and Indiana.

- Gaps:
  These exercises have served to enhance awareness and improve preparedness for space weather, but much still needs to happen, especially at state and local levels to ensure risks associated with space weather are well understood and addressed.