Improving U.S. Space Weather Capabilities

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Space weather is a natural threat to critical infrastructure in space and on Earth, and it affects the sustainable use of space. Executive branch efforts during the Obama and the first Trump administrations sought to better organize and task space weather-related federal entities to prepare and protect against disruptive space weather phenomena by augmenting research and operational forecasting capabilities, as well as establishing plans for response and recovery. These efforts have resulted in concrete suggestions by the Space Weather Advisory Group. To ensure continued advancement in anticipating and mitigating dangerous space weather effects, key legislation should be passed, executive branch collaboration should be continued, and nascent commercial space weather efforts should be supported.

Background

During the Sun's roughly 11-year sunspot cycle, activity ebbs and flows as the solar magnetic field changes orientation from north to south, or vice versa; 2020 marked the beginning of a new cycle as the Sun came out of a period of low activity, or a solar minimum. Since then, the activity has been building up to the next solar maximum in July 2025. Minimum and maximum differ by activity and are measured in numbers of sunspots and other active regions on the surface of the visible Sun. Sunspots are areas of high magnetic activity where the Sun's magnetic field lines become entangled and give rise to solar flares and coronal mass ejections (CMEs) when these tangled magnetic fields explosively realign. A CME is an immense cloud of charged particles hurled into space from the surface of the sun in a particular direction, sometimes toward Earth. When a CME arrives at Earth, it can produce a geomagnetic storm that can cause anomalies and disruptions to satellites, paralyze power grids on the ground, and confuse GPS equipment.

Additionally, solar activity expands and contracts the Earth's atmosphere during the solar cycle. The outer layers of the atmosphere interact with satellites to increase or decrease drag, which shortens orbital lifetimes but also throws off orbital propagation models used for predicting the future location of objects—both of which affect space situational awareness

Federal Efforts

Different entities within the U.S. government have been studying space weather for over 75 years. Well-documented incidents of extreme space weather during World War II, the Vietnam War,[1] and the Cold War[2] drew the attention of the military more broadly, as these events increased geopolitical tensions. Civil government research into space weather phenomena was spread across multiple executive branch agencies studying different portions of the Earth-Sun interactions. This bifurcated military/civil approach, compounded by further branching on the civil side, has prevented a whole-of-government approach for better understanding and mitigating the risks of extreme space weather.

Following roughly 20 years of on-again, off-again intragovernmental coordination,[3] the current version of executive branch space weather activities was solidified in 2015 with the Obama administration's *Space Weather Strategy and Action Plan*.[4] The Strategy and Action Plan laid out the structure and vision for the Space Weather Operations, Research, and Mitigation (SWORM) Task Force within the National Science and Technology Council. Including principals from multiple departments, agencies, and the Executive Office of the President, the SWORM laid out high-level strategic goals and plans to achieve them. The Trump administration maintained relative continuity and, in fact, updated the Strategy and Action Plan in March 2019.

The strategies were revisited and realigned across three overarching objectives:

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.*

Between 2017 and 2020, different versions of authorizing legislation related to government space weather activities have been introduced to the 115th and 116th Congresses.[5] These bipartisan bills were reconciled across chambers in the 116th Congress, and the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow Act (PROSWIFT Act) was passed by both chambers and signed into law in October 2020. The PROSWIFT Act largely codified the work of the SWORM Act into authorizing legislation and suggested some additional specific appropriations. These efforts ensure that the executive branch agencies continue to collaborate to address space weather research and preparedness while maintaining continuity. Since then, Congressional appropriations have partially supported the maintenance and modernization of satellites used for space-weather forecasting. In addition, the Infrastructure Investment and Jobs Act provided authorizations and appropriations that could be used to support space weather resilience, among many other purposes.

1 Knipp et al., "On the Little-Known Consequences of the 4 August 1972 Ultra-Fast Coronal Mass Ejecta: Facts, Commentary, and Call to Action", *Space Weather Journal*, AGU, 2018.

2 Knipp et al., "The May 1967 great storm and radio disruption event: Extreme space weather and extraordinary responses", *Space Weather Journal*, AGU, 2016.

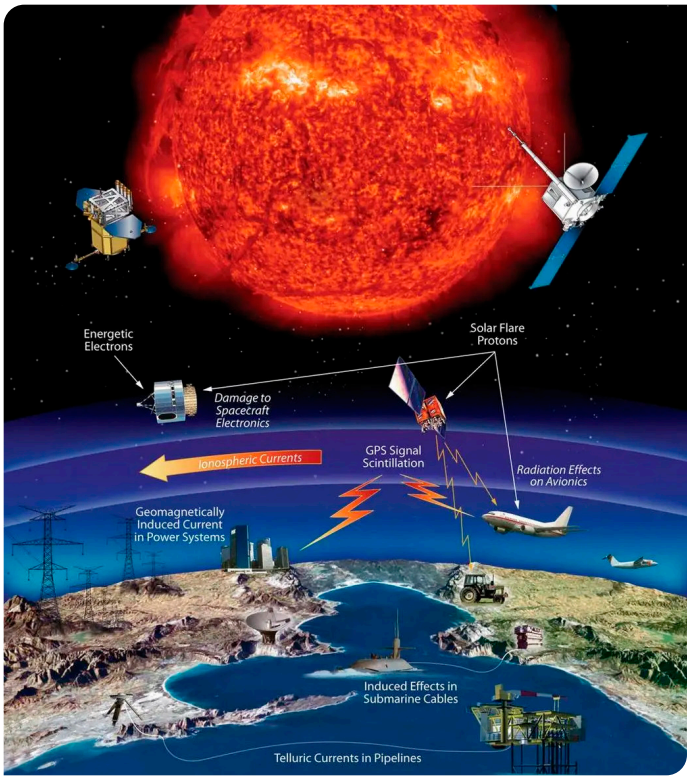
3 Bonadonna, Lanzerotti, & Stailey, "The National Space Weather Program: Two decades of interagency partnerships and accomplishments", *Space Weather Journal* , AGU, 2016.

4 Executive Office of the President of the United States, *National Space Weather Strategy and Action Plan* (Washington, DC: Executive Office of the President, March 2019), https://trumpwhitehouse.archives.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf.

5 H.R. 5260, PROSWIFT Act; S.881, Space Weather Research and Forecasting Act, 2020.

In December 2023, the White House Office of Science and Technology Policy (OSTP) released the Implementation Plan of the National Space Weather Strategy and Action Plan, which incorporated Congressional action under the PROSWIFT Act and seeks to serve as a roadmap for coordinated interagency efforts. It aims to enhance U.S. preparedness for and mitigation of space weather events by improving forecasting capabilities, protecting critical infrastructure, and coordinating across government agencies and the private sector.

Under the auspices of the PROSWIFT Act, the National Oceanic and Atmospheric Administration (NOAA), working with SWORM, established the Space Weather Advisory Group (SWAG). This group was tasked with providing recommendations for implementing the PROSWIFT Act and transforming the National Space Weather Enterprise (released April 2023) and with conducting a comprehensive user survey (released in September 2024).



Current Policy and Gaps or Shortcomings

The entities of the U.S. government that are focused on space weather are headed in the right direction. However, there is a danger that these gains could be shortlived; furthermore, there are emerging areas that require additional action. For instance, space weather research is a key challenge to the government-led human space exploration agenda, as dangerous levels of radiation remain a challenge for long-duration crewed space missions on the Moon, Mars, or en route to either. For instance, in between Apollo 16 and 17, a radiation storm struck the Earth-Moon system that would have killed any astronaut outside of the Earth's magnetic field. Today, private recreational spaceflight, from companies like Virgin Galactic, Blue Origin, and SpaceX, also face the radiation challenge; however, in this case, it would not just affect government workers but also private citizens. Outside of the human-related challenges, space situational awareness (SSA), which refers to the tracking and cataloging of space objects orbiting Earth, relies heavily on space weather models that are needed to make accurate predictions of orbital motion in near-Earth orbits, which is essential for space traffic coordination. As the low Earth orbit (LEO) satellite population balloons in the coming years, better SSA will require much more precise understanding and forecasting capabilities from the space weather community.

Some of these priorities include long-term support for continuity of critical operational observations, the development of new observations, and fundamental science necessary to advance space weather research. These need to be linked through a functional and funded research-to-operations process. ●

Figure 04 | Technological infrastructure affected by space weather events include satellites, aircraft, and power grids. A web of inter-dependencies makes the modern economy especially sensitive to solar storms. This is why advancing the understanding of the causes of space weather and improving its forecasting are critical goals. *Credit: NASA*

Policy Recommendations

→ Maintain whole-of-government focus across administrations and with support from Congress.

When the space weather-focused agencies of the executive branch work in tandem with the authorizing and appropriating committees in Congress, it can result in more effective policy. For consistency across presidential administrations and continuity of purpose for missions, the implementation of PROSWIFT Act and the accompanying recommendations made by the SWAG should guide the executive agencies. This includes ensuring adequate funding is made available for implementation.

→ Ensure continued data collection sources through the protection of space-, ground-, and air-based sensors.

The United States' solar observing satellites and other space weather observation infrastructure are aging, and unexpected failures could lead to gaps in data collection. As we go further into Solar Cycle 25, the erosion of capabilities across the solar observation fleet will only increase. In order to maintain data collection to advance monitoring and forecasting of extreme space weather, a pipeline of new space- and ground-based observing systems must be initiated.

→ Work with international partners to augment observations and research.

Similar to capacity in space exploration and R&D budgets, the United States spends the largest amount of money on space weather-focused science across the world. Yet, regional monitoring and capacity are necessary to better understand and mitigate the effects of space weather on localities around the world, ultimately also protecting U.S. assets and interests. U.S. leadership in these efforts can build global capacity and can work to augment capabilities rather than duplicate efforts.

→ Support the development of commercial space weather services.

Satellite companies, hardware manufacturers, researchers with operational concepts, and others are in the nascent stages of developing a commercial space weather enterprise. A delineation of what information and baselines the U.S. government will provide will go a long way to providing a stable innovation space for companies, while ensuring that commercial products meet the needs of U.S. space weather priorities.