Brief History of Federal Involvement in Space Weather Forecasting[1]

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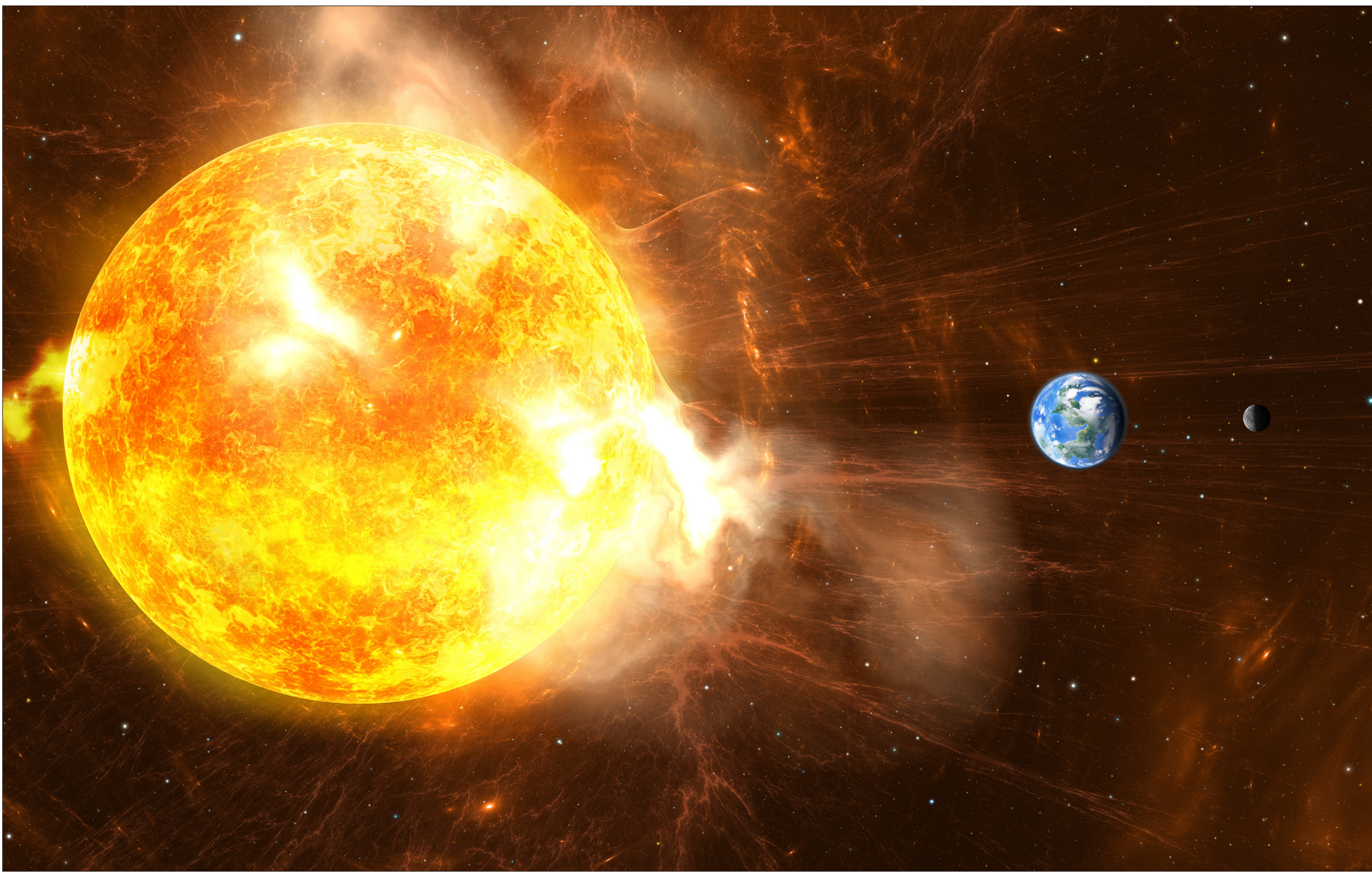
Space weather has the potential to adversely affect systems and technologies critical to public health and safety and poses a significant risk to national security. As a result, the federal government has taken efforts to prepare for and mitigate the effects of space weather events. Over the past decade, there has been an increase in federal activities to improve the nation's resilience to the hazards of space weather and to prepare for future space weather events. However, federal involvement in space weather policy and forecasting dates back much further. This paper provides an overview of the history of federal involvement in space weather forecasting from the early space weather-related research and forecasting conducted between World Wars I and II, through the Cold War and the Space Race, to the present.



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Understanding the Ionosphere

The early decades of the 1900s were marked by efforts to understand the ionosphere and its effects on new technologies and to develop and expand ionospheric forecasting capabilities. These efforts were spurred by the discovery and expansion of high-frequency radio wave propagation for long-distance communications and the growth of commercial aviation.

In 1902, scientists Arthur Kennelly and Oliver Heaviside independently published articles suggesting that an ionized upper region in the atmosphere existed that reflected radio waves (Kennelly 1902, 473; Heaviside 1902, 215; Kirby et al. 1934, 16). This layer would become known as the Kennelly-Heaviside layer, but it took over two more decades before direct experimentation confirmed its existence. In 1925, physicist Edward Appleton and his student Miles Barnett proved the existence of the ionosphere through a series of experiments (Appleton and Barnett 1925, 333). This evidence, combined with independent observations made by American physicists Gregory Breit and Merle Tuve, showed for the first time that radio waves could be reflected reliably from the ionized portion of the atmosphere (Breit and Tuve 1925, 357; Appleton and Barnett 1925, 333). The discovery of the ionosphere and the growing use of long-range wireless communication prompted researchers to explore further the connection between the Sun and interruptions in radio transmissions.

In the fall of 1935, a series of severe solar, ionospheric, and magnetic events coincided with radio fade-outs and transmission disruptions. John Dellinger, who would later become chief of the U.S. Department of Commerce National Bureau of Standards (NBS) Radio Section, mapped the reported occurrences of radio fade-outs and their duration to the associated phenomena (Dellinger 1935, 351). He later noted that the increased ionization was caused "by electromagnetic waves from a solar eruption" (Dellinger 1937, 51). Through his observations and analysis, Dellinger determined the existence of a direct correlation between radio fade-outs and disruptions and disturbances on the Sun.

During the early twentieth century, radio communications and aviation advanced as complementary technologies. Aviators came to depend on radio for wireless communications, radar, and navigation, so it is unsurprising the NBS received its first request for information on disruptions to radio communications from the nascent commercial aviation industry (Snyder and Bragaw 1987, 231). A scientist at the NBS prepared a report addressing the issue and providing a recommendation to adjust the frequency to avoid disruptions (Gilliland 1934, 231). This response illustrated the NBS's expanding role of providing practical support to radio users and, in 1939, the Radio Section initiated a formal service for forecasting radio transmission information and maximum useable frequencies.

These predictions represent the first publicly available, federally developed space weather products and are one of several examples of the growing number of products and services that the NBS began to provide to users (Gilliland et al. 1939, 227). The activities undertaken to understand the ionosphere and its impact on radio wave propagation in the early 1900s, together with the development of services to communicate the effects of ionospheric disruptions, provided a foundation for subsequent federal space weather research in both the civilian and defense sectors.

World War II and Postwar Years

Given the wide usage of radio in wireless communications and navigation, predicting potential ionospheric disruptions and ensuring continuity of these services became critical to the war effort. In 1942, the United States established the Interservice Radio Propagation Laboratory (IRPL) at the Radio Section of the NBS. The functions of the IRPL were to "centralize data on radio propagation and related effects, from all available sources; keep continuous world-wide records of ionosphere characteristics and related solar, geophysical, and cosmic data; and prepare the resulting information and furnish it to the Allied Military Services" (Gladden 1959, 16). By 1942, the IRPL provided Allied armed forces around the globe with predictions of useful radio frequencies for transmission (Cochrane 1966, 405).

In 1943, the IRPL published the "IRPL Radio Propagation Handbook," which described the behavior of the ionosphere and the theory behind lowest and maximum useful frequencies. In addition, the Handbook described the products, forecasts, and warnings provided by IRPL (Cochrane 1966, 404). After the war ended, the federal government recognized the need to continue centralized radio propagation and radio standards and services due to the expanding use of telecommunications among both civilians and the military. In 1946, the Central Radio Propagation Laboratory replaced the IRPL and assumed responsibility for radio propagation research and prediction at the NBS (Gladden 1959, 25). The laboratory continued to expand on the research of its predecessor, specifically by improving the understanding of solar disturbances and how to predict them.

On the military side, the U.S. Air Force (USAF), established in 1947, assumed the responsibility of weather reporting and forecasting for both the USAF and the Army (Nolan and Murphy 2000, 3). The USAF carried out this responsibility through its Air Weather Service. The Air Force Cambridge Research Laboratories (a predecessor to today's Air Force Research Laboratory) was established to continue building on advancements made during World War II including conducting research to improve ionospheric data and forecasting in support of military customers and operations. The USAF established the Sacramento Peak Observatory in New Mexico, operated by the Air Force Cambridge Research Laboratories, which enabled better imaging and analysis of the Sun. The research conducted there would later inform solar observations and forecasting efforts conducted during the Cold War.

The postwar years also saw a growing emphasis on international cooperation, particularly in areas of science. The International Geophysical Year is an important example of such cooperation, and the United States made significant contributions toward its success, particularly for the Third International Geophysical Year, in which the United States provided financial contributions and logistical support (Bullis 1973). Though international cooperation on scientific issues was gaining momentum, it was also strained by growing political tensions between the United States and the Soviet Union.

Cold War and Space Race

Continued federal investment in efforts to improve the understanding of and prediction capabilities for space weather events can make the United States not only better prepared for such hazards, but also better able to mitigate their effects.

The outbreak of the Cold War and the subsequent Space Race spurred U.S. federal investment and interagency cooperation in efforts to explore the space environment. In October 1957, the Soviet Union launched Sputnik. The United States followed with the launch of Explorer I in January 1958. Explorer I led to the development and refinement of research instrumentation, while data gathered from subsequent launches, primarily from Explorer III, led to the discovery of the Van Allen belts, solar radiation, and the magnetosphere (Newell 2010). The discovery of the Van Allen belts and the knowledge of solar radiation and its potential impacts proved critical to the newly established National Aeronautics and Space Administration (NASA) and its manned spaceflight program.

The United States succeeded in its mission to send the first human to the Moon in July 1969 with its Apollo program. Supporting this mission with critical space weather information was the Space Disturbances Laboratory (SDL). The SDL was responsible for operating the Space Disturbances Forecasting Center, which provided space weather forecasting, warnings, and alerts for manned space missions. The SDL also had several research programs aimed at better understanding the space environment and its impacts. These programs included studies of solar energetic particles, the magnetosphere, disturbed ionosphere, and solar physics (Olson 1969, 241).

U.S.-Soviet tensions nearly resulted in armed conflict when space weather storms in May 1967 significantly affected military and civilian operations. As a result, the USAF Air Weather Service was tasked with establishing an operational space weather capability (Knipp et al. 2016, 614; Townsend et al. 1982). The Space Environmental Support System (SESS) was conceived to support operations in space and to develop an operational network of solar optical telescopes to monitor the Sun (Townsend et al. 1982). The SESS and its capabilities continued to evolve as the Department of Defense increasingly came to rely on the USAF for information on the space environment and space assets.

Following successes of both manned and unmanned space exploration missions, the federal government continued to expand its space weather observation and forecasting capabilities. For example, NASA funded a series of ground-based solar observatories, collectively referred to as the Solar Particle Alert Network (SPAN), to support space weather monitoring during the Apollo missions (Reid 1971, 367). The SPAN, established in 1965, consisted of seven solar observatories located around the world that gave 24-hour coverage of solar activity at optical and radio frequencies, providing a near-continuous stream of solar data to better understand and forecast space weather (Robbins and Reid 1969, 502; (Hill et al. 2013, 392).

Federal departments and agencies also sought to develop new and enhanced scientific instruments and better satellite payloads in support of improved solar observational capabilities. For example the Geostationary Operational Environmental Satellite (GOES) program, a joint effort launched in 1975 between NASA and National Oceanic and Atmospheric Administration (NOAA), carries crucial space environment instruments that have been critical to obtaining valuable measurements of solar protons, electrons, and X-rays. The data collected by GOES continue to serve as a resource for space weather forecasters. The technological advancements made during and immediately after the Cold War served as a foundation for future innovation and exploration in the space environment.

Recent History

In the decades since the Cold War to the present, the federal government has funded, led, or supported myriad efforts and activities to improve space weather observation and forecasting capabilities. It has also sought to improve interagency, and international, collaboration and to enhance federal space weather forecasting services to address the hazard of space weather.

In 2014, the National Science and Technology Council established the Space Weather Operations, Research, and Mitigations (SWORM) Task Force, bringing together agencies focused on science and technology with those focused on homeland and national security to produce the National Space Weather Strategy and the National Space Weather Action Plan (Jonas and McCarron 2016, 54). The 2015 National Space Weather Strategy and the National Space Weather Action Plan documents articulate how the federal government will work to enhance national preparedness for space weather events and identifies high-level goals and nearly 100 specific activities in support of these broader goals. These goals include establishing benchmarks for space weather events; improving assessment, modeling, and prediction of impacts on critical infrastructure; and improving space weather services through advances in understanding and forecasting.

Pursuant to Executive Order 13744, "Coordinating Efforts to Prepare the Nation for Space Weather Events," the SWORM Task Force became a permanent subcommittee of the National Science and Technology Council, serving as the interagency coordination body for space weather across the federal government. The Executive Order builds on the significant progress represented by the National Space Weather Strategy and National Space Weather Action Plan and further establishes the commitment of the federal government to prepare for space weather events.

Conclusion

The evolving threat of space weather to the interconnected electric power grid, satellites in orbit, public health and safety systems, and other critical infrastructure continues to drive federal action and cooperation in space weather forecasting. Continued federal investment in efforts to improve the understanding of and prediction capabilities for space weather events can make the United States not only better prepared for such hazards, but also better able to mitigate their effects. Increasing reliance on technology for the provision of essential services, economic vitality, and social well-being will likely be primary drivers for continued federal involvement in forecasting space weather events.

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