



## FEATURE ARTICLE

10.1002/2016SW001523

## Special Section:

Reprise of 2001 Space Weather Monograph

## Citation:

Bonadonna, M., L. Lanzerotti, and J. Stailey (2016), The National Space Weather Program: Two decades of interagency partnership and accomplishments, *Space Weather*, 15, doi:10.1002/2016SW001523.

Accepted article online 24 NOV 2016

## The National Space Weather Program: Two decades of interagency partnership and accomplishments

Michael Bonadonna , Louis Lanzerotti , and Judson Stailey

**Abstract** This paper describes the development of the United States National Space Weather Program (NSWP) from early interests in space environmental phenomena and their impact through the culmination of the program in 2015. Over its 21 year run, the NSWP facilitated substantial improvements in the capabilities of Federal Space Weather services and fostered broad and enduring partnerships with industry and the academic community within the U.S. and internationally. Under the management of the Office of the Federal Coordinator for Meteorological Services and Supporting Research a coalition of 10 federal agencies worked together from 1994 to 2015 to advance the national space weather enterprise. The paper describes key events and accomplishments of the NSWP interagency partnership while recognizing the great achievements made by the individual agencies. In order to provide context, the paper also discusses several important events outside the NSWP purview. Some of these external events influenced the course of the NSWP, while others were encouraged by the NSWP partnership. Following the establishment of the Space Weather Operations, Research, and Mitigation Task Force of the National Science and Technology Council in the White House and the deactivation of the NSWP Council, the agencies now play a supporting role in the national effort as the federal engagement in the National Space Weather Partnership graduates to a higher level.

### Introduction

Since 1994, the National Space Weather Program (NSWP) has facilitated substantial improvements in the capabilities of United States Federal Space Weather services and research agencies. It has nurtured strong and mutually beneficial partnerships with industry and the academic community within the U.S. and around the world. This paper describes the NSWP from early interests in space environmental phenomena and their impact through the culmination of the program in 2015. Established under the management of the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) 10 federal agencies forged a strong partnership and have worked together to advance the national space weather enterprise.

One of the key objectives of the NSWP was to integrate and coordinate activities nationally and globally. In many cases, activities described in this paper were “inspired” by the NSWP. The U.S. NSWP leadership helped focus worldwide attention on space weather and its potential impacts leading to advancement of the field, public awareness, readiness, and response.

This paper highlights the key milestones and accomplishments reached through the NSWP interagency partnership, focusing on activities enabled by the program rather than the achievements of the individual partner agencies. In order to provide context, we also discuss several important events outside the NSWP purview. Some of these external events influenced the course of the NSWP, while others were encouraged by the NSWP partnership. Figure 1 provides a useful guide through the chronology.

Through official documentation, this paper describes many of the historical events that led the U.S. government to understand the need for strong interagency coordination of its interests in space weather phenomena, research, services, and preparation for potential impacts. Following this, the paper discusses the key NSWP actions and external events covering the 21 year evolution of the program from its inception to its culmination.

Space weather effects on technologies date back to the midnineteenth century with one of the earliest electrical technologies—the electrical telegraph. The electrical telegraph was a great advance over the optical semaphores previously used for “long-distance” communications, whose effectiveness was limited to line of sight and subject to obstruction by weather. Weather did not seriously affect the electrical telegraph, although spontaneous signals in the recording galvanometers could be induced by lightning strikes close to the telegraph wires. Rather, it was the other and—unknown—“spontaneous currents” in the telegraph lines that caused galvanometer malfunctions and even fires that were of concern to the telegraph companies.

## National Space Weather Program Milestones

<u>External Factors</u>		<u>NSWP Internal Actions</u>
Space Weather induced Hydro-Quebec Power Outage 1989		
		FCMSSR Established NSWP 1994
	1995	1st Strategic Plan 1995
1st Space Weather Workshop in Boulder, CO 1996		1st Implementation Plan 1997
NSSA Space Weather Architecture 1999		CCMC Framework Established 1999
NASA Living With a Star Program Initiated 1999		
	2000	2nd Implementation Plan 2000
Decadal Survey 2002		NSF Funds CISM at Boston Univ. 2002
AGU Launches Space Weather Journal 2002		
1st Annual AMS Space Weather Symposium 2003		Assessment of NOAA SEC 2003
Halloween Space weather Storm 2003		
NOAA Converts SEC to Operational SWPC 2005	2005	
NSWP Independent Assessment 2006		1st Space Weather Enterprise Forum (SWEF) 2007
NRC Severe Space Weather Impacts Study 2008		NPOESS / ACE Impacts Report 2008
		LEO Mitigation Options Report (COSMIC-2) 2009
		L-1 Mitigation Options Report (DSCOVER) 2009
	2010	
NASA Authorization Act 2010		
GAO Report 10-456, 2010		
SDR Grand Challenge Space Weather I-plan 2010		2nd NSWP Strategic Plan 2010
Lloyds Report: Solar Storm Risk 2010		
ACSWA Formation 2011		SEGA Reports 2011 – 2013
Supported Nat'l Earth Observing Report 2012		National Space Weather Portal 2012
Decadal Survey 2013		Unified National Space Weather Capability MOU 2013
Near-miss Carrington Analog Storm 2014		
SWORM Task Force Established 2014		3d NSWP Implementation Plan (Draft) 2014
Supported SWORM 2015 +	2015	NSWP Council Deactivated 2015

**Figure 1.** Parallel space weather activities. There were a number of important activities influenced by and influencing the NSWP. This chart diagrams the timeline of the key milestones and influences. It is important to emphasize that the achievements of the NSWP encouraged and enabled substantial progress in the Space Weather Enterprise including federal government, national security, academia, industry, foreign, and international.

Careful observations of the occurrences of these anomalous currents by early telegraph engineers indicated that sightings of the aurora accompanied the anomalous currents, as was early reported by W. H. Barlow, the superintendent engineer for the Midland Railway Company in England. It took nearly a half century, approximately coincident with Marconi's achievement in 1901 of trans-Atlantic wireless telegraphy, to fully realize that solar occurrences could produce such earthly phenomena as aurora, and thus disturbances on an essential human technology like the telegraph. Of course, Marconi's long-distance wireless was only achievable because of the ionosphere, which could also be disrupted by solar-originating disturbances. Indeed, Marconi wrote that "... times of bad fading practically always coincide with the appearance of large sunspots and intense aurora borealis usually accompanied by magnetic storms ..." These are "... the same periods when cables and land lines experience difficulties or are thrown out of action."

Solar-produced disturbances of Earth's environment in the early twentieth century, especially and notably in 1921 and 1940, affected not only communications by wires and wireless but also the long conductors in electrical power systems in the U.S. Thus, considerable interest was devoted to better understanding and predicting "extraterrestrial" effects on important industrial commercial systems.

Governmental activity and interest in what is now called space weather phenomena was greatly stimulated by the needs of communications in World War II. The military depended on highly reliable wireless communications. And new technologies introduced in the war were subject to solar effects. The large solar radio burst events of 1942 caused the complete disruption of radar defenses over Britain—the first time that solar radio bursts had been recorded. In 1942 the National Bureau of Standards (predecessor to the National

Institute of Science and Technology) established the Inter-Service Radio Propagation Laboratory (IRPL) to support WWII radio communications. The post-WWII era, and the advent of the space age, witnessed ever-growing understanding of solar-terrestrial processes and their relationships to effects on the ever-expanding technologies potentially impacted by these processes.

The solar radio event of May 1967, recently revisited in detail by *Knipp et al.* [2016], was the cause of intense national security concerns at the time. Severe interferences with radar and communications occurred for an extended interval across the nation and at high latitudes where security infrastructures were installed. *Knipp et al.* relate the considerable increase in the civil and military interest and organization of monitoring and forecasting solar effects following the national security alerts that the solar event produced. In particular, these authors outline the development and growth of some of the U.S. Air Force organizational activities in space weather that had begun in 1948 by Professor Donald Menzel's establishment of Air Force solar observatories. The need to support studies of radio propagation and communication motivated these activities. Following WWII, The North Atlantic Treaty Organization sponsored many studies in this early space age era related to space weather effects and especially the effects on communications of disturbances of solar origin [e.g., *Gerson*, 1962; *Gassmann*, 1963].

The need to understand Earth's trapped radiation environment following Van Allen's discovery of 1957 with the Explorer 1 satellite stimulated considerable interests in space weather monitoring and forecasting by other civil governmental agencies. This radiation could deleteriously affect both people and technologies placed into space, a concern as the U.S. ramped up its human flight program beginning with John Glenn's 1962 orbit of Earth (following the 1961 orbit of Yuri Gagarin). Solar particle radiation could seriously affect human flight outside Earth's magnetosphere, missions which would occur during the Apollo lunar program. Numerous robotic National Aeronautics and Space Administration (NASA) spacecraft were flown in the 1960s with instruments to understand not only the science of interplanetary space but also to better understand the radiation environment that would be experienced by Apollo astronauts. Fortuitously, the largest event of solar cycle 20 (with huge intensities of high-energy charged particles) occurred in August 1972, between the April 1972 and December 1972 Apollo 16 and 17 flights, respectively, so humans were not exposed.

At request of NASA in the late 1970s, the National Academies convened a committee, chaired by Dr. Stirling Colgate, to examine the role of solar and space physics in the nation's space research program. The 1979 Committee report *Space Plasma Physics* contained a short section ([http://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb\\_088218.pdf](http://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb_088218.pdf)) titled "Relevance of Solar-System Plasma Physics to Technology and Society." The panel materials that supported the discussions and conclusions of the Colgate Committee contained lengthier supporting materials related to the effects of solar and space physics processes on technologies and society. This was one of the first, if not the first, national report to bring together the importance and relevance to human concerns of what is now called space weather.

By the late 1970s, OFCM had established the Committee for Space Environmental Forecasting (CSEF) and produced a comprehensive analysis of the current state of space environmental services that existed at that time. In 1982, prompted by a substantial reduction in funds for space environment services in the National Oceanic and Atmospheric Administration (NOAA) budget, representatives from NOAA's Space Environment Laboratory (SEL) briefed a special meeting of the CSEF (which had not met in the six prior years). The SEL representatives recommended that OFCM develop a new federal plan for Space Environmental Services and Supporting Research. The Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR) approved this recommendation in July 1982 and published the plan in 1983. The CSEF updated the plan in 1988 and 1993 [*Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM)*, 1982a, 1982b].

In subsequent years, federal agencies supported the Solar Terrestrial Task Group (under the White House Federal Coordinating Council for Science, Engineering, and Technology's Committee for Atmospheres and Oceans). However, the federal government did not implement a recommendation by the task group that would have established a national program of research and services for space weather coordinated by the Office of Science and Technology Policy (OSTP) in the Executive Office of the President (EOP) [*OFCM*, 1982a, 1982b].

*Poppe* [2006] interestingly relates much detail of the historical developments of government interest and action in space weather, its predictions and forecasts, and the development and evolution of the current NOAA Space Weather Prediction Center (SWPC) from its earliest days. SWPC is a direct descendant of the Environmental Science Services Administration's Space Disturbance Laboratory, created in 1965 from the

National Bureau of Standards Central Radio Propagation Laboratory (CRPL). The CRPL itself replaced the IRPL in 1946 [Little, 1991].

The evolution of the close relationship that developed was built and exists today between the civilian SWPC and the United States Air Force, and its weather arm is also recounted by Poppe [2006]. Governmental civil interest and fiscal support were not always robust. At times, confusing organizational leadership and priorities (for example, studying Jupiter's magnetosphere) and serious budget challenges (such as in 1982 as noted above) occurred [Poppe, 2006]. It was frequently necessary to provide affirming interventions as to the importance of space environmental data and forecasts to Washington lawmakers by nongovernmental users of the data and forecasts of SWPC and its predecessors.

In March 1989, a coronal mass ejection produced a geomagnetic storm that created geomagnetically induced currents coupling into the electrical power distribution system in Quebec, Canada. Electrical power failed throughout Quebec, with large regional impacts elsewhere such as the failure of a large power transformer at the Salem nuclear power station in New Jersey. The March 1989 event demonstrated that space weather could have widespread significant impacts on the public and not just on a local city or specific aspects of communications or space operations. This event elevated space weather to a potential source of a substantial widespread disaster. As such, the need for the U.S. government to address space weather in a more robust and coordinated manner became clear. Ultimately, the 1994 formation of the National Space Weather Program (NSWP) finally began to bring the importance of space weather to the wide range of national interests—civilian and national security [Robinson and Behnke, 2001].

## Beginnings of the National Space Weather Program

### The First Decade: 1994–2004

In the early 1990s, NOAA's Space Environment Center and the Air Force's 50th Weather Squadron were providing operational space weather support services. The CSEF provided formal federal coordination to support their bilateral partnership. These providers were involved in meetings and workshops with commercial and research communities addressing potential space weather impacts.

As early as 1991, meetings conducted by the federal agencies engaged in space weather-related research (National Science Foundation (NSF) and NASA) strongly supported improving interagency coordination through the formation of a national space weather program [Robinson and Behnke, 2001]. The ICMSR established the Working Group for the National Space Weather Program (WG/NSWP) in 1994 under the CSEF to implement this initiative at the federal level [OFCM, 1994]. This led to the agreement by the highest coordinating body of the Federal Weather Enterprise, the Federal Committee for Meteorological Services and Supporting Research (FCMSSR), to establish a Program Council to guide the NSWP. The initial participants were the Department of Commerce (NOAA), the Department of Defense (DOD) United States Air Force (USAF) and Navy, the Department of the Interior United States Geological Survey (USGS), the National Science Foundation (NSF), and NASA. In the years that followed, interest in space weather grew, and the Federal Aviation Administration (FAA), Department of Energy (DOE), Federal Emergency Management Agency (FEMA), and Executive Office of the President (EOP) joined the NSWP.

The first task taken on by the WG/NSWP was to generate a strategic plan, which was published in August 1995 [OFCM, 1995a, 1995b]. This was followed by the publication of a NSWP Implementation Plan in January 1997 [OFCM, 1997] and the reformation of CSEF into the Committee for Space Weather (CSW) to support the NSWP Council.

With the NSWP firmly established, the member agencies focused their attention on the urgent issue of organizing ongoing space weather model development and operational transition activities. The federal partners began developing concepts for leveraging model development efforts in the academic community and providing a bridge for operational implementation. Following a recommendation from the CSW, the NSWP Program Council endorsed the establishment of the Community Coordinated Modeling Center (CCMC) [OFCM, 1999]. Since its inception in 1999, the CCMC has become the preeminent facility for the heliophysics community to develop, test, and prepare space weather models for operational use.

The NSWP updated its Implementation Plan in July 2000 [OFCM, 2000] to address space weather initiatives that the program had not considered or had moved forward since the original version published in 1997.

These initiatives included NASA's Living with a Star Program (FCM P31-2000, Appendix B), the National Security Space Architect's Space Weather Architecture Study (FCM P31-2000, Appendix C), and the CCMC [Robinson and Behnke, 2001].

In 2002, the National Research Council published the first decadal survey of solar and space physics at the request of NASA, NSF, NOAA, and the Air Force Office of Scientific Research. The report, *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics* (<http://www.nap.edu/catalog/10477/the-sun-to-the-earth-and-beyond-a-decadal-research>), addressed applications and policy implications of space weather issues in considerably more detail than in the 1979 Colgate report. The 2002 decadal survey report represented only the second time that the research community had addressed in a National Academies document the relevance of solar and space physics research illustrating the growing recognition of the importance of space weather and its potential impacts [NRC, 2003].

Following discussions among the NSWP partners in the science, research, and application communities working to advance heliophysics and space weather understanding, the NSF supported a proposal from the American Geophysical Union to establish a dedicated journal for space weather. This proposal was consistent with needs identified by the NSWP for better communication among the many scientific, engineering, operational, and application disciplines involved in space weather efforts. The AGU council formally approved the launch of *Space Weather: The International Journal of Research and Applications* in 2002 [Robinson, 2003].

As a result of an intense proposal competition across all NSF-funded disciplines, the Center for Integrated Space Weather Modeling was established under its Science and Technology Center Class of 2002. Managed by Boston University but engaging several other universities as well as the National Center for Atmospheric Research and industry, the center pursued the following goals: introducing Sun-to-Earth community models into space physics, introducing physics-based numerical models into space weather operational prediction and forecasting, and imbuing the notion that Sun-Earth science is a single unified discipline (<http://www.bu.edu/cism/index.html>). The center functioned for over 10 years with a total budget of over \$38 million. Together with the CCMC in 1999, the Federal Space Weather agencies were sowing the seeds for the education of future space service providers and related research scientists.

As the peak of solar cycle 23 crested and the public interest in space weather rose, the apparent similarities between "space weather" and "weather" began to be recognized in the meteorological community. Often broadcast (TV and radio) meteorologists were being asked to address space weather events. Space weather as a broadly accepted concept in the environmental observing and forecasting enterprise received a boost in early 2003 when the American Meteorological Society hosted its initial Space Weather Symposium at its annual meeting. The success of the symposium led to the establishment of the first American Meteorological Society (AMS) Space Weather Conference the following year, with change in nomenclature from "symposium" to "conference" signaling the establishment of routine annual meetings. The AMS has conducted 13 Space Weather Conferences to date. AMS has gone on to establish a standing Space Weather Committee under the Scientific and Technical Activities Commission, designating space weather as an accepted discipline within the society [Fisher and McCoy, 2011]. In 2009 and 2013, this committee developed policy statements on space weather to provide recommendations to the federal government, industry, and academia. CSW members had frequently discussed the concept of AMS engagement in space weather. This advocacy helped secure both AMS and NSWP Council support to implement AMS space weather initiatives.

In 2003, the NSWP responded to congressional budget pressure by assessing the importance of the NOAA Space Environment Center (SEC) to the nation. The council encouraged the chair of the Federal Committee for Meteorological Services and Supporting Research (FCMSSR), NOAA Administrator Vice Admiral (Ret.) Conrad Lautenbacher to send its assessment report to the President's Science Advisor and OSTP Director, Dr. John Marburger [OFCM, 2003]. Dr. Marburger concurred with the concerns expressed by the NSWP and conveyed those concerns to congress [OSTP, 2003].

In the midst of this process, a subcommittee of the House Committee on Science conducted a hearing on 30 October 2003, addressing space weather and responsibilities for forecasting it. The draft legislation at the time zeroed out funding for the SEC and suggested that the Air Force or NASA (funded through other bills) could assume SEC's responsibilities. Senior leaders from the SEC; the Air Force Weather Agency; NASA; and the power, airline, and communication industries testified at the hearing. The witnesses frequently cited the NSWP as evidence that the responsibilities for space weather research and operations had been carefully

coordinated and that SEC had an integral role to play in the enterprise. Because of this White House and congressional engagement by the NSWP, congress restored SEC funding.

Ironically, the 2003 Halloween Space Weather Storm occurred while the congressional subcommittee met to discuss the importance of space weather and of SEC's mission. The sun released a coronal mass ejection (CME) and an X4.5 flare. This event caused astronauts on the International Space Station to take shelter from increased radiation, ended the on-orbit life of a Japanese satellite, disrupted communications, degraded GPS performance, caused diversions in airline flights in polar regions, and forced electric utility operators to take measures to avoid damage to the grid.

The SEC's origins as the Space Environment Laboratory under NOAA's Office of Atmospheric and Oceanic Research (OAR) reflected the early thrust of NOAA involvement in space weather, which was the need to understand it better. The name change to Space Environment Center reflected the initial move toward an operational forecasting mission. NOAA acknowledged this shift through a "dotted line" relationship with the National Weather Service's National Centers for Environmental Prediction, while the SEC remained assigned to OAR. The SEC was operating on about \$7 million per year, of which only a part was focused on research. This represented a miniscule fraction of the combined \$1 billion Federal Space Weather research budget. In 2005, the decision was made to refocus the SEC mission on operational forecasting. The organization was reassigned to the National Weather Service, officially joined the ranks of the National Centers for Environmental Prediction (with the likes of the National Hurricane Center, the Storm Prediction Center, and others), and changed its name to the Space Weather Prediction Center (SWPC) [OFCM, 2013a, 2013b].

### **The Assessment and Beyond (2005–2010)**

In 2005, a decade after the start of the NSWP, the FCMSR requested the OFCM conduct a comprehensive review of the NSWP. The Federal Coordinator for Meteorology, Mr. Samuel Williamson, convened a committee of seven well-recognized commercial, academic, and government individuals with expertise encompassing the science and applications aspects of space weather.

The task statement for the committee encouraged it to explore all aspects of the NSWP. Mr. Williamson gave the committee complete freedom to set its agendas and schedules. The committee conducted detailed discussions at the OFCM with relevant entities and agencies. Additionally, the committee made site visits that included the NOAA SEC (now SWPC) in Boulder, the USGS in Denver, the Air Force Space Command in Colorado Springs, the Air Force Weather Agency in Omaha, the National Security Space Office in the Pentagon, the National Reconnaissance Office in Chantilly, and the Air Force Research Laboratory in Bedford.

As a result of their deliberations, the Assessment Committee concluded that the NSWP had a number of noteworthy achievements since its inception and that most of these would not likely have been attained without the program's existence. The committee also identified shortfalls in the program. Based upon its overall findings, the committee recommended continuation of the program. The committee wrote that the program had an enormous potential to enhance the nation's space weather mission over the next 10 years through improved operational capabilities, which would capitalize on the transition of innovative research. The committee noted that moving NOAA's operational space weather center (at that time the Space Environment Center) from its research organization to the National Weather Service (NWS) was a positive step to improve operational focus within the NSWP.

Upon receiving the report, the NSWP Council moved quickly to address and institute many of the recommendations and tracked the remaining items to their resolution. The Committee's Assessment Report [OFCM, 2006] had deep and long-lasting influence on the National Space Weather Program; civil and military user communities; the commercial space weather sector; and academia, foreign, and international space weather-related interests.

As the annual Space Weather Workshop (SWW) hosted by NOAA grew in popularity and influence, the sponsoring organizations (NOAA, DOD, NASA, and NSF) struggled with attracting attention of the Washington DC-based federal policymakers in the federal government and congress. In order to address this issue, NOAA leadership, consistent with advice in the 2006 Assessment Report, agreed to host an abbreviated forum of the SWW in the Washington DC area [Murtagh, 2007].

The first Space Weather Enterprise Forum (SWEF) took place over 2 days in Washington and drew over 200 attendees. After repeating the SWEF in 2008, NOAA requested the NSWP Council and OFCM take responsibility for planning and conducting the SWEF. Since 2009, the NSWP has continued to conduct the SWEF nearly every year drawing a regular attendance over 200 people from the federal government, congress, defense, industry, academia, foreign, and international organizations.

Following recommendations from the 2006 Assessment Report to quantify the value and economic impact of space weather, the National Academies of Sciences, Engineering, and Medicine issued a report in 2008 that had a profound effect on the implications for the nation of severe space weather. The workshop report *Severe Space Weather Events* (<http://www.nap.edu/catalog/12507/severe-space-weather-events-understanding-societal-and-economic-impacts-a>) written by subject matter experts from the NSWP agencies, industry, and academia found that the interdependence of critical national infrastructure components could inadvertently lead to a devastating cascade of failures. The report noted “An estimate of \$1 T–\$2 T during the first year alone was given for the societal and economic costs of a ‘severe geomagnetic storm scenario’ with recovery times of 4 to 10 years” [National Research Council, 2008].

In June 2007, OSTP saw an urgent need to examine the impact of diminished space weather sensing capabilities because of the restructuring of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program. The OSTP asked OFCM to engage the NSWP to examine the consequences from these reductions on national infrastructure such as the power grid. The report [OFCM, 2008] also included the impact of potential loss of solar wind data from NASA’s Advanced Composition Explorer spacecraft, which was already well beyond its design operational life. Based on the severity of these impacts, OSTP requested the NSWP provide with recommendations to mitigate these potential losses of space weather monitoring capabilities.

Following up on the 2008 Impact Report, the NSWP Council formed the Committee for Space Environmental Sensor Mitigation Options (CSESMO) consisting of members from the Federal Space Weather operations and research communities. Under the management of the newly appointed permanent NSWP Executive Secretary, Mr. Michael Bonadonna (OFCM), the 70-member CSESMO teams produced two reports [OFCM, 2009a, 2009b] by the end of 2009. These reports provided recommendations for solar wind and Low Earth Orbit space environmental sensing capability which formed the foundation of the interagency agreements and budget support for the Constellation Observing System for Meteorology, Ionosphere, and Climate version 2 (COSMIC-2) program; the DOD space-based space weather monitoring; the Deep Space Climate Observer (DSCOVER); and DSCOVER follow-on missions. The study also provided recommendations for the utilization of commercial space weather sensing capabilities and launch services.

After the publication of FCM R24-2006 and general increasing interest in space weather as a potential natural disaster scenario, OFCM received a request from the National Science and Technology Council (NSTC), Committee for Environment and Natural Resource Sustainability (CENRS) Subcommittee for Disaster Reduction (SDR), to produce a concise Space Weather Implementation Plan. The new plan would be included with the set of 14 other disasters encompassing their Grand Challenges for Disaster Reduction [National Science and Technology Council, 2010].

OFCM passed the task through the NSWP Council, which tasked the CSW to complete the plan. Although the CSW expeditiously completed the plan, the change of presidential administrations in 2009 caused a substantial delay in its publication until 2010.

Although the SDR Space Weather Implementation Plan had little impact within the space weather community, the emergency response and disaster preparedness agencies took note. The NSWP Council expanded to include Department of Homeland Security and Federal Emergency Management Agency (FEMA) as permanent members.

### **Key Events From 2010 to 2015**

By 2010, the activities of the NSWP and its member agencies had begun making significant headway in raising awareness and preparedness for space weather impacts in the general public. Space weather was real, it had potentially devastating impacts, and it needed to be addressed immediately.

In 2006, the NSWP Council endorsed the recommendation of the NSWP Independent Assessment Team documented in FCM R24-2006 to produce new strategic and implementation plans. Although there was no question that the original NSWP strategic plan served well to establish the program in 1995, the NSWP needed a new plan to reflect the space weather community's progress and point the way for future development of national space weather services and the applied research need to support it.

Due to limited resources and higher priorities, The NSWP delayed work on the new strategic plan until late 2009. Under the leadership of the NSWP Executive Secretary, a small writing team drafted the initial version of the strategic plan and circulated it for CSW and NSWP comments and approval. The NSWP released the plan for public comment in 2010 and published it later that summer.

The new strategic plan was concise but accurately documented the current state of the National Space Weather Enterprise. It also served as a very useful educational and outreach tool for the NSWP agencies.

In April 2010, the Government Accountability Office (GAO) cited the NOAA and DOD failure to plan for replacement of climate and space weather sensing capabilities from the scope reduction and eventual failure of the NPOESS program. The GAO recommended congress direct OSTP to release the NSWP reports that not only addressed the Low Earth Orbit but solar wind monitoring issue as well. These reports helped secure funding for the DSCOVR and COSMIC-2 programs. The GAO also recommended congress direct the NSWP Council to establish an interagency strategy for the long-term provision of space weather observations [GAO, 2010]. This recommendation was codified in the 2010 NASA Authorization Act [GPO, 2010], which directed OSTP to assess the current and planned space weather observing systems used for operations, as well as how those systems are capable of meeting operational space weather forecasting requirements over the next 10 years. Once again, OSTP turned to the NSWP to complete the analysis and report. The NSWP Council-formed Joint Action Group (JAG) for Space Environmental Gap Analysis (SEGA) produced a detailed report focused on the full range of space weather sensors available to support operational space weather services. The JAG/SEGA provided comprehensive and extensive analysis of observing requirements, the current and planned observing capabilities, identified the gaps present at the time of the analysis, and projected 10 years into the future. Their report also provided recommendations to address the coverage gaps [OFCM, 2013a, 2013b]. OSTP published the report in 2013.

On the international scene, the Electric Infrastructure Security (EIS) Council inaugurated a series of EIS Summit meetings beginning in London in September 2010. These summit meetings have become the primary forum for international infrastructure security cooperation and coordination in addressing "Black Sky" hazards—events that severely disrupt the normal functioning of society's critical lifeline infrastructures.

The Right Honorable, James Arbuthnot captured the EIS Summit's interest in space weather in his concluding remarks at the first EIS Summit. He stressed the grave dangers represented by the vulnerability of critical electric infrastructures in the UK and other developed nations. In his wrap-up, he also emphasized that, given the data reported at the summit from recent studies of severe space weather, the devastating threats facing our infrastructures "are not a case of 'if' but 'when'." A century-class severe solar flare that would devastate unprotected infrastructures "will definitely happen" (<http://www.eiscouncil.com/Summit>). This eventually led to important legislative actions in the U.S. in 2015 with the passage of the Fixing America's Surface Transportation Act (Public Law No. 114-94) that included key provisions to help protect the national power grid from geoelectric current caused by geomagnetic storms.

In 2010, the business and insurance industries took note of the report from Lloyds "Space Weather—Its Impacts on Earth and Implications for Business" [Lloyds, 2010]. In it, the prestigious and respected Lloyds Company examined a wide range of impacts from space weather events. The report strongly supported previous studies and the magnitude of potential impacts from a Carrington-level event. This report, along with the National Research Council, Severe Space Weather Impact report of 2008, represented the most well-respected assessments of space weather threat.

Several opinion editorials appeared in 2010 and 2011 that had significant impact. The New York Times published "The Sun Also Surprises" [Joseph, 2010] and "How's the Weather?" [Guhathakurta and Baker, 2011]. These op-eds accurately described the potentially devastating impacts of severe space weather and what was being done to mitigate the impacts. Another op-ed published in 2011 written by the U.S. President's Science Advisor and the UK Chief Science Advisor entitled "Celestial Storm Warnings" [Holdren

and Beddington, 2011] carried the legitimacy of the top science policy makers in the U.S. and UK. The weight of this op-ed helped establish space weather services in the UK and strengthen not only U.S.-UK partnership but international cooperation as well.

The behind-the-scene work by the NSWP member agencies to encourage and support these op-eds led to stronger policy and better support for operational support and research on both sides of the Atlantic [Lanzerotti, 2011].

Since 2007, NOAA SEC (now SWPC) conducted meetings with industry leaders at the Commercial Space Weather Interest Group (CSWIG) during the annual Space Weather Workshop conference in Boulder, CO. In 2011, the CSWIG leaders formed the American Commercial Space Weather Association (ACSWA) to promote space weather risk mitigation for critical national infrastructure related to national daily life, economic strength, and national security. Since that time ACSWA has been playing a vital role by identifying important data and technology gaps that can be filled by private or government actions and by developing value-added products and services for the benefit of human and property safety as well as for vibrant commerce (<http://www.acswa.us/>).

The formation and active partnership with ACSWA has given the NSWP agencies an important avenue of communication for mutual benefit of both industry and government [Intriligator, 2007].

As solar cycle 24 began its rise in 2011, space weather became a frequent side note on many news broadcasts, print, and internet outlets. Few portrayed space weather impacts accurately. Many were wildly sensational. However, the reporting did begin to raise awareness of space weather and over time a number of more accurate and realistic articles and reports were being released.

In 2011, OSTP established the National Earth Observations (NEO) Task Force. In response to congressional direction, the NEO Task Force drafted the National Earth Observation Strategy that outlines a process to identify, implement, and update national, civilian Earth observation priorities. The National Plan for Earth Observations is an implementation plan for sustaining and addressing critical Earth-observing requirements over the long term. Since the NSWP had just completed the SEGA report for OSTP all parties agreed to adapt the analysis and results of this report for use in the NEO portfolio assessment. This ensured consistency in OSTP reports to congress regarding space weather observing systems.

Meanwhile, the NSWP was working to improve its public awareness, readiness, and response efforts. In 2012, the CSW developed and launched the National Space Weather Portal modeled after and connected to the World Meteorological Organization Space Weather Portal. The portal provides a gateway to access federally funded space weather information, services, and activities. The portal connects to a system of existing portals and websites, providing national information to enhance understanding [Fisher and Bonadonna, 2012].

In 2013, the USAF, NWS, NASA, and NSF entered into a formal agreement documented in a memorandum of understanding (MOU) to strengthen the bond between the agencies in providing space weather services and conducting supporting research within the federal government [Williamson and Bonadonna, 2013; Lanzerotti, 2013]. The “Unified National Space Weather Capability” MOU helped raise awareness of space weather within the five agencies entering into the agreement and set the stage for improved interagency collaboration.

Just as the 2002 National Academies decadal survey for Solar and Space Physics had a far-reaching impact on the space weather community, the 2013 decadal survey *Solar and Space Physics: A Science for a Technological Society* (<http://www.nap.edu/catalog/13060/solar-and-space-physics-a-science-for-a-technological-society>) had an even more direct impact on the NSWP. Together with science and technical recommendations, the survey committee, building upon developments and understandings over the prior decade, recommended “...that, to coordinate the development of this plan, the NSWP should be re-chartered under the auspices of the National Science and Technology Council (NSTC) and should include the active participation of OSTP and the Office of Management and Budget.” Although the NSWP has not been “rechartered” as recommended, the establishment of the Space Weather Operations, Research, and Mitigation (SWORM) Task Force in 2014 essentially provides the NSTC oversight and direction for the NSWP agencies.

We almost realized our “worst” fears for a space weather event in July 2012 when the Sun launched an extremely powerful CME across the orbital path of the Earth. Dr. Daniel Baker of the University of Colorado, together with colleagues from NASA and other universities, published a seminal study of the

storm in the December 2013 issue of the journal *Space Weather* [Baker et al., 2013]. The paper, entitled “A major solar eruptive event in July 2012,” describes how a powerful CME tore through Earth orbit on 23 July 2012. They wrote, “It is the opinion of the authors that our advanced technological society was very fortunate, indeed, that the 23 July solar storm did not occur just a week or so earlier. Had the storm occurred in mid-July 2012, the Earth would have been directly targeted by the CME and an unprecedentedly large space weather event would have resulted. In fact, there is a very legitimate question of whether our society would still be “picking up the pieces” from such a severe event.” This “near miss” removed any doubt that action was needed to prepare for and mitigate the potential threat posed by severe space weather.

In January 2014, the NSWP Council directed the CSW to begin development of a new Implementation Plan to pursue the goals and objectives contained in the 2010 NSWP strategic plan. Over 50 subject matter experts from all 9 NSWP agencies participated in developing the Implementation Plan from March to August 2014. The CSW intended to produce the first draft of the completed document by the end of September 2014. However, once OSTP had established the SWORM Task Force, the NSWP agreed not to publish the plan. The CSW completed the document and provided it to the nascent SWORM Task Force for use in developing a new National Space Weather Strategy and Action Plan.

### **Culmination of the NSWP and Transition of National Space Weather Leadership (2014–2015)**

With all the mounting evidence of the potential national implications of severe space weather impacts, congressional direction, and a long series of recommendations for elevating the U.S. coordination of space weather services, science, preparedness, and response planning to the highest level, the NSTC established the SWORM Task Force in 2014. The SWORM Task Force seeks to meet the objectives of the NASA Authorization Act of 2010 (42 U.S.C § 18388): improving the nation’s ability to protect, mitigate, respond to, and recover from the potentially devastating effects of space weather events. The SWORM Task Force, now a permanent Subcommittee of the CENRS, serves as an interagency body to define coordinate and oversee goals and programmatic authorities of the federal science and technology activities related to space weather, including forecasting, event preparation, mitigation, response, and recovery [NSTC, 2015].

Following the retirement of Mr. Samuel Williamson, the long-seated Federal Coordinator for Meteorology and Chairman of the NSWP, OFCM conducted a thorough mission review of the Federal Meteorological Coordinating Infrastructure. The participating agencies sent a clear message that OFCM should streamline the infrastructure and the ICMSSR should absorb the functions of the four Program Councils. As a result, the ICMSSR deactivated the NSWP Council and assumed their responsibilities on 10 August 2015 [OFCM, 2015].

All NSWP agencies participate in and fully support the SWORM Subcommittee; however, the ICMSSR will remain engaged in and conduct complementary space weather activities not managed through the NSTC. As a group, the NSWP agencies view this development as the “Coming of Age” of the Federal Space Weather community and graduation to the next level.

### **Conclusion**

The federal agencies that established and participated in the NSWP can take credit for a long series of accomplishments facilitated through their interagency cooperation. The NSWP partnership improved communication among agencies and helped foster opportunities in the academic, commercial, and international space weather enterprise as well. Over its 21 year history, the NSWP was keenly aware of external factors and events regarding space weather and adapted to these new influences accordingly. The program provided an interagency framework for planning and advancement by the partner agencies.

Over the years, the original six-agency NSWP partnership grew to include the FAA, DOE, FEMA, and EOP. This may be attributable to the success of the program in raising awareness of space weather impacts and the need for mitigation and preparedness. With the CSW and NSWP Council meetings as interagency focal points, it is likely that the transition of the program to OSTP oversight would not have happened without the involvement of these additional agencies.

Despite occasional setbacks and shortcomings, the NSWP proved the value of coordination within the federal government; cooperation between the government and its commercial, academic, and international partners; and helped raise public awareness, readiness, and response. As the White House assumes the challenges of leadership, the National Space Weather Partnership stands ready to continue its essential work.

### Acknowledgments

References listed with OFCM as the author with no website link are on file at the Office of the Federal Coordinator for Meteorological Services and Supporting Research, Suite 7130, SSMC2, 1325 East West Highway, Silver Spring, MD, 20910, and are available to the public by telephone request at 301 628-0112. These documents are permanent official records and will be maintained in perpetuity. References listed as "For Official Use Only" may be obtainable through a formal "Freedom of Information Action" request to OFCM. Visit <https://www.foia.gov/> for process details. The authors would like to thank the anonymous reviewers for their insightful comments and suggestions that have contributed to improve this paper. No data were used in producing this manuscript.

### References

- Baker, D. N., X. Li, A. Pulkkinen, C. M. Ngwira, M. L. Mays, A. B. Galvin, and K. D. C. Simunac (2013), A major solar eruptive event in July 2012: Defining extreme space weather scenarios, *Space Weather*, *11*, 585–591, doi:10.1002/swe.20097.
- Fisher, G., and M. Bonadonna (2012), National Space Weather Portal is online, *Space Weather*, *10*, S07006, doi:10.1029/2012SW000831.
- Fisher, G., and R. McCoy (2011), American Meteorological Society embraces space weather, *Space Weather*, *9*, S02002, doi:10.1029/2011SW000655.
- GAO (2010), *Environmental Satellites—Strategy Needed to Sustain Critical Climate and Space Weather Measurements*. GAO-R 10-456, Government Printing Office, Washington, D. C.
- Gassmann, G. J. (Ed) (1963), *The Effect of Disturbances of Solar Origin on Communications*, Macmillan, New York.
- Gerson, N. C. (Ed) (1962), *Radio Wave Absorption in the Ionosphere*, Pergamon Press, New York.
- GPO (2010), *NASA Authorization Act 2010 Sect 809, (42 U.S.C § 18388)*, Government Printing Office, Washington, D. C.
- Guhathakurta, M., and D. Baker (2011), How's the weather, *New York Times*. [Available at <http://www.nytimes.com/2011/06/17/opinion/17baker.html>.]
- Holdren, J. P., and J. Beddington (2011), Celestial storm warnings, *New York Times*. [Available at <http://www.nytimes.com/2011/03/11/opinion/11iht-edholdren11.html>.]
- Intriligator, D. (2007), Collaboration between government and commercial space weather information providers, *Space Weather*, *5*, S10002, doi:10.1029/2007SW000348.
- Joseph, L. E. (2010), The Sun also surprises, *New York Times*. [Available at <http://nyti.ms/2dKagLX>.]
- Knipp, D. J., et al. (2016), The May 1967 great storm and radio disruption event: Extreme space weather and extraordinary responses, *Space Weather*, *14*, 614–633, doi:10.1002/2016SW001423.
- Lanzerotti, L. J. (2011), Government and public awareness of space weather, *Space Weather*, *9*, S07008, doi:10.1029/2011SW000710.
- Lanzerotti, L. J. (2013), Unified National Space Weather Capability, *Space Weather*, *11*, 387, doi:10.1002/swe.20067.
- Little, C. G. (1991), What on Earth happened to the Central Radio Propagation Laboratory (CRPL)?, *IEEE Antennas Propag. Mag.*, *33*, 24—26, doi:10.1109/74.84528.
- Lloyd's (2010), *360° Risk Insight: Space Weather: Its Impact on Earth and Implications for Business*, Lloyd's, London, U. K. [Available at [https://www.lloyds.com/~media/lloyds/reports/360/360%20space%20weather/7311\\_lloyds\\_360\\_space%20weather\\_03.pdf](https://www.lloyds.com/~media/lloyds/reports/360/360%20space%20weather/7311_lloyds_360_space%20weather_03.pdf).]
- Murtagh, W. (2007), Space Weather Enterprise Forum, *Space Weather*, *5*, S01003, doi:10.1029/2006SW000302.
- NRC (2003), *The Sun to the Earth—and Beyond: A Decadal Research Strategy in Solar and Space Physics*, *Solar and Space Physics Survey Committee, Committee on Solar and Space Physics*, *Space Studies Board, Division on Engineering and Physical Sciences, National Research Council*, The National Academies Press, Washington, D.C., doi:10.17226/10477.
- NRC (2008), *Severe Space Weather Events—Understanding Societal and Economic Impacts Workshop Report*, *Committee on the Societal and Economic Impacts of Severe Space Weather Events*, *National Research Council*, The National Academies Press, Washington D.C., doi:10.17226/12507.
- NSTC (2010), Grand challenges for disaster reduction: Space Weather Implementation Plan, *National Science and Technology Council Subcommittee on Disaster Reduction (SDR)*. [Available at <http://www.sdr.gov/Heliophysics:>]
- NSTC (2015), *National Space Weather Strategy*, *National Science and Technology Council*, October 2015. [Available at [https://www.whitehouse.gov/sites/default/files/microsites/ostp/final\\_nationalspaceweatherstrategy\\_20151028.pdf](https://www.whitehouse.gov/sites/default/files/microsites/ostp/final_nationalspaceweatherstrategy_20151028.pdf).]
- OFCM (1982a), Record of Actions, Subcommittee for Space Environmental Forecasting Meeting, June 1982.
- OFCM (1982b), Record of Actions, Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR) Meeting 82-2, July 1982.
- OFCM (1994), Record of Actions, Federal Committee for Meteorological Services and Supporting Research Meeting 94-2, December 1994.
- OFCM (1995a), Record of Actions, National Space Weather Program Council Meeting 95-11, August 1995.
- OFCM (1995b), The National Space Weather Program: The strategic plan, FCM-P30-1995. [Available at <http://www.ofcm.gov/publications/spacewx/nswpp30.pdf>.]
- OFCM (1997), Record of Actions, Committee for Space Weather Meeting 97-1, December 1997.
- OFCM (1999), Record of Action, Committee for Space Weather Meeting 99-1, Jul 1999.
- OFCM (2000), The National Space Weather Program: The Implementation Plan 2nd Edition, FCM-P31-2000. [Available at <http://www.ofcm.gov/publications/spacewx/nswpip.pdf>.]
- OFCM (2003), Federal Committee for Meteorological Services and Supporting Research letter to Office of Science and Technology Policy, August 5, 2003.
- OFCM (2006), Report of the Assessment Committee for the National Space Weather Program, FCM-R24-2006. [Available at <http://www.ofcm.gov/publications/spacewx/nswpr24.pdf>.]
- OFCM (2008), Impacts of NPOESS Nunn-McCurdy Certification and Potential Loss of ACE Spacecraft Solar Wind Data on National Space Environmental Monitoring Capabilities, (For Official Use Only).
- OFCM (2009a), Summary Report on NPOESS Space Environmental Sensor Mitigation Options and Recommendations, (For Official Use Only).
- OFCM (2009b), Summary Report on Solar Wind Monitoring Continuity Options and Recommendations, (For Official Use Only).
- OFCM (2013a), The Federal Role in Meteorological Services and Supporting Research—A Half-Century of Multi-Agency Collaboration, FCM-17-2013. [Available at <http://www.ofcm.gov/i-7/fcm-i7.pdf>.]
- OFCM (2013b), Report on Space Weather Observing Systems: Current Capabilities and Requirements for the Next Decade, April 20132013, NSWP report for OSTP. [Available at [https://www.whitehouse.gov/sites/default/files/microsites/ostp/spaceweather\\_2013\\_report.pdf](https://www.whitehouse.gov/sites/default/files/microsites/ostp/spaceweather_2013_report.pdf).]
- OFCM (2015), Interdepartmental Committee for Meteorological Services and Supporting Research Meeting 2015-1 Record of Action, August 2015.
- OSTP (2003), Office of Science and Technology Policy letter to NOAA Administrator, November 26, 2003, On file at OFCM.
- Poppe, B. B. (2006), *Sentinels of the Sun*, Johnson Books, Boulder, Colo.

Robinson, R. (2003), Space Weather Journal: The Space Weather Journal: How it began, *Space Weather*, 1(1), 1002, doi:10.1029/2003SW000019.

Robinson, R. M. and Behnke, R. A. (2001), The U.S. National Space Weather Program: A Retrospective, in *Space Weather*, edited by P. Song, H. J. Singer and G. L. Siscoe, AGU, Washington, D. C., doi:10.1029/GM125p0001.

Williamson, S. P., and M. F. Bonadonna (2013), Unified National Space Weather Capability (UNSWC) established, *Space Weather*, 11, 211, doi:10.1002/swe.20046.

**Michael F. Bonadonna** is the Secretariat for Federal Meteorological Coordination at the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) in Silver Spring, Maryland. Email: michael.bonadonna@noaa.gov.

**Louis J. Lanzerotti** is a Distinguished Research Professor of physics in the Center for Solar-Terrestrial Research at New Jersey Institute of Technology (NJIT) in Newark, New Jersey.

**Judson E. Stailey** is the Lead Meteorologist at the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) in Silver Spring, Maryland.