REPORT

ON

SPACE WEATHER OBSERVING SYSTEMS:

CURRENT CAPABILITIES AND

REQUIREMENTS FOR THE NEXT DECADE

April 2013

Prepared by the

Office of the Federal Coordinator for Meteorological Services and Supporting Research

National Space Weather Program Council

Joint Action Group for Space Environmental Gap Analysis

In response to a request by the
Office of Science and Technology Policy
Executive Office of the President

NATIONAL SPACE WEATHER PROGRAM COUNCIL (NSWPC)

PREFACE

In April 2011, the Office of Science and Technology Policy (OSTP) in the Executive Office of the President asked the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM), under the auspices of the National Space Weather Program Council (NSWPC), to lead a study to assess (1) the current and planned space weather observing systems and (2) the capacity of those systems to meet operational space weather forecasting requirements over the next 10 years.

The request from OSTP followed passage of the NASA Authorization Act of 2010, which directed OSTP to arrange for such an assessment and report the results to appropriate Congressional committees. The NSWPC formed an interagency Joint Action Group (JAG) to execute the study, comprising 25 people from 15 Federal offices. In August 2011, the JAG briefed the NSWPC on the interim results of the study, with OSTP and the Office of Management and Budget (OMB) present as observers. This report, which formally documents the study results, was reviewed and approved by all interagency NSWPC members.

This report describes the study process, the study requirements and their relevance and importance, an assessment and accounting of current and planned space weather observing systems used or to be used for operations, an analysis of gaps between the observing systems' capabilities and their ability to meet documented requirements, and a summary of key findings. The report provides OSTP with a consolidated consensus view of the National Space Weather Program Federal agency partners with regard to key capabilities that need to be maintained, replaced, or upgraded to ensure space weather observing systems can meet the requirements of the Nation's critical space weather forecasting capabilities for the next 10 years. Of course, specific program activities are subject to future budgetary decisions.

The National Space Weather Program is a Federal interagency initiative with the mission of advancing the improvement of space weather services and supporting research in order to prepare the country for the technological, economic, security, and health impacts that may arise from extreme space weather events. The goal of the program is to achieve an active, synergistic, interagency system able to provide timely, accurate, and reliable space weather, observations, warnings, analyses, and forecasts.

I want to thank the JAG for its excellent service crafting this report. Special praise is due to the group's co-chairs, Dr. Bill Denig and Colonel John Egentowich, whose strong leadership ensured the success of this difficult undertaking.

Samuel P. Williamson
Federal Coordinator for Meteorological Services
and Supporting Research
Chair, National Space Weather Program Council

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EXECUTIVE SUMMARY

The 2010 National Aeronautics and Space Administration (NASA) Authorization Act, Section 809 (see Appendix 1) acknowledges:

- the threat to modern systems posed by space weather events;
- the potential for "significant societal, economic, national security, and health impacts" due to space weather disruptions of electrical power, satellite operations, airline communications, and position, navigation, and timing systems; and
- the key role played by ground-based and space-based space weather observing systems in predicting space weather events.

In addition, the Act directed the Office of Science and Technology Policy (OSTP) to submit a report to the appropriate Congressional committees that details the following:

- "Current data sources, both space- and ground-based, that are necessary for space weather forecasting."
- "Space- and ground-based systems that will be required to gather data necessary for space weather forecasting for the next 10 years."

In response, OSTP requested the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) on April 8, 2011, to lead the coordination of a new interagency assessment, under the auspices of the National Space Weather Program Council (NSWPC), to address the Act's requirements. The NSWPC established the Joint Action Group for Space Environmental Gap Analysis (JAG/SEGA) on April 28, 2011, to perform an assessment of existing and planned space weather observing systems and observing system requirements to support operational space weather forecasting over the next 10 years. On August 2, 2011, the JAG briefed interim results of the assessment to the NSWPC, with representatives of OSTP and the Office of Management and Budget (OMB) present as observers. This report is provided to satisfy OSTP's request as well as requirements of the Act.

The JAG/SEGA considered the following when defining the scope of the assessment documented in this report:

- **Requirements**: Proceed from currently documented observing requirements for operational space weather services.
  - Derived space weather observing requirements from those recently validated by Department of Defense (DoD), Department of Commerce (DOC) National Oceanic and Atmospheric Administration (NOAA) and NASA; hence, a revalidation of requirements was not needed.
  - Limited to observing requirements and systems necessary to drive operational forecasts and services. Pure research-only requirements were not considered.
  - Requirements for observations needed to support space missions beyond Earth geosynchronous orbit (lunar, interplanetary, etc.) were also considered.
- **Observing Systems**: Use existing agency requirements, programs, initiatives, and plans for observing and forecasting systems.
  - Only existing or planned systems were considered. Potential new systems beyond those already planned were considered to be out of scope.

- Operational systems and research platforms that can be leveraged for operational use were considered; research systems not suited for operational use were not considered.
- International systems capable of supporting U.S. operational needs were considered.

The JAG/SEGA included 25 participants from 15 Federal organizations, representing the bulk of the U.S. Government space weather stakeholders. Representing the providers of the Nation's two primary operational space weather analysis and forecasting centers, leaders from the U.S. Air Force (USAF) and NOAA served as co-chairs for the JAG. Focusing on the specific goals set forth in the 2010 NASA Authorization Act, the JAG determined short-term and long-term space weather observing requirements needed to support operational space weather forecasting.

While the space weather observing requirements were specific to particular space weather environmental parameters, the JAG noted the importance of the requirements to the Nation's economy and security. As noted in the 2008 National Research Council (NRC) report, *Severe Space Weather Events*, "potential damage resulting from these critical dependencies [of critical infrastructure and systems to the space environment] can be minimized by having a robust capability to monitor, model, and predict what is happening in the space environment." Prominent potential impacts include:

- **Electric Power Grid:** Large scale blackouts and permanent damage to transformers, with lengthy restoration periods.
- **Global Satellite Communications:** Widespread service disruptions, which can impact financial, telemedicine, government, and Internet services, among many others.
- **GPS Positioning and Timing:** Degradations of military weapons accuracy, air traffic management, transportation, precision survey/construction/agriculture, energy exploration, ship navigation/commerce, financial transactions, and cell phone/broadband.
- **Satellites & Spacecraft:** Loss of satellites and capabilities, loss of space situational awareness (including detection of hostile actions), increased probability of satellite-debris collisions, degraded communication/navigation, and increased risk to astronaut safety.

In assessing the existing and planned space weather observing systems needed to minimize the risk of these impacts and meet national requirements, the JAG considered ground-based and space-based solutions specifically designed for operations, research systems that are capable of being exploited for operations, and other domestic or international solutions that could be leveraged for operations. The JAG then used its compilation of the requirements, along with the existing and planned observing systems to be used to satisfy those requirements, and performed an analysis to determine key requirements shortfalls, or gaps ("gap analysis").

In conducting its analysis, the JAG noted that an observational requirement is a documented need for *measurements* of the space environment, which are contingent on the "domain" of the space environment in which the measurements are being made. For this assessment, observing requirements were categorized within the following six domains of the space environment: Sun/Solar, Heliosphere, Magnetosphere, Aurora, Ionosphere, and the Upper Atmosphere.

Within each of these six domains, several specific environmental parameters were identified and assessed against documented observing requirements. While the analysis of the ability of current, planned, and potential systems to meet specific observing requirements was critical to the assessment, the JAG took an additional step to ensure that the end results were tied to real-world applications. Specifically, the JAG mapped the observing parameters for each of the six domains to analysis and forecast products (nowcast, short-term forecast, and long-term forecast) for the five key space weather phenomena:

- **Geomagnetic Storms**: A worldwide disturbance of the Earth's geomagnetic field resulting from increases in the solar wind pressure and interplanetary magnetic field at the dayside magnetopause. The occurrence of substorms within a geomagnetic storm period can negatively impact satellite operations, power systems, radio propagation, and navigation systems.
- **Radio Blackouts**: Disturbances of the ionosphere caused by X-ray emissions from the Sun, which can negatively impact radio propagation and navigation systems.
- **Radiation Storms**: Elevated fluxes of charged particle radiation that can negatively impact satellite operations, radio propagation, navigation systems, and can increase biological risks to humans in spacecraft or high-flying aircraft.
- **Ionospheric Storms**: Disturbances in the ionosphere caused by large increases in the fluxes of solar particles and electromagnetic radiation, often associated with the occurrence of geomagnetic storms. There is a strong coupling between the ionosphere and the magnetosphere that often results in both regimes being disturbed concurrently. These disturbances can negatively impact radio communications as well as satellite navigation and communications systems.
- **Atmospheric Drag**: Collisions with diffuse air particles (altitudes typically < 2000 km) cause spacecraft to slow, leading them to gradually descend to lower altitudes where the drag continues to increase with increased atmospheric density. This phenomenon is affected by space weather since the density of the air particles responds to solar activity, such as magnetic storms. Solar emissions cause the upper atmosphere to heat and expand, which in turn increases drag at a given altitude. This effect increases dramatically with high solar activity. If the increased solar activity triggers increased magnetic activity at the Earth, intense currents, flowing through the upper atmosphere, also contribute to increased heating and expansion of the upper atmosphere. Accurate analysis of atmospheric drag effects can reduce the error associated with determination of satellite orbital intersection with other satellites and space debris, reducing the need for expenditure of fuel for orbital maneuvers and thereby extending the mission life of the spacecraft.

When consolidating the requirements and considering the ability of the current/planned systems to monitor the five key space weather phenomena included in the analysis, high-level impacts due to a few key systems become apparent. Table ES-1 (A) illustrates the degradation of operational capability should various key systems be lost due to launch/system failure, budget cuts, or other reasons; and (B) depicts the sustainment of current capabilities over time if key systems are maintained or replaced. It is particularly noteworthy that the addition of planned replacements or new systems maintains our current capabilities while providing some incremental improvement; none of these planned/replacement systems meet all requirements. Perhaps more importantly, this demonstrates the significant degradation in current capability should these planned/replacement systems not reach operational status. In other words, the

Nation is at risk of losing critical capabilities that have significant economic and security impacts should these key space weather observing systems fail to be maintained and replaced.

Considering the rapidly growing dependency on space-based and space-enabled systems, which have permeated most facets of modern society, space weather observing and forecasting capabilities used to mitigate potential impacts will become even more critical in the future.

In performing the assessment of current and planned space weather observing systems and evaluating their ability to meet requirements, the JAG/SEGA arrived at the following key findings:

- A judicious mix of space-based and ground-based observing systems is currently used and needed to support operational space weather services.
  - The huge volume of the space environment means that even with the dozens of observing systems now used, there are still limited observational data to produce space weather forecasts.
- Research observing systems provide important data used to advance science; many of those also provide timely data and are used to support operational space weather services.
  - Several NASA heliophysics research missions will reach end-of-life within the next 10 years.
- Several NOAA and DoD space-based operational systems are scheduled to be replaced over the next 10 years subject to available funding.
- While NOAA, DoD and U.S. Geological Survey (USGS) ground-based systems are an important contributor to the space weather mission, sparse coverage limits their utility in meeting operational requirements.
- A number of foreign space-based and ground-based capabilities are used to help meet U.S. operational space weather needs.
  - More are available and provide the potential for future use.
  - While foreign data sources can provide additional capability, the economic and national security interests of the United States dictate that the Nation not rely exclusively on foreign assets to conduct the critical space weather mission.
- Most unexploited data sources (foreign and domestic) are not currently used due to lack of reliable or timely access, excessive expense, policy/security restrictions, or other practical reasons. Also, these data sources offer secondary capabilities that cannot replace key, primary systems. Nevertheless, many offer added value that could incrementally improve forecasting, and should be used when feasible and cost-effective.
- While space-based and ground-based observing systems are critical components needed to meet operational requirements, they are inextricably linked to other parts of the space weather architecture (such as models and other space weather forecasting capabilities), and thus should not be considered alone when assessing our ability to meet requirements.

Table ES-1. Requirements Satisfaction by Phenomena

(A) Worst Case

	Nowcasts (Current Conditions)			Short-term Forecasts (minutes to hours)			Long-term Forecasts (hours to days)		
Timeline (years)	0-3	4-7	8-12	0-3	4-7	8-12	0-3	4-7	8-12
Geomagnetic Storms	G	G	G	Y (3)	O	O	Y (4)	O	O
Radio Blackouts	G	G	G	O	O	O	Y	Y	Y
Solar Radiation Storms	G	G	G	Y (2)	R	R	O	O	O
Ionospheric Storms	Y (1)	O	O	Y (3)	O	O	Y (4)	R	R
Atmospheric Drag	Y (1)	O	O	Y (3)	O	O	Y (4)	R	R

Substantial degradation over time if systems aren't sustained or replaced

G	Meets Requirements
Y	Limited Capability
O	Severely Limited Capability
R	Fails to Meet Requirements

(1) Reduced DMSP coverage from two to one orbits
(2) Loss of relativistic electron data SOHO.
(3) Uncertainty of solar wind data from L1 to replace ACE.
(4) Uncertainty of getting a space-based coronagraph to replace SOHO and STEREO data.

(B) Best Case

	Nowcasts (Current Conditions)			Short-term Forecasts (minutes to hours)			Long-term Forecasts (hours to days)		
Timeline (years)	0-3	4-7	8-12	0-3	4-7	8-12	0-3	4-7	8-12
Geomagnetic Storms	G	G	G	Y (3)	Y (5)	G	Y (4)	Y	Y
Radio Blackouts	G	G	G	O	O	O	Y	Y	Y
Solar Radiation Storms	G	G	G	Y (2)	Y	Y	O	O	O
Ionospheric Storms	Y (1)	Y	Y	Y (3)	Y	Y	Y (4)	Y	Y
Atmospheric Drag	Y	O	O	Y (3)	Y	Y	Y (4)	Y	Y

Requirements Satisfaction maintained or Improved if key systems are sustained or replaced

G	Meets Requirements
Y	Limited Capability
O	Severely Limited Capability
R	Fails to Meet Requirements

(1) COSMIC-2 deployed
(2) Relativistic electron data from SOHO are obtained.
(3) Solar wind data from L1 to replace ACE is obtained.
(4) Space-base coronagraphs on SOHO and STEREO are replaced.
(5) Advanced plasma sensor on DSCOVR follow-on obtained.

Observing systems referenced above:

ACE: Advanced Composition Explorer
COSMIC-2: Constellation Observing System for Meteorology, Ionosphere, and Climate - 2
DMSP: Defense Meteorological Satellite Program
DSCOVR: Deep Space Climate Observatory
SOHO: Solar and Heliospheric Observatory
STEREO: Solar TErrestrial RElations Observatory

** Observing systems referenced above*:

COSMIC-2: Constellation Observing System for Meteorology, Ionosphere, and Climate - 2
GOES-R: Geostationary Operational Environmental Satellites - R
SEON: Solar Electro-Optical Network
SSAEM: Space Situational Awareness Environmental Monitoring

Space Weather Observing Systems: Current Capabilities and Requirements for the Next Decade

1. Introduction

On August 2, 2011, the Joint Action Group for Space Environmental Gap Analysis (JAG/SEGA) presented a briefing, titled *Space Environmental Gap Analysis*, to the National Space Weather Program Council (NSWPC), with staff members of the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) in the Executive Office of the President present as observers. The purpose of the briefing was to present interagency findings regarding space weather observing systems, including an assessment of the current systems and requirements for the next 10 years. This report formally documents the findings, including additional explanatory information, by directly capturing key text and graphics from the briefing. This introductory section provides background information, the objective and scope for the assessment, and the methodology of how the assessment was conducted (including JAG/SEGA participants). Subsequent sections provide additional context and supporting material, to include: a discussion of the relevance and requirements; a summary and description of space weather observing systems; a discussion of the analysis, to include the methodological framework and results; and a summary of the findings from the JAG/SEGA and of the NSWPC.

1.1 Background

The 2010 National Aeronautics and Space Administration (NASA) Authorization Act, Section 809 (see Appendix 1) acknowledges:

- the threat to modern systems posed by space weather events;
- the potential for "significant societal, economic, national security, and health impacts" due to space weather disruptions of electrical power, satellite operations, airline communications, and position, navigation and timing systems; and
- the key role played by ground-based and space-based space weather observing systems in predicting space weather events.

In addition, the Act directed OSTP to submit a report to the appropriate Congressional committees that details the following:

- "Current data sources, both space- and ground-based, that are necessary for space weather forecasting."
- "Space- and ground-based systems that will be required to gather data necessary for space weather forecasting for the next 10 years."

In response to Congressional guidance, OSTP asked the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) on April 8, 2011, to lead the coordination of a new interagency assessment, through the NSWPC, and to provide to OSTP a report to address the Act's requirements. To conduct the assessment, the NSWPC established the JAG/SEGA on April 28, 2011.

1.2 Objective

The primary objective of this assessment was to support OSTP in responding to Congressional guidance put forth in the 2010 NASA Authorization Act. As such, the specific objectives of this report are:

- Detail the current data sources, both space- and ground-based, that are necessary for space weather forecasting.
- Detail the space- and ground-based systems that will be required to gather data necessary for space weather forecasting for the next 10 years.

To meet these objectives, the NSWPC was tasked with the following deliverables to OSTP:

- Provide an interim status briefing by end of July 2011.
- Provide a Report by end of September 2011.

1.3 Scope

In defining the scope of this assessment, the JAG/SEGA used the following determinations to guide the methodology and completion of the assessment:

- **Requirements**: Proceed from currently documented observing requirements for operational space weather services.
  - Given the short timeline required for this assessment, and the fact that the observing requirements from Department of Defense (DoD), Department of Commerce (DOC) National Oceanic and Atmospheric Administration (NOAA), and NASA were recently validated (see section 2.4), a formal revalidation of these requirements was not considered to be needed to conduct this assessment.
  - The scope was limited to observing requirements and systems necessary to drive operational forecasts and services. Requirements for purely research purposes without operational applications were not considered within the scope of the study, noting that the ongoing National Research Council (NRC) Decadal Survey on Solar and Space Science is assessing research plans and needs.
  - Requirements for observations needed to support space missions beyond Earth geosynchronous orbit (lunar, interplanetary, etc.) were also considered.
- **Observing Systems**: Use existing agency requirements, programs, initiatives, and plans for observing and forecasting systems.
  - Only existing or planned systems were considered. Consideration of potential new systems beyond those already planned was considered to be out of scope.
  - Systems included in the assessment were operational systems and research platforms that are (or can be) leveraged for operational use. Research systems that are not conducive for operational use were not within the scope of the study.
  - International capabilities that can be leveraged to support U.S. operational needs were also considered.

1.4 Methodology

Leveraging the OFCM interagency coordinating infrastructure, the NSWPC established the Joint Action Group for Space Environmental Gap Analysis (JAG/SEGA) to perform an assessment of existing and planned space weather observing systems (see Appendix 2). The JAG/SEGA included representatives from the array of U.S. Government space weather stakeholders, with 25 participants from 15 organizations. As the providers of the Nation's two primary operational space weather analysis and forecasting centers, leaders from the U.S. Air Force (USAF) and the NOAA volunteered to serve as co-chairs for the JAG. The other JAG members represented the major stakeholder organizations in the national space weather enterprise, and made significant contributions to the assessment. Table 1 lists the key members of the JAG and other participating organizations; the full list of individual JAG members is contained in Appendix 2.

Table 1. JAG/SEGA Participants

JAG/SEGA Key Members and Participating Organizations	
Name (role)	**Organization**
Dr. Bill Denig *(Co-chair)*	NOAA National Environmental Satellite, Data, and Information Service (NESDIS)
Col John Egentowich *(Co-chair)*	Air Force Directorate of Weather (A3O-W)
Jerry Sanders *(Aurora Domain Lead)*	Air Force Weather Agency (AFWA)
Dr. Arik Posner *(Heliosphere Domain Lead)*	NASA HQ
Kelly Hand *(Ionosphere Domain Co-Lead)*	Air Force Space Command (AFSPC)/Aerospace Corp.
Dr. Therese Moretto Jorgensen *(Ionosphere Domain Co-Lead)*	National Science Foundation (NSF)
Dr. Michael Hesse *(Magnetosphere Domain Lead)*	NASA Goddard Space Flight Center (GSFC)
Bill Murtagh *(Solar Domain Lead)*	NOAA National Weather Service (NWS)
Clayton Coker *(Upper Atmos. Domain Lead)*	Naval Research Laboratory (NRL)
Michael Bonadonna *(Executive Secretary)*	Office of the Federal Coordinator for Meteorology (OFCM)
Other Participating Organizations	
Department of Energy (DOE) National Nuclear Security Admin. (NNSA)	Office of the Assistant Secretary of Defense for Networks and Information Integration [OASD(NII)]
Department of State (DOS)	
US Geological Survey (USGS)	AF Space & Missile Systems Center (SMC)

The methodology adopted by the JAG/SEGA was streamlined to focus on the specific goals set forth by Congress in the 2010 NASA Authorization Act, and to provide rapid results to meet the Act's timelines. The JAG collected, collated, and determined short-term and long-term space weather observing requirements needed to support operational space weather forecasting. A detailed description of the requirements is provided in Section 2.

In assessing the existing and planned space weather observing systems needed to meet these requirements, the JAG considered ground-based and space-based solutions specifically designed for operations, research systems that are capable of being exploited for operations, and other domestic or international solutions that could be leveraged for operations. A detailed description of these systems is provided in Section 3. Some additional information regarding international capabilities is included in the “Additional Notes” section below.

The JAG then used its compilation of the requirements, along with the existing and planned observing systems to be used to satisfy those requirements, to perform an analysis to determine key requirements shortfalls, or gaps (“gap analysis”). The methods used in performing the analysis, and well as the results of the analysis, are described in section 4. A summary of the key findings are then presented in section 5.

Additional Notes:

1. The JAG took a conservative approach with respect to funding of current and planned systems in order to define realistic “best case” and “worst case” scenarios for observing system availability. In this sense, the “best case” and “worst case” mean the following:

- “Best case” = all the identified key systems are funded and successfully deployed.
    - It does not mean that additional improved capabilities are fielded that are not already identified as a program, nor does it mean that new scientific breakthroughs are made.
- “Worst case” = none of the identified key systems are funded and successfully deployed.
    - It does not mean that other baseline observing capabilities and infrastructure are lost; those are assumed to continue as part of this scenario.

2. In conducting its analysis, the JAG took into consideration existing or planned and securely funded international efforts for space weather observations. In addition to those efforts, the JAG is aware of international organizations with space weather equities that could prove useful in the future in helping America meet its space weather observational requirements. Four of these efforts are discussed briefly below. While these collaborations do not drive the key findings found in this report, they provide a foundation for increased, mutually beneficial efforts that might aide U.S. efforts to meet its space weather observational needs.

- The World Meteorological Organization (WMO) has launched an Interprogramme Coordination Team for Space Weather (ICT-SW). This team consists of representatives from approximately 20 nations and is co-chaired by the United States and China. The ICT-SW has completed an assessment of space weather observation parameters and is preparing a Statement of Guidance, an effort broadly parallel to this JAG, with a nominal delivery to WMO by the end of the year.

- The International Space Environment Service (ISES) is a permanent service supported by four different international organizations. With its current Director based in Ottawa, ISES operates 13 space weather regional warning centers around the globe providing global, standardized, and free exchange of space weather information as well as monthly reports summarizing the status of satellites in Earth orbit and in the interplanetary medium.

- The International Living Star (ILWS) program is a coordinating activity between NASA and partners from international space agencies. The ILWS mission is to stimulate, strengthen, and coordinate space research to understand the governing processes of the connected Sun-Earth System as an integrated entity. ILWS activities include the entire spectrum from space mission coordination as well as planning for data sharing for space weather forecasting and analysis purposes.

- US government technical agencies, including NASA, NOAA, NSF, and USGS also maintain a wide range of international collaborations in addition to those identified elsewhere in the text.

2. Relevance, Context, and Requirements

A number of reports and assessments have documented the effects of space weather on activities, systems, and human health on the ground, in the air, and in space. Also, Congress acknowledged the importance of space weather's impacts on the Nation in its guidance to OSTP as part of the NASA Authorization Act of 2010. Therefore, only a brief reminder of the importance of space weather is given here to establish the broader context for the specific observing requirements that follow. A discussion of the manner in which requirements are defined is then provided, beginning with a description of how observing systems fit into the overall space weather context, followed by an explanation of how observing requirements are parsed across the relevant space environment domains, and concluding with a summary of where these requirements have been documented.

2.1 Relevance of Space Weather - Why It Is Important

National infrastructure and services are complex and interdependent; a major outage in any one area has a widespread impact. As noted in the 2008 NRC report, *Severe Space Weather Events*, "potential damage resulting from these critical dependencies can be minimized by having a robust capability to monitor, model, and predict what is happening in the space environment." Examples of key dependencies and impacts include:

- **Electric Power Grid:** Large-scale blackouts and permanent damage to transformers, with lengthy restoration periods.
- **Global Satellite Communications:** Widespread service disruptions, which can impact financial, telemedicine, government, and Internet services, among many others.
- **Global Positioning System (GPS) Positioning and Timing:** Degradations of military weapons accuracy, air traffic management, transportation, precision survey/construction, agriculture, energy exploration, ship navigation/commerce, financial transactions, and cell phone/broadband.
- **Satellites & Spacecraft:** Loss of satellites and capabilities, loss of space situational awareness (including detection of hostile actions), increased probability of satellite-debris collisions, degraded communications/navigation, and increased risk to astronaut safety.

For operators and decision makers to be able to take actions to mitigate these negative impacts, they must first have situational awareness of the space weather events that cause these impacts. Knowledge that a significant space weather event is occurring, as well as timely and accurate forecasts of the future state of the space environment, provides the means to take proactive measures to mitigate the impacts of these potentially damaging space weather events. It is this approach that led NOAA to develop Space Weather Scales for geomagnetic storms, solar radiation storms, and radio blackouts (see Appendix 3).

The impacts of space weather can have serious economic consequences. For example, geomagnetic storms during the 1990's knocked out several telecommunications satellites, which had to be replaced at a cost of about $200 million each. If another "once in a century" severe geomagnetic storm occurs (such as the 1859 "super storm"), the cost on the satellite industry alone could be approximately $50 - $100 billion. The potential consequences on the Nation's power grid are even higher, with potential costs of $1 - 2 trillion that could take up to a decade to completely repair.

(For above cost references, see: http://www.economics.noaa.gov/?goal=weather&file=events/space)

More detail on the importance of space weather impacts on society is provided in Appendix 4, which was previously published as part of the National Space Weather Program Strategic Plan (June 2010).

Based on knowledge of how space environmental conditions can negatively impact certain systems, space-environmental monitoring and forecasting provides actionable information to operators and decision makers who can take actions to mitigate these risks and impacts. This linkage of space environmental conditions, systems, impacts, and actions is depicted in Figure 1. The figure illustrates how three space weather conditions (blue boxes) disturb four domains in the near-earth environment (green boxes). These disturb systems highlighted in the middle of the figure with potential impacts (in the same color) directly below each system. Finally, actions that can be taken to mitigate the impacts are shown (in the same color) on the lowest tier.

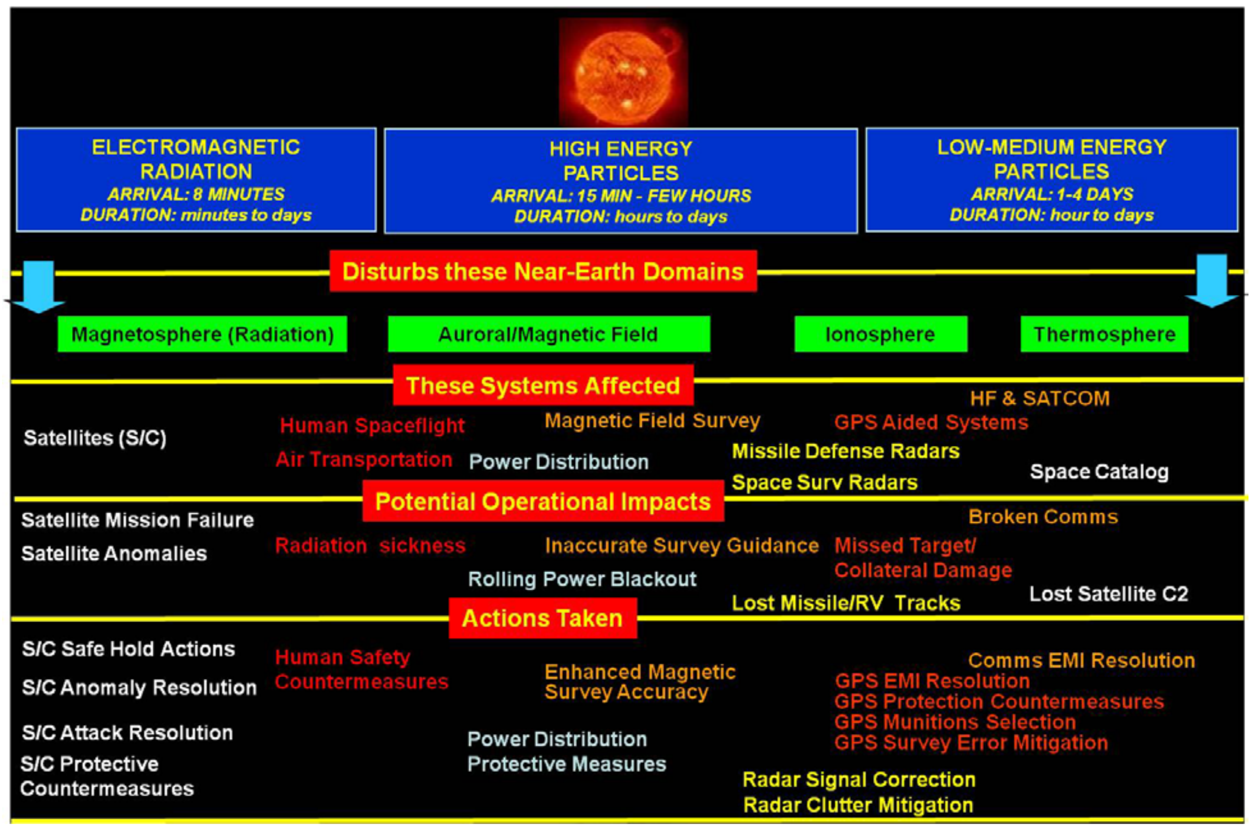

Figure 1. "Conditions-Systems-Impacts-Actions" Linkage

2.2 Space Weather Architecture

At a high level, the architecture for space weather observing and forecasting can be described in terms of three basic components, as depicted in Figure 2. The first component is the suite of space-based and ground-based observing systems that measure the space environment, which is the focus of the assessment detailed in this report. Measurements from these observing systems feed into the second component, which are the operational space weather centers composed primarily of the National Weather Service's Space Weather Prediction Center and the Air Force

Weather Agency, as well as NASA's Space Weather Laboratory. At these centers, the measurements from all available sensors are processed, assimilated, and used as input to numerical prediction models to produce analyses (i.e., "nowcasts"), short-term forecasts (on a timescale of minutes to hours), and long-range forecasts (on a timescale of hours to days) of space weather events that are used to provide actionable products to operational users. In so doing, the analyses and forecasts of the space environment enable the centers to provide warnings and forecasts to operational users that take action to mitigate the space weather effects and risks described above.

There are several foundational building blocks that help support operational users. First, data assimilation techniques are used to ensure that data are properly incorporated for use in forecast models. Second, the science and technical know-how behind the models, the assimilation techniques, and other components of the process are continually updated and enhanced through a "research to operations" approach that is supported by government and university modeling centers (e.g., Community Coordinated Modeling Center, NSF Center for Integrated Space Weather Modeling, NRL), developmental test-beds, and prototyping/ transition centers (e.g. AFWA, NOAA Space Weather Prediction Center (SWPC), Air Force Research Laboratory (AFRL) Space Weather Forecast Lab). Third, when combined with the underlying data networks and IT systems, the entire space weather analysis and forecasting *infrastructure* used by the centers is maintained to support the final component of the space weather architecture —the user community. Because all of these components are interdependent and linked, an assessment of the entire space weather architecture to meet current and future requirements must include an assessment of the analysis and forecast capabilities of the centers. The present assessment, however, is focused on the observing systems component.

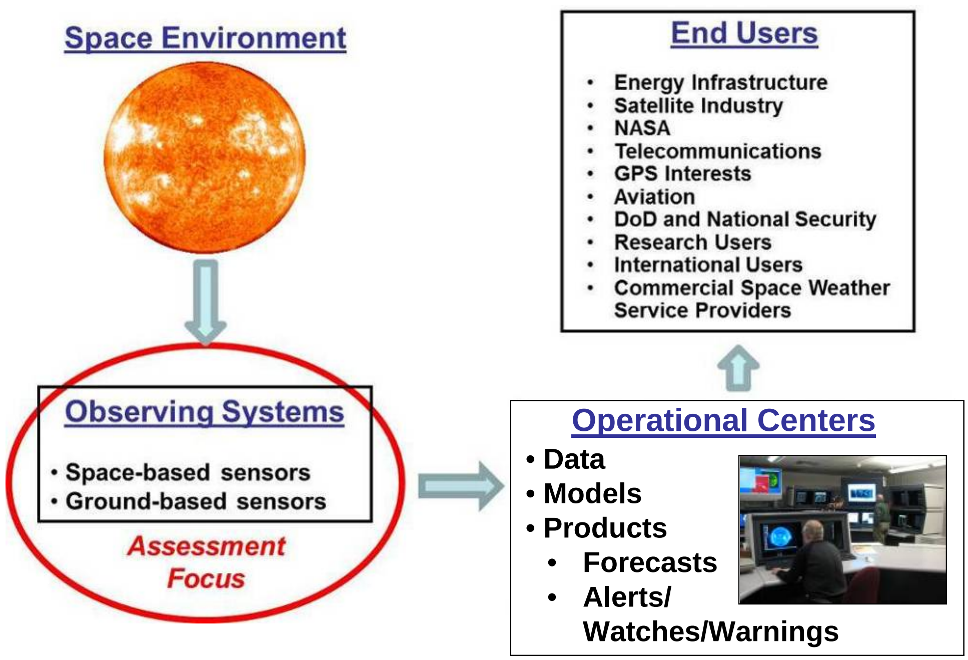

Figure 2. Space Weather Architecture

2.3 Space Weather Domain Descriptions

As noted in the previous section, this assessment focuses on space weather *observing* requirements and capabilities and does not delve into the intricacies of the remaining parts of the space weather architecture, such as forecast models and customer products. In this context, an observational requirement is defined as a documented need for a *measurement* of a space environmental parameter, and is contingent on the "domain" of the space environment in which the parameter is measured. For this assessment, observing requirements are categorized within the following six domains of the space environment: Sun/Solar, Heliosphere, Magnetosphere, Aurora, Ionosphere, and the Upper Atmosphere. As depicted in Figure 3, these domains span the space environment from the Sun to the Earth's atmosphere. Each domain has its own unique characteristics and importance to space weather, and is described in further detail below.

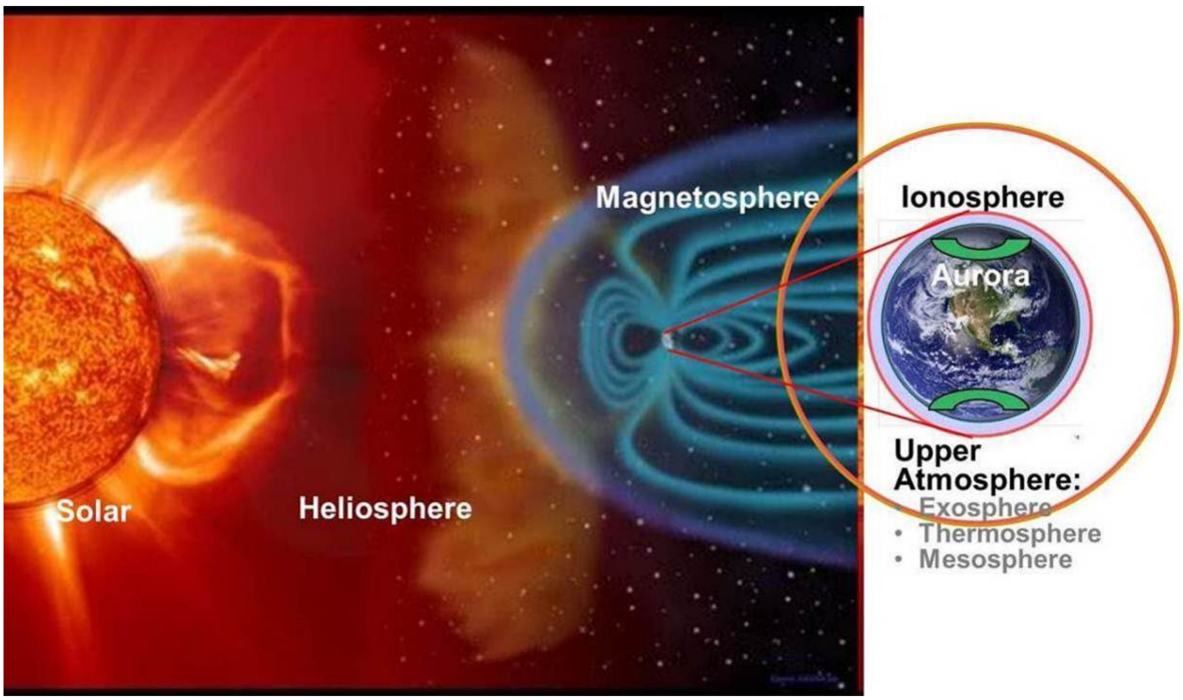

Figure 3. Space Weather Domains

Solar: The Sun is the ultimate source of all space weather on or near the Earth. The solar domain consists of conditions near the surface, including the solar corona out to approximately 20 solar radii (R_S) and within the interior of the Sun, and is important to space weather in several ways. Monitoring conditions on the surface and in the interior of the Sun are used to detect the occurrence and precursors of solar flares. Prompt effects of solar flares at the Earth include increased ionospheric densities from energetic photons, mostly within the X-ray band, that ionize atmospheric gases. Flares are also indicative of major solar events that release vast amounts of solar gases in coronal mass ejections (CME), and energetic protons resulting in geomagnetic storms and polar-cap absorption events, respectively.

Heliosphere: The heliosphere is the immense magnetic bubble containing our solar system, solar wind (the plasma of charged particles coming out of the Sun), and the entire solar magnetic field, stretching out some 18 billion kilometers from the Sun. For space weather impacts, the area of most concern is with the inner heliosphere from within 1 Astronomical Unit (AU), approximately 150 million kilometers at the Earth location, to about 1.5 AU for Mars. It takes approximately 8 minutes for solar photons traveling at the speed of light to reach Earth, whereas it can take up to several days for the solar wind and intermittent solar gases emitted from the Sun in the form of CMEs to cover the same distance. Monitoring the heliosphere allows space weather operators to forecast whether and when a solar transient, such as a CME, might cause a magnetic storm on Earth. Included in the current assets available to forecasters is the Advanced Composition Explorer (ACE) satellite at the L1 Lagrangian point close to the Earth at approximately 240 Earth Radii (R_E), approximately 1.5 million kilometers, along the Earth-Sun line. From this vantage point, operators can provide a short-term forecast, on the order of 45 minutes. Other assets monitor the inner heliosphere much closer to the Sun, thereby facilitating longer-term forecasts of up to several days.

Magnetosphere: The magnetosphere is the magnetic cavity surrounding the Earth, carved out of the passing solar wind by virtue of the Earth's magnetic field (or geomagnetic field), which prevents, or at least impedes, the direct entry of the solar wind plasma into the cavity. On the dayside extent (towards the Sun) of the magnetosphere, out to what is referred to as the magnetopause, is of order 8-10 R_E. This dayside protective shield essentially blocks the solar wind and is highly responsive to changes in the solar wind speed and direction plus variations in the orientation of the interplanetary magnetic field (IMF) that is carried with the solar wind and can couple into the geomagnetic field near the magnetopause. Large solar wind impulses at the magnetopause can be monitored as magnetic field perturbations by satellites in geostationary orbit at approximately 7.7 R_E and on the ground at magnetic observatories (such as those maintained by USGS). On the night side, the solar wind tends to drag out the geomagnetic field to distances of up to several hundred R_E into what is referred to as the magnetotail. Magnetic reconnection between the IMF and geomagnetic field on both the dayside and night side can transfer enormous amounts of energy from the solar wind to the geospace environment. Geomagnetic storms occur when energy transferred from the solar wind is deposited in the magnetotail, sometimes building up to point whereby a fraction of the energy is dumped into the near-Earth space environment in the form of a magnetic substorm. Monitoring the magnetosphere in terms of the magnetic topology and energetic space particles allows operators to detect the occurrence of geomagnetic storms and to forecast the likelihood of resultant magnetic substorms.

Aurora: The aurora is a phenomenon associated with geomagnetic activity which occurs mainly at high latitudes; typical auroras appear in the thermosphere at approximately 100-250 km above the ground. The optical aurora is due to the collisional interaction between atmospheric gases, mostly neutrals, and precipitating energetic electrons and protons that stream along magnetic field lines from the more distant magnetosphere. The precipitating charged particles are typically of sufficient energy to collisionally ionize the atmospheric gases resulting in increased electron densities within ionospheric E and F layers that can be disruptive to radiowave propagation for communications and navigation. During geomagnetic storm periods (typically days), the occurrence of geomagnetic substorms (typically hours in duration) can lead to dramatic increases and changes in the electron density profile within the auroral zone as well as spectacular auroral displays that, at times, can be seen overhead at lower latitudes in response to increased geomagnetic activity. Energy inputs from precipitating charged particles and incoming Alfven waves can lead to large spatial and temporal variations in electron density that causes, by way of one example, radar auroral clutter that can compromise the performance of military early warning radars. Energy inputs during geomagnetic storms can also cause increased satellite drag due to atmospheric heating and the resultant outward expansion (diffusion) of the upper atmosphere.

Ionosphere: The ionosphere is the region of the Earth's upper atmosphere containing a small percentage of free electrons and ions produced by photoionization of the constituents of the atmosphere by solar ultraviolet radiation at very short wavelengths (< 0.1 microns). While the fractional percentages of electrons and ions are small, the morphology of the ionosphere has profound effects on radio-wave propagation. Airline operations, particularly at high geographic latitudes, are critically dependent on the steady-state ionospheric structure for high-frequency (HF) communications; the occurrence of D-region absorption events (see Appendix 5), also referred to as polar-cap absorption events, is particularly troublesome. Radio propagation delay through the ionosphere impacts the accuracy of navigation, radar, and geolocation systems. Ionospheric scintillation resulting from small-scale variations in density can degrade the performance of communications and navigation systems. Low-latitude scintillation results from unstable height variations in density that can occur in the post-sunset low-latitude ionosphere. Scintillation can also occur at higher latitudes in the auroral zones (see radar auroral clutter in the Aurora domain discussion) due to particle precipitation and within the polar cap due to density variation in polar-cap patches. The ionosphere is a complex region of space that is intimately coupled to both the magnetosphere and atmosphere. While numerous operational assets are currently available to monitor the ionosphere, the complexity and temporal variability of this domain limits the utility of any single approach. Instead, the ensemble of data available from different techniques offers the best opportunity to fully specify and possibly forecast this domain.

Upper Atmosphere: The upper atmosphere is categorized as that part of the Earth's atmosphere above the stratosphere, made up of three distinct layers: the mesosphere (approximately 50-90 km), the thermosphere (approximately 90-600 km), and the exosphere (approximately 600-100,000 km). While the upper atmosphere is not nearly as complex as the ionosphere, the tools available for monitoring this domain are limited. Specifying this domain is important for calculating atmospheric drag effects on space systems including functioning satellites, space debris, and re-entry vehicles. Quasi steady-state specifications of the upper atmosphere can be effectively modeled for atmospheric drag using, for example, diurnal and longer term solar-cycle variations in solar heating. Less quantified are the variations in the heat flux from the magnetosphere during geomagnetic storms that can lead to dramatic changes in localized atmospheric drag. Specifying this domain is also important as it impacts the ionosphere in multiple ways. Variations in the thermospheric winds impact plasma redistribution in the ionosphere and are not effectively modeled.

2.4 Basis of Requirements

To adequately specify each of the six space weather domains previously discussed, several environmental parameters (i.e., specific observational requirements) must be measured. Table 2 lists the various environmental parameters needed to specify each domain. Specific environmental parameter measurements are used by the operations centers to provide nowcasts and forecasts of space weather. More details for each observed parameter, along with a description of why each is important, are presented in Appendix 5.

In analyzing the operational observing requirements, the JAG/SEGA made use of the most recent requirements documents from the two Federal departments that run the U.S. operational space weather centers, namely the DOC and DoD, as well as from NASA that operates research satellites (many of which are leveraged for operations) and their Space Weather Laboratory. The requirements used in this assessment are formalized in the following documents:

- NOAA Consolidated Operations Requirements List, 2011 (DOC).
- NOAA Program Observation Requirements Document – Space Weather Program, 2009 (DOC).
- Air Force Weather Space Weather Implementation Plan, Oct 2010 (DoD).
- Initial Capabilities Document for Meteorological and Oceanographic Environment, 2009 (DoD).
- Integrated Space Weather Analysis System Data Requirements, 2011 (NASA).
- Space Radiation Analysis Group Requirements, 2011 (NASA).
- Four-Dimensional Weather Functional Requirements for NexGen Air Traffic Management, 2008 (Joint Planning Development Office Weather Functional Requirements Study Group).

Table 2. Observing Requirements by Space Weather Domain

Solar	Heliosphere	Magnetosphere	Aurora	Ionosphere	Upper Atmosphere
Solar EUV &UV Flux	Solar Wind: 3D Mag. Field Components	Energetic Ions and Protons: Energy & Flux	Auroral Boundaries (Equatorial and Polar)	Ionospheric Scintillation: Phase and Amplitude	Mesospheric Temperature
Solar EUV and UV Imagery	Solar Wind Plasma Components: Composition, Density and Temperature	Medium Charged Particles: Total Flux and Energy	Auroral Energy Deposition	Plasma Fluctuations	Mesospheric Wind Speed and Direction
Solar Magnetic Field	Solar Wind: Speed and Direction (3D Plasma Velocity Components	Trapped Particles: Protons, Electrons, Waves	Auroral Emissions & Imagery: UV, Visible and IR	Plasma Temperature: Te & Ti Plasma Temps	Neutral Winds (Speed & Direction)
Solar Radio Emissions: (Total and spectral flux)	Sun-Earth line Heliospheric Imagery	Supra-thermal through Auroral Energy Particles: Diff. Dir., Energy, Flux	Precipitating Particles: Electrons; 20eV-1KeV; 1KeV-50KeV	Ionospheric Characterizations: Layer Height & Freq.	Neutral Density, Composition, and Temperature
Solar Radio Burst: (Location, Type, Polarization)	Off-angle Heliospheric Imagery	Magnetic Field Strength and Direction		Energetic Ions 1-500MeV	Neutral Density Profile
Solar Imagery IR and Optical	Solar Wind Radio Emissions	Earth Surface Geomagnetic Fields		Total Electron Content	
Solar Coronagraph	Relativistic Electrons			Electric Field	
Solar X-Ray Flux (total and discrete Freq.)	Solar High Energy Protons and Cosmic Rays			D Region Absorption	
Solar X-Ray Imagery	Off-angle Solar Wind In Situ Parameters			Electron Density Profile: Density, Features, Composition	
Off-angle Solar Imagery					
Helio-seismology					

3. Observing Systems for Operational Support

There are several parallels between traditional atmospheric weather observing that is needed for forecasting, and the similar processes used for space weather. First, some observations are best taken remotely while others must be taken in situ to be useful. Second, both space-based and ground-based sensors are needed to measure various key environmental parameters. Third, space-based sensors are needed in different orbits to meet operational and research needs.

One notable difference between these two environments is the density of observational data associated with each environment—the volume of insterstellar space is many orders of magnitude greater than the volume in which terrestrial weather conditions exist. Also, the number, variety, and coverage from space weather observing systems are small compared to atmospheric observing systems. While this results in limited observational data to produce space weather forecasts, the current suite of space weather observing systems, depicted in Figure 4, still provides significant capabilities in meeting many operational requirements.

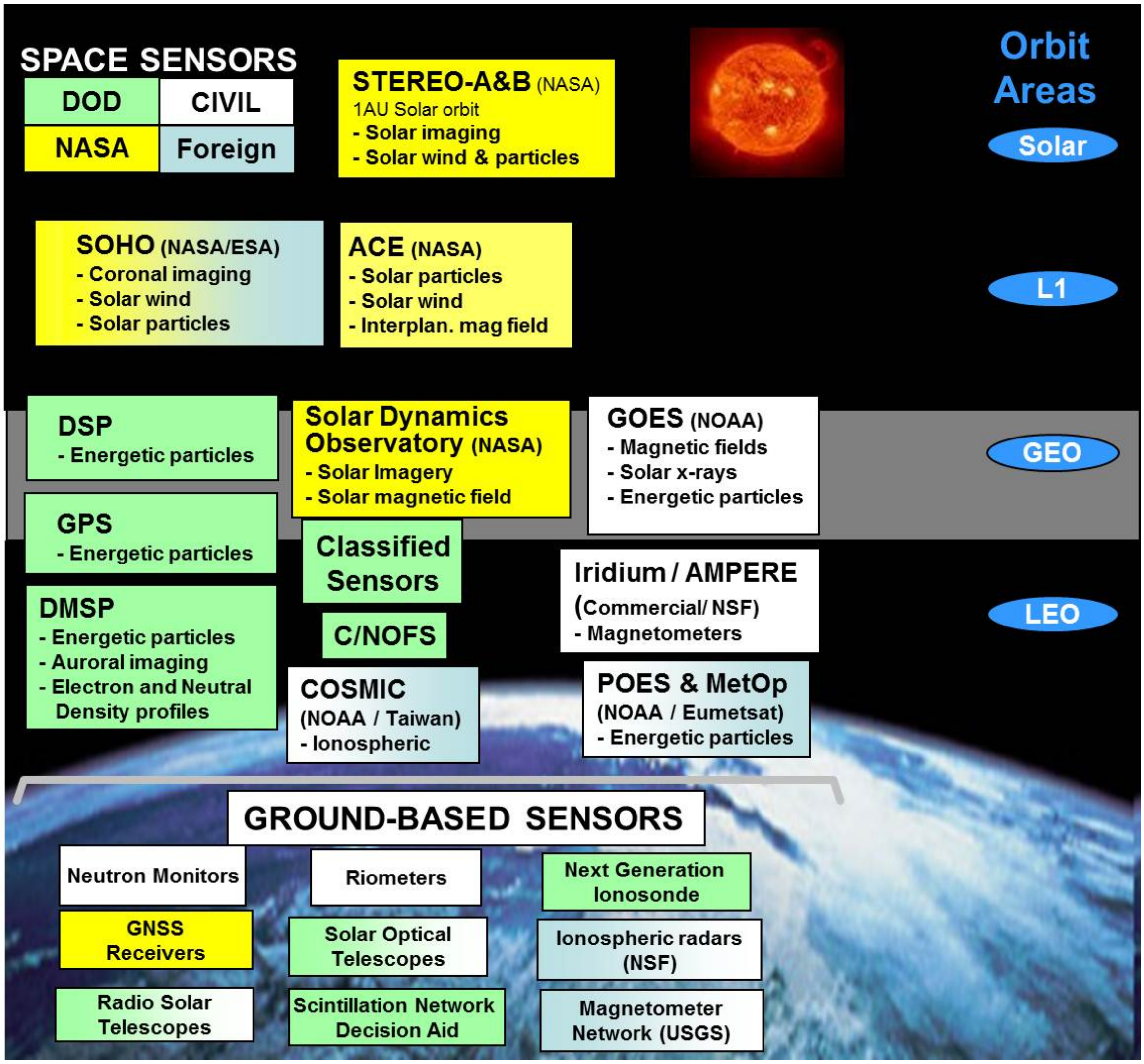

Figure 4. Space Weather Observing Systems

In the subsections that follow, each observing system considered in this assessment is described; also, systems are grouped as either a ground-based system or space-based system. The system descriptions are grouped into three subsections, according to the following structure:

- Existing systems currently used for operations.
- Existing systems not currently used for operations (but could be with additional effort).
- Future/planned systems to replace/upgrade existing systems.

3.1 Existing Systems Currently Used for Operations

GROUND-BASED SYSTEMS:

Digital Ionosonde Sounding System (DISS): Originally fielded by the USAF in the early 1990's, DISS was comprised of 20 unmanned automated sites strategically positioned to support USAF operations. DISS provides all standard ionosonde parameters, and data are retrieved in near-real-time for use in ionospheric models. DISS will be fully decommissioned by 2012 and replaced by NEXION. Figure 5 depicts the locations of DISS and other ionospheric sensors.

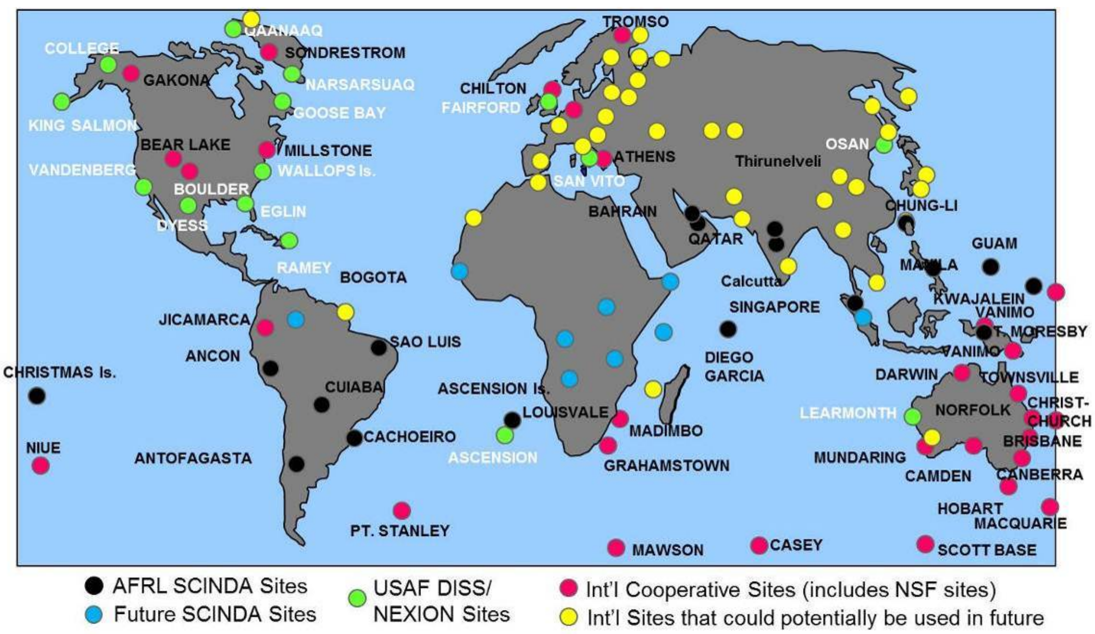

Figure 5. Current ground-based Ionospheric Sensors

Global Oscillation Network Group (GONG): The GONG is a community-based program to conduct a detailed study of solar internal structure and dynamics using helioseismology. To exploit this new technique, GONG has developed a six-station network of extremely sensitive and stable velocity imagers located around the Earth to obtain nearly continuous observations of the Sun's "five-minute" oscillations, or pulsations. GONG is supported by the NSF National Solar Observatory and is expected to operate through 2022, subject to the outcome of the NSF Astronomy Division's current Portfolio Review process. GONG capabilities will be enhanced to include solar H-alpha observations in support of USAF needs during the ISOON development and deployment. See Figure 6 below for current GONG locations.

Global Positioning System (GPS) Receivers: The superb accuracy of the GPS can be used to derive various ionospheric parameters, including Total Electron Content (TEC), Electron Density Profiles (EDP), and L-band scintillation. Within NOAA, the National Geodetic Survey (NGS) acquires GPS receiver data from approximately 1800 sites mostly within CONUS as part of the Continuously Operating Reference Stations (CORS) program. The CORS data are provided to the SWPC and assimilated into the US-TEC model. For DoD space weather operations, AFWA acquires globally-distributed GPS receiver data from the NASA Jet Propulsion Laboratory (JPL) TEC network. NASA uses the GPS data and information acquired from the Space Weather Application Center – Ionosphere (SWACI) operated by the German Aerospace Center. The increasing proliferation of ground receivers for GPS, as well as for other Global Navigation Satellite System (GNSS) programs, makes the use of these data attractive for space weather operations, although current sources are limited to land-based locations. Space-based GPS occultation sensors within the COSMIC and C/NOFS programs (discussed below) also make use of the GNSS network for space weather.

International Ionosondes: The U.S. space weather centers routinely access data from ionosondes operated by foreign agencies and organization to augment existing U.S. networks. The NOAA National Geophysical Data Center acquires international ionosonde data in near-real-time and provides these data to the operational centers. See Figure 5 above for locations of currently used sites, as well as potential new sites.

Neutron Monitors: The neutron monitor operated at Thule Air Base in Greenland provides real-time observations used to determine cosmic ray flux on the Earth's atmosphere. Galactic cosmic rays can be hazardous to people in space, on aircraft and on the ground, depending on the intensity. Solar cosmic rays can also be detected by the neutron monitors. Neutron Monitor data are the means to detect ground-level events. Data from several other neutron monitors are available through the European Space Agency (ESA) and other sources.

Next Generation Ionosonde (NEXION): Air Force Weather is currently fielding NEXION, a new digital solid-state sensor technology at up to 30 locations within the U.S. Air Force Ionospheric Data Network. These unmanned sensors provide near-real-time data to drive USAF ionospheric models for operational support. NEXION is expected to reach full operational capability in 2017 and remain in service well into the future. See Figure 5 for known NEXION locations.

Penticton Solar Radio Telescope: The Solar Radio Monitoring Program is a service operated jointly by National Research Council Canada and the Canadian Space Agency. Its function is to provide current and archival values of the 10.7cm Solar Flux solar activity index, which is a proxy indicator for the Extreme Ultraviolet (EUV) radiation striking the Earth's upper atmosphere giving rise to the ionosphere. The long uninterrupted history of 10.7cm flux measurements provides vital input for many ionospheric applications. Also, monthly Penticton 10.7 cm Radio Flux values are a primary input for measuring solar cycle progression.

Riometers: These sensors are used to measure the relative ionospheric opacity for radio signals and provide reliable information on the presence and density to the D-region of the ionosphere. Real-time riometer data are collected from Thule Air Base in Greenland and used by the operational space weather centers. Several other riometers are available but not routinely used.

Figure 6. Ground-based Solar Telescopes

Scintillation Network Decision Aid (SCINDA): SCINDA is a system designed to specify ionospheric scintillation in real time. Timely location of outage regions enable DoD users to effectively use satellite communication, navigation, or surveillance assets to modify mission plans and prevent errors as scintillation warnings become available. Specialized ground-based Ultra High Frequency (UHF) and L-Band receivers, monitoring signals from geosynchronous communication satellites, are used to measure scintillation intensities and zonal drift velocities. Data from the SCINDA sites are restricted for DoD use.

Solar Electro-Optical Network (SEON): Since the 1960's, the USAF has operated solar optical and radio telescopes to support various missions affected by space weather. The current SEON network provides 24x7 solar "patrol" which combines Hydrogen-alpha optical observations from the Solar Optical Observing Network (SOON), with a wide spectrum of solar radio emissions from the Radio Solar Telescope Network (RSTN). Continuing upgrades to SEON and its individual telescopes and components will keep the network services operating for the foreseeable future. See Figure 6 for SOON and RSTN locations.

USGS Magnetometers: The USGS owns and operates a network of 14 real-time magnetometers in the northern hemisphere across North America and the Pacific Ocean. Data from these sensors are used for a wide variety of purposes, including monitoring of changes in the Earth's magnetic field, electromagnetic conditions in the ionosphere, and density and height of the atmosphere, which affects Low Earth-Orbit (LEO) satellites.

Figure 7. USGS Magnetometers

SPACE-BASED SYSTEMS:

Advance Composition Explorer (ACE): Launched by NASA in 1997, ACE provides real-time scientific measurements of the solar wind from the Earth-Sun L1 point, located approximately 0.99 AU from the Sun and 1 million miles from Earth. It provides measurements of the interplanetary magnetic field, solar wind composition, speed, density, pressure and temperature. ACE plasma measurements can be severely degraded during solar radiation storms. ACE is roughly 10 years past its mission design life, but NASA plans to continue operating the mission through 2014 and may continue to operate it until 2020 subject to NASA funding and spacecraft health.

Communication and Navigation Outage Forecast System (C/NOFS): C/NOFS is an AFRL Advance Concept Development Test-bed mission composed of one small spacecraft in low inclination LEO, and associated ground systems. Launched in 2008, it provides data for quasi-operational and research use including ionospheric plasma fluctuations, ion velocity, in situ electric field, neutral wind parameters, electron density profiles, and many other parameters. C/NOFS mission end of life (EOL) is 2012 unless continuation funding is provided.

Constellation Observing System for Meteorology, Ionosphere & Climate (COSMIC): Taiwan's Formosa Satellite Mission #3, also known as COSMIC, uses the GPS radio occultation method for research and operational meteorological and ionospheric data. It provides cost effective measurements of atmospheric vertical temperature, moisture, and electron density profiles. COSMIC is a joint mission between Taiwan and the United States that is sponsored by NASA, NOAA, NSF, the Air Force Office of Scientific Research, the Office of Naval Research, and the Space and Missile Systems Center. COSMIC includes six microsatellites in LEO and associated ground systems. COSMIC EOL is expected in 2012.

Defense Meteorological Satellite Program (DMSP): DMSP has provided atmospheric and space environmental data for the DoD since the 1960's. The current DMSP spacecraft in sun-synchronous LEO provide fairly low latency (approximately 105 minutes) data including UV measurements of the ionosphere, auroral boundary and particle detection, in situ magnetic field, and other space weather parameters. The DMSP mission and observations should be available through 2025.

Geostationary Operational Environmental Satellite (GOES): The current series of NOAA's GOES is comprised of the three spacecraft (GOES-N, -O, and -P) and associated ground systems The space environmental sensors on GOES-NOP include a solar X-ray imager, X-ray flux monitor, energetic particle monitors, and a magnetometer. Data are provided to the operational centers in real time, which provides crucial data for the onset of solar radiation storms and radio blackouts. GOES-NOP EOL is approximately 2020.

Los Alamos National Laboratory (LANL) Geosynchronous Earth-Orbit (GEO): DOE's LANL provides a variety of space environmental in situ measures from geostationary platforms. These data include solar high energy proton and cosmic ray fluxes, medium and low energy charged particle data, and trapped radiation (protons and electrons). These data are used by the DoD for space weather analysis and monitoring and should be available through 2022 and beyond. At present, these data are not available for operational space weather outside of the DoD.

MetOp: MetOp is the polar-orbiting meteorological satellite system operated by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). The MetOp instrument complement includes a Space Environment Monitor 2 (SEM-2), identical to the SEM-2 particle sensors on POES (see below). Currently the MetOp-A satellite, launched in 2006, provides space environmental data in the mid-morning sun-synchronous circular polar orbit at approximately 840 km altitude. Overall, the MetOp A/B/C satellites will provide operational data through approximately 2021.

Polar Orbiting Environmental Satellite (POES): NOAA's POES satellites have provided continuous space environmental data from a LEO sun-synchronous orbit since 1978. The current series of POES spacecraft includes a SEM-2 package. Space environmental data are currently received from 5 POES spacecraft, although only the POES NOAA-19 satellite, launched in 2009, is considered operational. The POES series will end after NOAA-19, nominally in 2012. Although NOAA will provide continued meteorological satellite observations after POES, no SEM-like instrument is planned for the follow-on Joint Polar Satellite System (JPSS) spacecraft. After the NPOES restructuring in 2010, it was assumed that a DoD satellite with an AM orbit would provide a space environment monitoring package. Indeed, both the DMSP-19 and later, the DMSP-20 satellite will each include space environment measuring payloads in the early morning orbit. These measurements will continue until the end of life of the final satellite, DMSP-20, in the 2025-timeframe. In the mid-morning orbit, DMSP-18 will include the same payloads until it reaches end of life in the 2016-timeframe. Historically, these mid-morning observations are more consistently useful for taking these types of measurements. Therefore following the end of life for DMSP-18, the planned COSMIC-2 mission will be a key contributor to the collection of space environment measurements.

Solar Dynamics Observatory (SDO): The SDO was the first mission launched as a part of NASA's Living With a Star (LWS) Program, an initiative designed to understand the causes of solar variability and its impacts on Earth. Launched in 2010 into geostationary orbit, it provides high resolution spatial, spectral, and temporal observations of the Sun. In addition to providing science data sets to the research community, the SDO ground system provides a subset of data for real-time operational purposes. SDO's prime mission lasts until 2015. Extended operations are subject to NASA approval.

Solar and Heliospheric Observatory (SOHO): In 1995, NASA and the ESA launched SOHO to the L1 point to begin a two-year mission of scientific discovery. Some 16 years later, SOHO continues to provide critical solar and heliospheric observations, including the only space-based solar coronograph on the Sun-Earth line in operation today. Along with its other observations, this makes SOHO an important tool for space weather observation and forecasts. Extended mission operations are funded through 2014.

Solar Terrestrial Relations Observatory (STEREO): NASA's twin STEREO spacecraft were launched into heliocentric orbits at approximately 1 AU and have drifted nearly 120 degrees ahead and behind the Earth. Launched in 2006, the STEREO spacecraft provide "off-angle" observations of the Earth-Sun line, allowing space scientists and space weather operators to have 3-dimensional views of coronal mass ejections as well as observations of the far side of the Sun. The STEREO mission EOL is 2014, but may be extended pending funding and spacecraft status.

3.2 Existing Systems Not Currently Used for Operations

GROUND-BASED SYSTEMS:

Incoherent Scatter Radars: The NSF and a number of foreign and international organizations own and operate a variety of incoherent scatter radars that are primarily used for research studies and applications. They provide very accurate observations of the ionosphere and upper atmosphere, but only have limited regional coverage. A few of these systems currently have automatic and real-time data capabilities; with additional infrastructure upgrades they could be fully exploited for operations, should the value added be deemed worth the added cost.

Figure 8. NSF Incoherent Scatter Radar

International Real-time Magnetic Observatory Network (INTERMAGNET): INTERMAGNET is a global network of observatories monitoring the Earth's magnetic field. The program exists to establish a global network of cooperating digital magnetic observatories, adopting modern standard specifications for measuring and recording equipment in order to facilitate data exchanges and the production of geomagnetic products. Currently 44 countries provide data from 118 geomagnetic observatories. Data from INTERMAGNET could substantially improve analysis of the global and regional geomagnetic field if adequate communications could be secured to retrieve the data in near real time. See Figure 9 for worldwide locations of current INTERMAGNET sites.

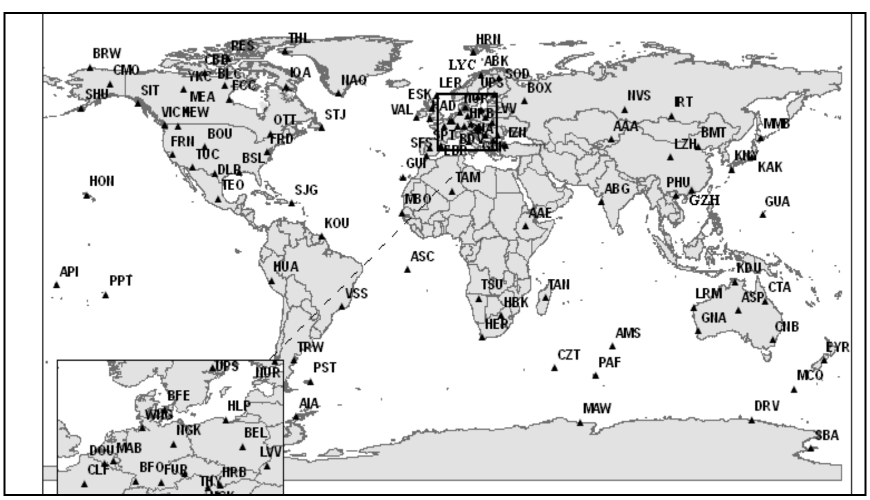

Figure 9. INTERMAGNET Sites

Super Dual Auroral Radar Network (SuperDARN): SuperDARN consists of over 20 radars, operating on frequencies between 8 - 20 MHz and focused on the Earth's polar regions, which measure the position and velocity of charged particles in the Earth's ionosphere. Because the movements of these particles are tied to the movements of the Earth's magnetic field, which in turn extends into space, SuperDARN data provide scientists with information regarding the Earth's interaction with the space environment. SuperDARN is an international collaboration involving scientists and funding agencies from over a dozen countries. Although primarily a research tool, SuperDARN could be used for specific operational support if the operational space weather service providers developed and implemented data assimilation tools to exploit the data.

SPACE-BASED SYSTEMS:

Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE): The NSF has funded the AMPERE project to retrieve magnetometer data from the commercial Iridium communication satellites. These data could be processed to extract geomagnetic data and infer a wide variety of electrodynamic conditions on a global basis, but would first require the development of new data assimilation tools to exploit the data.

Los Alamos National Laboratory (LANL) GPS: LANL operates a number of particle and radiation sensors on the GPS constellation. However, use of these data has not been fully exploited outside of DOE. New data exploitation techniques would need to be developed in order to use these data for operations. (Note: see discussion of LANL GEO in previous section)

WIND: Launched by NASA in 1994, WIND collects data at the L1 point on solar wind speed, temperature and density, as well as the interplanetary magnetic field. Although the spacecraft is still functional, real-time data are not retrieved due to ground antenna costs and schedule conflicts.

3.3 Future/Planned Systems to Replace/Upgrade Existing Systems

GROUND-BASED SYSTEMS: Several ongoing upgrade programs (e.g., NEXION and SEON) are covered in section 3.1. No additional planned upgrade programs were identified or assessed as part of this study.

SPACE-BASED SYSTEMS:

Constellation Observing System for Meteorology, Ionosphere & Climate - 2 (COSMIC-2): COSMIC-2 will build upon the successful joint U.S.-Taiwan COSMIC mission due to be completed in 2012. COSMIC-2 will also use the GPS radio occultation method for research and operational meteorological and ionospheric data. Current plans call for launching as early as 2015 pending funding commitments. (Note: also see discussion of COSMIC in section 3.1)

Deep Space Climate Observatory (DSCOVR): DSCOVR is the planned near-term ACE replacement for providing in situ measurements of the solar wind and the interplanetary magnetic field at the L1 point. DSCOVR will provide critical data to meet all documented operational requirements and allow time for the development of a long-term national strategy for solar wind observations. NOAA will acquire DSCOVR from NASA for refurbishment, while the USAF will procure the launch vehicle.

DSCOVR Follow-on (DSCOVR-F/O): NOAA has been investigating the use of a commercial provider for solar wind data from the L1 point. This is envisioned as a possible long-term solution, after DSCOVR, for obtaining reliable, cost effective data. Some consideration is also being given to obtaining GPS occultation data in the post COSMIC-2 time frame.

Geostationary Operational Environmental Satellite - R (GOES-R): GOES-R is the follow-on program to NOAA's current GOES-NOP series of geostationary meteorological satellites. As with past GOES missions, the space environmental observations consist of in-situ measurements of energetic charged particles and local magnetic fields plus related solar observations. GOES-R solar measurements will continue NOAA's operational record of solar X-ray observations while shifting to the extreme ultraviolet band for solar imagery. The first launch of the GOES-R series satellite is scheduled for 2015.

Joint Polar Satellite System (JPSS): JPSS atmospheric soundings will be used to observe very high altitude measurements needed for the characterization of the neutral upper atmosphere. A key instrument for the JPSS is the Visible/Infrared Imager /Radiometer Suite (VIIRS). The VIIRS Day-Night Band (DNB) will provide space-based observations of the aurora under conditions of limited cloud cover and lighting (Sun and moonlight). Certain JPSS capabilities will also exist on the Suomi NPOESS Preparatory Project (NPP) satellite launched October 28, 2011.

Radiation Belt Storm Probes (RBSP): The RBSP is a NASA mission under the LWS program scheduled to launch a pair of identical spacecraft in low-inclination, Highly Elliptical Orbit (HEO) in 2012. The mission of RBSP is to gain scientific understanding of how populations of relativistic electrons and ions in space form or change in response to changes in solar activity and the solar wind. NASA plans to make these data available for operational use via a near-real-time beacon relay.

Space Environmental Nanosat Experiment (SENSE): SENSE consists of two cubesats being built by Boeing for SMC, with launch targeted for Fiscal Year (FY) 2013. Both satellites have a GPS receiver for ionospheric radio occultation. In addition to the GPS receiver, one also carries the Wind Ion Neutral Composition Suite (WINCS), an in situ sensor to measure solar wind, ions, neutral composition and ion drift. The other one will carry the Cubesat Tiny Ionospheric Photometer (CTIP), a UV photometer. The combination of sensors provides ionospheric specification at higher resolution than can be provided by radio occultation alone.

4. Analysis

The JAG/SEGA, organized into six sub-groups for each of the space weather domains (see Appendix 2), performed a requirements analysis of space weather observing systems to respond to the Congressional direction posed in the 2010 NASA Authorization Act. Section 4.1 details the methodology used by the group to perform the analysis, while Section 4.2 details the results from the analysis.

4.1 Analysis Framework

The JAG/SEGA performed a detailed analysis for ground-based and space-based systems used to observe each of the six space weather domains. All current and planned observing systems used for operations were included in the assessment, as well as those not currently used but possibly useful for the future. Systems that are used exclusively for research and are not available for operations, for whatever reason, were excluded from the assessment. Each environmental parameter within the six space weather domains (see Appendix 5 for a list and description of the environmental parameters) was assessed against documented observing requirements.

While the analysis of the ability of current, planned, and potential systems to meet specific observing requirements was critical to the assessment, the JAG took an additional step to ensure that the end results were tied to real-world applications. The JAG mapped the observing parameters for each of the six domains to analysis and forecast products (nowcast, short-term forecast, and long-term forecast) for the five key space weather phenomena described below. The analysis included an assessment of the relative importance of each observed space environmental parameter for observing and forecasting the five space weather phenomena.

- **Geomagnetic Storms***: A worldwide disturbance of the Earth's geomagnetic field resulting from increases in the solar wind pressure and interplanetary magnetic field at the dayside magnetopause. The occurrence of substorms within a geomagnetic storm period can negatively impact satellite operations, power systems, radio propagation, and navigation systems.
- **Radio Blackouts***: Disturbances of the ionosphere caused by X-ray emissions from the Sun, which can negatively impact radio propagation and navigation systems.
- **Radiation Storms***: The occurrence of elevated fluxes of charged particle radiation which can negatively impact satellite operations, radio propagation, navigation systems, and biological risks to humans in spacecraft or high-flying aircraft.
- **Ionospheric Storms**: Disturbances in the ionosphere caused by large increases in the fluxes of solar particles and electromagnetic radiation, often associated with the occurrence of geomagnetic storms. There is a strong coupling between the ionosphere and the magnetosphere which results in both regimes being disturbed concurrently. These disturbances can negatively impact radio communications as well as satellite navigation and communications systems.
- **Atmospheric Drag**: Collisions with diffuse air particles (altitudes typically < 2000 km) slowly act to slow down the spacecraft, leading it to gradually descend to lower altitudes where the drag continues to increase with increased atmospheric density. This is affected

by space weather since the density of the air particles responds to solar activity, such as magnetic storms. Solar emissions cause the upper atmosphere to heat and expand, which in turn increases drag at a given altitude. This effect increases dramatically with high solar activity. If the increased solar activity triggers increased magnetic activity at the Earth, intense currents flowing through the upper atmosphere also contribute to increased heating and expansion of the upper atmosphere. Accurate analysis of atmospheric drag effects can reduce the error associated with determination of satellite orbital intersection with other satellites and space debris, reducing the need for expenditure of fuel for orbital maneuvers and thereby extending the mission life of the spacecraft.

***** *Phenomena included on NOAA's Space Weather Scales (see Appendix 3)*

4.2 Detailed Analysis Results by Space Environmental Domain

Using the methodology outlined in Section 4.1, the JAG/SEGA obtained detailed results within each of the six space weather domains. The specific details of this analysis are reported in Appendix 6, while the most significant results (i.e., the ones that most directly impact space weather operations) are provided below for each domain.

Sun/Solar: During the interval FY11-22, there is good coverage of the Sun provided by NOAA operational spacecraft, the various leveraged NASA assets, and the USAF SEON (which consists of the SOON and RSTN). During the operational transition from SOON to ISOON, additional ground-based optical coverage will be provided by the NSF GONG network. A high-risk capability over the next 10 years is the uncertain continuity of leveraged coronagraph observations provided by the NASA SOHO satellite which is currently operating in the "Bogart" mode, a reduced mode of operation at greatly reduced cost. In this mode, the critical white-light coronagraph observations from a Sun-Earth line view will continue, but from a satellite that is 14 years past its nominal mission lifetime. Additionally, while the NASA STEREO mission has demonstrated the utility of off-angle solar monitoring, the quality of off-angle coronagraph observations will diminish as the two satellites continue to depart from optimum position near the L4 and L5 Lagrangian locations and continue to separate in their heliocentric orbits.

Heliosphere: Reliable, operational observations of the solar wind and of the interplanetary magnetic field at L1 are perhaps the most important real-time data needed to create an effective level of operational space weather monitoring and forecasting. Currently, the availability of data for the heliospheric domain is heavily dependent on leveraged NASA assets. However, current real-time data provided by NASA research sensors are inadequate or may be interrupted during severe storm conditions, as demonstrated during the 2003 Halloween storms. Furthermore, the long-term continuity of NASA research-quality data is not assured through FY22. No current observational systems provide the capability to provide long-range forecasts of severe storms that have the potential to cause major impacts and drive most of the critical effects in geospace and on the surface. DSCOVR, along with the possibility of a potential commercial data buy solution, are planned and under consideration, respectively, as sequential follow-on replacements for ACE. While the current NOAA GOES-NOP satellites, which will transition to the GOES-R series after 2015, provide continuity of nowcasting, these satellites do not specifically address forecasting requirements. Current heliospheric imagery data provided by the Solar Mass Ejection Imager (SMEI) sensor on the Coriolis satellite, with its limited applicability to geomagnetic storm forecasting for Earth, will likewise be available only through the mid-term (4-7 years).

Magnetosphere: Key data for the magnetospheric domain are measurements of energetic charged particles. Measurements with thermal energies below 100 electron volts (eV) to 10's of keV are useful for surface charging assessments, while measurements of higher energy particles (in the MeV range) are used for high-latitude aviation interests, astronaut protection and to mitigate their deleterious effects on vehicle electronics. In addition, magnetic field measurements are important as they provide the means to assess the magnitude and progress of geomagnetic storms. A complete coverage of all relevant locations in geospace requires measurements along a variety of radial distances. Furthermore, it should be noted that data obtained from magnetospheric measurements alone strictly support only nowcasting and specifications, as well as post-event analyses. For forecasting purposes, solar wind measurements (e.g., from the L1 point or solar observations) are essential to augment even accurate specification of the current state of the magnetospheric environment. In the near-term (0-3 years) and midterm (4-7 years), the availability of leveraged energetic particle data from the pair of NASA RBSP spacecraft will provide good coverage of the magnetosphere during each 9-hour orbit period. Particle data from the NOAA GOES and POES spacecraft, along with the USAF DMSP satellites, provide supporting data, albeit with limited local time coverage. While there is the possibility to extend the lifetime of the RBSP, once this satellite mission ends the overall coverage of the magnetosphere will be substantially diminished. Space-based magnetic field measurements provided by the NOAA GOES and by the USAF DMSP are adequate but, again, limited in coverage. Ground-based magnetic field measurements available from the USGS network provide global warnings of geomagnetic storm activity, although localized regional warnings of geomagnetic storm intensity and duration would be enhanced through the use of international data from the INTERMAGNET consortium.

Aurora: Aurora formation begins with energetic solar particles following open magnetic field lines through the polar cusp into the Earth's polar regions. As the particles precipitate, they interact with atmospheric gas molecules and release large amounts of energy, some of which is in the visual spectrum. These visible emanations produce what is known as the Aurora Borealis and the Aurora Australis. Besides the visual aurora, the release of energy can cause scintillation within the polar ionosphere and ground-induced currents from the energized currents within the polar magnetic field. These conditions can change within seconds to minutes as the Earth experiences the sudden commencement of geomagnetic storms. Particle measurements available from the POES, MetOp and DMSP spacecraft are able to monitor the along-track location of the auroral boundary, as well as the auroral energy deposition from precipitating charged particles; the use of the DMSP UV scanning and limb sensors (SSUSI and SSULI) provides some off-track information as well. From these systems, coverage of the aurora domain is sufficient and provides continuous monitoring of auroral emissions and high-latitude scintillations.

Ionosphere: The ionosphere is a highly structured space weather domain, both vertically and horizontally. Ionospheric sounding data, available from the USAF DISS/NEXION network and other available international ionosondes, offer good vertical resolution, although the global coverage for these ground sensors is lacking. Powerful incoherent scatter radars can provide an excellent measurement of important ionosphere parameters and structure, but they too only cover a limited region and few exist worldwide. Although TEC measurements derived from ground-based GNSS receivers, such as the NASA JPL TEC and the NOAA CORS networks, can be extensive, this technique has poor vertical resolution and is currently limited to only land-based sites. The SSUSI and SSULI ultraviolet sensors on DMSP spacecraft provide some information, although the coverage is poor and the data latency from DMSP limits its stand-alone utility.

Likewise, the *in situ* sensors on DMSP provide information on ionospheric structure, but not continually, and only in a few local-time sectors. The planned COSMIC-2 system will provide unprecedented global coverage and sampling, although in this case, the horizontal resolution is limited. A preferred solution is to assimilate these diverse observational datasets into an environmental model which can then provide a global ionospheric specification. An example is the USAF GAIM model which is currently operational at AFWA and will soon be upgraded to a full physics-based version in 2014. The other aspect of this space weather domain is ionospheric scintillation which can have profound deleterious impacts on high-frequency radiowave communications and navigation, including precise geo-positioning. While the GPS radio occultation sensors on COSMIC-2 will be able to remotely sense GPS L-band scintillation, it is the availability of supporting observations, such as from the USAF C/NOFS and secondary sensors on board COSMIC-2, which will be able to monitor scintillation at other frequencies and aid in forecasting scintillation prior to their occurrence.

Upper Atmosphere: There are few operational assets available to sample the upper atmosphere at mesospheric (50 - 90 km) and thermospheric (90 - 1000 km) altitudes. The microwave radiometer on DMSP provides observations of mesospheric temperatures with limited altitude resolution and limited local time coverage. No observations of mesospheric winds are available operationally. Thermospheric neutral winds are observed by the Neutral Wind Meter (NWM), a single in situ sensor on the C/NOFS satellite that provides very limited altitude coverage and limited latitude coverage. However, visible light Doppler interferometers are under development with the capability to observe winds at a variety of thermospheric and mesospheric altitudes. Thermospheric neutral density profiles, neutral composition, and temperature observations are currently being provided for a range of altitudes (120 - 700 km), but with limited coverage in local time by the SSUSI and SSULI ultraviolet sensors on DMSP. The SENSE instrument, planned for operational demonstration in FY13, will carry an in situ sensor which provides neutral density, composition, and temperature at a fixed altitude (likely approximately 700 km). The proliferation of small in situ neutral density sensors on several orbit planes is one option for extending the local time coverage provided by the ultraviolet remote sensors on DMSP. These in situ sensors, however, are limited to altitudes above approximately 300 km, where satellite orbit lifetimes are prohibitively short due to effects of atmospheric drag. As in the case for the ionospheric domain, perhaps the best approach is to rely on atmospheric models that incorporate all available data, including calculated contributions from the coupled ionosphere.

Summary: The group's assessment of the ability of current and planned systems to satisfy documented space weather observing requirements is displayed in detail in Appendix 6. First, a detailed requirements analysis is presented for each of the six space weather domains, which includes an assessment of each observing system to measure the required environmental parameters within each of the domains (see Table 6-1 in Appendix 6). Second, detailed environmental parameter ratings for each of the five space weather phenomena are presented in terms of their impact/contribution on nowcasting, short-term forecasting, and long-term forecasting. These are evaluated for each relevant space environmental parameter, and then each parameter is prioritized as one of three factors: primary, secondary, or ancillary (see Table 6-2 in Appendix 6). A compilation of the detailed information from Appendix 6 is presented in Section 4.3 below.

4.3 Consolidated Analysis Results

A consolidated analysis of each space environmental parameter under each domain is presented in Table 3, below, which shows both the ability of current/planned instruments to meet observing requirements, as well as which environmental parameters are applicable to the five selected space weather phenomena at the three time scales (nowcasting, short-range forecasting, and long-range forecasting). The symbol and color assessments are directly linked to their respective environmental parameter ratings (EPR) from each domain worksheet for FY11 to FY22 (see Table 6-1 in Appendix 6). In terms of meeting requirements, those rated as "G" were the requirements that were mostly satisfied; "Y" were those requirements that were partly satisfied; "O" were those requirements that were addressed but with severe limitations; and "R" were those requirements that were not addressed or had severe limitations. As such, all were assigned the respective colors of green, yellow, orange, or red. Depending on the nature of the forecast requirements for a particular space weather scale, in some cases a "green" primary contributor (from Table 6-2 in Appendix 6) was sufficient to drive the overall roll-up assessment to green, whereas in other cases it was the ensemble of primary contributors that resulted in the overall roll-up color. Supporting contributors provided additional information for the roll-up, but these supporting contributors alone were not sufficient to drive the most favorable color. Ancillary contributors provided for the most part general situational awareness which represented at best a tertiary contribution to the overall score.

The top-level final roll-up chart presented in Table 4 provides a snapshot of the assessment to meet requirements to measure five key space weather phenomena. The symbol and color assessments are directly linked to their respective ratings for each environmental parameter used to monitor each phenomena from FY11 to FY22 (see Table 6-2 in Appendix 6), with a depiction of FY12, FY17, and FY21 as representative of years 0-3, 4-7, and 8-12, respectively. The ratings were directly traceable from this high level presentation to specific contributions provided by current and planned observational systems.

Common to both Tables 3 and 4, part (A) illustrates the degradation of operational capability should these key systems be lost due to launch/system failure, budget cuts, or other reasons (i.e., the "worst case" scenario where none of the identified key replacement/upgrade observing systems are available). Likewise, part (B) depicts the sustainment of current capabilities over time if all these key systems are maintained or replaced (i.e., the "best case" scenario).

When consolidating these requirements and considering the ability of the current/planned systems to monitor the five key space weather phenomena previously discussed, high-level impacts tied to few key systems become apparent. It is particularly noteworthy that the addition of planned replacements or new systems maintains or incrementally upgrades our current capabilities; as such, none of these planned/replacement systems meet all requirements. Perhaps even more importantly, this demonstrates the significant degradation in current capability should these planned/replacement systems not reach operational status. In other words, the Nation is at risk of losing critical capabilities that have significant economic and security impacts should these key space weather observing systems fail to be maintained and replaced. Considering the rapidly growing dependency on space-based and space-enabled systems, which have permeated most facets of modern society, space weather observing and forecasting capabilities used to mitigate potential impacts will become even more critical in the future.

Table 3. Requirements Satisfaction by Space Weather Domain (A) Worst Case

Domain and Category	Requirements Satisfaction												Geomag Storms			Radio Blackouts			Radiation Storms			Ionosph. Storms			Atmosph. Drag		
Solar Requirements	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Solar EUV & UV Flux	X	X	X	X	X	X	X	X	X	X	X	X												#			#
Solar EUV & UV Imagery	X	X	X	X	X	X	X	X	X	X	X	X	#			#			#	#		#	#				
Solar Magnetic Field	X	X	X	X	X	X	X	X	X	X	X	X	#			#			#			#					
Solar Radio Emissions (Total & spectral flux)	X	X	X	X	X	X	X	X	X	X	X	X	#			#						#			#	#	#
Solar Radio Burst: (Location, Type, Polarization)	X	X	X	X	X	X	X	X	X	X	X	X	#	#					#	#		#	#				#
Solar Imagery IR and Optical	X	X	X	X	X	X	X	X	X	X	X	X	#			#			#	#		#					
Solar Coronagraph	L	L	L	U	U	U	U	U	U	U	U	U	#						#	#		#			#		
Solar X-Ray Flux (total and discrete frequency)	X	X	X	X	X	X	X	X	X	X	X	X	#			#		#	#	#		#					#
Solar X-Ray Imagery	X	X	X	X	X	X	X	X	X	X			#			#			#	#		#					
Off-angle Solar Imagery (possibly L5)	X	X	X	L	L	L	L	L	L	L	L	L	#			#						#					
Helioseismology	X	X	X	X	X	X	X	X	X	X	X	X	#				#		#	#		#					
Heliosphere / Solar Wind	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Solar Wind: 3D Magnetic Field Components @ L1	X	X	X	L	L	L	L	L	L	L	L	L	#	#	#							#	#	#	#	#	#
SW Plasma Components: Comp, Den & Temp @ L1	L	L	L	U	U	U	U	U	U	U	U	U	#	#	#							#	#	#	#	#	#
Solar Wind: Speed and Direction @ L1	L	L	L	U	U	U	U	U	U	U	U	U	#	#	#							#	#	#	#	#	#
Sun-Earth Line based Heliospheric Imagery	U	U	U	U	U	U	U	U	U	U	U	U	#									#			#		
Off-Angle Heliospheric Imagery (L4 or L5)	L	L	L	U	U	[O]	[O]	[O]	[O]	[O]	[O]	[O]	#									#			#		
Solar Wind Radio Emissions	X	X	X	U	U	U	U	U	U	U	U	U	#									#			#		
Solar High Energy Protons and Cosmic Rays	X	X	X	X	X	X	X	X	X	X	X	X	#								#	#			#		
Solar Relativistic Electrons @ L1 or L2	L	L	L	U	U	U	U	U	U	U	U	U								#							
Off-Angle Solar Wind/Mag - In-situ (possibly L5)	X	X	X	L	L	L	L	L	L	L	L	L	#									#			#		
Magnetosphere	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Energetic Charged Particles: Energy & Flux	L	X	X	X	X	X	X	L	L	L	L	L			#			#			#			#		#	
Medium Charged Particles: Energy & Flux	L	X	X	X	X	X	X	L	L	L	L	L			#			#			#			#		#	
Trapped Radiation: Protons, Electrons, Waves	L	X	X	X	X	X	X	L	L	L	L	L			#						#		#	#			
Supra-thermal Charged Particles	L	X	X	X	X	X	X	L	L	L	L	L			#								#	#			
Magnetic Field - In-situ (GEO & LEO)	L	L	L	L	L	L	L	L	L	L	L	L			#									#			
Geomagnetic Field - Surface	X	X	X	X	X	X	X	X	X	X	X	X	#	#	#								#	#	#	#	
Aurora	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Auroral Boundary	X	X	X	X	X	X	X	X	X	X	X	X			#			#						#			#
Auroral Energy Deposition	X	X	X	X	X	X	X	X	X	X	X	X			#			#						#			#
Auroral Emissions & Imagery	L	L	L	L	L	U	U	U	U	U	U	U		#	#		#	#					#	#		#	#
Precipitating Charged Particles	X	X	X	X	X	X	X	X	X	X	X	X			#			#						#			#
Ionosphere	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Ionospheric Scintillation	L	L	L	L	L	L	L	L	L	U	U	U											#	#			
Plasma Density Fluctuations	L	L	L	L	L	L	L	L	L	L	L	(L)											#	#			
Plasma Temperatures (Te & Ti)	L	L	L	L	L	L	L	L	L	L	L	(L)												#			
Ionospheric Char: Layer Height & Density	L	L	L	L	L	L	L	L	L	L	L	U											#	#		#	
Energetic Ions (D-region absorption)	L	L	L	L	L	L	L	L	L	L	L	L						#									
Total Electron Content	L	L	L	L	L	L	L	L	L	L	L	U											#	#		#	
Electric Field	L	L	L	L	L	L	L	L	L	L	L	(L)			#								#	#		#	
D-Region Absorption	X	X	X	X	X	X	X	X	X	X	X	X						#									
Electron Density Profile	L	L	L	L	L	U	U	U	U	U	U	(U)						#									
Upper Atmosphere	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Mesospheric Temperature	U	U	U	U	U	U	U	U	U	U	U	(U)														#	#
Mesospheric Winds (Speed & Direction)	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]														#	#
Neutral Winds (Speed & Direction)	U	U	U	U	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]											#	#		#	#
Neutral Density, Composition & Temperature	L	L	L	L	L	U	U	U	U	U	U	(U)											#	#		#	#
Neutral Density Profile	L	L	L	L	L	U	U	U	U	U	U	(U)											#	#		#	#

Last Update: 3 April, 2012 (Worst Case)

LEGEND			
(green)	Meets requirements	X	Satisfactory (Fully or nearly meets requirements)
(yellow)	Meets most Requirements	L	Usable with limitations (Limited in capability and/or coverage)
(orange)	Meets some requirements	U	Usable with severe limitations (Limited in capability and/or coverage)
(red)	Fails to meet requirements	( )	Asset may not be available due to operational status, program funding, etc.
		[O]	No capability
		#	Environmental parameter is applicable to the space weather phenomenon

Table 3. Requirements Satisfaction by Space Weather Domain (continued)
(B) Best Case

Domain and Category	Requirements Satisfaction												Geomag Storms			Radio Blackouts			Radiation Storms			Ionosph. Storms			Atmosph. Drag		
Solar Requirements	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Solar EUV & UV Flux	X	X	X	X	X	X	X	X	X	X	X	X												#			#
Solar EUV & UV Imagery	X	X	X	X	X	X	X	X	X	X	X	X	#			#			#	#		#	#				
Solar Magnetic Field	X	X	X	X	X	X	X	X	X	X	X	X	#			#			#			#					
Solar Radio Emissions (Total & spectral flux)	X	X	X	X	X	X	X	X	X	X	X	X	#			#						#			#	#	#
Solar Radio Burst: (Location, Type, Polarization)	X	X	X	X	X	X	X	X	X	X	X	X	#	#					#	#		#	#				#
Solar Imagery IR and Optical	X	X	X	X	X	X	X	X	X	X	X	X	#			#			#	#		#					
Solar Coronagraph	L	L	L	L	L	L	L	L	L	L	L	L	#						#	#		#			#		
Solar X-Ray Flux (total and discrete frequency)	X	X	X	X	X	X	X	X	X	X	X	X	#			#		#	#	#		#					#
Solar X-Ray Imagery	X	X	X	X	X	X	X	X	X	X			#			#			#	#		#					
Off-angle Solar Imagery (possibly L5)	X	X	X	L	L	L	L	L	L	L	L	L	#			#						#					
Helioseismology	X	X	X	X	X	X	X	X	X	X	X	X	#				#		#	#		#					
Heliosphere / Solar Wind	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Solar Wind: 3D Magnetic Field Components @ L1	X	X	X	L	X	X	X	X	X	X	X	X	#	#	#							#	#	#	#	#	#
SW Plasma Components: Comp, Den & Temp @ L1	L	L	L	U	L	L	L	L	X	X	X	X	#	#	#							#	#	#	#	#	#
Solar Wind: Speed and Direction @ L1	L	L	L	U	L	L	L	L	X	X	X	X	#	#	#							#	#	#	#	#	#
Sun-Earth Line based Heliospheric Imagery	L	L	L	U	U	U	U	U	U	U	U	U	#									#			#		
Off-Angle Heliospheric Imagery (L4 or L5)	L	L	L	U	U	[O]	[O]	[O]	[O]	[O]	[O]	[O]	#									#			#		
Solar Wind Radio Emissions	X	X	X	U	U	U	U	U	U	U	U	U	#									#			#		
Solar High Energy Protons and Cosmic Rays	X	X	X	X	X	X	X	X	X	X	X	X	#								#	#			#		
Solar Relativistic Electrons @ L1 or L2	L	L	L	L	L	L	L	L	L	L	L	L								#							
Off-Angle Solar Wind/Mag - In-situ (possibly L5)	X	X	X	L	L	L	L	L	L	L	L	L	#									#			#		
Magnetosphere	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Energetic Charged Particles: Energy & Flux	L	X	X	X	X	X	X	L	L	L	L	L			#			#			#			#		#	
Medium Charged Particles: Energy & Flux	L	X	X	X	X	X	X	L	L	L	L	L			#			#			#			#		#	
Trapped Radiation: Protons, Electrons, Waves	L	X	X	X	X	X	X	L	L	L	L	L			#						#		#	#			
Supra-thermal Charged Particles	L	X	X	X	X	X	X	L	L	L	L	L			#								#	#			
Magnetic Field - In-situ (GEO & LEO)	L	L	L	L	L	L	L	L	L	L	L	L			#									#			
Geomagnetic Field - Surface	X	X	X	X	X	X	X	X	X	X	X	X	#	#	#								#	#	#	#	
Aurora	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Auroral Boundary	X	X	X	X	X	X	X	X	X	X	X	X			#			#						#			#
Auroral Energy Deposition	X	X	X	X	X	X	X	X	X	X	X	X			#			#						#			#
Auroral Emissions & Imagery	L	L	L	L	L	L	L	L	L	L	L	L		#	#		#	#					#	#		#	#
Precipitating Charged Particles	X	X	X	X	X	X	X	X	X	X	X	X			#			#						#			#
Ionosphere	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Ionospheric Scintillation	L	L	L	L	L	L	L	L	L	L	L	L											#	#			
Plasma Density Fluctuations	L	L	L	L	L	L	L	L	L	L	L	L											#	#			
Plasma Temperatures (Te & Ti)	L	L	L	L	L	L	L	L	L	L	L	L												#			
Ionospheric Char: Layer Height & Density	L	L	L	L	L	L	L	L	L	L	L	L											#	#		#	
Energetic Ions (D-region absorption)	L	L	L	L	L	L	L	L	L	L	L	L						#									
Total Electron Content	L	L	L	L	L	L	L	L	L	L	L	L											#	#		#	
Electric Field	L	L	L	L	L	L	L	L	L	L	L	L			#								#	#		#	
D-Region Absorption	X	X	X	X	X	X	X	X	X	X	X	X						#									
Electron Density Profile	L	L	L	L	L	L	L	L	L	L	L	L						#									
Upper Atmosphere	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now	Long	Short	Now
Mesospheric Temperature	U	U	U	U	U	U	U	U	U	U	U	U														#	#
Mesospheric Winds (Speed & Direction)	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]														#	#
Neutral Winds (Speed & Direction)	U	U	U	U	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]											#	#		#	#
Neutral Density, Composition & Temperature	L	L	L	L	L	U	U	U	U	U	U	U											#	#		#	#
Neutral Density Profile	L	L	L	L	L	U	U	U	U	U	U	U											#	#		#	#

Last Update: 3 April 2012 (Best Case)

LEGEND			
(green)	Meets requirements	X	Satisfactory (Fully or nearly meets requirements)
(yellow)	Meets most Requirements	L	Usable with limitations (Limited in capability and/or coverage)
(orange)	Meets some requirements	U	Usable with severe limitations (Limited in capability and/or coverage)
(red)	Fails to meet requirements	( )	Asset may not be available due to operational status, program funding, etc.
		[O]	No capability
		#	Environmental parameter is applicable to the space weather phenomenon

Table 4. Requirements Satisfaction by Phenomena

(A)Worst Case

	Nowcasts (Current Conditions)			Short-term Forecasts (minutes to hours)			Long-term Forecasts (hours to days)		
Timeline (years)	0-3	4-7	8-12	0-3	4-7	8-12	0-3	4-7	8-12
Geomagnetic Storms	G	G	G	Y (3)	O	O	Y (4)	O	O
Radio Blackouts	G	G	G	O	O	O	Y	Y	Y
Solar Radiation Storms	G	G	G	Y (2)	R	R	O	O	O
Ionospheric Storms	Y (1)	O	O	Y (3)	O	O	Y (4)	R	R
Atmospheric Drag	Y (1)	O	O	Y (3)	O	O	Y (4)	R	R

Substantial degradation over time if systems aren't sustained or replaced

G	Meets Requirements
Y	Limited Capability
O	Severely Limited Capability
R	Fails to Meet Requirements

(1) Reduced DMSP coverage from two to one orbits
(2) Loss of relativistic electron data SOHO.
(3) Uncertainty of solar wind data from L1 to replace ACE.
(4) Uncertainty of getting a space-based coronagraph to replace SOHO and STEREO data.

(B) Best Case

	Nowcasts (Current Conditions)			Short-term Forecasts (minutes to hours)			Long-term Forecasts (hours to days)		
Timeline (years)	0-3	4-7	8-12	0-3	4-7	8-12	0-3	4-7	8-12
Geomagnetic Storms	G	G	G	Y (3)	Y (5)	G	Y (4)	Y	Y
Radio Blackouts	G	G	G	O	O	O	Y	Y	Y
Solar Radiation Storms	G	G	G	Y (2)	Y	Y	O	O	O
Ionospheric Storms	Y (1)	Y	Y	Y (3)	Y	Y	Y (4)	Y	Y
Atmospheric Drag	Y	O	O	Y (3)	Y	Y	Y (4)	Y	Y

Requirements Satisfaction maintained or Improved if key systems are sustained or replaced

G	Meets Requirements
Y	Limited Capability
O	Severely Limited Capability
R	Fails to Meet Requirements

(1) COSMIC-2 deployed
(2) Relativistic electron data from SOHO are obtained.
(3) Solar wind data from L1 to replace ACE is obtained.
(4) Space-base coronagraphs on SOHO and STEREO are replaced.
(5) Advanced plasma sensor on DSCOVR follow-on obtained.

5. Key Findings

In performing the assessment of current and planned space weather observing systems and evaluating the ability of those systems to meet documented requirements, the JAG/SEGA made several key findings summarized below.

5.1 Summary of Key Findings

In performing its assessment, the JAG/SEGA reached the following key findings:

- A judicious mix of space-based and ground-based observing systems are currently used and needed to support operational space weather services.
    - The huge volume of the space environment means that even with the dozens of observing systems now used, there are still limited observational data to produce space weather forecasts.
- Research observing systems provide important data used to advance science; many of those also provide timely data and are used to support operational space weather services.
    - Several NASA heliospheric research missions will reach end-of-life within the next 10 years.
- Several NOAA and DoD space-based operational systems are scheduled to be replaced over the next 10 years subject to available funding.
- While ground-based systems are in important component to the space weather mission, sparse coverage limits their utility in meeting operational requirements.
- A number of foreign space-based and ground-based capabilities are used to help meet U.S. operational space weather needs.
    - More are available and provide the potential for future use.
    - While foreign data sources can provide additional capability, the economic and national security interests of the United States dictate that the nation not rely exclusively on foreign assets to conduct the critical space weather mission.
- Most unexploited data sources (foreign and domestic) are not currently used due to lack of reliable or timely access, excessive expense, policy/security restrictions, or other practical reasons. Also, these data sources offer secondary capabilities that cannot replace key, primary systems. Nevertheless, many offer added value that could incrementally improve forecasting and should be used when feasible and cost-effective.
- While space-based and ground-based observing systems are a critical components needed to meet operational requirements, they are inextricably linked to other parts of the space weather architecture (such as models and other space weather forecasting capabilities), and thus should not be considered alone when assessing our ability to meet requirements.

6. Summary

As part of the 2010 NASA Authorization Act, Congress asked OSTP to submit a report to the appropriate committees of Congress that (1) details the current data sources, both space- and ground-based, that are necessary for space weather forecasting; and (2) details the space- and ground-based systems that will be required to gather data necessary for space weather forecasting for the next 10 years. In turn, OSTP requested the assistance of the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM)-sponsored National Space Weather Program Council (NSWPC). The NSWPC immediately stood up the Joint Action Group for Space Environmental Gap Analysis (JAG/SEGA) to perform the assessment to provide the requested information to OSTP. The JAG/SEGA, comprised of 25 individuals from 15 different Federal organizations, analyzed current and planned space weather observing systems and assessed their ability to meet existing requirements formally documented by DOC (NOAA), DoD, and NASA. Interim results were presented to the NSWPC on August 2, 2011, with OSTP and OMB present as observers. This report constitutes the final results, which includes results from the JAG's assessment.

As the Sun approaches its next peak of solar activity, expected in 2013, our Nation faces multiplying uncertainties from increasing reliance on technologies for communications, navigation, security, and other activities, many of which both underpin our national infrastructure and economy and are vulnerable to the effects of space weather. Our Nation also faces increasing exposure to space-weather-driven human health risks as trans-polar flights and space activities, including space tourism and space commercialization, increase. Therefore, for the benefit of our national security, economy, and public welfare, it is more important than ever to ensure that the Nation's space weather observing and forecasting capabilities are supported and maintained.

APPENDICES

APPENDIX 1: NASA Authorization Act of 2010

The following excerpt from Section 809 of the NASA Authorization Act of 2010 is presented in its entirety, and shows the guidance from the Congress provided to the Office of Science and Technology Policy (OSTP) which resulted in this report.

SEC. 809. SPACE WEATHER.

(a) FINDINGS.—The Congress finds the following:

(1) Space weather events pose a significant threat to modern technological systems.

(2) The effects of severe space weather events on the electric power grid, telecommunications and entertainment satellites, airline communications during polar routes, and space-based position, navigation and timing systems could have significant societal, economic, national security, and health impacts.

(3) Earth and Space Observing satellites, such as the Advanced Composition Explorer, Geostationary Operational Environmental Satellites, Polar Operational Environmental Satellites, and Defense Meteorological Satellites, provide crucial data necessary to predict space weather events.

(b) ACTION REQUIRED.—The Director of OSTP shall—

(1) improve the Nation's ability to prepare, avoid, mitigate, respond to, and recover from potentially devastating impacts of space weather events;

(2) coordinate the operational activities of the National Space Weather Program Council members, including the NOAA Space Weather Prediction Center and the U.S. Air Force Weather Agency; and

(3) submit a report to the appropriate committees of Congress within 180 days after the date of enactment of this Act that—

(A) details the current data sources, both space- and ground-based, that are necessary for space weather forecasting; and

(B) details the space- and ground-based systems that will be required to gather data necessary for space weather forecasting for the next 10 years.

(from S. 3729—pages 30-31)

APPENDIX 2: JAG/SEGA Organization and Participants

The National Space Weather Program Council (NSWPC) established the Joint Action Group for Space Environmental Gap Analysis (JAG/SEGA) in April 2011, as a temporary body to conduct the assessment. The JAG/SEGA, under the leadership of two co-chairs, organized the assessment under six space weather domains, and appointed leads for the analysis performed for each domain. The complete list of JAG/SEGA leaders, other key personnel, domain leads, and participants is provided below.

Joint Action Group/Space Environmental Gap Analysis (JAG/SEGA)	
JAG/SEGA Leaders and Key Personnel	**Organization**
Dr. Bill Denig *(Co-chair)*	NOAA/NESDIS (DOC)
Col John Egentowich *(Co-chair)*	HQ USAF/A3O-W (DoD)
Michael Bonadonna *(Executive Secretary)*	OFCM
Jerry Sanders *(Aurora Domain Lead)*	AF Weather Agency (AFWA)
Dr. Arik Posner *(Heliosphere Domain Lead)*	NASA HQs
Kelly Hand *(Ionosphere Domain Co-Lead)*	AF Space Command / Aerospace Corp.
Dr. Therese Moretto Jorgensen*(Ionosphere Domain Co-Lead)*	National Science Foundation (NSF)
Dr. Michael Hesse *(Magnetosphere Domain Lead)*	NASA Goddard Space Flight Center
Bill Murtagh *(Solar Domain Lead)*	Space Weather Prediction Center (NOAA)
Clayton Coker *(Upper Atmos. Domain Lead)*	Naval Research Laboratory (NRL)
Dr. Mike Farrar *(Executive Secretary support)*	OFCM / Science & Technology Corp. (STC)
Participants	**Organization**
Jeff Cox	AFWA / Aerospace Corp.
Marsha Korose	DOD-OASD(NII)
Lt Col David Rodriguez	DOE-NNSA
Dr. James Head	Dept of State (DOS-OSAT)
Col Dan Edwards, Lt Col Chris Cantrell, Lt Col Brad Green	HQ USAF/A3O-WX
Dr. Chris St. Cyr, Dr. John Allen	NASA
Dr. Genene Fisher	NOAA/National Weather Service
Dr. Bob Robinson	National Science Foundation (NSF)
Dr. Simon Plunkett	Naval Research Laboratory (NRL)
Kevin Scro	USAF Space and Missile Center (SMC)
Dr. Jeffrey Love	U.S. Geological Survey (USGS)

APPENDIX 3: NOAA Space Weather Scales

NOAA Space Weather Scales

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).**	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).**	Kp=8	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).**	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).**	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).**	Kp=5	1700 per cycle (900 days per cycle)

* Based on this measure, but other physical measures are also considered.
** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.swpc.noaa.gov/Aurora)

Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. *** Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

* Flux levels are 5 minute averages. Flux in particles·s^{-1}·$ster^{-1}$·cm^{-2} Based on this measure, but other physical measures are also considered.
** These events can last more than one day.
*** High energy particle (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women are particularly susceptible.

Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 ($2x10^{-3}$)	Fewer than 1 per cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side of the Earth, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side of the Earth, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux, measured in the 0.1-0.8 nm range, in W·m^{-2}. Based on this measure, but other physical measures are also considered.
** Other frequencies may also be affected by these conditions.

URL: *www.swpc.noaa.gov/NOAAscales*

April 7, 2011

APPENDIX 4: Space Weather Impacts on Society

(Excerpted from the National Space Weather Program Strategic Plan, June 2010)

The following sections provide additional details on the impacts space weather has on advanced technologies and other activities that are so critical to the normal conduct of our daily lives.

A. ***Satellite Systems***. Space weather affects satellite missions in a variety of ways, depending on the orbit and satellite function. Our society depends on satellites for weather information, communications, navigation, exploration, search and rescue, research, national defense, future space travel, and routine business transactions, involving automated teller machines and charge card purchases. The impact of satellite system failures is more far reaching than ever before, and the trend will almost certainly continue.

Energetic particles that originate from the Sun, from interplanetary space, and from the Earth's magnetosphere continually impact the surfaces of spacecraft. Highly energetic ions penetrate electronic components, causing bit-flips in a chain of electronic signals that can result in spurious commands within the spacecraft or erroneous data from an instrument. These spurious commands have caused major satellite system failures that might have been avoided if ground controllers had had advance notice of impending particle hazards. Less energetic particles contribute to a variety of spacecraft surface charging problems, especially during periods of high geomagnetic activity. In addition, energetic electrons responsible for deep dielectric charging can degrade the useful lifetime of internal components.

Highly variable solar ultraviolet radiation continuously modifies terrestrial atmospheric density and temperature, affecting spacecraft orbits and lifetimes. Increased far ultraviolet radiation heats and expands the atmosphere, causing significant perturbations in low-altitude satellite trajectories. At times, these effects have been severe enough to cause premature re-entry of orbiting assets. It is important that satellite controllers be warned of these changes and that accurate models are in place to realistically account for the resulting atmospheric effects. The main problems due to drag effects are related to attitude control, orbit decay, and tracking of space debris. The existing and future spacecraft are also vulnerable to changes in atmospheric drag; re-entry calculations for such vehicles are highly sensitive to atmospheric density, and errors can threaten the safety of the vehicles and their crews.

> Japan launched Nozomi (1998)--its representative in an international fleet of Mars probes. A strong burst of solar energy (April 2002) knocked out the communications and electrical systems, ultimately altering its trajectory. The 11BYen ($88M) satellite will remain in a highly elliptical orbit around Mars but will not complete its mission.

The solar proton flux associated with intense solar activity can be strong enough to affect the sensitive guidance systems on launch vehicles and could cause damage to payloads. Because of the sensitivity and critical timing of most launch activities, space weather is a consideration in pre-launch scheduling and preparations. The enormous cost of launches and payloads demands that an accurate assessment be made at the time of launch.

B. ***Power Systems***. Modern electric power grids are extremely complex, extensive, and interrelated. The long power lines that link users throughout the Nation are susceptible to electric currents induced by the dramatic changes in high-altitude ionospheric currents that occur during geomagnetic storms. Surges in power lines from induced currents can cause massive network failures and permanent damage to transformers and to multimillion-dollar equipment in power-generation plants.

Present electric power distribution systems have acquired a much increased susceptibility to geomagnetically induced currents due to widespread grid interconnections, complex electronic controls and technologies, and large inter-area power transfers. The phenomenon occurs globally and simultaneously, and there is little redundancy or operating margin to absorb the effects. Mitigation of such effects is quite possible, provided that advance notice is given of an impending storm and specific strategies to minimize disruption and damage exist within the power industry. An equally important economic issue from the industrial standpoint is that of preventing or minimizing costly false alarms.

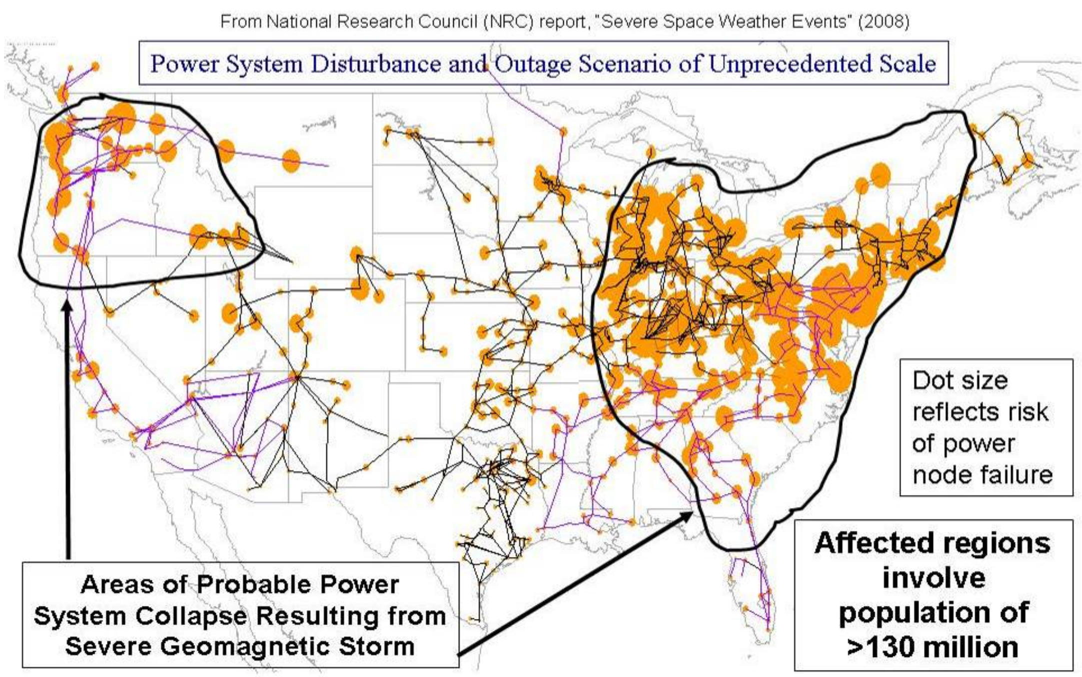

Figure 5-1. Simulation of ground induced current flows and possible power system collapse for the U.S. electric power grid due to an extreme geomagnetic super-storm disturbance scenario. (Source: Kappenman, J., W. Radasky, "Too Important to Fail", Space Weather, 3, 2005.)

Future so-called ‘smart’ grids may have greater susceptibilities to space weather impacts both because of the greater separation between wind and solar power generation sites and metropolitan centers and because of the sophisticated electronic command and control and power systems they will support.

C. *Navigation*. Most modern navigation systems depend upon satellites such as the Global Positioning System (GPS). A GPS receiver uses radio signals from several orbiting satellites to determine the range from each satellite and from these it determines its own precise geographic location. The radio signals must pass through the ionosphere, and significant errors in positioning can result when the signals are refracted and slowed by ionospheric conditions or intentional interference techniques. Use of advanced receiver technology, such as dual-frequency receivers, can eliminate some of the uncertainty. Ionospheric delay corrections for a region can be determined from a network of precisely positioned dual-frequency receivers, and then transmitted in near-real-time to users of single frequency GPS receivers in the region. This is the principle behind the U.S. Wide Area Augmentation System (WAAS) that is being developed by the Federal Aviation Administration (FAA) and the Department of Transportation (DOT) for use in precision flight approaches. However, rapidly varying structures in the ionosphere associated with sharp density gradients can have time scales faster than the WAAS message repetition rate of six minutes. This can lead to loss of availability for many hours, during extreme geomagnetic storm events—a problem that defines one of the greatest challenges to the WAAS program.

D. *Communications*. Communications at all frequencies are affected by space weather. High frequency (HF) radio communications are more routinely affected because this frequency depends on reflection by the ionosphere to carry signals great distances. Ionospheric irregularities contribute to signal fading; highly disturbed conditions, usually near the aurora and across the polar cap, can absorb the signal completely and make HF propagation impossible. Accurate forecasts of these effects can give operators more time to find an alternative means of communication. Telecommunications companies increasingly depend on higher frequency radio waves that penetrate the ionosphere and are relayed via satellite to other locations. Signal properties can be altered by ionospheric conditions so that they can no longer be received at the Earth's surface. This may cause degradation of signals, but, more importantly, can prohibit critical communications, such as those used in search and rescue efforts, military operations, and other critical computer-linked networks.

> In May 1998, communications were lost with a geostationary satellite. This affected 90 percent of the pager and cell networks in the United States, and also television, cable sources and numerous private networks (such as credit card transfers). Recovery involved moving spacecraft and using backup capabilities as available. At the time, the space environment had been disturbed for two weeks. Similar disruptions of the ionosphere have been associated with failures of spaceborne

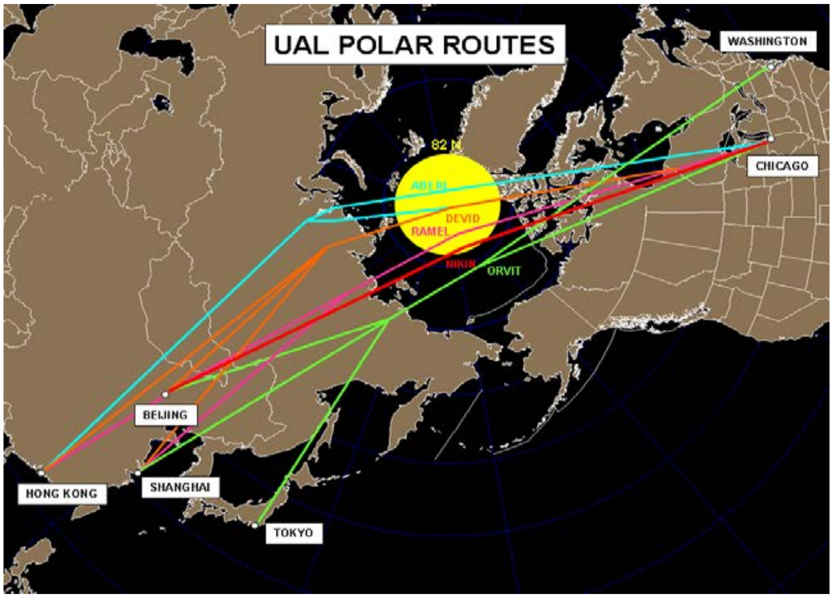

Figure 5-2. In 2009, United Airlines operated 1411 of the total 8527 polar flights, utilizing the four existing polar routes over Russia. *(Source: United Airlines, Mike Stills)*

E. ***Aviation***. Space weather impacts on aviation have long been recognized as a problem in military missions, especially high-altitude reconnaissance missions and flights over polar regions. Recent years have seen an immense growth in civil aviation. With commercial airliners flying higher and longer, the aviation industry has started to pay attention to space weather conditions that might affect equipment, crews, and passengers. The rapidly increasing number of flights between North America and the Far East that follow routes across the northern polar cap are cause for particular concern. Changes in the ionosphere caused by space weather can disrupt high frequency radio communications and disrupt or reduce the accuracy of satellite navigation systems. In addition, intense solar flares produce increased levels of high-energy particle radiation that add to the enhanced exposure to galactic cosmic rays already present at higher altitudes and latitudes. In common with the response to severe terrestrial weather, flights have been delayed or rerouted because of concerns over space weather, which can incur significant expenses for the airlines as well as potential health hazards for passengers and crews.

F. ***Human Space Exploration***.
Energetic particles present a health hazard to astronauts on space missions as well as threats to satellite systems. The atmosphere protects us from these particles since it ultimately absorbs all but the most energetic cosmic ray particles. During space missions, astronauts performing extra-vehicular activities are relatively unprotected. The fluxes of energetic particles can increase to dangerous levels (by factors of hundreds) following an intense solar flare or during a large geomagnetic storm. Timely warnings are essential to give astronauts sufficient time to return to their spacecraft prior to the storm’s arrival. Even during intra-vehicular activities, crew

> In 2001, during the inaugural launch of an Athena rocket with four payloads from Kodiak, Alaska, an intense solar flare with a strong proton storm caused numerous problems. The launch was ultimately delayed 72 hours. Nearby communications and HF radio were hampered for this entire time. The payload might have been damaged and the guidance system knocked out if the launch had gone as scheduled. A $3M booster and four-satellite payload were saved.

members are exposed to radiation levels well above any terrestrial occupation. Periods of increased solar activity only heighten the exposure. Adequate prediction of such events allows crew members to move to locations within their spacecraft that are more adequately shielded.

The same applies even more so to potential human excursions on wholly unprotected surfaces such as that of the Moon. Without appropriate countermeasures, an increase in cancer risk is most severe for flights that leave the protection of the Earth’s magnetosphere. This is particularly the case for longer duration human flights such as those to near-Earth objects or Mars, because of the long-term accumulated dose from penetrating galactic cosmic rays.

G. Surveying. Magnetic disturbances associated with geomagnetic storms precipitated by space weather directly affect operations that use the Earth’s magnetic field for guidance, such as magnetic surveys, directional drilling, or the use of magnetic compasses. Aeromagnetic surveys are an efficient but costly method of geophysical prospecting for minerals. These surveys can be seriously compromised if sudden disruptions of the Earth's magnetic field occur during the flights and are not sufficiently accounted for. Situational awareness and knowledge of space weather conditions is thus a necessary requisite in cost-effective geophysical surveying.

Figure 5-3. GPS precision surveying. *(Source: http://www.gps.gov)*

Directional, often horizontal, drilling is a technique employed by the oil and gas industry to extract the maximum amount from oil field reserves by drilling outward in many directions from a vertical rig. Magnetic field guidance is a cost-effective navigation technique for this but is prone to large inaccuracies during magnetic storms. Directional drilling requires a directional accuracy of 0.1 degree over a typical horizontal traverse of 5 to 10 km. The orientation of the Earth’s field at a North Sea location may change up to 0.2 degree daily. During a magnetic storm, deviations are often on the order of several degrees. Accurate position information translates into helpful geological information to guide drilling exploration in the deep ocean. Over vast areas of the ocean, precise positioning enables accurate altimeter measurements for ocean surveying ships to pinpoint desired drilling locations, which results in major reductions in time-on-station operational costs and enhanced success in the discovery of oil reserves.

H. *Mitigation Strategies*. Design engineers make use of information on space climate to specify the extent and types of protective measures that need to be designed into a system and to develop operating plans to minimize deleterious space weather effects. They also make use of space environment information, after the fact, to determine the sources of equipment failures and to develop corrective actions.

Response Options to Mitigate Space Weather Impacts

Satellites	• Turn off sensitive spacecraft subsystems. • Avoid satellite maneuvers during adverse space weather conditions. • Increase monitoring of satellite operations for anomalies. • Adjust calculations of low-Earth orbits to account for increased drag. • Reschedule launch activities to prevent damage or loss.
Electric power	• Prepare to reduce system load. • Disconnect system components. • Plan and schedule power station maintenance efficiently.
Navigation	• Prepare for use of backup systems. • Safely plan and schedule precision sensitive maneuvers.
Communications	• Seek alternate frequencies. • Alter ray paths or relay to undisturbed regions to avoid scintillation effects. • Prepare for use of alternate means of communication.
Aviation	• Reroute polar flights with minimal impact. • Prepare for Wide Area Augmentation System degradation.
Humans in space	• Increase specific protection against radiation exposure. • Plan and schedule extravehicular activities and launches efficiently. • Delay or postpone space tourism launches or activities to reduce radiation exposure.
Surveying	• Plan and schedule high-resolution geological surveying and exploration efficiently. • Plan and schedule high-resolution magnetic surveying efficiently.

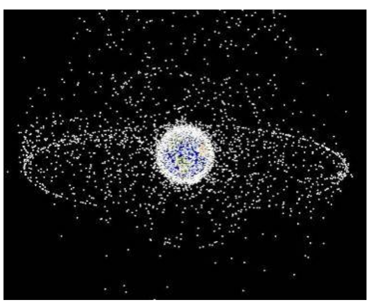

Figure 5-4. Orbit Debris Simulation *(Source: NASA Johnson Space Center)*

I. ***Space Weather in a Broader Context***. Space weather research, observations, and technology development have broader application to other disciplines important to modern civilization. For example, the knowledge gained in studying solar processes can be applied to research on solar variability on long-time scales and its association with climate change. The Sun is the dominant forcing factor responsible for the Earth's climate, and variations in total solar irradiance may be causally linked to changes in regional environmental conditions. Although the National Space Weather Program concentrates on explosive space weather variations (i.e. solar flares and coronal mass ejections) that can have an immediate effect on terrestrial systems and space travelers, the understanding of solar dynamo processes, resulting from space weather research, can also contribute to studies of more long-term variations in solar radiation.

Similarly, mitigating hazards to spacecraft resulting from orbital debris is becoming increasingly more challenging as the number of space objects continues to grow exponentially. The ability to avoid collision with debris requires accurate tracking of objects under the influence of constantly changing atmospheric densities. Space weather research allows for more accurate specification and forecasting of atmospheric density and better predictions of orbits.

While the approach of Near-Earth Objects (NEO) cannot be avoided, space weather observational assets include space-based and ground-based instruments capable of detecting and tracking objects that may potentially impact the Earth. To meet space weather objectives, these observational capabilities undergo continuous improvement in sensitivity and coverage, thereby increasing the probability of early detection of approaching objects and the accuracy of subsequent tracking of those objects. An example is the Large Angle and Spectrometric Coronagraph (LASCO) instrument on the Solar and Heliospheric Observatory (SOHO) that, in the process of continuously observing the Sun, has also observed many previously undiscovered comets. These data can be used for orbit determination and potential threat identification.

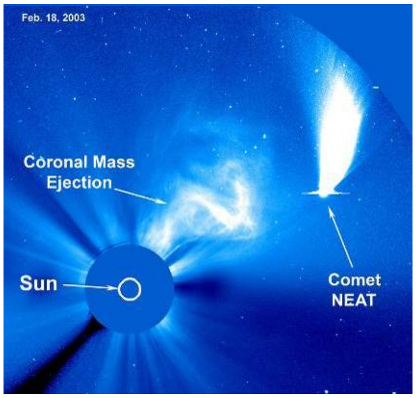

Figure 5-6. Comet NEAT passed through SOHO's coronagraph field of view. *(Source: NASA Goddard Space Flight Center)*

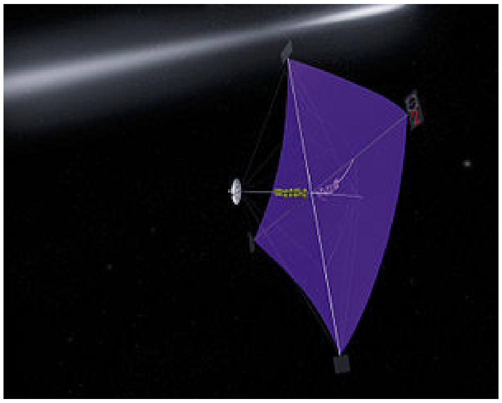

Figure 5-7. Artist's concept of a solar sail-powered spacecraft. *(Source: NRC Decadal Survey, courtesy of NASA Marshall Space Flight Center.)*

Another important technology area is plasma science, which aims to study the behavior of ionized gases. Because the entire space weather system is dominated by magnetized plasma, space weather research will advance understanding of basic plasma processes—knowledge that can be applied to the development of new technologies. These include industrial and medical devices, lighting and laser equipment, fusion and energy production, and many others.

New propulsion and power technologies are needed to enable further planetary and heliospheric missions. An important part of any space mission is the ability to loft a spacecraft into space and propel it to its intended orbit or destination. Solar sails have long been envisioned as a simple, inexpensive means of propulsion that could provide access to and maintenance of unstable orbits that would otherwise require large, expensive propulsion systems. Solar sails have the potential to provide earlier solar wind warning. The potential of solar sails is being explored for a number of missions and has, in fact, been tested in space. The National Research Council 2003 Decadal Survey on Solar and Space Physics strongly recommended continued research and development of this technology.

APPENDIX 5: Requirements for Space Weather Observing

For each space weather domain, several physical parameters are required to be measured in order to adequately analyze the state of the space weather environment. Each of these required space weather observing requirements are described below in more detail, along with relevant impacts each may have that are important to operational users.

Sun/Solar Domain

Solar EUV &UV Flux: Extreme Ultraviolet (EUV) radiation has major impacts on the Ionosphere. An excess can result in radio blackouts of terrestrial High Frequency (HF) communications. EUV emissions also reduce the lifetime of Low Earth Orbiting (LEO) satellites by causing increased atmospheric drag. They do this by depositing large amounts of energy in Earth's upper atmosphere (thermosphere), causing it to expand into these satellites' orbits. Consequentially, EUV measurements aid in preserving ground-based radio communications and navigation systems, as well as satellite orbit.

Solar EUV and UV Imagery: Space-based solar EUV imagery provides space weather forecasters with images of the Sun in several different EUV spectral bands. These high resolution images reveal details about the structure of active solar regions. Higher-level products made from this imagery provide early warning of potential hazards, such as radiation storms, solar flares and radio blackouts, and geomagnetic storms.

Solar Magnetic Field: A key component in solar flare and radiation storm forecasting. They indicate locations where there is an accumulation of magnetic field on the Sun's surface. Changes in the structure and connections of these fields often lead to eruptions on the Sun.

Solar Radio Emissions (Total and spectral flux): Emissions of the Sun at radio wavelengths from centimeters to decameters, under quiet conditions. This is also used as a proxy for EUV emissions, which have major impacts on the ionosphere. EUV emissions reduce the lifetime of Low Earth Orbiting (LEO) satellites by causing increased atmospheric drag. Radio emissions (2800 MHz) aid in preserving ground-based radio communications and navigation systems, as well as satellite orbit.

Solar Radio Burst (Location, Type, Polarization): Emissions of the Sun at radio wavelengths from centimeters to decameters, under disturbed conditions. Both ground- and space-based measurements are used for space weather forecasting, and to alert customers impacted by solar radio bursts. Key sectors serviced with solar radio burst information include, emergency response, navigation, aviation, and communications.

Solar Imagery (IR and Optical): Ground-based solar Imagery products provide space weather forecasters with various images of the Sun. These images reveal details about the structure of active solar regions. Higher-level products made from these imagery products provide early warning of potential hazards, such as radiation storms, solar flares and radio blackouts, and geomagnetic storms.

Solar Coronagraph: Coronagraph imagery provides critical information for early warning of a geomagnetic storm (20-90 hours). Geomagnetic storms can have a significant impact on our Nation’s electric power industry, satellite operations, space missions, navigation, and communication systems. Timely and accurate geomagnetic storm warnings provide emergency managers, government officials, and space weather sensitive businesses the information necessary to develop preparedness plans to mitigate geomagnetic storm impacts on critical infrastructure.

Solar X-Ray Flux (total and discrete freq.): Solar X-ray flux provides the data for NOAA’s Solar Flare Radio Blackout alerts in the NOAA Space Weather Scales. These Radio Blackouts impact critical communications and GPS systems, and are an important input to radiation and geomagnetic storm forecasts. X-ray data also provide the basis for critical unclassified and classified warnings for DoD missions.

Solar X-Ray Imagery: The Solar X-Ray imagery provides space weather forecasters with images of the Sun, critical for space weather forecasting. These images reveal details about the structure of active regions associated with sunspots. Derived products made from the imagery provide early warning of potential hazards, such as radiation storms, solar flares and radio blackouts, and geomagnetic storms.

Off-angle Solar Imagery: The Earth's L5 Lagrange point, separated from the Earth by 60 degrees in heliographic longitude, is an excellent location for solar imagers. Active solar regions on the far side can be viewed before rotating into geoeffective position allowing early warning of potential problems to technology. The L5 point is also an appropriate location for making side-view observations of geo-effective coronal mass ejections, critical for timely and accurate warning of geomagnetic storms. With advance warning, important mitigating actions can be taken by the electric utilities to ensure the stability of the Nation’s power grid.

Helio-seismology: Provides information of the magnetic activity at the far side of the Sun by using a helioseismology technique. The Sun is oscillating continuously because of waves propagating in the solar interior and bouncing at the surface. This technique can be used to calculate maps of active regions at the surface of the far-side of the Sun by observing the oscillations on the Sun’s front-side. This helps forecasters understand solar region development before the region rotates into geoeffective position on the front side of the Sun, allowing early warning of potential problems to technology. This also allows for better support to deep space missions anywhere in the heliosphere.

Heliosphere Domain

Solar Wind (3D Mag. Field Components): In-situ measurements of the Interplanetary Magnetic Field (IMF), encountered at L1 tens of minutes to one hour before it is swept over the Earth with the solar wind, are used to forecast the IMF conditions at Earth. Components of the IMF that couple to the geomagnetic field can cause geomagnetic storms. The dominant causal factor for storms is the IMF Bz component with significant negative values resulting in more geo-effective coupling between the solar wind and the magnetosphere, but IMF Bx and By in GSE coordinates can contribute depending on season and time of day. The magnitude of the IMF is typically several nanoTesla (nT) the several tens of nT.

Solar Wind Plasma Components (Composition, Density, and Temperature): In-situ measurements of the thermal characteristics of the solar wind plasma are used to forecast the occurrence of geomagnetic storms. The dominant operational element is the solar wind density which, when combined with the solar wind bulk speed, is used to calculate the solar-wind pressure on the dayside magnetopause. The solar wind density typically ranges from less than 1 up to approximately 100 protons/cm^3, while the calculated solar wind pressure (P_{SW}) ranges from .1 to 400 nanoPascals (nP).

Solar Wind, Speed, and Direction (3D Plasma Velocity Components): In-situ measurements of the solar wind bulk plasma flow are used, in conjunction with the solar wind density, to forecast and most precisely time the occurrence of geomagnetic storms. The solar wind speed is typically in the range of several hundred km/s but can reach speeds of approximately 2000 km/s during extreme events. (See the previous discussion on the solar wind dynamic pressure.)

Sun-Earth line Heliospheric Imagery: Remote-sensing measurements of visible light scattered by solar wind electrons along a line of sight. The method is most effective for observing the dynamics of transient disturbances that propagate away from the Sun-Earth line. Early detection of transient disturbances is being used in connection with solar wind global modeling to forecast the arrival of geomagnetically active solar wind structures at Earth hours to days ahead of time. The method complements in-situ measurements from L1. It is not capable of detecting the internal structure of the transient magnetic field and the arrival time accuracy is much worse (approximately 6 hours) as compared to the in situ solar wind method (minutes). The speed of transient disturbances close to the Sun is in the range of several hundred to approximately 4,000 km/s, which in concert with the field of view defines the minimum cadence of imagery required for this type of measurement. The observations can coincide with significant fluxes of solar energetic protons.

Off-angle Heliospheric Imagery: Remote-sensing measurements of light scattered by solar wind electrons along the line of sight. The method is effective in observing the dynamics of transient disturbances that propagate along the Sun-Earth line. Early detection of transient disturbances is being used in connection with solar wind global modeling to forecast the arrival of geomagnetically active solar wind structures at Earth hours to days ahead of time. The method complements in-situ measurements from L1. It is not capable of detecting the internal structure of the transient magnetic field and the arrival time accuracy, although better than Sun-Earth line Heilospheric imagery, is still worse than the in situ solar wind method. The speed of transient disturbances is in the range of several hundred to approximately 4,000 km/s, which in concert with the field of view defines the minimum cadence of imagery required for this type of measurement. The observations can coincide with significant fluxes of solar energetic protons.

Solar Wind Radio Emissions: Remote-sensing measurement of radio waves generated at shock waves ahead of major transient disturbances with the potential to forecast some geomagnetic disturbances days in advance. This method can identify whether a transient disturbance drives a major shock wave in the solar wind. The speed of the transient disturbance can be inferred through the drift in radio frequency. However, current capability to utilize the observations to infer directionality of the disturbance and thus to answer the question of whether or which part of the disturbance will encounter the Earth are limited. The frequency-range of type-II bursts spans from approximately 150 MHz close to the Sun down into kHz at larger distances. Space-based observations are necessary to cover the heliospheric propagation of transient disturbances due to the ionospheric cut-off at around 15 MHz. The method cannot provide information about the more frequent transient disturbances that do not drive significant shock waves and it cannot provide information about the magnetic structures within those disturbances that do.

Solar Relativistic Electrons: *In-situ* observations of near-light-speed electrons generated in solar energetic particle (SEP) events. All SEPs that cause proton radiation exposure risks to astronauts generate relativistic electrons. SEPs drive astronauts' risk for short-term equivalent dose rate exposure during any human operations in interplanetary space, on the moon, or in high-latitudes segments of low-Earth orbit. Utilizing the faster propagation speed from the Sun to 1 AU, relativistic electrons measured outside the Earth's magnetosphere provide forecasting potential on the order of tens of minutes to hours for all prompt SEP events at proton energies of tens of MeV, the minimum threshold energy for protons that could affect astronauts vital organs. Relativistic electrons of >500 keV occur with intensities up to 10^5/ cm^2 s sr MeV and can coincide with significant fluxes of solar X-rays.

Solar High Energy Protons and Cosmic Rays: In-situ observations of the flux of energetic protons. The rapidly changing energetic proton flux from solar energetic particle (SEP) events and the more constant galactic cosmic rays (GCRs) drives and translates directly into equivalent dose rates for astronauts. The measurement is vital to human operations in interplanetary space, on the moon, or in high-latitudes segments of low-Earth orbit. The energetic proton flux from SEPs and GCRs can also affect radiation-sensitive space hardware such as electronics and charged coupled devices. SEP forecasting potential of tens of minutes to a few hours exists only at relativistic (GeV) proton energies. Utilizing the faster propagation speed from the Sun to 1 AU, this measurement can be utilized to forecast onsets of fluxes of prompt major SEP events at lower proton energies of tens of MeV, the minimum threshold energy for protons that could affect astronauts' vital organs. The method cannot provide forecasts for the more frequent SEP events that do not generate relativistic protons though. Energetic protons of tens of MeV occur with intensities up to 10^4 /cm^2 s sr MeV.

Off-angle Solar Wind In Situ Parameters: *In-situ* measurement of the Interplanetary Magnetic Field (IMF) at 1 AU at a location that corotating, quasi-stationary solar wind structures encounter days before they are swept over the Earth. This method is in a limited way useful to forecast from the L5 point geomagnetically active fast solar wind stream structures during the solar minimum. However, the method cannot be used during solar active periods or applied to any transient disturbances from the Sun that are the cause of all major geomagnetic disturbances. For measurement parameters compare with the first 3 items described for this domain related to the Solar Wind.

Magnetosphere Domain

Energetic Ions and Protons (Energy & Flux): Spacecraft internal electrostatic discharge effects are caused by high-energy electrons (> 100 keV) that exist, for example, in the dynamic outer radiation belt of the Earth, typically located inside geosynchronous orbit, but extending beyond during periods of strong geomagnetic activity. Accompanying ion measurements are needed to specify the system in preparation for predictive models, and as a source population for acceleration to even higher energies. Deep dielectric discharging affects robotic and human missions alike.

Medium Charged Particles (Total Flux and Energy): Spacecraft surface charging is caused by low-energy (< 100 keV) electrons, which are abundant, for example, in the inner magnetosphere during magnetospheric substorms. Strong differential surface charging can lead to discharges and equipment damage on both robotic and human space missions. Ion measurements are required for assessment of total spacecraft charge, as the latter is a balance of electron flux, ion flux, and photo ionization.

Trapped Particles (Protons, Electrons, Waves): Single event upset effects are due to high-energy (> 10 MeV) protons and heavier ions generated, for example, in solar flares and in coronal mass ejection (CME) shock fronts, or by particle decay processes. These particles can be trapped in the Earth's inner radiation belts. Electron measurements are important also to predict the evolution of radiation levels. Particles of these energy levels are harmful to humans in space, and they can lead to erroneous commanding on both human and robotic missions.

Supra-thermal through Auroral Energy Particles (Diff. Dir., Energy, Flux): Auroral downward electron flux in the energy range of tens of eV to 10 keV is affecting spacecraft primarily through surface charging effects. Strong differential surface charging can lead to discharges and equipment damage on both robotic and human space missions.

Magnetic Field Strength and Direction: The extent and evolution of geomagnetic activity in space are monitored by means on magnetic sensors in inner magnetospheric missions, including on geosynchronous orbit. These measurements are important for the assessment of impacts, determination of the overall state of the system, and for input into models.

Earth Surface Geomagnetic Fields: The extent and evolution of geomagnetic activity, as well as present impacts on the power grid, are monitored by means on magnetic sensors on the surface of the Earth. These measurements are important for the assessment of impacts, determination of the overall state of the system, and for input into models.

Aurora Domain

Auroral Boundaries (Equatorial and Polar): In situ and remote measurements of the poleward and equatorward extent of the Aurora Borealis and the Aurora Australis. This information is used by DoD and Civil authorities to predict impacts to a variety of users including U.S. early warning radars and power supply companies, and input to ionospheric specification models. Primary input to this parameter is the lower energetic particle monitors (30 eV to 30 KeV).

Auroral Energy Deposition: In situ and remote measurements of the particle environment in the auroral zone. This information is used by DoD and Civil authorities to predict impacts to a variety of users including U.S. early warning radars and power supply companies, and input to spacecraft drag specification/predictive models. Primary input to this parameter is the lower energetic particle monitors (30 eV to 30 KeV).

Auroral Emissions & Imagery (UV, Visible and IR): *In situ* and remote measurements of the aurora leading edge luminosity. This information is currently provided by the DMSP SSUSI, SSULI, OLS Photo Multiplier Tube, and the VIIRSDay-Night Band on the Suomi NPP satellite.

Precipitating Particles/Electrons (20 eV-1 KeV; 1 KeV-50 KeV): *In situ* and remote measurements of the particle environment in the auroral zone. This information is used by DoD and Civil authorities to predict impacts to a variety of users including U.S. early warning radars and power supply companies, and input to spacecraft drag specification/predictive models. Primary input to this parameter is the lower energetic particle monitors (30 eV to 30 KeV).

Ionosphere Domain

Ionospheric Scintillation (Phase and Amplitude): Ionospheric scintillation refers to the measurement of rapid fluctuations in both amplitude and phase of radio waves propagating through the ionosphere. This degradation in the fidelity of the electromagnetic signal is caused by variations in electron density along the transmission path. Being able to specify and forecast ionospheric scintillation enables users of satellite communication and/or terrestrial-based HF communications, GPS-aided navigation, and military radar systems to attribute, predict, and mitigate the effects of scintillation on their systems and associated operational activities.

Plasma Density Fluctuations: This environmental parameter refers to the direct measurement of plasma density spatial variations which distort the propagation through space of radio wave signals and are responsible for radio wave scintillation (see Ionospheric Scintillation). Impacted mission operations include GPS navigation, SATellite COMmunications (SATCOM), HF communications, space surveillance radars and missile warning/defense radars. Steep horizontal density gradients and unstable vertical density structures; that is, ionospheric bubbles, are the principal sources of plasma density fluctuations in the ionosphere that can severely degrade radio-based navigation and communications. Having operational knowledge of ionospheric conditions and their associated system impacts enables system users and operators to mitigate the effects on their particular systems or to implement work-around solutions to assure mission success.

Plasma Temperature (Te & Ti Plasma Temps): Temperature of ions and electrons constituting the space plasma. Being able to measure this parameter is used as an additional driver (e.g. to electric field data) for operational specification and forecast ionospheric density and scintillation models. For general applications, see descriptions above for Ionospheric Scintillation and Plasma Density Functions.

Ionospheric Characterizations (Layer Height & Freq.): The ionospheric electron density profile (EDP) exhibits several peaks with the F2-peak being the largest and most important. Accurate knowledge of the heights and plasma frequencies of the reflective layers of the ionosphere and the plasmasphere is critical for continuous and high quality HF radio reception.

Energetic Ions (D region absorption): These are energetic ions (approximately 1-500 MeV) of sufficient flux into the polar caps to cause ionization down to and including the D-region and thereby cause absorption of HF signals. When this ionization happens, radio waves propagating through those heights are absorbed, sometime to the extent that HF communications across the polar cap are impossible (i.e. aircraft or ground polar communications blackout). These energetic ions are also covered in the magnetospheric section.

Total Electron Content (TEC): This is a measure of the number of electrons in a volume of air along a signal path, in numbers of electrons per square meter. Today, this important measurement is usually taken by space and ground-based GPS (also other country navigation satellite signal) receiver enabled sensors. The time difference of arrival of the two navigation signals (L1 and L2) is used to calculate the total # of electrons between the satellite and the receiver. These data are fed into operational assimilation models that support operational communications, GPS, radar system operators and users to account for the actual and predicted effects of the ionosphere on their systems and activities.

Electric Field: This parameter provides the electrodynamic characteristic of the ionosphere. Electromagnetic forces constitute a main source for ionospheric variability and electric field data are essential for predicting changes in ionospheric density conditions. In addition, large electric fields can drive plasma instabilities; creating ionospheric irregularities that lead to scintillation (see I-1). Specifically, electric field data in the auroral and polar cap regions are needed for real-time input to operational space environment models of the magnetosphere, ionosphere and upper atmosphere. Magnetospheric models use electric field data to enable operational users and decision makers to assess and predict conditions associated with spacecraft anomalies. Upper atmospheric models use electric field data as a key input to predict the amount of drag due to changing heat input into the upper atmosphere and the resulting density changes. This knowledge is incorporated into accurately maintaining the space catalog, enhancing the efficiency and effectiveness of the nation's limited space surveillance sensors, and increase satellite operator confidence as to when to maneuver to avoid collisions. Accurate ionospheric predictions can help users of satellite communication and/or terrestrial-based HF communication systems, GPS-aided systems, and radar systems mitigate the effects of scintillation on their systems and assure mission success.

D-region Absorption: D-region absorption is due to energetic ions (associated with solar energetic proton events) at energies sufficient to penetrate to the D-region height of the ionosphere. The collisions between these ions and the upper atmosphere ionize neutral atoms or molecules and produce free electrons and a resulting enhanced D-region ionosphere across the polar cap. When this ionization happens, the energy of radio waves propagating through those heights are absorbed, sometime to the extent that HF communications across the polar cap are impossible (i.e., polar communications blackout).

Electron Density Profile (Density, Features, and Composition): Describes the vertical profile of electron density through the ionosphere. This is used to determine layer heights and densities (I-4) and as input to ionospheric specification and forecast models (see Plasma Density Functions). An EDP is often the output of an assimilative model that is fed by a series of space and ground-based measurements (e.g. ionosponde, GPS Occultation, ground-based or space-based Total Electron Content monitor).

Upper Atmosphere Domain

Mesospheric Temperature: Remotely sensed measurements of temperature in the Earth's atmosphere from 50 km to 100 km are used to specify the conditions in the mesosphere. Waves and tides with origins in the lower stratosphere and troposphere propagate through the mesosphere, modify the general circulation of the atmosphere, and transfer energy into the thermosphere. The magnitude of the temperature ranges from 280 K (7°C) at the lower altitudes to 170 K (-103°C) at the upper altitudes.

Mesospheric Wind (Speed & Direction): Remotely sensed measurements of vector wind speed in the Earth's atmosphere from 50 - 100 km altitude are used to specify the conditions in the mesosphere. Waves and tides with origins in the lower stratosphere and troposphere propagate through the mesosphere, modify the general circulation of the atmosphere, and transfer energy into the thermosphere. The magnitude of the wind is typically a few 10's of m/s and is measured up to a few 100's of m/s.

Neutral Winds (Speed & Direction): In situ and remotely sensed measurements of vector wind speed of neutral gas in the Earth's atmosphere from 90 km to 500 km altitude are used to specify the movement of neutral gas in the thermosphere. Neutral winds play a major role in the redistribution of plasma in the ionosphere and contribute to atmospheric drag of objects in the near Earth space environment. The magnitude of the neutral wind is typically a few 100's of m/s and is measured up to 1500 m/s.

Neutral Density, Composition, and Temperature: In situ and remotely sensed measurements of neutral gas density, atomic composition, and temperature in the Earth's atmosphere from 90 km to 4000 km altitude are used to specify the conditions in the thermosphere. The thermosphere is the primary contributor to atmospheric drag of objects in the near Earth space environment. The distribution, composition and temperature of neutral gases in the thermosphere play key roles in the production and loss of plasma in the ionosphere. Neutral density ranges from $2x10^{-19}$ g/cm^3 at the upper altitudes to $5x10^{-9}$ g/cm^3 at the lower altitudes in the thermosphere. The neutral gas at 100 km altitude is primarily composed of molecular Nitrogen (N_2), molecular Oxygen (O_2) and atomic Oxygen (O) with much smaller percentages of Helium (He) and Hydrogen (H). Above approximately 200 km, Oxygen (O) becomes the dominant constituent and above 500-600 km the lighter gases Helium (He) and Hydrogen (H) become dominate. Temperature at the bottom of the thermosphere is about 170 K and rises dramatically with altitude to values that are quite variable and often well above 1000 K.

Neutral Density Profile: Remotely sensed measurements of neutral gas density as a function of altitude are used to specify the conditions in the thermosphere from 90 km to 4000 km altitude. Global observations of neutral density profiles provides for improved atmospheric drag estimation at all altitudes. The altitude distribution of neutral gases in the thermosphere plays a key role in the production and loss of plasma in the ionosphere. Neutral density ranges from $2x10^{-19}$ g/cm^3 at the upper altitudes to $5x10^{-9}$ g/cm^3 at the lower altitudes in the thermosphere.

APPENDIX 6: Gap Analyses by Space Weather Domain

The general methodology used by the JAG in its assessment was a 4-tiered rating scheme based, in general, on the level of "satisfaction." This term, satisfaction, is subject to interpretation, although the JAG took pains to apply these rating is a consistent manner across each of the domain spreadsheets as they applied to the requirements for each environmental parameter and in the roll-up to the final overall color chart (see Table 4). The ratings used for the asset ratings (AR) and the environmental parameter ratings (EPR), along with the corresponding colors for requirements satisfaction, are summarized in the box below and described in further detail in the narrative that follows. While subjective color ratings are mostly intuitive for the casual reader, they do represent, in fact, the quantitative analysis that the JAG undertook in its space environmental gap analysis.

	AR	EPR	Color
Satisfactory	X	X	Green[1]
Applicable with limitations	L	L	Yellow[1]
Applicable with severe limitations	U	U	Orange
Little or no capability	blank	[O]	Red

[1]For the AR assessment, the questionable availability of a given asset led to a color downgrade.

Asset Ratings (AR) -- Table 6-1: Within each spreadsheet, the various assets or systems that do or may contribute to an environmental parameter are assessed for each year covered by this study. If an asset effectively contributed to the documented requirements for an environmental parameter, it was marked with the symbol "X." If the asset contributed with modest limitations, then the asset in each year was marked with the symbol "L." If the asset contributed with severe limitations, then it was marked with the symbol "U." If this particular asset was not available within a given year, then the entry was left blank. The ratings were further quantified by the use of parentheses "( )" to indicate that the availability of the asset was not assured. The cell for each year was then color coded using the following rules; an "X" was green, "(X)" was yellow, "L" was yellow, (L) was orange, "U" was orange, "(U)" was orange (no distinction), and a blank cell as left unfilled. Within the asset ratings, no consideration was given to coverage; that is, the amount of global coverage that was provided by a particular system architecture, although in some cases the coverage limitations were noted in the "Comments" column.

Environmental Parameter Ratings (EPR) -- Table 6-2: The contributions from various assets were then "rolled-up" to the environmental parameter level to determine in the ensemble of assets how well the documented requirements for that parameter were met, including coverage. The ratings were as follows: (1) "X" was used if the requirements were mostly met; (2) "L" was used if the requirements were met with modest limitations; (3) "U" was used if the requirements were addressed with severe limitations; and (4) "[O]" was used if no asset was available to contribute meaningfully to the environmental parameter. The rules for the cell fill colors were: "X" was green, "L" was yellow, "U" was orange, and "[O]" was red.

Table 6-1. Observing Platform Asset Ratings by Space Environment Domains
(A) Sun/Solar Domain

Environmental Parameter	Platform/Asset (owner)	Requirements			Measurement Type				Data Availability												Comments
		DOC	DOD	NASA	Space	Ground	In-situ	Remote	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	
Solar EUV & UV Flux		T	T	T					X	X	X	X	X	X	X	X	X	X	X	X	
	GOES-R/EXIS (DOC)	*		*	#			#						X	X	X	X	X	X	X	GOES-R // Launch: FY15 / Operational: FY16 (Guess)
	POES/SBUV (DOC)	*			#			#	X	X	X										POES // EOL: FY13
	SDO/EVE (NASA)	*		*	#			#	X	X	X	X	X	X	(X)						SDO // EOL: FY16
Solar EUV & UV Imagery		T		T					X	X	X	X	X	X	X	X	X	X	X	X	
	GOES-R/SUVI (DOC)	*			#			#						X	X	X	X	X	X	X	GOES-R // Launch: FY15 / Operational: FY16
	SOHO/EIT (NASA)	*	*	*	#			#	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	SOHO Currently Operating in "Bogart Mode"
	SDO/AIA (NASA)	*		*	#			#	X	X	X	X	X	X	(X)						SDO // EOL: FY16
	STEREO/SECCI/EUVI (NASA)	*		*	#			#	X	X	X	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	STEREO // EOL: FY13 (extention subject to senior review)
Solar Magnetic Field		T	T	T					X	X	X	X	X	X	X	X	X	X	X	X	
	GONG LOS MAGNETOGRAM (NSO)	*	*	*		#		#	X	X	X	X	X	X	X	(X)	(X)	(X)	(X)	(X)	Funded by DoD; Line of-sight (LOS) only
	SEON/SOON (DoD)	*	*			#		#	X	X											
	SEON ISOON (DoD)	*	*			#		#						X	X	X	X	X	X	X	
	SOHO/MDI (NASA)	*		*	#			#	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	SOHO Currently Operating in "Bogart Mode"
	SDO/HMI (NASA)			*	#			#	X	X	X	X	X	X	(X)						SDO // EOL: FY16
Solar Radio Emissions (Total & spectral flux)		T	T						X	X	X	X	X	X	X	X	X	X	X	X	
	SEON/RSTN (DoD)	*	*			#		#	X	X	X	X	X	X	X	X	X	X	X	X	Extended operations / RSTN upgrade in FY14 / Lacking polarization information (SWPC)
	PENTICTON/CANADA (NRCC)	*	*			#		#	X	X	X	X	X	X	X	X	X	X	X	X	Foreign Dependency - non operational asset
Solar Radio Burst: (Location, Type, Polarization)				T					X	X	X	X	X	X	X	X	X	X	X	X	
	SEON/RSTN (DoD)	*	*			#		#	L	L	L	L	L	L	L	L	L	L	L	L	Extended operations / RSTN upgrade in FY14
	Korean Radio Research Agency RIMS (.02-18GHz)	*				#				X	X	X	X	X	X	X	X	X	X	X	
	STEREO/SWAVES (NASA)	*		*	#		#		X	X	X	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Proof of Principle only
Solar Imagery IR and Optical		T	T	T					X	X	X	X	X	X	X	X	X	X	X	X	
	SEON/SOON (DoD)	*	*			#		#	X	X											
	GONG White light / H-alpha (NSO)	*	*	*		#		#	X	X	X	X	X	X	(X)	(X)	(X)	(X)	(X)	(X)	Anticipate DoD Support FY13-16
	SEON/ISOON (DoD)	*	*			#		#						X	X	X	X	X	X	X	ISOON // FOC: FY16
	National/International Assets	*	*			#		#	X	X	X	X	X	X	X	X	X	X	X	X	
Solar Coronagraph		T	T	T					L	L	L	U	U	U	U	U	U	U	U	U	
	SOHO/LASCO (NASA)	*	*	*	#			#	L	L	L	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	SOHO //EOL: FY13 (DOC L1 requirement); Lack of severe storm coverage
	STEREO/SECCHI/COR1&COR2 (NASA)	*		*	#			#	L	L	L	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	STEREO // EOL: FY13; DOC requirement is L5; Less than optimum geometry beyond L4/L5
Solar X-Ray Flux (total and discrete frequency)		T	T	T					X	X	X	X	X	X	X	X	X	X	X	X	
	GOES-NOP/XRS (DOC)	*		*	#			#	X	X	X	X	X	X	X	X	X	X			GOES N-O-P // EOL: FY20
	GOES-R/EXIS (DOC)	*		*	#			#						X	X	X	X	X	X	X	GOES-R // Launch: FY15 / Operational: FY16
Solar X-Ray Imagery			T	T					X	X	X	X	X	X	X	X	X	X			Mission objectives satisfied by GOES-R/SUVI FY16-FY22
	GOES-NOP/SXI (DOC)	*		*	#			#	X	X	X	X	X	X	X	X	X	X			GOES N-O-P
Off-angle Solar Imagery (possibly L5)		T		T					X	X	X	L	L	L	L	L	L	L	L	L	
	STEREO/SECCI/EUVI (NASA)	*	*	*	#		#		X	X	X	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Proof of Principle only
Helioseismology		T		T					X	X	X	X	X	X	X	X	X	X	X	X	
	GONG/FT (NSO)	*		*		#		#	X	X	X	X	X	X	X	X	X	X	X	X	Assumed continuity of funding
	SDO/HMI (NASA)	*		*	#			#	X	X	X	X	X	X	(X)	(X)	(X)	(X)	(X)	(X)	SDO // EOL: FY16

Table 6-1. Observing Platform Asset Ratings by Space Environment Domains
(B) Heliosphere Domain

Environmental Parameter	Platform/Asset (owner)	Requirements			Measurement Type				Data Availability												Comments
		DOC	DOD	NASA	Space	Ground	In-situ	Remote	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	
Solar Wind: 3D Magnetic Field Components @ L1		T	T	T	#		#		X	X	X	L	L	L	L	L	L	L	L	L	
	ACE/MAG (NASA)	*	*	*	#		#		X	X	X	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	ACE extension subject to SR and National Needs Assessment; late extended phase s/c
	WIND/MFI (NASA)				#		#		L	L	L	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	Wind extension subject to SR and National Needs Assessment; late extended phase s/c, s/c
	DSCOVR/Plasma-Mag (DOC)	*	*	*	#		#						(X)	(X)	(X)	(X)	(X)				DSCOVR // Launch: 2015
	DSCOVR F/O (DOC)	*	*	*	#		#										(X)	(X)	(X)	(X)	Under consideration
SW Plasma Components: Comp, Den & Temp @ L1		T	T	T	#		#		L	L	L	U	U	U	U	U	U	U	U	U	with DSCOVR, Commercial Data Buy
	ACE/SWEPAM (NASA)	*	*	*	#		#		L	L	L	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	[1]Does not fulfill requirements (SEP susceptibility); late extended phase s/c
	WIND/SWE (NASA)				#		#		L	L	L	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	Subject to SR; Does not fulfill requirements (SEP susceptibility); late extended phase s/c
	DSCOVR/Plasma-Mag (DOC)	*	*	*	#		#						(L)	(L)	(L)	(L)	(L)				DSCOVR // Launch: 2015 [1]Does not fulfill requirements (Speed range)
	DSCOVR F/O (DOC)	*	*	*	#		#										(X)	(X)	(X)	(X)	*Very uncertain*
Solar Wind: Speed and Direction @ L1		T	T	T	#		#		L	L	L	U	U	U	U	U	U	U	U	U	With DSCOVR, Commercial Data Buy
	ACE/SWEPAM (NASA)	*	*	*	#		#		L	L	L	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	Subject to SR; Does not fulfill requirements (SEP susceptibility); late extended phase s/c
	WIND/SWE (NASA)				#		#		L	L	L	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	Subject to SR; Does not fulfill requirements (SEP susceptibility); late extended phase s/c
	DSCOVR/Plasma-Mag (DOC)	*	*	*	#		#						(L)	(L)	(L)	(L)	(L)				DSCOVR // Launch: 2015; Does not fulfill requirements (Speed range)
	DSCOVR F/O (DOC)	*	*	*	#		#										(X)	(X)	(X)	(X)	Very uncertain
Sun-Earth Line based Heliospheric Imagery		T	T	T	#			#	U	U	U	U	U	U	U	U	U	U	U	U	
	CORIOLIS/SMEI (DoD)				#			#													Not presently useful within operations
	SOHO/LASCO[1] (NASA)	*	*	*	#			#	U	U	U	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	(U)	[1]Does not fulfill requirements (limited NRT, SEP susceptibility); late extended phase s/c
Off-Angle Heliospheric Imagery (L4 or L5)		T		T	#			#	L	L	L	U	U	(O)	(O)	(O)	(O)	(O)	(O)	(O)	
	STEREO/SECCHI/HI (NASA)	*	*	*	#			#	L	L	L	(L)	(L)								Moves too far past L4 and L5; Does not fulfill requirements (SEP susceptibility)
Solar Wind Radio Emissions					#			#	X	X	X	U	U	U	U	U	U	U	U	U	
	STEREO/SWAVES (NASA)			*	#			#	X	X	X	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Moves too far beyond L4, L5; Proof of Principle only
	WIND/WAVES (NASA)				#			#	L	L	L	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	Subject to SR; Does not fulfill requirements (SEP susceptibility); Late extended phase s/c
Solar High Energy Protons and Cosmic Rays		T	T	T	#	#	#		X	X	X	X	X	X	X	X	X	X	X	X	
	GOES-NOP/HEPAD (DOC)	*	*	*	#		#		X	X	X	X	X	X	X	X	X	X			GOES N-O-P SEM // EOL: FY20
	GOES-R/SGPS & EHIS (DOC)	*	*	*	#		#							X	X	X	X	X	X	X	GOES-R SIESS // Launch: FY15 / Operational: FY16
	ACE/SIS[1] (NASA)			*	#		#		L	L	L	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(X): ACE extension subject to SR and National Needs Assessment [1]Does not fulfill requirements (E
	THULE NEUTRON MONITOR (DoD)	*	*			#	#		L	L	L	L	L	L	L	L	L	L	L	L	Operated by AFRL [1]Does not fulfill requirements (E range)
	LANL GPS/BDD & CXD (DoD/DOE)		*		#		#		(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Hosted on GPS but data feeds potentially available from LANL
	LANL GEO/SOPA & ESP & SABRS (DOE)		*		#		#		(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Data feeds potentially available from LANL
	Neutron Monitor Data Base[1] (ESA)			*		#	#		L	L	L	L	L	L	L	L	L	L	L	L	
Solar Relativistic Electrons @ L1 or L2		T	T	T	#		#		L	L	L	U	U	U	U	U	U	U	U	U	
	SOHO/COSTEP[1] (ESA-NASA)	*	*	*	#		#		L	L	L	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	Limited NRT coverage, lack of severe storm coverage; late extended phase s/c
Off-Angle Solar Wind/Mag - In-situ (possibly L5)		T			#		#		X	X	X	L	L	L	L	L	L	L	L	L	
	STEREO/IMPACT (NASA)	*	*	*	#		#		X	X	X	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Solar wind magnetic field; Proof of Principle only
	STEREO/PLASTIC (NASA)	*	*	*	#		#		X	X	X	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Solar wind density, velocity, temperature; Proof of Principle only

Table 6-1. Observing Platform Asset Ratings by Space Environment Domains (C) Magnetosphere Domain

Environmental Parameter	Platform/Asset (owner)	Requirements			Measurement Type				Data Availability												Comments
		DOC	DOD	NASA	Space	Ground	In-situ	Remote	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	
Energetic Charged Particles: Energy & Flux		T	T	T					L	X	X	X	X	X	X	L	L	L	L	L	L where assets fulfill mission requirements but overall sensor coverage is insufficient
	RBSP/MagEIS			*	#		#			X	X	X	X	X	X						Launch FY12, science lifetime FY14, extended mission tbd, Rad-belt appropriate orbit
	GOES-NOP/EPEAD (DOC)	*	*	*	#		#		X	X	X	X	X	X	X	X	X	X			GOES N-O-P // EOL: FY20
	GOES-R/SGPS (DOC)	*	*	*	#		#							X	X	X	X	X	X	X	GOES-R // Launch: FY15 / Operational: FY16
	POES/SEM-2/TED (DOC)	*	*	*	#		#		L	L											Data feeds potentially available from LANL
	MetOp/SEM-2 (EUMETSAT)	*	*		#		#		L	L	L	L	L	L	L	L	L	L	L	L	
	LANL GPS/BDD & CXD (DoD/DOE)		*		#		#		(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Hosted on GPS but data feeds potentially available from LANL
	LANL GEO/SOPA & ESP (DOE)		*		#		#		(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Data feeds potentially available from LANL
Medium Charged Particles: Energy & Flux		T	T	T					L	X	X	X	X	X	X	L	L	L	L	L	L where assets fulfill mission requirements but overall sensor coverage is insufficient
	RBSP/HOPE			*	#		#			X	X	X	X	X	X						Launch FY12, science lifetime FY14, extended mission tbd
	GOES-NOP/MAGP/ED (DOC)	*	*	*	#		#		X	X	X	X	X	X	X	X	X	X			GOES N-O-P // EOL: FY20
	GOES-R MPS-HI (DOC)	*	*	*	#		#							X	X	X	X	X	X	X	GOES-R // Launch: FY15 / Operational: FY16
	POES/SEM-2/MEPED (DOC)	*	*	*	#		#		L	L											Data feeds potentially available from LANL
	MetOp/SEM-2 (EUMETSAT)	*	*		#		#		L	L	L	L	L	L	L	L	L	L	L	L	
	LANL GPS/BDD & CXD (DoD/DOE)		*		#		#		(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Hosted on GPS but data feeds potentially available from LANL
	LANL GEO/SOPA (DOE)		*		#		#		(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Data feeds potentially available from LANL
Trapped Radiation: Protons, Electrons, Waves		T	T	T					L	X	X	X	X	X	X	L	L	L	L	L	L where assets fulfill mission requirements but overall sensor coverage is insufficient
	RBSP/REPT			*	#		#			X	X	X	X	X	X						Launch FY12, science lifetime FY14, extended mission tbd
	GOES-NOP/MAGP/ED (DOC)	*	*	*	#		#		X	X	X	X	X	X	X	X	X	X			GOES N-O-P // EOL: FY20
	GOES-R MPS-HI (DOC)	*	*	*	#		#							X	X	X	X	X	X	X	GOES-R // Launch: FY15 / Operational: FY16
	POES/SEM-2/MEPED (DOC)	*	*	*	#		#		L	L											Data feeds potentially available from LANL
	MetOp/SEM-2 (EUMETSAT)	*	*		#		#		L	L	L	L	L	L	L	L	L	L	L	L	
	LANL GPS/BDD & CXD (DoD/DOE)		*		#		#		(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Hosted on GPS but data feeds potentially available from LANL
	LANL GEO/SOPA & ESP (DOE)		*		#		#		(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Data feeds potentially available from LANL
Supra-thermal Charged Particles		T	T	T					L	X	X	X	X	X	X	L	L	L	L	L	L where assets fulfill mission requirements but overall sensor coverage is insufficient
	RBSP/MagEIS			*	#		#			X	X	X	X	X	X						Launch FY12, science lifetime FY14, extended mission tbd
	LANL GEO/MPA & SABRS (DOE)		*		#		#		X	X	X	X	X	X	X	X	X	X	X	X	Data feeds potentially available from LANL
	DMSP/SSJ4 (DoD)		*		#		#		L	L	L	L	L	L	L	L	L	L	L	(L)	EOL for DMSP F-19 (2021)
	MetOp/SEM-2 (EUMETSAT)	*	*		#		#		L	L	L	L	L	L	L	L	L	L	L	L	
	POES/SEM-2/TED (DOC)	*	*	*	#		#		L	L											Data feeds potentially available from LANL
	GOES-R MPS-LO (DOC)	*	*	*	#		#							X	X	X	X	X	X	X	GOES-R // Launch: FY15 / Operational: FY16; Useful for limited regions of the GEO orbit
Magnetic Field - In-situ (GEO & LEO)		T	T	T					L	L	L	L	L	L	L	L	L	L	L	L	L due to lack of LEO sensors
	GOES-NOP/MAG (DOC)	*	*	*	#		#		X	X	X	X	X	X	X	X	X	X			GOES N-O-P // EOL: FY20
	GOES-R /MAG (DOC)	*	*	*	#		#							X	X	X	X	X	X	X	GOES-R // Launch: FY15 / Operational: FY16
	DMSP/SSM (DoD)		*		#		#		X	X	X	X	X	X	X	X	X	X	X	(X)	EOL for DMSP F-19 (2021)
Geomagnetic Field - Surface		T	T						X	X	X	X	X	X	X	X	X	X	X	X	
	Ground-based Magnetometers (USGS)	*	*	*		#	#		X	X	X	X	X	X	X	X	X	X	X	X	Limited global coverage
	International Magnetometers	*	*	*		#	#		L	L	L	L	L	L	L	L	L	L	L	L	INTERMAGNET enhanced usage and connectivity; Derived indices

Table 6-1. Observing Platform Asset Ratings by Space Environment Domains (D) Aurora Domain

Environmental Measurement	Platform/Asset (owner)	Requirements			Measurement Type				Data Availability												Comments
		DOC	DOD	NASA	Space	Ground	In-situ	Remote	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	
Auroral Boundary		T	T						X	X	X	X	X	X	X	X	X	X	X	X	
	THEMIS All-sky camera network (CSA)					#		#	U	U											Status unknown, Canadian asset
	AMPERE (NSF)				#		#		L	L	L	L	L	L	L	L	L	L	L	L	Caveat: Field-aligned current boundaries don't necessarily correspond to auroral oval boundary
	DMSP/SSJ (DoD)		*		#		#		X	X	X	X	X	X	X	X	X	X	X	(X)	EOL for DMSP F-19 (2021)
	POES/MetOp SEM-2/LEPS (DOC)	*			#		#		X	X	X	X	X	X	X	X	X	X	X	X	
	SuperDARN (NSF)								(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	National & international assets - *TBD*
Auroral Energy Deposition		T	T						X	X	X	X	X	X	X	X	X	X	X	X	
	DMSP/SSUSI (DoD)		*		#			#	X	X	X	X	X	X	X	X	X	X	X	(X)	Energy flux can be inferred from LBH observations; EOL for DMSP F-19 (2021)
	AMPERE (NSF)				#		#		L	L	L	L	L	L	L	L	L	L	L	L	Could use to get Joule heating inputs
	DMSP SSJ (DoD)		*		#		#		X	X	X	X	X	X	X	X	X	X	X	(X)	Current stated EOL for DMSP is 2021 per CSAT
	POES/MetOp SEM-2/LEPS (DOC)	*			#		#		X	X	X	X	X	X	X	X	X	X	X	X	
Auroral Emissions & Imagery		T	T						L	L	L	L	L	U	U	U	U	U	U	U	
	DMSP/SSUSI (DoD)		*		#			#	X	X	X	X	X	U	U	U	U	U	U	U	Partial aororal zone only; Also DMSP OLS (poor)
	DMSP/SSULI (DoD)		*		#			#	L	L	L	L	L	U	U	U	U	U	U	U	Potential of SSULI data to contribute to auroral characterization not fully explored
	DMSP/OLS (DoD)		*		#			#	U	U	U	U	U	U	U	U	U	U	U	U	Used for situational awareness only
	NPP/VIIRS-DNB (DOC)	*								U	U	U									Will be used for situational awareness only
	JPSS/VIIRS-DNB (DOC)	*												(U)	(U)	(U)	(U)	(U)	(U)	(U)	Will be used for situational awareness only
	THEMIS All-sky camera network (CSA)					#		#	U	U	(U)										Status unknown, Canadian asset
Precipitating Charged Particles		T	T	T					X	X	X	X	X	X	X	X	X	X	X	X	
	DMSP/SSUSI (DoD)		*		#			#	L	L	L	L	L	U	U	U	U	U	U	U	DMSP F-19 // EOL: FY21; Latency > 120 min; Terminator orbit problematic
	DMSP SSJ (DoD)		*		#		#		X	X	X	X	X	X	X	X	X	X	X	(X)	EOL for DMSP F-19 (2021)
	POES-MetOp SEM-2/LEPS (DOC)	*		*	#		#		X	X	X	X	X	X	X	X	X	X	X	X	

Table 6-1. Observing Platform Asset Ratings by Space Environment Domains
(E) Ionosphere Domain (1 of 2)

Environmental Parameter	Platform/Asset (owner)	Requirements			Measurement Type				Data Availability												Comments
		DOC	DOD	NASA	Space	Ground	In-situ	Remote	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	
Ionospheric Scintillation		T	T						L	L	L	L	L	L	L	L	L	U	U	U	
	SCINDA (DoD)		*			#		#	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Mostly Equatorial; Limited release outside DoD; Included within C/NOFS
	C/NOFS/Beacon (DoD)		*		#			#	L	L	L										C/NOFS // EOL: FY12; Extended mission uncertain; Equatorial only
	COSMIC-2/GNSSRO (DOC)	*	*		#			#					(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	COSMIC-2-L (SSAEM): FY15-19; COSMIC-2-H: FY18-23; L-band scintillation only
	COSMIC-2/SSAEM/BEACON (DoD)		*		#			#					(X)	(X)	(X)	(X)	(X)				COSMIC-2-L (SSAEM): FY15-19; COSMIC-2-H: FY18-23; Required ground receivers
	SENSE/GPSRO (DoD)		*		#			#			L	L									SENSE // EOL: FY14; Single satellite; Limited coverage
Plasma Density Fluctuations			T						L	L	L	L	L	L	L	L	L	L	L	(L)	
	DMSP SSIES		*		#		#		L	L	L	L	L	L	L	L	L	L	L	(L)	DMSP F-19 // EOL: FY21; Latency > 120 min; Capability never implemented
	C/NOFS PLP (DoD)		*		#		#		L	L	L										C/NOFS // EOL: FY12; Extended mission uncertain; Equatorial only;
	COSMIC-2/SSAEM/PLP (DoD)		*		#		#						(X)	(X)	(X)	(X)	(X)				COSMIC-2-L (SSAEM): FY15-19; COSMIC-2-H: FY18-23; SSAEM Langmuir probe
	SENSE/WINCS (DoD)		*		#		#				L	L									SENSE // EOL: FY14; Single satellite; Limited coverage
Plasma Temperatures (Te & Ti)		T	T						L	L	L	L	L	L	L	L	L	L	L	(L)	
	DMSP SSIES		*		#		#		L	L	L	L	L	L	L	L	L	L	L	(L)	DMSP F-19 // EOL: FY21; Latency > 120 min; Capability not fully utilized
	C/NOFS PLP (DoD)		*		#		#		L	L	L										C/NOFS // EOL: FY12; Extended mission uncertain; Equatorial only;
	C/NOFS/IVM (DoD)		*		#			#	L	L	L										C/NOFS // EOL: FY12; Extended mission uncertain; Equatorial only;
	SENSE/WINCS (DoD)		*		#		#				L	L									SENSE // EOL: FY14; single satellite; Limited coverage
	COSMIC-2/SSAEM/PLP (DoD)	*	*		#		#						(X)	(X)	(X)	(X)	(X)				COSMIC-2-L (SSAEM): FY15-19; COSMIC-2-H: FY18-23; SSAEM Langmuir probe
	COSMIC-2/SSAEM/IVM (DoD)	*	*		#		#						(X)	(X)	(X)	(X)	(X)				COSMIC-2-L (SSAEM): FY15-19; COSMIC-2-H: FY18-23; SSAEM driftmeter
Ionospheric Char: Layer Height & Density		T	T						L	L	L	L	L	L	L	L	L	L	L	U	
	DISS Ionosonde (DoD)		*			#		#	L	L											DISS // EOL: FY12; Not complete global coverage
	NEXION Ionosonde (DoD)		*			#		#	L	L	L	L	L	L	L	L	L	L	L	L	NEXION // FOC: FY17, fielding 30 sites around the globe, for AF "backbone" system
	International Ionosondes (DOC)	*	*			#		#	L	L	L	L	L	L	L	L	L	L	L	L	Leveraged capability; Limited coverage with ~70 international sites - optimum ~400
	DMSP/SSULI (DoD)		*		#			#	L	L	L	L	L	U	U	U	U	U	U	U	DMSP F-19 // EOL: FY21; Latency > 120 min; Terminator orbit problematic
	DMSP/SSUSI (DoD)		*		#			#	L	L	L	L	L	U	U	U	U	U	U	U	DMSP F-19 // EOL: FY21; Latency > 120 min; Terminator orbit problematic
	COSMIC/GPS-RO (NSF)		*		#			#	L	L	(L)	(L)									COSMIC // EOL: FY12; Extended mission uncertain; Limited spatial coverage
	COSMIC-2/GNSSRO (DOC)	*	*		#			#					(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	COSMIC-2-L (SSAEM): FY15-19; COSMIC-2-H: FY18-23; Limited horizontal resolution
	C/NOFS GPSRO (DoD)		*		#			#	L	L	L										C/NOFS // EOL: FY12; Extended mission uncertain; Equatorial only;
	SENSE/GPSRO (DoD)		*		#			#			L	L									SENSE // EOL: FY14; Single satellite; Limited coverage
	SENSE/CTIP (DoD)		*		#			#			L	L									SENSE // EOL: FY14; Single satellite; Limited coverage
	Incoherent Scatter Radars (NSF)					#		#	L	L	L	L	L	L	L	L	L	L	L	L	Leverage capability; Limited national & internation coverage; Limited NRT capability
Energetic Ions (D-region absorption)		T	T						L	L	L	L	L	L	L	L	L	L	L	L	
	POES-MetOp SEM-2/MEPED (DOC)	*			#		#		L	L	L	L	L	L	L	L	L	L	L	L	Single satellite, limited local time coverage

Table 6-1. Observing Platform Asset Ratings by Space Environment Domains (E) Ionosphere Domain (2 of 2)

Environmental Parameter	Platform/Asset (owner)	Requirements			Measurement Type				Data Availability												Comments
		DOC	DOD	NASA	Space	Ground	In-situ	Remote	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	
Total Electron Content		T	T	T					L	L	L	L	L	L	L	L	L	L	L	U	
	JPL/TEC (NASA)		*			#		#	L	L	L	L	L	L	L	L	L	L	L	L	Mostly CONUS-based; Incomplete global coverage
	NGS CORS/TEC (DOC)	*				#		#	L	L	L	L	L	L	L	L	L	L	L	L	Incomplete global coverage
	SCINDA/GPS (DoD)		*			#		#	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Mostly Equatorial; Limited release outside DoD; Included within C/NOFS
	NGA/GPS (DoD)		*			#		#	L	L	L	L	L	L	L	L	L	L	L	L	Only 13 realtime stations
	GPS/USNDS TEC (DoD/DOE)		*		#			#	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Hosted on GPS but data feeds potentially available from LANL
	DMSP/SSULI (DoD)		*		#			#	L	L	L	L	L	L	L	L	L	L	L	(L)	DMSP F-19 // EOL: FY21; Latency > 120 min; Terminator orbit problematic
	DMSP/SSUSI (DoD)		*		#			#	L	L	L	L	L	L	L	L	L	L	L	(L)	DMSP F-19 // EOL: FY21; Latency > 120 min; Terminator orbit problematic
	COSMIC/GPS-RO (NSF)		*		#			#	L	L	(L)	(L)									COSMIC // EOL: FY12; Extended mission uncertain; Limited spatial coverage
	COSMIC-2/GNSSRO (DOC)	*	*		#			#					(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	COSMIC-2-L (SSAEM): FY15-19; COSMIC-2-H: FY18-23; Limited horizontal resolution
	C/NOFS GPSRO (DoD)		*		#			#	L	L	L										C/NOFS // EOL: FY12; Extended mission uncertain; Equatorial only;
	SENSE/GPSRO (DoD)		*		#			#			L	L									SENSE // EOL: FY14; Single satellite; Limited coverage
	SENSE/CTIP (DoD)		*		#			#			L	L									SENSE // EOL: FY14; Single satellite; Limited coverage
	SWACI TEC (DLR)			*		#		#	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	(X)	Leveraged asset (DLR); International GNSS Service RT Pilot Project; Limited coverage
Electric Field		T	T						L	L	L	L	L	L	L	L	L	L	L	(L)	
	C/NOFS/IVM (DoD)		*		#			#	L	L	L										C/NOFS // EOL: FY12; Extended mission uncertain; Equatorial only;
	SENSE/WINCS (DoD)		*		#		#				L	L									SENSE EOL: FY14; single satellites; limited coverage
	COSMIC-2/SSAEM/IVM (DoD)		*		#			#					(X)	(X)	(X)	(X)	(X)				COSMIC-2-L (SSAEM): FY15-19; COSMIC-2-H: FY18-23; Limited horizontal resolution
	DMSP SSIES		*		#		#		L	L	L	L	L	L	L	L	L	L	L	(L)	DMSP // EOL: FY21; Latency > 120 min; Capability never implemented
	Super DARN (NSF)					#		#	L	L	L	L	L	L	L	L	L	L	L	L	Leveraged nationa/international asset; Limited coverage; Requires radar backscatter
D-Region Absorption		T	T						X	X	X	X	X	X	X	X	X	X	X	X	Agency requirements not sell articulated
	Thule Riometer (DoD)	*	*			#		#	X	X	X	X	X	X	X	X	X	X	X	X	Monitoring Polar Cap Absorption (Northern hemisphere only); Operated by AFRL
	Circum-Polar Riometer Network (NRCC)	*				#		#		X	X	X	X	X	X	X	X	X	X	X	Canadian POC is David Boteler (NRCC) dboteler@nrcan.gc.ca
	Bartol Neutron Monitor Network (NSF)	*	*			#		#													Mostly supported by the University of Delaware with some NSF support
Electron Density Profile		T	T						L	L	L	L	L	U	U	U	U	U	U	(U)	
	DMSP/SSULI (DoD)		*		#			#	L	L	L	L	L	U	U	U	U	U	U	U	DMSP F-19 // EOL: FY21; Latency > 120 min; Terminator orbit problematic
	DMSP/SSUSI (DoD)		*		#			#	L	L	L	L	L	U	U	U	U	U	U	U	DMSP F-19 // EOL: FY21; Latency > 120 min; Terminator orbit problematic
	DMSP/SSIES (DoD)		*		#			#	L	L	L	L	L	L	L	L	L	L	L	(L)	DMSP F-19 // EOL: FY21; Latency > 120 min; Terminator orbit problematic
	COSMIC/GPS-RO (NSF)		*		#			#	L	L	(L)	(L)									COSMIC // EOL: FY12; Extended mission uncertain; Limited spatial coverage
	COSMIC-2/GNSSRO (DOC)	*	*		#			#					(L)	(L)	(L)	(L)	(L)	(L)	(L)	(L)	COSMIC-2-L (SSAEM): FY15-19; COSMIC-2-H: FY18-23; Limited horizontal resolution
	C/NOFS/GPS Receiver (DoD)		*		#			#	L	L	L										C/NOFS // EOL: FY12; Extended mission uncertain; Equatorial only;
	Commercial Data Buy (DOC)	*			#			#								(X)	(X)	(X)	(X)	(X)	Possible follow-on to COSMIC-2
	SENSE/GPSRO (DoD)		*		#			#			L	L									SENSE // EOL: FY14; Single satellite; Limited coverage
	SENSE/CTIP (DoD)		*		#			#			L	L									SENSE // EOL: FY14; Single satellite; Limited coverage
	SENSE/WINCS (DoD)		*		#		#				L	L									SENSE // EOL: FY14; Single satellite; Limited coverage
	DISS Ionosonde (DoD)		*			#		#	L	L											DISS // EOL: FY12; Limited global coverage
	NEXION Ionosonde (DoD)		*			#		#	L	L	L	L	L	L	L	L	L	L	L	L	NEXION // FOC: FY17; Fielding 30 sites around the globe - AF "backbone" system
	International Ionosondes (DOC)	*	*			#		#	L	L	L	L	L	L	L	L	L	L	L	L	Leveraged capability; Limited coverage with ~70 international sites - optimum ~700
	Incoherent Scatter Radars (NSF)					#		#	L	L	L	L	L	L	L	L	L	L	L	L	Leveraged capability; Limited national & internation coverage; Limited NRT capability

Table 6-1. Observing Platform Asset Ratings by Space Environment Domains
(F) Upper Atmosphere Domain

Environmental Parameter	Platform/Asset (owner)	Requirements			Measurement Type				Data Availability												Comments
		DOC	DOD	NASA	Space	Ground	In-situ	Remote	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	
Mesospheric Temperature			T						U	U	U	U	U	U	U	U	U	U	U	(U)	
	TIMED/TIDI (NASA)				#			#													TIMED // EOL: FY14; No NRT data available
	TIMED/SABER (NASA)				#			#													TIMED // EOL: FY14; No NRT data available
	DMSP/SSMIS (DoD)				#			#	U	U	U	U	U	U	U	U	U	U	U	(U)	Current stated EOL for DMSP F19 is 2021 per CSAT
	JPSS/ATMS (DoC)				#			#								[O]	[O]	[O]	[O]	[O]	JPSS // EOL: >FY22; Mesosphere capability discussed but not planned
	MetOp/AMSU (EUMETSAT)				#			#								[O]	[O]	[O]	[O]	[O]	MetOp // EOL: >FY22; Mesosphere capability not planned
	AURA/MLS (NASA)				#			#	(L)	(L)	(L)	(L)									AURA // EOL: uncertain; Utiltity is good; Availability is uncertain
	ODIN/OSIRIS (ESA)				#			#													ODIN // EOL: TBD
	Lidar Network (NSF)					#		#													NSF-sponsored ground stations at a handful of American sector and Europian sites
	VHF Radars (NSF)					#		#													NSF-sponsored ground stations at a handful of American sector and Europian sites
Mesospheric Winds (Speed & Direction)			T						[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	
	TIMED/TIDI (NASA)				#			#													TIMED // EOL: FY14; No NRT data available
	MF/HF Radars (NOAA & NSF)					#		#													NSF sponsored ground stations at a handful of American sector and Europian sites
	VHF Radars (NSF)					#		#													NSF sponsored ground stations at a handful of American sector and Europian sites
Neutral Winds (Speed & Direction)		T	T						U	U	U	U	[O]	[O]	[O]	[O]	[O]	[O]	[O]	[O]	
	C/NOFS/NWM (DoD)		*		#		#		U	U											C/NOFS EOL: FY12 ; quality has been limited by solar conditions, single satellite
	SENSE/WINCS (DoD)		*		#		#				U	U									Coverage limited by single in situ measurement
	TIMED/TIDI (NASA)				#			#													TIMED EOL: FY14, no NRT data available
	Optical Interferometer Network (NSF)					#		#													NSF-sponsored ground stations at a handful of American sector and Europian sites
Neutral Density, Composition & Temperature		T	T						L	L	L	L	L	U	U	U	U	U	U	(U)	
	DMSP/SSUSI (DoD)		*		#			#	L	L	L	L	L	U	U	U	U	U	U	(U)	Current stated EOL for DMSP F-19 is 2021 per CSAT
	DMSP/SSULI (DoD)		*		#			#	L	L	L	L	L	U	U	U	U	U	U	(U)	DMSP F-19 // EOL: FY21, Limited data quality on F18 also on F17 & F19 terminator orbits
	SENSE/WINCS (DoD)		*		#		#				U	U									SENSE EOL: FY14 coverage limited by single in situ measurement
	GRACE (NASA)				#		#														GRACE in extended mission ops.; No NRT data available
	GOCE (ESA)				#		#														GOCE // EOL: FY12, No NRT data available
	SWARM (ESA)				#		#														SWARM // EOL: FY16, NRT data availability unknown; operational products not assured
	TIMED/TIDI (NASA)																				TIMED // EOL: FY14, No NRT data available
	TIMED/SABER (NASA)				#			#													TIMED // EOL: FY14, No NRT data available
	Optical Interferometer Network (NSF)					#		#													NSF-sponsored ground stations at a handful of American sector and Europian sites
Neutral Density Profile		T	T						L	L	L	L	L	U	U	U	U	U	U	(U)	
	DMSP/SSUSI (DoD)		*		#			#	L	L	L	L	L	U	U	U	U	U	U	(U)	Current stated EOL for DMSP F-19 is 2021 per CSAT
	DMSP/SSULI (DoD)		*		#			#	L	L	L	L	L	U	U	U	U	U	U	(U)	DMSP F-19 // EOL: FY21, Limited data quality on F18 also on F17 & F19 terminator orbits
	Space Surveillance Network (DoD)					#		#													Low resolution NDP from HASDM ingest of space tracking data; No realtime product

Table 6-2. Environmental Parameter Ratings by Space Weather Phenomena

(A) Geomagnetic Storms

Utility Assessment for Geomagnetic Storms		FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
		Data Availability / Performance											
Nowcast													
Assessment		G	G	G	G	G	G	G	G	G	G	G	G
Geomagnetic Field - Surface	*1-Primary*	X	X	X	X	X	X	X	X	X	X	X	X
Auroral Boundary	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Auroral Emissions & Imagery	*2-Supporting*	L	L	L	L	L	U	U	U	U	U	U	U
Auroral Energy Deposition	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Electric Field	*2-Supporting*	L	L	L	L	L	L	L	L	L	L	L	(L)
Energetic Charged Particles: Energy & Flux	*2-Supporting*	L	X	X	X	X	X	X	L	L	L	L	L
Magnetic Field - In-situ (GEO & LEO)	*2-Supporting*	L	L	L	L	L	L	L	L	L	L	L	L
Medium Charged Particles: Energy & Flux	*2-Supporting*	L	X	X	X	X	X	X	L	L	L	L	L
Precipitating Charged Particles	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Supra-thermal Charged Particles	*2-Supporting*	L	X	X	X	X	X	X	L	L	L	L	L
Solar Wind: 3D Magnetic Field Components @ L1	*3-Ancillary*	X	X	X	L	L	L	L	L	L	L	L	L
Solar Wind: Speed and Direction @ L1	*3-Ancillary*	L	L	L	U	U	U	U	U	U	U	U	U
SW Plasma Components: Comp, Den & Temp @ L1	*3-Ancillary*	L	L	L	U	U	U	U	U	U	U	U	U
Trapped Radiation: Protons, Electrons, Waves	*3-Ancillary*	L	X	X	X	X	X	X	L	L	L	L	L
Short-term Forecast													
Assessment		Y	Y	Y	O	O	O	O	O	O	O	O	O
Solar Wind: 3D Magnetic Field Components @ L1	*1-Primary*	X	X	X	L	L	L	L	L	L	L	L	L
Solar Wind: Speed and Direction @ L1	*1-Primary*	L	L	L	U	U	U	U	U	U	U	U	U
SW Plasma Components: Comp, Den & Temp @ L1	*1-Primary*	L	L	L	U	U	U	U	U	U	U	U	U
Auroral Emissions & Imagery	*2-Supporting*	L	L	L	L	L	U	U	U	U	U	U	U
Geomagnetic Field - Surface	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Radio Burst: (Location, Type, Polarization)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Long-term Forecast													
Assessment		Y	Y	Y	O	O	O	O	O	O	O	O	O
Off-Angle Heliospheric Imagery (L4 or L5)	*1-Primary*	L	L	L	U	U	[O]	[O]	[O]	[O]	[O]	[O]	[O]
Solar Coronagraph	*1-Primary*	L	L	L	U	U	U	U	U	U	U	U	U
Solar EUV & UV Imagery	*1-Primary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Magnetic Field	*1-Primary*	X	X	X	X	X	X	X	X	X	X	X	X
Sun-Earth Line based Heliospheric Imagery	*1-Primary*	U	U	U	U	U	U	U	U	U	U	U	U
Geomagnetic Field - Surface	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Helioseismology	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Off-angle Solar Imagery (possibly L5)	*2-Supporting*	X	X	X	L	L	L	L	L	L	L	L	L
Off-Angle Solar Wind/Mag - In-situ (possibly L5)	*2-Supporting*	X	X	X	L	L	L	L	L	L	L	L	L
Solar Imagery IR and Optical	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Radio Burst: (Location, Type, Polarization)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Radio Emissions (Total & spectral flux)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Wind: 3D Magnetic Field Components @ L1	*2-Supporting*	X	X	X	L	L	L	L	L	L	L	L	L
Solar Wind: Speed and Direction @ L1	*2-Supporting*	L	L	L	U	U	U	U	U	U	U	U	U
Solar X-Ray Flux (total and discrete frequency)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar X-Ray Imagery	*2-Supporting*	X	X	X	X	X	X	X	X	X	X		
SW Plasma Components: Comp, Den & Temp @ L1	*2-Supporting*	L	L	L	U	U	U	U	U	U	U	U	U
Solar High Energy Protons and Cosmic Rays	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Wind Radio Emissions	*3-Ancillary*	X	X	X	U	U	U	U	U	U	U	U	U

Last Update: 3 April, 2012 (Worst Case)

Table 6-2. Environmental Parameter Ratings by Space Weather Phenomena (B) Radio Blackouts

Utility Assessment for		Data Availability / Performance											
Radio Blackouts		FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Nowcast													
Assessment		G	G	G	G	G	G	G	G	G	G	G	G
D-Region Absorption	*1-Primary*	X	X	X	X	X	X	X	X	X	X	X	X
Energetic Charged Particles: Energy & Flux	*1-Primary*	L	X	X	X	X	X	X	L	L	L	L	L
Energetic Ions (D-region absorption)	*1-Primary*	L	L	L	L	L	L	L	L	L	L	L	L
Solar X-Ray Flux (total and discrete frequency)	*1-Primary*	X	X	X	X	X	X	X	X	X	X	X	X
Medium Charged Particles: Energy & Flux	*2-Supporting*	L	X	X	X	X	X	X	L	L	L	L	L
Auroral Boundary	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Auroral Emissions & Imagery	*3-Ancillary*	L	L	L	L	L	U	U	U	U	U	U	U
Auroral Energy Deposition	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Precipitating Charged Particles	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Short-term Forecast													
Assessment		O	O	O	O	O	O	O	O	O	O	O	O
Auroral Emissions & Imagery	*3-Ancillary*	L	L	L	L	L	U	U	U	U	U	U	U
Helioseismology	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Long-term Forecast													
Assessment		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Off-angle Solar Imagery (possibly L5)	*2-Supporting*	X	X	X	L	L	L	L	L	L	L	L	L
Solar EUV & UV Imagery	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Imagery IR and Optical	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Magnetic Field	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Radio Emissions (Total & spectral flux)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar X-Ray Flux (total and discrete frequency)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar X-Ray Imagery	*2-Supporting*	X	X	X	X	X	X	X	X	X	X		

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(C) Solar Radiation Storms

Utility Assessment for		Data Availability / Performance											
Solar Radiation Storms		FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Nowcast													
Assessment		G	G	G	G	G	G	G	G	G	G	G	G
Energetic Charged Particles: Energy & Flux	*1-Primary*	L	X	X	X	X	X	X	L	L	L	L	L
Solar High Energy Protons and Cosmic Rays	*1-Primary*	X	X	X	X	X	X	X	X	X	X	X	X
Medium Charged Particles: Energy & Flux	*2-Supporting*	L	X	X	X	X	X	X	L	L	L	L	L
Trapped Radiation: Protons, Electrons, Waves	*2-Supporting*	L	X	X	X	X	X	X	L	L	L	L	L
Short-term Forecast													
Assessment		Y	Y	Y	R	R	R	R	R	R	R	R	R
Solar Relativistic Electrons @ L1 or L2	*2-Supporting*	L	L	L	U	U	U	U	U	U	U	U	U
Solar Radio Burst: (Location, Type, Polarization)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Helioseismology	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Coronagraph	*3-Ancillary*	L	L	L	U	U	U	U	U	U	U	U	U
Solar EUV & UV Imagery	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Imagery IR and Optical	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar X-Ray Flux (total and discrete frequency)	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar X-Ray Imagery	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X		
Long-term Forecast													
Assessment		O	O	O	O	O	O	O	O	O	O	O	O
Solar Coronagraph	*2-Supporting*	L	L	L	U	U	U	U	U	U	U	U	U
Solar Imagery IR and Optical	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Magnetic Field	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Radio Burst: (Location, Type, Polarization)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar X-Ray Flux (total and discrete frequency)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar X-Ray Imagery	*2-Supporting*	X	X	X	X	X	X	X	X	X	X		
Helioseismology	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar EUV & UV Imagery	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X

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Table 6-2. Environmental Parameter Ratings by Space Weather Phenomena (D) Ionospheric Storms

Utility Assessment for Ionospheric Storms/Scintillation		FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
		Data Availability / Performance											
Nowcast													
Assessment		Y	Y	Y	Y	Y	O	O	O	O	O	O	O
Electron Density Profile	*1-Primary*	L	L	L	L	L	U	U	U	U	U	U	(U)
Ionospheric Char: Layer Height & Density	*1-Primary*	L	L	L	L	L	L	L	L	L	L	L	U
Ionospheric Scintillation	*1-Primary*	L	L	L	L	L	L	L	L	L	U	U	U
Neutral Winds (Speed & Direction)	*1-Primary*	U	U	U	U	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)
Total Electron Content	*1-Primary*	L	L	L	L	L	L	L	L	L	L	L	U
Auroral Emissions & Imagery	*2-Supporting*	L	L	L	L	L	U	U	U	U	U	U	U
Auroral Energy Deposition	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Electric Field	*2-Supporting*	L	L	L	L	L	L	L	L	L	L	L	(L)
Plasma Density Fluctuations	*2-Supporting*	L	L	L	L	L	L	L	L	L	L	L	(L)
Precipitating Charged Particles	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Wind: 3D Magnetic Field Components @ L1	*2-Supporting*	X	X	X	L	L	L	L	L	L	L	L	L
Solar Wind: Speed and Direction @ L1	*2-Supporting*	L	L	L	U	U	U	U	U	U	U	U	U
Supra-thermal Charged Particles	*2-Supporting*	L	X	X	X	X	X	X	L	L	L	L	L
SW Plasma Components: Comp, Den & Temp @ L1	*2-Supporting*	L	L	L	U	U	U	U	U	U	U	U	U
Auroral Boundary	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Energetic Charged Particles: Energy & Flux	*3-Ancillary*	L	X	X	X	X	X	X	L	L	L	L	L
Geomagnetic Field - Surface	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Magnetic Field - In-situ (GEO & LEO)	*3-Ancillary*	L	L	L	L	L	L	L	L	L	L	L	L
Medium Charged Particles: Energy & Flux	*3-Ancillary*	L	X	X	X	X	X	X	L	L	L	L	L
Neutral Density Profile	*3-Ancillary*	L	L	L	L	L	U	U	U	U	U	U	(U)
Neutral Density, Composition & Temperature	*3-Ancillary*	L	L	L	L	L	U	U	U	U	U	U	(U)
Plasma Temperatures (Te & Ti)	*3-Ancillary*	L	L	L	L	L	L	L	L	L	L	L	(L)
Solar EUV & UV Flux	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Trapped Radiation: Protons, Electrons, Waves	*3-Ancillary*	L	X	X	X	X	X	X	L	L	L	L	L
Short-term Forecast													
Assessment		Y	Y	Y	O	O	O	O	O	O	O	O	O
Electric Field	*1-Primary*	L	L	L	L	L	L	L	L	L	L	L	(L)
Electron Density Profile	*1-Primary*	L	L	L	L	L	U	U	U	U	U	U	(U)
Ionospheric Char: Layer Height & Density	*1-Primary*	L	L	L	L	L	L	L	L	L	L	L	U
Neutral Winds (Speed & Direction)	*1-Primary*	U	U	U	U	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)
Solar Wind: 3D Magnetic Field Components @ L1	*1-Primary*	X	X	X	L	L	L	L	L	L	L	L	L
Solar Wind: Speed and Direction @ L1	*1-Primary*	L	L	L	U	U	U	U	U	U	U	U	U
SW Plasma Components: Comp, Den & Temp @ L1	*1-Primary*	L	L	L	U	U	U	U	U	U	U	U	U
Geomagnetic Field - Surface	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Ionospheric Scintillation	*2-Supporting*	L	L	L	L	L	L	L	L	L	U	U	U
Solar EUV & UV Imagery	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Radio Burst: (Location, Type, Polarization)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Total Electron Content	*2-Supporting*	L	L	L	L	L	L	L	L	L	L	L	U
Auroral Emissions & Imagery	*3-Ancillary*	L	L	L	L	L	U	U	U	U	U	U	U
Neutral Density Profile	*3-Ancillary*	L	L	L	L	L	U	U	U	U	U	U	(U)
Neutral Density, Composition & Temperature	*3-Ancillary*	L	L	L	L	L	U	U	U	U	U	U	(U)
Plasma Density Fluctuations	*3-Ancillary*	L	L	L	L	L	L	L	L	L	L	L	(L)
Supra-thermal Charged Particles	*3-Ancillary*	L	X	X	X	X	X	X	L	L	L	L	L
Trapped Radiation: Protons, Electrons, Waves	*3-Ancillary*	L	X	X	X	X	X	X	L	L	L	L	L
Long-term Forecast													
Assessment		Y	Y	Y	R	R	R	R	R	R	R	R	R
Off-Angle Heliospheric Imagery (L4 or L5)	*2-Supporting*	L	L	L	U	U	(O)	(O)	(O)	(O)	(O)	(O)	(O)
Off-angle Solar Imagery (possibly L5)	*2-Supporting*	X	X	X	L	L	L	L	L	L	L	L	L
Off-Angle Solar Wind/Mag - In-situ (possibly L5)	*2-Supporting*	X	X	X	L	L	L	L	L	L	L	L	L
Solar Coronagraph	*2-Supporting*	L	L	L	U	U	U	U	U	U	U	U	U
Solar EUV & UV Imagery	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Imagery IR and Optical	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Magnetic Field	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Sun-Earth Line based Heliospheric Imagery	*2-Supporting*	U	U	U	U	U	U	U	U	U	U	U	U
Helioseismology	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar High Energy Protons and Cosmic Rays	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Radio Burst: (Location, Type, Polarization)	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Radio Emissions (Total & spectral flux)	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Wind Radio Emissions	*3-Ancillary*	X	X	X	U	U	U	U	U	U	U	U	U
Solar Wind: 3D Magnetic Field Components @ L1	*3-Ancillary*	X	X	X	L	L	L	L	L	L	L	L	L
Solar Wind: Speed and Direction @ L1	*3-Ancillary*	L	L	L	U	U	U	U	U	U	U	U	U
Solar X-Ray Flux (total and discrete frequency)	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
SW Plasma Components: Comp, Den & Temp @ L1	*3-Ancillary*	L	L	L	U	U	U	U	U	U	U	U	U

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Table 6-2. Environmental Parameter Ratings by Space Weather Phenomena (E) Atmospheric Drag

Utility Assessment for		Data Availability / Performance											
Atmospheric Drag		FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Nowcast													
Assessment		Y	Y	Y	Y	Y	O	O	O	O	O	O	O
Neutral Density Profile	*1-Primary*	L	L	L	L	L	U	U	U	U	U	U	(U)
Neutral Density, Composition & Temperature	*1-Primary*	L	L	L	L	L	U	U	U	U	U	U	(U)
Solar EUV & UV Flux	*1-Primary*	X	X	X	X	X	X	X	X	X	X	X	X
Auroral Boundary	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Auroral Emissions & Imagery	*2-Supporting*	L	L	L	L	L	U	U	U	U	U	U	U
Auroral Energy Deposition	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Mesospheric Temperature	*2-Supporting*	U	U	U	U	U	U	U	U	U	U	U	(U)
Mesospheric Winds (Speed & Direction)	*2-Supporting*	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)
Neutral Winds (Speed & Direction)	*2-Supporting*	U	U	U	U	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)
Precipitating Charged Particles	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Radio Burst: (Location, Type, Polarization)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Radio Emissions (Total & spectral flux)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Solar X-Ray Flux (total and discrete frequency)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Short-term Forecast													
Assessment		Y	Y	Y	O	O	O	O	O	O	O	O	O
Solar Wind: 3D Magnetic Field Components @ L1	*1-Primary*	X	X	X	L	L	L	L	L	L	L	L	L
Solar Wind: Speed and Direction @ L1	*1-Primary*	L	L	L	U	U	U	U	U	U	U	U	U
SW Plasma Components: Comp, Den & Temp @ L1	*1-Primary*	L	L	L	U	U	U	U	U	U	U	U	U
Auroral Emissions & Imagery	*2-Supporting*	L	L	L	L	L	U	U	U	U	U	U	U
Electron Density Profile	*2-Supporting*	L	L	L	L	L	U	U	U	U	U	U	(U)
Geomagnetic Field - Surface	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Ionospheric Char: Layer Height & Density	*2-Supporting*	L	L	L	L	L	L	L	L	L	L	L	U
Mesospheric Temperature	*2-Supporting*	U	U	U	U	U	U	U	U	U	U	U	(U)
Mesospheric Winds (Speed & Direction)	*2-Supporting*	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)
Neutral Density Profile	*2-Supporting*	L	L	L	L	L	U	U	U	U	U	U	(U)
Neutral Density, Composition & Temperature	*2-Supporting*	L	L	L	L	L	U	U	U	U	U	U	(U)
Solar Radio Emissions (Total & spectral flux)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Total Electron Content	*2-Supporting*	L	L	L	L	L	L	L	L	L	L	L	U
Electric Field	*3-Ancillary*	L	L	L	L	L	L	L	L	L	L	L	(L)
Energetic Charged Particles: Energy & Flux	*3-Ancillary*	L	X	X	X	X	X	X	L	L	L	L	L
Medium Charged Particles: Energy & Flux	*3-Ancillary*	L	X	X	X	X	X	X	L	L	L	L	L
Neutral Winds (Speed & Direction)	*3-Ancillary*	U	U	U	U	(O)	(O)	(O)	(O)	(O)	(O)	(O)	(O)
Long-term Forecast													
Assessment		Y	Y	Y	R	R	R	R	R	R	R	R	R
Geomagnetic Field - Surface	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Off-Angle Heliospheric Imagery (L4 or L5)	*2-Supporting*	L	L	L	U	U	(O)	(O)	(O)	(O)	(O)	(O)	(O)
Off-Angle Solar Wind/Mag - In-situ (possibly L5)	*2-Supporting*	X	X	X	L	L	L	L	L	L	L	L	L
Solar Coronagraph	*2-Supporting*	L	L	L	U	U	U	U	U	U	U	U	U
Solar Radio Emissions (Total & spectral flux)	*2-Supporting*	X	X	X	X	X	X	X	X	X	X	X	X
Sun-Earth Line based Heliospheric Imagery	*2-Supporting*	U	U	U	U	U	U	U	U	U	U	U	U
Solar High Energy Protons and Cosmic Rays	*3-Ancillary*	X	X	X	X	X	X	X	X	X	X	X	X
Solar Wind Radio Emissions	*3-Ancillary*	X	X	X	U	U	U	U	U	U	U	U	U
Solar Wind: 3D Magnetic Field Components @ L1	*3-Ancillary*	X	X	X	L	L	L	L	L	L	L	L	L
Solar Wind: Speed and Direction @ L1	*3-Ancillary*	L	L	L	U	U	U	U	U	U	U	U	U
SW Plasma Components: Comp, Den & Temp @ L1	*3-Ancillary*	L	L	L	U	U	U	U	U	U	U	U	U

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APPENDIX 7: Abbreviations and Acronyms

3D	3 Dimensional
A3O-W	Air Force Directorate of Weather
ACE	Advanced Composition Explorer
ACE/MAG	ACE Magnetometer
AFRL	Air Force Research Laboratory
AFSPC	Air Force Space Command
AFWA	Air Force Weather Agency
AIA	Atmospheric Imaging Assembly
AMPERE	Active Magnetosphere and Planetary Electrodynamics Response Experiment
AMSU	Advanced Microwave Sounding Unit
ATMS	Advanced Technology Microwave Sounder
AU	Astronomical Unit
BDD	Burst Detector Dosimeter
cm	centimeter(s)
CME	Coronal Mass Ejection
C/NOFS	Communications/Navigation Outage Forecast System
CORS	Continuously Operating Reference Stations
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
CSA	Canadian Space Agency
CTIP	Cubesat Tiny Ionospheric Photometer
CSW	Committee for Space Weather
CXD	Combined X-ray Dosimeter
DISS	Digital Ionospheric Sounding System
DMSP	Defense Meteorological Satellite Program
DNB	Day-Night Band
DOC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
DOS	Department of State
DOT	Department of Transportation
DSCOVR	Deep Space Climate Observatory
DSN	Deep Space Network
EDP	Electron Density Profile
EHIS	Energetic Heavy Ion Sensor
EIT	Extreme ultraviolet Imaging Telescope
EOL	End of Life
EPR	Environmental Parameter Ratings
EPS-HES	Energetic Particle Sensor - High Energy Sensor
ESA	European Space Agency
ESP	Energetic Spectrometer for Particles
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites

EUV	Extreme Ultraviolet
EUVI	Extreme UltraViolet Imager (LMSAL)
eV	electron Volt
EVE	Extreme Ultraviolet Variability Experiment
EXIS	EUV and X-ray Irradiance Sensors
FAA	Federal Aviation Administration
FOC	Full Operational Capability
FY	Fiscal Year
GAIM	Global Assimilation of Ionospheric Measurements
GCR	Galactic Cosmic Rays
GEO	Geosynchronous Earth Orbit
GNSS	Global Navigational Satellite System
GOCE	Gravity field and steady-state Ocean Circulation Explorer
GOES	Geostationary Operational Environmental Satellites
GOES NOP	GOES N-O-P Series Satellites
GOES MAG	GOES Magnetometer
GOES-R	GOES - R series satellites
GOES-R /MAG	GOES-R Magnetometer
GONG	Global Oscillation Network Group
GONG/FT	GONG Fourier Tachometer
GPS	Global Positioning System
GPSRO	GPS Radio Occultation
GRACE	Gravity Recovery and Climate Experiment
GSFC	Goddard Space Flight Center
GTO	Geosynchronous Transfer Orbit
HASDM	High Accuracy Satellite Drag Model
HEO	Highly Elliptical Orbit
HEPAD	High Energy Particle Detector
HF	High Frequency
HMI	Helioseismic and Magnetic Imager
HOPE	Helium Oxygen Proton Electron
IOC	Initial Operational Capability
IMF	Interplanetary Magnetic Field
INTERMAGNET	International Real-time Magnetic Observatory Network
ISOON	Improved Solar Observing Optical Network
IT	Information Technology
IVM	Ion Velocity Monitor
JAG	Joint Action Group
JAG/SEGA	Joint Action Group for Space Environmental Gap Analysis
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
keV	kilo electron Volt
kHz	kiloHertz
km	kilometer(s)

L1	Earth-Sun Lagrangian point 1
L2	Earth-Sun Lagrangian point 2
L4	Earth-Sun Lagrangian point 4
L5	Earth-Sun Lagrangian point 5
LANL	Los Alamos National Laboratory
LASCO	Large Angle and Spectrometric Coronagraph
LBHl/LBHs ratio	Lyman-Birge-Hopfeld auroral i/s ratio
LEO	Low Earth Orbit
LEPS	Low Energy Particle Sensor
LOS	Line of Sight
LWS	Living With a Star
MagEIS	Magnetic/electric Field Instrument Suite
MDI	Michelson Doppler Imager
MEPED	Medium Energy Proton and Electron Detector
MetOp	Meteorological Observation satellite (EUMETSAT)
MeV	Mega electron Volt
MF/HF	Medium Frequency /High Frequency
MHz	Megahertz
MLS	Microwave Limb Sounder
MPA	Magnetospheric Plasma Analyzer
MPS-HI	Magnetospheric Particle Sensor - High
MPS-LO	Magnetospheric Particle Sensor -Low
NASA	National Aeronautics and Space Administration
NDP	Neutral Density Profile
NESDIS	National Environmental Satellite Data and Information Service
NEXION	Next Generation Ionosonde
NGA	National Geospatial-Intelligence Agency
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
nP	nano Pascals
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NRC	National Research Council
NRCC	National Research Council of Canada
NRL	Naval Research Laboratory
NRT	Near Real Time
NSF	National Science Foundation
NSO	National Solar Observatory
NSWPC	National Space Weather Program Council
nT	nano Tesla
NWM	Neutral Wind Meter
NWS	National Weather Service
OFCM	Office of the Federal Coordinator for Meteorological Services and Supporting Research
OLS	Operational Linescan System

OMB	Office of Management and Budget
OSIRIS	Optical Spectrograph and InfraRed Imager System
OSTP	Office of Science and Technology Policy
PLP	Planar Langmuir Probe
POES	Polar Operational Environmental Satellite
RBSP	Radiation Belt Storm Probe
R_E	Earth Radii
REPT	Relativistic Electron Proton Telescope
RIMS	RSTN Radio Interference Measurement Set
R_S	Solar Radii
RSTN	Radio Solar Telescope Network
SABER	Sounding of the Atmosphere using Broadband Emission Radiometry
SABRS	Space Atmospheric Burst Reporting System
SATCOM	Satellite Communications
SBUV	Solar Backscatter Ultraviolet
S/C	Spacecraft
SCI	Sensitive Compartmented Information
SCINDA	Scintillation Network Decision Aid
SDO	Solar Dynamics Observatory
SECCHI	Sun Earth Connection Coronal and Heliospheric Investigation
SEM	Space Environmental Monitor
SEM-2	Space Environmental Monitor - 2
SEM-N	Space Environmental Monitor - Next
SENSE	Space Environmental Nanosat Experiment
SEON	Solar Electro-Optical Network
SEP	Solar Energetic Particle
SGPS	Solar and Galactic Proton Sensor
SIESS	Space Environment In-Situ Suite
SIS	ACE Solar Isotope Spectrometer
SMC	Space and Missile Systems Center
SMEI	Solar Mass Ejection Imager
SOHO	Solar and Heliospheric Observatory
SOON	Solar Observing Optical Network
SOPA	Synchronous Orbit Particle Analysis
sr	steradians
SSAEM	Space Situational Awareness Environmental Monitoring
SSIES	Special Sensors-Ions, Electrons, and Scintillation
SSJ	Special Sensor J
SSM	Special Sensor Magnetometer
SSMIS	Special Sensor Microwave Imager Sounder
SSULI	Special Sensor UV Limb Imager
SSUSI	Special Sensor UV Spectrographic Imager
STC	Science and Technology Corporation
STEREO	Solar TErrestrial RElations Observatory

SuperDARN	Super Dual Auroral Radar Network
SUVI	Solar Ultraviolet Imager
SWACI	Space Weather Applications Center - Ionosphere
SWEPAM	Solar Wind Electron Proton Alpha Monitor
SWPC	Space Weather Prediction Center
SXI	Solar X-Ray Imager
TEC	Total Electron Content
THEMIS	Time History of Events and Macroscale Interactions
TIDI	TIMED Doppler Imager
TIMED	Thermosphere Ionosphere Mesosphere Energetics and Dynamics
UHF	Ultra High Frequency
U.S.	United States
USAF	United States Air Force
USGS	United States Geological Survey
USNDS	U.S. Nuclear Detonation (NUDET) Detection System
UV	Ultraviolet
UVI	UV Imager
VHF	Very High Frequency
VIIRS	Visible Infrared Imaging Radiometer Suite
WINCS	Wind Ion Neutral Composition Suite
XRS	Solar X-Ray Sensor

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