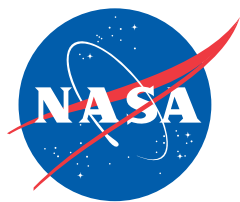


**NASA/CP-2012-216003**



## **Workshop Report on Space Weather Risks and Society**

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Report of a workshop  
sponsored by and held at  
NASA Ames Research Center  
Moffett Field, California  
on October 15-16, 2011

**February 2012**

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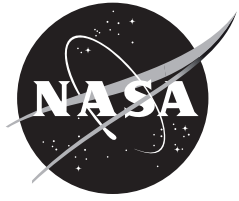
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## Acknowledgement

The authors would like to acknowledge the many people that made this workshop possible. First and foremost we would like to thank Rho Christensen and Desiremoi Bridges for their role in preparing for and hosting the event, and Marco Boldt and Mike Toillion for their expert handling of all of the audio-visual aspects of the workshop. Finally, we would like to thank all the presenters for their help in ensuring the accuracy of the talks that are summarized in this report.

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## Executive Summary

A weekend workshop entitled *Space Weather Risks and Society* was held at NASA Ames Research Center on October 15-16, 2011, to discuss humanity's escalating susceptibility to space weather events. The term *space weather* refers to the time-variable conditions in the space environment that are produced by the Sun. The potential effects of space weather are well known. High-energy electromagnetic radiation from flares can cause radio blackouts on the dayside. Solar energetic particles can cause satellite damage and radiation exposure; they also cause radio blackouts in polar regions. Geo-magnetic storms that arise when the coronal mass ejected from the Sun reaches the Earth can cause transformer damage leading to potential electric grid collapse, pipeline corrosion, GPS errors and loss of lock, and increased satellite drag in low-Earth orbit. The greatest concern is the prolonged shut-down of the electric grid, because many other key infrastructures depend on it.

How do we quantify the rate of violent solar events and the risks they pose to the existing infrastructure? If our current infrastructure were exposed to a space weather event of the magnitude of the 1859 Carrington event, what would happen? How many of our satellites (representing over \$150 billion dollars of investment) would experience failure or anomalies? Our electric grid continues to grow larger (currently with over 160,000 miles of high-voltage lines) and more interconnected, thereby presenting a larger antenna. We continue to increase the operating voltage in our high-voltage transmission lines. Our transformers are becoming more efficient and therefore, more susceptible to saturation by geomagnetically induced currents. All of these technological advancements make us more susceptible to space weather and lowers the threshold of what would be considered a large-impact space weather event.

The workshop participants unanimously agreed that the threat of space weather is real. The participants also resonated with a finding from the 2008 NRC report on a workshop on "Severe Space Weather Events" which stated that "... while this workshop, along with its report, has gathered in one place much of what is currently known or suspected about societal and economic impacts, it has perhaps been most successful in illuminating the scope of the myriad issues involved, and the gaps in knowledge that remain to be explored in greater depth than can be accomplished in a workshop. A quantitative and comprehensive assessment of the societal and economic impacts of space weather will be a truly daunting task ..." One critical problem in that task formed one of the focus themes of the Ames workshop: how to bring together an interdisciplinary group of scientists, engineers, modelers, operators, societal leaders, emergency responders, etc., to make a quantitative and comprehensive assessment of the societal and economic impacts of severe space weather?

One of the main focal points of the workshop was whether we needed a dedicated organization to make these quantitative estimates of the societal impacts of space weather. A straw man concept for an organization to transform our extensive knowledge of space weather into options for protecting society was circulated at the workshop (the straw man concept paper is included at the end of the report). Throughout this workshop report we have referred to this organization as a Society and Space Weather Institute (SSWI). A key goal of the workshop was to further elucidate and refine the functions that such an institute might have, and how it would be organized and funded.

As we approach the next solar maximum, space weather has the attention of scientific advisors and key political and business leaders. Some workshop participants felt that this presented a window of opportunity to get the new institute started. Generally, it was felt that the SSWI should initially focus on establishing the degree to which space weather is a real threat. Currently, we do not have consensus on the impact of space weather on the electric grid. The system modeling and analysis techniques to predict the impact of geomagnetic disturbances on the electric power grid are not very robust. The response of the transformers to geomagnetically-induced currents depends on the detailed design of the transformer and depends rather sensitively on estimates for the ground resistivity. An accurate assessment of transformer vulnerability on a regional or national scale is a formidable task. A SSWI institute could bring together an interdisciplinary team to better define the risks and impacts of space weather. It could determine the cost/benefit ratio and whether action was needed to mitigate the risks. We cannot move forward on space weather policies until we quantify the cost/benefit ratio in a manner that its validity can be understood and appreciated by non-space scientists!

There was general agreement at the workshop that a SSWI needed to be an interdisciplinary, independent, and international organization. It must be independent to bring our international partners in fully, and to provide independent and unbiased advice to policy makers. The SSWI needs to be interdisciplinary, because space weather crosses many disciplines. Finally, it needs to be international, because space weather has a large geographical footprint that crosses national boundaries. Various models for the institute were discussed at the workshop, based on currently existing institutes. Many favored the idea of a virtual institute that could easily bring in our international partners. Another model is to rely on in-kind contributions that would provide an affordable approach to obtaining contributions across the full range of national expertise. While no decision was made on the details of how the institute should be organized and funded, a group of volunteers was assembled to continue the SSWI start-up effort.

The threat of space weather is real. It is not a question of “if”, but a question of “when”. We cannot be satisfied with status quo. A space weather calamity of epic proportions should not have to occur before we get the funds needed to protect our critical infrastructure. A relatively small investment to better define the frequency of large space weather events and their impacts on our existing infrastructure would mitigate the potentially large downside risks that space weather poses for society.



# Workshop Report on Space Weather Risks and Society

Dr. Stephanie Langhoff<sup>1</sup> and Dr. Tore Straume<sup>1</sup>

## Introduction

As technological innovations produce new capabilities, complexities, and interdependencies, our susceptibility to the societal impacts of space weather increase. There is real concern in the scientific community that our infrastructure would be at significant risk if a major geomagnetic storm should occur. To discuss the societal impacts of space weather, we brought together an interdisciplinary group of subject matter experts and societal stakeholders to participate in a workshop entitled *Space Weather Risks and Society*. The workshop was held at Ames Research Center (ARC) on 15-16 October 2011. The workshop was co-sponsored by NASA Ames Research Center (ARC), the Lockheed Martin Advanced Technology Center (LMATC), the Space Weather Prediction Center (SWPC, part of the National Oceanic and Atmospheric Administration NOAA), and the Rutherford Appleton Laboratory (RAL, part of the UK Science and Technology Facilities Council STFC). The workshop is part of a series of informal weekend workshops hosted by Center Director Pete Worden.

The Program Organizing Committee included Stephanie Langhoff (ARC), Tore Straume (ARC), Karel Schrijver (LM Solar Astrophysics Lab), Alan Title (LMATC), Tom Bogdan (SWPC/NOAA), and Mike Hapgood (RAL/STFC). The 66 participants at the workshop included representatives from government, industry, and academia. There was a strong international contingent at the workshop, which reflects the global footprint of space weather events.

The program for the workshop is included near the end of the report. The first day of the workshop focused on characterizing the threat of space weather. Presentations were divided into four sessions:

1. An overview of space weather consequences on society.
2. What is the strategy for dealing with the space weather threat?
3. A science prospective—what do we know (and not know) about the major components of space weather: solar flares, coronal mass ejections, solar energetic particles, and geomagnetic storms?
4. What are the impacts of space weather on humans and infrastructure?

The second day of the workshop focused on what can be done to address the threat—from mitigation to response to recovery. If we could establish a dedicated institute for space weather, what would be its roles and how should it start?

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<sup>1</sup>Ames Research Center, Moffett Field, California

# **I. Space Weather Consequences on Society**

## **I.1 Some Thoughts on the Societal Impacts of Space Weather**

Dr. Alan Title, Senior Fellow at the Lockheed Martin Advanced Technology Center, began the workshop by providing his perspective on space weather effects on society. While he did not know the function that predicts the rate of violent solar events or how these events impact power distribution, communications, or global positioning systems (GPS) on Earth, he did know that billions of dollars worldwide are being spent on studying the Sun, the magnetosphere, and the upper atmosphere. Furthermore, he believed that there are unknown risks with very serious consequences to society from a range of solar events.

Dr. Title introduced a new organization, the Society and Space Weather Institute (SSWI), which has started a study to quantify the rate of violent solar events based on the study of historical records, ice core data, and observations of thousands of solar type stars in the Kepler database. He felt that through this new entity we could set up a structure to manage the development of the information necessary to set policy and develop regulations tailored to limit the effects of space weather. From the workshop, he hoped there would emerge a mutual agreement that there exists a risk to society from space weather. Secondly, plans would emerge to quantify that risk by using existing data to develop better estimates of the rate of violent solar events and to evaluate the dangers these solar-driven events pose to existing systems. The institute could provide the infrastructure for communications between the scientific, technical, economic, and political structures, and act as an interface between the research community, the modelers, the forecasters, and society. This new infrastructure could advise business and government on appropriate responses to space weather, could act as an independent assessor of the impacts of new technologies, and could develop training tools for managers of space weather responses.

In the questions following the presentation, Dr. Title stressed that this new entity was an advisory body, not an operational organization such as the Space Weather Prediction Center (SWPC) at the National Oceanic and Atmospheric Administration (NOAA). To the question of how do we promote the concept of this new institution in the context that these “super storm” space weather events are low-probability, high-consequence events, his response was that he believed there is sufficient concern to warrant a research effort to further evaluate the risks. We don’t necessarily need a large space weather event to have problems with the expanding infrastructure, especially considering the increasing complexity and interconnectedness of new technologies.

## **I.2 Space Weather Growth in Importance for Economy and Security**

Dr. Louis Lanzerotti, professor of physics at New Jersey Institute of Technology, discussed our increasing susceptibility to the effects of space weather. He began by noting that as technological innovations produce new capabilities and complexities, the opportunities for unexpected impacts of the solar-terrestrial environment always occur. This began in 1859 with the first published occurrence of the effects of space weather, namely the spontaneous electrical currents observed

in the wires of the electric telegraph. The first widespread effects on power distribution systems, such as transformer tripping and power surges, were observed in the magnetic storm of 1940. Early wireless communications were also observed to be sensitive to magnetic storms. Radar operators reported “jamming”, which periodically completely disrupted the British radar defense system in WWII. This was later recognized to be interference by solar radio noise. Solar radio bursts also affect Global Positioning Systems (GPS) receivers. The Wide Area Augmentation System (WAAS) coverage and availability was severely impacted by the December 2006 solar radio burst event.

Another new technology that is significantly impacted by the radiation environment from space weather is satellites. For example, Telstar 1 was launched in 1962 and then failed in 1963 from radiation damage. The more recent failure of Galaxy 15 was also attributed to a solar storm. Dr. Lanzerotti showed a plot (see figure 1) of spacecraft anomalies and failures as a function of time that was published in the National Academy workshop report on the Societal and Economic Impacts of Severe Space Weather Events in 2008. Although most of the events and failures are not attributed to space weather, it is noteworthy that the majority occurred in the 2003 Halloween Storm. Another major concern is the increasing vulnerability of the energy grid to space weather events (see Section IV.2 for further discussion). A major conclusion from his presentation is that we live in an evolving landscape, where new technologies and capabilities drive demand for space weather products. New drivers for space weather understanding include civil precision Global Navigation Satellite System (GNSS) users, the Next Generation Air Transportation System (NextGen), increased vulnerability of the power grid, the satellite industry, and exploration beyond Low-Earth Orbit (LEO).

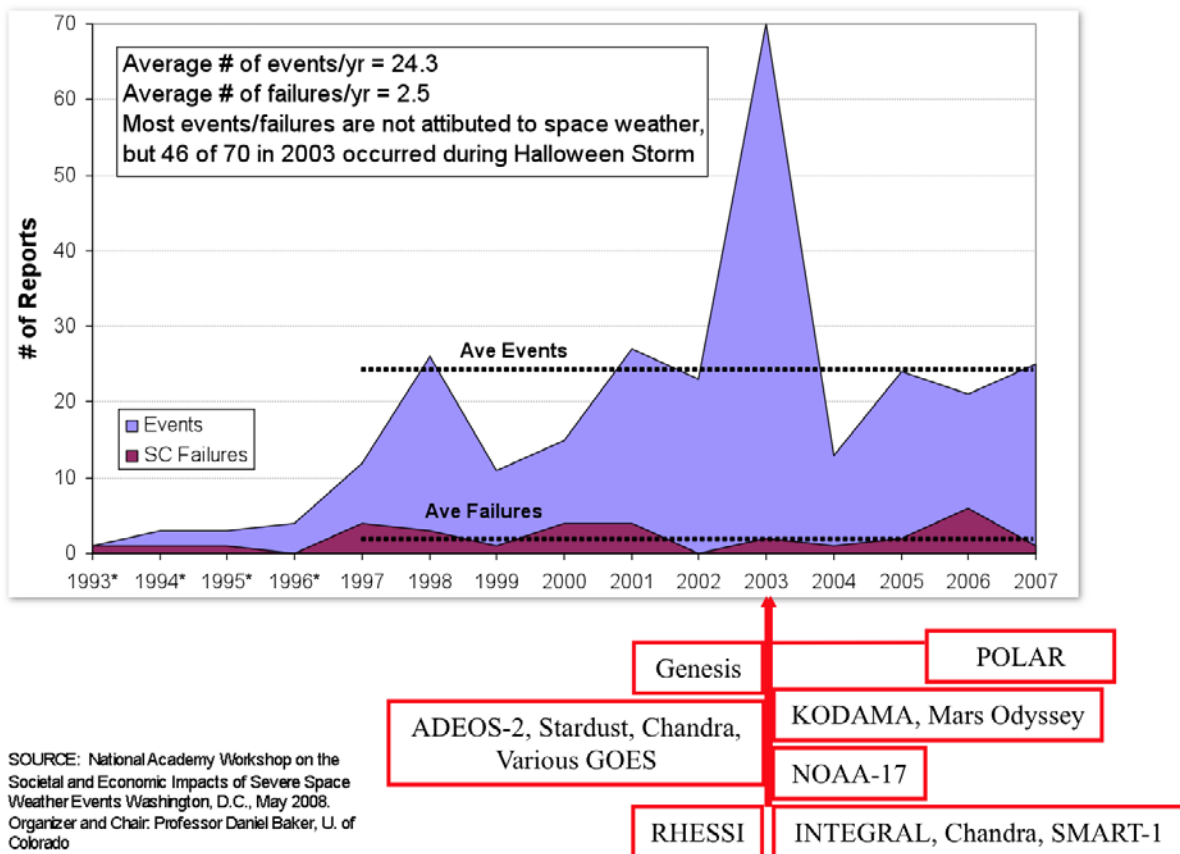


Figure 1. Plot of spacecraft anomalies and failures as a function of time.

### **I.3 Overview of the Short to Long-Term Risks and Consequences of Space Weather**

Dr. Mike Hapgood, research scientist at Rutherford Appleton Laboratory (RAL), provided an overview of the short to long-term risks and consequences of space weather. Echoing the message of the previous speaker, Dr. Lanzerotti, he noted that our advanced technologies create our vulnerability to space weather. For example, he contrasted the Concorde that was first flown in 1969, with the Airbus A380, first flown in 2005, which uses far more modern technologies that make it more susceptible to the effects of space weather. Threats of space weather include induced currents in the power grid, human radiation exposure, upsets in electronics, communications, digital control systems, GPS, impacts on satellites, and interference with wireless devices.

Dr. Hapgood made the point that engineering matters! The first line of defense for space weather is to build robust systems that can operate through bad space weather conditions. He discussed the key effects of space weather beginning with solar-flare electromagnetic radiation that reaches the Earth at the speed of light. The X-ray flash creates a layer that absorbs high frequency (HF) radio, causes blackout of aviation and military communications, and creates extra ionization that affects GPS. Since the flare's light travels at the speed of light, one must search for precursors to provide any warning and look to engineering to reduce susceptibility. Shortly behind the solar flare are the Solar Energetic Particles (SEPs). These energetic >Megaelectron Volt (MeV) ions penetrate spacecraft electronics causing single event effects, have large impacts on avionics, and can cause problems with ground-based electronics. The SEPs create atmospheric neutrons that are harmful to humans, and they require astronauts outside the spacecraft to seek cover. While nowcasts are valuable to satellite operators, the speed of the SEP event again requires looking for precursors for prediction. Then comes the Coronal Mass Ejection (CME), which plows through the solar wind to reach Earth in 1-4 days after the flare. Unlike the first phases of the solar event that happen very quickly, there is time to take procedural measures to increase the resilience of systems. The geomagnetic storm can have very pronounced impacts on power systems, GPS, spacecraft, etc. In addition, geomagnetic storms and high-speed solar wind streams create hot plasma in the magnetosphere and this plasma causes spacecraft charging. It has been observed that space weather can cause cumulative damage, for example, the gradual loss of insulation in power transformers, pipeline corrosion, and spacecraft orbital changes. Because the more severe space weather events tend to occur near solar maxima, which vary on an approximately 11-year cycle, we tend to forget lessons learned from previous events. In addition, the technology can change on an even faster time scale to create new or enhanced vulnerabilities.

Dr. Hapgood discussed what we know about the long-term behavior of space weather, specifically solar particle events, using proxy data from nitrates in ice cores. However, interpretation of this data is still the subject of considerable debate (see further discussion in Section III.3). A key question that needs to be answered—what is the 1-in-200 year risk? This is especially important considering that the risks of space weather are increasing due to the greater interconnectivity of key infrastructures. For example, loss of a key infrastructure like electrical power could take down other key supported infrastructures, such as refrigeration, water/sewage, retail finance, transport, heating, etc. He ended by discussing how we could discourage media hype that has occurred in newspapers in Britain.

## I.4 Space Weather: From Science to Forecast to Societal Impact

Dr. Thomas Bogdan, Director of the National Oceanic and Atmospheric Administration's Space Weather Prediction Center (SWPC), discussed the impacts of space weather on society. He discussed SWPC's measurement scales (shown in figure 2) that characterize the three principal agents of space weather. The R-scale measures the mostly short-wavelength (ultra-violet and X-ray) radiation from the flare, which travels at the speed of light reaching the Earth in just 8 minutes with no advance warning other than forecasts. This high-energy radiation causes radio blackouts on the dayside, GPS errors and loss of lock, and increased satellite drag in low-Earth orbit. The S-scale measures the severity of the charged-particle radiation that reaches the Earth in between 10-30 minutes after the event. Charged-particle radiation causes satellite damage and radiation exposure. Finally, the G-scale measures the severity of the geomagnetic storm that arises when the coronal mass ejected from the Sun reaches the Earth in between 18-96 hours. Key adverse effects include transformer damage leading to potential grid collapse and pipeline corrosion. It is important to keep in mind that as the complexity of our systems increase, the threshold of what constitutes an extreme event slowly decreases.

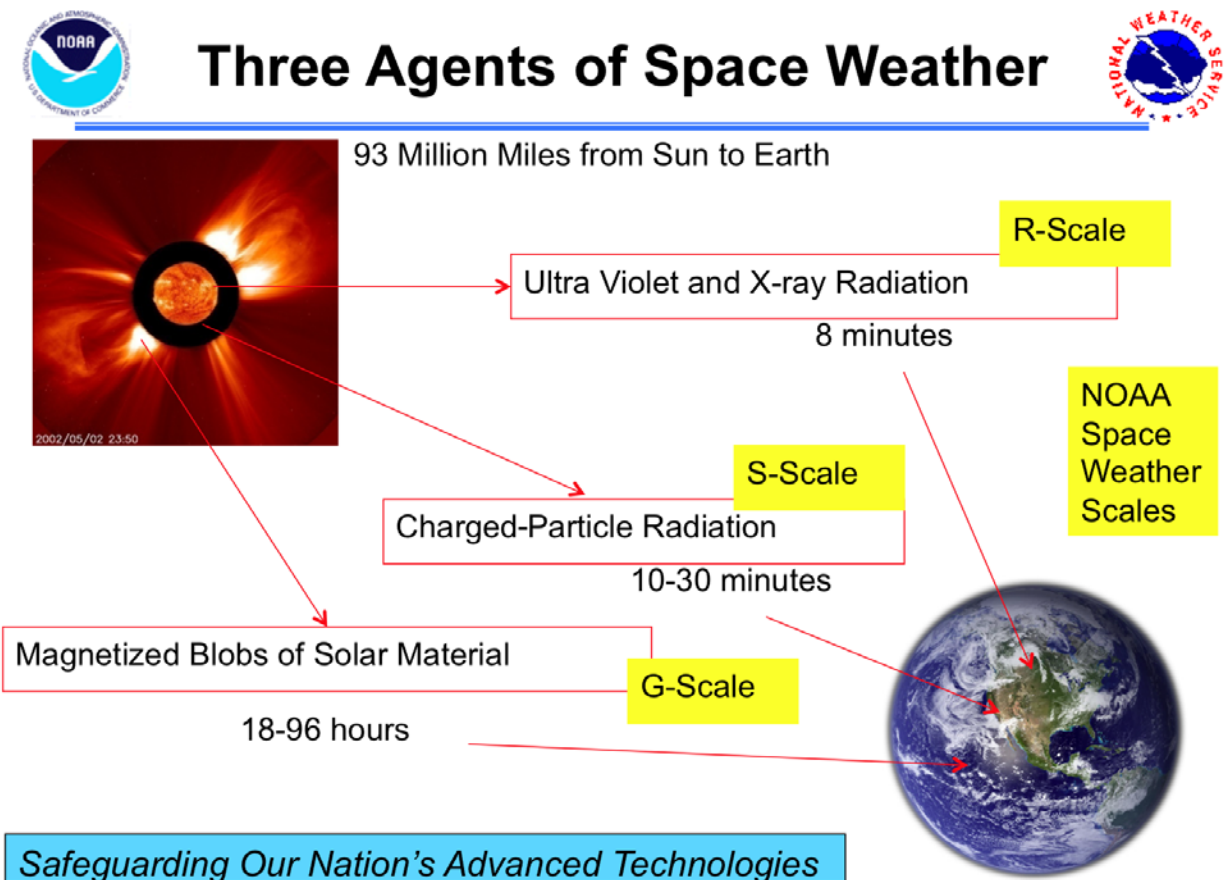


Figure 2. The Space Weather Prediction Center's three scales that measure the severity of the three agents of space weather—flares (R-scale), SEPs (S-scale), and geomagnetic storms (G-scale).



Dr. Bogdan described the Space Weather Prediction Center's vision as preparing the Nation to mitigate the effects of space weather through the understanding and use of alerts, forecasts, and data products. Their goal is to "provide the *right* information... in the *right* format... at the *right* time... to the *right* people... to make the *right* decisions." He indicated that NOAA and the Federal Emergency Management Administration (FEMA) have a good working relationship. Space weather warnings are being distributed to the FEMA National Response Coordination Center and the FEMA Operations Center. NOAA is working with the White House, Congress, and government leadership to develop and implement mitigation strategies to safeguard critical infrastructure from the impacts of severe space weather. He showed that the customer base for SWPC product subscription service has dramatically increased, even though the solar activity has been relatively weak. He felt that the very high current interest in space weather, both in the U.S. and Europe, create a window of opportunity to perhaps launch a dedicated space weather institute. However, he cautioned that in dealing with the public, managing expectations is important—we want to raise awareness of the dangers of space weather without scaring the public with electronic Armageddon.

In the questions that followed, the good working relationship between SWPC and FEMA was again mentioned. FEMA has learned that R, S, and G scale events at the 1-3 level do not significantly impact society. FEMA begins issuing alerts to customers for S4 and G4 storms. The analogy between terrestrial climate and space weather was raised here for the first time. Dr. Bogdan felt that the space weather community needs to learn from the climate community more effective ways to manage its message so that the risks from severe space weather are viewed in an appropriate context.

## **I.5 State Department Perspective on Space Weather**

Dr. James Head, American Association for the Advancement of Science (AAAS) Science and Technology Fellow at the U.S. Department of State, provided a State Department perspective on space weather. He provided an overview of the Office of Space and Advanced Technology (SAT), the space portfolio, and space weather activities. The most relevant activities in the space portfolio include GPS and Global Navigation Satellite Systems (GNSS), space weather and space situational awareness, and satellite-based Earth observation and remote sensing. The State Department has a key role in the international aspects of national space policy. SAT space weather activity in the U.S. government includes the National Space Weather Program Council and the Committee for Space Weather. They are responsible for issuing the National Space Weather Program strategic plan. The latest version (June 2010) has five key elements: (1) Discover and understand the physical conditions and processes that produce space weather and its effects; (2) Develop and sustain the necessary observational capabilities; (3) Provide tailored and accurate space weather information where and when it is needed; (4) Raise national awareness of the impacts of space weather; and (5) Foster communications among government, commercial, and academic organizations.

## I. Discussion Session

The discussion period that followed session 1 was very lively. Some of the key points that were made include the following:

- The amount of funds that would be required to start a dedicated institute for space weather is minuscule compared with the potential losses due to a space weather event or compared to the funds spent on heliophysics research each year.
- To get a new institute started we need to make a good business case. We should think about analogies from other endeavors, for example, IT security where no one would take ownership of the problem.
- We need to look at the broader hazards landscape—for example, the Icelandic volcanoes that caused chaos in Europe because no one knew what a plane could fly through. Also, we can learn from the Japanese tsunami where precautions were appropriate for a 1 in 200 year event, but the actual event was larger.
- It is important to understand what the impacts of space weather are. We should form teams to sell the need for action to minimize the downside risk.
- The research community has to learn how to transfer knowledge, if the papers submitted to Space Weather magazine are any example. The papers are too complex to be understood by the user community. We need individuals that can interface between the scientists and the user community.
- Satellite manufacturers are very reticent to admit that their systems are susceptible to space weather.
- We should look to other examples where low probability/high impact events have successfully been brought to congressional attention, such as for Earth orbit crossing asteroids.

## **II. Strategic Response to the Space Weather Treat to Society**

### **II.1 Lessons Learned from Successful Earth Science Research-to-Operation Efforts**

Dr. James Spann, a research scientist at NASA's Marshall Space Flight Center (MSFC), discussed some of the lessons learned in transferring Earth science research into operational efforts. He described two decision-making tools to help nations manage areas for societal benefit, such as disasters, biodiversity, climate, etc. The first software package, the Regional Visualization and Monitoring System (SERVIR), helps governments make decisions by providing Earth observations and predictive models based on data from orbiting satellites. The second product is the Short-term Prediction Research and Transition (SPoRT) tool to assist transitioning observations and research capabilities to the operational weather community to improve short-term forecasts on a regional scale. Dr. Spann noted that we could profit from lessons learned by transitioning these two Earth science tools to operational status in our efforts to improve communication between the providers and users of space weather data.

Some of the lessons learned were a need for patience (nothing happens overnight), a commitment for the provider and the users to work together, a commitment at all levels of management, and finally the importance of end-user engagement from the beginning. The provider and user exist in very different cultures. The provider, usually a research scientist, focuses on detail, while the user is primarily concerned with making the tool work. The researcher must live in the user world long enough to understand it. Since the user must have some investment in the product in order for them to eventually own it, they should be involved in the entire transitioning process. The user's needs must be identified and reassessed over time to identify conditions of satisfaction. The data must be accessible to the user at the appropriate frequency of update and in their chosen format. Just because we (i.e., NASA) have a good product, we cannot expect the user to adjust to it. Often the user does not have the resources needed to ingest the product. The researcher must include training and building capacity in the transition process. Of key importance is developing a trusted relationship with the user. To help in marketing the tool, one must demonstrate how the user benefits, especially from a standpoint of economic impact. Developing a strong advocate in the user world helps convince others to use the product.

### **II.2 Large Scale Analysis of GMD Impacts on the Electric Grid: Need for Improved Models and Analysis Techniques**

Dr. Randy Horton, research scientist at the Electric Power Research Institute (EPRI), discussed the need for improved modeling and analysis techniques to accurately predict the impact of geomagnetic disturbances on the electric power grid. The system modeling and analysis approach for power transformers is illustrated in figure 3. It begins with creating a DC system model to which one inputs the estimated electric fields that result from the interaction of the CMEs with the Earth's magnetic field. The output of the model is an estimate of the "quasi-DC" Geomagnetically Induced



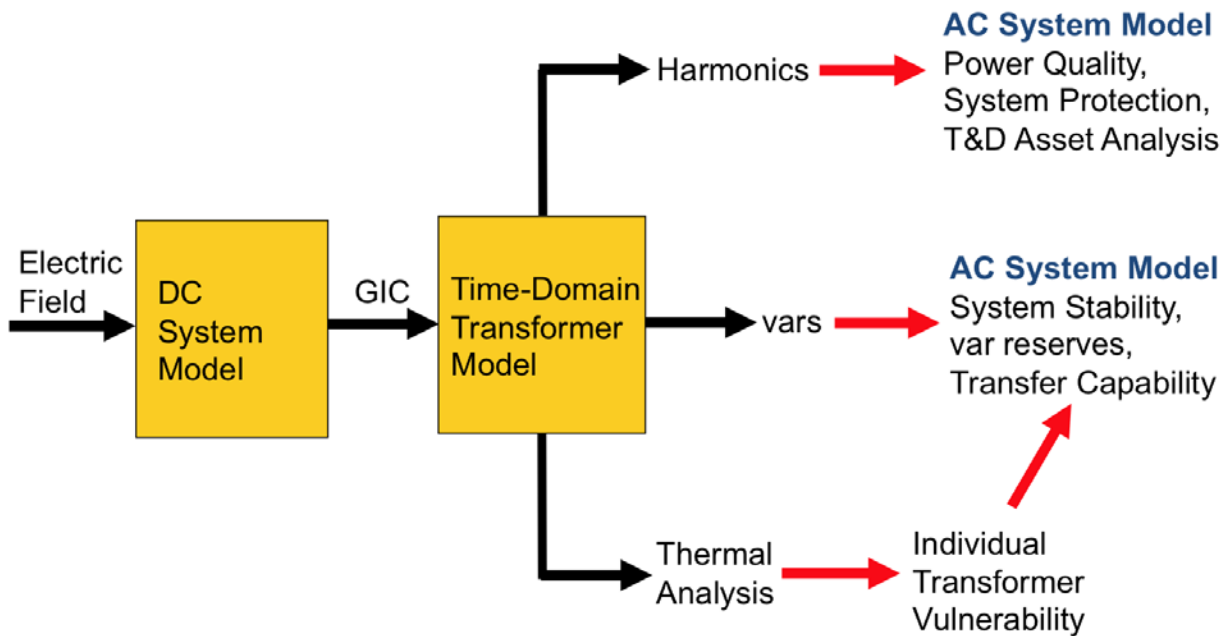


Figure 3. The system modeling and analysis approach for power transformers.

Current (GIC). The electric field and consequently the corresponding GIC depend rather sensitively on estimates for the ground resistivity. The GIC is then input into a time-domain transformer model. Dr. Horton stressed the importance of having accurate transformer models in the impact analysis. Transformer design is an important consideration—e.g., the response of the transformer to GIC depends heavily on the core design of the transformer. Details of the transformer design are often proprietary, which further complicates the development of accurate models. With the transformer model, estimates can be made of AC waveform distortion from harmonics as well as changes in reactive power demand or vars (vars or volt-amperes reactive is the reactive power that is stored in the electric and magnetic fields of the transformer). Increased var demand from storms can be substantial. Lastly, a thermal analysis is possible to estimate individual transformer vulnerability. However, the accuracy of the thermal analysis depends critically on having an accurate thermal model of the transformer. In summary, the flow of GIC (quasi-DC) in the power transformers causes semi-saturation of the core (half-cycle saturation), which leads to increased var demand, harmonics, and heating. When performing studies to determine the impact of geomagnetic disturbances on the electric power grid, the transformer is among the most important and difficult elements to model.

Considering the challenge of properly modeling a single transformer on the grid, it is not surprising that performing an AC system analysis on a continental (or national) level is a formidable task. To date, AC system analysis has been limited to the utility or regional level. Thus, if large-scale models become necessary to assess the impact of wide area geomagnetic disturbances, there will be numerous issues to overcome. A key conclusion of Dr. Horton’s talk was that uncertainties in the transformer models along with uncertainties in determining GIC values, because of electric field variations and changes in the Earth’s conductivity, make accurate calculations difficult. More research is certainly needed to improve estimates of the effects of geomagnetic disturbances on the energy grid.

A comment following the talk noted that power producers would like to have better models for large space weather storms such as the Carrington event to make their own assessments of impact. It was also noted that what the models need as input is the electric field, whereas the scientific community provides changes in the magnetic field with time (dB/dt). Other comments focused on how we might provide incentives for manufacturers to be more forthcoming with proprietary data that is critical in providing accurate transformer models.

### **II.3 Effects on Wide Area Augmentation System (WAAS)**

Kenneth Ward from the Federal Aviation Administration (FAA) discussed the effects of space weather on the Wide Area Augmentation System (WAAS). The WAAS is an air navigation aid developed by the FAA to augment the Global Positioning System (GPS), with the goal of improving its accuracy, integrity, and availability. The WAAS architecture consists of 38 ground-based reference systems, 3 master stations, 6 ground Earth stations, 3 geostationary satellite links, and 2 operational centers. The WAAS specification requires it to provide a position accuracy of 25 ft or better in both lateral and vertical measurements at least 95% of the time. Actual performance is far better, making WAAS capable of enabling precision approach landings of aircraft. Mr. Ward discussed some of the current and planned upgrades to the system, such as new receivers, communication upgrades, and an improved ionosphere model. WAAS is used in all phases of aviation including enroute navigation, terminal navigation, and approach and landing. WAAS is also used for general navigation of cars, trucks, trains and ships. WAAS improves the capacity of the air system by providing guided departures, flexible routes, vector free arrivals, wake turbulence management, and enhanced weather avoidance. It is an integral part of the Next Generation Air Transportation System (NextGen). He discussed Localizer Performance with Vertical Guidance (LPV) approaches that can only be flown with a WAAS receiver. As of June 30<sup>th</sup>, 2011, there were 2,520 LPVs serving 1,295 airports in the U.S.

Space weather effects on WAAS come from two principal sources—ionosphere disturbance and scintillation. However, other WAAS failure mechanisms such as unintentional and intentional jamming, equipment and system failures, and tropospheric effects are considered to be a greater problem. He showed the effects of a “normal” space weather event. Loss of LPV approach capability occurred over large parts of the U.S. If GPS and WAAS had been the only means of navigation and approach services, the impacts to air navigation would be significant disruption causing diversion to other airports, comparable to a winter weather event. Since other means of navigation and approach are available, the impact of space weather is manageable, albeit with a considerable economic impact. The effects of a very severe or “Black Swan” event are not known, but the realistic worst-case scenario would be a significant decrease in the capacity of the air system.

## II.4 Space Weather: Impact on Cascading Power Grid Failures—A Simple Model and Illustration

Dr. Elisabeth Pate-Cornell, professor of management science and engineering at Stanford University, presented a simple model of the impact on cascading power grid failures due to space weather. This was a student project by three of her students—Cecilia Larrosa, Lewis Kaneshiro, and Jingjing Zhao. The project scope was to assess the effect of space weather on linked elements of the power grid in different states to analyze the effects of grid operator actions on cascading grid failures and to identify optimal management policies across the grid. The model involved loads, capacities, and economics. It specifically accounted for the solar activity forecast and the effects of solar activity and geomagnetic storms (loads) in different locations. The power grid system was simplified to three states, namely Washington, Oregon, and California. The model used a simplified electric power grid that included generators, transmission lines, and consumers. The load cascading model is a dynamic model of deteriorations and cascading failures over time. The operation optimization assumes a pre-event load distribution that maximizes customer benefits. Given a warning of a solar event, operators lower capacity and re-route flow. The cascading failure dynamics simulation is based on a network model containing nodes (generators, transformers, lines, and customers). The assumption is made that the state of each node is influenced only by the state of its neighbors.

The results of the simulations show that more and more components (grid points) are lost as the severity of the event increases as expected when the operators take no action. Less grid points are lost when the operators take the extreme action of reducing production in each state by 50%, but still better results were obtained when the grid operators took independent action. However, the optimal result was for Oregon and California to coordinate their actions. Conclusions from the study were that the power grid system is very vulnerable if there is no warning of the solar event. Given a warning, the best result (i.e., minimal loss of grid points) occurs when the grid operators coordinate their actions. A comment from the floor was made that it would be better to use a time-domain stability model in their analysis.

## **III. Science Perspective—Solar Flares, CMEs, SEPs and Geomagnetic Storms**

### **III.1 What Do We Not Yet Know About Solar Flares and Solar Energetic Particles (SEPs)**

Dr. Richard Harrison, space physicist at the Rutherford Appleton Laboratory in the UK, discussed what we do not yet know about solar flares and Solar Energetic Particles (SEPs) in the context of space weather. The solar events that are important are the ones that produce impact at Earth, such as SEPs, Coronal Mass Ejections (CMEs), and electromagnetic enhancements. Thus what is most relevant is the prediction of onsets, arrivals, and impacts. At the heart of the question is the relationship between flares and CMEs. Recent work has disconnected the flare and CME onset. His study of 151 CMEs showed a strong association between CME and flare onsets, but many CMEs occur without flares, and the relative timing between flare onset and CME onset can vary considerably with either leading. He showed the solar events of August 2010, an example where the observed flares and CMEs are separated both in time and location on the Sun's surface. Thus he challenged the standard flare model. Instead, current observations indicate that in many cases magnetically complex systems on the Sun result in flares and/or CMEs driven by a magnetic “driver”, not each other, and each may or may not occur depending on local conditions.

SEP production also occurs in association with solar events. Energetic particles consist mainly of energetic electrons (~1 KeV to tens of MeV) and ions (~50 MeV per nucleon to ~10 GeV). SEP events are of two general types—impulsive and gradual. Impulsive SEPs are accelerated in flares, are electron rich, have durations of hours, and occur in a relatively narrow longitude cone. Gradual SEPs are accelerated in CME shocks or in Co-rotating Interaction Regions (CIRs). They tend to be proton rich, have durations of days, and occur in a wide longitude cone.

Key remaining issues include the resolution of the flare-CME relationship and improving our tracking and prediction techniques to understand onset processes, to project arrivals at Earth, and to understand how Earth cuts through the CME structure. Outstanding questions include how the SEP production depends on the complex structure of the CME, and how SEPs depend on CME-CME interactions when there are CMEs close together travelling at different speeds. Magnetohydrodynamics (MHD) heliospheric models are very dependent on input, such as the CME directions and sizes and the shock development in the models.

### **III.2 What Do We Not Know About Geomagnetic Couplings and Responses to Solar Eruptions**

Dr. Robert McPherron, professor emeritus in the Department of Earth and Space Science at UCLA, discussed the coupling between the solar wind and the Earth's magnetosphere. The strength of the interaction is determined by the rate of magnetic flux transport when magnetic reconnection occurs between interplanetary magnetic fields and the Earth's magnetic field. Anti-parallel fields reconnect

most efficiently. Coupling depends on many things including the solar cycle. The short forecast lead times require that measurements obtained from satellites in orbit around Earth-Sun L1 be propagated to Earth. Propagation methods are inadequate and produce large errors. In addition, since we cannot look directly at the Sun, the parcel of plasma that we monitor near L1 does not necessarily hit the Earth's magnetic field.

The empirical and physics-based models require accurate drivers (magnetic flux and magnetic field strengths). We would like to study the response of the magnetosphere for large events, but super storms are so rare that we do not have sufficient data to empirically determine the relationship between driver and the ring current. The probability that the hourly ring current exceeds 400 nanotesla (nT) is only about 1 in  $10^{-5}$  or about once per solar cycle. Strong geomagnetic storms only occur preferentially when there is a strong solar wind and when the resulting magnetic compression lasts a long time.

In summary, we cannot accurately predict the waveforms of drivers that will eventually arrive at Earth, in part because we cannot propagate waveforms accurately either radially or azimuthally. It is likely that we will never be able to provide accurate models of the driving waveforms except with observations immediately upstream of the bow shock, and these details matter in the geomagnetic response to solar wind. Instead of trying to predict accurate waveforms, Dr. McPherron recommends doing probabilistic forecasting by ensemble climatology to provide a means of calculating a range of response (e.g., there is 50% probability that the disturbance parameter would lie in some range). Ensemble averages from multiple simulation runs driven by appropriate climatology is a possible way to obtain reasonable forecasts.

### **III.3 Extremes of Solar Storms: How to Determine Statistics of Rare Solar Events Based on Existing or Obtainable Records or Models?**

Dr. Karel Schrijver, solar physicist at the Lockheed Martin Solar Astrophysics Laboratory, discussed how to determine the statistics of extreme solar storms ("Black Swan" events). The Sun has been observed with instruments spanning a wide wavelength range for only about 50 years. During this time we are unlikely to have seen the most extreme events that can be expected from the Sun in its present evolutionary stage. To quantify the likelihood of infrequent extreme events, we need to go back further in time by making use of geological records or by looking at a sample of other stars of comparable age as the Sun.

One strategy is to look for solar energetic particle (SEP) events in ice cores. The correlation between flare intensity (measured using photons) and SEPs will not be perfect, because energetic particles are produced by flares as well as in interplanetary coronal mass ejections (ICMEs), yet statistically it is feasible to use SEPs as a proxy for estimating the magnitude of solar explosive events. Therefore, if SEPs interact with the Earth's atmosphere to produce ionization shifts, inducing chemical signatures that can precipitate to be captured in long-lived ice deposits, conceivably this would provide a pre-historic (i.e., before ~1950) record of solar activity. The specific signature that was searched for was nitrate ( $\text{NO}_3$ ). It should be noted that  $\text{NO}_3$  signatures are also produced by terrestrial events (biomass burning), and also there is controversy as to whether there is a sufficiently

rapid pathway for incorporation of nitrate into the ice to leave a short-duration spike around the time of the flare/ICME. Of the 15 or so ice cores that have been examined to date, only one showed a nitrate signature that could be correlated with the Carrington event in 1859, one of the largest flares, if not the largest, observed on the Sun. The present conclusion from the ice-core data is therefore that the potential correlation of nitrate spikes in ice cores with SEP events needs to be revisited, and that no quantitative results from ice-core analysis can presently be used to constrain solar flare frequency spectra.

The second approach was to get meaningful data by looking at flares from other stars. For example, the Kepler satellite has observed flares in white light that are thousands of times larger than the Carrington event. However, these very active stars observed by Kepler are much younger than the Sun, making direct comparison problematic. In fact, these young stars that flare a lot appear inconsistent with flare data from the present Sun, even when the data is scaled to correct for the mean stellar level of activity. Thus, the only way we can say anything about what “Black Swan” events have occurred in the last 10,000 years is either to observe the Sun for this many years, or to observe flares from a large sample of Sun-like stars to obtain a statistical basis for predicting events on the Sun.

Dr. Schrijver ended his talk by discussing possible follow-on activities depending on priorities. If solar spectral irradiance variability is most important, then we should collect and study panchromatic observations of solar neighborhood stars. If the solar energetic particle distribution is most important, we should revisit the atmospheric studies and ice-core analysis. Possibly the differential exposure of rocks on the Earth, Moon, and asteroids would reveal the history of large SEP events.

Following the talk it was asked why the Kepler data isn't good enough to give insight into Black Swan events. The response was that the Kepler data are good enough to answer the question of whether an X1000 flare will occur, but since it is a visible-light instrument, it cannot provide insight into the hardness (spectral irradiance) of the flare in the X-ray and EUV domains. Combining data from Kepler and X-ray observatories along with other observational data might suffice, but a concerted and focused effort is needed. Another question arose about extrapolating the age distribution of the Kepler data. The response was that they did do an extrapolation using the rotational rate of the star as proxy for age, but the active stars currently studied from the Kepler database are most likely not old enough to make the extrapolation all the way to the Sun. A comment was made that what we really need to know is the extremes of the solar wind.

### **III.4 Towards Physically Motivated Operational Flare Forecasting**

Dr. Shaun Bloomfield, School of Physics at Trinity College Dublin, discussed the current state-of-the-art in flare forecasting. Since solar flares pose significant space weather risks by producing greatly increased levels of ionosphere-altering X-ray and UV radiation, a worthy goal is to have an operational flare forecasting method that is physically motivated by the end user's requirements. Predicting “no flares” may appear to be easy simply because 90-95% of the days are free of flares larger than a relatively small M1.0 flare, but forecasting large flares accurately is yet beyond our means. The specific questions that Dr. Bloomfield addressed were how well is the research community quantifying flare forecasts, how well do existing flare probability forecasts perform, and what



are the relevant flare forecasts for the space-weather community? He discussed forecasts using a contingency table with four elements—true positives, true negatives, false negatives (missed flares), and false positives (false alarms). He recommended using a true skill statistic that scales correctly with increasing flare occurrence. Existing forecast methods can be divided into three categories— theoretical based on behavior pattern learning, statistical from either historical flare rates or from Poisson flare distributions, and more recently empirical, such as artificial neural networks, decision trees, and wavelet predictors. There is no physics model in any of these forecast methods.

Dr. Bloomfield discussed the McIntosh Sunspot group classification scheme in conjunction with the Poisson prediction method. In this approach one observes a specific Sunspot McIntosh class (a measure of the complexity of a given Sunspot region) and based on the historical flare rate for that class, assigns a % Poisson probability. If that probability exceeds a threshold then a flare is predicted. The thresholds are tuned to the performance. The Poisson probability optimized scheme works well especially for predicting medium sized (M-class) and large sized (X-class) flares. The desired flare forecasts differ by user community. For example, commercial satellite operators want few false alarms to avoid unnecessarily powering down, whereas an astronaut flight surgeon would want few missed flares, especially X flares. Questions were directed at what are the relevant flare forecasts for the space weather community. It was also pointed out that flares are not always associated with a single active region on the Sun.

### **III.5 The Impacts of Ionospheric Space Weather**

Dr. Anthony Mannucci of the Jet Propulsion Laboratory (JPL) discussed the impact of ionospheric space weather. The variability of the ionosphere affects navigation, radar, and communication. Deep space navigation is significantly impacted by space weather. NASA's Deep Space Navigation system uses 3 large antennas on the ground to communicate with spacecraft. When the signal passes through the ionosphere, the variability in the electron density introduces a Doppler shift that affects the precision of the position measurement. There is considerable day-to-day variability in the ionosphere, but the vertical Total Electron Count (TEC) in the ionosphere can be dramatically increased during a space storm. Using the two frequencies available with GPS, it is possible to partially correct for errors. However, the measurement needed to remove the effects of increased TEC is never on exactly the correct line of sight. The International GNSS Service (IGS) global GPS receiver network is a valuable resource in making these corrections. This network of GPS receivers provides a continuous data stream. He showed ionospheric TEC maps that illustrate regions of significantly increased TEC during space storms. In major space weather storms there is too much structure in the ionosphere to give accurate corrections.

Civil aircraft navigation is another space weather application. Because of safety-of-life considerations, very reliable bounds are required for the ionospheric error. An extreme storm detector has been created to warn pilots and to deny WAAS ionosphere correction during intense storms if required navigational accuracy is not met. Another potential threat is the under sampling of a highly localized “irregularity” in ionospheric TEC. He showed an example where this occurred at night over Florida, resulting in vertical ionospheric delay errors on the order of 1-10 meters if left undetected.

Radar applications are also affected by the Earth's ionosphere. Since applications often use a satellite within the Earth's ionosphere, electron density models of the ionosphere as a function of altitude are needed to make corrections. Other applications of space-based radar such as ocean altimetry and the use of synthetic aperture radar to make high-resolution images of auroral arcs are also affected by ionosphere variability. Communications are affected by small-scale ionosphere irregularities that cause radio frequency signals to scintillate.

Dr. Mannucci ended by noting that he had summarized the challenges of nowcasting, that is, estimating how applications are affected by ionospheric conditions based on limited data from a different time and place. However, what the community would like to have are accurate forecasts. Estimating the impact of space weather hours to days in advance is a formidable challenge, and one that requires good observational data.



## **IV. Impacts of Space Weather Events On Humans and Infrastructure**

### **IV.1 Predictions of Space Weather Influences on Aircraft Radiation Exposure**

Dr. Christopher Mertens, NASA Langley Research Center (LaRC), discussed predictions of space weather influences on aircraft radiation exposure. Key to this effort is the Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) model. NAIRAS is a real-time global radiation exposure model that can predict radiation exposure (including galactic cosmic rays and solar energetic particles (SEPs)) for airline pilots and crew for a representative set of domestic, international and polar routes. It is a decision support tool that can take specific actions, such as altering the route or altitude of an aircraft during SEP events. A study done in collaboration with the National Institute for Occupational Safety and Health (NIOSH) shows that median U.S. pilot radiation exposures would trigger monitoring in European Union states.

The NAIRAS uses the best available space weather data in its analysis of dose rates. The NAIRAS real-time predictions are available on line and as an iPhone app. He showed the effective dose rates at three altitudes for representative storms. International Commission on Radiological Protection (ICRP) radiation standards were not exceeded for the Halloween 2003 event, but were exceeded for polar and high latitude routes during the January 2005 event. He showed the dosage rates for a simulated Carrington-like event using the available SEP spectral flux and geomagnetic storm “data” that have been estimated from the historical record. During a storm of this magnitude, high-energy particles are seen at the lower latitudes of the United States. Studies show that a Carrington-like event would result in ICRP prenatal and annual limits being exceeded on nearly all U.S. flights, both domestic and international.

Some of the issues that need to be solved to improve the NAIRAS model are the spectrum fitting of the SEP ion spectral energy distribution. Satellites are needed with greater than 1 GeV particle detectors to define the high-energy tail of the particle energy distribution. Another issue is to reduce the errors in the modeled cutoff rigidity, which is particularly important for flights along the north Atlantic corridor region where the magnetosphere open-closed boundary is typically located. The cutoff rigidity enables a specification of the minimum energy that a charged particle must have for transport through a magnetic field. Currently particles are transported through the magnetosphere using the Center for Integrated Space Weather Modeling (CISM)-Dartmouth particle trajectory geomagnetic cutoff rigidity code, driven by real-time solar wind parameters and interplanetary magnetic field data provided by the Advanced Composition Explorer (ACE) satellite. For the future, Dr. Mertens would like to fly particle spectrometers on the Stratospheric Observatory for Infrared Astronomy (SOFIA) to validate the model and eventually have radiation instrumentation flying continuously.

## IV.2 Space Weather and U.S. Electric Power Grid Vulnerabilities: An Overview of the Risks to this Critical Infrastructure and Research Necessary to Assess Vulnerability and Mitigate Impacts

John Kappenman, owner of Storm Analysis Consultants, discussed the threats of space weather on the U.S. electric power grid. The Electromagnetic Pulse (EMP) Commission, FEMA Executive Order 13407, and the National Academy of Sciences investigation results all agree that space weather risks have the potential to create large scale blackouts, and to permanently damage transformer assets resulting in a lengthy restoration. The large geographic footprint of a space weather event makes it particularly serious. Loss of electric supply will impact all other interdependent infrastructures on the order of hours to days. The threat is that a rapidly changing geomagnetic field over large regions will cause Geomagnetically-Induced Currents (GICs) to flow into the continental interconnected electric power grids (see figure 4). The magnetic field of the electrojet induces a voltage potential on the surface of the Earth. GICs enter the power system through ground connections. The risk to society has been escalating as a result of several factors. First, the electric grid is getting larger, thereby producing a larger antenna to cause GIC. Secondly, the operating voltage in transmission lines has been increasing with time. Finally, improvements in transformer efficiency have made them more susceptible to space weather, as less GIC is needed to saturate the cores. We have been stacking risk multipliers on top of risk multipliers. His analysis shows that large scale storms such as the 1921 event or the 1859 Carrington event could cause wide spread blackouts, especially in the Northeast. This could leave 100 million people without power for an extended period of time considering the time required to replace transformers.

A rapidly changing geomagnetic field over large regions will induce Geomagnetically-Induced Currents to flow in the continental interconnected Electric Power Grids

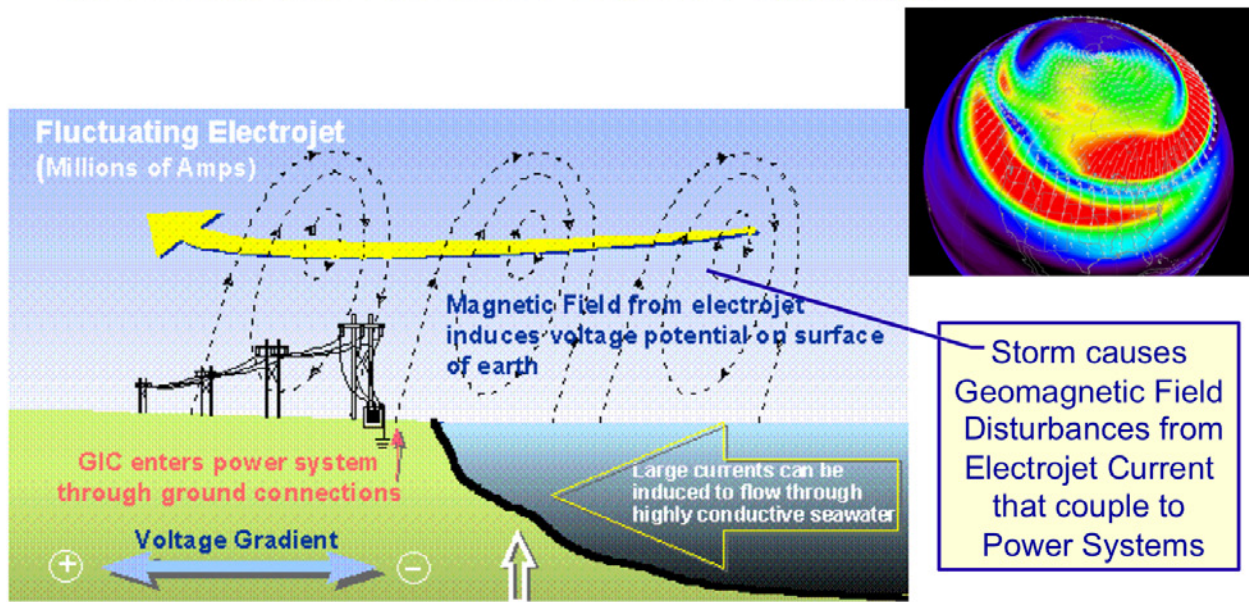


Figure 4. Illustration of how GICs get into the continental interconnected electric power grids.

In summary, for several decades the Nation has experienced a failure to understand how risk has migrated into our electric grid infrastructures from space weather threats. The failure has been collective spanning the space weather community to the power grid infrastructure operators. We have not agreed upon a design code or operating procedures to mitigate the threat. He closed by noting that finding means to mitigate the threat of space weather to the electric grid might be an issue for a space weather institute to take on.

A question was asked if there are mitigating actions that a power company could take in response to a severe space weather event. His response was that even if we had perfect forecasts, the lack of an operational plan for responding to space weather would probably result in a disaster scenario. We need to eliminate the risk from the infrastructure itself if we are to avoid a catastrophic result from a major solar geomagnetic storm. He was asked to compare the threat of space weather to other major threats—e.g., Electromagnetic Pulse (EMP), pandemic, nuclear attack, etc. He contrasted space weather as an event that was sure to happen some time in the future. Hardening against space weather would also help harden susceptibility to the slow pulse of an EMP.

### **IV.3 Impacts of Space Weather on Department of Defense Operations and Systems**

Dr. Dale Ferguson, Kirtland Air Force Base, discussed the impacts of space weather on the Department of Defense (DOD) operations and systems. Flares have an immediate impact on HF radio communication due to ionization of the D layer of the ionosphere by X-rays. Heating of the upper atmosphere increases drag on satellites. Solar weather affects the prediction of orbital drag on satellites by increasing errors that increase with altitude. Scintillation occurs during magnetic storms, resulting in loss of communication, especially at high and low latitudes. Scintillation negatively impacts navigation by degrading the reliability of GPS systems. Large gradients in electron density profiles cause geo-location errors that affect surveillance and intelligence operations. Radio bursts directly interfere with GPS, communication, and radar systems, causing false targeting and blinding surveillance radars. SATCOM (satellite communications) are also impacted due to signal interference and loss. Satellite sensors are blinded and degraded by solar energetic particle events.

Dr. Ferguson spent considerable time discussing sources and types of satellite anomalies. The two key sources of anomalies are spacecraft surface charging and deep dielectric charging. Spacecraft surface charging is caused by lower energy particles that can cause Electrostatic Discharges (ESDs) and arcing on solar arrays and power cables. Deep dielectric charging is caused by higher energy particles that either cause internal arcing or single event upsets caused by the ionization trail of a single high-energy particle in sensitive electronics. The effects can be both transient, such as bit flips in electronics, or permanent, such as arcs and ESDs that cause damage to the electronics or a solar array failure. He discussed a few anomalies and their probable causes. An example is Galaxy 15 in 2010 where ESD caused an electronics problem coming out of eclipse during a severe geomagnetic storm.

A key goal for DOD is space situational awareness. The DOD must determine whether anomalies are due to space weather or to hostile actions. DOD goals are real-time anomaly resolution and 72-hour predictive space weather capability. DOD satellites tend to fail because of charging in dangerous periods, such as large SEP events or when coming out of eclipse. Some of the ways to prevent space weather charging anomalies are to harden all vital electronics, coat surfaces with grounded conductors, design for more secondary electron emission and less photoemission, and design spacecraft to prevent deep dielectric discharges. Operations can also mitigate space weather-related effects, such as turning off sensitive electronics, thrusters, and focal-plane arrays. Ideally one would also like to fly charge monitors and charging mitigation systems. A question was asked if the DOD was concerned about autonomous systems going into fail-safe mode during space weather events. He noted that this was a concern and that spacecraft need to be designed to survive minor glitches such as these.

#### **IV.4 Impact of a Solar Superstorm on Critical Communications and Society**

Mark MacAlester, supervisory telecommunications manager at the Federal Emergency Management Agency (FEMA), discussed the potential impact of a solar superstorm on critical communications and society. He discussed some of the extreme space weather events that have happened in the past. The Carrington-Hodgson event in 1859 that disrupted telegraph service worldwide is the largest recorded event. Anecdotal historical observations suggest a storm of this magnitude may occur once in 500 years. The May 16, 1921 event, called the “Great Storm”, disrupted telegraph service, caused fires, and burned out cables in New York. A storm of this magnitude may occur once every 100 years. The March 13, 1989 geomagnetic storm collapsed the Quebec power grid, and came within seconds of collapsing the Northeast and Midwest U.S. power grids. The 2003 “Halloween Storms” interrupted GPS, blacked out HF radio, forced emergency procedures at nuclear power plants, and destroyed several large electrical power transformers in South Africa.

FEMA has determined that radio blackouts (R), solar radiation storms (S), and geomagnetic storms (G) at levels 1-3 on the NOAA space weather scales ([http://www.swpc.noaa.gov/NOAA\\_scales/index.html](http://www.swpc.noaa.gov/NOAA_scales/index.html)) have little impact on normal operations. Even solar radio blackouts up to level R5 generally do not have a major impact on FEMA’s operations. Terrestrial line-of-sight public safety radio that uses Very High Frequency (VHF), Ultra High Frequency (UHF), and microwave communications are not impaired. He also noted that while the North American Power Grid is potentially vulnerable to a major geomagnetic storm, at least some of the electric utility providers are implementing mitigation and response measures and stockpiling transformers. Furthermore, new transformer manufacturing capability is coming online in the U.S.

In partnership with NOAA’s Space Weather Prediction Center, other Federal agencies, and private sector telecommunications services providers, FEMA performed a meta-analysis of the largest experienced event, in this case a repeat of the September 1-2, 1859 Carrington-Hodgson event. Taking into account all three types of space weather—radio blackout, solar radiation storms, and geomagnetic storms—he showed how this extreme event scenario might play out in the U.S. Ini-



tially, Earth is struck by multiple minor to strong radio blackout events causing HF disruption on the daylight side lasting from minutes to three hours and some shorter disruption in GPS. When a Carrington-scale solar flare erupts, resulting in a R5 radio blackout event, HF and GPS are more severely impacted. Due to the speed of this event, the solar radiation storm begins about twenty minutes after the solar flare and builds to an S5 level. One estimate suggests that approximately 15% of the satellite fleet may be lost because of solar panel damage, and the remaining satellites will experience a significantly elevated number of satellite anomalies. Satellite communications (SATCOM) may be significantly impacted. When a Coronal Mass Ejection with a southward magnetic orientation arrives at Earth approximately 18 hours after the solar flare, it causes an extreme (G5) geomagnetic storm. SATCOM and GPS may be severely disrupted due to scintillation—variations of amplitude, phase, polarization, and angle-of-arrival of radio signals that bounce off of, or pass through, the ionosphere. However, by far the major impact of the geomagnetic storm could be widespread voltage collapse (blackouts) and potential damage to a significant number of transformers that would bring down large portions of the U.S. electric grid. He continued the scenario assuming that portions of the electric grid were disabled. When power is lost, customers with television, phone, and Internet services delivered over fiberoptic or coaxial cables will lose those services unless they have onsite backup power. Additionally, the distribution nodes that connect homes and offices to the telephone or cable central office generally have battery power for only about 8-40 hours. Many cellular towers will fail after 8-24 hours. In other types of disasters, homes and businesses without power have lost their phone service and connection to the Internet in the first 24 hours, causing businesses and consumers to revert to a cash economy. If power is not restored, the Public Switched Telephone Network (PSTN) will begin to fail in impacted areas within approximately 3-7 days. Satellite service providers that rely on the PSTN and the Internet may not be able to provide services to their customers.

He concluded by noting that if electric power remains available, even the worst predicted space weather event would be inconvenient, but not catastrophic for society. The actual impact of a 100- or 500-year storm on the electric power grid is hotly debated. It is unclear, at present, what the real impact will be. His recommendations are that we diversify. Redundant and resilient satellite, radio, and terrestrial communication systems can provide critical communications throughout a “super storm”. It is also important to have backup power available and to have a plan to mitigate the impact on people, particularly those needed to help restore the electric grid.

Following the presentation, the question was asked whether satellites could be knocked out sooner than in his scenario. He said that this question was difficult to answer because satellite providers are uncomfortable discussing their vulnerabilities. Someone noted that losing the electric grid could cause immediate harm to people, for example, to individuals in dialysis centers. He agreed and said that this kind of liability precisely describes the complexity that decision makers must face during a space weather event.

## **IV.5 Impact of Ionospheric Scintillation on Commercial GNSS Timing Receivers**

Dr. Joaquim Fortuny from the Institute for the Protection and Security of the Citizen (IPSC) discussed the impact of ionospheric scintillation on commercial Global Navigation Satellite System (GNSS) timing receivers. Critical infrastructures on the ground rely on GNSS-based services for precise timing and synchronization. IPSC is currently investigating the vulnerabilities of GNSS systems to both anthropogenic interference sources, such as digital video broadcasting and radio frequency interference, and natural interference systems such as space weather. The vulnerability of satellite navigation to space weather has been the topic of a number of studies, most recently the American Meteorological Society Report (March 2011). Some of the recommendations from previous studies are that GNSS should be classified as a critical infrastructure, GNSS receivers and antennas should be hardened, backup systems and standards for more resilient GNSS receivers should be established, and the impacts of interference on critical timing and synchronization services be quantified.

Space weather affects the accuracy of GPS by causing perturbations in the ionosphere. Ionospheric range delay results from normal signal propagation through the ionosphere. These effects are slow and correctable. Scintillations result from severe ionospheric signal scattering. These effects are fast, unpredictable, and hard to rectify. Amplitude fading or signal to noise degradation is also caused by solar radio bursts. Extensive tests were conducted on 7 different GPS clocks/time servers used in the telecom sector. It was found that the quality of the local oscillator determines the performance of a GPS clock in case of a temporary outage or in the presence of radio frequency interference. Work is continuing to test receivers under amplitude scintillation using signal generators. The overarching goal is to construct GPS servers and receivers that are more resilient to scintillation.

## **IV.6 Climatic Changes in Space Weather: Sustained Minima and Maxima in Solar Activity**

Dr. Mike Hapgood, research scientist at Rutherford Appleton Laboratory (RAL), discussed climatic changes in space weather and sustained minima and maxima in solar activity with time. This was largely the work done by his colleagues Mike Lockwood, Luke Barnard, and Chris Davis in the Department of Meteorology at the University of Reading. He showed the striking anti-correlation of cosmic rays with Sunspot numbers. This occurs because greater solar activity correlates with solar wind activity, which in turn pushes out the coronal source flux to give a stronger heliospheric field that partially shields the Earth from cosmic rays. This is significant because cosmic rays penetrate electronics causing single event effects and structural damage. Cosmic rays impact ground, aviation, and space systems. Estimates of cosmic ray abundance come from  $^{14}\text{C}$  and  $^{10}\text{Be}$  spallation products that get incorporated into the biomass and ice sheets rather quickly after creation by cosmic rays in reactions involving oxygen, nitrogen, and argon in the troposphere and stratosphere. These cosmogenic isotope abundances in terrestrial reservoirs correlate well with solar activity. Thus, cosmogenic isotopes give unique insight into solar variability on millennial timescales.

Dr. Hapgood showed the millennial variation of the solar intensity for the last ~9000 years (see figure 5). This shows that the Sun has been unusually active over the last several decades. However, extrapolating the recent linear declines in the solar wind speed, magnetic field strength, and open solar flux, indicates that we are nearing the end of the latest grand maximum. All reasonable extrapolations show the next 50 years to be a period of reduced solar activity. This reduced solar activity will result in cosmic ray fluxes increasing in space and at aircraft cruise altitudes. Also, there is increasing probability of very large radiation storms, since they are often correlated with lower solar activity. The future projections of lower solar activity also may have implications for global climate change.

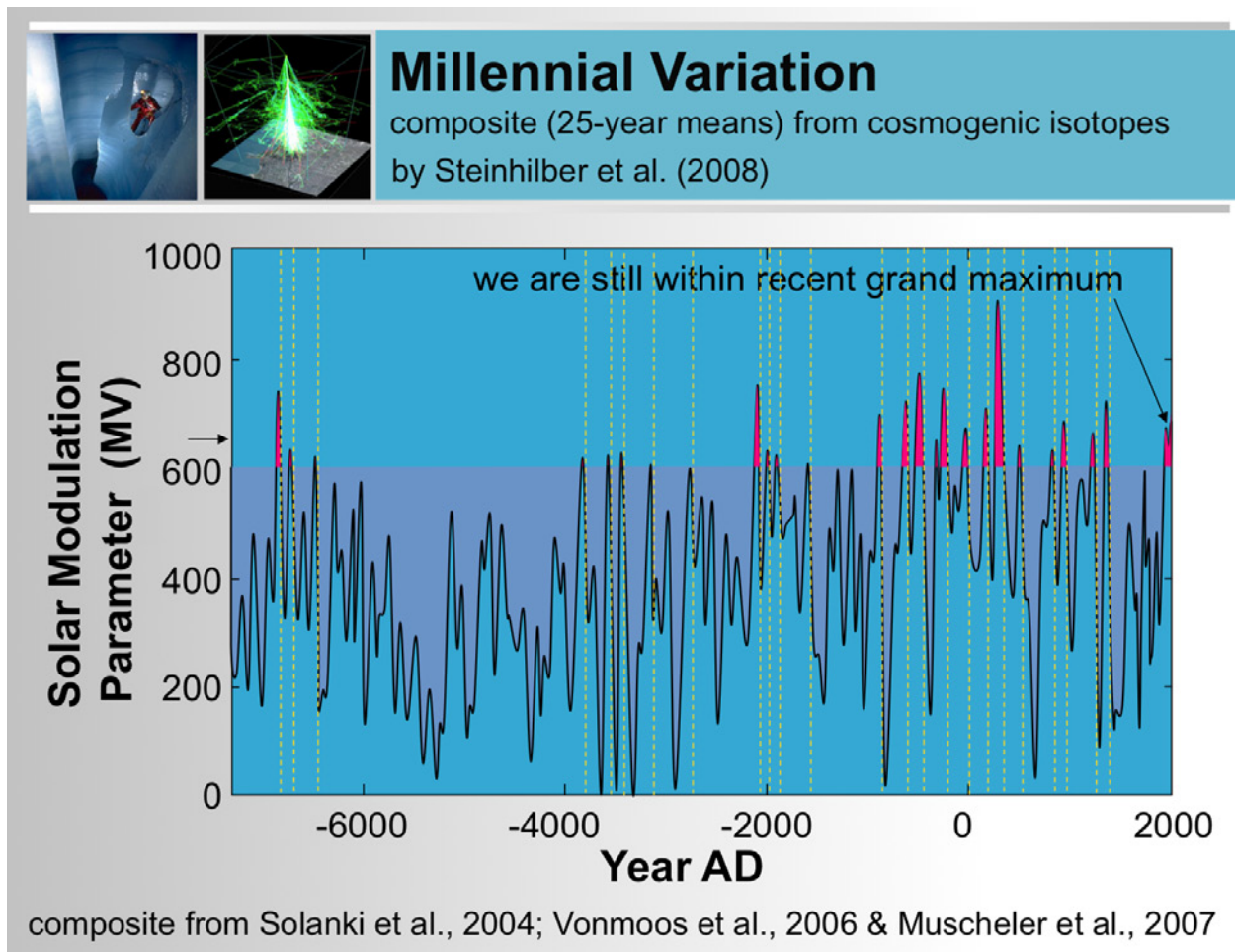
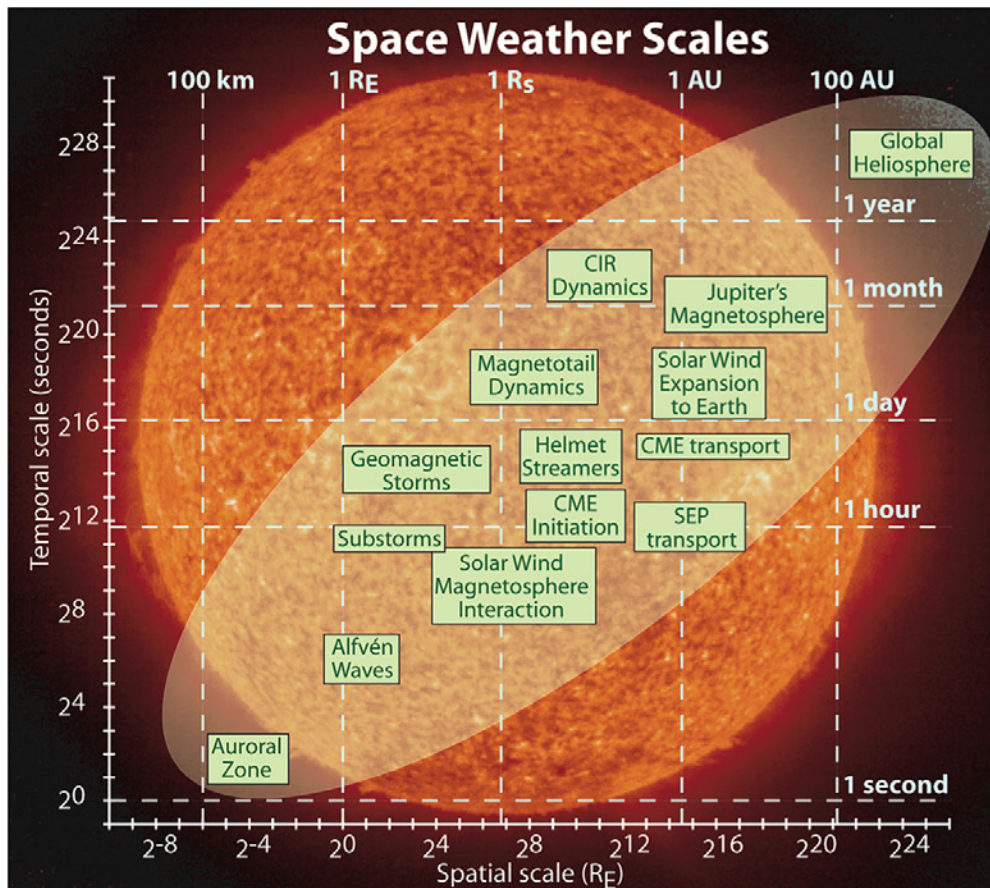


Figure 5. The millennial variation of the solar intensity, as inferred from cosmogenic isotopes, over the last 9000 years.

## V. Do We Need a Dedicated Space Weather Institute

### V.1 NASA Heliophysics Research Program: Past, Present and Future

Dr. Madhulika Guhathakurta, of the Heliophysics Division at NASA Headquarters, discussed NASA's heliophysics research program. Heliophysics is a rather new scientific discipline, which deals with the interaction of three forces—pressure, gravity, and magnetism. The underlying universal physical processes governing order and disorder are still not well understood, because the Sun is a variable magnetic star with many different temporal and spatial scales. Processes operating at one scale can influence phenomena at other scales. This is well illustrated in Figure 6, which shows some of the interacting components in this complex system. Several of NASA's earliest scientific successes involved heliophysics, e.g., the discovery of the radiation belts by Explorer 1 in 1958, and the detection of the solar wind by Mariner 3 in 1963. She discussed some of the elements of the Heliophysics Division (HPD) strategy. The HPD roadmap must be consistent with the National Research Council (NRC) Decadal Study (2003) and the NASA Science Mission Directorate strategic plan (2010). Two of the key elements in the heliophysics portfolio are the Explorers program and a competed Research and Analysis (R&A) program.



Processes operating at one scale can influence phenomena at other scales.

Image credit: Gombosi, CSEM, U of Mich

Heliophysics Summer School

Figure 6. Some of the processes operating at different spatial and temporal scales on the Sun.



At NASA, heliophysics is an integrated program involving data collection with an array of satellites, a Community Coordinated Modeling Center (CCMC), and a theory program. Thus the NASA heliophysics program provides theory, data, and modeling development to support the national efforts in space weather. The five research satellites that provide most of the data in support of space weather are the Advanced Composition Explorer (ACE), the Solar and Heliophysics Observatory (SOHO), the two Solar Terrestrial Relations Observatories (STEREO), and the Solar Dynamics Observatory (SDO). These satellites can observe active regions, flares, and coronal mass ejections around the full circumference of the Sun.

Education of the next generation of solar physicists is another aspect of the heliophysics program at NASA. She mentioned the outstanding series of three volumes on heliophysics edited by Karl Schrijver and George Siscoe (an outgrowth of the Living With a Star (LWS) summer school series). NASA also has a Heliophysics Postdoctoral Fellowship program, now the Eddy Fellowship program in honor of John Eddy, who was an early pioneer best known for his work in recovering the history of the Sun. To inform the public about what is happening on the Sun, the NASA heliophysics division has developed the 3D Sun App, which can be downloaded for free to either the iPhone or iPad.

Dr. Guhathakurta ended her presentation talking about the future of heliophysics. She noted that accurate forecasts of space weather would become increasingly important as humans extend their presence into the solar system. Advancing the reach of space weather throughout the solar system will require advances in theory, observations, and computing power. She discussed the possible formation of an interplanetary space weather institute. Her vision was an institute modeled after the Astrobiology Institute that would bring an interdisciplinary consortium of experts scattered across many universities and agencies under a virtual NASA umbrella.

A question was asked about the prospects for developing an integrated ground and space-based observational program of the Sun. She declined to comment, since the ground-based program was under the purview of the National Science Foundation (NSF). A second question related to protecting astronauts from space weather and whether the new Human Exploration and Operations (HEO) mission directorate at NASA was addressing it. She indicated that discussions with HEO on this subject had been initiated.

## **V.2 Severe Space Weather and the National Response Framework**

Dr. Ron Turner, ANSER Fellow at Analytic Services, Inc., discussed the National Response Framework for responding to severe space weather. In the event of a space weather event of national scope and impact, there is a structure responsible for coordinating the response among local, state, and federal government agencies. The main role of the space weather community will be to provide alerts, warnings, and general space situation awareness to the decision makers. The landscape is complex, as it involves not only the federal, state and local governments, but the public, media, academia, the private sector, as well as issues around critical infrastructure. Key federal guidance documents are Homeland Security Presidential Directives (HSPDs) on management of domestic incidents and critical infrastructure identification, prioritization, and protection, and the Presiden-

tial Policy Directive on national preparedness. These directives establish a single comprehensive National Incident Management System (NIMS), which provides a systematic, proactive approach to guide departments and agencies to work together to prevent, protect against, respond to, recover from, and mitigate the effects of incidents. The NIMS is distinct from the National Response Framework (NRF), which provides the structure and mechanisms for national-level policy for incident management. The Catastrophic Incident Annex to the NRF (NRF-CIA) establishes the context and overarching strategy for implementing and coordinating an accelerated, proactive national response to a catastrophic incident.

In the event of a major space weather event, the President will lead the response. The FEMA administrator is the principal advisor to the President. NOAA, USAF, NASA and critical infrastructure subject matter experts will be the principal advisors to FEMA. Figure 7 shows the principal steps required for the preparation and implementation of the national response. The first step in the preparation is to obtain national consensus on the impacts of a severe space weather event. Considering the on-going debate on the vulnerability of the electric grid to space weather effects, the space weather community has yet to achieve this national consensus. This significantly complicates forming response plans across all impacted sectors.

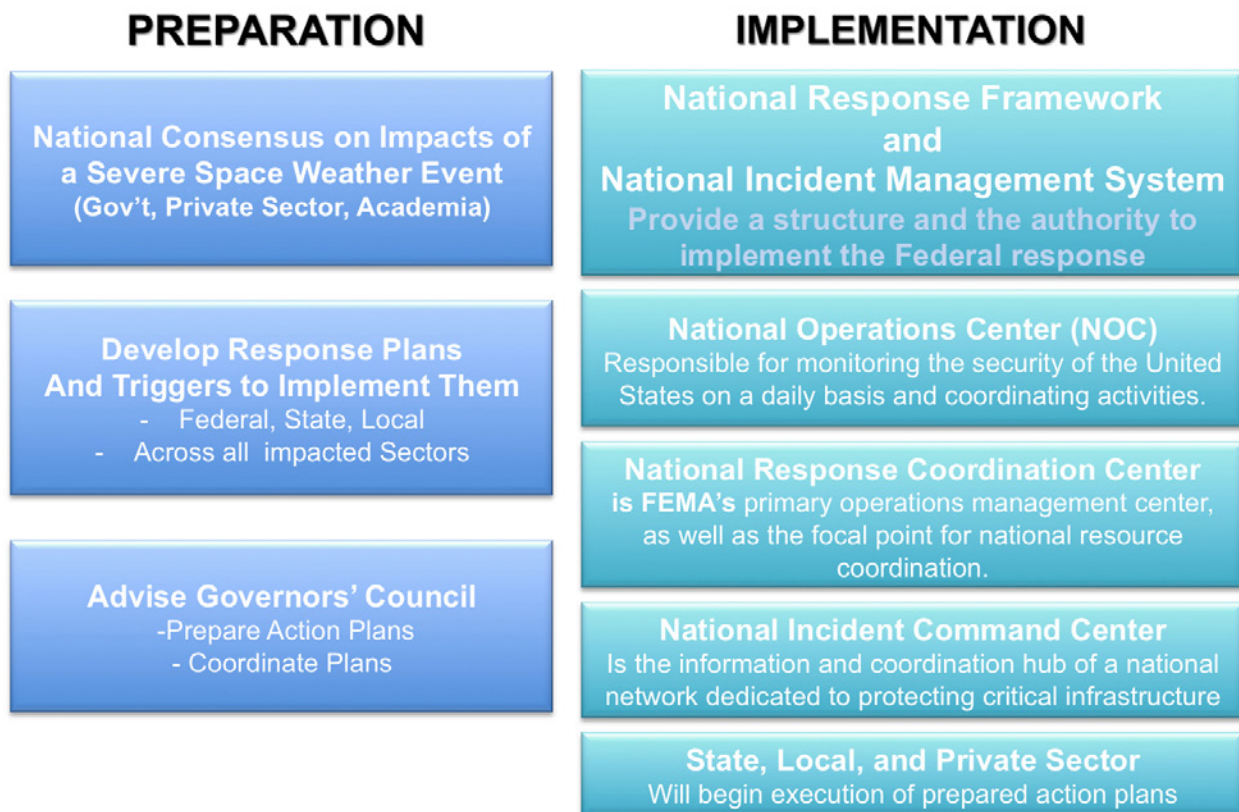


Figure 7. The principal steps required for the preparation and implementation of the national response to space weather.

Dr. Turner noted that communication is a critical component of the response. In the case of an impending storm, NOAA/SWPC will issue progressively more urgent alerts and the federal response network will be alerted, but not implemented. It is important that the space weather community deliver a coordinated and consistent message using all available public media to appropriately communicate the risk. Once the storm is imminent, the White House will convene the National Security Council and crisis management teams will be initiated. The outcome of the response is uncertain, because our increasingly complex infrastructure has yet to experience a severe space weather event.

In the comments following the presentation, the need for a single voice from the space community to provide advice in a major space weather event was stressed. In the UK they have a single “go to” authority to provide advice. As its sole source of authoritative advice, FEMA uses the NOAA/SWPC. It was also noted that under the 10th amendment to the U.S. Constitution, that the general welfare of the people are the providence of the state. FEMA acts in support of the states in case of an emergency. The states use the Threat and Hazard Identification and Risk Assessment (THIRA) tool in assessing the threat. One of the actions of the meeting was to provide a statement on the societal risks of space weather to be included in the National Preparedness Report (NPR).

### **V.3 Space Weather Services at NASA GSFC Space Weather Lab**

Dr. Masha Kuznetsova of NASA Goddard Space Flight Center (GSFC) gave an overview of GSFC space weather services. The two main pillars of this service are the Community Coordinated Modeling Center (CCMC) in operation since 2000 and the Integrated Space Weather Analysis System (iSWA) in operation from 2009. The CCMC hosts a broad range of most advanced space weather models, provide modeling, visualization, and model output analysis services to the research community, and serve as a tool by which research models are transitioned to operations. The iSWA is focused on collecting data and model outputs from diverse sources to create custom space weather products data for dissemination to customers. These web-based tools are available worldwide from the GSFC web sites (<http://ccmc.gsfc.nasa.gov> and <http://iswa.gsfc.nasa.gov>). The CCMC tests and evaluates modes, designs real-time modeling systems, leads and supports community-wide metrics challenges, and supports operational space weather models selection. The iSWA is a user-configurable web-based system for analyzing space weather. The web site contains modeling results and comprehensive sets of observational data ready to be used by space weather forecasters. Examples of space weather tools out of more than 300 products include CME, flare and SEP forecasting, heliospheric tomography models, global magnetohydrodynamics (MHD) models of the Earth’s magnetosphere, radiation belt modeling, and ionospheric models.

The Solar Shield project at the space weather lab is a partnership with EPRI for the development of an innovative GIC forecast system. The goal is to provide level 1 forecasts with lead times of 1-2 days, and level 2 forecasts with lead times of 30-60 minutes. Other functions of the space weather services are to provide assistance in spacecraft anomaly resolution and weekly space weather reports and alerts regarding adverse conditions throughout the solar system to NASA mission operators. A series of examples were given demonstrating CME forecasting. She closed by reiterating

that GSFC has developed a world-leading information collection and public dissemination system, which supports NASA missions and other interests such as the electric power grid. Furthermore, there is still additional potential to address national space weather needs in innovative, collaborative, and cost-effective ways.

#### **V.4 Plenary Panel Discussion: Do We Need a Dedicated Institute for Societal Impacts of Space Weather and If So, Why?**

One of the key focuses of the workshop was to evaluate the need for an institute that would address specifically the societal impacts of space weather. To kick off this discussion, we held a plenary panel discussion on the need for such an institute in the morning of the second day. The panel consisted of the following subject matter experts: Drs. Karel Schrijver, Mike Hapgood, Louis Lanzerotti, Alan Title, and Tom Bogdan. Each panel member was allowed a few minutes for opening remarks.

Karel Schrijver's comments focused on the need to quantify the risks, likelihood, and cost of space weather to society. Without this assessment it is impossible to develop a business case for building resilience. He made the analogy with Earthquake preparedness, where we have a better assessment on the potential impacts to society. An institute could provide a mechanism for bringing together the wide range of expertise necessary to make the business case.

Mike Hapgood felt a key function of the institute could be to improve communication. A dedicated Society and Space Weather Institute (SSWI) could bring together the disparate expertise necessary to break down the barriers to transforming what we know about the physics to those that need this knowledge to make policy decisions. It could help break down barriers to getting private and public organizations to work together, and would provide a conduit for international collaboration that is especially important considering the potentially very large geographical footprint of a major space weather event.

Louis Lanzerotti discussed the straw man concept paper for a Society and Space Weather Institute (SSWI) that was handed out at the end of the first day of the workshop. The paper presented a concept for an international organization to transform our knowledge of space weather into options for protecting society. He noted that the marketplace says a lot about what is needed for disaster response. We need to know how much money the commercial sector is spending on space weather, before we can make decisions on the breakdown of how a SSWI is funded between government (NASA, NSF, DOE, DOD) and industrial partners. He also raised the question of how we narrow down the mission of the SSWI. Would it just be another academic exercise? Would it be allowed to grow and compete for R&A funds from NASA and NSF, thereby becoming too competitive for the taxpayer? Although he felt that the concept paper had merit, he thought we needed to think hard about the role of government and the commercial sector in a SSWI.

Alan Title, reflecting on Jim Spann's presentation in section (II.1), noted that most scientists don't have the time or inclination to interact well with operational people. An organization is needed to establish an interface to bring scientists together in an environment that encourages dialogue with

people whose job it is to protect society, to develop products, and to deliver functions. Ultimately, state and local governments are going to have to make decisions. It is difficult to believe that a set of NOAA alerts is going to influence a state governor to tell power companies to turn off their power. There have to be trusted employees rather high up in the organization that can make these decisions. A significant role of the SSWI would be to develop a core of people that fit in these interfaces and provide respected advice.

Tom Bogdan began by noting the product of vulnerability x exposure x risk of probability sets the cost/benefit ratio. The amount of additional resources required to fund the SSWI is minuscule compared with the potential cost of a space weather event. However, until we quantify that cost/benefit ratio in a manner that can be understood and appreciated as being valid by non-space scientists, we are not going to make progress. The draft document of the SSWI, which is innovative, inspired, and imperative, provides a means of how we might compute the cost/benefit ratio along with the uncertainties. There is another theme of three I's that relate to the institute—Interdisciplinary, International, and Independent. Space weather is an extremely interdisciplinary and international problem. As a government organization, NOAA has significant constraints on dealing with international partners. The organization must be independent to bring our international partners in fully, and to provide independent and unbiased advice to policymakers. Although there are many other problems, such as how to transition to operations and what are the roles of commercial entities, these should not distract the institute from focusing on the one problem that it can best solve, namely, computing the cost/benefit ratio.

**Question:** What is the sense of urgency, especially considering other competing issues and the severe budget constraints?

**Answer:** Considering the consequences of taking out the energy grid for an extended period of time, a small additional investment is the morally and economically imperative thing to do.

**Comment:** Perhaps we could augment the NOAA/SWPC budget to address issues like these.

**Question:** Who would be the target audience and who would be initial sponsors for getting the institute started?

**Answer:** We have already made the business case, since we currently have the attention of the President, the Prime Minister of the UK, business leaders, and other key scientific advisors.

**Question:** What analogous issues have come with other institutes?

**Answer:** We need greater industry involvement in the institute. Independence from government is important for European countries to be involved.

**Question:** What are the objectives of the institute and how are they different from other space weather entities?

**Answer:** The institute should focus on one thing—computing the cost/benefit ratio. Selection of the work of the institute should be based on a peer-review process. Another function of the institute should be education.



**Question/Comment:** How do you envision assembling a staff that could span the disciplines required to solve the problem? One model would be to use scientists funded by other institutions from which you would elicit in-kind contributions. This would provide an affordable approach to obtaining contributions across the full range of national expertise. The institute would have to be independent to get wide endorsement from industry. The National Research Council is a successful model that uses in-kind contribution.

**Answer:** That is exactly our concept. My hope is that a couple of people at this meeting would volunteer to sit on a task group to define one of these problem areas. They would draft a document that raises these concerns and include how much it might cost to mitigate the problems.

**Comment:** There are a number of virtual institutes within NASA such as the Astrobiology Institute that have been extremely successful and have been a great model for international collaboration. You can set up nodes around the country and run the institute with a very small core of people.

**Comment:** The word policy should be added to the SSWI draft. I don't agree that we have a political will to launch a new institute—we are not even able to make the advocacy for replacing ACE.

**Answer:** Getting the political will depends on making the business case. The potential roles of the SSWI were contrasted with the International Space Science Institute (ISSI), a nonprofit organization in Bern, Switzerland. ISSI is an institute for advanced studies where scientists meet in a multi- and interdisciplinary setting to establish the state-of-the-art of various scientific disciplines. ISSI publishes books that are the output of workshops.

**Final comments of the panel:** Keep people talking. Volunteer to be on a task group that works on one of these problems. We have a window of opportunity that will soon close.

## **V.5 How does Space Weather Research fit into the UK Strategic Program?**

Dr. John Rees of the Natural Environment Research Council (NERC) in the UK discussed how space weather research fits into the UK strategic program, and how the UK could contribute to research in a dedicated SSWI. He noted that the interest in space weather has been increasing in the UK, as evidenced by the establishment of a space environment impact group of experts to advise the government on worst case scenario planning for the UK national risk assessment. In the UK there is a strong focus on impacts and mitigation techniques. He agreed with earlier comments made by Dr. Tom Bogdan that given the increased societal and political interest in space weather, now is the opportune time to consider the formation of a dedicated SSWI.

Dr. Rees discussed the solar-terrestrial physics that is being carried out in NERC and in the Science and Technology Facilities Council (STFC) in the UK. NERC is responsible for all Earth oriented solar-terrestrial physics, whereas STFC is responsible for space-based facilities and solar-terrestrial physics. He also discussed briefly the U.S.-UK collaborations in space weather led by Rutherford Appleton Laboratory (RAL). Dr. Rees discussed options for UK contributions to a dedicated SSWI. Research interests at NERC, such as the coupling of energy, momentum, and chemistry between

the mesosphere, stratosphere, and thermosphere, and on weather, climate, and ground-based hazard impacts, would fit well within a dedicated SSWI. He discussed options for collaborative research programs and noted that a virtual institute would be an ideal structure to foster collaboration. Mechanisms for research collaboration need to be explored, and consideration should be given to how a collaborative initiative between the U.S. and UK would be most effectively developed within a dedicated SSWI.

In the subsequent discussion it was noted that if staffing of the institute were under a virtual model, it would be easier to see how European partners could contribute, although potential European partners might have to use different business models to sell the concept to their governments. The speaker concurred with these comments.

## **V.6 The National Space Weather Program**

Mr. Michael Bonadonna, Executive Secretary of the National Space Weather Program (NSWP) Council, discussed the strategic goals, organization, vision, and activities of the NSWP. The mission of NSWP is to serve as the focal point for the Federal government's national space weather enterprise and partnerships. By providing an active synergistic, interagency forum for collaboration, the NSWP facilitates mutually beneficial interactions among the Nation's research and operational communities. The vision for NSWP is a Nation that capitalizes on advances in science and forecasting to better cope with the adverse impacts of space weather on human activity and on advanced technologies.

Key goals of NSWP include understanding the physical conditions and processes that produce space weather, developing and sustaining necessary observational capabilities, providing tailored and accurate space weather information, raising national awareness of space weather impacts, and fostering communication among government, commercial, and academic organizations. A program council that contains many member agencies, including NOAA, NASA, NSF, and Homeland Security, runs the NSWP. The capabilities, strategies, goals, research, etc. are laid out in the 2000 NSWP implementation plan that can be downloaded from the following website:

<http://www.ofcm.gov/nswp-ip/tableofcontents.htm>. One of the key functions of NSWP is to provide reports for the Executive Office of the President and the Office of Science and Technology Policy (OSTP). The most recent report by the NSWP was on the current and planned space weather observing systems. The NSWP has also partnered with the National Science and Technology Council's subcommittee on disaster reduction to publish the "grand challenges for space weather". Another function of the NSWP is to host forums on space weather, such as the 2011 forum in Washington DC entitled "Solar Maximum: Can we Weather the Storm?" In the year ahead, the NSWP is focused on publishing an action plan and an updated implementation plan. In the discussion following, it was noted that while NSWP would be supportive of a SSWI, they would not be able to contribute to its funding.

## V.7 UK Resilience and the Role of Scientific Advice in Emergencies

Anita Friend of the Civil Contingencies Secretariat discussed UK resilience and the role of scientific advice in emergencies. The resilience planning cycle in the UK is a holistic process that begins by identifying and assessing the risks. Once the risks are identified, strategies for mitigating both the likelihood of risks occurring and their impact are identified and these approaches evaluated. Civil emergency risks are assessed against three time horizons (over 5 years to inform contingency planning and capability building, over the longer term to provide strategic foresight and over the next 6 months to allow specific emergencies to be anticipated). The National Risk Assessment (NRA) identifies and assesses civil emergency risks to inform capability planning and capability building to mitigate the impacts of emergencies, if they occur. The importance of a generic risk depends both on its relative impact (limited to catastrophic) and the relative likelihood of the event. The NRA therefore assesses the likelihood and impact of reasonable worst-case scenario (the worst manifestation of the risk if implausible scenarios are removed) for each generic risk. These assessments inform planning decisions with the highest priority given to likely and catastrophic risks. Preparations for responding to emergencies when they occur are on the whole focused on managing the common consequences of a range of risks. More intensive, specific planning is reserved for the highest priority risks. Input by subject matter experts from the intelligence, scientific, economic, and policy-making communities feed into the NRA assessments. Because of the consequence-focused approach to preparing for emergencies, it is important to know what emergencies (such as severe space weather) would look like if they occurred, including societal impacts and the scale of impacts.

Dr. Chris McFee continued by discussing how scientists fit into the risk assessment and planning process. The planning process involves a chief scientific advisor in each government department and science advisory committees and groups. The Space Environmental Impacts Experts group provides subject matter experts for space weather. In the case of an emergency, a meeting in the Cabinet Office Briefing Room (COBR) is called, which is chaired by the Prime Minister if the emergency is serious. This group is responsible for formulating an operational response. Science providers give input through the UK Chief Scientific Adviser (currently John Beddington). He showed how this process played out for the recent nuclear disaster event in Japan. He closed by discussing efforts to create timelines to guide the response process.

In the discussion period following these two presentations, it was noted that FEMA was working on timelines also, and that response protocols had been established between FEMA and NOAA that depend on the projected intensity of the space weather event. The question was asked whether there was a consistent policy on how different departments perform their risk analysis. The response was that similar expertise and criteria for assessment was brought to each risk assessment. It was asked how warnings go out to local planners in the UK? The answer was that a briefing tool was used to provide information on emerging situations. This draws on evidence collated from a range of sources? It was asked whether the UK was continuing to update the assessment of the electric power grid. The response was that this is part of the overall risk assessment that was being updated annually. A final question was about the aging satellite fleet and the possibility of losing critical observations of solar events. The response was that they were aware of the risk, but a business case would have to be made before any mitigation of the problem could be attempted given the limited resources available.



## V.8 Space Weather and the NSO Synoptic Program

Dr. Mark Giampapa, Deputy Director of the National Solar Observatory (NSO), discussed the space weather related activities at NSO, which is funded by NSF and managed under a cooperative agreement by the Association of Universities for Research in Astronomy. NSO currently operates long-term observing networks at the Kitt Peak National Observatory near Tucson, and the Sacramento Peak Observatory in New Mexico. A major new NSO initiative is the 4-meter Advanced Technology Solar Telescope that will begin construction soon at Haleakala in Maui. The NSO Synoptic Program that is most relevant to space weather is comprised of two major facilities, the Solar Long-Term Investigations of the Sun (SOLIS) and the Global Oscillation Network Group (GONG). SOLIS has a suite of instruments located at Kitt Peak. The most important instrument is the Vector SpectroMagnetograph (VSM), which provides daily 2k by 2k full disk vector and longitudinal magnetograms in the photosphere and chromosphere of the Sun. The GONG network consists of six sites geographically distributed to provide continuous viewing of the Sun. The principal data product of GONG is full disk 1k by 1k Doppler images every minute to support helioseismology studies that provide for far-side imaging of the Sun. The GONG far-side maps are used by NOAA/SWPC for long-range forecasts. The GONG H $\alpha$  images are used by the U.S. Air Force Weather Agency for operational nowcasting of space weather conditions. Dr. Giampapa also discussed the possibility of predicting flares through helioseismology.

Dr. Giampapa ended his presentation by talking about work done at NSO to look at the mean magnetic strengths of the Sun as a function of time (see figure 8). The data that extend to the beginning of cycle 24 show a clear decline in the maximum field strength with time. Various extrapolations are shown, the most accurate being the solid line that includes the cycle 24 data. Once the magnetic field strength passes below about 1500 gauss, the Sunspots will fade into the photosphere. If the extrapolations are accurate, Sunspot activity will be close to zero in the 2020-2025 timeframe. A question

was asked if we are entering into another grand minimum similar to the Maunder Minimum in the 17th century? He replied that this is one possibility, but this would not eliminate the possibility of a major geomagnetic storm, because geomagnetic activity continues even in the absence of Sunspots. Another question was whether all of the data being taken by NSO was being fully analyzed. He said that efforts were underway to better exploit the data by improving the modeling.

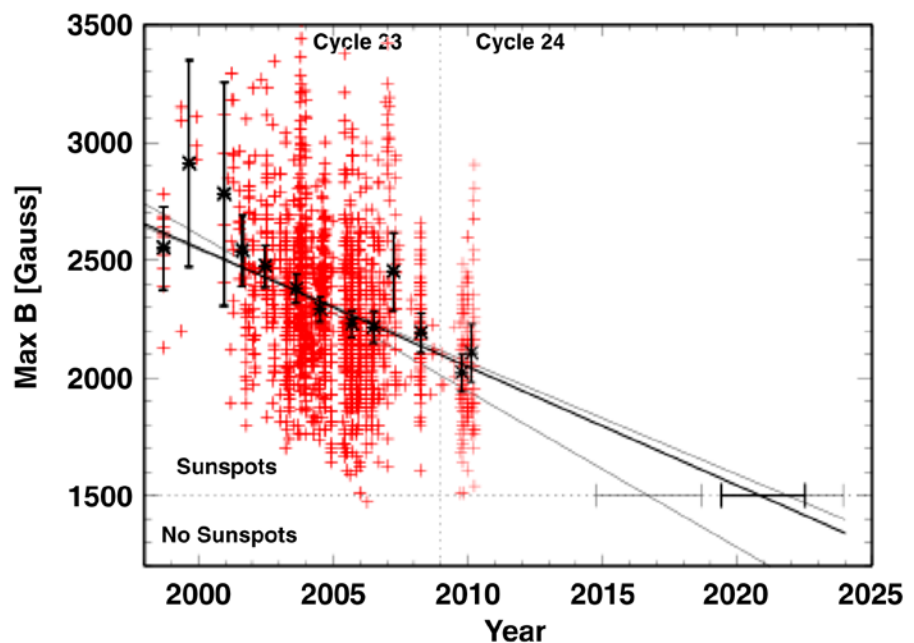


Figure 8. The mean magnetic strength of sunspot umbrae extrapolated out to the year 2025.

## VI. How Would an Institute Function Most Usefully and Economically?

### VI.1 Plenary Panel Discussion: What Functions Should an International Weather Institute Have?

The second panel discussion focused on what are the appropriate functions and business models for a dedicated space weather organization (referred to here as a Society and Space Weather Institute (SSWI)). To set the stage, it is worth noting that some of the goals identified in the straw man concept paper were presented to the workshop participants at the end of the first day. Some of the potential roles for the institute that were identified in the concept paper include: (1) integrating and evaluating knowledge of space-weather phenomena and consequences; (2) developing moderate-event and extreme-event scenarios with realistic analysis-based impacts; (3) providing evaluations of space-weather impacts on new technological applications; (4) interfacing with scientists, forecasters, and leaders in government and society in emergency planning and preparedness, in policy development, and in international coordination; and (5) developing educational and informational materials and courses for scientists, societal leadership, emergency responders, media, and the public. The principal goal of this panel discussion was to engage the workshop participants in further defining these goals. The panel consisted of the following subject matter experts: Drs. Karel Schrijver, Mike Hapgood, James Head, Alan Title, John Kappenman, and Madhulika Guhathakurta.

In opening remarks, Karel Schrijver indicated that education would certainly be a key function of the institute, but how far an institute might delve into policy was still uncertain. Mike Hapgood noted that the international aspect of the institute was important considering the global extent of space weather. While he felt that an institute would focus on the big picture, this would not preclude customization—e.g., customizing a response for a large continent like the U.S. versus an island surrounded by ocean like the UK. James Head identified potential roles of an institute as science or generating new knowledge, education, policy analysis, and policy advocacy. He contrasted policy advocacy and lobbying. Alan Title stressed one of the major themes emerging from the workshop. The function of the institute should be foremost “to establish that the space weather threat is real.” We have not yet established this, and we must do so before we can make any further progress in mitigating the threat. John Kappenman spoke about the threat analyses that he has done for the electric grids of several countries. In his opinion, considerable vulnerability exists in all of the electric grids he has analyzed. He feels that electric grid operators as well as satellite operators are in denial of the risks, in part because they are reluctant to talk about their vulnerabilities. We received a warning from the 1989 event, but we believe that storms an order of magnitude larger are possible. Considering the downside risk, such as losing power to nuclear plants, the situation is untenable. Madhulika Guhathakurta stressed the need for succinctly defining the role of the proposed new institute and explaining how its role is distinct from existing organizations that deal with space weather.

**Question:** Considering the need for the institute to establish a policy, how do we keep the institute from becoming partisan, which could reduce its credibility?

**Answer:** This is a problem for any scientist entering the policy realm. You can be accused of being partisan just because someone disagrees with you. Opinions vary on whether non-governmental

Organizations (NGOs) should be involved in policy. Climate gate is an important lesson for us—it shows that presentation of an issue is important. We need to create an institute that can convince industry that they must look at the downside risk. There is serious debate in the electric industry as to whether transformers can be damaged by GICs.

**Comment:** I am concerned that forming a “new” organization is going to be perceived as an attack on people’s budget. However, if we said that we are already spending a lot of money on this issue and that the institute will provide a more efficient means of doing this research, it might be perceived much more favorably.

**Comment:** We should ask the question “who would care if we were successful in documenting the hazards of space weather?” Will industry cooperate and will they help finance it? We now spend about 750 million per year on scientific studies related to heliophysics and space weather. Justification for these expenditures is based in part on the societal benefits of the research. What is the business case for industry to participate? The one incentive that industry does respond to is business development. There may be business in this for them. For example, we don’t have an adequate space monitoring system. We need constellations of satellites to provide adequate warning from space weather. We would need to spend approximately 200 million/year on infrastructure investment to build an adequate system.

**Comment:** We have to be careful when selling the impact of various scenarios of space weather on the electric grid. When you start talking about the specifics of how many transformers might fail, we simply do not have reliable information. The electric industry realizes the inadequacy of their models, but they are working with EPRI to improve the models and to better assess the vulnerabilities in their systems.

**Comment:** I would like to approach the problem from the standpoint of a customer. This year the White House tasked FEMA with providing the Federal interagency response plan to space weather. We have had difficulty getting this off the ground, because we cannot even agree on a scenario. To develop a scenario we need to know the impacts, and without the impacts we cannot do the risk assessment. We need models based on sound science that are accepted by the community.

**Comment:** We need spacecraft to get space weather data. The community needs new and innovative ways to ensure a continuing stream of space weather data.

**Comment:** Back to the question of how to avoid partisanship. Global climate change is probably not a good analogy for space weather, because the issue is skewed by the coal and gas industry that has a vested financial interest. However, everyone is completely dependent on GPS, satellites, electricity, etc. We need to emphasize that everyone has a common interest when we try to find funding for the SSWI.

**Comment/Question:** A theme that I keep hearing is that a lot of work is being done on space weather and many agencies are involved. Perhaps we can package this as a better way of organizing our portfolio of space weather. Does it make sense to ask for 2 million to initiate this institute when we are spending 750 million already? What can we do to redirect funds so that we can fund the institute? This is an especially good idea if we have a very narrow scope for the institute.

**Comment:** Because we are coming from a physics base there is no tradition of supporting a pathway into which the research moves towards some stakeholder. What is the motivation for business? One motivation is compliance with design codes. By law industry is required to meet various codes and environmental requirements. The self-regulated electric companies do not have code requirements that address issues with space weather.

**Comment:** We should make every effort to get more out of our space data by using advanced IT technologies.

## **VI.2 Plenary Panel Discussion: What are the Possible Business Models for the Institute?**

The third panel discussion focused on possible business models for a dedicated space weather institute. To initiate the session, Dr. Carl Pilcher, Director of the NASA Astrobiology Institute (NAI) and session chair provided an overview of the NAI, one of the most successful virtual institutes in NASA. He felt that some of the advantages of a virtual institute would be applicable to the proposed SSWI. The virtual model is extremely good at two things—bringing people together seamlessly who would not otherwise come together, and secondly, bridging geographical bounds. The NAI is very interdisciplinary, promoting collaboration between many scientific disciplines, such as astronomy, geology, paleontology, planetary and Earth science, etc. The NAI consists of 14 competitively selected science teams, each a consortium. It includes ~600 members at ~150 participating institutions. International partners are either associate or affiliate members. The NAI mission contains five elements—collaborative interdisciplinary research, providing leadership in NASA science missions, information technology research, training the next generation of astrobiologists, and education and outreach. The NAI has a yearly budget of ~25 million dollars, the vast bulk of which goes out to the scientific community. A participant commented that he liked the NAI approach because it is very inclusive.

**Comment:** We have consensus that the effects of space weather are real, and considering the dire consequences, we must do something about it. Exception was taken to earlier statements that the majority of spacecraft would survive. He estimated that half of the satellites would be lost to a Carrington-scale event because of surface charging.

**Comment:** The NAI was able to get started with strong advocacy from NASA senior management. This is not our situation—who in government has the responsibility for space weather? While we spend something like 750 million dollars on space science research, these funds are highly committed. We need to find someone to provide funding for a demonstration project that could eventually lead to a long-term program with government funding. In the current environment, we are going to have to demonstrate the value of a SSWI before we are going to be able to find substantial funding.

**Comment:** It was stressed that we are far more susceptible to space weather now with all of our technological advances.

**Comment:** Two UK efficiency initiatives were discussed, the first involving flooding and the second involving international disaster risk reduction. Both agendas have many players involved. Until recently these efforts were very fragmented, but now they have developed a joint strategy about not just the science needs but observational requirements as well. This new effort is viewed as evolutionary, because all the partners are talking and working together, but retaining their independence. Perhaps a collaborative model like this could be usefully applied to the SSWI.

**Comment:** One way to reallocate funds is to work with institutions that have funding to see whether these new efforts could be put into their strategic plans. Reallocation of funds would hinge on making the economic rational for these new studies.

**Comment:** Another model that was suggested as a possible template was the NASA Human Health and Performance Center (NHHPC), which connects organizations interested in advancing human health and performance innovations. There are ~100 widely different organizations involved in this virtual organization, which has a relatively small budget on the order of 200,000 dollars.

**Comment:** We have a serious credibility problem. Outside our community, we do not have consensus that space weather is a serious threat. Using NRC sponsored workshops as an example, we could perhaps convince the Office of Space and Technology Program (OSTP) to fund a pilot study to better define the risks and impacts of space weather.

**Comment:** Space-related international governance models currently in use as compiled by the U.S. Department of State were shown. The Planetary Science Institute, a research institute based in Tucson, Arizona focusing on planetary science, was suggested as another model that we should consider as a template for the SSWI.

**Comment:** When presenting a business case for the institute to decision makers in Washington, we should include an example from an operational product that provides real time guidance on space weather effects, such as the reliability of GPS. This demonstrates that space weather is real and that we have the ability to put together operational systems to at least mitigate the impacts of space weather.

**Comment:** Perhaps we should NOT try to find funding for the institute by reallocating existing research funds, but go after new money.

**Comment:** I am involved in preparing the state of Alaska for natural disasters. I am prepared to deliver to all of my counterparts in all 50 states a 300-500 word concise statement of the threats of space weather. However, we must act now to get space weather recognized as a credible threat before the National Preparedness Report (NPR) goes to the President on March 31st. If you formulate concisely the consequences of space weather, we can get it to the decision makers.

**Discussion:** We have such a concise statement on the OSTP website. A cogent statement of the effects of space weather exists on the web at (<http://www/sdr/gov>). It is part of the Grand Challenges for Disaster Reduction, which is a ten-year strategy crafted by the National Science and Technology Council's Subcommittee on Disaster Reduction (SDR). We must incorporate a statement on space weather in the NPR if we want it to be taken seriously by the states. It was emphasized previously



that the states have primary responsibility to respond to natural disasters in their states. Discussion continued on how to write a short cogent statement of the impacts and consequences of space weather in the near future so that it will be incorporated into the NPR before it goes to the President. This was one of the actions coming out of the workshop.

### **VI.3 Discussion: Priorities—Where do we go from here?**

The final session of the workshop focused on actions and strategy for continuing the momentum of the workshop. The panel consisted of four of the workshop sponsors: Drs. Pete Worden (NASA), Ken Washington (LMATC), Mike Hapgood (RAL Space), and Tom Bogdan (NOAA). Pete Worden began by raising four questions. First, is a dedicated space weather institute really needed? A show of hands indicated that a significant majority of the workshop participants thought it was needed. A few participants were still undecided. Secondly, what is the problem? We need to develop a coherent statement of the problem that everyone can agree on. Third, there appear to be some near-term opportunities, such as identifying space weather as a threat in the next version of the National Preparedness Report (NPR) that will be delivered to the President by March 31st. We need to prepare a succinct and authoritative statement of the risk to be incorporated into this report. Finally, where does the funding for the new institute come from? Pete Worden was willing to pursue NASA as one of the contributors. We need to leave the workshop with people willing to work on answering these questions.

Ken Washington discussed the roles of LMATC in providing solar research and being a thought leader in heliophysics. LM builds instruments that acquire space weather data, they do analysis on the data, they publish journal papers and books on the science, and they engage in dialogue with the international community. To help ensure a continued stream of funding for solar physics, he funded the straw man concept paper (SSWI) that outlined what a dedicated institute might do and how it might be organized and funded. He felt that we currently do not speak with a common voice. He concurred with Dr. Worden that we need to pull a cogent statement of the problem together to be used for the NPR or other risk preparation documents. A key issue is how to get the institute started in the current budget environment. How do you give the community a sense of urgency considering that space weather is a low-probability, high-risk event? We need the right kind of advocacy to make this happen and we do not yet have that advocacy. However, he was committed to finding a way to push the institute concept forward, considering the large downside risk of a major space weather storm.

Tom Bogdan stated that the threat of space weather is real. It is not a question of “if”, but a question of “when”. The most important thing we can do as a community is to quantify “when”. The institute provides a pathway to answer this question, but it may not be the only way. Our chance of finding funds for this activity is more likely to come from outside our community. We cannot be satisfied with the status quo. Many of the calamities that have occurred in the recent past have come from our lack of preparation. I don’t want space weather to be one of those areas where a calamity of epic proportions has to occur before we get the funds needed to protect our critical infrastructure. Once we know “when,” we will know how much we have to spend to buy down the risk.

Mike Hapgood stated that the most important thing the community can do is to quantify the risk. We have to build a case to convince policymakers and industry leaders who do not want to believe that the risk is in fact real. It is largely a question of diplomacy. He cautioned the community to not be too prescriptive about the solution. For example, the engineers may want to harden systems while scientists want to issue warnings. He disagreed with Tom Bogdan that it was just a question of “when”. The problem needs to be in terms of a probability distribution. Even if the probability of a catastrophic space weather event is only 1/1000 of happening in any given year, the impact is still too large to not mitigate the risk.

**Question:** Are there specific actions that the group wants to see emerge from the workshop? If so, how are they going to be defined, what are they, and who is going to take these actions? For example, a succinct statement of the risks of space weather should be written for inclusion in the National Preparedness Report. A list was created with names of participants willing to work on these actions. It was agreed that there would be a core group of individuals that would take the lead supported by the volunteers. It was suggested that we formulate a 1- or 2-year plan with milestones to guide this activity.

**Question:** Do we all agree that space weather is a credible threat? Based on a show of hands, it was demonstrated that we had consensus of the participants in attendance. However, while everyone agrees that space weather is a credible threat, the nature of that threat requires further clarification. What are our near-term targets of opportunity to further define the risk? There is reason to believe that there is negotiating space in our existing portfolio of research to find funds to support a focused research project to better define the risks and impacts of space weather.

**Question:** What is it that gives the institute credibility? To make it credible you need the authority from those that are recognized as experts. Some kind of international peer review might be warranted. The institute might also gain from having several well-respected supporting organizations such as NASA, NOAA, and NSF. Another important consideration is that the institute be independent so as not to be perceived as biased.

**Question:** I am concerned with configuration control. How are we going to move forward? Could you provide some guidance as to what you require from the volunteer group? Also, there are others that did not attend this meeting that could help us move forward.

**Question:** Is it ground based or space based infrastructure that is more at risk? It is difficult to say considering the interdependencies of the infrastructures. Technological advances have made our infrastructure much more vulnerable to space weather. Because of this increased complexity and interconnectedness, our energy, finance, communication, and transportation systems are all at risk during a space weather event.

The workshop closed with a commitment to continue working together to better define the societal impacts and risks of space weather.



## Agenda - Space Weather Risks and Society Workshop

<b>Space Weather Risks and Society Workshop</b>			
		<b>DAY ONE</b>	<b>Sat, October 15th</b>
<b>Time</b>	<b>Time min</b>	<b>Provisional Titles of Presentations</b>	<b>Speakers &amp; Discussion leaders</b>
8:00	30	Registration	
8:30	5	Logistics	Stephanie Langhoff
8:35	10	Welcome/Objectives	Pete Worden, Director ARC
8:45	10	Introduction of Participants	Stephanie Langhoff
<b>Space Weather Consequences on Society</b>			<b>Tore Straume, ARC</b>
8:55	15	Some Thoughts on the Societal Impacts of Space Weather	Alan Title, Lockheed Martin Solar and Astrophysics Lab
9:10	5	Question Period	
9:15	15	Space Weather Growth in Importance for Economy and Security	Louis Lanzerotti, NJIT, editor Space Weather journal
9:30	5	Question Period	
9:35	15	Overview of the Short to Long-term Risks and Consequences of Space Weather	Mike Hapgood, Science and Technology Council, UK
9:50	5	Question Period	
9:55	15	Space Weather: From Science to Forecast to Societal Impact	Tom Bogdan, NOAA
10:10	5	Question Period	
10:15	15	State Department Perspective on Space Weather	James Head, State Department
10:30	20	Session Discussion	
10:50	15	Break	
<b>Strategic Response to Space-Weather Threat to Society</b>			<b>Jill Dahlburg, NRL</b>
11:05	15	Lessons Learned from Successful Earth Science Research-to-Operation Efforts	Jim Spann, MSFC
11:20	5	Question Period	
11:25	15	Large Scale Analysis of GMD Impacts on the Electric Grid: Need for Improved Models and Analysis Techniques	Randy Horton, EPRI
11:40	5	Question Period	
11:45	15	Effects on Wide Area Augmentation System (WAAS)	Ken Ward, FAA Navigation Services
12:00	5	Question Period	
12:05	15	Space Weather: Impact on Cascading Power Grid Failures— A Simple Model and Illustration	Elisabeth Pate-Cornell, Stanford
12:20	20	Session Discussion	
12:40	60	Lunch	
<b>Science Perspective— Solar Flares, CMEs, SEPs and Geomagnetic Storms</b>			<b>Tom Bogdan, NOAA</b>
13:40	15	What Do We Not Yet Know About Solar Flares and Solar Energetic Particles (SEPs)	Richard Harrison, Science and Technology Council, UK
13:55	5	Question Period	
14:00	15	What do We Not Yet Know About Geomagnetic Couplings and Responses to Solar Eruptions	Robert McPherron, UCLA
14:15	5	Question Period	
14:20	15	Extremes of Solar Storms: How to Determine Statistics of Rare Solar Events Based on Existing or Obtainable Records or Models?	Karel Schrijver, LMSAL
14:35	5	Question Period	
14:40	15	Towards Physically-Motivated Operational Flare Forecasting	Shaun Bloomfield, Trinity College Dublin
14:55	5	Question Period	
15:00	15	The Impacts of Ionospheric Space Weather	Tony Mannucci, JPL
15:15	20	Session Discussion	
15:35	15	Break	

## Agenda - Space Weather Risks and Society Workshop

<b>Impacts of Space-Weather Events on Humans and Infrastructure</b>			<b>Richard Harrison, RAL</b>
15:50	15	Predictions of Space Weather Influences on Aircraft Radiation Exposure	Christopher Mertens, Langley
16:05	5	Question Period	
16:10	15	Space Weather and US Electric Power Grid Vulnerabilities: An Overview of the Risks to this Critical Infrastructure and Research Necessary to Assess Vulnerability and Mitigate Impacts	John Kappenman, Storm Analysis Consultants
16:25	5	Question Period	
16:30	15	Impacts of Space Weather on Department of Defense Operations and Systems	Dale Ferguson, AFRL
16:45	5	Question Period	
16:50	15	Impact of a Solar Superstorm on Critical Communications and Society	Mark Macalester, FEMA
17:05	5	Question Period	
17:10	15	Impact of Ionospheric Scintillation on Commercial GNSS Timing Receivers	Joaquim Fortuny-Guasch, EC Joint Research Centre
17:25	5	Question Period	
17:30	15	Climatic Changes in Space Weather: Sustained Minima and Maxima in Solar Activity	Mike Hapgood, Science and Technology Council, UK
17:45	20	Session Discussion	
18:05	5	Adjourn	
18:10	45	Wine and Cheese Reception	
19:30	<b>DINNER: Chef Chu's, 1067 N San Antonio Rd, Los Altos</b>		

*AGENDA CONTINUED NEXT PAGE*

## Agenda - Space Weather Risks and Society Workshop

		DAY TWO	Sun., October 16th	
Time	Time min	Provisional Titles of Presentations		Speakers & Discussion leaders
		<b>Do We Need a Dedicated Space Weather Institute?</b>		<b>Ken Washington, LMATC</b>
8:30	15	NASA Heliophysics Research Program: Past, Present & Future		Madhulika Guhathakurta/NASA HQ, Heliophysics Division
8:45	5	Question Period		
8:50	15	Severe Space Weather and the National Response Framework		Ron Turner, Analytic Services
9:05	5	Question Period		
9:10	15	Space Weather Services at NASA GSFC Space Weather Lab		Masha Kuznetsova, GSFC
9:25	5	Question Period		
9:30	40	Plenary Panel Discussion: Do we need a Dedicated Institute for Societal Impacts of Space Weather and if so, Why?		Mike Hapgood, Louis Lanzerotti, Karel Schrijver, Alan Title, Tom Bogdan
10:10	20	Discussion		
10:30	15	Break		
10:45	15	How does Space Weather Research fit into the UK Strategic Science Program?		John Rees, Natural Environmental Research Council (NERC), UK
11:00	5	Question Period		
11:05	15	The National Space Weather Program		Michael Bonadonna, National Space Weather Program
11:20	5	Question Period		
11:25	10	How Space Weather Risks are Integrated into the General Scheme for Government Risk Management		Chris McFee, UK: Gov. Office for Science
11:35	10	UK Resilience and the Role of Scientific Advice in Emergencies		Anita Friend, UK Cabinet Office
11:45	5	Question Period		
11:50	15	Space Weather and the NSO Synoptic Program		Mark Giampapa, National Solar Observatory
12:05	15	Session Discussion		
12:20	60	Lunch		
		<b>How Would an Institute Function Most Usefully and Economically?</b>		<b>Carl Pilcher, NASA Ames</b>
13:20	40	Plenary Panel Discussion: What Functions Should an International Weather Institute Have?		Karel Schrijver, Mike Hapgood, James Head, Alan Title, John Kappenman, and Madhulika Guhathakurta
14:00	20	Discussion		
14:20	40	Plenary Discussion: What are the Possible Business Models for the Institute?		All participants
15:00	20	Discussion		
15:20	15	Break		
15:35	40	Discussion: Priorities— Where do we go from here?		Pete Worden, Ken Washington, Thomas Bogdan, Mike Hapgood
16:15		Adjourn		

## Acronyms and Abbreviations

AAAS	American Association for the Advancement of Science
ACE	Advanced Composition Explorer satellite
ARC	Ames Research Center
CCMC	Community Coordinated Modeling Center
CIA	Catastrophic Incident Annex
CIR	Co-rotating Interaction Region
CISM	Center for Integrated Space Weather Modeling
CME	Coronal Mass Ejection
COBR	Cabinet Office Briefing Room
dB/dt	Time variation of the magnetic field
DOD	Department of Defense
EMP	Electromagnetic Pulse
EPRI	Electric Power Research Institute
ESDs	Electrostatic Discharges
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Administration
GeV	Gigaelectron volts
GIC	Geo-magnetically Induced Current
GNSS	Global Navigation Satellite System
GONG	Global Oscillation Network Group
GPS	Global Positioning Systems
GSFC	Goddard Space Flight Center
HEOMD	Human Exploration and Operations Mission Directorate
HF	high frequency
HPD	Heliophysics Division
HSPDs	Homeland Security Presidential Directives
ICRP	International Commission on Radiological Protection
IGS	International GNSS Service
IPSC	Institute for the Protection and Security of the Citizen
ISSI	International Space Science Institute
iSWA	Integrated Space Weather Analysis System
JPL	Jet Propulsion Laboratory
KeV	Kiloelectron Volts
LaRC	Langley Research Center
LEO	Low-Earth Orbit
LMATC	Lockheed Martin Advanced Technology Center
LPV	Localizer Performance with Vertical Guidance
LWS	Living With a Star
L1	Lagrange point between the Sun and Earth
MeV	Megaelectron Volts
MHD	Magnetohydrodynamics
MSFC	Marshall Space Flight Center
NAI	NASA Astrobiology Institute
NAIRAS	Nowcast of Atmospheric Ionizing Radiation for Aviation Safety

## Acronyms and Abbreviations

NASA	National Aeronautics and Space Administration
NERC	Natural Environment Research Council
NextGen	Next Generation Air Transportation System
NGO	Non-Government Organization
NHHPC	NASA Human Health and Performance Center
NIMS	National Incident Management System
NIOSH	National Institute for Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
NPR	National Preparedness Report
NRA	National Risk Assessment
NRC	National Research Council
NRF	National Response Framework
NSF	National Science Foundation
NSO	National Solar Observatory
NSWP	National Space Weather Program
nT	nanotesla (magnetic-field strength)
OSTP	Office of Science and Technology Policy
PSTN	Public Switched Telephone Network
RAL	Rutherford Appleton Laboratory
R&A	Research and Analysis
SAT	Space and Advanced Technology
SATCOM	Satellite Communications
SDO	Solar Dynamics Observatory
SDR	Subcommittee on Disaster Reduction
SEP	Solar Energetic Particle
SERVIR	Regional Visualization and Monitoring System
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliophysics Observatory
SOLIS	Solar Long-Term Investigations of the Sun
SPoRT	Short-term Prediction Research and Transition
SSWI	Society and Space Weather Institute
STEREO	Solar Terrestrial Relations Observatories
STFC	Science and Technology Facilities Council
SWPC	Space Weather Prediction Center
TEC	Total Electron Count
THIRA	Threat and Hazard Identification and Risk Assessment
UHF	ultra high frequency
UK	United Kingdom
USAF	United States Air Force
var	volt-amperes reactive
VHF	very high frequency
VSM	Vector SpectroMagnetograph
WAAS	Wide Area Augmentation System

## List of participants

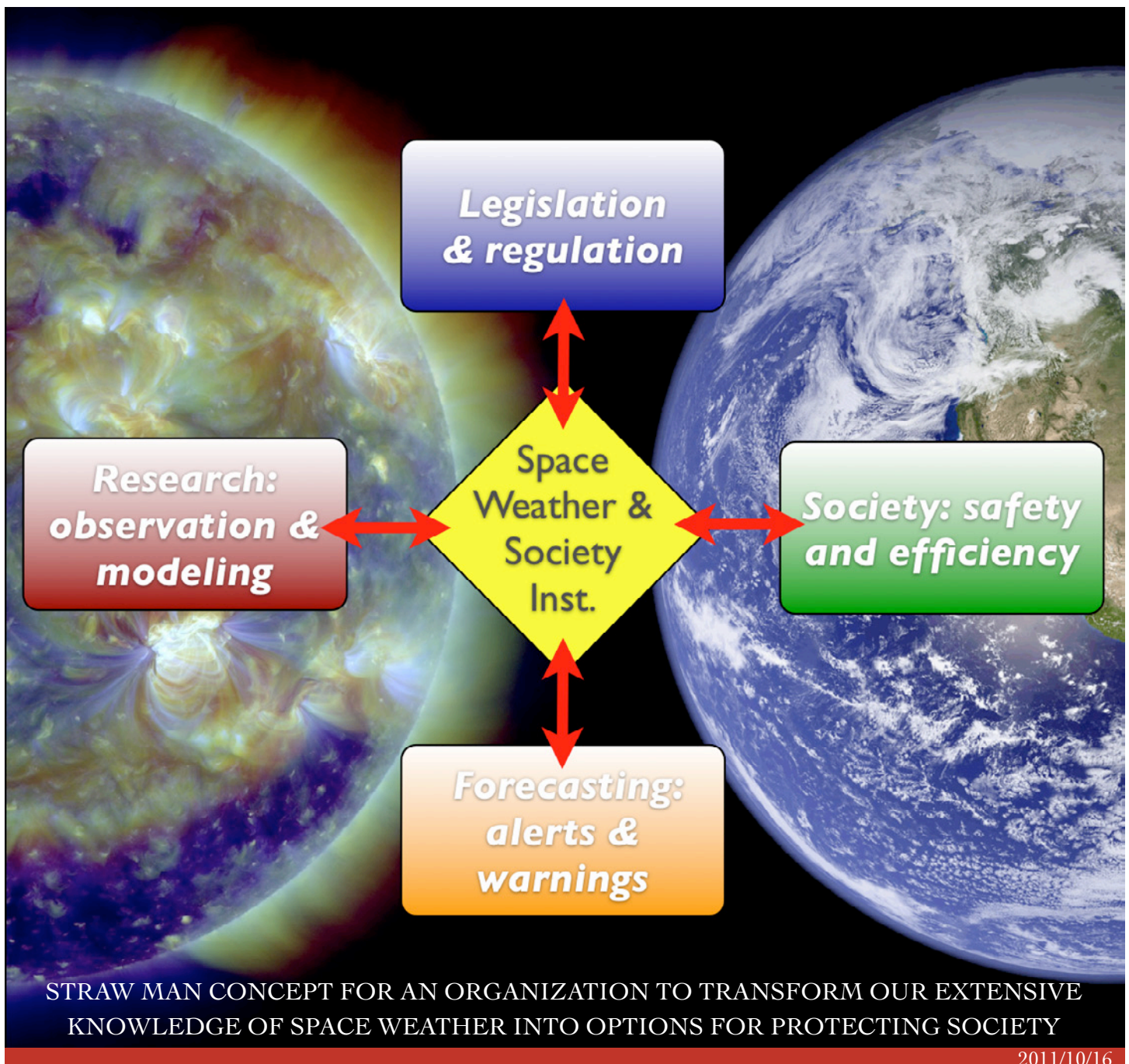
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22	Head, James	U.S. Department of State
23	Holland, Mike	Allied Pilots Association
24	Horton, Randy	Electric Power Research Institute
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26	Jaroux, BJ	NASA Ames Research Center
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# Society and Space Weather



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<http://science.nasa.gov/media/medialibrary/2010/06/04/SpWeatherPoster1.jpg>

## EXECUTIVE SUMMARY

Our globally-connected society, its security and its economic well-being depend critically on the reliable availability of electrical power, communications systems, precision timing and spatial positioning, and Earth-observing satellites. The large-scale electrical grids and the space-based technologies needed for this are susceptible to space weather, which has triggered satellite failures, power-grid blackouts, and communications outages. Space weather is continually varying. Observations of Sun-like stars suggest that space storms can be much larger than experienced in the modern electronic age, even as our society becomes ever more dependent on these susceptible systems. Societal costs of severe space weather may run into trillions of dollars (p. 11).

Our understanding of space weather and - in particular - its impacts on society are in their infancy. Societal sensitivity to high-impact, low-frequency events is obviously substantial. The investigation of how space weather impacts various components of our high-tech society is essential to national and international economic and military security, and should

be a core ingredient in strategic design, regulation, and construction of a resilient technological infrastructure.

The multidisciplinary nature of societal impacts of space weather suggests the formation of an Institute shaped by a partnership between government, industry, and academia. The Institute's fundamental goal of studying societal effects of space-weather phenomena ensures that it will complement - not duplicate or compete with - existing organizations for research, forecasting, and advice.

The Institute will (1) integrate and evaluate knowledge of space-weather phenomena and consequences from all relevant sources, (2) develop moderate-event and extreme-event scenarios with realistic analysis-based societal impacts, (3) provide evaluations of space-weather impacts on new technological applications, (4) assess enhanced discovery potential with advancing instrumentation, methodologies, synergies, and funding structures, (5) provide independent assessment and evaluation of effectiveness of forecasting and monitoring systems, of response plans and resources, and of space-weather information-distribution and alert systems, (6) interface with scientists, forecasters, engineers, and leaders in government and society in emergency planning and preparedness, in policy development, and in international coordination, and (7) develop courses for scientists, societal leaders, emergency responders, media, and public, and serve as a training center for all categories of stakeholders. The Institute would provide guidance and assess options for policy makers on improving society's resilience and on reducing susceptibility.

This document outlines how such an Institute can take shape, growing from a 3-year maturation phase to its full-scale operation. In its fully-operational mode (at approximately \$8M/y) it would be supported by grants from government and industry, subject to periodic performance reviews, while setting its own priorities and initiating its studies subject to advice from a Board of Directors and a Panel of Experts. A draft plan for its structure is presented on pp. 8 and 9.

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# Limiting society's susceptibility to space weather

*Space weather has many parallels to weather on Earth. It, too, comes in mild and extreme forms, affects our technological infrastructure, and is studied so that it can be forecast, accommodated for in system designs, and considered in catastrophe scenarios. Space weather, originating in the Sun's magnetism, involves electromagnetic forces that lie outside day-to-day experience, but the impacts are as real as those of terrestrial weather. Storms in space result in satellite outages, interruptions in electrical power, communications, navigation, financial services, the internet ... Space weather affects everything that relies on our electrical and electronic technologies.*

A workshop organized by the National Research Council on understanding of societal and economic impacts of space weather (see excerpts on p. 11) concluded that "[w]hile this workshop, along with its report, has gathered in one place much of what is currently known or suspected about societal and economic impacts [of space weather], it has perhaps been most successful in illuminating the scope of the myriad issues involved, and the gaps in knowledge that remain to be explored in greater depth than can be accomplished in a workshop. A quantitative and comprehensive assessment of the societal and economic impacts of severe space weather will be a truly daunting task [...]"

Our society has evolved to respond to the benefits and threats posed by weather: our infrastructure is designed so that it can withstand what we can commonly expect from the daily and seasonal weather changes. For extreme weather - such as hurricanes, floods, ice storms, and heat waves - risk assessments result in design decisions, building codes, requirements on infrastructure resilience, warning systems, and evacuation plans.

An effective response to space weather requires an understanding of the many pathways by which strong electromagnetic pulses impact the complex, computer-operated systems that form the controlling core of our societal infrastructure. Proper response plans for space-weather hazards remain to be developed because the nature of the risk is not understood well enough. Electric power companies, for example, may be increasingly aware of space weather, but preparedness for the complex system-level interactions that it may cause is not yet fully developed. DHS/FEMA may incorporate space-weather impacts in emergency exercises, but these start from hypothetical scenarios for the initial damage caused by the solar event or how its effects propagate through the electronic and electrical infrastructure.

Because of the weak understanding of the linkages from causes to effects, it has not been possible to formulate optimal regulations, design rules, and

emergency plans for a resilient society subject to space weather. Designs for communication, navigation, and other technologies do not yet adequately reflect known space-weather threats, while the Sun may have more extreme events in store.

Dealing with space weather threats necessarily involves many segments of society (illustrated in the cover image): legislators, emergency planners, industry sectors, forecasters, and scientists with a wide variety of backgrounds. Taking space weather events, in their rich diversity (illustrated in the figure on the facing page), into the equally rich diversity of societal aspects requires that experts from all of the disciplines and impacted parties interacting in an environment that stimulates the exchange of knowledge and the development of new ideas.

*Assessing societal risks from space weather requires an organization that coordinates investigations of the many pathways in which space weather affects the highly-coupled systems of economy and security, and that provides options on how to make national and international infrastructures secure and resilient against the effects of space weather, from the moderate ever-present variability to the low-frequency, high-impact extremes.*

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*Internet addresses to various international organizations, and excerpts from studies from government and industry are provided on pages 11 through 15 in this brochure.*



# International by its nature

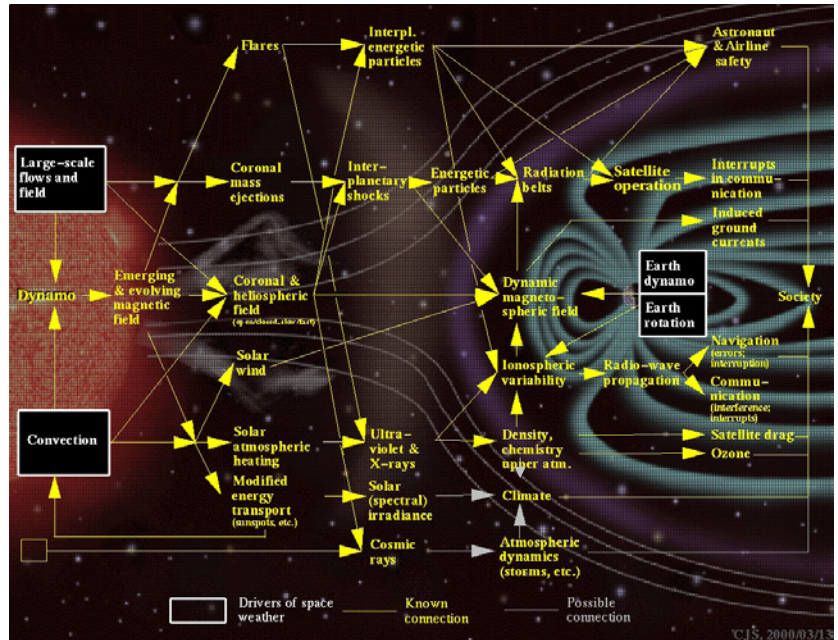
Space weather effects do not respect international boundaries, and local space-weather impacts readily cause global consequences in our tightly connected world economy.

Geomagnetic storms couple sensitive high-latitude regions from the northern US and Canada to Scandinavia and other northern European countries, into their continental surroundings through the web of power grids. Solar eruptions cause ionospheric perturbations over the entire Sun-facing hemisphere of the Earth. Energetic-particle storms affect navigation, communication, and surveillance satellites regardless of their country of origin. Low-frequency extreme events - such as hurricanes, tsunamis, volcanic eruptions, nuclear power plant failures, and oil spills - have recently demonstrated that highly coupled economic systems can

suffer very expensive consequences when one significant portion fails and its effects cascade through society.

Institutes for Society and Space Weather in different parts of the world can and must work side by side

without duplication of effort, creating the opportunity for industries and governments of diverse origin to work together, train together, and decide together on the priorities for research, preparation, resilience, and response.



## UNIQUE CHARACTERISTICS OF SPACE WEATHER

### LARGE SPACE-WEATHER EVENTS ARE RARE

- High-impact, low-frequency events like solar storms do not occur with sufficient regularity to instill experience-based awareness. Therefore, stakeholders must promote awareness through detailed simulations of disturbances throughout the complex electronic infrastructure and of lessons learned from national and international disaster/crisis management exercise programs.

### SPACE STORM CONSEQUENCES ARE GLOBAL

- Large impacts can span multiple continents, so impact is global, interest is inherently international, and multi-national stakeholders benefit from sharing of knowledge and resources.

### SPACE WEATHER IMPACTS MULTIPLE TECHNOLOGIES SIMULTANEOUSLY

- Power grid, GPS, communication, surveillance, transportation, ...

### SPACE WEATHER IS OUTSIDE THE REALM OF EVERYDAY EXPERIENCE

- The often complex electro-magnetic effects complicate communication from expert scientist to impacted societal leader and vice versa.

# Institute for Society and Space Weather

## Needs from the users communities

Reports from government, industry, and academia (some are quoted below, see other excerpts on pp. 11-13, and web resources on p. 15) suggest that an Institute for Society and Space Weather should have at least the following functions (distilled into its core roles in the box below):

### TRANSLATE FORECASTS, NOWCASTS, AND KNOWLEDGE OF THE SUN-EARTH SYSTEM INTO ACTIONABLE KNOWLEDGE

- Translation of industry/government needs to science community. Translation of scientifically formulated impact potential to estimates societal impacts. Integration of experts/researchers and emergency management in response teams during both real and rehearsed emergencies. Need to “provide sufficient clarity of the

threat so that organizations can understand how the danger is relevant to their operations.”

“Workshop participants highlighted the need to assess the vulnerability of technological systems that could be impacted by space weather conditions.”

### PROVIDE ADVICE BEFORE, DURING, AND AFTER SPACE WEATHER INDUCED DISASTROUS EVENTS

- Expert knowledge needed to integrate knowledge, to assess its practical value and limitations, assess its usefulness as technologies and sensitivities change, and to present it in a coherent way to both scientists and end users. “In many cases, both the private and public sectors do not fully understand the level of interconnectivity between various infrastructures and therefore do not grasp the extent of the space weather threat.”

- Resource needed to interact with media and general public. “This point of contact can encourage and facilitate communication with the private sector on space weather issues, contingency plans, and recovery procedures.”

### ACT AS A TRAINING RESOURCE

- Training resource for leaders in government, industry, and science as they frequently rotate through assignments. “It is recommended that stakeholders build a process for sharing the knowledge of subject matter experts (SMEs) during space weather-related exercise planning and conduct.” “The participants suggested the development of educational mechanisms that leaders and staffers can access when they arrive in office.”

### STIMULATE INTERNATIONAL COLLABORATION, COORDINATION, AND INFORMATION SHARING

## INSTITUTE’S ROLES

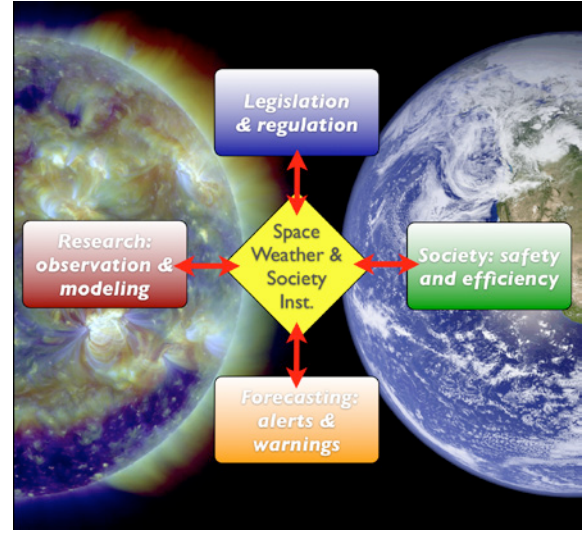
1. Integrate and evaluate knowledge of space-weather phenomena and consequences from all relevant sources (in part by acting as a research center with professional staff and visitors of a wide range of backgrounds and interests) to establish probabilities of occurrence of impacts of a given magnitude
2. Develop moderate-event and extreme-event scenarios with realistic analysis-based impacts on power, navigation, timing or communications systems that change with evolving technologies, and provide event-response manuals for the various national and international responding organizations
3. Provide evaluations of space-weather impacts on new technological applications
4. Assess enhanced discovery potential with advancing instrumentation, methodologies, synergies, and funding structures
5. Provide independent assessment and evaluation of effectiveness of forecasting and monitoring systems, of response plans and resources, and of space-weather information-distribution and alert systems
6. Interface with scientists, forecasters, and leaders in government and society in emergency planning and preparedness, in policy development, and in international coordination.
7. Develop educational and informational materials and courses for scientists, societal leadership, emergency responders, media, and public; and serve as training center for all classes of stakeholders



# - a partnership



*An Institute for Society and Space Weather forms the natural hub for interactions between research, forecasting, regulation, and economy on any of the multitude of societal components that can be affected by space-weather events.*



## Research into space weather

Space agencies, NASA foremost among them, are pushing the frontiers of our understanding of our variable space environment. Additional research is supported by NSF, DOD and DOE. In Europe and Asia, space research organizations and national research foundations add to those efforts in the international collaboration of research.

## Space weather modeling

The vastness of the space between us and the Sun means that sensor networks can only sample space weather locally. Numerical models, in which physics-based computer codes extend the sensor sites to cover the Sun-to-Earth pathways, are critical complements to space- and ground-based instruments. University and National Laboratory research modules and the NASA Community Coordinated Modeling Center (CCMC) are examples of these model environments, supported by NASA, NSF, and other partners of the National Space Weather Program.

## Forecasting space weather

Within NOAA, the Space Weather Prediction Center is responsible for providing space-weather forecasts and alerts to a large variety of customers, based on observations, models, and decades-long expertise of the expert forecasting staff.

## What is missing?

Awareness and understanding of the needs of society by the research community and their funding organizations must be increased substantially. Part of that role resides in the US National Space Weather Program, which manages the multi-agency strategy. But even that organization does not have the required expertise to assess risks for everyday or catastrophic space weather impacts on the variety of societal segments that are susceptible to space weather.

## How to proceed?

We need to transcend the boundaries of scientific discipline of heliophysics, and seek support from space weather stakeholders and regulatory communities. A partnership

can be established that reaches beyond NASA and NSF with funding from, e.g., DOE, and DOD, complemented by industrial partners in communication, navigation, and electricity branches, to establish an independent organization that can integrate knowledge from diverse sources into value-enhanced products that can be used in day-to-day dealings with space weather, as well as in the development of policy guidelines for government, industry, and academia.

*The next step in the chain requires translation of the forecasts into actionable knowledge and risk assessments. This requires that we understand the predictive value of the forecasts. But it also requires that we understand what impacts it is likely to have, how extensive the impacts may be, how the impacts may percolate from one technology to another thus cascading through societal segments. All these issues for space weather are analogous to what we would ask about weather on Earth. Where can one turn to find out?*

# Institute structure

## Mission description

The primary functions of the Institute for Society and Space Weather (ISSW) - detailed on p. 6 - are to integrate, evaluate, disseminate, and teach knowledge of space weather and its diverse impacts on society, and act as a source of public domain knowledge and advice to all partners. ISSW operates as a non-governmental, not-for-profit organization, funded by several government organizations and industrial and academic partners.

During an initial 3-year maturation phase the mode of operation and the balance of its activities are being tuned to the needs of its societal partners, guided by a board of directors from those partners and by an advisory expert panel. In this phase, ISSW should grow to a professional staff of four to six experts in disciplines that include heliophysics, engineering, economics, and security, partnering with academic groups in science and business schools. A support staff of administration, IT functions, and PR personnel is also foreseen. This staff will operate in a facility with visitor offices, meeting facilities, and a computer center.

After the 3-year startup phase, ISSW should be funded to execute its activities independently, subject to periodic external review, with general funding to be allocated by its directors and panel of experts.

## Products and services

ISSW will have six primary functions (with a distribution approximately as in the chart below):

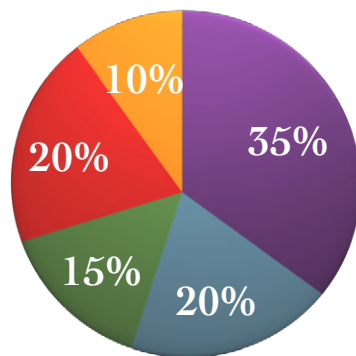
1. Study-team reports: Expert teams, assembled from both community-based proposals and by ISSW initiative, will study a variety of aspects from Sun to society, to be published in peer reviewed journals or on line by ISSW.
2. Educational materials and courses for on-site teaching (with 'expert certification' in space weather) for all interested parties, produced at cost to the customers.
3. Reports or advice in response to requests from government or industry, published as public domain materials after internal review.
4. Self-directed meta-analyses in which literature studies are interpreted and combined into broader knowledge and subject review publications.
5. Scenarios with quantitative risk information on space weather impacts.
6. Expert advice for emergency simulations and responses.

## Sponsors

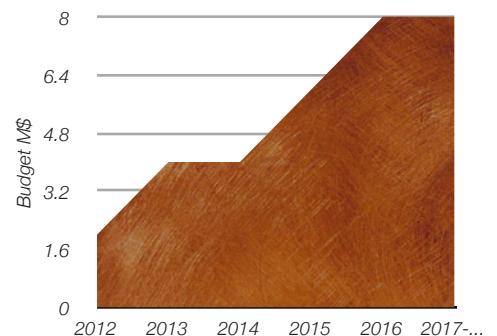
ISSW will seek funding and indirect support from a variety of sources:

- *Government:* DHS/FEMA, FAA, DOE, DOD, NASA, NSF
- *Academia:* business and management schools and risk analysis and mitigation centers. These partnerships may involve the development of curricula and undergraduate and graduate student internships at the Institute.
- *Industry:* communication, navigation, aviation, etc.
- *Private foundations.*

ISSW will seek three types of funding: (1) undirected grants in support of general activities from lasting partners, (2) support for community-initiated study teams and meta-analyses and their publication mostly through NASA and NSF, (3) funding for studies, reports, and impact scenarios through charges by the sponsors, to be published by the Institute subject only to interval review by directors and panel of experts.



- Study-team support
- Educational materials/Courses
- Advice/reports on space weather impacts
- Self-directed meta-analyses
- Scenario development/Impact analysis



Projected budget growth from a 3-year maturation phase (in which customer needs and course materials are established) to a fully operational phase in which all activities, as shown in the pie chart to the left, are deployed.

# Institute structure cnt'd

## Management

The Institute will be managed as a not-for-profit NGO. A Board of Directors and an Expert Panel would advise the directors on the strategic and tactical planning for activities, respectively. The Board will ensure alignment with domestic and international priorities, guidance on strategic partnerships, liaising with advisory bodies in government and academia, etc. The Expert Council will advise on the selection of study topics, setting priorities for internal independent research, guidance on the development of training courses and educational materials, etc.

The Institute is to operate as an independent organization, accepting funding without specific direction for its research and training activities, and contract funding for specific tasks resulting in public domain reports. The Institute will be subject to peer review for continuation of its grants in a review process jointly organized by its primary sponsors.

## Operations

The Institute's primary products (summarized on p. 8) suggest a professional staff of 6 subject experts (either full-time employed or a comparable complement of part-time staff), with a support staff of four administrative assistants. Together, this staff is to engage in its own meta-analyses and support study teams. These study teams, supported for their local expenses to meet a few times per year for approximately a week each time) would be constituted from the communities of academia, government and industry, either as per external proposal or at the initiative of the Institute itself.

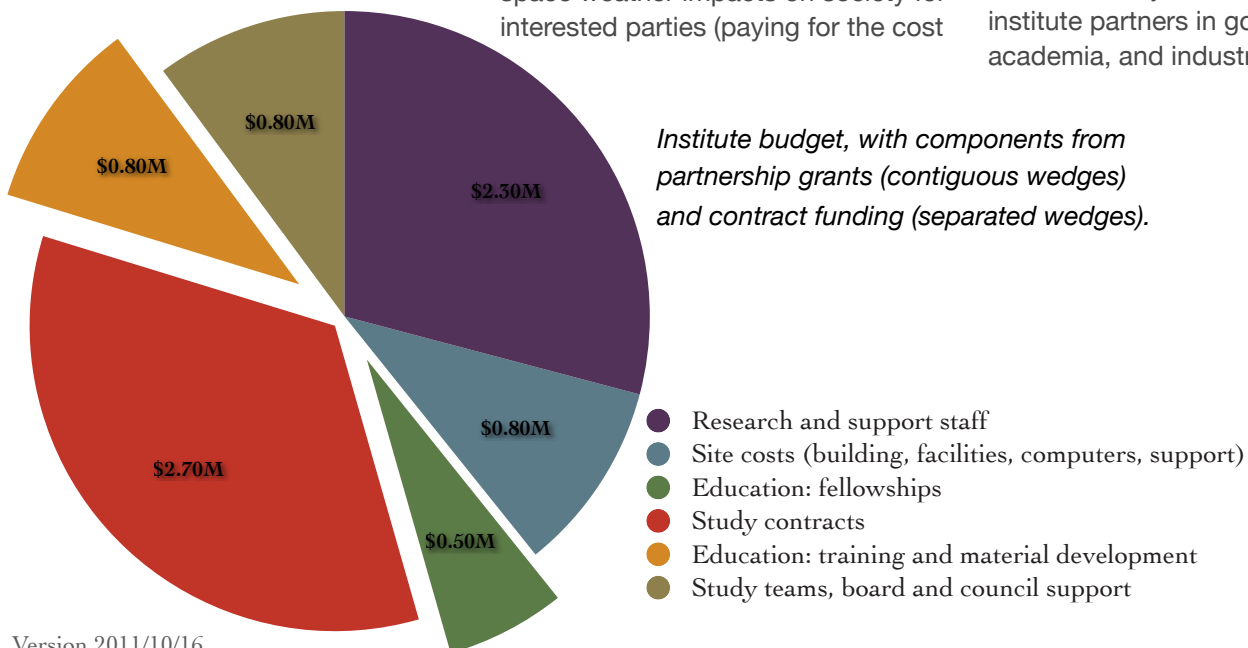
The Institute will be able to host interns of a variety of backgrounds in training at universities, and can host fellows that bring specific expertise to projects for periods of weeks up to a year.

The Institute will also host (at least on-site, and perhaps at other locations if useful) certificate training courses in space weather impacts on society for interested parties (paying for the cost

of the course, and thus eventually a cost-neutral element of the overall budget).

Overall, *half of the Institute's funding should come from lasting strategic partnership grants and half from contracts on education, training, and targeted studies.*

The Institute's studies linking societal impacts to physical processes would be directed by an expert panel composed of the Institute's professional staff, designated members of the Board of Directors, and external experts including liaisons to associated university departments and academic centers, with a total membership of about 18. The members of this Panel would prioritize the Institute's activities, guide studies and reporting activities, review study reports and advise the authoring groups from their wide backgrounds and expertise; at least one Panel member will participate in each study in a leading role. This management structure ensures communication between study teams, staff, and institute partners in government, academia, and industry.



# Principles of operation

## Charges

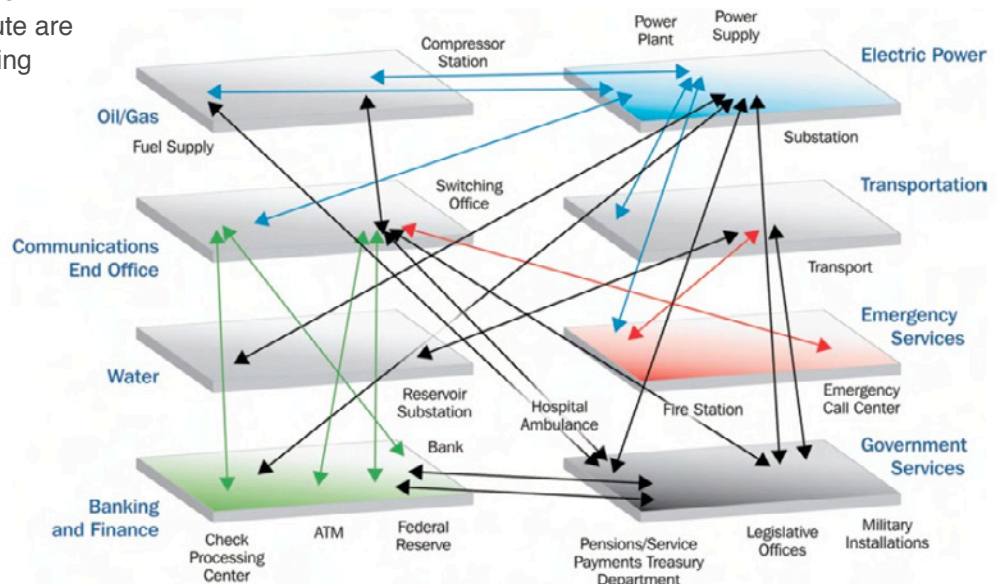
The charge of any organization for a study will be evaluated and approved by the staff and the permanent committee. If during the course of a study the group carrying it out should find that essential issues not originally included in the charge would need to be included to reach a sound conclusion, the Institute director will notify the funder that there are important issues not included in the charge. The funder will then have several options: 1) to end support for the study and have the unexpended funds refunded; 2) to encourage the study to continue and to provide additional funds to expand the evaluation; 3) to discuss any reasons why expanding on the charge would not be valuable. Regardless of the decision of the funder, the Institute can use any information that it has obtained to develop the report as recommended by the committee of advisors. Reports from the Institute are not subject to review by the funding organization.

## Reporting

The Institute will shape its reports in the form of options for action scenarios supported by detailed rationales. Different organizations may, and probably will, have different responses to the assessments made by the Institute. The options will hopefully bound the range of recommended responses that are made at the then current state of knowledge. In a changing state of both our knowledge of space weather and the interactions of our technologies, the relevance of any set of options will most certainly evolve. The options given for dealing with serious issues will be regularly reviewed and the Institute will respond to requests of its funders and its board of directors about option reviews.

## Review

Institute studies will be reviewed by the board of directors, the permanent committee, and selected outside reviewers who may have additional insights to the topics considered. The Institute will not be bound to comply with the concerns of either outside reviewers or the funders. The decision to publish resides entirely within the judgment of the director and the permanent committee. The main form of publication will be electronic and open to all. In those cases where options concern national security, distribution or the report may be limited.



Connections and interdependencies across the economy. Schematic showing the interconnected infrastructures and their qualitative dependencies and interdependencies. SOURCE: Department of Homeland Security, National Infrastructure Protection Plan, available at [http://www.dhs.gov/files/programs/editorial\\_0827.shtm](http://www.dhs.gov/files/programs/editorial_0827.shtm)



Quotes from the literature

# Severe Space Weather Events - Understanding Societal and Economic Impacts

"Because of the interconnectedness of critical infrastructures in modern society, the impacts of severe space weather events can go beyond disruption of existing technical systems and lead to short-term as well as to long-term collateral socioeconomic disruptions. Electric power is modern society's cornerstone technology, the technology on which virtually all other infrastructures and services depend. [...] Collateral effects of a longer-term outage would likely include, for example, disruption of the transportation, communication, banking, and finance systems, and government services; the breakdown of the distribution of potable water owing to pump failure; and the loss of perishable foods and medications because of lack of refrigeration."

"Our knowledge and understanding of the vulnerabilities of modern technological infrastructure to severe space weather and the measures

developed to mitigate those vulnerabilities are based largely on experience and knowledge gained during the past 20 or 30 years, during such episodes of severe space weather as the geomagnetic superstorms of March 1989 and October–November 2003. As severe as some of these recent events have been, the historical record reveals that space weather of even greater severity has occurred in the past—e.g., the Carrington event of 1859 and the great geomagnetic storm of May 1921—and suggests that such extreme events, though rare, are likely to occur again some time in the future."

"[...] the nation's electric power grids remain vulnerable to disruption and damage by severe space weather and have become even more so, in terms of both widespread blackouts and permanent equipment damage requiring long restoration times.

According to a study by the Metatech Corporation, the

occurrence today of an event like the 1921 storm would result in large-scale blackouts affecting more than 130 million people and would expose more than 350 transformers to the risk of permanent damage."

**"[...] an estimate of \$1 trillion to \$2 trillion during the first year alone was given for the societal and economic costs of a "severe geomagnetic storm scenario" with recovery times of 4 to 10 years."**

"What are the societal and economic impacts of severe space weather? [...] While this workshop, along with its report, has gathered in one place much of what is currently known or

suspected about societal and economic impacts, it has perhaps been most successful in illuminating the scope of the myriad issues involved, and the gaps in knowledge that remain to be explored in greater depth than can be accomplished in a workshop. A quantitative and comprehensive assessment of the societal and economic impacts of severe space weather will be a truly daunting task [...]"



***From "Severe Space Weather Events--Understanding Societal and Economic Impacts: a Workshop Report"; Committee on the Societal and Economic Impacts of Severe Space Weather Events, National Research Council; published in 2008***  
<http://www.nap.edu/catalog/12507.html>

Quotes from the literature

# Space Weather - Its impact on Earth and implications for business

"The risks posed by space weather are now magnified through what some commentators have called "creeping dependency", which means the growth of interconnected systems that business and other activities rely on. [...] Therefore a space weather event could have wider regional and even global impacts: by triggering cascading failures across systems."

"In recent years, satellite navigation services in Europe and the US have been strengthened by 'augmentation systems', which generate ionospheric correction data and enable satnav receivers to measure aircraft altitudes with accuracy to approximately 10 metres. However, during the severe space weather storms in October 2003 the vertical error limit of 50 metres set by the FAA was exceeded, even with the augmentation system, and could not be used for aircraft navigation and specifically precision landings."

"The 2003 [space weather] events also revealed some novel aspects of the threat to power grids. The loss of 14 transformers in South Africa and the loss of 13% of power in the grid showed that cumulative damage due to a series of moderate space weather events - rather than a single big event, as in 1989 - can be just as harmful."

"Time-stamping of financial transactions is critical to the operation of many financial markets. In general, these timestamps are derived from satellite navigation services and sometimes via intermediary services on the internet. They are therefore vulnerable to disruption of access to those satellite services by space weather; for example, loss of signal in severe space weather conditions."

"The ideal response to space weather risks is to build robust assets and systems that can operate through bad space weather conditions. [...] The building of robust systems will

impose extra costs on business, and some measures may reduce the capacity of businesses to deliver services to customers, therefore reducing potential income. [...] This approach relies on obtaining information on space weather

conditions and converting to a useful format."

"The market demand for specialist services has been the subject of several studies funded by the European Space Agency. A market survey carried out in 2000 and 2001 found a strong need for services focused on customer needs:

- Potential customers were willing to pay for space weather services that convert scientific data into forms that are meaningful to operations staff with a

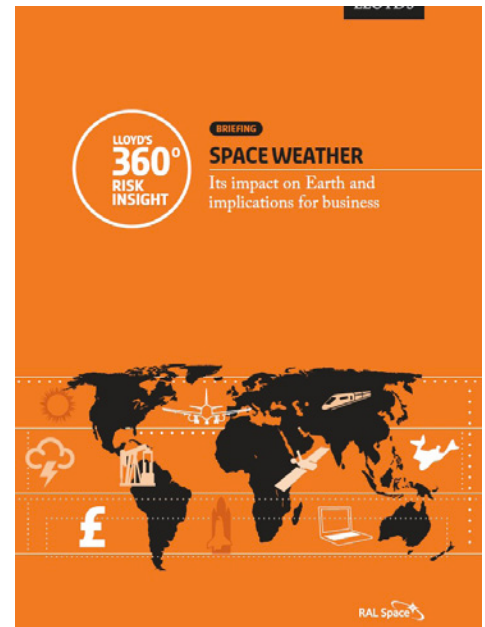
minimum of additional training. For example, a simple index indicating the level of threat.

- It also found that potential customers were not willing to pay for scientific data. They saw that as a raw product that should be generated by public sector activities.

It seems not much has changed in the last ten years. Many existing services remain science-led and fail to provide this focus on customer needs."

***From "Space Weather - Its impacts on Earth and implications for business", a Briefing in Lloyd's 360-degree Risk Insight; published in 2011.***

***<http://www.lloyds.com/360>***





Quotes from the literature

# Managing Critical Disasters in the Transatlantic Domain - The Case of a Geomagnetic Storm

"[...] expert knowledge is of the essence for emergency managers before, during, and after disastrous events. This is especially true in novel events, or during infrequent contingencies. It is also important that experts are aware of how the emergency management sector functions and that a mutual understanding exists regarding the critical importance of providing timely information and advice."

"Workshop participants highlighted the need to assess the vulnerability of technological systems that could be impacted by space weather conditions. They raised concerns that, in many cases, both the private and public sectors do not fully understand the level of interconnectivity between various infra-structures and therefore do not grasp the extent of the space weather threat.

If industry leaders understand the impacts of geomagnetic storms on the electrical generation and transmission system and

technological equipment, they can develop plans and procedures to make systems more resilient."

"[A] geomagnetic storm can destroy large electrical transformers which are expensive and time consuming to replace. Because of the cost, most electric companies do not keep spare transformers on-hand. Even if an electric company is able to locate spare transformers, transportation and installation would take at least three weeks. New orders for replacement equipment can take up to 18 months or even longer to fulfill. If Sweden, Great Britain, and the United States all suffered transformer damage from a geomagnetic storm, it would be difficult for equipment providers to prioritize which countries should receive replacement parts."

"Population centers have limited food and commodity inventories on hand. Hospital supply systems, for instance, operate on a just-in-time replenishment cycle.

Generators are seldom installed and are often intended to be used for a very short period.

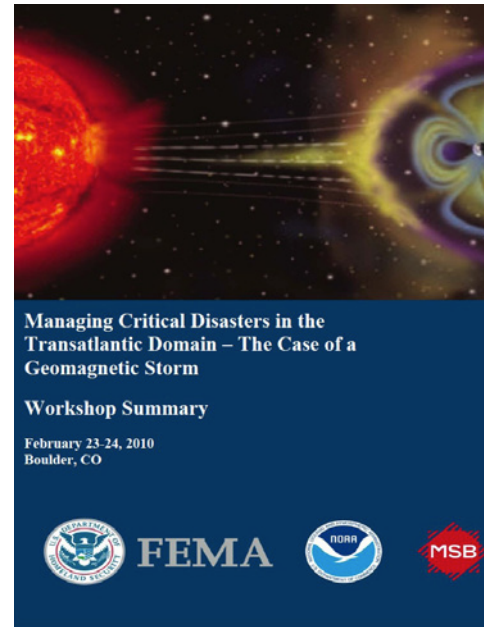
Major electrical outages would wreak havoc with the supply chain management system for these and other critical supplies.

Replenishing these supplies requires operable telecommunications systems, data processing capability, and the fuel to transport shipments."

"It is recommended that a centralized government point of contact for media and public inquiries be in place for space weather-related issues. This point of contact

can encourage and facilitate communication with the private sector on space weather issues, contingency plans, and recovery procedures. Social media, such as Facebook and Twitter, should be employed along with videos and podcasts on Government web sites to educate the public on space weather and its impacts."

***From "Managing Critical Disasters in the Transatlantic Domain – The Case of a Geomagnetic Storm", a workshop report by the Federal Emergency Management Agency (FEMA) in partnership with the European Union, European Commission, Swedish government, U.S. National Weather Service (NWS), and the U.S. National Oceanic and Atmospheric Agency (NOAA); published in 2010.***



# Select web resources

- NOAA Space Weather Scales [http://www.swpc.noaa.gov/NOAA\\_scales/NOAA\\_scales.pdf](http://www.swpc.noaa.gov/NOAA_scales/NOAA_scales.pdf)
- Severe Space Weather Events – Understanding Societal and Economic Impacts <http://www.nap.edu/catalog/12507.html>
- A Profile of Space Weather [http://www.swpc.noaa.gov/primer/primer\\_2010.pdf](http://www.swpc.noaa.gov/primer/primer_2010.pdf)
- National Response Framework (NRF) Resource Center <http://www.fema.gov/emergency/nrf/index.htm>
- Service Assessment: Intense Space Weather Storms October 19 – November 07, 2003 [http://www.nws.noaa.gov/os/assessments/pdfs/SWstorms\\_assessment.pdf](http://www.nws.noaa.gov/os/assessments/pdfs/SWstorms_assessment.pdf)
- International Space Environment Service <http://www.ises-spaceweather.org/>
- Environment Fact Sheet: Civil Protection: Together We Are Stronger [http://ec.europa.eu/environment/civil/pdffdocs/2007\\_factsheet.pdf](http://ec.europa.eu/environment/civil/pdffdocs/2007_factsheet.pdf)
- Global Disaster Alert and Coordination System [http://www.gdacs.org/about/GDACS\\_JRC.pdf](http://www.gdacs.org/about/GDACS_JRC.pdf)
- Joint Research Centre: European Commission <http://ec.europa.eu/dgs/jrc/index.cfm?id=1370>  
[http://ec.europa.eu/dgs/jrc/downloads/jrc\\_passport\\_en.pdf](http://ec.europa.eu/dgs/jrc/downloads/jrc_passport_en.pdf)
- From Floods to Forest Fires: Early Warning Systems [http://ec.europa.eu/dgs/jrc/downloads/jrc\\_leaflet\\_warning\\_systems\\_en.pdf](http://ec.europa.eu/dgs/jrc/downloads/jrc_leaflet_warning_systems_en.pdf)
- U.S. National Infrastructure Protection Plan (NIPP) [http://www.dhs.gov/xlibrary/assets/NIPP\\_Plan.pdf](http://www.dhs.gov/xlibrary/assets/NIPP_Plan.pdf)
- Programme for Critical Infrastructure Protection (EPCIP) [http://europa.eu/legislation\\_summaries/justice\\_freedom\\_security/fight\\_against\\_terrorism/133260\\_en.htm](http://europa.eu/legislation_summaries/justice_freedom_security/fight_against_terrorism/133260_en.htm)
- SWPC, Space Weather Prediction Centre (US) <http://www.swpc.noaa.gov>
- SWENET, Space Weather European Network (ESA) <http://www.esa-spaceweather.net/swenet>
- IPS Radio and Space Services (Australia) <http://www.ips.gov.au>
- ISES, International Space Environment Service <http://www.ises-spaceweather.org>
- SolarMetrics, Professional Space Weather Services for Aerospace <http://www.solarmetrics.com>
- QinetiQ Atmospheric Radiation Model <http://www.qarm.space.qinetiq.com>
- GIC Now! [http://www.aurora.fmi.fi/gic\\_service/english/index.html](http://www.aurora.fmi.fi/gic_service/english/index.html)
- GIC Simulator <http://www.spaceweather.gc.ca/se-gic-eng.php>
- Solar Wind Monitoring and Induction Modeling for GIC <http://www.geomag.bgs.ac.uk/gicpublic>
- Metatech Corporation, Applied Power Solutions Division & Geomagnetic Storm Forecasting Services <http://www.metatechcorp.com/aps/apsmain.html>
- BGS Geomagnetism Applications and Services <http://www.geomag.bgs.ac.uk/services.html>
- Space Weather Service for Pipelines <http://www.spaceweather.gc.ca/se-pip-eng.php>
- Space Weather; the International Journal of Research and Applications <http://www.agu.org/journals/sw/>



# NOAA Space Weather Scales



Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
<b>Geomagnetic Storms</b>				
<b>G 5</b>	Extreme	<b>Power systems:</b> widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. <b>Spacecraft operations:</b> may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. <b>Other systems:</b> 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 Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days) 4 per cycle (4 days per cycle)
<b>G 4</b>	Severe	<b>Power systems:</b> possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. <b>Spacecraft operations:</b> may experience surface charging and tracking problems, corrections may be needed for orientation problems. <b>Other systems:</b> 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)
<b>G 3</b>	Strong	<b>Power systems:</b> voltage corrections may be required, false alarms triggered on some protection devices. <b>Spacecraft operations:</b> surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. <b>Other systems:</b> 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)
<b>G 2</b>	Moderate	<b>Power systems:</b> high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. <b>Spacecraft operations:</b> corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. <b>Other systems:</b> 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)
<b>G 1</b>	Minor	<b>Power systems:</b> weak power grid fluctuations can occur. <b>Spacecraft operations:</b> minor impact on satellite operations possible. <b>Other systems:</b> 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](http://www.swpc.noaa.gov/Aurora))

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

\* Flux levels are 5 minute averages. Flux in particles-s<sup>-1</sup>-ster<sup>-1</sup>-cm<sup>-2</sup>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.

<b>Radio Blackouts</b>			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
<b>R 5</b>	Extreme	<b>HF Radio:</b> 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. <b>Navigation:</b> 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 <sup>-3</sup> )	Fewer than 1 per cycle
<b>R 4</b>	Severe	<b>HF Radio:</b> HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. <b>Navigation:</b> 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 <sup>-3</sup> )	8 per cycle (8 days per cycle)
<b>R 3</b>	Strong	<b>HF Radio:</b> Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. <b>Navigation:</b> Low-frequency navigation signals degraded for about an hour.	X1 (10 <sup>-4</sup> )	175 per cycle (140 days per cycle)
<b>R 2</b>	Moderate	<b>HF Radio:</b> Limited blackout of HF radio communication on sunlit side of the Earth, loss of radio contact for tens of minutes. <b>Navigation:</b> Degradation of low-frequency navigation signals for tens of minutes.	M5 (5x10 <sup>-5</sup> )	350 per cycle (300 days per cycle)
<b>R 1</b>	Minor	<b>HF Radio:</b> Weak or minor degradation of HF radio communication on sunlit side of the Earth, occasional loss of radio contact. <b>Navigation:</b> Low-frequency navigation signals degraded for brief intervals.	M1 (10 <sup>-5</sup> )	2000 per cycle (950 days per cycle)

\* Flux, measured in the 0.1-0.8 nm range, in W-m<sup>-2</sup>. Based on this measure, but other physical measures are also considered.  
\*\* Other frequencies may also be affected by these conditions.