Risk Mitigation Consulting Inc.

Intelligence and Analysis Division

WHITE PAPER SERIES

Effects of Space Weather

INTENT

This white paper is designed to provide analysis of relevant, publicly available information on threat and hazard events/trends and their potential impacts to the interests of the United States, both at home and abroad. This product is not intended to be an all-encompassing assessment of the subject.

Effects of Space Weather

Introduction

The term "space weather" encompasses a variety of phenomena. Space weather, unlike terrestrial weather on Earth, is concerned with varying conditions in the magnetosphere, ionosphere, thermosphere, and exosphere. It observes and studies the fluctuations in the space environment between the sun and Earth. Some space weather, such as an aurora, has little to no effect on our day to day life. There are a few types of space weather, however, that have the ability to impair or damage systems and technologies in orbit and on Earth.[1]

Space weather phenomena include: Aurora, Coronal Holes, Coronal Mass Ejections, Earth's Magnetosphere, F10.7 cm Radio Emissions, Galactic Cosmic Rays, Geomagnetic Storms, Ionosphere, Ionospheric Scintillation, Radiation Belts, Solar EUV Irradiance, Solar Flares (Radio Blackouts), Solar Radiation Storm, Solar Wind, Sunspots/Solar Cycle, and Total Electron Content.

Vulnerable Technology

Over the last 200 years, technologies have been developed that depend on systems vulnerable to fluctuation in space weather. Communications satellites, weather satellites, GPS, and a variety of radio signal dependent technology are all vulnerable to interference from space weather.

Several types of space weather can affect multiple technologies on Earth. Solar flares can produce strong x-rays that degrade or block high-frequency communication radio waves. Shortwave radio (1 to 30 MHz) is reflected by the ionosphere. These frequencies are used by amateur (ham) radio operators and many industries such as commercial airlines. They are also used by a number of government agencies such as the Federal Emergency Management Agency and the Department of Defense. New technology has brought about other methods of communications, but shortwave radio remains critical for vessels that do not carry the newer equipment and as a critical backup system for others. Space weather events can create irregularities in the ionosphere that scatter these high frequency (HF) signals, preventing shortwave radio communications. Recently, emergency response communications were interrupted during hurricane season in September 2017 in the Caribbean. [1,2,6]

Solar Energetic Particles can penetrate satellite electronics and cause electrical failure. These energetic particles also block radio communications at high latitudes during Solar Radiation Storms. Geomagnetic storms can also modify the signal from radio navigation systems causing degraded accuracy. The Wide Area Augmentation System (WAAS) operated by the US Federal Aviation Administration (FAA) is used as a navigation tool for North American commercial aviation. The WAAS is disabled by every major space weather event.[1,6]

Additionally, Coronal Mass Ejections (CMEs), geomagnetically induced currents (GIC), and the resulting Geomagnetic Storms have the potential to impair power grids the world over. During magnetic storms, rapid changes in the Earth's magnetic field can generate electric fields in the subsurface of the Earth. These fields can drive electric currents into metal networks on the ground, such as power grids. [5,6]

Solar Flares

Solar flares are large eruptions of electromagnetic radiation from the Sun lasting from minutes to hours. The sudden outburst of electromagnetic energy travels at the speed of light. The effects are therefore instantaneous, occurring at the same time the event is observed.

When solar flares strike the atmosphere, they create auroras around the North and South poles. However, when a strong enough solar flare occurs, shortwave HF radio signals to become degraded or completely absorbed. This results in a radio blackout – the absence of HF communication, primarily impacting the 3 to 30 MHz band. Solar flares also have the power to wipe out communications satellites, disable electronic devices and cause airplanes to malfunction. At their worst, solar flares can blow out power stations, disable GPS navigation and ground emergency services. Solar flares on this scale are rare – they only strike once every 100 to 200 years.[1,2]

Solar Radiation Storm

Solar radiation storms occur when a large-scale magnetic eruption, often causing a coronal mass ejection and associated solar flare, accelerates charged particles in the solar atmosphere to very high velocities. NOAA categorizes Solar Radiation Storms using the NOAA Space Weather Scale on a scale from S1 - S5. A Solar Radiation Storm can persist for time periods ranging from hours to days.[1]

Solar Radiation Storms cause several impacts near Earth. When energetic protons collide with satellites or humans in space, they can penetrate deep into the object that they collide with and cause damage to electronic circuits or biological DNA. During Solar Radiation Storms at the S2 level, individuals in high flying aircraft at high latitudes may be exposed to radiation risk. When the energetic protons collide with the atmosphere, they ionize the atoms and molecules thus creating free electrons. These electrons create a layer near the bottom of the ionosphere that can absorb HF radio waves making radio communication difficult or impossible.[1]

Geomagnetic Storms

A geomagnetic storm, also known as solar storm, is a major disturbance of Earth's magnetosphere that occurs when there is a very efficient exchange of energy from the solar wind into the space environment surrounding Earth. The largest storms that result from these conditions are associated with solar CMEs. During a CME, the sun releases a burst (or bursts) of plasma carrying intense magnetic fields. CMEs can arrive in as short as 18 hours, but typically take several days to arrive at Earth. Another solar wind disturbance that creates conditions favorable to geomagnetic storms is a high-speed solar wind stream. Solar flares, coronal holes, and sunspots are frequent solar storm triggers.[1,4]

Geomagnetic storms result in intense currents in the magnetosphere, changes in the radiation belts, and changes in the ionosphere, including heating the ionosphere and upper atmosphere region called the thermosphere. These storms can modify the path of radio signals and create errors in the positioning information provided by GPS. These storms can disrupt navigation systems such as the Global Navigation Satellite System and create harmful geomagnetic induced currents in the power grid and pipelines.[1]

The Geomagnetic Storm, or G-Scale, is used to describe space weather that can disrupt systems on Earth. Geomagnetic storms rank from "minor G1 storms" to extreme "G5 storms" on the official SWPC hazard scales. Minor G1 storms may cause power grid fluctuations and minor satellite impacts. Extreme storms, however, risk complete power grid blackouts, satellite disruptions, a shutdown of radio frequencies and spacecraft operation issues. Severe magnetic storms are some of the most dangerous of the space weather phenomena because of the threat they pose to power grids and radio-based technologies. [1,5]

Case Studies

March 1989: Quebec, Canada

The 13-14 March 1989 geomagnetic storm is one of the most well-known for its effect on power systems. The geomagnetic storm struck around 3 a.m. Eastern Time on 13 March and collapsed the Hydro-Quebec power grid in less than two minutes. Geomagnetic storm activity can induce geoelectric fields in the Earth's conducting lithosphere. Corresponding voltage differentials can find their way into electric power grids through ground connections, driving uncontrolled electric currents that interfere with grid operation, damage transformers, trip protective relays and sometimes cause blackouts. This complicated chain of causes and effects was demonstrated during the magnetic storm of March 1989. The problems triggered a protective shutdown, and it took 9 hours to restore normal operations. The collapse of the Hydro-Quebec electric-power grid left nine million people without electricity. The possible occurrence of an even more intense storm led to operational standards intended to mitigate induction-hazard risks, while reinsurance companies commissioned revised risk assessments.[3,4,6]

October 2003

In late October 2003, three large active regions were present on the solar surface. One of these was responsible for the majority of the flaring and eruptive activity during the 2003 storm events. Minor power grid disturbances were experienced in North America, including a capacitor trip in the Northwest, and transformer heating in the Northeast. Ground magnetic field fluctuations were stronger over Northern Europe. Sweden experienced a blackout of less than an hour, affecting around 50,000 customers and twelve transformers in South Africa were damaged.[4]

Observation

Space weather is monitored at ground level by observing changes in the Earth's magnetic field over periods of seconds to days, by observing the surface of the Sun, and by observing radio noise created in the Sun's atmosphere. The Sun's photosphere is observed continuously for activity that can be the precursors to solar flares and CMEs, such as the number and size of sunspots present. The number and total area of sunspots are related to the brightness of the Sun in the extreme ultraviolet (EUV) and X-ray portions of the solar spectrum and to solar activity such as solar flares and coronal mass ejections (CMEs). Fundamental space weather monitoring data are provided by ground-based magnetometers and magnetic observatories. Ground magnetometer data provide real-time situational awareness for post-event analysis. Magnetic observatories have been in continuous operations for decades to centuries, providing data to inform studies of long-term changes in space climatology. A variety of space craft are also utilized to monitor patterns and fluctuations in space weather.[1]

Mitigation

As noted earlier, there are a variety of technologies that are vulnerable to the effects of space weather. Space weather is not always predicable, nor can communication, navigation, and satellite systems be completely protected from the effects. It is important, however, to prepare for and mitigate the effects of space weather on communication, navigation, and satellite systems, as well as any potential effects on the power grid.

Modern high-voltage power grids are increasingly susceptible to space weather impacts. In the case of electric power grids, the systems' operations and the design decisions in networks around the world have tended to significantly enhance geomagnetic storm impacts. The result is an increase in vulnerability to space weather disturbances. Given the extensive impact geomagnetic storms can have on the electric grid and power supply, preventative measures that may mitigate the effect of these storms are important. According to the Atmospheric and Environmental Research, there are several steps that can be taken to harden the electric grid against geomagnetically induced currents, such as "neutral-current-blocking capacitors can be installed to block GIC from flowing into at-risk transformers, series-line capacitors can be installed on autotransformers, improvements can be made to the tripping techniques to avoid false tripping from GIC harmonics, and the utilisation of GIC monitors at transformers will ensure that current levels remain stable." [4,5]

Lloyd's 360° Risk Insight writes, "The ideal response to space weather risks is to build robust assets and systems that can operate through bad space weather conditions." As technology continues to advance, systems may become increasingly vulnerable to space weather phenomena. For example, operating without the use of GPS may present an increasing challenge to certain private companies and branches of critical infrastructure. However, utilizing high-quality satnav receivers can reduce signal loss. Engineering and operational awareness can assist in preparing for any interference resulting from space weather. [6]

Source List

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2. *Solar Activity & HF Propagation*. 2005 FDIM Symposium. https://www.qrparci.org/resource/FDIM81.pdf.
3. Allen, Joe & Frank, Lou & Sauer, Herb & Reiff, Patricia. *Effects of the March 1989 solar activity*. October 1989.
4. The Washington Post. *Solar Storm Risk to the North American Electric Grid.* Atmospheric and Environmental Research, Inc.

5. John Kappenman. *Geomagnetic Storms and Their Impact on the U.S. Power Grid*. January 2010.

6. Lloyd's 360° Risk Insight. *Space Weather: Its Impact on Earth and Implications for Business.*