SPACE WEATHER

For the purpose of this mitigation plan, the term Space Weather is used to describe conditions in the region of space close to the earth, especially the presence of electromagnetic radiation and charged particles emitted by the sun that can affect human activity and technology. According to NASA, the term space weather generally refers to conditions on the sun, in the solar wind, and within earth's magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems with the potential to endanger human life or health.

10.1 Identifying and Profiling Space Weather Hazards

Space Weather includes solar wind, solar flares, and coronal mass ejections, including any condition in outer space that impacts technology on earth. Heliophysics is the science of space weather.

ELECTROMAGNETIC PULSE (EMP)

An Electromagnetic Pulse (EMP) can be generated by weapons or can be caused by solar flares and storms (space weather) disrupting the earth's magnetic field. EMPs can impact a wide range of electronic systems and devices such as those found in control and communication systems on the power grid and global-positioning systems (GPS). Weaponry includes portable equipment that can generate high-energy bursts and be used in a simultaneous, coordinated attack. A high-altitude nuclear explosion represents the most comprehensive man-made EMP threat. The higher the altitude, the larger the area affected. The strength of the EMP is relative to the magnitude of the explosion. Effective mitigation against the impact of solar magnetic disturbances may be effective, to varying degrees, against non-nuclear EMP weaponry or a high-altitude nuclear explosion. In September 2016 the Federal Energy Regulatory Commission updated its reliability standards for geomagnetic disturbances as part of 18CFR Part 40.

For additional information specific to the North American Bulk Power System, refer to High-Impact, Low-Frequency Event Risk to the North American Bulk Power System, a jointly-commissioned summary report of the North American Electric Reliability Corporation and the U. S. Department of Energy.

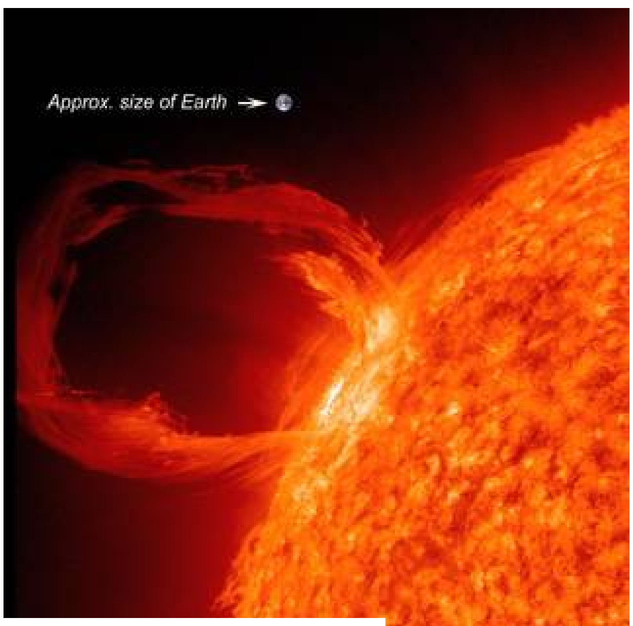
In the mid-1800's disruptions of the telegraph system by solar flares were recorded including one event on September 2, 1859 when telegraph service was disrupted for several days by a severe solar storm.[1]

When radio was invented in the early 1900's operators noticed that the sun interfered with radio transmissions.

A geomagnetic storm CME ejected from the sun on March 9, 1989 caused transformer failure and the collapse of the Hydro-Québec power network on March 13, 1989 leading to a nine hour blackout that affected over 6 million people.[2]

In the 1960's space weather caused problems including outages and loss of data for weather satellites. The term "space weather" was coined to define this solar activity.

Airlines fly over 7,500 polar routes per year to latitudes where satellite communication cannot be used and flight crews must rely on high-frequency (HF) radio to maintain communication with air traffic control, as required under federal regulations. The propagation of radio waves is affected by solar radiation resulting in radio blackouts that can last for several days, causing the necessity for aircraft to be diverted to latitudes where satellite communications can still be used. Changes in the ionosphere during geomagnetic storms also interferes with high-frequency radio communications, GPS navigation and radio communications for commercial airliners on transpolar crossing routes.



A solar eruptive prominence as seen in extreme UV light on March 30, 2010 with Earth superimposed for a sense of scale. Credit NASA/SDO

Spacecraft exposure to solar radiation causes temporary operational anomalies, damages critical electronics, degrades solar panels, and blinds optical systems including imagers and star trackers. Human and robotic expeditions across our solar system are impacted by solar radiation because surface-to-orbit and surface-to-surface communications are sensitive to space weather storms. No large scale solar energetic particle events have happened during a manned space mission but a large event happened on August 7, 1972, between the Apollo 16 and Apollo 17 lunar missions. The dose of particles that would have hit astronauts outside of

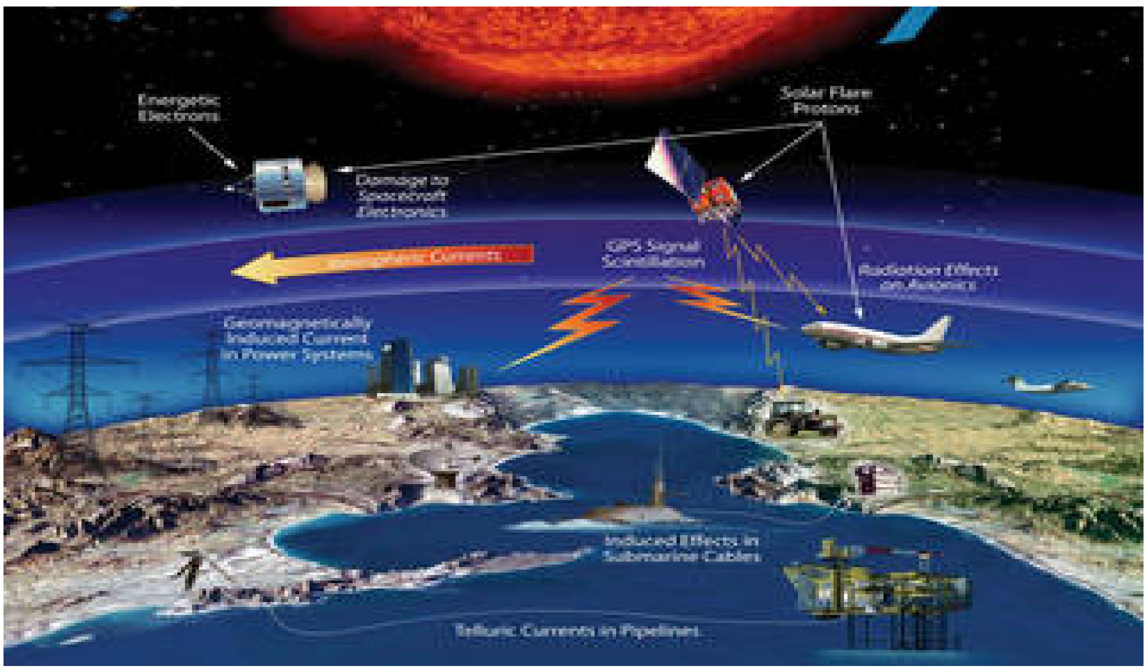
[1] https://www.nasa.gov/mission_pages/sunearth/spaceweather/index.html
[2] https://www.nasa.gov/topics/earth/features/sun_darkness.html

earth's protective magnetic field could have been life threatening. [3]

The sun our earth revolves around emits a continuous stream of plasma called solar wind and periodically releases billions of tons of matter called CME that cause large magnetic storms around our planet affecting earth's magnetosphere and upper atmosphere and disrupting our technology infrastructure.

Magnetic storms produce many noticeable effects on and near earth including:

- Aurora borealis, the northern lights, and aurora australis, the southern lights
- Communication disruptions
- Radiation hazards to orbiting astronauts and spacecraft
- Current surges in power lines
- Orbital satellite degradation
- Corrosion of oil pipelines



Technological infrastructure affected by space weather events.
Credit NASA

The earth's magnetosphere protects the population and our infrastructure from most of the particles the sun emits. When a CME high-speed stream of solar radiation bombards earth it buffets the magnetosphere and interacts strongly with the oppositely oriented magnetic field of the earth. The earth's magnetic field is then peeled open like an onion allowing energetic solar wind particles to stream down the field lines to hit the atmosphere over the poles. At the earth's surface a magnetic storm is observed as a rapid decrease in the earth's

[3] https://www.nasa.gov/topics/earth/features/sun_darkness.html

magnetic field strength lasting about 6 to 12 hours. The earth's magnetic field gradually recovers over a period of several days.

Aurora are a well-known example of the impacts of space weather events. ***Credit University of Alaska***

An aurora is a natural display of light in the sky that can be seen with the unaided eye at night. An auroral display in the Northern Hemisphere is called the aurora borealis, or the northern lights. A similar phenomenon in the Southern Hemisphere is called the aurora australis. Auroras are the most visible effect of the sun's activity on the earth's atmosphere. Auroral displays are associated with the solar wind, the continuous flow of electrically charged particles from the sun. When these particles reach the earth's magnetic field, some get trapped. Many of these particles travel toward the earth's magnetic poles. When the charged particles strike atoms and molecules in the atmosphere, energy is released. Some of this energy appears in the form of auroras. Auroras occur most frequently during solar maximum, the most intense phase of the 11-year solar or sunspot cycle. Electrons and protons released by solar storms add to the number of solar particles that interact with the earth's atmosphere. This increased interaction produces extremely bright auroras.

Most auroras occur in far northern and southern regions. The most common color in an aurora is green. But displays that occur extremely high in the sky may be red or purple. Most auroras occur about 50 to 200 miles above the earth. Some extend lengthwise across the sky for thousands of miles. Strong electrical currents along the earth's surface during auroral events disrupt electric power grids and causes the corrosion of oil and gas pipelines.

NASA operates a system observatory of heliophysics missions, utilizing the entire fleet of solar, heliospheric, and geospace spacecraft to monitor space. NASA's Heliophysics Division routinely partners with other agencies like NOAA satellites and some NASA scientific satellites to do space weather research and accomplish the operational objectives of the US. Space weather "beacons" on NASA spacecraft provide real-time science data to space weather forecasters. NASA will continue to cooperate with other agencies to measure conditions in space critical regions for both operational and scientific research.

To facilitate and enable this cooperation, NASA's makes its Heliophysics research data sets and models continuously available to industry, academia, and other civil and military space weather interests via existing internet sites. These include the Combined Community Modeling Center (CCMC) and the Integrated Space Weather Analysis System (ISWA), both are associated with NASA's Goodard Space Flight Center (GSFC). There are also websites and apps available to the public.

The forecast center in NOAA's Space Weather Prediction Center in Boulder, CO.
Credit NOAA SWPC

NOAA's Space Weather Prediction Center (SWPC) is the nation's official source of space weather alerts, watches and warnings responsible for sending alerts when solar and geophysical events are occurring. It provides real-time monitoring and forecasting for the SWPC as part of the National Weather Service and one of the nine National Centers for Environmental Prediction.

A multiagency organization responsible for tracking the progress of the National Space Weather Program has also been created to facilitate interagency coordination in space weather activities through the Committee on Space Weather hosted by the Office of the Federal Coordinator for Meteorology and co-chaired by representatives from NASA, NOAA, DoD, and NSF.

Forecasting space weather requires data analysis and the use of numerical models to accurately predict changes in the earth's space environment. A good space weather forecast begins with a thorough analysis of ground and space-based observations to assess the current state of the solar-geophysical environment from the Sun to the Earth. Space weather forecasters analyze the 27-day recurrent pattern of solar activity, analyze current conditions, and compare them to past situations using numerical models similar to weather models to predict space weather in hours and weeks.

As society's reliance on technological systems grows, so does our vulnerability to space weather. The ultimate goal in studying space weather is to develop the ability to foretell events and conditions on the Sun before they reach Earth to warn the public and affected infrastructure about space weather events that may produce potentially harmful effects on society and the economy. If we can create a warning system with sufficient advanced notice and reliable accuracy then preventive or mitigating actions can be taken.

Solar flares affect the ionosphere immediately, with adverse effects upon communications and radio navigation. Solar energetic particles arrive in 20 minutes to several hours and threaten the electronics of spacecraft and unprotected astronauts. Ejected bulk plasma and its magnetic field arrive in 30 to 72 hours setting off a geomagnetic storm and causing currents to flow in the magnetosphere and particles to be energized causing atmospheric heating and increased drag for satellite operators and damage to spacecraft electronics. The energetic particles adversely affect pipelines, communications and radio navigation and electric power grids.

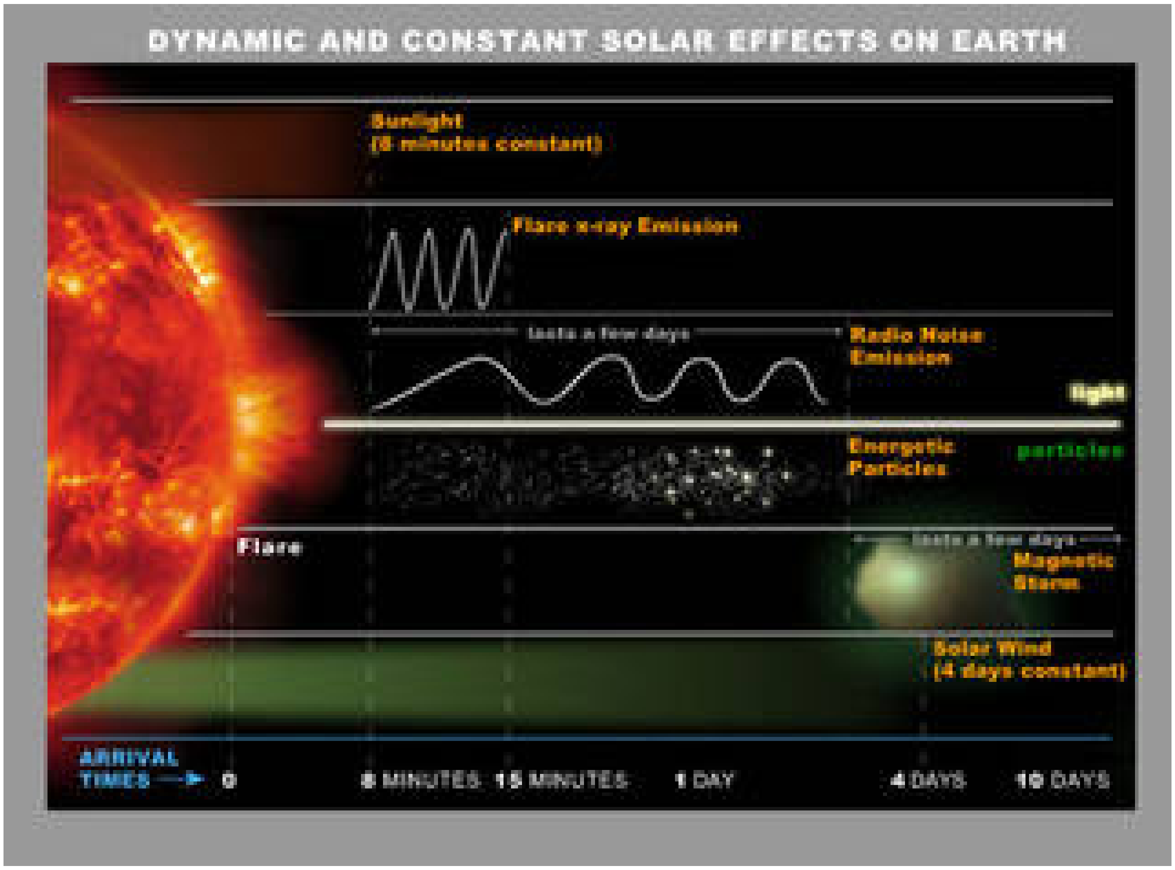


Illustration of the various dynamic and constant solar effects on Earth. The two solar constants, sunlight and solar wind, takes 8 minutes and 4 days, respectively, to reach Earth. Arrival times of dynamic solar events such as Flares, solar energetic particles and CMEs, are approximated and range from immediate effect to several days.
Credit NASA/Berkley

10.2 Assessment of Local Space Weather Vulnerability and Potential Losses

No assessments of local space weather vulnerability and potential losses in Utah counties have been conducted. However, as space weather can have widespread effects a list of state facilities and their insured values is listed below.

Table 1. State-Owned Facilities and Insured Value

County	Count Facilities	Insured Value of Facilities
Beaver	35	$41,032,093
Box Elder	200	$298,041,925
Cache	613	$3,340,693,369
Carbon	113	$162,484,250

Daggett	20	$3,415,881
Davis	278	$1,393,256,017
Duchesne	72	$37,934,210
Emery	108	$41,071,459
Garfield	59	$20,808,298
Grand	81	$62,763,853
Iron	224	$490,154,483
Juab	41	$13,469,125
Kane	51	$15,679,404
Millard	78	$94,808,959
Morgan	48	$25,152,828
Piute	23	$4,841,000
Rich	84	$11,160,077
Salt Lake	1,463	$7,274,528,270
San Juan	111	$111,325,088
Sanpete	204	$437,926,899
Sevier	135	$209,506,871
Summit	128	$158,297,671
Tooele	89	$296,471,019
Uintah	117	$262,341,461
Utah	577	$2,272,452,584
Wasatch	178	$104,105,879
Washington	215	$620,545,353
Wayne	33	$4,730,187
Weber	317	$1,267,926,750
Total	5,695	$19,076,925,263

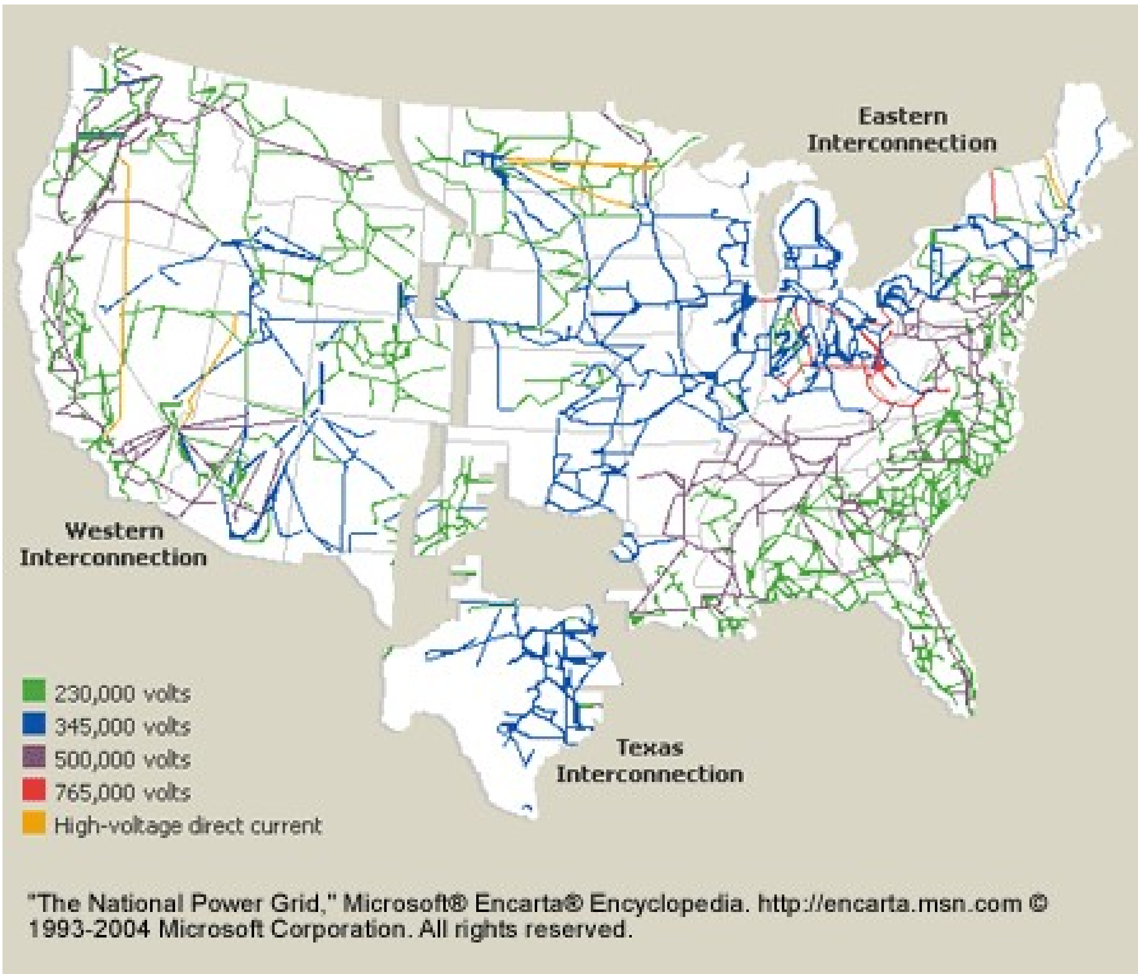
10.3 Assessment of State Space Weather Vulnerability and Potential Losses

No state assessment of space weather vulnerability and potential losses has been conducted, but the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack published a report about the US's critical national infrastructure vulnerability in April 2008. Specific mitigation measures for the electric industry were recommended by the Commission in their report including:

*Protecting high-value assets through hardening
*Providing adequate communication assets dedicated or available to electrical system operators
*Securing the use of emergency power supplies and fuel delivery and providing for their sustained use as part of the protection of critical loads

*Separate the present interconnected systems, specifically the Eastern Interconnection, into several nonsynchronous connected sub-regions or electrical islands
*Install substantially more black start generation units coupled with specific transmission that can be readily isolated to balancing loads
*Improve, extend, and exercise recovery capabilities

The National Power Grid

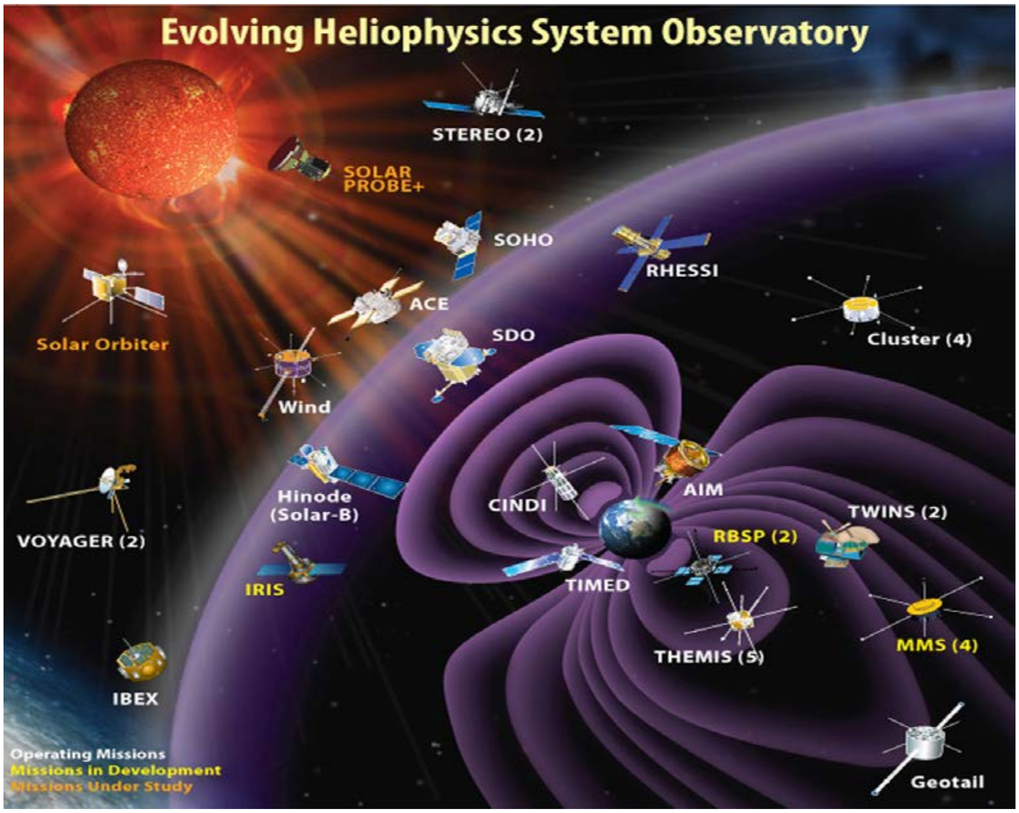


Source Energy.gov

Geomagnetic storm and EMP events have the potential to damage electronic equipment throughout North America's critical infrastructure specifically high voltage transformers, power systems and Supervisory Control and Data Acquisition (SCADA) systems. Upgrading the country's infrastructure will be expensive and require substantial time and financial resources as NERC works to coordinate various planning and mitigation actions with North American governmental authorities and other critical infrastructure sectors.

10.4 Mitigation Efforts for Space Weather Hazards

Sunlight sustains life but it also produces radiation and magnetic energy that can disrupt our satellites and communication equipment. NASA studies space weather in order to send spacecraft and astronauts through it safely. Extreme space weather can interfere with our communications, satellites and power grids, so NASA's heliophysics division studies the sun's 11-year solar cycle, solar flares, CMEs, and the solar wind. NASA maintains a fleet of Heliophysics spacecraft to monitor the sun, geospace, and the space environment between the Sun and the Earth.



The Heliophysics System Observatory (HSO) showing current operating missions, missions in development, and missions under study.
Credit NASA/Goddard

The national weather service and NOAA have a space weather prediction center under the national oceanic and atmospheric administration. The Space Weather Prediction Center (SWPC) provides alerts, watches and warnings to the public about the severity of the solar activity expected to impact the earth's environment. Understanding how the geospace region around the earth responds to a variety of solar drivers is the key to predicting space weather.

NASA cooperates with other U.S. agencies to enable new knowledge in studying the sun and its processes. To facilitate and enable this cooperation, NASA's Heliophysics Division makes its vast research data sets and models publicly available online to industry, academia, and other civil and military space weather interests. Also provided are publicly available sites for citizen science and space situational awareness through various cell phone and e-tablet applications.

The national weather service and NOAA have a space weather prediction center under the national oceanic and atmospheric administration. The Space Weather Prediction Center (SWPC) provides alerts, watches and warnings to the public about the severity of the solar activity expected to impact the Earth's environment.