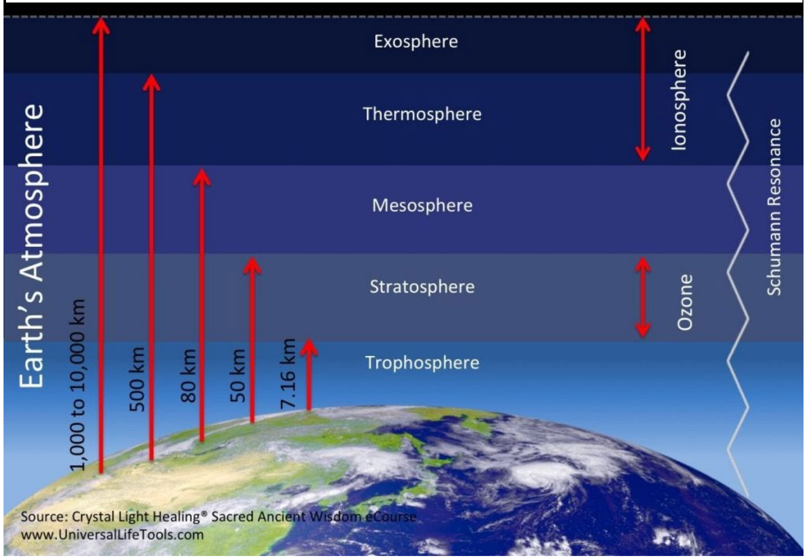
4.12 SPACE WEATHER

4.12.1 Description

NASA defines space weather as encompassing a range of phenomena occurring on the Sun, within the solar wind, and throughout the Earth's magnetosphere, ionosphere, and thermosphere. The adverse effects of space weather on technological systems have the potential to pose risks to human life and health. Examples of space weather phenomena include solar flares, solar wind, and coronal mass ejections, as well as any other extraterrestrial events that may impact Earth's technological infrastructure. The study of space weather is known as heliophysics.

The official source of space weather forecasts and warnings is NOAA's Space Weather Prediction Center (SWPC), which is responsible for issuing alerts during solar events. The SWPC leverages a range of solar-observing instruments on board satellites, such as NASA's Solar Dynamics Explorer and the NASA/European Space Agency Solar and Heliospheric Observatory, in addition to a wealth of other observations from ground-based magnetometers operated by the US Geological Survey and other partners. With these resources, the SWPC runs sophisticated models that enable the prediction of the arrival, duration, and severity of solar-generated storms.

Figure 4-111 Layers of the Earth's Atmosphere



Source: Crystal Light Healing® Sacred Ancient Wisdom eCourse
www.UniversalLifeTools.com

While space weather forecasting is still an evolving field, the SWPC has demonstrated the ability to provide accurate and timely warnings of space weather events, such as solar flares and coronal mass ejections. These warnings can help protect infrastructure and personnel that could be affected by space weather, such as power grids and astronauts on spacewalks. That being said, space weather is a complex and unpredictable phenomenon, and there are limitations to the accuracy of current forecasting capabilities.

4.12.2 Geographic Area

The entirety of the State is potentially exposed to space weather events, which typically occur on a regional scale.

4.12.3 Extent/Magnitude

Solar activity associated with space weather can be divided into four main components: solar flares, coronal mass ejections, high-speed solar wind, and solar energetic particles.

- **Solar flares** affect the ionosphere immediately, with adverse effects upon communications and radio navigation. Solar energetic particles reach the Earth within 20 minutes to several hours and threaten the electronics of spacecraft and any unprotected astronauts. Ejected bulk plasma and its magnetic field arrive in 30 to 72 hours, setting off a geomagnetic storm, causing currents to flow in the magnetosphere, and energizing particles. The currents cause atmospheric heating and increased drag for satellite operators; they also induce voltages and currents in long conductors at ground level, adversely affecting pipelines and electric power grids. The energetic particles cause auroras, as well as surface and deep dielectric charging of spacecraft. The subsequent electrostatic discharge of the excess charge build-up can damage spacecraft electronics. As the ionosphere departs from its normal state due to the currents and the energetic particles, it adversely affects communications and radio navigation.

- **Coronal mass ejections** (CMEs) are bubbles of gas and magnetic fields that are suddenly and violently released from the confined solar atmosphere of the sun, structured by strong magnetic fields in the outer solar atmosphere, known as the corona. When a large CME occurs, it can contain a billion tons of matter that is accelerated to several million miles per hour in a spectacular explosion. As a result, solar material streams out, impacting any planet or spacecraft in its path. While CMEs are sometimes associated with flares, they can also occur independently.
- **Solar wind** is a stream of charged particles emitted by the Sun that interacts with Earth's magnetosphere, a natural shield that protects our planet and its infrastructure from the majority of solar particles. When a high-speed stream of solar radiation, like a CME, occurs, the magnetosphere interacts with the oppositely oriented magnetic field of the Earth, peeling open the Earth's magnetic field. This allows energetic solar wind particles to stream down the field lines and impact the Earth's atmosphere over the poles. When these particles collide with atoms and molecules in the atmosphere, energy is released, resulting in the appearance of auroras. The result is a magnetic storm, which manifests as a rapid decrease in the Earth's magnetic field strength lasting around 6 to 12 hours, followed by a gradual recovery period of several days. Strong electrical currents along the Earth's surface during auroral events can disrupt electric power grids or cause corrosion of oil and gas pipelines.

Figure 4-112 The Aurora Borealis

Credit: University of Alaska, Fairbanks

- **Solar energetic particles** are high-energy charged particles believed to be mainly released by shocks formed at the front of CMEs and solar flares. When a CME cloud plows through the solar wind, high-velocity solar energetic particles can be produced. Since solar energetic particles are charged, they are constrained to follow the magnetic field lines that pervade the space between the Sun and the Earth. Therefore, only the charged particles that follow magnetic field lines intersecting with the Earth will result in impacts. Solar energetic particles pose a threat to spacecraft electronics and unprotected astronauts.

An additional hazard from space weather is the generation of an electromagnetic pulse (EMP), which can occur as a result of the interaction between the Earth's magnetosphere and solar wind or a CME from the Sun. An EMP could also be the result of a targeted weapons attack, although no such case has been documented. The impacts of EMPs can extend to a broad range of electronic systems and devices, including those utilized in control and communication systems on the power grid and global positioning systems (GPS). Mitigation strategies that are effective against the effects of solar magnetic disturbances may also have varying degrees of effectiveness in protecting against non-nuclear EMP weaponry or a high-altitude nuclear explosion. In September of 2016, the Federal Energy Regulatory Commission updated its reliability standards for geomagnetic disturbances, as outlined in 18CFR Part 40.[25]

A range of indices are utilized to measure space weather. These include the sunspot number, geomagnetic indices, solar wind parameters (density and speed), flare index, solar x-ray flux, and others. Among the most commonly utilized indices are the smoothed sunspot number (SSN) and the geomagnetic planetary A index (Ap). It is important to note, however, that while SSN values range from zero to over 300 and are used to indicate solar activity, they do not necessarily signify activity with respect to flares and CMEs. The Ap index gives a measure of the storminess of the Earth's magnetic field. Ap may range from 0 to about 400.

Table 4-88 below indicates the level of solar activity as the sunspot number changes.

Table 4-88 SSN Scale and Corresponding Solar Activity Levels

SSN	Solar Activity
>250	Extreme
150-250	Very High
80-150	High
40-80	Moderate
20-40	Low
0-20	Very Low

Source: https://www.swpc.noaa.gov/products/predicted-sunspot-number-and-radio-flux

Table 4-89 below indicates the level of geomagnetic activity as the value of Ap changes.

Table 4-89 Ap Scale and Corresponding Geomagnetic Activity Levels

Ap	Geomagnetic Activity
>100	Severe Storm
50-99	Major Storm
30-49	Minor Storm
16-29	Active
8-15	Unsettled
0-7	Quiet

Source: https://www.swpc.noaa.gov/products/station-k-and-indices

Table 4-90 below indicates the level of geomagnetic activity as the value of the Kp-Index changes.

Table 4-90 The Planetary K-Index

Kp-Index	Descriptor	Effect(s)
0-4	Calm or small geomagnetic disturbance	No effect on devices or people

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[25] 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.

Kp-Index	Descriptor	Effect(s)
5	Weak/minor geomagnetic storm	Weak fluctuations in the electrical grid, minor effects on the operation of space satellites, as well as on the migration of animals are quite possible
6	Moderate geomagnetic storm	Power systems located at high latitudes can experience emergency situations. Prolonged geomagnetic storms can damage transformers. High-frequency radio signals may weaken.
7	Strong geomagnetic storm	False alarms may be triggered on some protective electronic devices. Correction of satellite orientation and navigation in outer space may be required
8	Severe geomagnetic storm	There may be widespread problems with power grid voltages. Satellite navigation may worsen for several hours, and low-frequency radio navigation may be disrupted
9	Extreme geomagnetic storm	Power systems may experience transformer damage and a complete collapse. High frequency radio communications may not be possible. Satellite navigation may be disrupted

Source: https://www.swpc.noaa.gov/sites/default/files/images/NOAAscales.pdf

4.12.4 Past Occurrences

There have been several recorded instances of space weather interfering with electric grids and satellites.

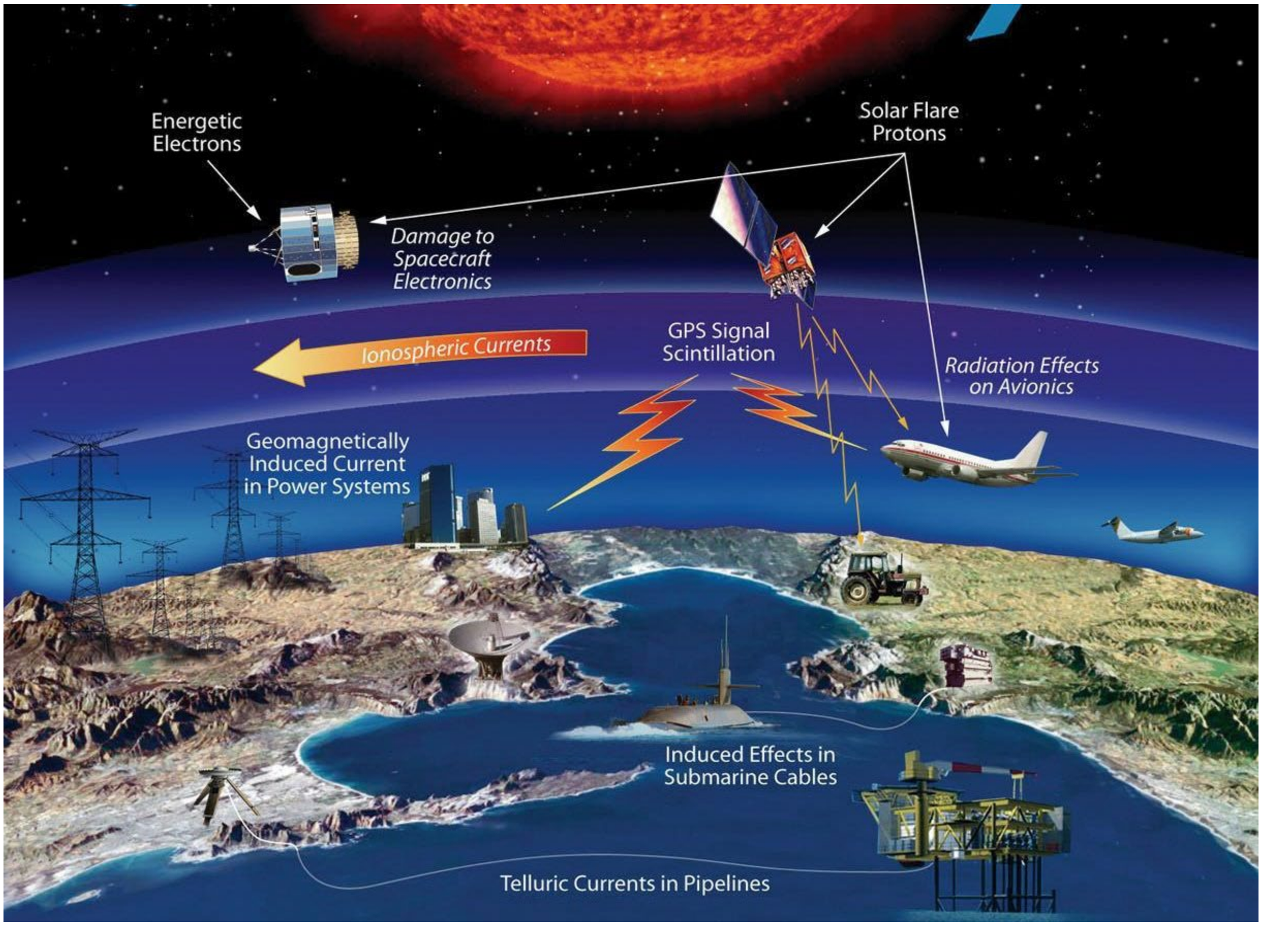
A powerful geomagnetic storm, known as the Carrington Event, occurred on September 2, 1859, when a CME hit the Earth's magnetosphere. Many telegraph systems across Europe and North America were disrupted or completely knocked out of service due to induced electric currents. Telegraph operators reported sparks and shocks, and in some cases, their equipment caught fire. Aurora displays were visible as far south as the Caribbean, and in some places, the auroras were so bright that they cast shadows at night. Some compasses even malfunctioned, and there were reports of unusual magnetometer readings. The event was named after the astronomer Richard Carrington, who observed the solar flare that caused the event. It is considered the largest geomagnetic storm in recorded history.

The space weather storm of May 1967 was a major solar event that occurred. On May 23, a powerful solar flare erupted from the Sun, producing intense bursts of X-rays and radio waves. The flare was so strong that it caused radio blackouts and communication disruptions around the world, and even caused some electrical power outages. Subsequently, record-setting geomagnetic and ionospheric storms compounded the disruptions.

The August 1972 solar storms were a series of powerful space weather events that were triggered by a massive solar flare that erupted from the Sun on August 4, 1972. The resulting CME arrived at the Earth's magnetosphere on August 5, the fastest CME transit time recorded, triggering a severe geomagnetic storm that caused widespread disruption to radio communications and power systems, causing electrical power outages in the northeastern United States and in parts of Canada. In addition to the geomagnetic storm, the event also produced a high-energy proton event that was detected by several spacecraft. The proton event caused several malfunctions in satellite and spacecraft electronics, including the loss of several high-altitude reconnaissance satellites. The dose of particles that would have hit astronauts on August 7, 1972, if there had been a mission outside of Earth's magnetic field, had the potential to be life threatening. Additionally, severe technological disruptions caused accidental detonation of numerous magnetic-influence sea mines.

On March 13, 1989, a severe geomagnetic storm was caused by a CME that had been released by the Sun on March 9th. When the CME arrived at the Earth, it interacted with the planet's magnetic field, causing it to fluctuate rapidly. The resulting geomagnetic storm caused a series of power outages in the Canadian province of Quebec, leaving over 6 million people without electricity for nine hours. In addition to the power outages, the storm also caused disruptions to radio communications and satellite operations. Several satellites were temporarily shut down, and some experienced permanent damage to their electronics.

Figure 4-113 Technological Infrastructure Affected By Space Weather Events



Credit: NASA

4.12.5 Probability

Space weather events occur regularly, but their frequency and severity vary depending on the activity of the Sun. The Sun goes through a roughly 11-year cycle of activity, with periods of high activity (known as the solar maximum) and low activity (the solar minimum). During the solar maximum, the Sun is more active and produces more space weather events. During the solar minimum, the Sun is less active, and these events are less frequent. During periods of low activity, space weather events can still occur and impact Earth. However, the likelihood and severity of these events are generally lower than during the solar maximum.

According to the Solar Cycle 25 Prediction Panel, co-chaired by NOAA and NASA, the solar minimum between Solar Cycle 24 and 25 happened in December 2019 when the 13-month smoothed sunspot number fell to 1.8 (NOAA 2020). Thus, began Solar Cycle 25, with peak sunspot activity expected in July 2025. Solar Cycle 24 was average in length at 11 years and had the fourth-smallest intensity since regular record-keeping began with Solar Cycle 1 in 1755. It was also the weakest cycle in 100 years. Solar maximum occurred in April 2014 with sunspots peaking at 114 for the solar cycle, well below average, which is 179. Solar Cycle 25 is forecast to be a fairly weak cycle, the same strength as cycle 24, with a solar maximum peak of 115 sunspots.

The effect of climate change on the probability of space weather is discussed in Section 4.12.6 *Climate Change Considerations*. Discussion of the populations likely to be most severely impacted is provided in Section 4.12.8 *Vulnerability of Jurisdictions*, specifically in the subsection titled *Population Impacts*.

4.12.6 Climate Change Considerations

There are two possible ways in which climate change and space weather can interact: space weather can influence the effects of climate change, and climate change can influence the effects of space weather.

Space weather can affect climate change through gradual or sudden factors. Many of the gradual types of space weather factors are linked to cloud formation. Cosmic rays can affect cloud formation by ionizing the atmosphere and influencing chemical processes (Dorman, 2009). Clouds are essential to the Earth's climate system as they have a significant impact on the energy budget, water cycle, and transport of trace gases and aerosols through precipitation. Clouds cool the planet on average, and any alteration in cloud amount or distribution could thereby affect the climate.

The sudden space factors that may affect climate change include supernova explosions and asteroid impacts, which would likely be catastrophic to our civilization. Recent observations of binary pulsars Geminga and PSR J0437–4715, and of supernova SN 1987A, strengthen the hypothesis that one or more supernova extinctions have occurred during the Phanerozoic era (Dorman, 2009). A nearby supernova explosion would result in depletion of the ozone layer, exposing both marine and terrestrial organisms to lethal solar UV radiation. Photosynthesizing organisms, such as phytoplankton and reef communities, would be especially vulnerable to such exposure.

Ways in which climate change affects the Earth’s susceptibility to space weather are not well understood. However, it is likely that the effects climate change has had, and will continue to have, on the Earth’s magnetic field and atmosphere will make the Earth more susceptible to space weather. Courtilt and others (2007) observed correlations between changes in climate and magnetic field variations. Such variations could weaken the protective influence of the Earth’s magnetic field and make it more vulnerable to the effects of space weather. In addition, climate change also affects the composition of the Earth's atmosphere. Changes in GHG concentrations, for example, can lead to changes in temperature and circulation patterns in the atmosphere. These changes can affect the behavior of the ionosphere, potentially weakening the Earth’s resistance to space weather events (Laštovička et al., 2008).

4.12.7 Vulnerability of State Assets

No assessments of local space weather vulnerability and potential losses in Utah counties have been conducted. Space weather can have widespread effects, but it is difficult to predict a specific loss estimate. As a planning-level assessment of exposure and potential future dollar loss to potential space weather events a list of 13 Utah Communications Authority facilities and their insured values are listed below. These facilities related to communications may have the highest vulnerability to a significant space weather event. Impacts of space weather could potentially create temporary disruptions in state communication infrastructure and possible continuity of services ramifications. As noted previously there is much uncertainty with the impact of climate change on space weather, so vulnerability of state assets is not likely to change.

Table 4-91 State-Owned Communication Facilities and Insured Value

COUNTY	ASSET NAME	VALUE
Box Elder	Dunn Peak	$1,000
Daggett	Telecommunications - Dutch John	$6,840
Iron	New Harmony	$83,833
Juab	Levan Peak	$69,232
Kane	Spencers Bench	$86,338
Kane	Big Water Microwave Tower	$32,458
Kane	Vermillion Cliffs	$65,465
Salt Lake	Jordan Aqueduct	$174,691
Sevier	Monroe Peak Communication	$169,605
Tooele	Telecommunications - Delle	$44,830
Utah	Ford Ridge Comm. Building	$19,770
Washington	Hurricane Mesa	$82,731
Weber	ITS Communications Building	$112,000
	Total Value	**$948,793**

Source: Utah Division of Risk Management, WSP Analysis

4.12.8 Vulnerability of Jurisdictions

Only a few LHMPs addressed space weather in their HIRAs. Iron County (in the Five County Plan) has two cities that mention solar storms: Enoch City has a brief section on solar storms within their Severe Weather section, and Cedar City mentions it within one of their mitigation steps. The Mountainland AOG Plan (which covers Summit, Utah, and Wasatch Counties) identifies solar flares as a hazard at the start of their Hazard Identification and Analysis section). However, the plan does not select solar flares as a hazard in the plan and it does not appear elsewhere.

Space weather is not a hazard addressed in FEMA's NRI.

Population Impacts

While research of the effects of space weather to human health is a developing field, there are some indications that suggest a positive correlation between space weather anomalies and biological reactions. Several studies have found statistical significance between the influence of geomagnetic activity levels and higher rates of leukemia, higher blood pressure, increases in depression, and severe migraine attacks, among other conditions (Mavromichalaki et al., 2016) (Unger, 2019) (Vencloviene and Babarskiene, 2016) (Zenchenko and Breus, 2021). These impacts are likely to be more pronounced in unprotected astronauts than those on earth. In addition, people with compromised immune systems may be more susceptible. Evaluation of population impacts is complicated by a poor understanding of how, or if, exposure is variable across the state.

Whatever the exposure of space weather, the impacts are not experienced the same by all people. For any specific exposure, vulnerable populations tend to experience impacts more severely (see Section 3.5.1). People in counties with high social vulnerability (Figure 3.6, and 3.7) are likely to be more vulnerable to negative impacts. Piute and San Juan Counties are the greatest concern in this regard, while persons in Carbon, Garfield, Grand, Kane, and Washington Counties are of marginally lower concern. Additional and more detailed information on populations within each county likely be most affected to specific hazards is typically left to local analyses, especially county hazard mitigation plans.

Additional study at a local level may not be warranted at this point. State-level analysis of niche hazards such as space weather is especially useful to identify that problems likely exist. It is not clear that this has been established. If anything, local monitoring, especially local monitoring of vulnerable populations, can help provide data points for state officials to verify if space weather is a significant hazard or problem.

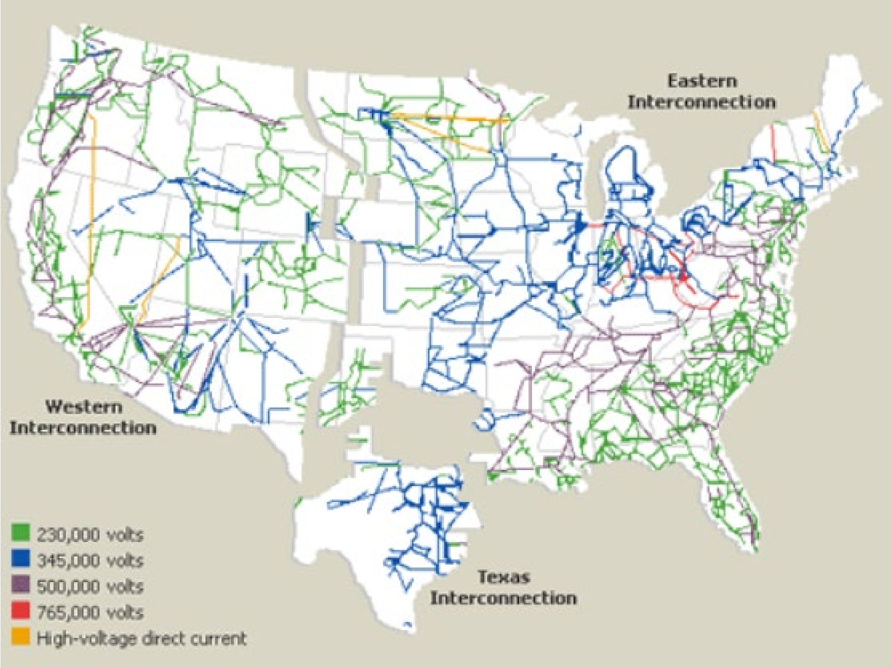
Community Lifelines and Infrastructure

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, and to be able to warn the public 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 preventative or mitigating actions can be taken.

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 radio to maintain communication with air traffic control, as required under federal regulations. Changes in the ionosphere during geomagnetic storms can interfere with these high-frequency radio communications, GPS navigation, and radio communications for commercial airliners. The propagation of radio waves is affected by solar radiation, which can cause radio blackouts that can last for several days and the necessity for aircraft to be diverted to latitudes where satellite communications can still be used. A summary of local critical facilities/lifelines provided in Section 4.3 indicates there are 523 communications lifelines exposed across the counties in Utah.

Geomagnetic storms 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. It's hard to overstate how dependent modern society is on electricity. Electricity powers almost every aspect of our daily lives, from our homes and workplaces to transportation and communication systems. Hardening the country's infrastructure against space weather will be expensive and require substantial time and financial resources.

Figure 4-114 The National Power Grid



Credit: US Department of Energy

4.12.9 Changes in Development

Space weather poses a significant, though remote, risk for future development, especially for communication and power systems. To mitigate the impact of space weather events, future development must consider redundancy in critical systems. All critical facilities, including power grids and communication networks, should consider including backup power and communication systems. In addition, the implementation of advanced warning systems and protocols for space weather events can help organizations prepare for and respond to potential disruptions.

An analysis of development trends in LHMPs (see Section 3.7 Development Trends) did not yield any specific concerns with space weather,

Certain technological advancements and infrastructure developments on Earth can influence how space weather impacts our technological systems. For instance, large geomagnetic storms, often associated with space weather events, can induce electric currents in power lines and disrupt communication networks. Changes in the development and expansion of power grids and communication infrastructure may influence vulnerability to space weather-related disruptions.