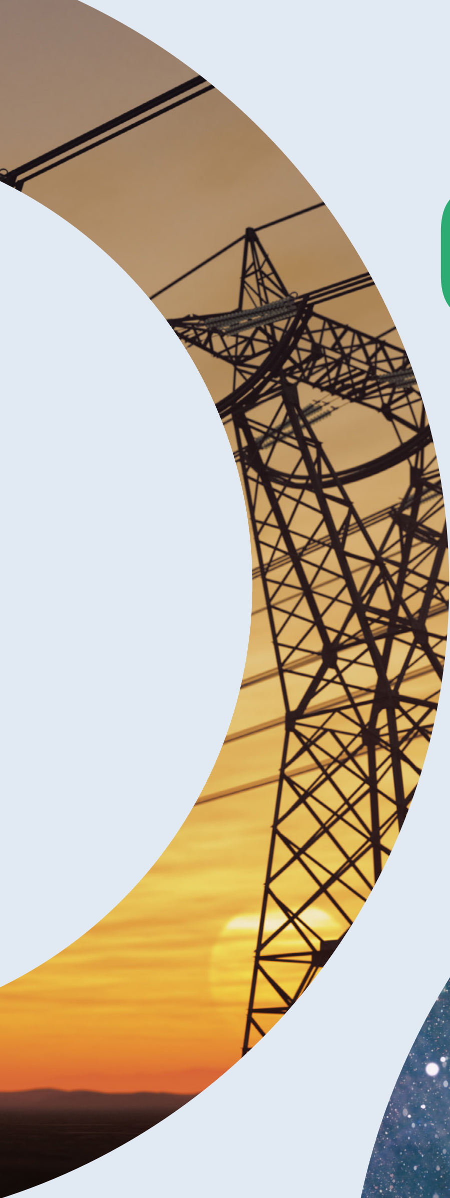

COMMENTARY PAPER

EFI GLOBAL

Electric weather poses a significant threat to electrical systems and infrastructure

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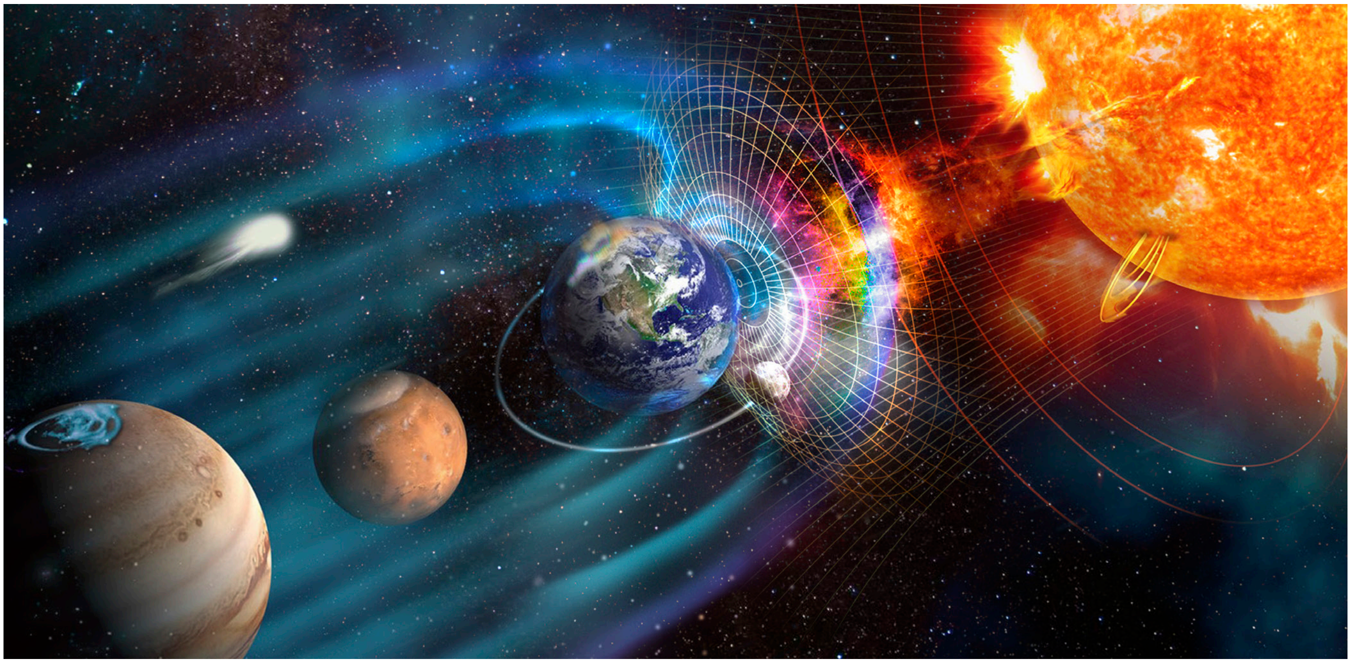


A looming threat to infrastructure

The Earth is a dynamic and ever-changing entity, constantly influenced by the interplay of various natural forces. Solar wind is amongst these forces and is formed by a continuous stream of charged particles emanating from the sun, which interacts with the Earth's magnetic field and upper atmosphere. This interaction, known as "solar wind coupling", can give rise to a phenomenon called "electric weather", a term that encompasses a range of space weather events with the potential to wreak havoc on our electrical systems and infrastructure on a local, regional, and global scale.

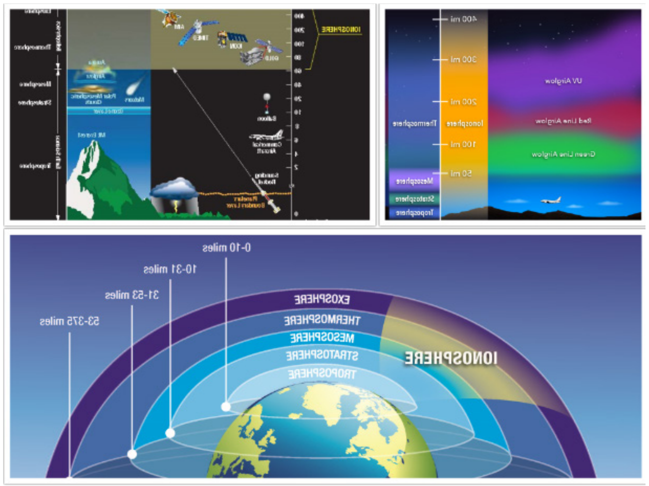
Electric weather is a complex and multifaceted phenomenon that encompasses various processes, including geomagnetically induced currents (GICs), penetrating electric fields, and cosmic ray cascades. These processes — driven by the dynamic interplay between the solar wind and the Earth's magnetosphere — can have far-reaching consequences, from disrupting power grids and communication networks to damaging sensitive electronics and posing radiation hazards.

Geomagnetically induced currents: the silent threat

One of the most significant aspects of electric weather is the formation of geomagnetically induced currents. These currents are generated when fluctuations in the Earth's magnetic field — caused by solar wind disturbances — induce electric currents in long conductors, such as power lines, pipelines, and telecommunication cables.

GICs can wreak havoc on electrical systems in several ways. In power grids, they can cause transformer saturation, leading to increased reactive power demand, harmonic distortion, and, in extreme cases, permanent damage to transformers or other equipment. This can result in widespread power outages, potentially affecting millions of people and causing significant economic losses.

Transformer saturation - A transformer is like a sponge that soaks up electricity. When too much electricity flows through it during an electric weather event, it's like forcing too much water into the sponge. The transformer gets overwhelmed and can't work properly, just like a soaked sponge. This is called transformer saturation, and it can cause the transformer to overheat and, if it goes on for too long, result in damage and ultimately failure.



Credit: NASA Scientific Visualization Studio

Moreover, GICs flowing through pipelines can accelerate corrosion rates, increasing the risk of leaks or failures. This poses a significant threat to the integrity of our energy infrastructure, as well as potential environmental hazards.

The spatial variations in the strength and direction of GICs add an extra layer of complexity, as these currents can vary significantly across geographic regions due to differences in the Earth's conductivity structure, the orientation of conductors, and the characteristics of the geomagnetic disturbance.

Penetrating electric fields: ionospheric disruptions

Another critical aspect of electric weather is the penetration of electric fields into the Earth's upper atmosphere and ionosphere. The ionosphere is a layer of the Earth's upper atmosphere that is filled with electrically charged particles, called ions. Think of it as an invisible blanket wrapped around our planet, starting about 60 miles above the surface and extending up to 600 miles high. When charged particles from the sun, known as the solar wind, collide with the Earth's magnetic field, some of these particles are channeled down towards the magnetic poles. There, they crash into the ionosphere, causing the atoms and molecules to become excited and release energy in the form of light. This creates the beautiful, colorful displays of the aurora borealis (northern lights), and the aurora australis (southern lights) in the night sky, with oxygen creating green and red light, while nitrogen glows blue and purple.

As noted, during certain space weather events, such as when the interplanetary magnetic field (IMF) has a strong southward component, electric fields can map down along the Earth's magnetic field lines and penetrate the ionosphere. These penetrating electric fields can cause various disturbances in the ionosphere, including the generation of plasma instabilities, irregularities in ionospheric density, and the formation of ionospheric currents. These disturbances can have far-reaching impacts on various technologies that rely on the ionosphere, such as high-frequency (HF) radio communications, satellite navigation systems (i.e., GPS), and over-the-horizon radar systems.

Cosmic ray cascades: the hidden radiation hazard

While not directly related to solar wind coupling, cosmic ray cascades, also known as cosmic ray air showers, are another aspect of electric weather that cannot be ignored. These cascades occur when high-energy cosmic rays — primarily protons or heavier atomic nuclei — interact with the Earth's atmosphere, producing a shower of secondary particles, including muons, which can penetrate deep underground.

Consider this example: Imagine a cosmic ray, which is a highly energetic particle from space, zooming towards Earth at nearly the speed of light. When this cosmic ray collides with the Earth's atmosphere, the high-speed crash shatters the particle into many smaller pieces called secondary particles. These secondary particles, including muons (which are analogous to heavy electrons), continue to race downwards, creating a cascade or "shower" of particles. The cascade of particles can be so powerful that some of them, especially the muons, can pass through buildings and even reach deep underground. This phenomenon is called a cosmic ray cascade or cosmic ray air shower, and it's a fascinating example of how particles from the far reaches of the universe can interact with our planet's atmosphere, creating a unique form of "electric weather".

Cosmic ray cascades pose a radiation hazard to personnel and electronics in underground facilities, such as mines, particle physics experiments, and other subterranean structures. Furthermore, they can influence atmospheric chemistry and ionization levels, potentially affecting radio communication and navigation systems.

The global electric circuit: a delicate balance

To fully understand electric weather, it is essential to consider the global electric circuit, a vast atmospheric electrical pathway that allows the continuous flow of electric currents between the Earth's surface and the ionosphere. This circuit is driven by thunderstorm activity and maintains a potential difference (voltage) between the Earth's surface and the ionosphere, which serves as the two "electrodes" of the circuit.

Disturbances in the global electric circuit can have far-reaching consequences, affecting atmospheric electricity, lightning, and even cloud formation processes. Changes in the circuit's dynamics can influence atmospheric chemistry and potentially contribute to climate change.

Differentiating electric weather damage from lightning strikes

While both electric weather phenomena and lightning strikes can cause damage to electrical systems and infrastructure, the nature of the damage and its manifestation can differ significantly.

Lightning strikes typically cause localized, intense damage due to the extremely high currents and voltages involved. Common signs of lightning damage include burn marks or pitting on metal surfaces where the lightning arc attached, melted, or vaporized components along the lightning path, punctured holes in enclosures or insulation, and severe physical damage to insulators, conductors, and other components in the lightning's path.

In contrast, damage from electric weather events, particularly those involving geomagnetically induced currents, tends to be more widespread and less localized. Instead of intense physical damage, the effects are usually seen in larger electrical systems rather than individual components. Typical signs of GIC-related damage include overheating and insulation breakdown in transformers, reactors, and other wound com ponents, increased corrosion or erosion in pipelines, tripping of protective relays or circuit breakers due to abnormal currents or voltages, and saturation of transformers leading to increased reactive power demand and potential voltage instability.

While lightning strikes cause immediate, intense physical damage, the effects of electric weather events can be more gradual and may manifest over time through accelerated aging or degradation of electrical systems.

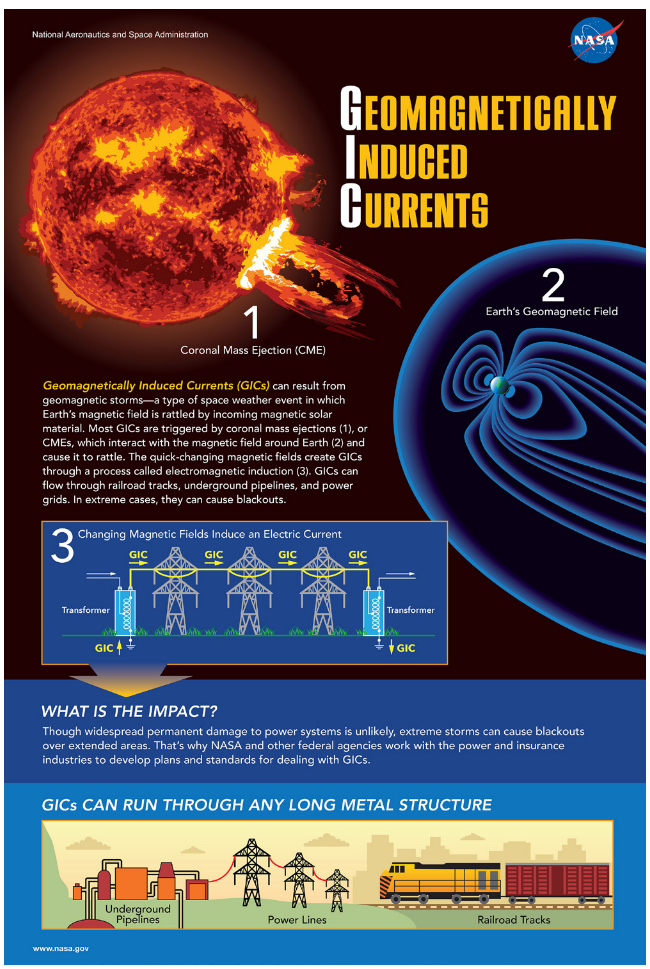
In some cases, the damage caused by GICs may not be immediately apparent and may require careful analysis of system performance and diagnostic data to identify the root cause.

The challenge of differentiating electric weather degradation from normal wear and tear

Distinguishing between degradation caused by electric weather events and normal wear and tear of electrical equipment can be a complex task. Several factors must be considered:

- Timing and correlation with space weather events: If the degradation or failure of equipment coincides with periods of heightened solar activity, geomagnetic storms, or known solar wind coupling events, it may point to space weather as a contributing factor. Cross-checking with space weather data and forecasts can help establish a correlation.

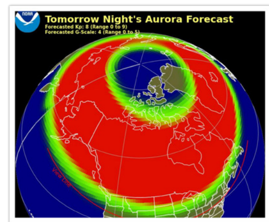
Geographic patterns: Electric weather effects are often seen over larger geographic areas simultaneously. If multiple systems or components across a region exhibit similar degradation patterns, it could be indicative of a space weather event rather than localized wear and tear.

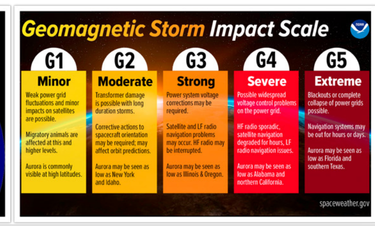


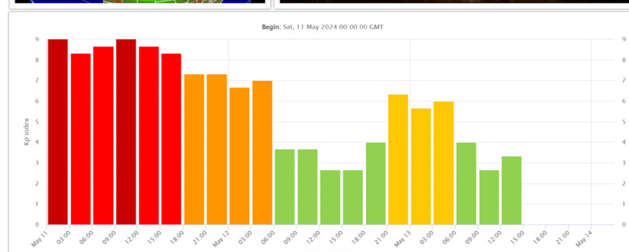
Let's explore some common failures in sectors sensitive to electric weather events:

Power grid infrastructure

- Transformer failures: High-energy particles can induce geomagnetically induced currents in power lines, leading to voltage regulation problems and, in severe cases, transformer failures. Simultaneous transformer failures across a wide area could indicate a space weather event.
- Tripped circuit breakers: The sudden surges caused by electric weather can trip circuit breakers and protective systems, leading to widespread power outages.





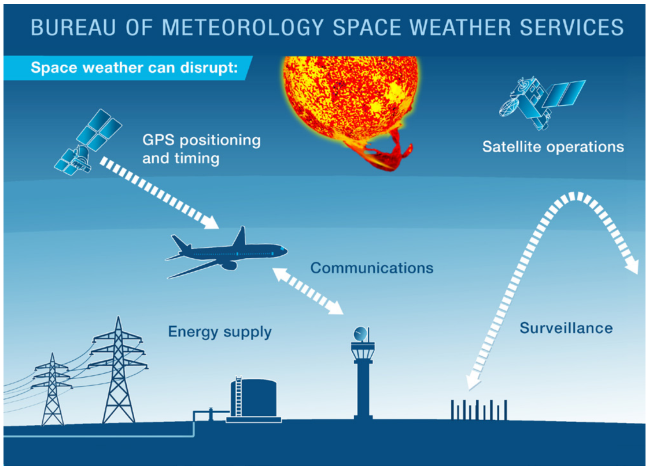


Telecommunications

- Satellite communication disruptions: Charged particles from solar flares and coronal mass ejections can interfere with satellite communications. Widespread disruptions to satellite-based services like GPS, television, and radio could suggest an electric weather event.
- Radio wave propagation anomalies: Changes in the ionosphere during electric weather events can affect the propagation of radio waves. Unusual patterns of radio wave reception across a large area may be a sign of space weather influence.

Aviation

- Increased radiation exposure: During strong solar flares, radiation levels at high altitudes can increase. If multiple flights in a region report higher than normal radiation levels, it could be due to an electric weather event.
- Navigation system errors: Electric weather can interfere with aviation navigation systems that rely on GPS or other satellite-based technologies. Simultaneous reports of navigation issues from multiple aircraft in a region could indicate a space weather event.



- Inspection and testing: Inspecting and testing affected equipment can reveal clues about the nature of the degradation. For example, transformers affected by GICs may show signs of overheating, insulation damage, or core saturation, while pipeline corrosion patterns may indicate GIC flow.
- Analysis of system data: Analyzing operational data, such as power quality measurements, transformer reactive power demand, harmonic distortion levels, and protective relay operations, can help identify anomalies that may be related to electric weather events.
- Material analysis: Conducting metallurgical or chemical analyses on failed or degraded components can sometimes reveal signatures of space weather-related damage mechanisms, such as enhanced corrosion or specific material degradation patterns.
- Modeling and simulations: Computer models and simulations can be used to replicate the effects of electric weather events on electrical systems. By comparing the simulated results with observed degradation, it may be possible to determine if space weather played a role.
- Elimination of other factors: If other potential causes, such as manufacturing defects, environmental conditions, or human errors, can be ruled out, and the degradation pattern is consistent with known space weather effects, it may increase the likelihood of electric weather being the culprit.

It's important to note that in some cases, the degradation caused by electric weather events may be subtle or gradual, making it difficult to distinguish from normal wear and tear. Collaboration between space weather experts, forensic engineers, and material scientists may be necessary to accurately identify and attribute the root cause.

Solar storm events

1859 - The week the sun touched the earth | The Carrington Event

The Carrington Event, the most powerful solar storm on record, occurred in early September 1859. Following an intense white light flare from the sun, a massive coronal mass ejection, consisting of charged particles, reached Earth in approximately 17 hours. The resulting geomagnetic storm led to breathtaking auroras visible as far south as the Caribbean. Telegraph systems worldwide experienced failures, with some operators witnessing sparks and fires from their equipment. This event underscored the potential for solar activity to disrupt technology and acted as an early alert for the field of space weather forecasting. The event was named after British astronomer Richard Carrington, who was the first to observe the solar flare that triggered the storm.

1972 - August storm

During a period of increased solar activity in August 1972, a noteworthy solar storm occurred, carrying substantial consequences for both military and civilian technology. Between August 2 and August 11, 1972, the Earth was bombarded by a sequence of solar flares and coronal mass ejections. These events led to geomagnetic storms that interfered with communication and radar systems utilized during the Vietnam War, necessitating a halt in naval operations. Additionally, auroras were observed at remarkably low latitudes, and heightened radiation levels resulted in damage to certain satellites.

March 1989 magnetic storm damage to a high-voltage transformer at a nuclear power center in Salem, New Jersey.

1989 - The Quebec blackout

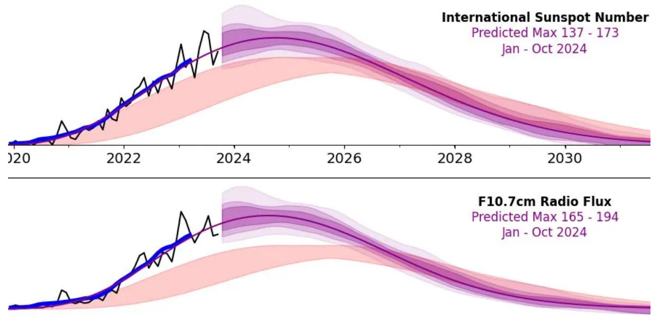
In March 1989, a powerful solar storm wreaked havoc on Earth, triggering a widespread blackout in the Canadian province of Quebec. The storm, fueled by a massive burst of solar material known as a coronal mass ejection, inundated the planet with charged particles and induced electric currents that overwhelmed Quebec's power infrastructure. The resulting power outage left millions of residents in the dark for over nine hours, causing significant economic losses estimated to be in the hundreds of millions of dollars. The solar storm's impact extended beyond Quebec, causing minor disruptions in other regions of North America and parts of Europe, highlighting the potential global consequences of severe space weather events.

2000 - The Bastille Day event

In the year 2000, a significant event, referred to as the Bastille Day Event (in honor of the French national holiday on July 14) occurred. This event marked one of the most potent solar storms of the early space age. A massive solar flare occurred, accompanied by a coronal mass ejection, which arrived on Earth approximately 24 hours later. This powerful storm resulted in vivid auroras that could be seen across Europe and North America. Furthermore, it caused temporary malfunctions in certain satellites, as well as disturbances in radio communications and GPS signals, leading to complications in aviation and maritime navigation.

2003 - Halloween storms

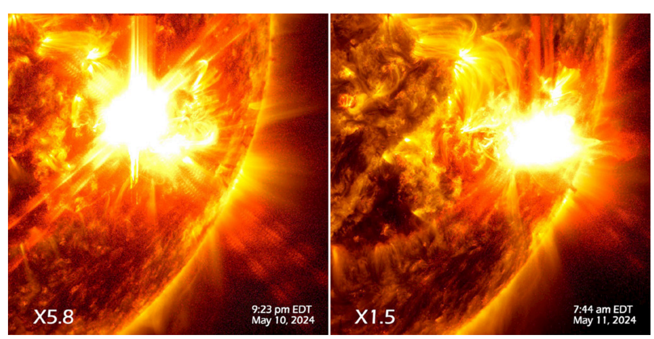
In 2003, a series of intense solar storms, later dubbed the "Halloween Storms," began on October 19 and reached their peak intensity around the time of the Halloween celebration. These storms originated from multiple coronal mass ejections that were in quick succession from the sun. The events led to extensive auroral displays, which could be observed as far south as Texas and Florida, and caused significant disruptions to satellite communications, GPS navigation, and electrical



power networks. To ensure the safety of passengers and crew, airlines were forced to alter flight paths to minimize exposure to elevated radiation levels. Meanwhile, the astronauts aboard the International Space Station had to seek shelter to protect themselves from the heightened radiation environment resulting from the solar storms.

2024 - May solar storms

In their article titled, "The Strongest Solar Storm in 20 Years Did Little Damage, but Worse Space Weather Is Coming", Jonathan O'Callaghan and Lee Billings from Scientific American discuss a recent severe space weather event, which was one of the strongest solar outbursts in the past two decades. Despite the potential for significant damage, years of careful public and private planning helped to mitigate the effects of the storm. The most noticeable effects were dazzling auroras, but the event also impacted air traffic, satellite operations, global communications, and GPS-guided farm equipment. The article emphasizes that while this event was successfully managed, it is not a time for complacency. Experts warn that more intense solar activity is a matter of "when," not "if." The article concludes with a quote from Shawn Dahl, a space weather forecaster at the National Oceanic and Atmospheric Administration's Space Weather Prediction Center, who states that the recent storm was "nowhere close" to the strength of more powerful known historical events.



The insurance conundrum: preparing for the unpredictable

As electric weather events become more frequent and intense due to increasing solar activity — and our electrical infrastructure grows in complexity — the insurance industry faces a significant challenge. Most standard property insurance policies do not explicitly cover damage caused by space weather events or their effects on electrical systems and infrastructure.

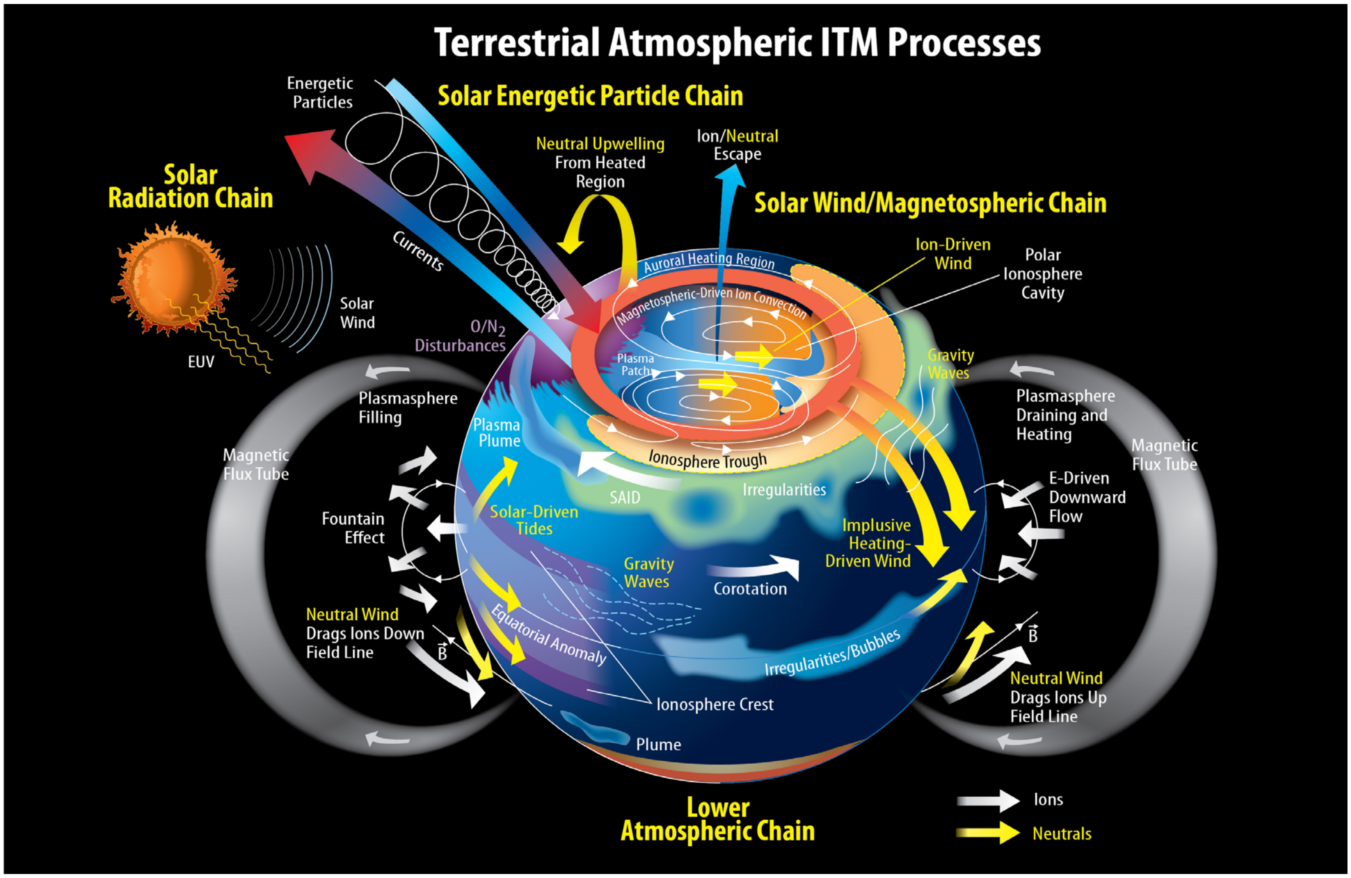
Typically, these policies are designed to cover more common risks, such as fires, severe weather (hurricanes, tornadoes, etc.), theft, and other localized perils. While some policies may provide limited coverage for certain aspects of electric weather damage, such as business interruption (BI) coverage or electrical surge/power surge coverage, the coverage is often not explicitly stated or comprehensive. Some may perceive space weather events as "acts of nature" or "force majeure" events, which are typically excluded from coverage in standard policies. As a result, property owners, especially those with critical infrastructure or sensitive electrical systems, may need to explore specialized insurance products or endorsements specifically designed to address space weather risks.

However, such specialized coverage is still relatively uncommon. This presents a conundrum for both insurers and policyholders, as the risks associated with electric weather are increasing, but the insurance industry has yet to fully adapt and provide comprehensive coverage for these emerging threats.

To address this challenge, several steps need to be taken:

- Risk assessment and modeling: Insurers need to invest in research and modeling efforts to better understand and quantify the risks posed by electric weather events. This includes studying historical data, analyzing potential damage scenarios, and developing predictive models to estimate the likelihood and severity of future events.
- Collaboration with experts: Insurers should collaborate with space weather experts, scientists, forensic engineers, and industry stakeholders to gain a deeper understanding of the mechanisms and impacts of electric weather phenomena. This multi-disciplinary approach can help inform risk assessment and develop effective mitigation strategies.
- Policy development: Based on the risk assessment and expert input, insurers should develop new insurance products or endorsements specifically tailored to address electric weather-related damage.
- Public awareness and education: Both insurers and policyholders need to increase awareness and understanding of the potential impacts of electric weather on infrastructure and property. Educational campaigns can help property owners recognize the risks and take proactive measures to mitigate potential damage.
- Regulatory and government support: Collaboration with regulatory bodies and government agencies can help establish guidelines, standards, and incentives for protecting critical infrastructure against electric weather events. This can include implementing protective measures, developing contingency plans, and promoting resilient design practices.

As the frequency and severity of electric weather events continue to increase, the insurance industry must adapt and evolve to provide adequate coverage and protection for property owners and infrastructure operators.



Credit: NASA Scientific Visualization Studio

Conclusion:

Electric weather is a complex and multifaceted phenomenon that poses a significant threat to our electrical systems and infrastructure. From geomagnetically induced currents to penetrating electric fields and cosmic ray cascades, these space weather events can cause widespread damage, disrupt critical services, and potentially endanger human lives.

Differentiating the damage caused by electric weather from other sources, such as lightning strikes or normal wear and tear, can be challenging and requires a deep understanding of the underlying mechanisms and diagnostic techniques. As our reliance on electrical systems continues to grow, it is imperative that we prioritize the study and mitigation of electric weather risks.

The insurance industry must also adapt to this emerging threat, by developing specialized policies and risk management strategies specifically tailored to address the unique challenges posed by electric weather events. Collaboration between insurers, policyholders, scientists, engineers, and regulatory bodies is crucial to ensure that our infrastructure and property are adequately protected against these unpredictable and potentially devastating natural phenomena.

Ultimately, electric weather serves as a reminder of the delicate balance between our technological advancements and the powerful forces of nature. By embracing a proactive approach, investing in research and resilience, and fostering cross-disciplinary collaboration, we can navigate the challenges posed by electric weather and safeguard our vital systems and infrastructure for generations to come.

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