

Severe space weather



Transport networks and infrastructure increasingly depend on global navigation satellite systems (GNSS), communications and electrical power. Severe space weather events can disrupt these technologies, affecting vehicle operations, air traffic control, railway signalling systems and power networks. Understanding these risks can help the transport sector prepare, reduce vulnerability and manage disruptions effectively.

The Department for Transport, Met Office and partners have created this series of **transport hazard summaries** to explain natural hazards and other hazards that are not the result of malicious acts, their impacts and how they may change in the future.

This summary will introduce what is meant by severe space weather and how it can impact transport, and offers further information to help decision makers manage and adapt to these risks.

On 4 November 2015, a powerful space weather event disrupted European air traffic control radars, temporarily shutting down Sweden's air traffic control system and impacting flights across the region.*

* UK Civil Aviation Authority, 'Impacts of space weather on aviation', available at: <https://www.caa.co.uk/our-work/publications/documents/content/cap1428/>

What is severe space weather?

Space weather describes the ever-changing interaction of particles and energy from the Sun with the Earth and its surroundings.* The auroras (the Northern and Southern Lights) are the most visible results of space weather, but space weather can cause events that are invisible to the human eye yet impact our infrastructure and transport systems.† There are three main forms of space weather: solar flares, coronal mass ejections and high-energy particles.



Solar flares

Solar flares are the sudden release of energy across the entire electromagnetic spectrum (including visible light and radio waves). They are hard to predict, and the energy reaches the Earth's atmosphere 8.5 minutes after a solar flare occurs. Solar flares can cause radio blackouts, affecting high-frequency communications such as those used by transport.



Coronal mass ejection (CME)

A CME is a large ejection of plasma (super-heated, electrically charged gas) from the Sun, carrying an associated magnetic field. CMEs typically take between one and three days to reach Earth. CMEs can cause geomagnetic storms by disturbing the Earth's magnetic field and the upper atmosphere that helps relay long-range, high-frequency radio communications. CMEs are the space weather phenomena that pose the greatest risk of impacts on Earth.



High-energy particles

High-energy particles, the size of atoms and smaller, can be accelerated to very high speeds close to the Sun in events often associated with solar flares or CMEs. These particles can reach Earth within 10 minutes to a day, occasionally reaching the ground. They can damage or disrupt sensitive electronics, such as those on satellites and aircraft.

* Met Office, 'What is space weather?', available at: <https://weather.metoffice.gov.uk/learn-about/space-weather/what-is-space-weather>

† Met Office, 'Northern lights', available at: <https://weather.metoffice.gov.uk/learn-about/weather/optical-effects/northern-lights>

How does severe space weather affect the Earth?

Space weather can produce geomagnetic storms and solar radiation storms on the Earth.



Geomagnetic storms

Geomagnetic storms are major disturbances of the Earth's protective magnetic field. They can induce electric currents in long conductors such as power lines and rail tracks, potentially leading to power grid outages and false rail signals. Geomagnetic storms can also disrupt satellites and high-frequency communications, as well as degrading or causing outages to GNSS.



Solar radiation storms

Solar radiation storms occur when high-energy particles penetrate the Earth's magnetic field. These particles can damage or temporarily disrupt satellites and aircraft electronics. In severe events, increased radiation can also affect electronics on the Earth's surface, disrupt high-frequency radio communications, and result in increased radiation doses for aircraft passengers and crew.



Where does it occur?

Apart from solar flares, which affect the Sun-facing side of the Earth, space weather can affect anywhere, with more significant impacts at higher latitudes and near the poles.



When does it happen?

The amount of space weather is dependent on activity on the Sun, which naturally rises and falls over time, reaching a maximum approximately every 11 years. Severe space weather can occur at any time, even during periods of less activity.



How long does it last?

The duration of space weather effects varies by type: effects from solar flares can last from a few minutes to a few hours, solar radiation storms can last from a few hours to several days, and geomagnetic storms can generally last one to two days. Severe space weather events can include one or more solar flares, CMEs and high-energy particle events clustered in time. When this happens, effects on the Earth could last for over a week.

How is the risk from severe space weather changing?

There are no human factors that affect when space weather occurs or the magnitude of events.* However, our ever-increasing reliance on technology, communication systems and GNSS leads to space weather having more significant impacts.† As an example, in an event known as the 2003 Halloween Storms, 47 satellites experienced operational interruptions including one total loss. If a similar event occurred today, it could mean disruption to hundreds of satellites due to the increased number of satellites in space.

Space weather and climate

Space weather is not directly impacted by climate change. However, as severe weather events become more frequent there is a greater likelihood of overlap with a severe space weather event. This could lead to disruption to communications, GNSS or power coinciding with any impacts from Earth's weather. This was seen during Hurricane Irma, when radio communications were disrupted by a severe space weather event, hampering the emergency response to the hurricane.‡

* Met Office, 'What is space weather?', available at: <https://weather.metoffice.gov.uk/learn-about/space-weather/what-is-space-weather>

† Met Office, 'Space weather impacts', available at: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/business/public-sector/space-weather/space_weather_impacts.pdf

‡ Redmon, R.J., Seaton, D.B., Steenburgh, R., He, J. and Rodriguez, J.V., Space Weather, 'September 2017's Geoeffective Space Weather and Impacts to Caribbean Radio Communications During Hurricane Response', volume 16, issue 9, pages 1190 to 1201, 2018, available at: <https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2018SW001897>

Case studies

The impacts of space weather vary depending on the type and severity of the event.* Below are three examples of events that had differing impacts on transport networks.

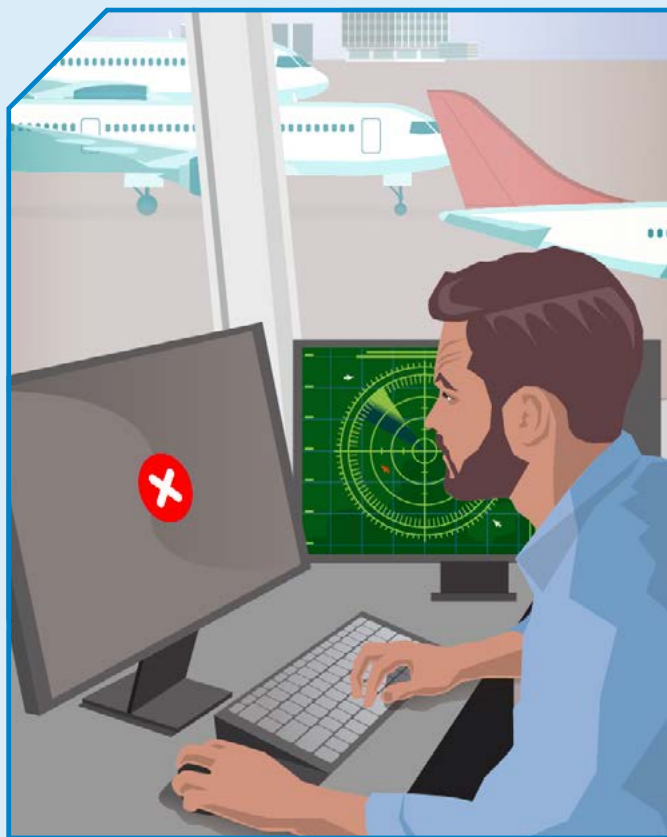
Severe and infrequent  September 2017 Caribbean Very large solar flares and solar radiation storm High-frequency radio blackouts in the Caribbean hindered the response to Hurricane Irma. Air traffic was re-routed to avoid increased radiation in affected airspace.  1 in 10-year recurrence  Notable event with some limited impacts to specific users	Extreme and rare  March 1989 Quebec and Russia Regional geomagnetic storm caused by a CME Quebec faced power disruption for hours. Some satellites lost contact for almost a week. Automated railway systems in Russia were disrupted.  1 in 50-year recurrence  Regional disruption across a variety of technologies	Catastrophic and very rare  September 1859 Carrington event Global event caused by CMEs and solar flares Telegraphic and railway signals malfunctioned or were damaged, while auroras were visible as far south as the Caribbean sky for several nights.  1 in 100-year to 200-year recurrence  Global impacts possible to technology if a similar event happened today
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The 1859 Carrington event is considered the realistic worst-case scenario for extreme space weather. Due to the infrequency of such events, there is no case study for the impacts of a similar event on modern technology. A Royal Academy of Engineering report estimated that if a similar event were to occur today, there would be significant impacts or outages on technologies such as the electricity grid, satellites, aircraft electronics, GNSS and radio communications.†

* Met Office, 'Space Weather Impacts', available at: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/business/public-sector/space-weather/space_weather_impacts.pdf

† Royal Academy of Engineering, 'Extreme space weather: impacts on engineered systems and infrastructure', available at: https://raeng.org.uk/media/lz2fs5ql/space_weather_full_report_final.pdf

Direct transport impacts due to severe space weather

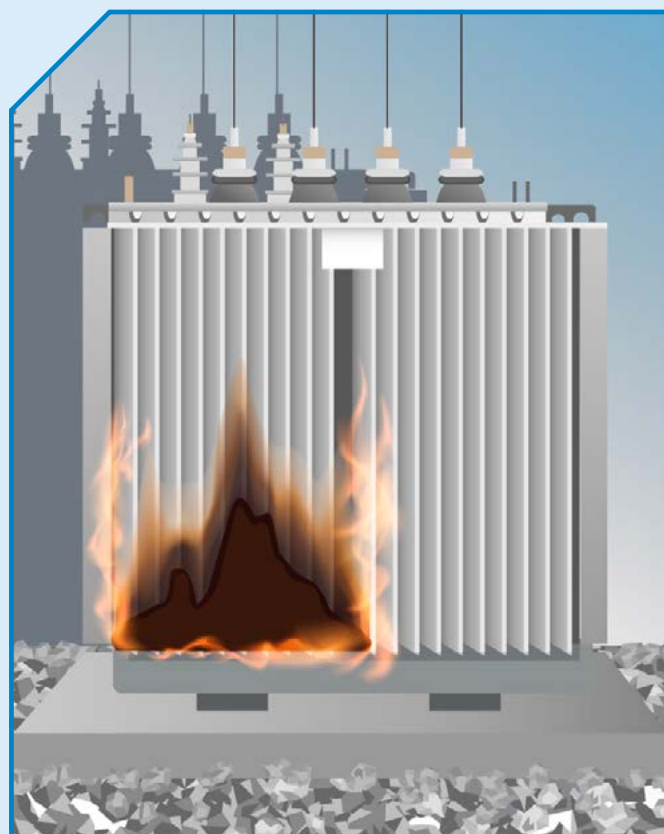


Vehicle and service operations

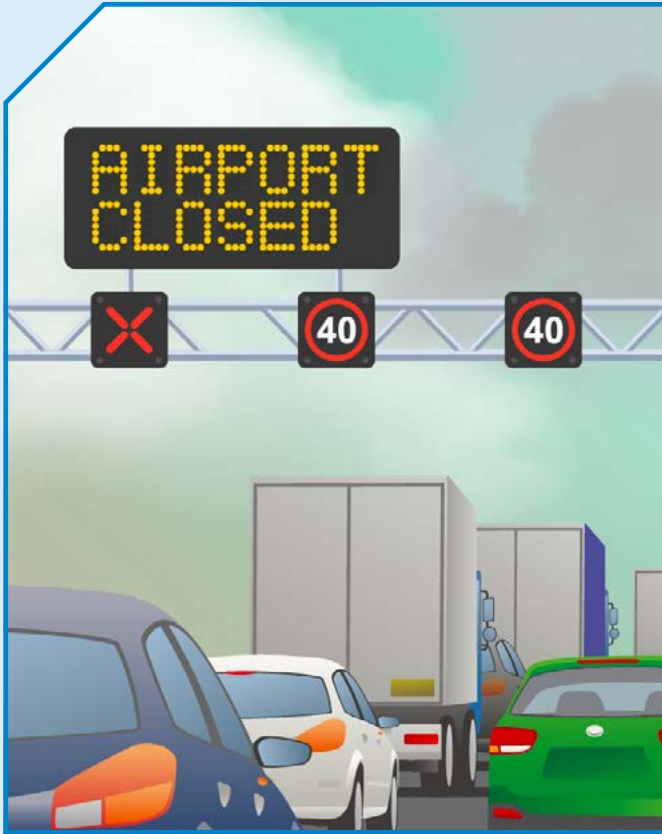
- ⚠ Loss of GNSS is impactful for transport systems that rely on satellite timing and communications, for example satellite-based clocks for co-ordination across the rail network and long-range satellite communication for maritime vessels.
- ⚠ Solar radiation storms may cause errors or failures in aviation electronics, leading to an increased workload for pilots and air traffic controllers in order to handle aircraft system failures.*
- ⚠ Loss of high-frequency communications can disrupt services such as air traffic control and maritime radio.

Infrastructure

- ⚠ Geomagnetic storms may cause damage to electrical infrastructure, leading to instability in the electricity network or power outages.
- ⚠ Power outages may have widespread impacts, from airport IT systems to communication networks and electric train services.
- ⚠ Severe solar radiation storms may lead to increased radiation at ground level which can damage electronics such as control systems.
- ⚠ Induced currents in train tracks may lead to false signals.



* Royal Academy of Engineering, 'Extreme space weather: impacts on engineered systems and infrastructure', available at: https://raeng.org.uk/media/lz2fs5ql/space_weather_full_report_final.pdf



Navigation

- ⚠ GNSS failures can cause navigation equipment to fail or give errors. This may cause traffic congestion, as well as flight and shipping delays that disrupt freight supply chains.
- ⚠ GNSS is used for monitoring and maintenance of transport infrastructure such as bridges. If GNSS fails, these assets may need closing as a precaution.

Human health and safety

- ⚠ Space weather can raise radiation levels at high altitude, leading to increased radiation doses for aircraft passengers and crew. As a result, aircraft may change their routes to avoid the areas where radiation levels are likely to be highest near the poles.

Interdependencies: space weather can cause effects across multiple sectors, increasing the likelihood of cascading failures. For example, a power outage can halt electric trains and disrupt communications, making it harder to mitigate the impacts to passengers.



Risk mitigation and adaptation

The UK currently employs a range of measures to lessen the impact of severe space weather on its transport network. Examples include:

- reinforcing airport and railway electronic control systems with shielding and surge protection to minimise interference during geomagnetic storms
- running exercises so that pilots, sailors, drivers and signallers can work safely without guidance from satellite-based services
- integrating Met Office space weather alerts and warnings into emergency response processes
- ensuring road signs and markings are kept clear to help people navigate in the event of disruption to GNSS
- retaining ground-based position, navigation and timing systems to ensure safe transport operations if GNSS is degraded by space weather



Questions for decision makers

- Have you identified which aspects of your area of transport are most vulnerable to prolonged GNSS disruptions?
- Are there robust, operational backup systems in place if satellite-based navigation or communication fails during severe geomagnetic storms?
- Are your procedures sufficiently robust to address simultaneous failures of different technologies?
- Is your organisation signed up for space weather alerts and warnings such as those issued by the Met Office?
- Have transport staff been sufficiently trained and drilled on procedures to manage prolonged communication and power outages?
- What partnerships or frameworks do you have to ensure that you can rapidly share information and co-ordinate with your stakeholders during a severe space weather event?



Further reading

Aircrew exposure to cosmic radiation – UK Civil Aviation Authority

Extreme space weather: impacts on engineered systems and infrastructure – Royal Academy of Engineering

Impacts of space weather on aviation – Civil Aviation Authority

Space weather forecast, including a link to sign up for sector-specific forecasts and alerts – Met Office

Space weather videos – Met Office

Space weather warnings explained – Met Office

UK Severe Space Weather Preparedness Strategy – Department for Business, Energy and Industrial Strategy

What is space weather? – Met Office



Risk assessment

See the 'Transport hazards, risks and resilience' transport hazard summary for more information on identifying and planning for risks to transport.