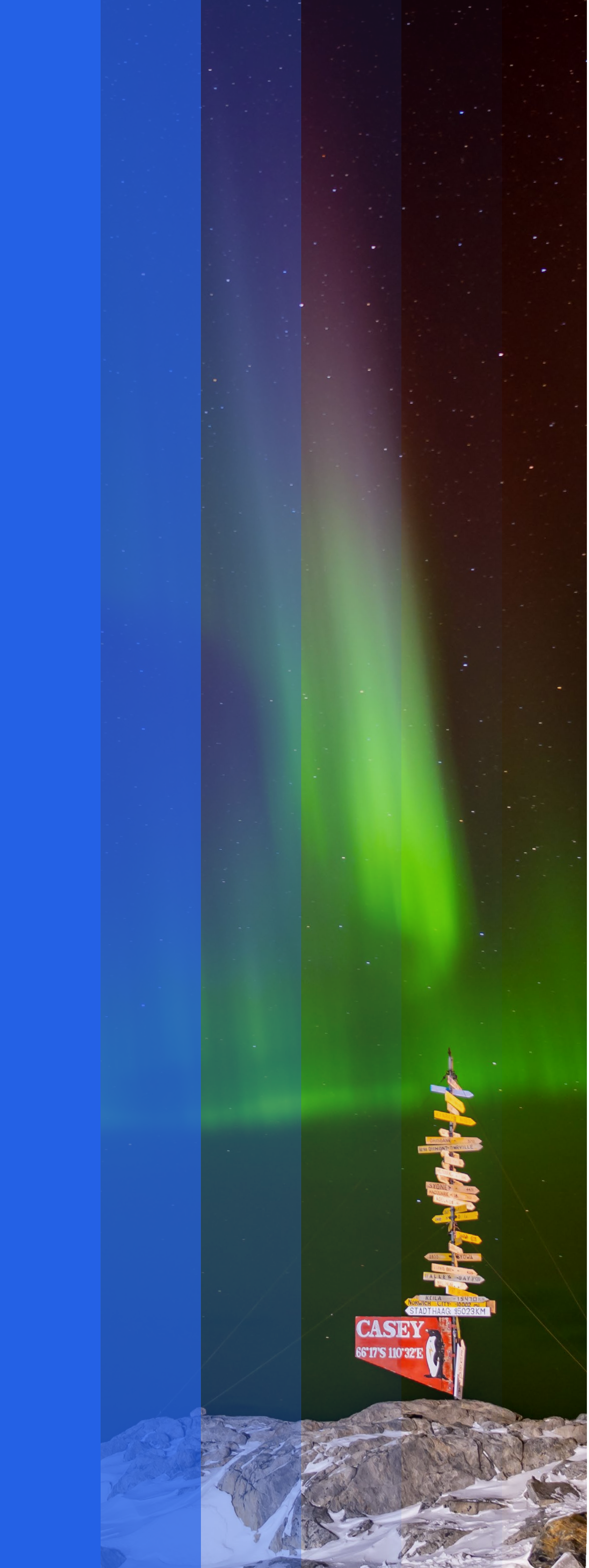
Australian Government
Bureau of Meteorology

Space weather and the Aviation sector



A severe space weather event can disrupt electrical currents in power lines, increase radiation in the atmosphere, disrupt communications and navigation, damage satellites and harm human health. Impacts for the aviation sector can be serious. Response and mitigation planning is necessary.

Key points

- Severe space weather can significantly impact high frequency (HF) communications and satellite-based navigation and surveillance technologies. These technologies may become unusable.
- Severe space weather can significantly increase the ionising radiation environment on polar or near-polar flights, with potential impacts to aircraft avionics and human health.
- The aviation sector relies on extensive ground and space-based infrastructure, such as airports, navigation beacons and fuel. This makes it very vulnerable to the impact of space weather on other sectors. For example, the loss of power to an airport or to critical ground-based navigation or surveillance infrastructure would have a significant impact across the sector.
- Further engagement with the aviation sector is required to identify and mitigate the cross-sectoral threats.

What causes space weather?

The main driver of space weather is the Sun. Solar activity and the resulting space weather vary day-to-day, seasonally, and over multi-year cycles. Irregular solar activity, including explosive eruptions called solar flares and coronal mass ejections, can have a significant impact on the near-Earth space environment.

Major solar flares can be associated with an increase in:

- X-ray and radio emissions that reach Earth within 8 minutes
- energetic protons, reaching the Earth in 20 minutes to 6 hours
- solar wind particles and magnetic field strength, typically reaching Earth within half a day to 3 days.

During a coronal mass ejection, billions of tonnes of magnetised solar plasma erupt into space at up to 3,000 km/s. If the material is directed towards the Earth, geomagnetic, ionospheric and radiation storms can occur.

Severe space weather can significantly impact the technologies we rely on in different ways and over different time scales.

How does space weather affect the aviation sector?

Solar variations modify a layer of the Earth's upper atmosphere known as the ionosphere. The ionosphere extends upwards from 90 km above the Earth's surface. This is of particular concern for the aviation sector because of the way its communications and navigation systems can be affected.

High-frequency (HF) radio communication relies on the ionosphere reflecting radio waves back down to the ground. Long-range voice and data communication, including the range of usable HF frequencies, can vary according to the state of the ionosphere.

Satellite communication (SATCOM) and satellite-based navigation and surveillance (SATNAV) that use global navigation satellite systems (GNSS) rely on the transmission of signals through the ionospheric layer. These signals can be modified in various undesirable ways as they travel through the ionosphere, depending on its density and structure.

Space weather events that modify the density and/or structure of the ionosphere can significantly impact the performance of HF communications, SATCOM and SATNAV systems.

The release of high-energy particles from the Sun during solar disturbances can cause increased, potentially dangerous, radiation at cruising levels on polar or near-polar flights. Radiation exposure increases with altitude and with closer proximity to the poles.

Under an extreme space weather event impacting power supply, ground based navigation, communications and airport infrastructure may experience loss of power for a significant period.

High-frequency radio communications

Emissions associated with solar flares and high-energy solar particles can increase the density of the lower ionosphere, causing increased absorption of HF radio waves and reducing the range of usable frequencies for HF communication. These 'absorption events' usually impact just the lower HF radio frequencies. However, very strong solar X-ray flares can cause HF radio blackout conditions that affect all frequencies. These can last for minutes to hours on the entire daylight side of the Earth.

Bursts of high-energy particles from the Sun (solar proton events) can impact the polar regions, producing HF radio blackout conditions that can last from hours to days. Absorption events can also occur in the auroral oval regions surrounding the poles, lasting for minutes to hours. During these events, HF radio operators are advised to try higher frequencies, or in the case of blackouts, use an alternate means of communication.

Geomagnetic storms can reduce the density of electrons in the upper ionosphere, again resulting in a reduced range of frequencies available for HF communications. These 'ionospheric depression' events usually impact just the higher HF radio frequencies and can last from hours to days. During these events, radio operators are advised to try lower HF frequencies.

Satellite-based navigation and surveillance

The aviation sector is increasingly reliant on positioning navigation and timing signals from GNSS satellites for navigation and surveillance of aircraft. An example of this is GPS.

One of the largest sources of error in GPS results from the satellite signal passing through the upper atmosphere.

Under normal space weather conditions, these errors are corrected. However during ionospheric storms this correction may be inadequate and lead to increased positioning errors.

Precision navigation systems that autocorrect for the ionosphere are susceptible to errors during severe ionospheric storms. These systems include differential GPS, or GPS augmentation systems such as the satellite-based augmentation system (SBAS) or ground-based augmentation system (GBAS).

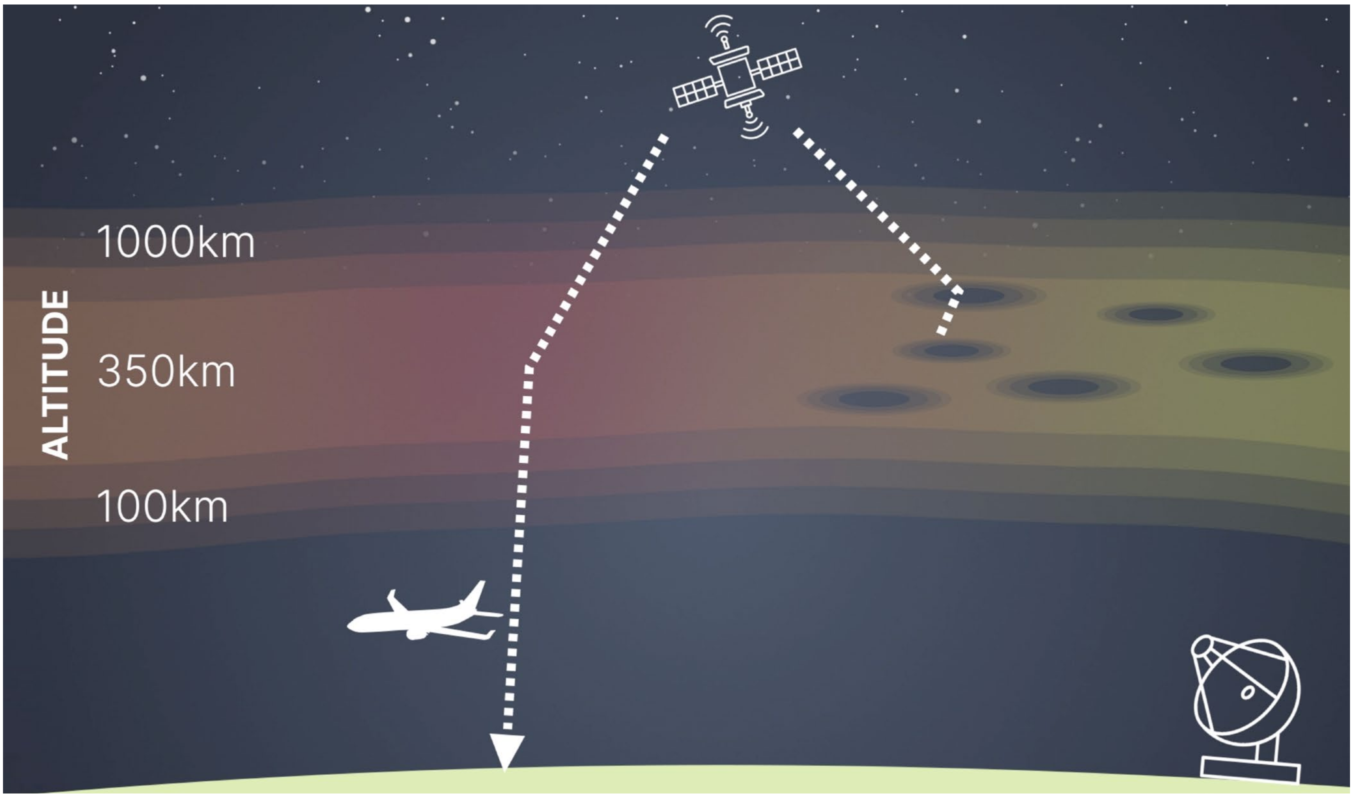
GNSS positioning is also susceptible to interference from solar radio bursts in the ultra-high-frequency (UHF) range. There is potential for significant loss of satellite tracking for up to tens of minutes in severe cases. Strong radio bursts have also been known to impact surveillance radar used for aviation.

Example: Solar flare activity impacts air-traffic radar for 90 minutes

On 4 November 2015 air traffic control centres in Stockholm and Malmö, Sweden noticed that radar stations of the Swedish Air Navigation Service Provider were not relaying the correct data.

The disruption was attributed to solar flare activity occurring near sunset in Sweden, when the angle of the Sun is directed into the radar station. While the cause was rapidly identified and measures taken, the interference resulted in a 90-minute impact to radar across Swedish airspace.

Another impact of space weather is ionospheric scintillation. This is the rapid fluctuation of power and/or phase of radio signals passing through the ionosphere. Scintillation effects are most significant in L-band (below 2 GHz) SATCOM and SATNAV applications. Scintillation occurs primarily in the equatorial region of the Earth (+/- 20° latitude) between dusk and midnight. It is caused by large electron-density depletions known as equatorial plasma bubbles. However, scintillation can also occur in high-latitude regions.



Errors in GPS systems can occur due to the effect of space weather on the upper atmosphere. GPS signals are typically impacted in two ways. Spots of variation can break the connection with satellite signals, while changes in upper atmospheric conditions can cause incorrect positioning information. Large variations in the upper atmosphere can seriously disrupt positioning systems.

Example: Space weather storms cause GPS errors

A series of significant space weather storms occurred in late October 2003 (the 'Halloween storms'). During the storms, the Wide Area Augmentation System (WAAS), which corrects GPS signals, was affected. Its vertical error limit was exceeded for a period of about 30 hours. WAAS was unavailable for precision aircraft approaches during that time. The integrity of the system however was not lost.

For SATNAV, the rapid signal fluctuations impede the ability of GNSS receivers to track signals from individual GNSS satellites. This causes reduced positioning accuracy and, in more severe cases, a complete loss of GNSS positioning for up to tens of minutes. For SATCOM, scintillation can result in reduced signal-to-noise ratio and poor communication quality.

Radiation exposure on polar routes

During solar eruptive events, large numbers of energetic particles may be released from the Sun. This increases radiation at high altitudes in the polar regions.

The Earth's atmosphere and magnetic field provide a degree of shielding for most of the planet. However, the near-vertical magnetic field in the polar regions leaves these areas more susceptible to increased levels of ionising radiation. Hence, the radiation exposure of flight crew and passengers on polar or near-polar flights can significantly increase during solar energetic particle events. Radiation levels increase with altitude and latitude.

Cross-sectoral impacts

The aviation sector relies on extensive ground and space-based infrastructure, such as airports, navigation beacons and fuel. This makes it very vulnerable to the impact of space weather on other sectors, such as energy.

Space weather impacts on electricity transmission can cause power loss to an airport or to critical ground-based navigation or surveillance infrastructure. This would have very significant impacts across the aviation sector.

Response to a severe space weather event

Like for any severe weather, it is critical to plan and prepare for a severe space weather event.

The Bureau provides forecasting and real-time observations of space weather. This gives the opportunity to take protective action and prepare for disruptions. In extreme events we provide a severe space weather warning service.

We work closely with the aviation sector to limit space weather risks, through delivery of:

- space weather forecasts, warnings and alerts
- customised web pages supporting aviation operators, including HF radio frequency selection tools
- consultancy and training.

International Civil Aviation Organization space weather advisory service

The International Civil Aviation Organization (ICAO) has implemented an internationally standardised global space weather advisory service for aviation. Aviation operators receive notifications from the ICAO space weather advisory service and have plans to mitigate impacts.

The ICAO service targets 3 key areas of space weather impacts on aviation:

1. performance of GNSS-based navigation and surveillance
2. performance of HF communications systems
3. the level of radiation exposure for passengers and aircrew, particularly on polar routes.

Advisories are issued for each effect at two impact levels: moderate and severe. Further information on the ICAO space weather advisories can be found on our Aviation Weather Services Knowledge Centre page at http://www.bom.gov.au/aviation.

ICAO does not define the operational responses to its space weather advisories. These are assumed to be the responsibility of aircraft operators and in some cases air navigation service providers. Mitigating actions will depend on operator circumstances and risk assessments.

ICAO has published guidance for aviation operators in its Manual on Space Weather (https://store.icao.int/en/manual-on-space-weather-information-in-support-of-international-air-navigation-doc-10100). Chapter 4 contains general advice on the use of advisory information to mitigate space weather impacts as follows:

Responding to a space weather event – extract from ICAO Doc 10100

Flight crew

Advisories of imminent or ongoing disruptions to HF and GNSS and of radiation effects enable alternate route planning or delayed use of polar routes. Options may include:

a. time — delayed entry into regions specified in the advisory. Radiation and some HF advisories typically have very short (minutes) lead times, whereas the majority of the HF and GNSS advisories may have hours before the threshold is reached; and
b. distance — not only avoiding specified regions, but in the case of radiation, flying at a non-optimal but lower altitude for more shielding by the atmosphere. A roughly 2,100-metre (7,000 ft) decrease in altitude lowers the radiation dose by approximately 50 per cent. Polar flights may consider planning lower latitude routes where practicable (the geomagnetic latitude where Earth's magnetic field provides an appreciable boost of shielding is about 60°).

Mitigation options for GNSS and HF degradations are limited to:

a. time — wait for the disturbance to abate;
b. distance — an element of the disruption is due to the movement overhead of structures in the ionosphere. If those trajectories can be known, then potentially a mitigation strategy could be a change in course. Changing altitude has no effect; and
c. other — HF can sometimes improve by using higher frequencies during HF absorption events (solar flares, solar radiation storms) or employing lower frequencies during HF depressions (ionospheric storms). Guidance is found in the remarks section of the space weather advisory.

Operators

Operators should develop operational procedures for managing flights in areas impacted by space weather events.

Procedures should include the use of risk assessment techniques to determine informed actions based on the provision of space weather advisory information. This includes flight planning tracks using forecasts and tactical nowcasts for inflight situational awareness. The best situation is to be able to plan 12 to 20 hours ahead, making allowances for flight re-routes, fuel, and crew schedules. Long-haul flights may be the most problematic as options are constrained by fuel, particularly if the aircraft is en route when an unpredicted event occurs.

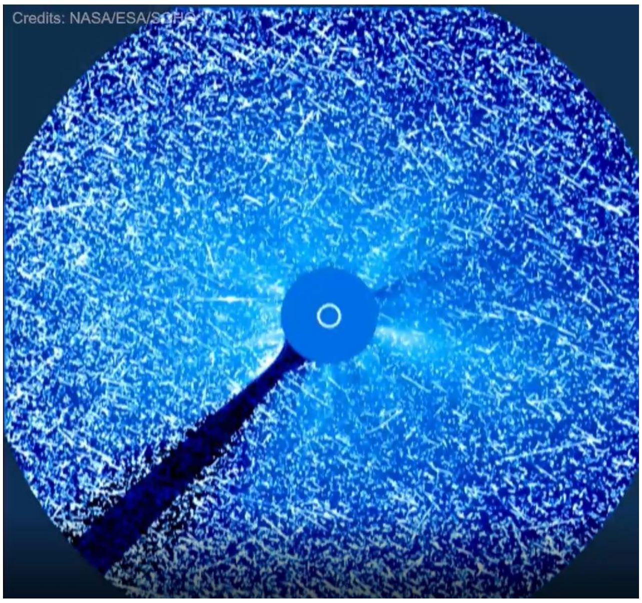
As with Air Navigation Service Providers (ANSPs), situational awareness is very important for safe and efficient flight management. Operators should work with Space Weather Centres to familiarize themselves with the products and services provided, as well as to develop a strong working relationship.

Air Navigation Service Providers

Situational awareness, in the broader context of managing multiple (numerous) flights, is vital for maintaining safe and efficient operations. The insidious nature of space weather impacts to critical systems necessitates a well-designed and useful advisory. Unlike convective weather, there is no visual clue for space weather impacts.

ANSPs are well aware of HF issues and have many years of experience working around them. GNSS uncertainties may require greater spacing between aircraft as a function of phase of flight. Terminal and en route requirements differ in the degree to which GNSS errors become significant. Ongoing work with the ICAO Navigation Systems Panel is focused on understanding relevant values.

Reference: International Civil Aviation Organization, 'Manual on Space Weather Information in Support of International Air Navigation', Doc 10100, First edition, 2018



Strong particle radiation storm captured by the Solar and Heliospheric Observatory (SOHO). Credit: NASA/ESA/SOHO

Short-term mitigation measures

To mitigate the short-term effects of severe space weather, operators might take the following actions.

High-frequency radio communications

- Switch to lower HF radio frequencies during ionospheric storms and higher HF radio frequencies during solar flares/HF absorption events (as per ICAO recommendations).
- Use alternate forms of communication, where available, such as satellite or very high frequency (VHF) radio.
- Delay or re-route flights where alternative communication technology is inadequate, particularly in polar regions.

Satellite-based navigation and surveillance

- Increase spacing between aircraft on the ground or in-flight to mitigate increased GNSS position uncertainties.
- Use alternative navigation technology in impacted locations. Impacts are strongest in high latitudes, and near the equator after dusk.
- Ground-based and space-based GNSS augmentation system operators should monitor service performance and execute risk mitigation plans. Actions might include setting the augmentation service to 'unavailable' when regulated accuracy tolerances are exceeded.

Radiation exposure on polar routes

- Reduce altitude of polar flights. A 2,100 m decrease in altitude lowers the radiation dose by approximately 50%.
- Re-route polar flights to lower latitudes. The Earth's magnetic field provides greater shielding against dangerous radiation at latitudes less than about 60°.

Longer-term mitigation measures

Understanding space weather risks also means designing and managing processes, systems, and infrastructure differently. With targeted research and development Australia's resilience can be increased. To ensure the aviation sector becomes more resilient in the future, the Bureau will:

- contribute to space weather risk assessments to obtain a comprehensive understanding of the direct and indirect impacts of space weather on the sector, along with dependencies across other sectors
- support the coordination of Australia's response to severe space weather across relevant departments, agencies and industry, informed by appropriate risk assessment findings
- collaborate with industry, government, and academia to develop and improve models and forecast capabilities, validated with expanded industry observations, that enhance industry's ability to adequately mitigate severe space weather with minimum disruption to society.

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Aurora viewed from an aeroplane.
(Credit: Piriya Photography/Getty Images)

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