Australian Government
Bureau of Meteorology

Space weather and the Defence sector

A severe space weather event can disrupt Defence operations including satellite-based communication, navigation, surveillance, radar and radio communications. Impacts can be serious, requiring response and mitigation planning.

Key points

- Key technologies used by Defence are vulnerable to disruption from the effects of severe space weather on technology and the near-Earth space environment.
- Improved understanding of how space weather affects military systems increases our ability to manage disruptions and outages.
- Maintaining technological diversity and designing robust systems are vital to building Defence resilience to severe space weather.

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 (CMEs), can have a significant impact on technology and 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.

During a CME, billions of tonnes of magnetised solar plasma erupt into space at up to 3,000 km/s, typically reaching Earth within 3 days. 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 Defence?

Many of the technologies used by Defence are vulnerable to disruption by space weather. In addition, radiation associated with severe space weather can damage satellites and electronic equipment in aircraft and can harm the health of personnel working at high altitudes and in polar regions. Space weather can lead to:

- day-to-day variations in the optimum high frequency (HF) radio frequencies, through to complete loss of HF radio and radar
- degraded global navigation satellite system (GNSS) positioning, satellite communication or satellite surveillance
- electricity grid impacts, with a risk of power loss for extended periods.

Spacecraft operations

Most satellites orbit within the protection of the Earth's magnetic field. When solar wind from the Sun increases in strength, the additional pressure on the Earth's magnetic shield causes it to shrink. Satellites in geosynchronous orbits, above 36,000 km, can be exposed to additional cosmic and solar radiation and high-energy solar particles. This can result in temporary or permanent failures of on-board computers and equipment.

The energy dissipated in the Earth's upper atmosphere by space weather events can cause the atmosphere to expand outwards into space.

Satellites orbiting at low altitudes (below 2,000 km) are likely to experience increased air resistance, or drag, which causes them to drop in altitude below their planned orbits. This shortens their effective satellite life. Without sufficient fuel to restore their course, satellite orbits continue to decay until the satellite disintegrates in the Earth's atmosphere or crashes.

High-energy protons and electrons associated with solar flares can degrade solar panels or cause a build-up of static electric charge on satellites. Subsequent electrical discharges can cause brief interruptions to operations, potentially leading to temporary loss of control from ground stations and corruption of satellite sensor data. In extreme cases, the interruptions can be longer, or permanently disable the satellite.

Disruption of satellite operations can have flow-on effects to communication, navigation and reliant timing systems.

Space object tracking

Ionospheric scintillations are rapid fluctuations in electron density in the upper atmosphere. They are more likely to occur during major solar storms. C-band (4–8 GHz) radar used for tracking satellites and space debris can be affected by severe ionospheric scintillation.

Increased drag can change satellite and space debris orbits, making it hard to accurately catalogue known objects.

Example: Demise of first US space station Skylab

Skylab's 1979 destruction is an example of a spacecraft re-entering Earth's atmosphere prematurely because of higher-than-expected solar activity. The US Space Command had to post new orbital elements for over 1,000 affected objects. The Solar Maximum Mission satellite fell out of orbit in December the same year.

Satellite communication

Satellite communication systems operating in the very high frequency (VHF) and lower part of the ultra-high (UHF) band can be affected by even moderate ionospheric scintillation. More severe scintillation can degrade L-band satellite communication systems such as Iridium and Inmarsat.

These effects are most common when the signal passes through either the equatorial or polar ionosphere. Equatorial scintillation affects systems mostly after sunset until a few hours after midnight.

Solar radio bursts can interfere with VHF, UHF and L-band communications satellites. Geostationary satellites closer to the Sun during the equinox are particularly affected by these bursts. Mobile systems with large beamwidths and low signal-to-noise ratios are also impacted.

Satellite navigation

Military uses of global navigation satellite systems include precise position and timing for all mobile units including air, land and maritime platforms. Some weapon systems are critically dependent on the availability and accuracy of these systems.

If GPS satellites survive the impacts of an extreme space weather event, the signals they send are likely to be disrupted by ionospheric density gradients and scintillation, causing communication drop-outs and unusually large errors in positioning and timing. During extreme events, position errors from single-frequency receivers could be up to hundreds of metres. These impacts could last up to a few days.

Extreme space weather can also disrupt augmented GNSS systems, such as those used for airport landings. Severe geomagnetic storms can cause precision magnetic compasses to become unreliable.

Aviation flight operations

The potential impacts of severe space weather on military aviation can include:

- increased radiation exposure for flight crew at high altitudes and especially in polar regions
- possible interruption or failure of electronic equipment due to increased radiation
- possible disruptions to HF, VHF and UHF communication systems and radar
- possible disruptions to the precision and availability of satellite-based navigation systems, such as GPS.

Example: Solar flare impacts air traffic control radar for 90 minutes

In November 2015 secondary air traffic control radars were strongly disturbed in Sweden and some other European countries. The disturbances coincided with the peak of an exceptionally strong solar radio burst in a relatively narrow frequency range around 1 GHz.

Radio communication

Severe space weather affects radio frequencies used by Defence.

Long-distance communication with submarines using very low frequency (VLF) and low frequency (LF) bands

During or following severe geomagnetic storms, signal strength can be degraded for a day or two. Sudden changes in ionospheric density can produce brief phase anomalies in these frequency bands.

Long-distance communication with aircraft, ships or remote land-based units using medium frequency (MF) and high frequency (HF) bands

X-rays emitted by solar flares can produce shortwave fadeouts, blocking MF and HF communication for up to a few hours. Ionospheric storms also affect HF communication by decreasing the maximum useable frequency, or degrading their quality, for up to a few days.

Ionospheric storm effects usually begin near the poles and move towards the equator during the storm. The long-term changes in the solar ultraviolet radiation throughout the 11-year solar cycle result in predictable changes in the range of frequencies available for HF communication. Some seasonal and daily variations are also predictable. However, the variations occurring during individual geomagnetic storms are difficult to forecast.

Line-of-sight communication between mobile units, including ship-to-shore and air-to-ground, using VHF and UHF

Solar radio bursts associated with solar flares can briefly interfere with VHF and UHF signals in the sunlit hemisphere of the Earth, when the sun is low on the horizon.

Mobile phone communication can be impacted by these bursts in the same way, as it operates within the UHF frequency band.

Land-based fixed line-of-sight communication links using microwave L-band

Solar radio bursts can briefly interfere with L-band communication links.

Mobile phone networks

4G and 5G networks use GPS synchronisation to avoid interference between cell coverage. When space weather interferes with GPS, signal interference is more likely. Because some 5G networks use multiple GPS satellites simultaneously, they are more susceptible to space weather than earlier technology.

Example: Severe space weather disrupts military communication

May 1967

The storm made its initial mark with a colossal solar radio burst causing radio interference at frequencies between 0.01 and 9.0 GHz and near-simultaneous disruptions of dayside radio communication by intense fluxes of ionizing solar X-rays. Aspects of military control and communication were immediately challenged. Within hours a solar energetic particle event disrupted high-frequency communication in the polar cap. Subsequently, record-setting geomagnetic and ionospheric storms compounded the disruptions.

(Reference: DJ Knipp et al, 'The May 1967 great storm and radio disruption event: extreme space weather and extraordinary responses', 2016, https://doi.org/10.1002/2016SW001423)

Over-the-horizon radar

The Jindalee over-the-horizon radar network HF radio signals are subject to the same effects as HF radio communications. Solar flares, solar radio bursts and ionospheric storms can all impact radar performance.

When a strong ionospheric storm penetrates to equatorial and tropical regions, the loss of higher frequencies can reduce the effective range of the radars.

Storm-induced fluctuations in the height at which the radar signals are refracted by the ionosphere can also impact coordinate registration. This can result in difficulties mapping targets and/or inaccurate speed and range information.

Solar flares and solar radio bursts can blind HF radar from several minutes to up to an hour.

Response to a severe space weather event

Like for any severe weather, it is critical to plan and prepare. The Bureau provides forecasting and real-time space weather observations, and in extreme events, a severe space weather warning service.

We work closely with Defence to help them prepare for disruptions and to take action to limit space weather risks by providing:

- space weather forecasts, warnings and alerts
- customised Defence space weather website
- daily reports, special forecasts and post-event analysis for the Australian Space Operation Centre
- International Civil Aviation Organisation (ICAO) Aviation Space Weather Advisories
- real-time ionospheric modelling for HF radio communication
- propagation prediction software and tools for radio frequency communication
- consultancy and training.

Delaying or fast-tracking a mission could be an appropriate mitigation strategy in response to an expected major solar storm. It is important to monitor space weather conditions through forecasts, warnings and alerts, and to understand the possible reasons for system degradation.

Other potential actions include:

- switching to lower HF radio frequencies during ionospheric depressions and higher HF radio frequencies during solar flares
- strategies for over-the-horizon radar, including
  - monitoring space weather forecasts, warnings and alerts
  - utilising Royal Australian Air Force unit 1RSU to notify Defence units of expected mission impacts
  - switching to lower HF radio frequencies during ionospheric depressions and high HF radio frequencies during solar flares.
- longer-term mitigation measures including understanding space weather risk and designing and managing processes, systems and infrastructure differently.

To support Defence resilience, the Bureau:

- contributes 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
- supports the coordination of Australia's response to severe space weather across relevant departments, agencies and industry, informed by appropriate risk assessment findings
- collaborates with industry, government, and academia to develop and improve models and forecast capabilities. This is validated with expanded industry observations that enhance industries' ability to mitigate severe space weather with minimum disruption to society
- encourages development and maintenance of diverse communication technologies.

Contact us space@bom.gov.au www.bom.gov.au