Australian Government
Bureau of Meteorology

Overview of space weather and potential impacts and mitigation for Defence

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

Key points

- Key technologies used by Defence are vulnerable to disruption by severe space weather. These include satellite-based communication, navigation, surveillance, radar and radio communications.
- Radiation associated with severe space weather can damage satellites and electronic equipment in aircraft. It can also harm the health of personnel operating at high altitudes especially in polar regions.
- Improved understanding of how space weather affects military systems will increase our capacity to attribute the cause of disruptions and outages.
- Maintaining technological diversity and designing robust systems will be vital to building Defence's 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 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 CME, billions of tonnes of magnetised solar plasma erupt into space at up to 3000 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 Defence?

Many of the technologies used by Defence are affected by space weather. The level of impact varies in severity. There can be day-to-day variations in the optimum high frequency (HF) radio frequencies, through to complete loss of HF radio and radar. There can also be degraded global navigation satellite system (GNSS) positioning, satellite communication or satellite surveillance. The electricity grid can also be impacted by extreme space weather, with a risk of power loss for extended periods.

Spacecraft operations

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

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 2000 km) are likely to experience increased air resistance (drag). Drag causes satellites to drop in altitude below their planned orbits, requiring additional propellant to restore their correct orbit. This reduces effective satellite lifetimes. Without propellant, satellite orbits will continue to decay until the satellites disintegrate in the Earth's atmosphere or crash-land.

High-energy protons and electrons associated with solar flares can degrade the efficiency of solar panels or cause a build-up of static electric charge on the satellite's exterior or interior. Subsequent electrical discharges can cause brief interruptions to the satellite's normal operations. Sometimes this causes temporary loss of control from ground stations, or corrupted data from the satellite's sensors. In extreme cases, the interruptions can be longer, or permanently disable the satellite.

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

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 (solar flares, CMEs, solar energetic particle events). C-band (4–8 GHz) radar used for tracking satellites and space debris can be affected by severe ionospheric scintillation.

As mentioned earlier, increased drag can change satellite orbits. Orbits of space debris are also affected, leading to difficulties maintaining an accurate catalogue of known objects.

EXAMPLE: FAMOUS DEMISE OF FIRST US SPACE STATION SKYLAB IN 1979

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 1000 objects affected, and 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 civilian satellite communication systems (for example. Iridium and Inmarsat). These effects are most common when the signal passes through either the equatorial ionosphere or the 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. This particularly affects geostationary satellites around equinox, when they lie close to the direction of the Sun at certain times of day. Mobile systems with large beamwidths and low signal-to-noise ratios are also impacted.

Satellite systems using linear polarisation multiplexing (horizontal and vertical channels) can experience signal depolarisation. The effect is more severe at the lower (VHF) frequencies. But at times of high solar activity even C-band systems may experience a reduction in signal strength and interference between channels. Most satellite systems use circular polarisation to avoid these effects.

EXAMPLE: DEATHS OF US SOLDIERS MAY BE DUE TO SATELLITE DISRUPTION

4 Mar 2002 – The deaths of 3 American soldiers in Afghanistan's Takur Ghar may be due to satellite communication disruptions caused by plasma bubbles.

Satellite navigation

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

As mentioned above, major solar flares, CMEs and geomagnetic storms can increase the flux of high-energy subatomic particles, disrupting or disabling satellites. This includes global positioning system (GPS) satellites. Even if GPS satellites survive an extreme space weather event, the signals they send are likely to be disrupted by ionospheric density gradients and scintillation, causing drops-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, but the errors will be less for dual-frequency receivers. These impacts could last for up to a few days.

Extreme space weather can also disrupt augmented GPS systems, for example, airport landing systems. Severe geomagnetic storms can also cause precision magnetic compasses to become unreliable.

EXAMPLE: INTENSE SOLAR RADIO BURSTS

6 December 2006 – Solar radio bursts were sufficiently intense to be measurable with civilian GPS receivers, including those employed by the Wide Area Augmentation System. This is a system of satellites and ground stations that provides GPS signal corrections.

Aviation flight operations

The potential impacts of space weather on military aviation are like those on civil aviation. The impacts are summarised in greater detail in the aviation sector fact sheet. Briefly, severe space weather can produce the following effects:

- 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: AIR TRAFFIC CONTROL RADAR DISTURBANCE

4 November 2015 – Secondary air traffic control radar was strongly disturbed in Sweden and some other European countries. The disturbances coincided with the time of peaks 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)

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 HF

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 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 and x-ray 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 predict.

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

Solar radio bursts (SRBs) 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 SRBs in the same way (as it operates within the UHF frequency band).

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

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

Modern digital communications

2G networks often use GPS timing signals for synchronisation between adjacent cells to avoid interference where cell coverage areas overlap. In 4G and 5G networks where GPS synchronisation is required, outages of an hour or so can be tolerated, but longer outages have an impact on the network.

When space weather interferes with GPS signals the likelihood of mobile phone interference increases. Because some 5G networks use multiple GPS satellites simultaneously, they are more susceptible to space weather than earlier generations.

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: The May 1967 great storm and radio disruption event: Extreme space weather and extraordinary responses, doi.org/10.1002/2016SW001423)

Over-the-horizon radar

The Jindalee over-the-horizon radar network (JORN) employs HF radio signals, so is subject to the same effects as discussed above for HF radio communications. Solar flares, solar radio bursts and ionospheric storms all impact the performance of the radars.

Especially when a strong ionospheric storm penetrates to the equatorial and tropical regions, the loss of higher frequencies can reduce the effective range of the radars. This limits the geographic area that can be covered. 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 to the ground and/or inaccurate speed and range information.

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

Undersea communications cables

There is a possible threat from space weather to communication using long-distance undersea optical fibre cables. Optical signals travelling along these cables require boosting from repeaters spaced along the cable. The repeaters are powered by long electric wires running parallel to the optical fibre cables. As with any other long electrical conductors, these wires are impacted by the geomagnetically induced currents (GICs) that occur during geomagnetic storms. It is unclear whether GICs at strengths sufficient to disrupt or damage these repeaters are likely to occur. This space weather impact is an active area of research.

EXAMPLE: LARGE VOLTAGES RECORDED ON TRANSATLANTIC COMMUNICATIONS CABLE

March 1989 – 'At the time of the March 1989 storm, a new transatlantic telecommunications fibre-optic cable was in use. It did not experience a disruption, but large induced voltages were observed on the power supply cables. Future cables, because of improvements in the fibre optics, may use fewer repeaters and require a lower driving voltage. However, downsizing the power feed equipment without taking account of the induced voltages may leave future systems more vulnerable to geomagnetic effects.' (Reference: Geomagnetic Effects on Communication Cables, spaceweather.gc.ca/tech/se-cab-en.php)

Response to a severe space weather event

Like 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 Defence to limit its space weather risks, including delivery of:

- space weather forecasts, warnings and alerts
- daily reports, special forecasts and post-event analysis
- 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 planning
- 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 (forecasts, warnings and alerts) to understand the possible reasons for system degradation.

Other potential actions are outlined below.

Aviation flight operations

Reduce altitude and latitude of aviation platforms during radiation storms.

Radio communication and radar

Switch to lower HF radio frequencies during ionospheric depressions and to higher HF radio frequencies during solar flares.

Over-the-horizon radar

- Monitor space weather forecasts, warnings and alerts.
- Royal Australian Air Force unit 1RSU to notify Defence units of expected mission impacts.
- Switch to lower HF radio frequencies during ionospheric depressions and to higher HF radio frequencies during solar flares.

Longer-term mitigation measures

Understanding space weather risk also means designing and managing processes, systems, and infrastructure differently. With targeted research and development Australia's resilience can be increased.

To ensure Defence resiliance the Bureau:

- continue to conduct risk assessments to obtain a comprehensive understanding of the direct impacts of space weather on the various industries within this sector and subsequent indirect impacts due to dependencies across other sectors.
- continue to practice under the Australian Government Crisis Management Framework to respond to space weather events that coordinates 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.
- develop and maintain communication technology diversity.
- all critical military systems backed up with diesel, solar or wind generators.

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