Australian Government
Bureau of Meteorology

# Overview of space weather and potential impacts and mitigation for the space sector

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

## Key points

- Space weather can impact essential space technology, including satellite-based communication and global positioning system (GPS) navigation. These technologies are increasingly vital to many sectors, including finance, aviation, transport and national security.
- Severe space weather can disrupt the normal functioning of spacecraft or cause complete failure.
- People in space are exposed to the harmful radiation associated with severe space weather, risking health.
- Ongoing space weather research will help the space sector plan and prepare for severe events.
- Further engagement with the space sector is required to understand the cross-sectoral impacts of 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 the space sector?

The world is becoming increasingly dependent on space-based systems and technologies. Many of these are vulnerable to space weather. Satellite-based communication and navigation systems (such as GPS) are critical to many economic sectors. The financial, aviation and transport, and national security sectors are particularly dependent.

The space economy is on the increase. Some estimates indicate the global space sector could generate as much as USD$1 trillion in revenue by 2040, up from $350 billion in 2020. A severe space weather event may cause satellite anomalies or failure, leading to a high cost of replacement.

## Satellites, communication and GPS navigation

Satellites spend their lifetime in the near-Earth space environment so are very exposed to space weather. Their sensitive electronic equipment and solar panels can sustain costly damage from radiation.

Satellite components are becoming smaller, which also makes them more vulnerable to the effects of space weather. Impacts include reduced performance and, in some cases, system failure.

The main source of damaging radiation is the Sun. However the Earth's own radiation belts and distant cosmological sources such as black holes can also disrupt satellites. Radiation can interact with satellite electronic systems in several ways, causing temporary disruption or permanent damage.

### EXAMPLE: SATELLITE ANOMALIES AND LOSS DURING SPACE WEATHER STORMS

During the 2003 Halloween space weather storms, 10% of all satellites in orbit reported anomalies. One scientific satellite was lost, and 10 satellites lost operational service for more than one day.

Severe space weather doesn't just threaten satellites themselves, but also the functions they perform, including communication and navigation services. The space sector uses these communication and navigation systems to manage their space assets.

Severe space weather can interrupt radio waves passing between satellites and ground receivers. This disrupts satellite-based communication and navigation services. Estimates show that during a major storm, there could be a complete loss of global navigation satellite system service for one day, and an extended loss of service for three days.

Impacts on the space sector include:

- outages in position and timing information for spacecraft in low-Earth orbit
- reduced control of satellites due to poor performance or outages of satellite navigation systems
- reduced GPS navigation accuracy, degrading the performance of space assets

### EXAMPLE: SEVERE SPACE WEATHER CAUSES LOSS OF DATA AND TELEVISION SERVICES IN CANADA

In 1994 severe space weather caused the failure of two Canadian communications satellites within 9 hours of each other. The failure caused disrupted data transmissions across Canada, and disconnected data and television services to over 1600 remote communities for several hours. Full commercial service of one of the satellites wasn't restored for over 6 months. This resulted in losses of at least $13 million to the satellite operator.

## Space object location

Space weather can affect a space object's orbit, causing it to lose altitude, and even re-enter the atmosphere. Object tracking and control can also be affected by severe space weather. This increases the risk of collision with other space objects, resulting in space debris. Debris can damage spacecraft and is a potential risk to human life.

During severe space weather, the Earth's upper atmosphere may become denser, this leads to increased drag on satellites and changes their orbit. These changes need to be corrected to avoid collision or loss of control.

### EXAMPLE: SATELLITE ENDS MISSION EARLY BECAUSE OF SPACE WEATHER

Japan's ASCA satellite had to end its mission early in July 2000 because of changes to its orbit caused by space weather. The satellite reentered the atmosphere in 2001 following loss of altitude control.

## Spacecraft launch

Space weather can affect spacecraft launches. If there is too much radiation, crucial control and guidance systems can be damaged during high-altitude launch stages.

### EXAMPLE: NASA DELAYS ROCKET LAUNCH TO AVOID RADIATION

In January 2014, the launch of a rocket from one of NASA's flight facilities had to be delayed because of a coronal mass ejection. The international space stations resupply mission was rescheduled to the following day when radiation levels had subsided.

### People in space

Radiation is a serious risk to the people who live and work in space. With mass space tourism set to become a reality in the next 10–20 years, more people will be exposed. Radiation can seriously affect life expectancy. Extreme radiation storms can be lethal.

### EXAMPLE: ASTRONAUTS IN THE INTERNATIONAL SPACE STATION AFFECTED BY RADIATION

In October–November 2003, radiation levels were so intense that the astronauts in the International Space Station had to shelter deep within the habitation module. Despite this, the astronauts reported experiencing the effect of radiation exposure, including ocular shooting stars.

## Response to a severe space weather event

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

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. Users can subscribe to alerts and warnings via the Bureau's Space Weather Services website.

To limit space weather risks, the Bureau works closely with the space sector, including:

- general space weather forecasts, warnings and alerts
- customised real-time data services supporting the Australian Space Agency's Mission Control Centre
- aviation weather services in support of space launch and return
- post-event analysis of satellite system anomolies.

To mitigate the immediate effects of severe space weather and ensure continuity of operations, the space sector can:

- switch spacecraft to safe mode to prevent its damage or complete loss
- modify the schedule of mission-critical spacecraft maneuvers
- delay the launch of space assets.

## 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 the space sector becomes more resilient in the future, the Bureau:

- develop a national plan across relevant departments, agencies and industry sectors to identify cross-sector impacts and design appropriate mitigation strategies.
- invest in further research on how the space sector can strengthen its resilience to severe space weather.
- embed space weather data into mission control operations.
- invest in observing equipment for the space environment.
- use and maintain alternative land-based communication and navigation systems.
- design satellite systems to operate autonomously throughout outages.
- increase real-time awareness of satellite locations.
- increase orbital modelling capability to detect changes during solar storms.

- develop spacecraft technology to allow autonomous orbital correction.
- include radiation monitors on satellites to help understand spacecraft anomalies.
- design radiation-hardened spacecraft and payloads.
- develop safe hibernation recovery modes for use during severe radiation events.
- 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.