Australian Government
Bureau of Meteorology

Australian Space Weather Alert System

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Disclaimer:

Contents

Australian Space Weather Alert System

This alert system has been developed to communicate space weather conditions and their possible effects on Australian industry sectors and the community. It also outlines mitigating actions that can be taken by operators and decision-makers in response to the alert thresholds.

The Bureau of Meteorology space weather capability

The Bureau monitors and forecasts space weather to provide warnings and alerts to Government, including the Department of Home Affairs, National Situation Room (NSR), industries including energy, aviation and space, and all Australians who could be affected. This allows Government and relevant sectors to take precautions and prepare to reduce the effects of a space weather event.

The Bureau offers forecasting and real-time observations of space weather. For significant space weather events, the Bureau's space weather specialists deliver warnings and alerts.

The Bureau works closely with all sectors to help limit risks to their operations, providing:

- space weather forecasts, warnings and alerts
- customised online information
- space weather education.

In the Australian Space Weather Forecasting Centre, space weather forecasters assess the behaviour of the Sun and local space environment, and issue space weather products such as reports, warnings and alerts.

What is space weather?

The Sun is the principal driver of what is known as space weather.

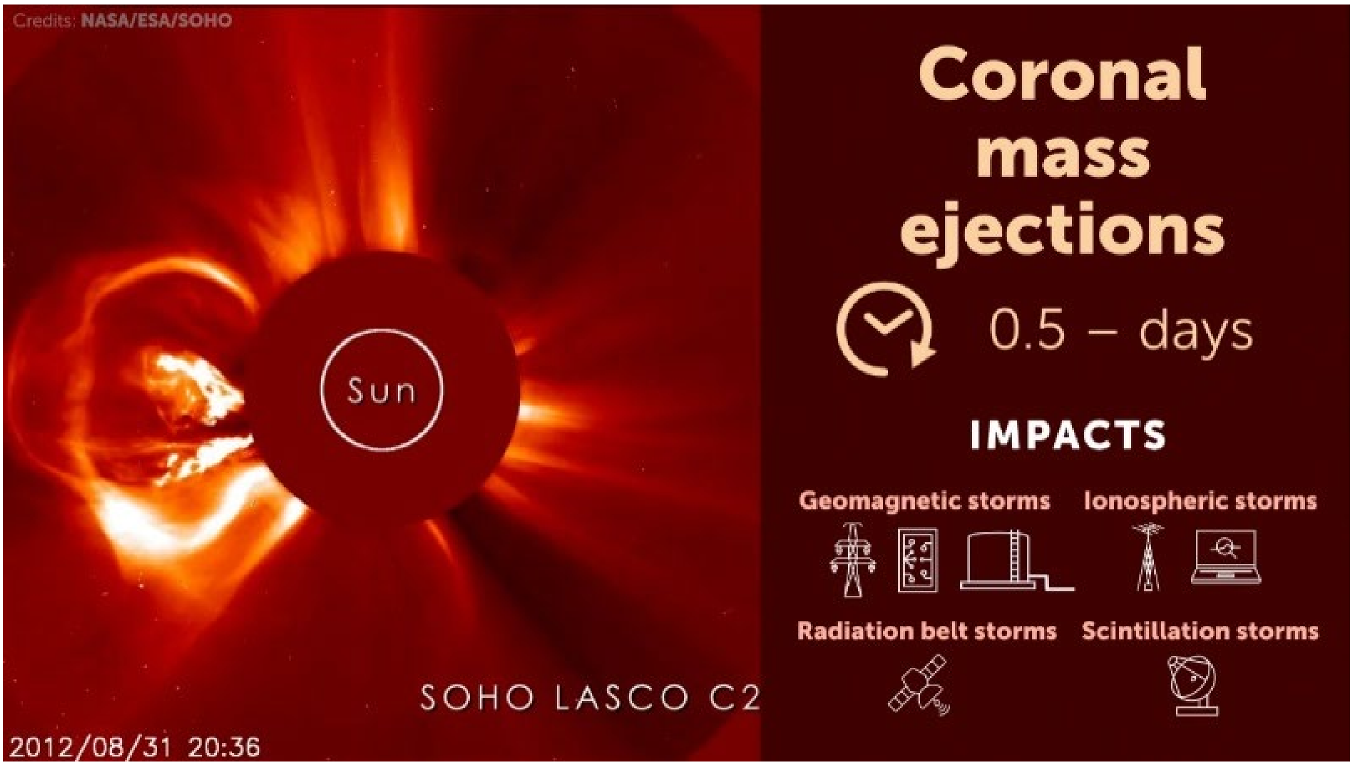
Space weather can affect our technology and the near-Earth space environment by:

- varying the Earth's magnetic field
- enhancing electrical fields and currents in the atmosphere and the ground
- increasing the amount of radiation entering the upper atmosphere
- varying the density and stability of the upper atmosphere.

Space weather can disrupt many of Australia's critical services, such as Global Positioning System (GPS) navigation and radio communications. It can also damage satellites, disrupt electricity transmission networks and affect aviation and the safety of air passengers and crew.

Space weather events include coronal mass ejections (CMEs), particle radiation and solar flares.

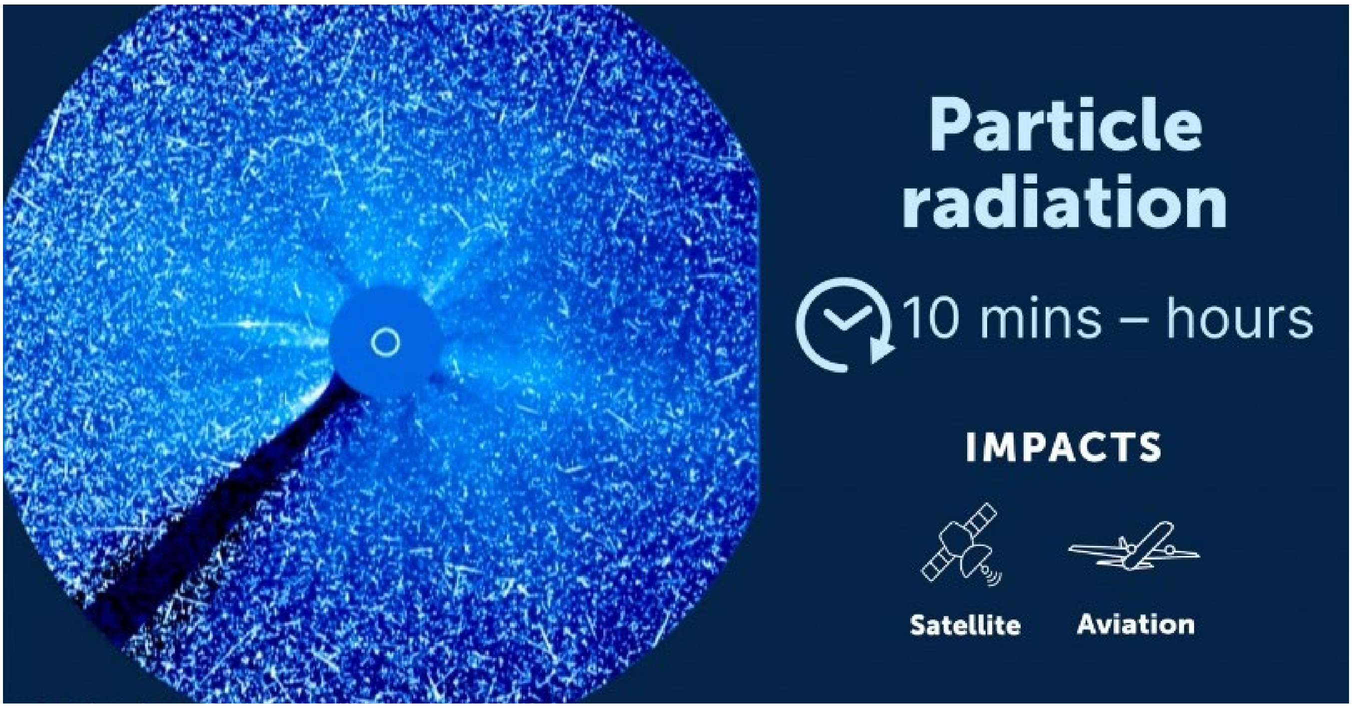
Coronal mass ejections



Coronal mass ejections (CMEs) occur when large clouds of plasma and magnetic fields erupt in the Sun's outer atmosphere. When the plasma from a CME arrives at Earth, usually within 15 hours to several days, it causes geomagnetic storms.

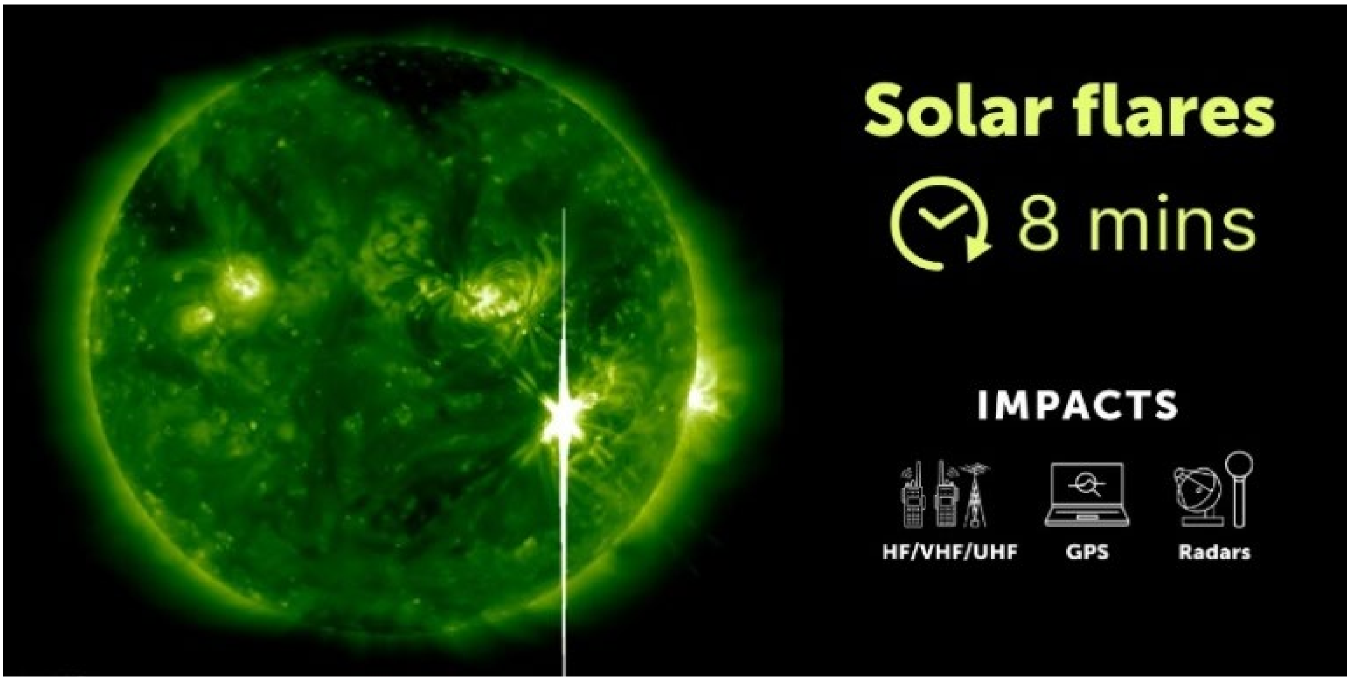
Geomagnetic storms can disrupt electricity grids, data centres, treatment plants and other critical technology. These events can subsequently lead to ionospheric storms, which can impact high frequency and satellite communications; radiation belt storms, which can impact satellites; and scintillation storms, which can impact radar. Image credit: NASA/ESA/SOHO

Particle radiation



Solar energetic particle events are bursts of high-energy protons accelerated in the Sun's outer atmosphere. The protons are accelerated to speeds comparable to the speed of light. When directed towards Earth, they arrive ten minutes to hours after occurring. Particle radiation can impact satellites and can cause health concerns for astronauts and air passengers and crew. Image credit: NASA/ESA/SOHO

Solar flares



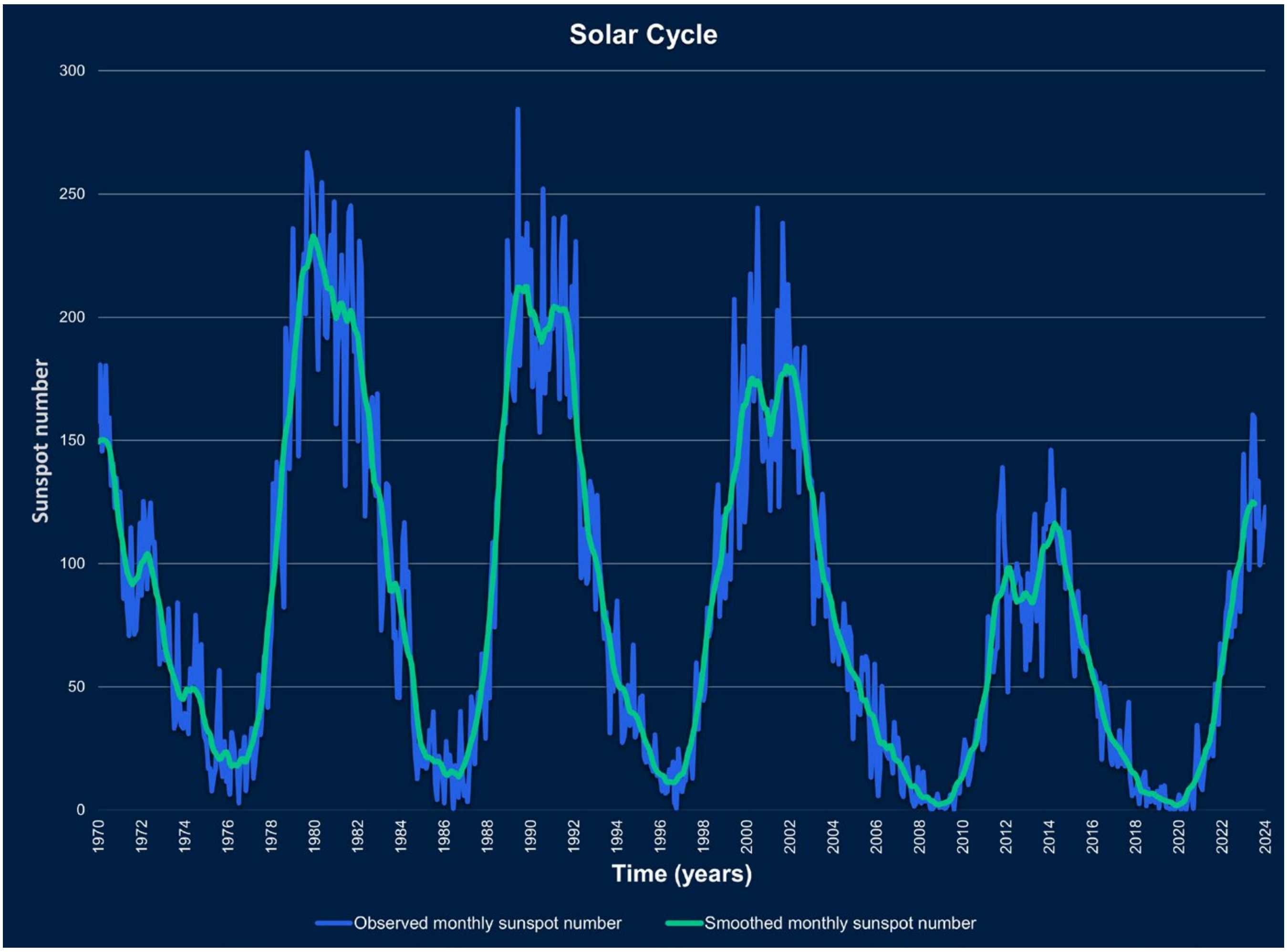
Solar flares are sudden bursts of X-ray energy from the Sun. The X-rays travel at the speed of light and impact Earth within eight minutes of occurring. They can impact high frequency communications, GPS and radar technology. Image credit: NASA/ESA/SOHO

The solar cycle

The Sun has a cycle of activity over approximately 11 years called the solar cycle.

A solar cycle begins at solar minimum with little solar activity and few sunspots. Sunspots are dark areas on the Sun that indicate solar activity. As the cycle evolves, events such as flares and coronal mass ejections increase in number, as do sunspots. The peak of the cycle, where solar activity is greatest, is called solar maximum. Following this, solar activity gradually declines, returning to solar minimum at the end of the cycle.

Space weather events occur more frequently and with increased intensity around the solar maximum, however, significant space weather events have been observed at other times too.



The graph shows smoothed (green line) and observed (blue line) monthly sunspot numbers from 1970 onwards. Solar cycle 24, which started in 2008, was the least active since solar cycle 14 which started in 1902. Data source: Solar Influences Data Analysis Center, Belgium.

Major space weather event timeline

Our knowledge of the occurrence of extreme solar storms is gradually improving as ancient records and geological (radioisotope) signatures are discovered. For example, there is evidence of extreme solar storms occurring during late Roman times and the so-called Dark Ages of around 500–1000 AD. These storms may have been far more intense than any event occurring in the past 200 years. There is clearer evidence of the storms that have occurred in the last half century, since technology to monitor these events has been available.

The following timeline is a summary of documented major space weather events. All these storms reached G5, S5 and/or R5 conditions.

The 2003 Halloween Storms described below were the last known extreme storms of the 21st century. Solar cycle 24, which ended in 2019, was the weakest solar cycle in a century. There were no G5, S5 or R5 events during cycle 24. The Sun was exceptionally benign during this period.

September 1770

Sunspot drawings show a solar active region twice the size of the region responsible for the famous Carrington Event of 1859. Generally auroras are sighted at higher latitudes in polar regions. However more than 100 accounts have documented unusually intense auroral displays at low latitudes throughout East Asia. These events may have equalled or exceeded the intensity of the Carrington Event.

September 1859

The Carrington Event is the most extreme solar storm ever documented. Telegraph machines reportedly shocked operators and caused small fires. Auroras were visible in tropical regions. Hundreds of articles have been published discussing the widespread observations and impacts.

February 1872

Again, historical records throughout East Asia corroborate a great geomagnetic storm, possibly equalling or exceeding the intensity of the Carrington Event. Auroras were observed as far south as Mumbai in India.

November 1882

A great auroral beam was observed at Greenwich Observatory near London and some telegraph wires were rendered inoperable. The Savannah Morning News reported that ‘the switchboard at the Chicago Western Union office was set on fire several times, and much damage to equipment was done’.

October 1903

An extreme solar storm produced widespread disruptions to the telegraph service, the ‘internet’ of the age. Bright auroras were observed at unusually low latitudes. The noteworthy feature of this event is its occurrence shortly after solar minimum during one of the weakest solar cycles on record.

May 1921

This geomagnetic storm was probably the most extreme of the 20th century. There were severe, widespread disruptions to the telegraph service. The induced ground currents started fires in some telephone stations. Widespread outages of High Frequency (HF) radio communications lasted for days.

January 1938

This geomagnetic storm was remarkable for the widespread reports of bright auroras down to low latitudes. All transatlantic radio communication was disrupted, and Canada suffered a 12-hour short-wave radio blackout. The electricity grid, which was still in its infancy, experienced minimal disruption.

September 1941

This great storm produced radio blackouts and interfered with telephone calls. The bright auroras may have illuminated a transatlantic shipping convoy exposing it to attack by German submarines.

May 1967

The 1967 geomagnetic storm almost started nuclear warfare between the USA and the USSR. Blackout of polar surveillance radars during the Cold War led to the mobilisation of US nuclear bomber squadrons for a strike on the USSR, until the Sun was identified as the source of the radio interference.

August 1972

The 1972 geomagnetic storm detonated numerous magnetic sea mines, possibly as many as 4000, off the coast of North Vietnam. There were other widespread technological impacts, including disruptions to the electricity grid in the USA.

March 1989

The 1989 storm is considered the most powerful since the great storm of 1921. It produced electrical power blackouts throughout Quebec, Canada and north-east USA, resulting in major direct and indirect economic losses. Numerous radio communication blackouts and satellite anomalies were reported. The Australian Army lost HF radio communication during a peacekeeping deployment in Namibia.

August 1989

A major geomagnetic storm is thought to have caused the failure of the Toronto stock market computer systems, causing a halt in trading for 3 hours.

October–November 2003

The sequence of intense solar flares and geomagnetic storms occurring throughout October and November are known as the Halloween solar storms. They included a rare, exceptionally powerful solar flare with an estimated magnitude of at least X28. During the main geomagnetic storm, ground-induced currents caused a 1-hour power blackout in Sweden. There were widespread disruptions to satellites and communication systems. Civil aviation was advised to avoid high altitude flights near the polar regions because of HF radio blackouts and the increased radiation hazard.

Australian Space Weather Alert System scales

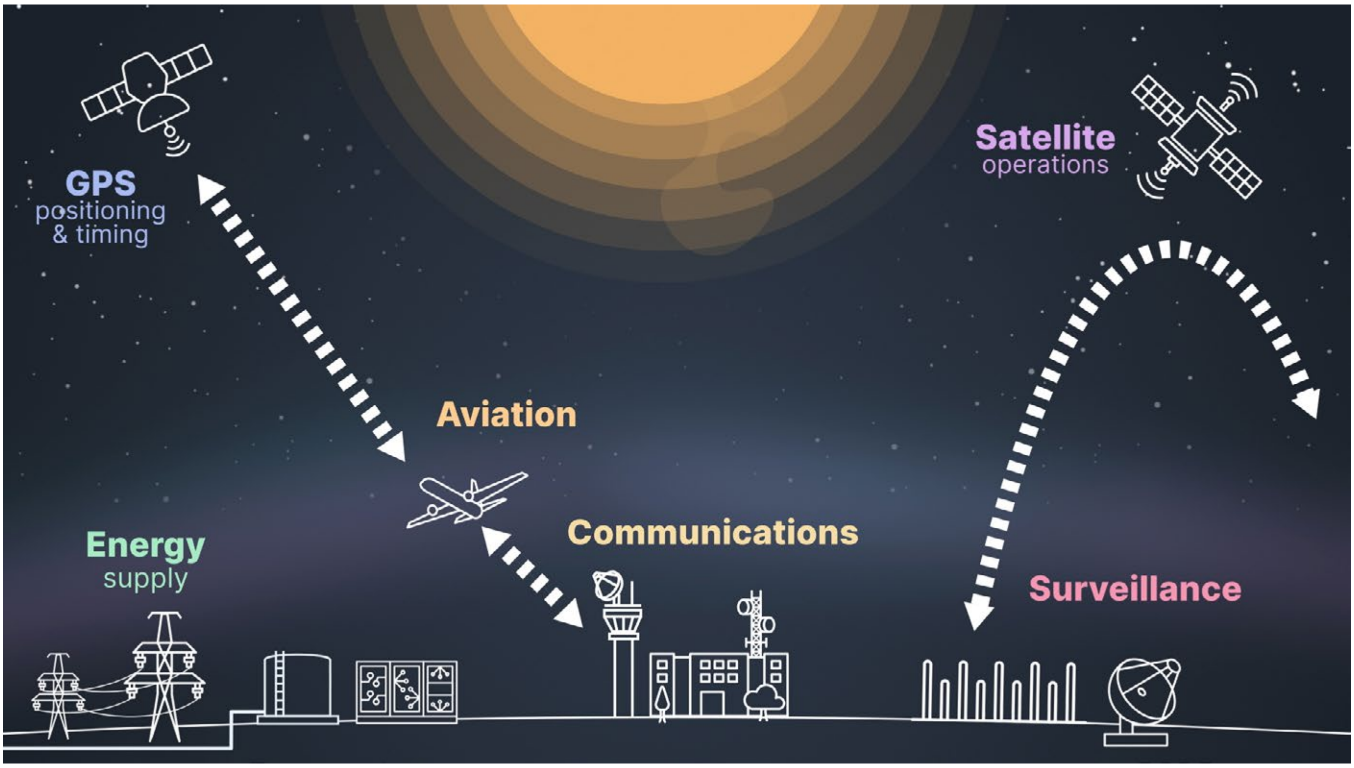
The Australian Space Weather Alert System uses 3 scales:

- G-scale for geomagnetic storms
- S-scale for solar radiation storms
- R-scale for radio blackouts.

Each scale ranges from 1 to 5. An event of the weakest intensity is 1 and the strongest is 5. An event at 3 or higher may require action by operators of technology systems in some space weather affected sectors to mitigate risks. The higher the number, the greater the likelihood that a larger number of systems will be impacted to a greater degree.

Estimates of the frequency of occurrence of these categories of space weather events within a typical solar cycle are based on less than 100 years of observations. The most severe conditions will occur more frequently during some solar cycles, yet not at all in others. Every solar cycle is unique. Solar storm impacts are not globally uniform. For example, high latitude locations are more likely to directly experience the effects of a storm.

The scales are adapted for Australian use from those produced by the United States National Oceanic and Atmospheric Administration (NOAA). These scales are not formally agreed by the World Meteorological Organization, however are internationally accepted and used by many space weather monitoring agencies.



Space weather can disrupt many of our critical services, such as GPS navigation and radio communications.

Geomagnetic storms

The G-scale is for global geomagnetic activity – variations to Earth's magnetic field.

Geomagnetic storms of G4 to G5 levels may cause:

- partial failure to complete collapse of some power grids
- disruption of satellite functions or temporary/permanent loss of some satellites
- disruption to satellite communication systems
- degradation to satellite navigation systems
- failures of high frequency (HF) communications systems.

Geomagnetic activity is measured by the variation in magnetic field fluctuation caused by currents flowing in space. Globally, magnetic field fluctuations are measured by Kp values, calculated every 3 hours.

The G-scale is determined by the global Kp values. For example, a Kp value between 5 and 6 is the threshold used to designate a G1 event, and a Kp value of 9 and above is used to designate a G5 event.

The longer a significant geomagnetic storm lasts the stronger its effects will be. Geomagnetic storms generally last between one to four days.

The estimated frequency of these events per solar cycle has been determined by examining events since 1932, over eight solar cycles.

A NASA space physicist took this picture during a geomagnetic storm while attending a scientific conference to study auroras in Poker Flat, Alaska. Image credit: NASA/James Spann

G5 – Extreme

G5 conditions are extreme, measured by a Kp value of 9 or above. Globally, these conditions occur approximately four times per solar cycle. Australian region Geomagnetic Storm conditions are often weaker than planetary conditions. The greatest probability of a G5 is in the declining phase of the solar cycle, one to three years after solar maximum.

Sector impacts and risk mitigation

Energy

- Geomagnetically induced electric currents (GICs) may flow in multiple locations in the electricity grid. Assets may be damaged and power outages are possible.
- Transmission network service providers may advise transformers to be de-rated or removed from service at multiple locations. Australian Energy Market Operator (AEMO) may issue load-shedding instructions to maintain system security.

Aviation

- Global Navigation Satellite system (GNSS) positioning accuracy and availability may be degraded.
- Impacts will be more severe in the equatorial and high-latitude regions but they may also extend to middle latitudes for extreme events.
- Ground-based augmentation systems (GBAS) for GPS may be compromised.
- High frequency (HF) communications may be severely degraded or unavailable in some regions.
- The strongest effects are likely over the polar regions where both GNSS-based positioning and HF communications may be completely unavailable.
- The International Civil Aviation Organization (ICAO) provides a global advisory service with thresholds for GNSS, HF communication, and radiation. These levels do not correspond directly to the G-scale but enable the industry to manage the risk of increased geomagnetic activity. It is expected that aviation operators have access to the ICAO advisories and a plan to mitigate impacts.
- Aircraft operators can monitor for ICAO advisories and activate operational procedures. Operators may use alternate or modified routes, or delay flights to avoid affected areas. GNSS uncertainties may require greater spacing between aircraft according to phase of flight. GNSS errors can affect airports and en-route aircraft to different degrees. Use of alternate means of communication and/or navigation may be required in specific locations, particularly at high latitudes. GBAS may be set to ‘unavailable’ in response to Bureau advisories.

Defence

- Performance of HF radio and radar may be degraded for several hours. Possible temporary failures of GNSS, satellite communication and internet. Payloads on military satellites may fail.
- Defence may switch to alternative communication and surveillance systems and delay using GNSS-dependent systems.

Space

- Loss of tracking of numerous low Earth orbit objects (LEOs) due to changes in their orbits. LEOs may re-enter the Earth's atmosphere. Services provided by satellites may be disrupted.
- Space operators can adjust orbits to avoid collisions and re-entry. Space domain awareness sensors to be tasked 24/7 with recovery of lost objects. New launches should be postponed.

Community

- Auroras may be visible from as far north as southern Queensland and other low-latitude locations.
- The community should be advised to follow the advice of police and emergency services in the event that communication systems, energy systems and transportation fails.

G4 – Severe

A G4 event is when the Kp value is between 8 and 9. Globally, these conditions occur approximately 100 times per solar cycle. Australian region Geomagnetic Storm conditions are often weaker than planetary conditions.

Sector impacts and risk mitigation

Energy

- Significant GICs may flow in isolated locations in the electricity grid. Isolated asset damage is possible.
- Transmission network service providers may advise for transformers to be de-rated or removed from service. AEMO may issue load-shedding instructions to maintain system security.

Aviation

- Global Navigation Satellite system (GNSS) positioning accuracy and availability may be degraded.
- Ground-based augmentation systems (GBAS) for GPS may be compromised.
- HF communications may be severely degraded or unavailable in some regions.
- Strongest effects are likely over the polar regions where both GNSS-based positioning and HF communications may be completely unavailable.
- Aviation operators can monitor for ICAO space weather advisories (GNSS and HF communication) and activate operational procedures. Mitigating actions might include use of alternate or modified routes or delaying flights to avoid affected areas. Use of alternate means of communication and/or navigation may be required at times in specific locations, particularly at high latitudes.

Defence

- Performance of HF radio and radar may be degraded for several hours. Temporary failures of GNSS and satellite communication and internet are possible. Payloads on military satellites may fail.
- Defence can consider postponing operations with critical dependencies on affected technologies.

Space

- Expect loss of tracking of some LEOs due to changes in their orbits. LEOs may re-enter the Earth's atmosphere. Services provided by satellites may be disrupted.
- Space operators can adjust orbits to avoid collisions and re-entry. Space domain awareness sensors to be tasked with recovery of lost objects. Postpone new launches.

Community

- Bright auroras will be visible at unusually low latitudes, including dark-sky locations near Sydney and Perth.

G3 – Strong

A G3 event is when the Kp value is between 7 and 8. Globally, these conditions occur approximately 200 times per solar cycle. Australian region Geomagnetic Storm conditions are often weaker than planetary conditions.

Sector impacts and risk mitigation

Energy

- Enhanced GICs may flow in multiple locations in the electricity grid.
- AEMO or transmission network service providers may maximise dynamic reactive reserves across the power system and instruct the restoration of transmission outages.

Space

- Minor changes to the orbits of LEOs are likely. Some service disruptions are possible.
- Space operators can stand by to adjust orbits and monitor the quality of services requiring transmission of radio frequency signals between the satellite and Earth.

Aviation

- Reduced performance of HF radio, particularly at higher frequencies. Intermittent degradation in GNSS performance, primarily across the polar region and near the equator between dusk and midnight.
- Aviation operators can monitor for ICAO space weather advisories and activate operational procedures. Mitigating actions are likely to affect flights across or near the polar regions and may include delaying or re-routing flights to avoid affected areas. Prepare for the potential loss or significant degradation of GNSS-based positioning and satellite communications near the equator between dusk and midnight.

Community

- Aurora sightings from dark-sky locations in southern Australia are very likely, including Tasmania and southern Victoria.

Defence

- The available bandwidth for HF radio and radar may be limited for significant periods. Increased risk of temporary failure of GNSS, satellite communications and satellite internet access near the equator and at high latitudes.
- Amber condition for missions with critical dependency on HF communications and radar, and GNSS. Expect dropouts in GNSS and satellite communications near the equator between dusk and midnight.

G2 – Moderate

A G2 event is when the Kp value is between 6 and 7. Globally, these conditions occur approximately 600 times per solar cycle. Australian region Geomagnetic Storm conditions are often weaker than planetary conditions.

Sector impacts and risk mitigation

Energy

- Enhanced GICs may flow in isolated locations in the electricity grid.
- AEMO and transmission network service providers can maintain increased situational awareness and increased awareness of GIC monitoring equipment levels on the power system.

Aviation

- Reduced performance of HF radio, particularly at higher frequencies. Minor intermittent degradation in GNSS performance across the polar regions.
- Aviation operators can monitor for ICAO space weather advisories and implement operational procedures for flights through the affected area. Mitigation might include ensuring suitable alternatives for communication and navigation/ surveillance.

Defence

- Reduced performance of HF radio and radar. Intermittent dropout of GNSS near the equator.
- Amber conditions for missions with critical dependency on HF communication and radar, and GNSS. Temporary dropouts in GNSS and satellite communications near the equator at dusk.

Space

- Change to orbits and service disruptions are expected to be minor.
- The space industry can monitor spacecraft health and orbits in case the geomagnetic storm intensifies.

Community

- Auroras visible from Tasmania and southern Victoria.

G1 – Minor

A G1 event is when the Kp value is between 5 and 6. Globally, these conditions occur approximately 1700 times per solar cycle. Australian region Geomagnetic Storm conditions are often weaker than planetary conditions.

Sector impacts and risk mitigation

Energy

- Weak GICs may flow in isolated locations in the electricity grid.
- AEMO and transmission network service providers can monitor the evolving space weather conditions and the GIC monitoring equipment levels on the power system.

Aviation

- Reduced performance of HF radio, particularly at higher frequencies. Minor intermittent degradation in GNSS performance across the polar regions.
- Aviation operators can monitor for ICAO space weather advisories and implement operational procedures for flights through the affected area. Mitigation might include ensuring suitable alternatives for communication and navigation/surveillance.

Defence

- Reduced performance of HF radio and radar. Intermittent dropout of GNSS near the equator.

Solar radiation storms

The S-scale is for solar radiation storms – surges in high-energy protons directed towards the Earth from the Sun. Solar radiation storms typically last from several hours to two days and they are very difficult to forecast.

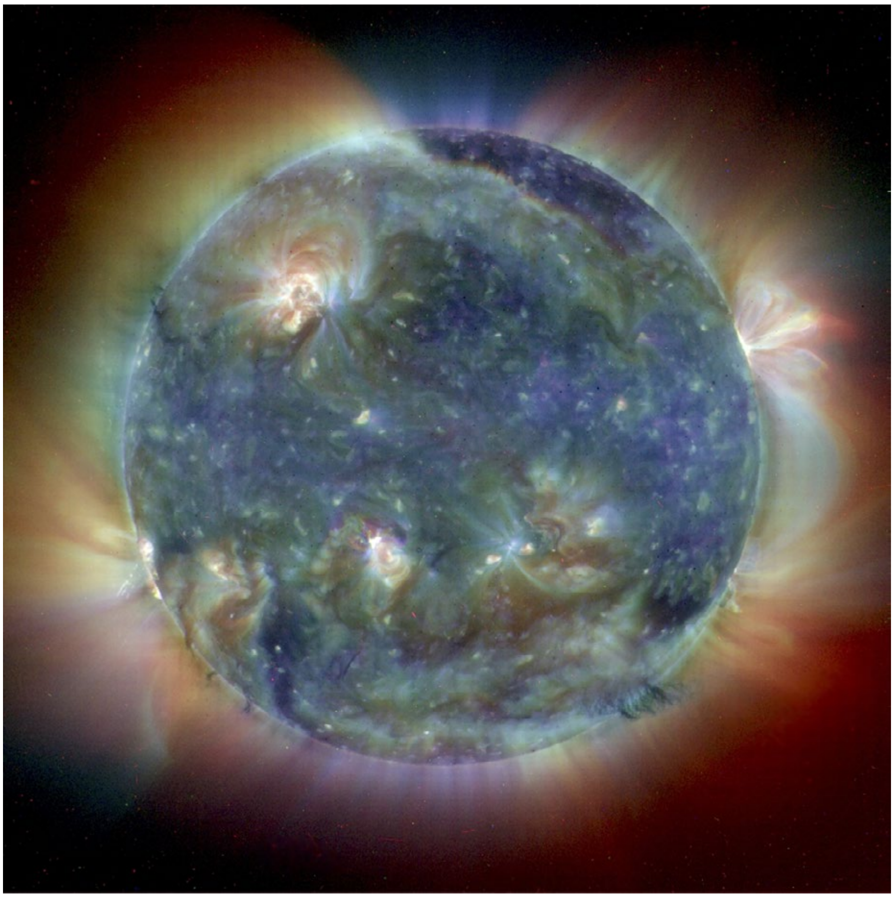
Solar radiation storms of S4 to S5 levels may:

- lead to high radiation hazard to astronauts and people in high-flying aircraft at high latitudes
- disrupt satellite operations in various ways
- cause position errors in navigation
- lead to complete blackout of HF communication in the polar regions.

The GOES-18 weather satellite has a radiation detector that measures the arrival of protons with energies greater than the energy obtained when accelerated through a voltage of 10 million volts. The solar radiation S-scale is determined by the number of these high-energy protons reaching Earth per second, per unit area, per unit solid angle.

One proton flux unit is equal to one proton with an energy of 10 million volts or greater reaching Earth per second, per unit area, per unit solid angle.

The frequency of these events per solar cycle has been determined by examining events since 1976, over four solar cycles.



This composite image combines extreme ultraviolet imaging telescope (EIT) images from three wavelengths (171Å, 195Å and 284Å) into one that reveals solar features unique to each wavelength. Since the EIT images come to us from the spacecraft in black and white, they are color coded for easy identification. For this image, the nearly simultaneous images from May 1998 were each given a color code (red, yellow and blue) and merged into one. Image credit: SOHO (ESA & NASA).

S5 – Extreme

An S5 radiation event corresponds to the high-energy proton flux exceeding 100,000 proton flux units. These extreme conditions are very rare and occur fewer than once per solar cycle. These events typically last from several hours to two days. The last S5 event happened prior to 1976.

Sector impacts and risk mitigation

Aviation

- Passengers and aircrew flying on cross-polar and high latitude routes are at risk of increased radiation exposure.
- Increased risk of electronic equipment malfunctions on polar flights.
- High frequency (HF) radio communications unavailable in the polar regions for up to a week.
- International Civil Aviation Organization (ICAO) has a global advisory service for health and mechanical impacts, based on effective radiation dose-rate at flight altitude. It also covers the level of absorption of HF radio waves, which affect polar HF radio communications. These levels do not correspond directly to the S-scale but enable the industry to manage the risk of increased radiation levels at flight altitudes.
- It is expected that aviation operators have access to the ICAO advisories and a plan to mitigate the impact of radiation. Mitigating actions might involve alternate route planning (lower altitude and/or latitude) or delaying use of polar routes.

Defence

- Space-based capabilities including communication, navigation and intelligence, surveillance and reconnaissance for electronic warfare and cyber security (ISR) may be unavailable, in some cases permanently. Electronic equipment may fail at high altitude and latitude. HF radio communication will be unavailable for high-latitude circuits.
- Defence may delay military operations relying on space-based capabilities or HF radio and radar at high latitudes.

Space

- Astronauts are at increased risk of lethal radiation exposure. Some satellites may be permanently damaged and rendered inoperable.
- Astronauts must seek maximum radiation shielding. Spacecraft should be placed in safe mode and launches postponed.

Community

- Passengers flying on high-latitude routes are at increased risk of receiving radiation doses that exceed national standards for health and safety.
- Pregnant women should be advised to reconsider flying, especially on high-latitude routes.

S4 – Severe

An S4 radiation event corresponds to the high-energy proton flux exceeding 10,000 proton flux units. These severe conditions occur approximately three times per solar cycle and typically last from several hours to two days.

Sector impacts and risk mitigation

Aviation

- Passengers and aircrew flying on cross-polar and high latitude routes are at risk of increased radiation exposure.
- Increased risk of electronic equipment malfunctions on polar flights.
- HF radio communication will be unavailable in the polar regions for up to a week.
- If ICAO advisories are issued, mitigating actions might involve alternate route planning (lower altitude and/or latitude) or delayed use of polar routes.

Defence

- Space-based capabilities including communication, navigation and ISR may be disabled. Electronic equipment may fail at very high altitude. HF radio communication will be unavailable for high-latitude circuits.
- Defence can delay military operations depending on space-based capabilities or HF radio and radar at high latitudes.

Space

- Increased health risk to astronauts and radiation damage to spacecraft components.
- Astronauts must seek maximum radiation shielding. Spacecraft should be placed in safe mode and space launches postponed.

Community

- Passengers flying on high latitude routes are at increased risk of receiving radiation doses exceeding national standards for health and safety.
- Pregnant women should be advised to reconsider flying, especially on high-latitude routes.

S3 – Strong

An S3 radiation event corresponds to the high-energy proton flux exceeding 1000 proton flux units. These conditions occur approximately eight times per solar cycle and typically last from several hours to two days.

Sector impacts and risk mitigation

Aviation

- Passengers and aircrew flying on cross-polar and high latitude routes are at risk of increased radiation exposure.
- Increased risk of electronic equipment malfunctions on polar flights.
- HF radio communications will be unavailable in the polar regions for days.
- If ICAO issues advisories, mitigating actions might involve alternate route planning (lower altitude and/or latitude) or delaying use of polar routes.

Defence

- Increased risk of space-based capability failure. Electronic equipment may fail at high altitude on polar flights. HF radio communication will be unavailable for high latitude circuits. Radiation-susceptible ISR payloads may be disabled and reduce battlespace awareness.
- Defence can delay operations that are dependent on HF radio and radar at high latitudes.

Space

- Increased radiation risk to astronauts and radiation damage to spacecraft components.
- Space operators can reconsider astronaut 'space walks' and space launches.

Community

- Frequent flyers, such as aircrews, on high-latitude routes might acquire a small increased long-term health risk from radiation exposure.
- The community should follow the advice and direction of flight carriers.

S2 – Moderate

An S2 radiation event corresponds to the high-energy proton flux exceeding 100 proton flux units. These radiation conditions occur approximately 18 times per solar cycle and typically last from several hours to two days.

Sector impacts and risk mitigation

Aviation

- Passengers and aircrew flying on cross-polar and high-latitude routes are at risk of increased radiation exposure.
- Increased risk of electronic equipment malfunctions on polar flights.
- HF radio communications are unavailable in the polar regions for hours to days.
- Aviation operators can monitor ICAO advisories and prepare for potential loss of HF communication on polar flights.

Defence

- Slightly elevated risk of space-based capability failure. Electronic equipment may fail at high altitude on polar flights. HF radio communication may be impacted at polar latitudes. Radiation-susceptible ISR payloads may be affected but recover quickly.

Space

- Increase in payload failures due to higher radiation.
- Space operators can reconsider astronaut 'space walks'.

Community

- Frequent flyers, such as aircrews, on high-latitude routes might acquire an increased long-term health risk from radiation exposure. The risk on any single flight is minor.

S1 – Minor

An S1 radiation event corresponds to the high-energy proton flux exceeding 10 proton flux units. These radiation conditions occur approximately 40 times per solar cycle and typically last from several hours to two days.

Sector impacts and risk mitigation

Aviation

- Areas within the polar regions may experience loss of HF radio communication or degraded HF conditions.
- Aviation operators can monitor ICAO advisories and prepare for potential loss of HF communication on polar flights.

Defence

- No major disruptions of operational systems, including space-based systems.
- Defence can remain alert for possible spacecraft anomalies.

Space

- Slight increase in payload failures due to higher radiation.
- Space operators can remain alert for possible spacecraft anomalies.

Community

- No significant health concerns.

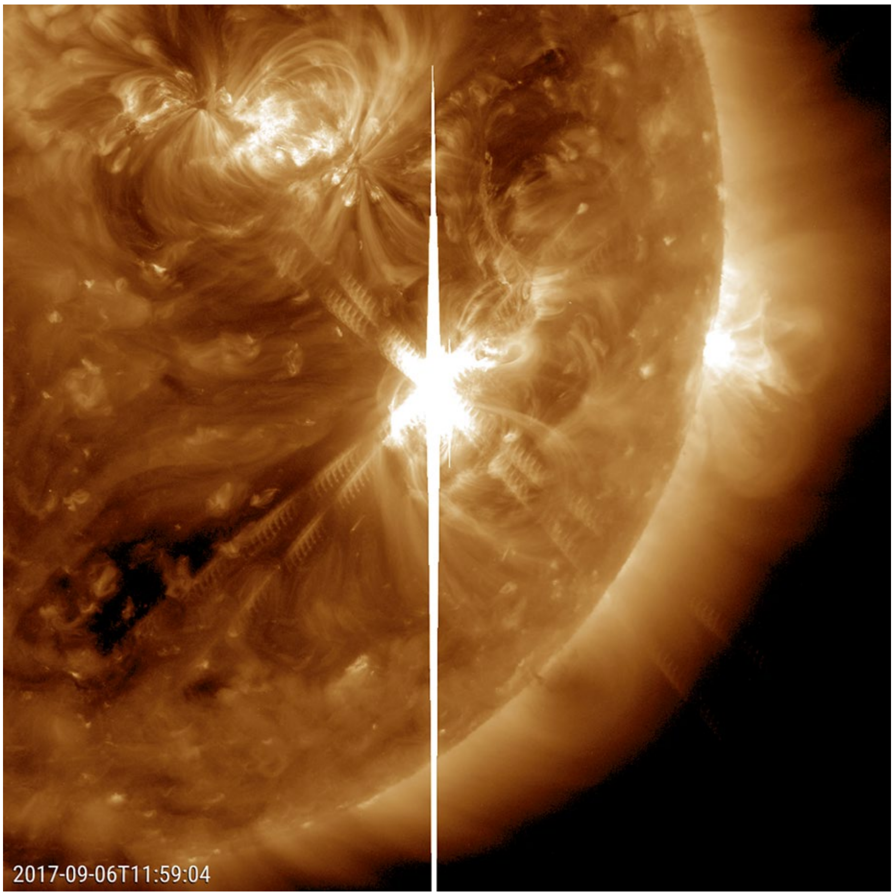
Radio blackouts

The R-scale is for radio blackouts. Also known as shortwave fadeouts, these are caused by large eruptions of electromagnetic energy from the Sun, mainly in the X-ray and extreme ultraviolet frequencies. These eruptions are known as solar flares. Several radio blackouts may occur in one day.

Radio blackouts of R4 to R5 levels may mean:

- complete radio blackout on the daylight side of the Earth, lasting from about ten minutes up to a few hours
- outages of low-frequency navigation systems causing loss in positioning and increased satellite navigation errors.

Conditions that cause radio blackouts are measured by how much X-ray radiation from the Sun is arriving at Earth. The intensity of solar flares is described by a sequence of letter classes A, B, C, M and X, with X-class flares being the most powerful eruptions. Each letter class is further divided into a 10-point scale. For example, an M9 flare is 9 times more powerful than an M1 flare. The frequency of these events per solar cycle has been extracted from the NOAA scales.



Strong solar flare: A large sunspot was the source of a powerful solar flare (an X9.3) on 6 September 2017. The flare created a strong shortwave radio blackout over Europe, Africa and the Atlantic Ocean. The bright vertical line and rays with barred lines are aberrations in the observing instruments caused by the bright flash of the flare. Image credit: NASA Jet Propulsion Laboratory and NASA/GSFC/Solar Dynamics Observatory, PIA21949

R5 – Extreme

R5 radio blackout conditions occur less than once per solar cycle. They involve complete radio blackout on the daylight side of the Earth, lasting from about ten minutes up to a few hours. These conditions occur for rare extreme solar flares of X20 class and greater. The last R5 event was in November 2003, estimated to be at least X28.

Sector impacts and risk mitigation

Aviation

- Complete loss of HF radio communication in daylight areas for one or more periods of up to a few hours. On rare occasions, there may be reduced availability of global navigation satellite systems (GNSS) in daylight areas. This may last for tens of minutes or many hours.
- The International Civil Aviation Organization (ICAO) provides a global advisory service. It is expected that aviation operators have access to the ICAO advisories and a plan to mitigate the impact of HF radio communication and GNSS outages.
- R5 is above ICAO's highest advisory threshold. Operators might switch to alternative communication systems, such as satellite communications or very high frequency (VHF) radio. They may delay or re-route flights where HF communication outages cause loss of system redundancy.

Defence

- Major impacts on operational systems for the duration of the solar flares. Prolonged and complete failure of HF radar and radio in daylight areas. Reduced availability of GNSS, satellite communication and satellite internet access.

Space

- Communication and navigation systems may fail.
- Spacecraft operators can engage safe operating modes.

Community

- Communication and navigation technology may fail for brief periods. Mobile phone calls may drop out. HF ham radio will lose many contacts.

R4 – Severe

R4 radio blackout conditions occur approximately eight times per solar cycle. They involve complete radio blackout on the daylight side of the Earth, lasting from about ten minutes up to a few hours. These conditions occur for severe solar flares of X10 to X20 class.

Sector impacts and risk mitigation

Aviation

- Complete loss of HF radio communications in daylight areas for one or more periods of up to a few hours. On rare occasions there will be reduced availability of GNSS in daylight areas for tens of minutes.
- R4 corresponds to ICAO's severe advisory level. Operators might switch to alternative communication systems, such as satellite communications or VHF. They may delay or re-route flights where HF communication outages result in loss of system redundancy.

Defence

- Complete failure of HF radar and radio in daylight areas. Reduced availability of GNSS, satellite communication and satellite internet access.
- Major impacts on operational systems for the duration of the flares.

Space

- Communication and navigation systems may fail.
- Spacecraft operators can engage safe operating modes.

Community

- Communication and navigation technology may fail for brief periods. Mobile phone calls may drop out. HF ham radio will lose many contacts.

R3 – Strong

R3 radio blackout conditions occur approximately 175 times per solar cycle. They involve a partial to complete radio blackout on the daylight side of the Earth, lasting from about ten minutes up to a few hours. These conditions occur for solar flares of X1 to X10 class.

Sector impacts and risk mitigation

Aviation

- Periodic loss of HF radio communications in daylight areas for up to an hour.
- R3 corresponds to ICAO moderate advisory level. Operators may switch to higher radio frequencies or alternative means of communication, such as satellite communications or VHF.

Defence

- Brief disruptions of HF radio and radar coverage.
- Some impacts on operational systems for the duration of the flares.

Space

- Impacts are possible if the radio frequency noise is unusually strong.
- Space operators can remain alert for possible increased activity.

Community

- HF ham radio will struggle to make contacts on affected circuits.

R2 – Moderate

R2 radio blackout conditions occur approximately 350 times per solar cycle. They involve a partial radio blackout on the daylight side of the Earth, lasting from about ten minutes up to a few hours. These conditions occur for M-class flares of M5 and greater.

Sector impacts and risk mitigation

Aviation

- Periodic loss of HF radio communications in daylight areas for tens of minutes.
- Aviation operators can monitor for ICAO advisories and prepare for potential loss of HF communication in daylight areas.

Defence

- Minor disruptions of HF radio and radar coverage.
- Defence can reconsider operations in or near the sub-solar point – where the Sun is directly overhead.

Space

- Impacts are possible if the radio frequency noise is unusually strong.
- Space operators can remain alert for possible increased activity.

Community

- HF ham radio will experience some dropouts.

R1 – Minor

R1 radio blackout conditions occur approximately 2000 times per solar cycle. They involve a partial radio blackout on the daylight side of the Earth, lasting from about ten minutes up to a few hours. These conditions occur for solar flares of M1 class and greater.

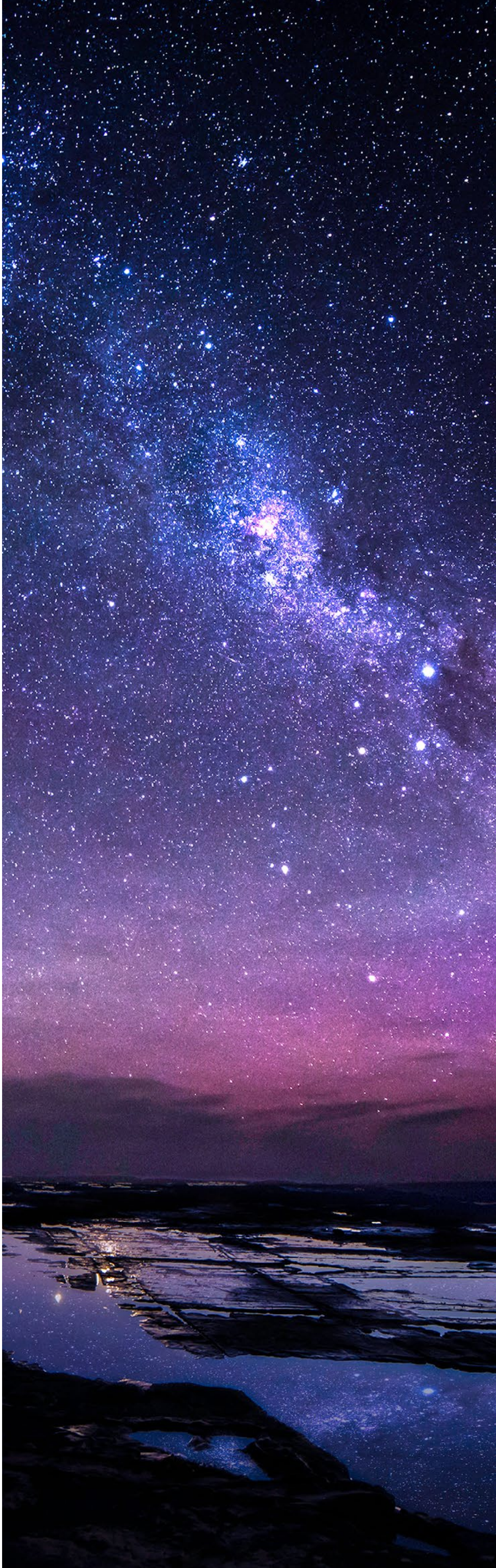
Sector impacts and risk mitigation

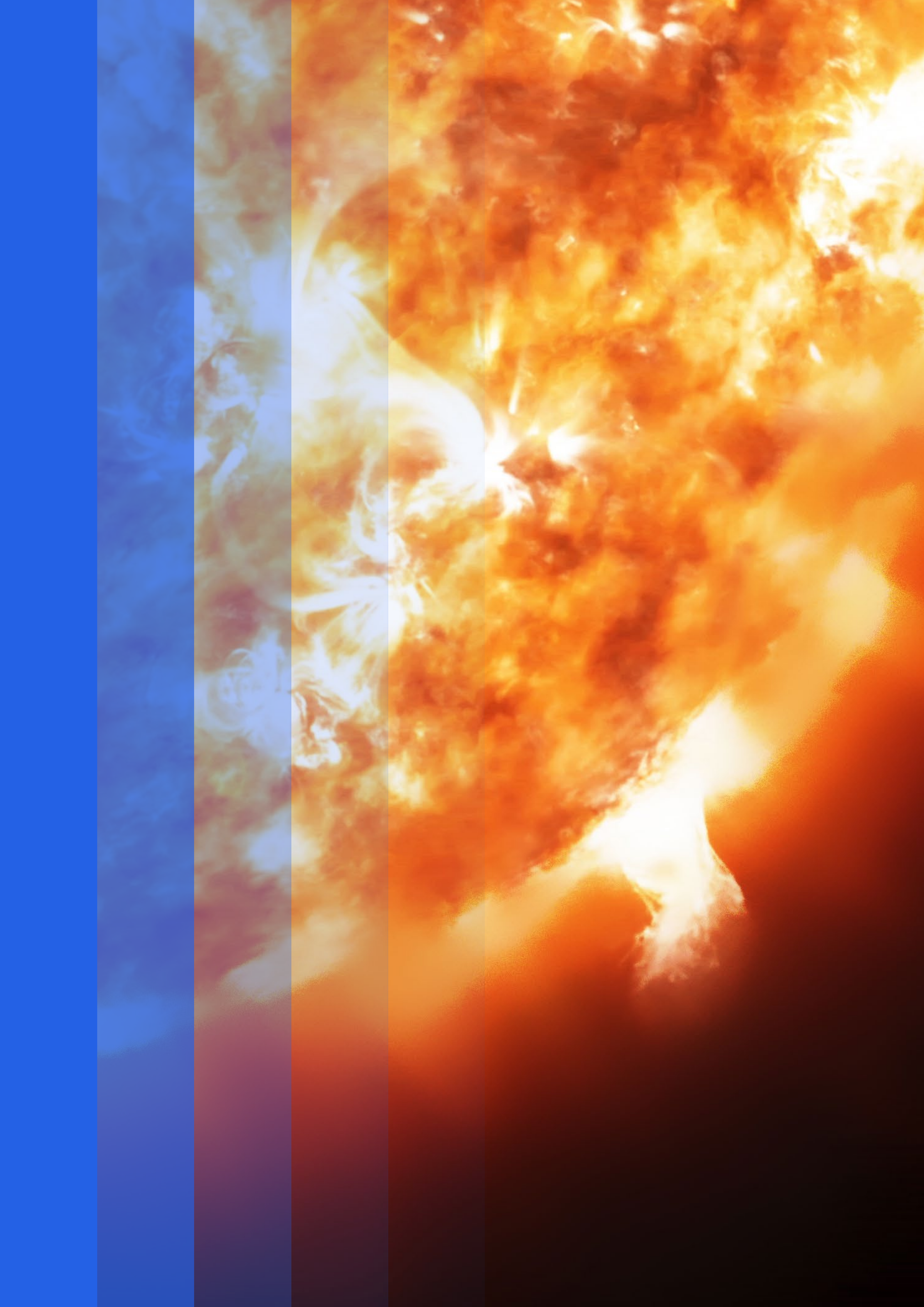
Aviation

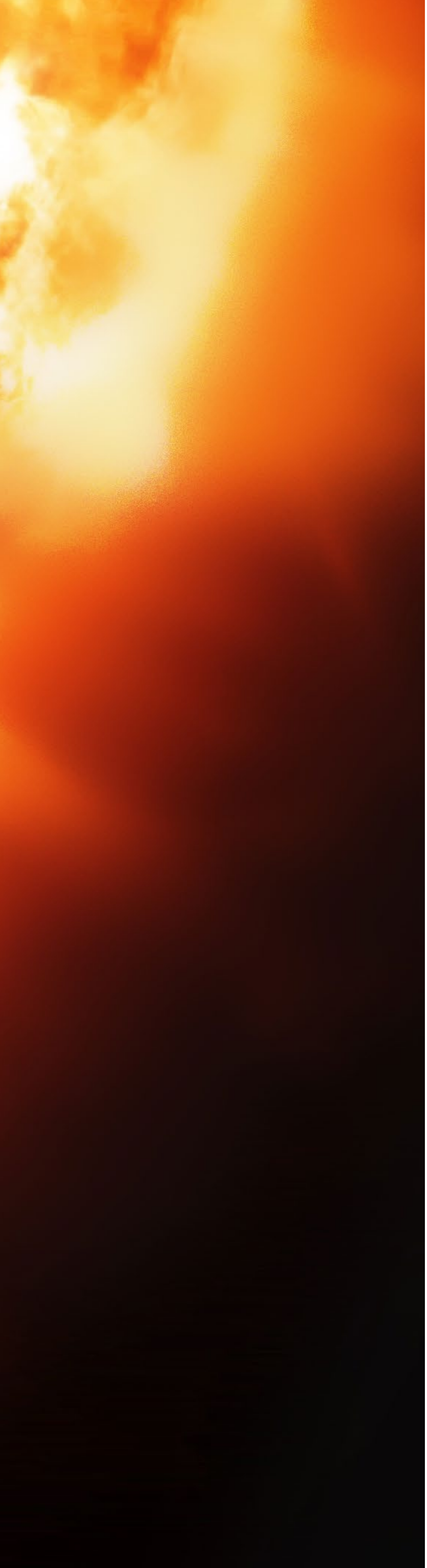
- Minor degradation of HF radio communications in daylight areas.
- No operational response required.

Defence

- Minor disruptions of HF radio and radar coverage.
- Defence can reconsider operations in or near the sub-solar point.







Acronyms

A, B, C, M, X	Letter class for solar X-ray flares where A class flares are minor and X class flares are the most powerful
ADS	automatic dependent surveillance
AEMO	Australian Energy Market Operator
GBAS	ground-based augmentation systems
GIC	geomagnetically induced currents
GNSS	global navigation satellite systems (for example, GPS, GLONASS, Galileo, Compass)
HF	high-frequency (radio) 3–30 MHz
ICAO	International Civil Aviation Organization
ISR	intelligence, surveillance and reconnaissance for situational awareness
LEO	low Earth orbit object
NOAA	National Oceanic and Atmospheric Administration
UHF	ultra-high frequency (radio) 300MHz–3GHz
VHF	very-high frequency (radio) 30–300 MHz

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