Australian Government
Bureau of Meteorology

AUSTRALIAN SPACE WEATHER ALERT SYSTEM

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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 watches 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 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. In extreme events, the Bureau's space weather specialists produce severe space weather warnings and alerts.

The Bureau works closely with all sectors to limit their risks, and provide:

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

In the Australian Space Forecast Centre, space weather specialists and forecasters assess the behaviour of the Sun and local space environment before issuing daily reports at 10am AEST every day of the year.

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.

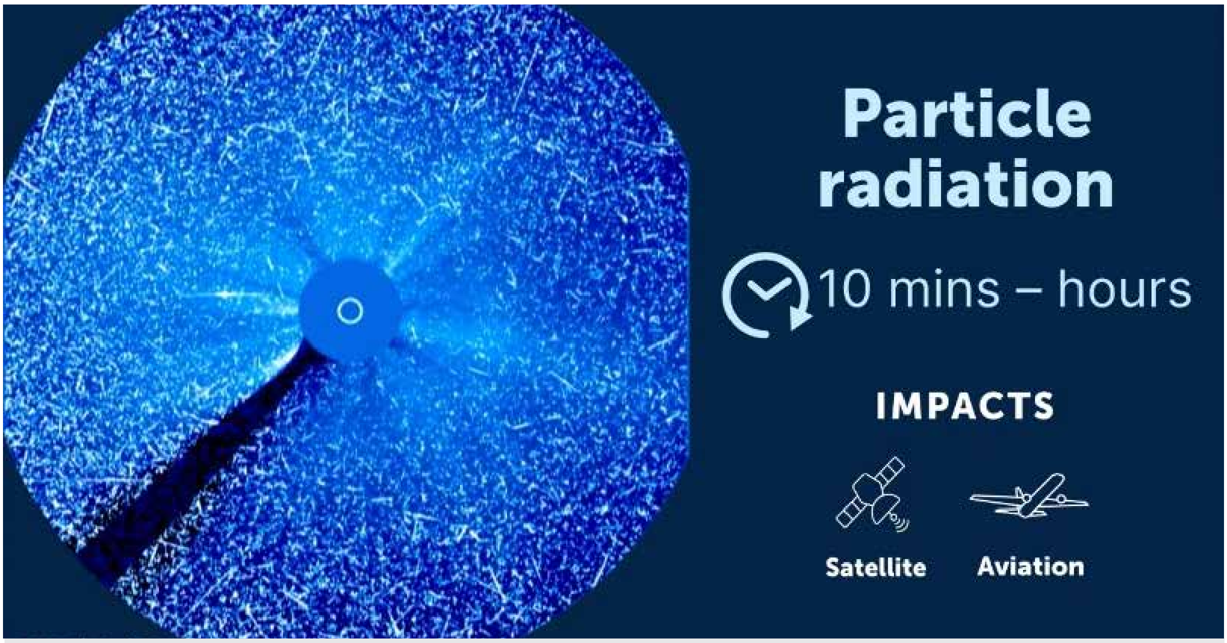
Space weather can disrupt many of Australia's critical services, such as Global Position Systems (GPS) navigation and radio communications. It can also damage satellites and the electricity transmission network and affect aviation and air passenger safety.

Among these events are coronal mass ejections (CME), particle radiation and solar flares.

Coronal mass ejections

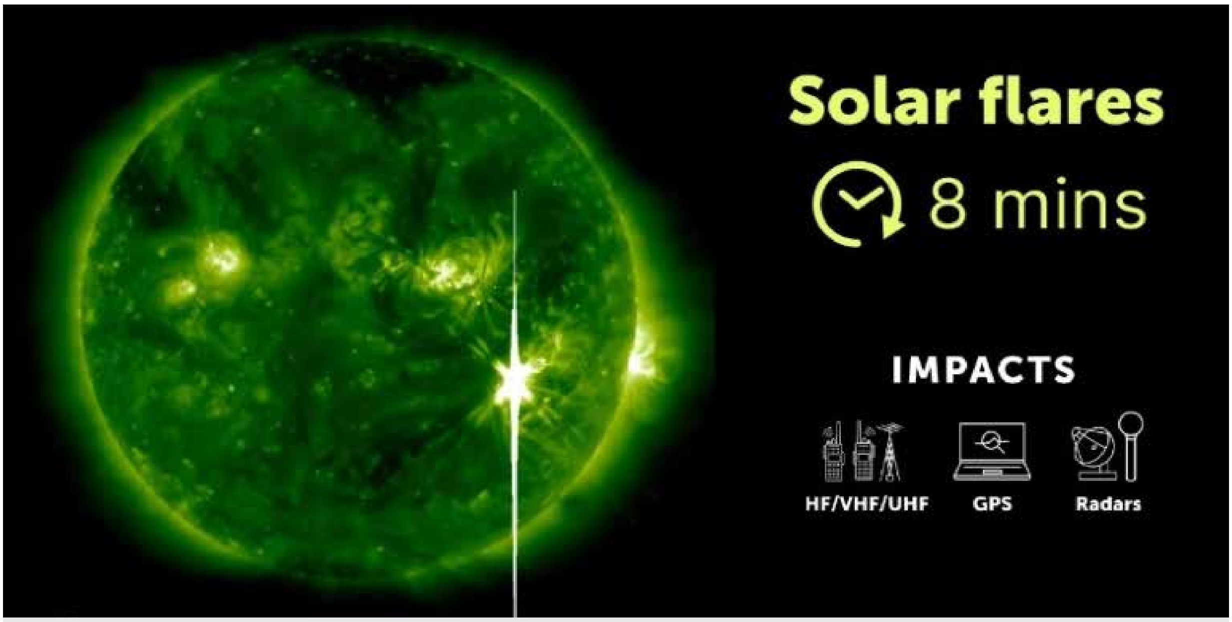
Coronal mass ejections occur when large clouds of plasma and magnetic field erupt in the Sun's outer atmosphere. When the mass ejections hit Earth, they cause geomagnetic storms that can disrupt electricity grids, as well as other critical technology. Image credit: NASA/ESA/SOHO

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 beamed towards Earth, they arrive ten minutes to hours after occurring. They affect satellites and cause health concerns for astronauts and airline passengers. Image credit: NASA/ESA/SOHO

Solar flares



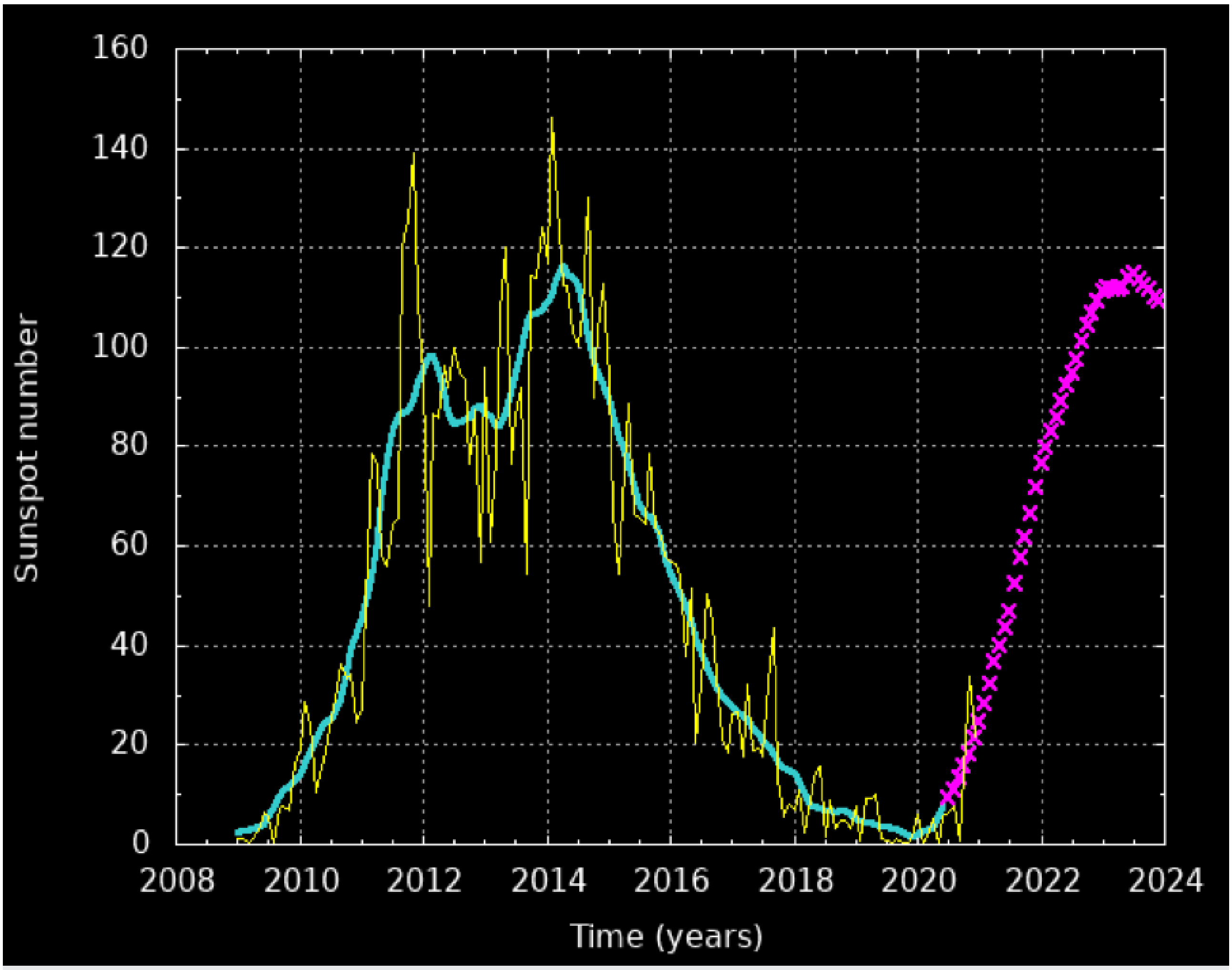
Solar flares are sudden bursts of X-ray energy from the Sun. The X-rays travel at the speed of light and impact Earth within eight minutes of occurring. Radio communications, GPS and radar technology can all be affected. Image credit: NASA/ESA/SOHO

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 it, solar activity gradually declines, returning to solar minimum and the end of the cycle.

Severe space weather happens more frequently and with increased intensity around the solar maximum. But strong space weather events have been observed at other times too.



The graph showing sunspot measurements for solar cycle 24, which ended in 2019, (thick turquoise line) and prediction for solar cycle 25 (magenta crosses). The observed monthly sunspot numbers are shown by the thin yellow line. Solar cycle 24 was the least active since solar cycle 14, which started in 1902. The prediction of the current and future solar cycles is uncertain. Solar activity might return to the higher levels experienced throughout most of the 20th century.

Major severe 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. However, clearer evidence exists about the storms which have occurred in the last half century, especially during the space age when technology to monitor events are now available.

The following timeline is a summary of documented severe space weather events which have occurred throughout recent history. 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.

1770 September:

Sunspot drawings show a solar active region twice the size of the region responsible for the famous Carrington Event of 1859. Generally aurora 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. More than 100 documents have been discovered corroborating unusually intense auroral displays at low latitudes throughout East Asia. This event may have equalled or exceeded the intensity of the famous Carrington Event.

1859 September:

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

1872 February:

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

1882 November:

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'.

1903 October:

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.

1921 May:

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

1938 January:

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 was still in its infancy and experienced minimal disruption.

1941 September:

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.

1967 May:

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.

1972 August:

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

1989 March:

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 peace keeping deployment in Namibia.

1989 August:

An intense solar flare (X15) is thought to have caused the failure of the Toronto stock market computer systems, causing a halt of trading for 3 hours.

2003 October–November:

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 X45 class solar flare. 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.

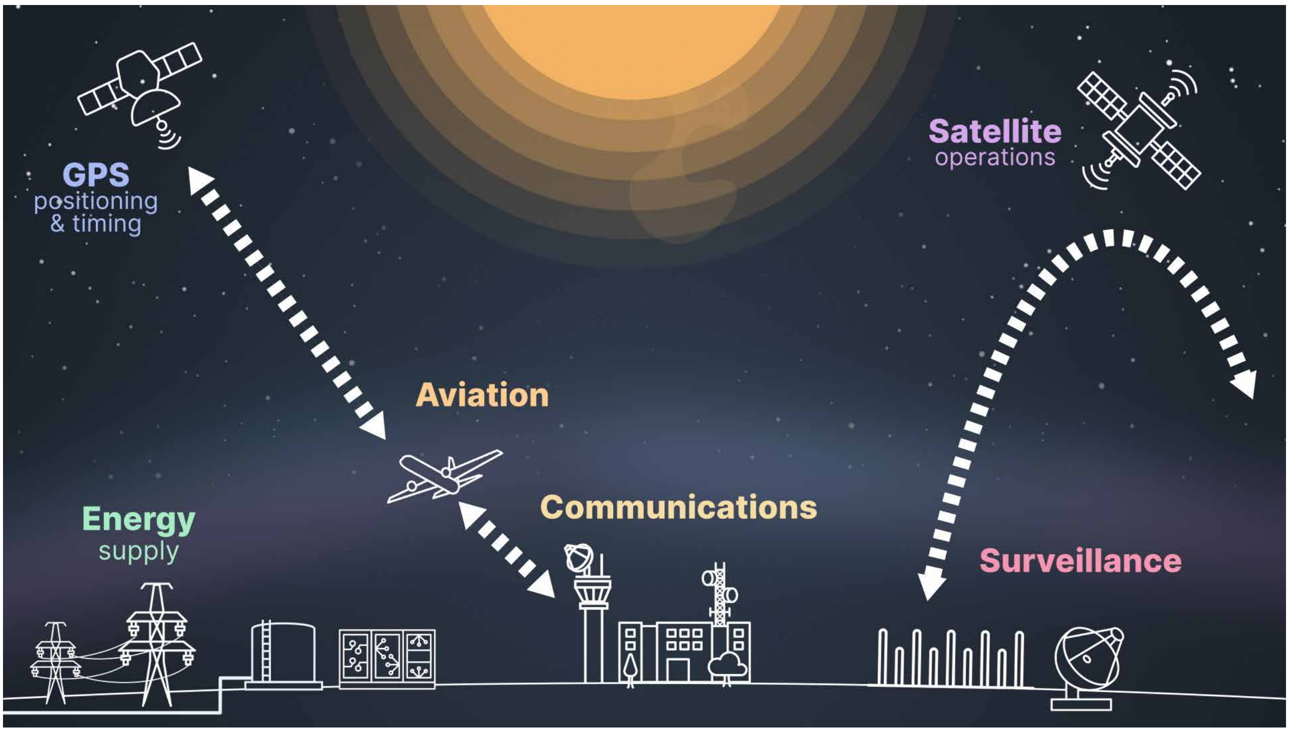
- G-scale for geomagnetic storms
- S-scale for solar radiation storms
- R-scale for radio blackouts.

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 is likely to require action by operators of technology systems to mitigate risks to various sectors. The higher the number, the greater the likelihood that a larger number of systems will be impacted to a greater degree.

The ocurrence frequency of different G, S and R values in the scales are for representative solar cycles based upon fewer than 100 years of direct observations. The most severe conditions will occur more frequently during some solar cycles, yet not at all in others. Every solar cycle is unique.

The occurrence frequency information is global as space weather events affect the Earth. It's not possible to provide frequency information where impacts are localised to geographic regions or countries.

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 international accepted and adopted amongst many space weather monitoring agencies.



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 for days
- 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, measured 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 severe geomagnetic storm lasts the stronger its effects will be. Geomagnetic storms generally last between one to four days.

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

As an increasingly intense geomagnetic storm rages in the North, a NASA space physicist took this picture 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. These conditions occur around three times per solar cycle. The greatest probability of a G5 is in the declining phase of the solar cycle, one to three years after solar maximum.

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 will be degraded, impacting aircraft navigation and GNSS-based surveillance of aircraft. For example, availability of location information with vertical guidance through LPV-200 and position data through automatic dependent surveillance (ADS) may be affected.
- Impacts will be more severe in the equatorial and high-latitude regions but they may also extend to middle latitudes for severe 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 and 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. Airport and en-route requirements differ in the degree to which GNSS errors become significant. 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.

G5 – extreme (continued)

G5 conditions are extreme, measured by a Kp value of 9 or above. These conditions occur around three times per solar cycle. The greatest probability of a G5 is in the declining phase of the solar cycle, one to three years after solar maximum.

Sector effects and risk mitigation

Defence

- Performance of HF radio and radar may be degraded for many hours. Possible temporary failures of GNSS, satellite communication and internet. Payloads on military satellites may fail. Malicious actors may exploit space weather effects to mask attacks, including cyber attacks.
- 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. Many 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. These conditions occur around 20 times per solar cycle.

Sector effects and risk mitigation

Energy

- Significant GICs may flow in isolated locations in the electricity grid. Isolated asset damage possible.
- Transmission network service providers may advise 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 will be degraded, impacting aircraft navigation and GNSS-based surveillance of aircraft. For example, availability of location information with vertical guidance through LPV-200 and position data through ADS may be affected. Impacts will be more severe in the equatorial and high-latitude regions but they may also extend to middle latitudes.
- 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 many 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. These conditions occur around 44 times per solar cycle.

Sector effects 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.

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.

Defence

- The available bandwidth for HF radio and radar may be limited for significant periods. Increased 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.

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.

Community

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

G2 – moderate

A G2 event is when the Kp value is between 6 and 7. These conditions occur around 101 times per solar cycle.

Sector effects 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. These conditions occur around 188 times per solar cycle.

Sector effects 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 beamed towards the Earth from the Sun. Solar radiation storms typically last from several hours to two days and they are very difficult to predict.

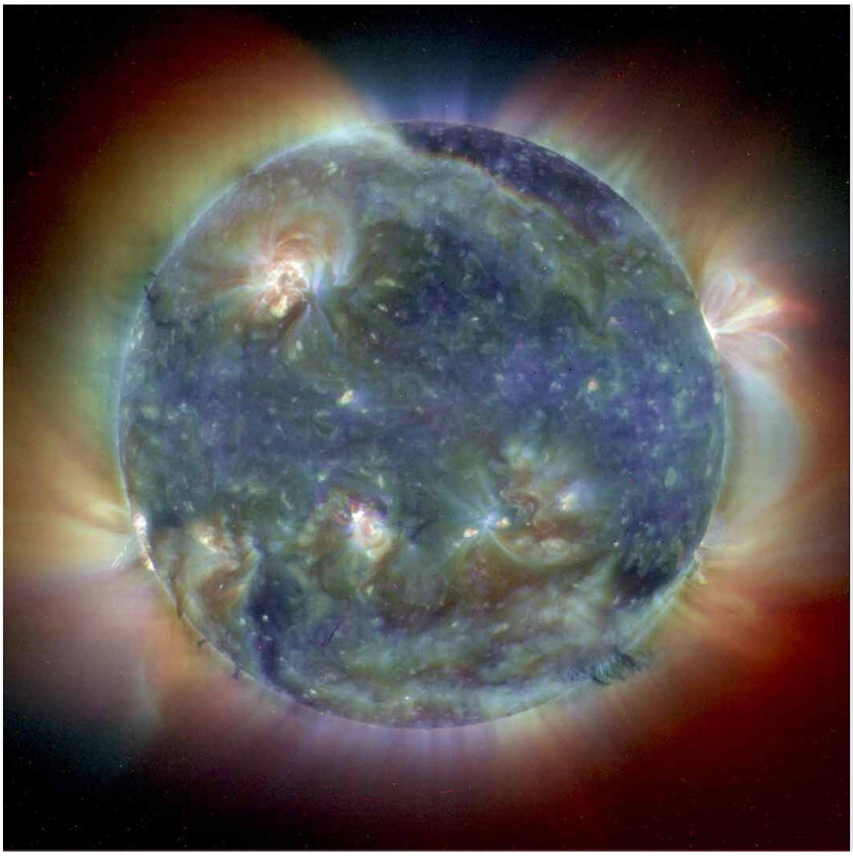
Solar radiation storms of S4 to S5 levels may:

- 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-16 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 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 typically last from several hours to two days. They are very difficult to predict. The last S5 event happened prior to 1976.

Sector effects 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 based on effective radiation dose-rate at flight altitude, for health and mechanical impacts. It also covers the level of absorption of HF radio waves, which affect polar HF radio communications. These levels do not correspond directly to these scales 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 around three times per solar cycle, typically last from several hours to two days.

Sector effects 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 radiations 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 around eight times per solar cycle, typically last from several hours to two days.

Sector effects 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 around 18 times per solar cycle, typically last from several hours to two days.

Sector effects 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 around 40 times per solar cycle, typically last from several hours to two days.

Sector effects 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.

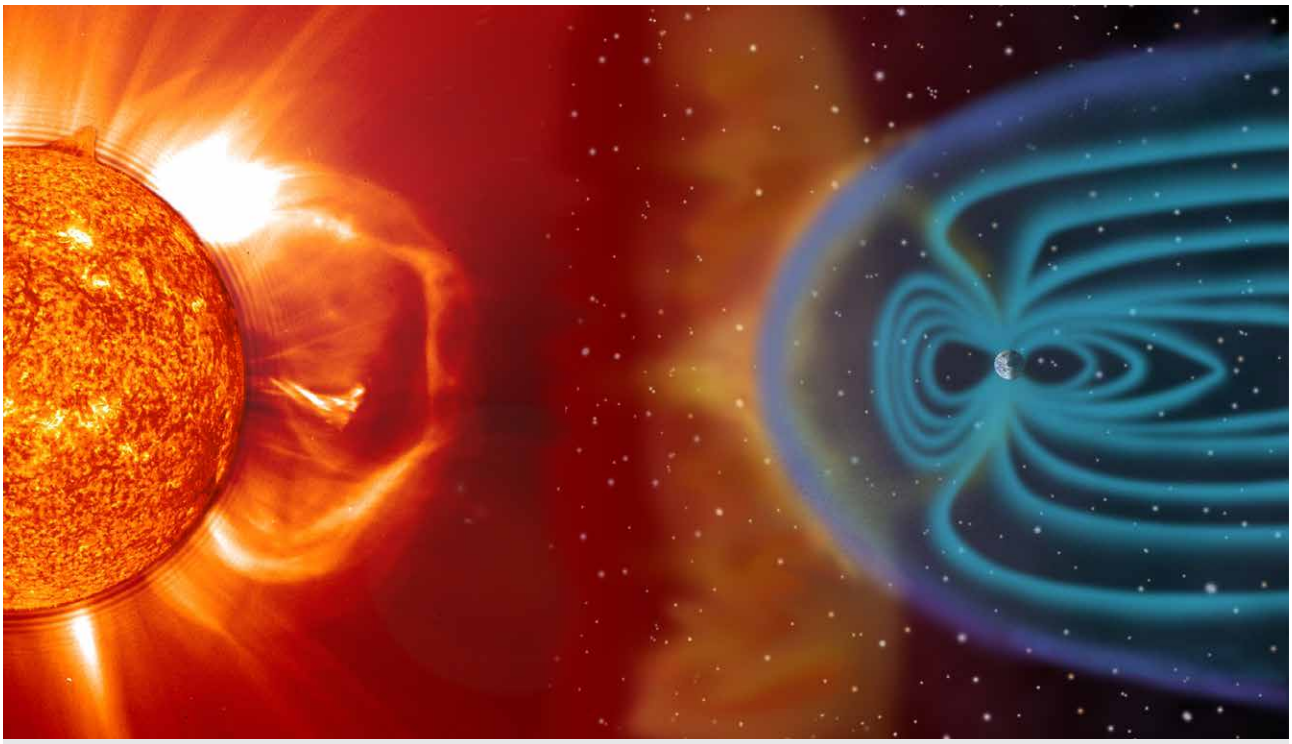
Radio blackouts

The R-scale is for radio blackouts. Also known as short wave 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. A-class flares are minor eruptions and X-class flares are 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.



CME blast and subsequent impact at Earth – This illustration shows a CME blasting off the Sun's surface in the direction of Earth. This left portion is composed of an EIT 304 image superimposed on a LASCO C2 coronagraph. Two to four days later, the CME cloud is shown striking and beginning to be mostly deflected around the Earth's magnetosphere. The blue paths emanating from the Earth's poles represent some of its magnetic field lines. The magnetic cloud of plasma can extend to 30 million miles wide by the time it reaches Earth. These storms, which occur frequently, can disrupt communications and navigational equipment, damage satellites, and even cause blackouts. Image credit: SOHO (ESA & NASA).

R5 – extreme

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

Sector effects and risk mitigation

Aviation

- Complete loss of HF radio communication on 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 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 (15 minutes to 2 hours). 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

These radio blackout conditions occur roughly eight times per solar cycle. Complete radio blackout on the daylight side of the Earth, lasting from about ten minutes up to a few hours. They occur for severe solar flares of X10 class and greater.

Sector effects 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 (15 minutes to 2 hours).

Space

- Communication and navigation systems may fail.
- Space operators can enter spacecraft into safe operating modes.

Community

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

R3 – strong

These radio blackout conditions occur roughly 175 times per solar cycle. Complete radio blackout on the daylight side of the Earth, lasting from about ten minutes up to a few hours. They occur for solar flares of X1 class and greater.

Sector effects 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 might 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.
- Impacts on operational systems during the flares (15 minutes to 2 hours).

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

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

Sector effects 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

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

Sector effects 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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