Solar radiation storms

The impact of solar radiation storms (consisting primarily of protons) is to cause sudden lack of signal in high frequency (HF) and very high frequency (VHF) comms in the polar regions. This is called polar cap absorption.

Category		UK Effect	US and Global Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects			
Solar radiation storms				Flux level of >= 10 MeV particles (ions)*	Number of events when flux level was met (number of storm days**)
S5	Extreme	**Biological:** Passengers and crew in aircraft on certain routes may be exposed to increased radiation levels. The increase depends on flight path and the detailed storm characteristics.*** **Spacecraft operations:** Some satellites may suffer temporary outages due to memory impacts which can cause loss of control, serious noise in image data or orientation problems and permanent damage to solar panels. **Aircraft operations:** Some aircraft electronic systems may experience single event effects (SEE) which can cause upsets or unexpected behaviour. The rate of SEE depends on flight path and the detailed storm characteristics.***	**Biological:** unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** **Satellite operations:** satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. **Aircraft operations:** pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**	10^5	Fewer than 1 per cycle
S4	Severe	**Biological:** Passengers and crew in aircraft on certain routes may be exposed to increased radiation levels. The increase depends on flight path and the detailed storm characteristics.*** **Satellite operations:** Some satellites may suffer temporary outages due to single event effects on electronics which can cause unexpected behaviours, noise in image data or orientation problems and permanent damage to solar panels.*** **Aircraft operations:** Some aircraft electronic systems may experience single event effects (SEE) which can cause upsets or unexpected behaviour. The rate of SEE depends on flight path and the detailed storm characteristics.***	**Biological:** unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** **Satellite operations:** may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. **Aircraft operations:** blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S3	Strong	**Biological:** Passengers and crew in aircraft on certain routes may be exposed to increased radiation levels. The increase depends on flight path and the detailed storm characteristics.*** **Satellite operations:** A small number of satellites may experience outages due to single event effects, which can cause unexpected behaviours, noise on imaging systems and orientation problems. **Aircraft operations:** Some aircraft electronic systems may experience single event effects (SEE) which can cause upsets or unexpected behaviour. The rate of SEE depends on flight path and the detailed storm characteristics.***	**Biological:** radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** **Satellite operations:** single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. **Aircraft operations:**degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S2	Moderate	**Biological:** No additional risk. **Satellite operations:** Infrequent single-event upsets possible. **Aircraft operations:** Unlikely to have significant effect.***	**Biological:** passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** **Satellite operations:** infrequent single-event upsets possible. **Aircraft operations:** small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S1	Minor	**Biological:** none. **Satellite operations:** none. **Aircraft operations:** Unlikely to have an effect***	**Biological:** none. **Satellite operations:** none. **Aircraft operations:** minor impacts on HF radio in the polar regions.	10	50 per cycle

* Flux levels are 5 minute averages. Flux in particles·s-1·ster-1·cm-2. Based on this measure, but other physical measures are also considered.
** These events can last more than one day.
*** High energy particle measurements (>400 MeV) are a better indicator of radiation risk to aircraft avionics, passengers and crews. Pregnant women are particularly susceptible.

Met Office

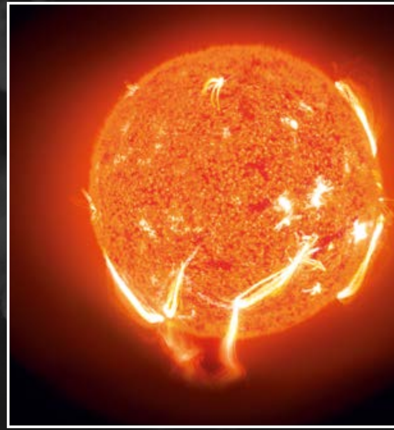
Measuring space weather impacts - the UK Impact Scales

Different aspects of space weather have a variety of impacts on mankind and our technology.

The National Oceanic and Atmospheric Administration (NOAA) Space Weather scales are used world-wide to classify space weather conditions and communicate the impact on people and systems. These are numbered scales analogous to those used to describe hurricanes or earthquakes.

They describe the level of disturbance and possible impacts for three types of space weather, radio blackouts (R scale), geomagnetic storms (G scale) and solar radiation storms (S scale).

The level of impact is dependent on the systems in use and these vary widely across the globe. For example the UK power grid has much shorter and more highly connected transmission lines than those in North America so it is less susceptible to space weather. In 2013 the Royal Academy of Engineering Report on extreme space weather reported on the impacts on engineered systems and infrastructures specific to the UK. On the basis of this report and subsequent work with Government, the Met Office developed a UK specific impact scale which is used in our forecasts, alerts and warnings.



please visit www.metoffice.gov.uk/space-weather for more information

Radio blackouts

The ionosphere is a dynamic part of the upper atmosphere which acts as a reflector for long range, high frequency communications (HF comms). During a solar flare the increase in x-ray radiation from the Sun causes the ionosphere to absorb rather than reflect signals, disrupting communications systems on the sun-lit side of the Earth. Even during periods of quiet solar activity turbulence in the ionosphere can result in a scattering of electromagnetic waves disrupting navigation systems, like Global Navigation System (GNSS - often known as GPS) and radio bands up to the GHz frequencies.
These are referred to as radio blackouts.

Category		UK Effect	US and Global Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	**Descriptor**	**Duration of event will influence severity of effects**			
Radio blackouts				**GOES X-ray peak brightness by class and by flux**	**Number of events when flux level was met; (number of storm days**
R5	**Extreme**	**HF Radio:** Complete HF (high frequency*) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector.	**HF Radio:** Complete HF (high frequency*) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. **Navigation:** Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 (2×10^{-3})	Less than 1 per cycle
R4	**Severe**	**HF Radio:** HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time.	**HF Radio:** HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. . **Navigation:** Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R3	**Strong**	**HF Radio:** Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth.	**HF Radio:** Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. **Navigation:** Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R2	**Moderate**	**HF Radio:** Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes.	**HF Radio:** Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. **Navigation:** Degradation of low-frequency navigation signals for tens of minutes.	M5 (5×10^{-5})	350 per cycle (300 days per cycle)
R1	**Minor**	**HF Radio:** Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact.	**HF Radio:** Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. **Navigation:** Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Other frequencies may also be affected by these conditions.

Space weather scale for geomagnetic storms

Geomagnetic Storms are large disturbances in the Earth's magnetic field caused by the solar wind and interplanetary magnetic field (IMF) structures such as coronal mass ejections (CMEs). Their effect can be felt for a number of days.

When the IMF has a strong southward component it reconnects with the Earth's magnetic field allowing the transfer of energy from the solar wind towards the Earth. The ability to predict the magnetic orientation of CMEs as they leave the Sun's surface and the time taken to travel to the Earth are key to improving space weather forecasts.

Category		UK Effect	US and Global Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	**Descriptor**	**Duration of event will influence severity of effects**			
Geomagnetic storms				**Kp values***	**Number of storm events when Kp level was met; (number of storm days)**
G5	**Extreme**	**Power systems:** Localised voltage control and protective system problems may occur leading to potential for localised loss of power. Transformers may experience damage. **Spacecraft operations:** may experience extensive surface charging, drag may increase on low-Earth-orbit satellites, problems with orientation, uplink/downlink and tracking satellites. **Other systems:** HF (high frequency) radio communication may be impossible in many areas for one to two days, GNSS(GPS) satellite navigation may be degraded for days with possible effects on infrastructure reliant on GNSS (GPS) for positioning or timing, low-frequency radio navigation can be out for hours, and aurora may be seen across the whole of the UK.	**Power systems:** widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. **Spacecraft operations:** may experience extensive surface charging, drag may increase on low-Earth-orbit satellites, problems with orientation, uplink/downlink and tracking satellites. **Other systems:** pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp = 9	4 per cycle (4 days per cycle)
G4	**Severe**	**Power systems:** No significant impact on UK power grid likely. **Spacecraft operations:** may experience surface charging and tracking problems, drag may increase on low-Earth-orbit satellites, corrections may be needed for orientation problems. **Other systems:** HF radio propagation sporadic, GNSS(GPS) satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora may be seen across the whole of the UK.	**Power systems:** possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. **Spacecraft operations:** may experience surface charging and tracking problems, corrections may be needed for orientation problems. **Other systems:** induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp = 8, including a 9-	100 per cycle (60 days per cycle)
G3	**Strong**	**Power systems:** No significant impact on UK power grid likely. **Spacecraft operations:** Surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. **Other systems:** Intermittent GNSS(GPS) satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent. Aurora may be seen in Scotland and Northern Ireland and as low as Mid-Wales and the Midlands.	**Power systems:** voltage corrections may be required, false alarms triggered on some protection devices. **Spacecraft operations:** surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. **Other systems:** intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.	Kp = 7	200 per cycle (130 days per cycle)
G2	**Moderate**	**Power systems:** No impact on UK power grid. **Spacecraft operations:** Corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. **Other systems:** HF radio propagation can fade at higher latitudes, and aurora may be seen across Scotland.	**Power systems:** high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. **Spacecraft operations:** corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. **Other systems:** HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.	Kp = 6	600 per cycle (360 days per cycle)
G1	**Minor**	**Power systems:** No impact on UK power grid. **Spacecraft operations:** Minor impact on satellite operations possible. **Other systems:** Aurora may be seen as low as Northern Scotland.	**Power systems:** weak power grid fluctuations can occur. **Spacecraft operations:** minor impact on satellite operations possible. **Other systems:** migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	Kp = 5	1700 per cycle (900 days per cycle)

*The Kp-index used to generate these messages is derived from a real-time network of observatories the report data to SWPC in near real-time. In most cases the real-time estimate of the Kp index will be a good approximation to the official Kp indices that are issued twice per month by the German GeoForschungsZentrum (GFZ) (Research Center for Geosciences). ** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (Tips on Viewing the Aurora)