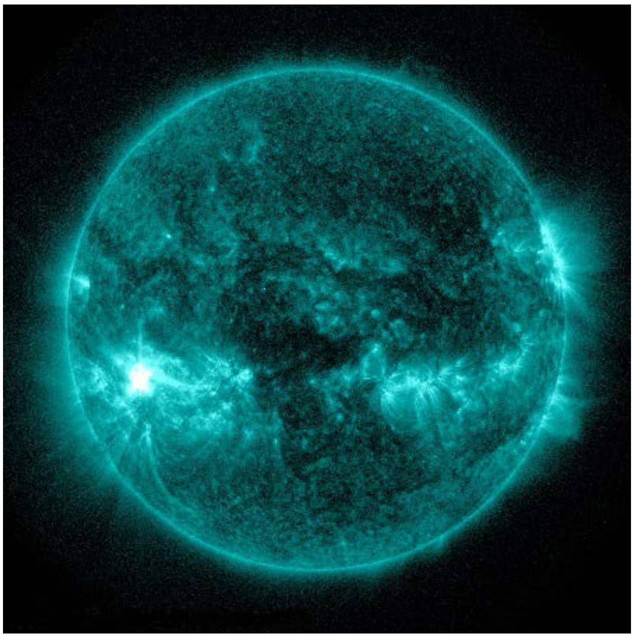
The Bureau of Meteorology

Aviation services

Space weather

Hazardous phenomena

Space weather events may cause disruptions to aviation communications, navigation and surveillance systems, and increase radiation exposure at aircraft cruising levels.



Credit: NASA/GSFC/Solar Dynamics Observatory.

What is space weather?

Space weather broadly describes the impact of solar activity on technological systems and human well-being here on earth. Dynamic variations on the surface of the sun can release large amounts of energy in various forms including electromagnetic radiation, charged particles and eruptions of huge clouds of ionised gas. These phenomena can significantly affect the earth's upper atmosphere and surrounding space environment with impacts felt all the way down to technological systems on the ground.

Particularly concerning for communications and navigation systems, solar variations both directly and indirectly modify a layer of the earth's upper atmosphere known as the ionosphere. The ionosphere extends upwards from 90 km above the earth's surface.

High frequency (HF) radio communication (HF COM) relies on the ionosphere reflecting radio waves back down to the ground. Long-range voice and data communication, including the range of usable HF frequencies, can vary according to the state of the ionosphere.

The aurora is the visible manifestation of space weather in the polar regions. Credit: NASA.

Satellite communication (SATCOM) and satellite-based navigation and surveillance (SATNAV) that use Global Navigation Satellite Systems (GNSS) (e.g. Global Positioning System (GPS)), rely on the transmission of signals through the ionospheric layer. These signals are modified in various ways as they travel through the ionosphere, depending on its density and structure.

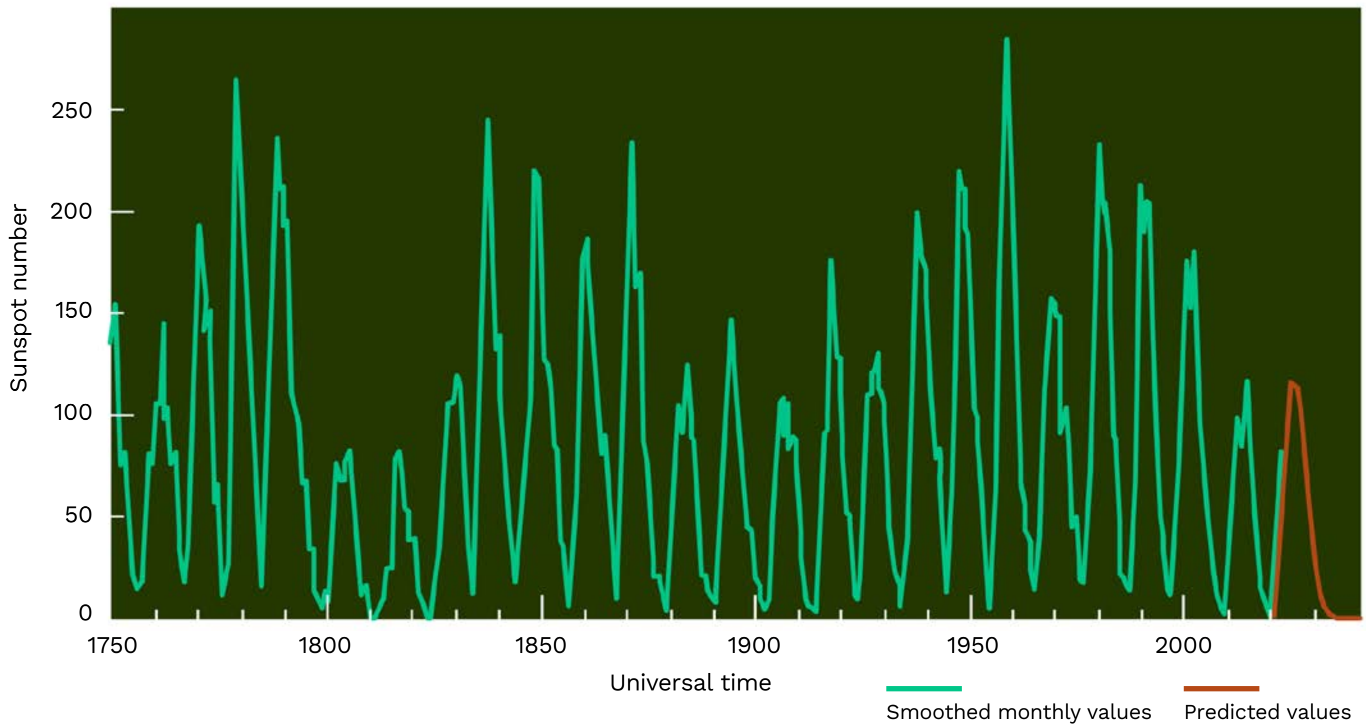
Space weather events that modify the density and/or structure of the ionosphere can therefore significantly impact the performance of HF COM, SATCOM and SATNAV systems.

Apart from effects associated with the ionospheric layer, the release of highly energetic particles from the sun, during solar disturbances, can result in increased and potentially dangerous radiation at aircraft cruising levels. Radiation exposure increases with altitude and with closer proximity to the poles.

Solar activity cycle

The level of solar activity varies typically over an 11-year cycle. While space weather events impacting aviation can occur at any time during a solar cycle, they are most common and generally more intense around the peak of the cycle (sunspot number at its highest). A single solar eruption can trigger a series of space weather events with effects lasting over a period of 1–3 days. Impacts often occur in bursts, separated by prolonged periods of no significant activity.

International Space Environment Service (ISES) solar cycle sunspot number progression



The 11-year solar activity cycle illustrated by sunspot number over the last 250 years. Solar minimum occurred during 2019. The ‘predicted values’ indicate a solar maximum in 2025. The sunspot number is an index of solar activity based on counting sunspots and sunspot groups. Sunspots have been observed since the time of Galileo. Credit: The Bureau of Meteorology.

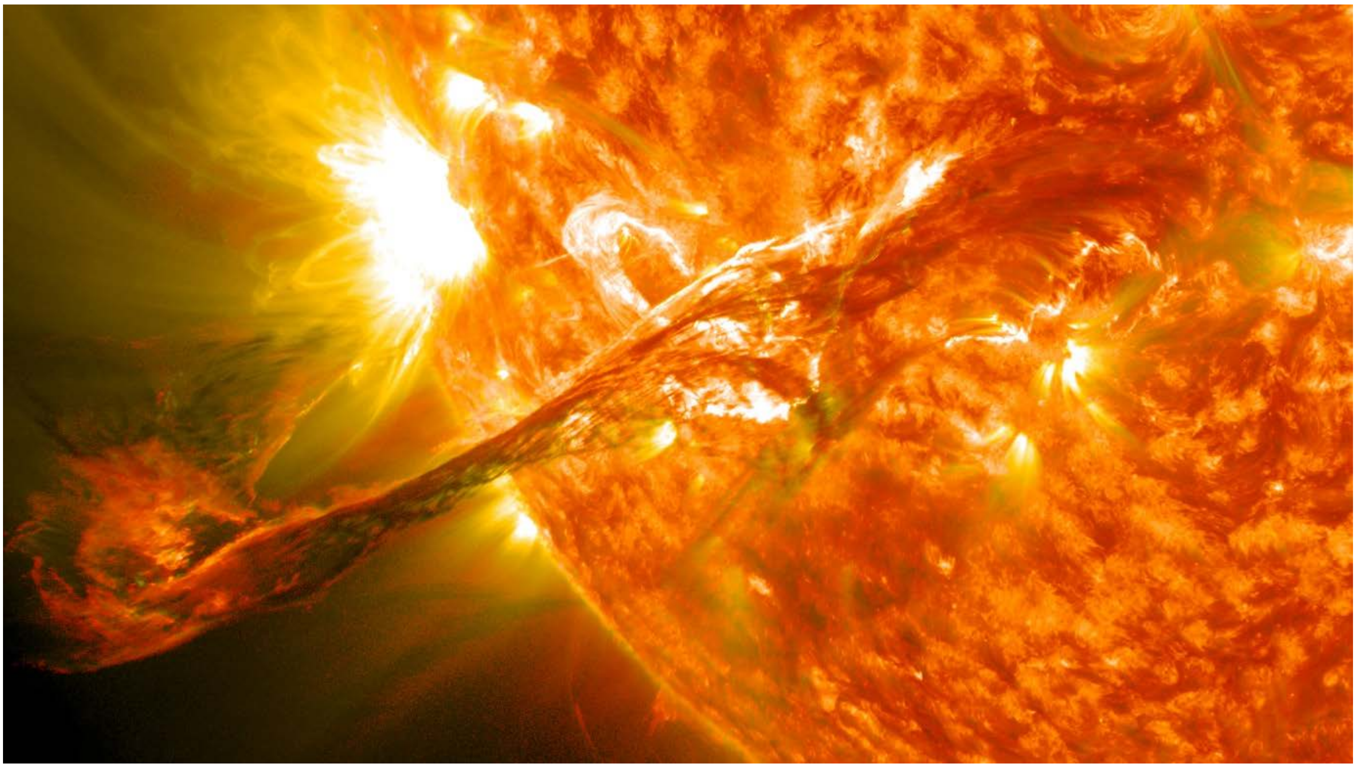
Space weather impacts on aviation

High frequency radio communications (HF COM)

Radiation produced by the sun in the extreme ultraviolet (EUV) and X-ray frequency range is typically absorbed in the ionosphere at altitudes above 90 km. This region of charged particles supports HF COM by reflecting HF radio waves back down towards the ground, enabling long distance communications. Emissions associated with solar flares and high-energy solar protons can also ionise the earth’s atmosphere at lower altitudes, causing increased absorption of HF radio waves and reducing the range of usable HF frequencies.

These ‘absorption events’ usually impact just the lower HF radio frequencies. Very strong solar X-ray flares, however, can result in HF radio blackout conditions (affecting all frequencies) that can persist for minutes

Credit: Jessica Neaves.



On Friday 31 August 2012, a long filament of solar material that had been hovering in the sun's atmosphere, the corona, erupted out into space at 4:36 pm EDT. The coronal mass ejection, or CME, travelled at over 900 miles per second. The CME did not travel directly towards earth, but did connect with earth's magnetic environment, or magnetosphere, causing aurora to appear on the night of Monday 3 September. Pictured here is a brightness enhanced blended version of the 304 and 171 angstrom wavelengths. Credit: NASA/GSFC/SDO NASA Goddard Space Flight Centre.

to hours on the sunlit side of the earth. Bursts of high-energy protons emitted by the sun (solar proton events) can impact the polar regions, producing radio blackout conditions that can last from hours to days. Similarly auroral absorption (AA) events occur in the auroral oval regions surrounding the poles and can persist for minutes to hours. During these events, radio operators are advised to try higher frequencies or use an alternate means of communication.

In addition to absorption events, geomagnetic storms can reduce the density of electrons in the ionosphere, again resulting in a reduced range of frequencies available for HF COM. These 'ionospheric depression' events usually impact just the higher HF radio frequencies and can persist from hours to days. During these events, radio operators are advised to try lower HF frequencies.

GNSS-based navigation and surveillance

One of the largest sources of error in Positioning Navigation and Timing (PNT) signals from GNSS satellites is due to the passage of the satellite signal through the relatively dense electron environment of the upper atmosphere. These errors are compensated for by GPS receivers that use an ionospheric delay correction model. During ionospheric storms, or periods where the ionosphere deviates significantly from normal conditions, these models may be inadequate and lead to uncorrected positioning errors. Precision navigation systems that autocorrect for the ionosphere, such as differential GPS, or GPS augmentation systems such as the Satellite-Based Augmentation System (SBAS) or Ground-Based Augmentation System (GBAS), are still susceptible to errors during severe ionospheric storms. GNSS positioning is also susceptible to interference from solar radio bursts in the ultra high frequency (UHF) range, leading to significant loss of satellite tracking for up to tens of minutes in severe cases.

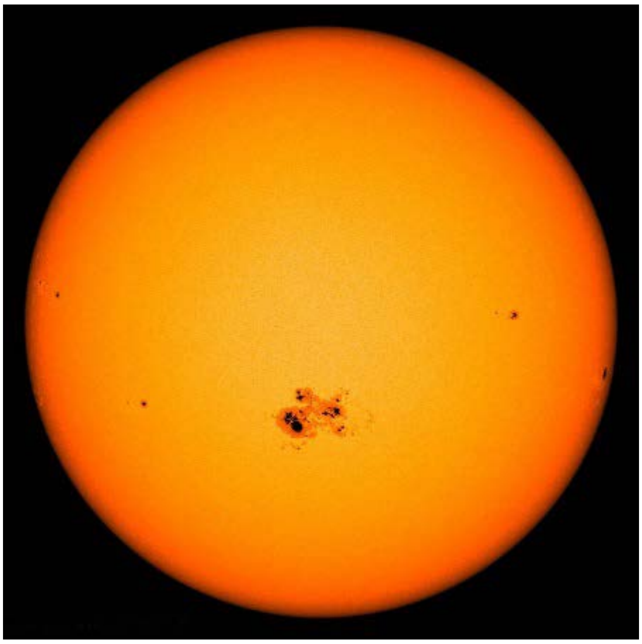
Ionospheric scintillation is the rapid fluctuation of the power and/or phase of radio signals passing through the ionosphere. Scintillation occurs when a radio frequency signal, up to a few gigahertz (GHz), passes through a region of small-scale irregularities in the ionospheric electron density. The effect can be compared to the twinkling of stars as their light passes through the earth's atmosphere.

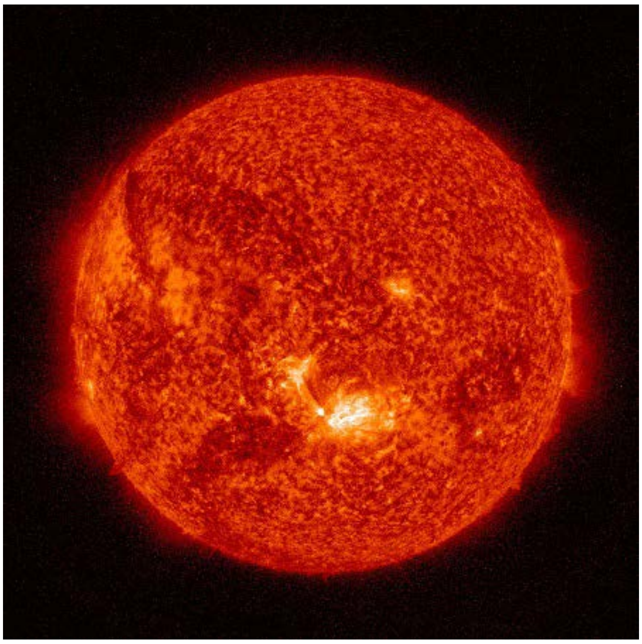
Scintillation occurs primarily in the equatorial region of the earth (+/- 20° latitude) between dusk and midnight. This is due to large electron density depletions, known as Equatorial Plasma Bubbles, in the ionosphere above those areas. Scintillation can also occur in high-latitude regions. Scintillation effects are most significant in L band* SATCOM and SATNAV applications where GHz frequency signals travel through the ionosphere. For SATNAV, the rapid signal fluctuations impede the ability of GNSS receivers to track signals from individual GNSS satellites. This results in fewer satellites available for positioning and reduces positioning accuracy. In the worst-case scenario, scintillation can result in a complete loss of GNSS positioning for up to tens of minutes. For SATCOM, scintillation can result in reduced signal-to-noise ratio and poor communication quality.

Radiation

During solar eruptive events, large numbers of energetic particles may be released from the sun and travel to earth. The particles travel along earth's magnetic field lines, collide with air molecules and produce showers of secondary particles in the atmosphere. These particles are ultimately stopped by the relatively dense lower atmosphere of the earth. In the equatorial and mid-latitude regions, the earth's near-horizontal magnetic field acts as a shield. In the polar regions however, where the magnetic field is closer to vertical, the energetic particles can cascade down to lower altitudes or even reach the ground, increasing radiation exposure for people in the vicinity. As these particles are weakened (slowed and absorbed) by passage through the atmosphere, higher altitudes are exposed to higher levels of radiation. The radiation exposure of flight crew and passengers can significantly increase during these solar energetic particle events, particularly on polar or near-polar flights. Avionics can also malfunction when exposed to high levels of radiation.

* L band refers to the operating frequency range of 1 to 2 GHz.





Credit: NASA/GSFC/Solar Dynamics Observatory.

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