EASA
European Union Aviation Safety Agency

Safety Information Bulletin

Airworthiness – Operations – ATM/ANS

SIB No.: 2012-09R1

Issued: 28 April 2021

Subject: **Effects of Space Weather on Aviation**

Revision:

This SIB revises EASA SIB 2012-09 dated 23 May 2012.

Ref. Publications:

- Council Directive 2013/59/EURATOM dated 05 December 2013.
- EASA SIB 2012-10R1 dated 28 April 2021.
- Appendix 1 of this SIB contains a list of useful websites and identifies those that provide information on actual space weather.
- International Civil Aviation Organization (ICAO) Annex 3: Meteorological Service for International Air Navigation, 20th Edition 2018.
- ICAO Document 10100: Manual on Space Weather Information in Support of International Air Navigation, 1st Edition 2019.

Applicability:

All aircraft and their operations, all Air Traffic Management/Air Navigation Services (ATM/ANS) systems and their operations, all aerodromes and their operations.

Description:

This SIB informs aircraft operators and manufacturers, avionics systems designers, electronic equipment and component manufacturers, ATM/ANS service providers, aerodrome operators and competent authorities of the effects of space weather on electronic devices, communication, navigation and surveillance services and human beings, and should be read in conjunction with EASA SIB 2012-10R1 for on-board systems.

Space weather is a generic term, which refers to the environmental conditions in the space around the Earth extended up to the Sun. The major drivers for the space weather are flows of energetically charged particles and electromagnetic radiation, both of which penetrate and interact with the Earth's atmosphere and magnetic field. The main contributors to space weather can be further separated into Solar and Galactic radiation, described later in this publication, and referred to as -atmospheric radiation from now on.

The figure below is a graphical, not to scale, representation of atmospheric radiation and their interaction with the Earth magnetosphere and ionosphere. The sun activity is the main contributor.

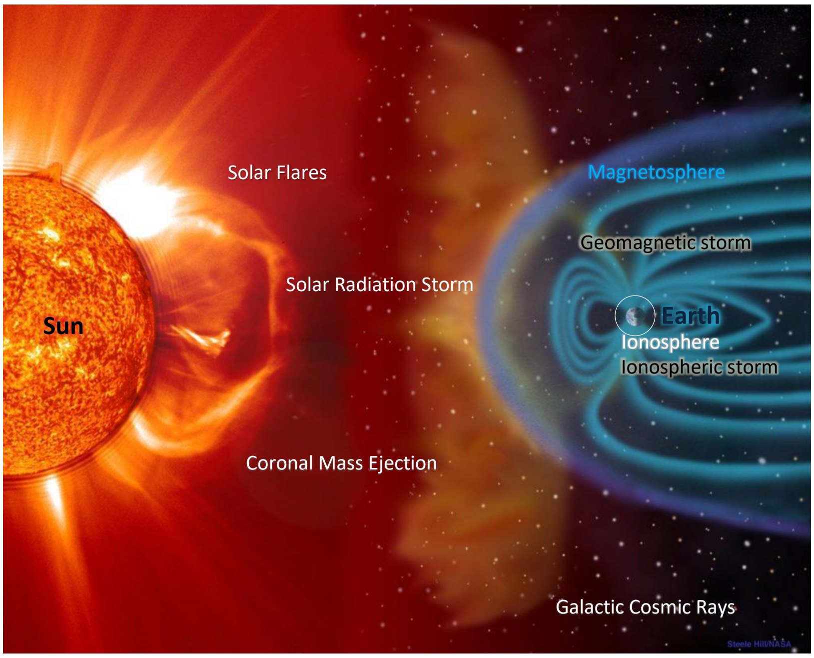


Figure 1. Space weather phenomena,
adapted from https://picryl.com/media/space-science-12eac1

The solar activity follows an eleven year cycle. The last peak was in April 2014 and the next one is forecasted for 2025 (as published on 15 September 2020 on https://www.weather.gov/news/201509-solar-cycle; also refer to paragraph on solar radiation timeline in this SIB).

Classification:
There are several classifications possible. The following list of phenomena, as per ICAO manual on space weather, is taken into consideration in this SIB, however, it is not exhaustive:

1. Geomagnetic storm:

Geomagnetic storms, strong disturbances to the Earth's magnetic field in the solar wind, pose problems for many activities, technological systems and critical infrastructure. The topology of the Earth's magnetic field changes in the course of a storm, as the near-Earth system attempts to adjust to the jolt of energy from the Sun carried in the solar wind. Coronal Mass Ejections and the shocks they drive are often the causative agent, and can send the geomagnetic field into a disturbed state for days at a time. The frequency of geomagnetic storms, in general, mimics the 11-year solar activity in a bi-modal distribution. The strongest storm cluster near solar maximum, whereas a second peak happens during the declining phase of the cycle.

2. Solar radiation storms:

Solar radiation storms occur when large quantities of charged particles, primarily protons, are accelerated by processes at or near the Sun and then the near-Earth environment is bathed with these charged particles. These particles cause an increase in the radiation dose to humans, and create an increased possibility of single event upsets in electronics. The Earth's magnetic field and atmosphere offer some protection from this radiation, but that shielding decreases with altitude, latitude, and magnetic field strength and direction. The polar regions on the Earth are most open to these charged particles, because the magnetic field lines at the poles extend vertically downwards intersecting the Earth's surface, which allows the particles to spiral down the field lines and penetrate into the atmosphere increasing the ionization.

3. Solar flare radio blackout:
Solar flare radio blackouts primarily affect high frequency (HF), (3-30 MHz), although detrimental effects may spill over to very high frequency (VHF), (30-300 MHz), and beyond in fading and diminished ability for reception. The blackouts are a consequence of enhanced electron densities caused by the emissions from solar flares that ionize the sunlit side of the Earth. For example, the powerful solar flare of 04 November 2003 resulted in lost or degraded HF communications for several hours.

4. Ionospheric storms:
Ionospheric storms arise from large influxes of solar particle and electromagnetic radiation, which give rise to the occurrence of geomagnetic storms. There is a strong coupling between the ionosphere and the magnetosphere, which results in both regimes being disturbed concurrently.

5. Galactic cosmic rays:
Galactic cosmic rays (GCR) are originated in distant supernovae and they are kept to a minimum near the Earth, especially when the Sun related phenomena are predominant, being inversely correlated with the solar activity cycle. GCR cause radiation which increase with altitude, achieving its maximum at around 60-65,000 feet. Their main impact is on health-related issues of the aircrew and passengers, as well as on functionality of avionics.

Potential Effects on the Aviation System:
The effects on the aviation system can be separated into two broad categories: effects on people on board and effects on systems and services.

1. People on board:
Solar radiation storms, occurring under particular circumstances, cause an increase in radiation dose to flight crews and passengers. As high polar latitudes and high altitudes have the least shielding from the particles, the threat is the greatest for executive jet and higher altitude commercial polar flights. Operators are already required to monitor the occupational exposure of aircrew to cosmic radiation (refer to Council Directive 2013/59/Euratom on ionising radiation).

2. Systems and services affected:
- Avionics
- HF communication
- Low frequency communication
- Global Navigation Satellite System (GNSS)
- Communication satellites
- Weather satellites
- Potentially any on-board system containing electronic devices
- Air traffic control facilities/services including datalink
- Communications, navigation and surveillance facilities/services

Each of the above systems or services may experience degraded operation or loss of function during periods of high solar and/or galactic radiation levels.

3. Summary for people, systems and services:

The following table provides an overview of the effects on people, services and systems:

<table>
<tr><th>Space weather phenomena / Effects on</th><th>Solar flare radio blackout</th><th>Geomagnetic storms and solar radiation storms</th><th>Ionospheric scintillation</th><th>Galactic cosmic ray</th></tr>
<tr><td>HF Communications</td><td rowspan="3">Solar flares are large eruptions of electromagnetic radiation from the Sun. The increased level of radiation results in ionization in the lower layers of the ionosphere.</td><td rowspan="3">Storms result in intense currents in the magnetosphere and changes in the ionosphere leading to potential impacts on GNSS and HF, VHF and ultra high frequency communications.</td><td rowspan="3">Scintillation of radio waves impacts the power and phase of the radio signal.</td><td rowspan="5">Although GCR particles are shielded by the Earth's own magnetic field and pose little threat to humans and systems on the ground, at high latitudes -can result in increased radiation exposures for aircrew and passengers.</td></tr>
<tr><td>Satellite Communications</td></tr>
<tr><td>GNSS</td></tr>
<tr><td>Avionics</td><td colspan="2">Main threat for avionics are single event effects (SEE) those are caused by solar energetic particle (SEP) coming from highly energetic protons and ions that interact with molecules in the upper atmosphere and produce cascades of secondary particles such as neutrons.</td><td>-</td></tr>
<tr><td>Occupants of aircraft</td><td colspan="2">Increased radiation exposures for aircrew and passengers.</td><td>-</td></tr>
</table>

Table 1. Summary of space weather phenomena and their main impacts in aviation. Adapted from International Electrotechnical Commission Technical Report 62396 Part 6: Extreme space weather /ICAO Manual of Space Weather Information in Support of Air Navigation / National Oceanic and Atmospheric Administration of United States of America (NOAA), https://www.swpc.noaa.gov

Effects of Atmospheric Radiation on Society:

Atmospheric radiation affects the whole of society and not only aviation: satellites systems, electric power grids, communication and navigation systems may be affected. Some of these systems (e.g. power grids) are outside the control of aviation authorities, but it is important to highlight that they can be affected too.

The following risk considerations are relevant:

a. An increased reliance on GNSS as the main source for navigation and time.
b. In a similar manner, an increased reliance on satellite based communications.
b. The aviation system is a developing network.
c. The use of polar routes for aircraft trajectory is increasing as it provides reduction in travel times. Especially on such routes, airlines also need to consider the effects of solar activity on HF communication: poorer quality, a shift to lower usable frequency bands, and more noise or fading. During extreme solar activity, HF communications may not be available in the polar region.

d. Peaks of solar radiation are cyclic, and occur every 11 years.
e. The availability, continuity, integrity and accuracy of un-augmented GNSS in the region close to the magnetic equator can rapidly change in time during the event. Figure 2 shows that scintillation is most intense around the magnetic equator.

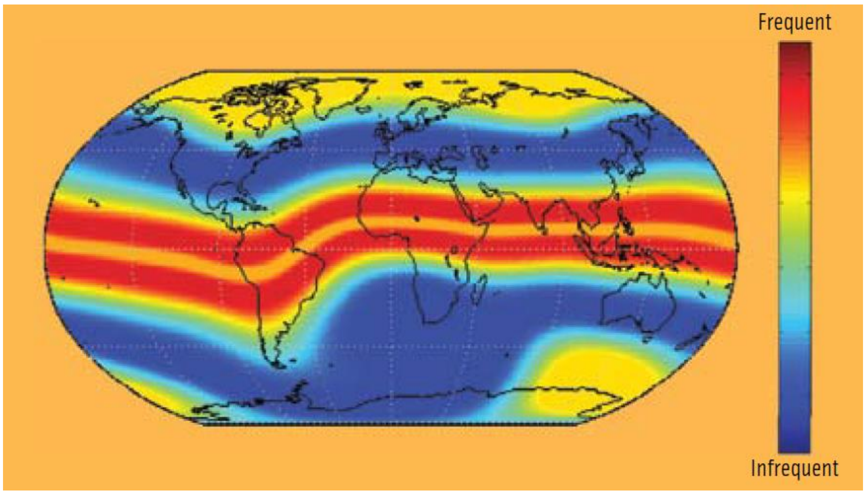
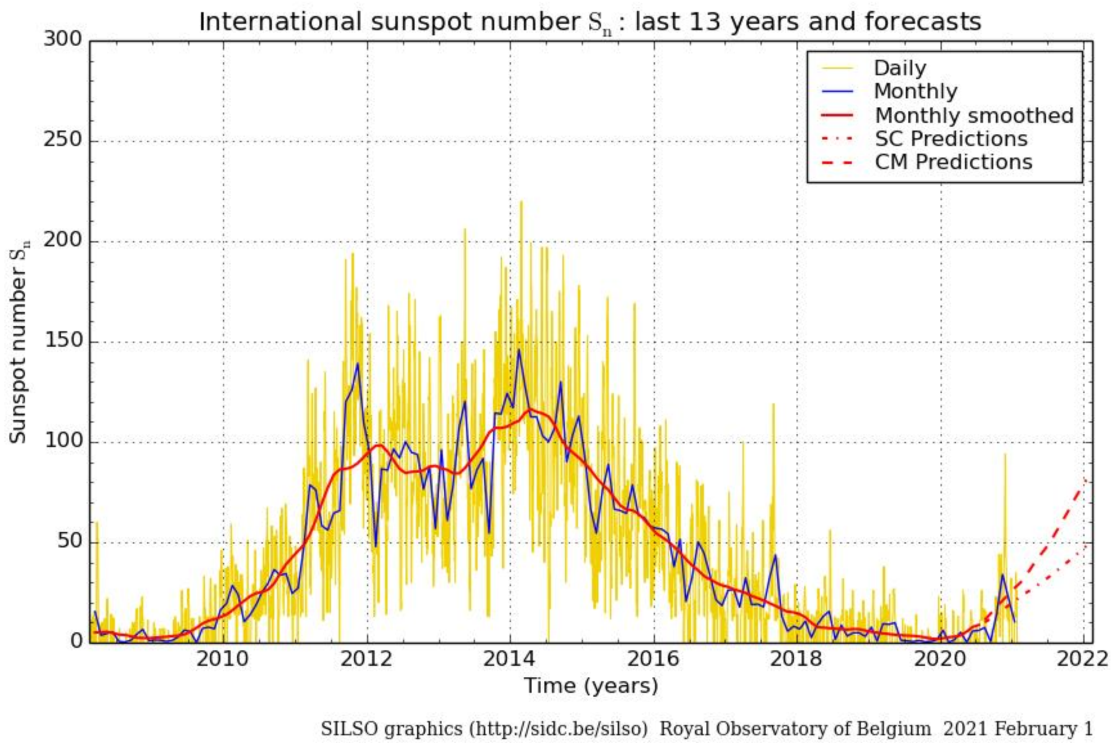


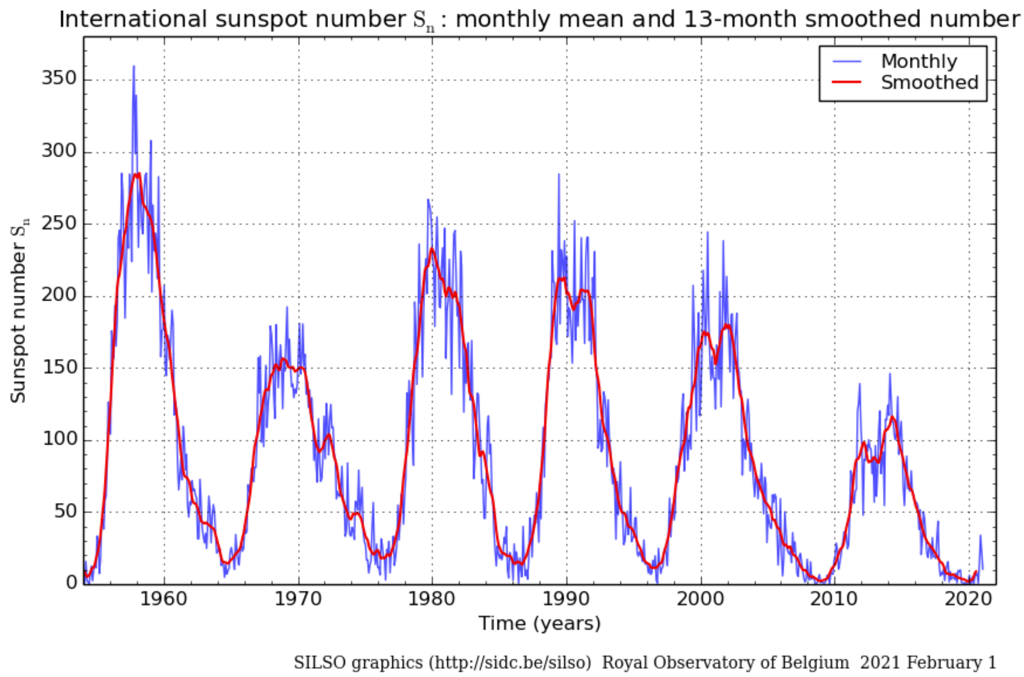
Figure 2. Scintillation map showing the frequency of disturbances at solar maximum.
https://www.insidegnss.com/auto/julyaug09-kintner.pdf

Solar Radiation Timeline:
Sunspots are darker spots also known as umbra, observed on the Sun's photosphere. It has been observed through the years that the point of highest sunspot activity which is correlated with a complete flip of the Sun's magnetic field, corresponds to solar maximum, reproduced every eleven years. Sunspot number are therefore used as a measure of the solar cycle and solar magnetic activity cycle.

In December 2019 the solar cycle 25 officially started, since sunspot number reached its minimum. The chart below provides the number of sunspot observations for last 13 years and gives an indication of when the Earth will be subjected to an increased solar radiation.



The picture below presents the cycles since the mid of the 20th century (from Royal Observatory of Belgium):



Space Weather Information Service:
Since late 2019 a new service has been launched to provide real-time and worldwide space weather updates for commercial and general aviation. This service is generating and sharing space weather advisories, using the aeronautical fixed network. It is provided according to the space weather advisory information Standards and Recommended Practices introduced in ICAO Annex 3 Amendment 78.

A space weather centre is a centre designated to monitor and provide advisory information on space weather phenomena expected to affect HF radio communications, communications via satellite, GNSS based navigation and surveillance systems, and/or which pose a radiation risk to aircraft occupants. ICAO Space Weather Information Service is provided by three global centres established by: ACFJ consortium of Australia, Canada, France and Japan, PECASUS consortium comprising Austria, Belgium, Cyprus, Finland, Germany, Italy, Netherlands, Poland and the United Kingdom and a third centre operated by the United States. It is planned to be extended at least to two additional centres. Each centre is providing the service for 2 weeks in turn: one in duty and others in back-up service.

At this time, the safety concern described in this SIB is not considered to be an unsafe condition that would warrant Airworthiness Directive (AD) action under Regulation (EU) 748/2012, Part 21.A.3B, nor Safety Directive (SD) action under Commission Regulation (EU) 965/2012, Annex II, ARO.GEN.135(c), or under Commission Regulation (EU) 2017/373, ATM/ANS.AR.A.025.

Recommendation(s):

In case of imminent or on-going space weather event, flight crew should consider alternate route planning, or delay use of polar routes. Options could also include flying at a lower altitude to take benefit from the shielding effect of the atmosphere.

Aircraft operators should continue to make their crews aware of the effects of space weather. Operators should also monitor the predicted solar weather information websites to mitigate potential effects of atmospheric radiation levels. They should develop operational procedures for managing flights in areas impacted by space weather events, for example, flight planning tracks using forecast and tactical nowcasts for inflight situational awareness and re-planning.

Aircraft manufacturers, avionics systems designers, electronic equipment and component manufacturers should consider the effects of atmospheric radiation in their designs and demonstrate mitigation means for potential failures. They should continue to work together, via the existing industry groups, to assess the potential effects of atmospheric radiation at component, systems and aircraft level and provide fault tolerant architectures systems.

ATM/ANS service providers, aerodrome operators and competent authorities should continue to make their relevant personnel aware of the phenomenon and the potential effects.

Contact(s):

For further information contact the EASA Safety Information Section, Certification Directorate,
E-mail: ADs@easa.europa.eu.

Appendix 1

Useful websites

1. ICAO - concept of operations, high level requirements and manual: http://www.icao.int/safety/meteorology/iavwopsg/Space%20Weather/Forms/AllItems.aspx

2. Word Meteorogical Organisation - this site contains a space weather portal that provides links to several other organisations dealing with space weather: http://www.wmo.int/pages/prog/sat/spaceweather-intro_en.php

3. European Space Agency (ESA) - Aviation Service, part of ESA's Space Situational Awareness - Space Weather Service Network, provides graphical information about the impact of solar activity on the radiation environment and ionospheric conditions. It includes updated dashboard-based information on the three main aviation impacts of space weather: radiation, GNSS and HF communications as well as service to aviation menu including tools and products and Space Weather Data Browsing and Analysis: https://swe.ssa.esa.int/ssa-space-weather-activities

4. PECASUS for ICAO – website of the Pan-European consortium providing space weather advisories according to ICAO regulations, online Space Weather Advisory situation service: http://pecasus.eu/

5. ACFJ - website of the consortium of Australia, Canada, France and Japan in charge of providing space weather advisories according to ICAO regulations, online Space Weather Advisory situation service: http://www.bom.gov.au/aviation

6. NOAA - website of the space weather prediction centre of NOAA; a subscription service is available to receive alerts, online Space Weather Advisory situation service: http://www.swpc.noaa.gov/

7. SKYBRARY: http://www.skybrary.aero/index.php/Cosmic_Radiation