Space Weather Scientific Background and impact on Aviation Operations

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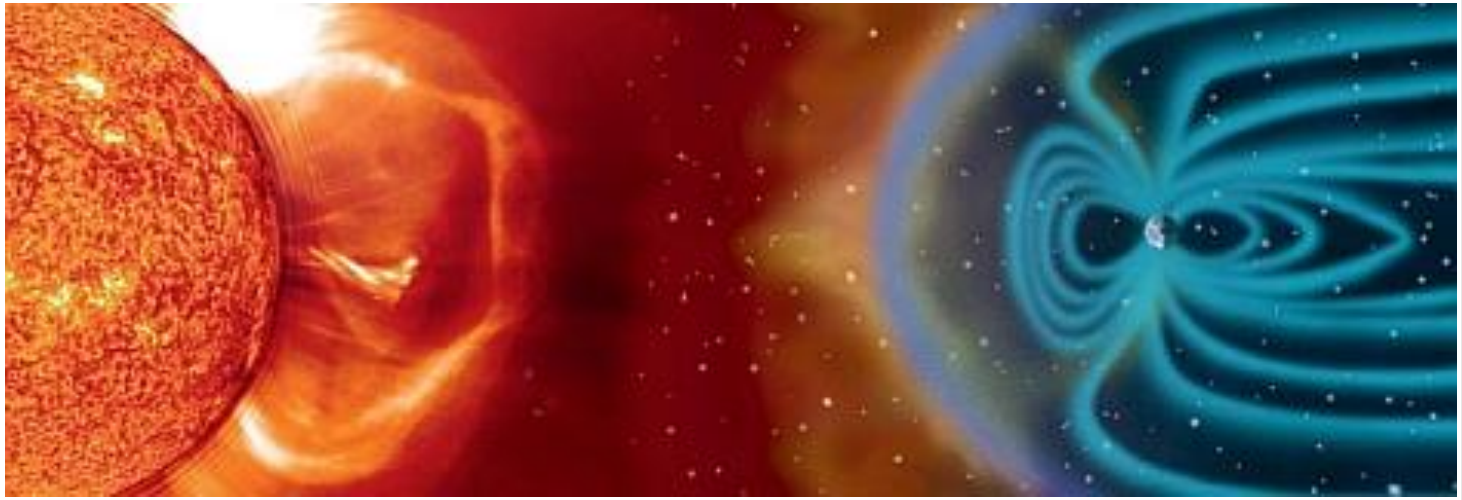
Outline

- ❑ What is space weather?
- ❑ Why should Aviation care about space weather?
- ❑ Example of Space Weather events that affects Aviation:
  - ✓ Radiation exposure
  - ✓ Impact on HF communications
  - ✓ Impact on GNSS

WHAT IS SPACE WEATHER ?

Sun-Solar Wind-Magnetosphere-Ionosphere-Thermosphere



Space Weather refers to conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems.

What, Where, How, and Why of Space Weather

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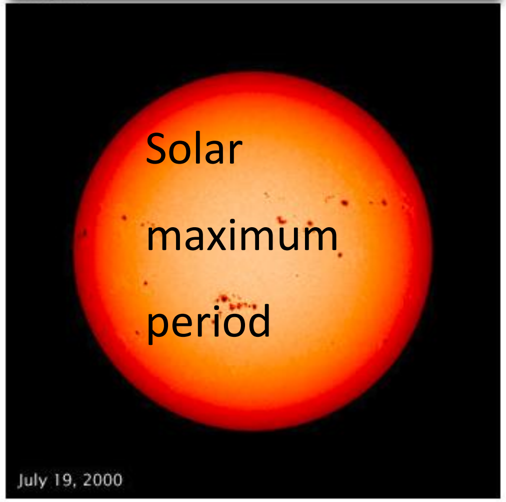
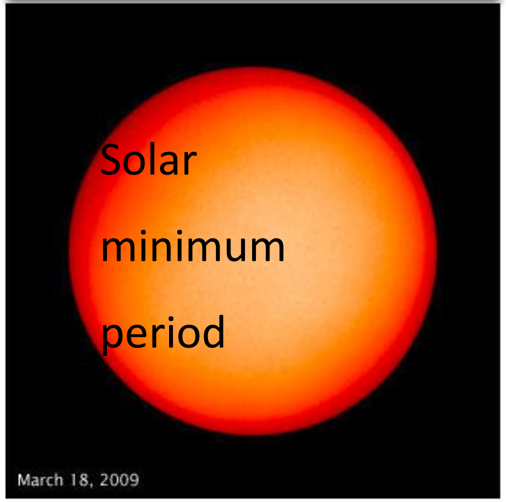
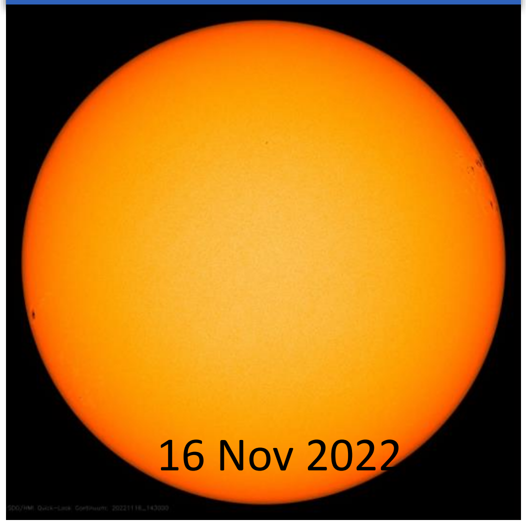
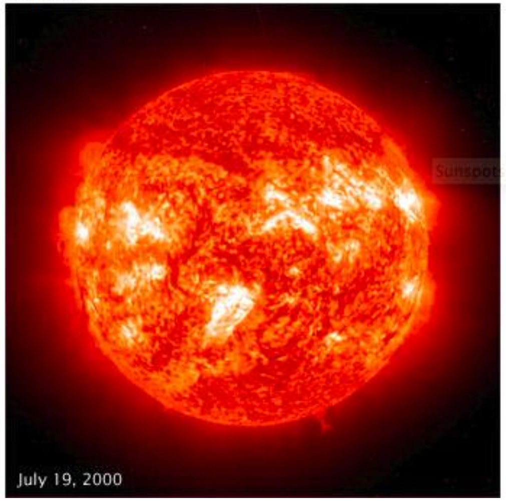
ACTIVE SUN | QUIET SUN | NOW SUN

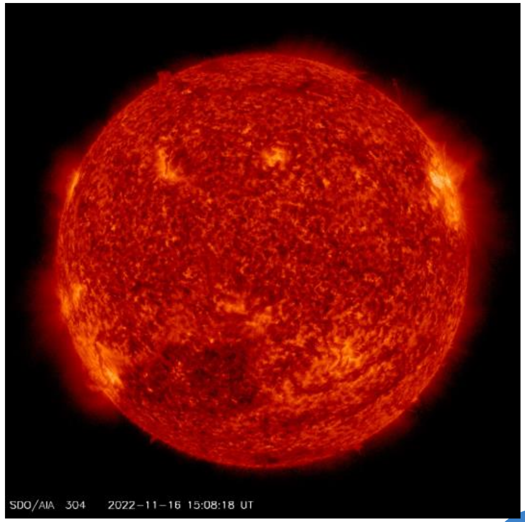






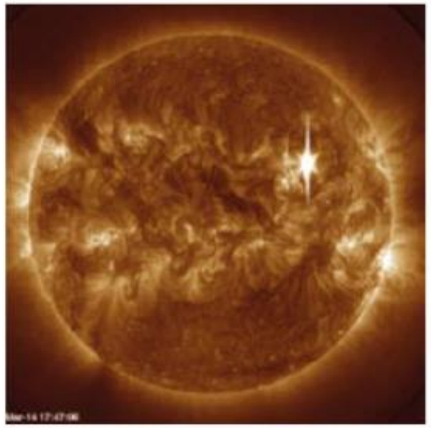
Ultraviolet





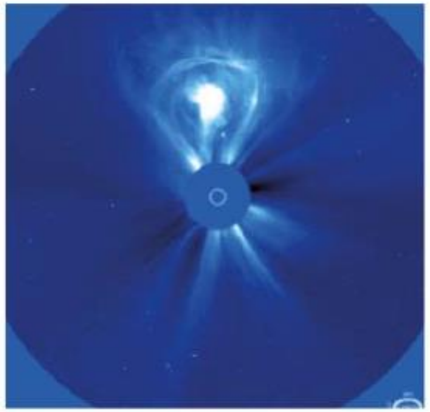
https://sdo.gsfc.nasa.gov/data/
http://www.realclimate.org/

Flares



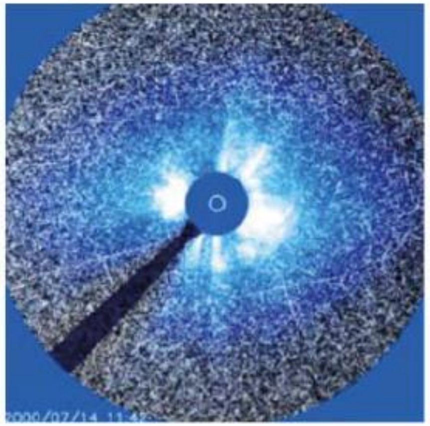
- atmospheric heating
- ionospheric changes
- HF communication problems

Coronal mass ejections



- geo-magnetic storms
- electricity network interruptions
- possibility of cascading failures
- GNSS errors

Solar energetic particles

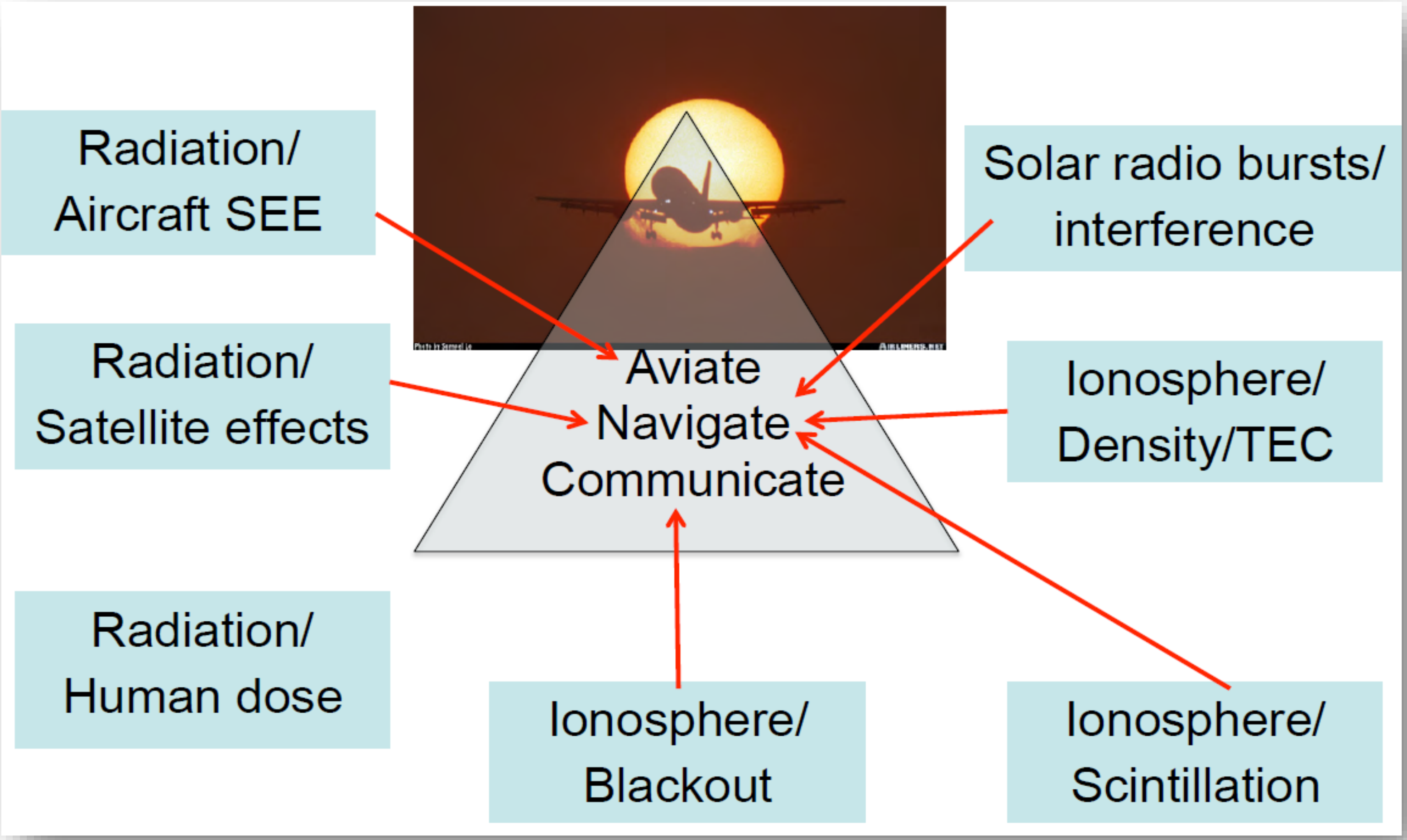


- ionising radiation at aircraft altitudes
- damage to spacecraft and aircraft electronics
- HF communication problems

Space weather keywords

- **Solar flare:**
  a sudden burst of radiation including X-rays and UV from a localised region in the Sun's atmosphere.
- **Solar wind:**
  a constant but gusty outward flow of material into the Solar System.
- **Coronal mass ejection:**
  an ejection of electrically charged gas and magnetic field.
- **Solar energetic particles:**
  high-energy electrically charged particles that can travel with speeds close to the speed of light.
- **Geomagnetic storm:**
  temporary disturbance to the Earth's magnetic field.
- **Solar cycle:**
  the rise and fall of solar activity levels over an (approximately) 11-year timescale. Large space weather events can occur at any phase of the cycle.

Why Aviation must care about Space weather

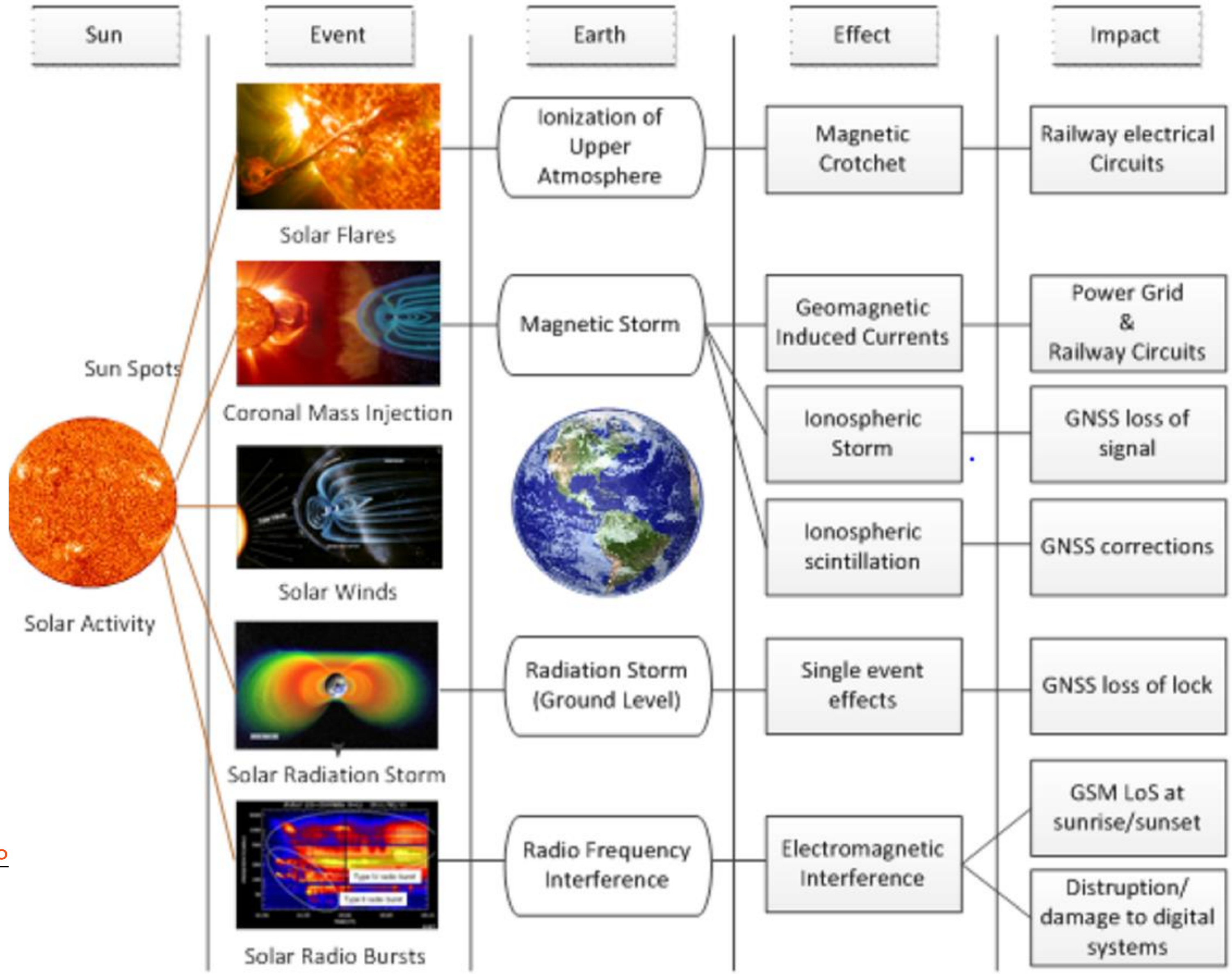


ICAO has identified solar flares and solar storms as potential hazards that affect communications, navigation, aircraft crew and passengers. They have requested early warnings of space weather activity.

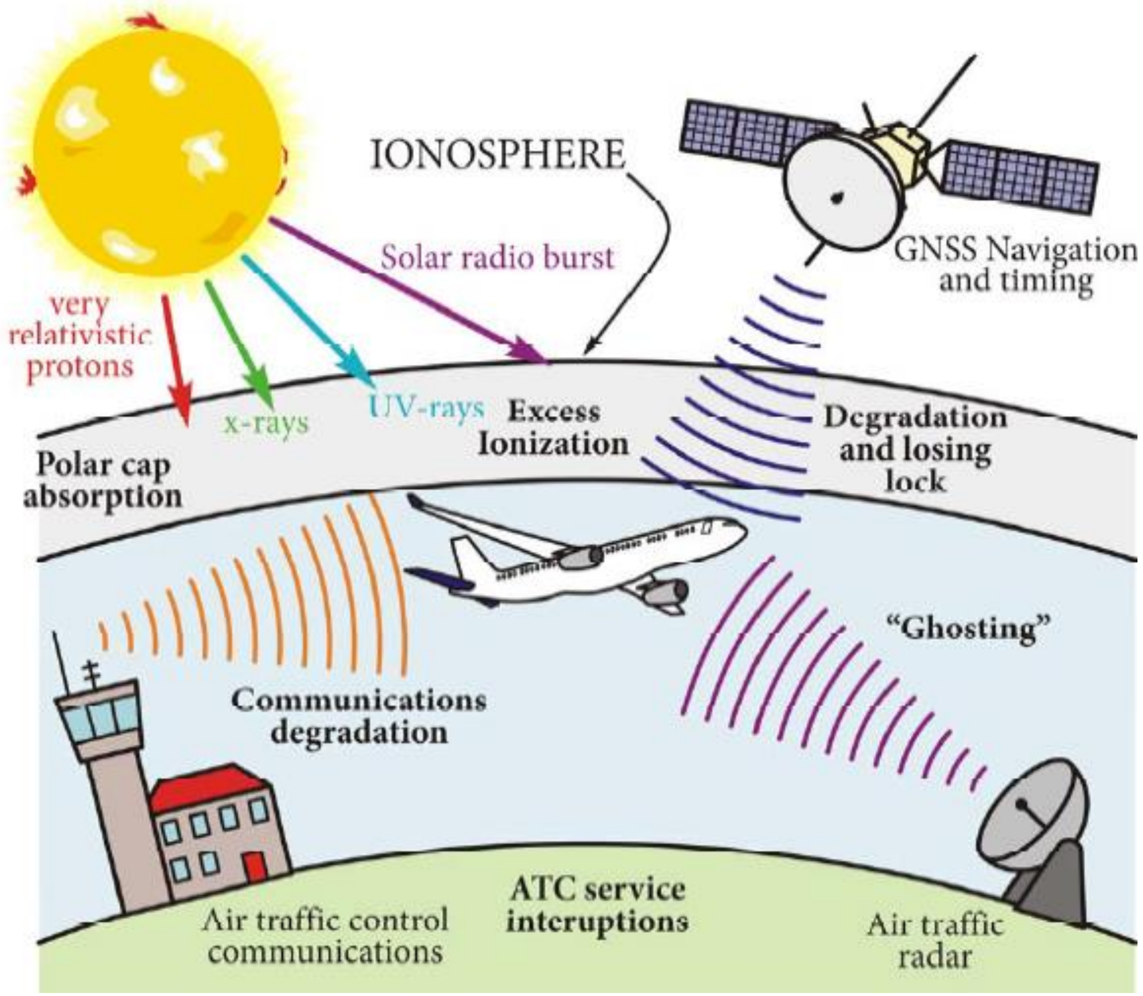
Impact of Space Weather Impact on Aviation in the following areas:

- HF communications,
- Satellite (loss of lock, scintillation, damages on electronics),
- GPS/GNSS
- Radiation exposure.

WHY SPACE WEATHER IS IMPORTANT



Overview of the multiple routes by which space weather events can impact aviation.



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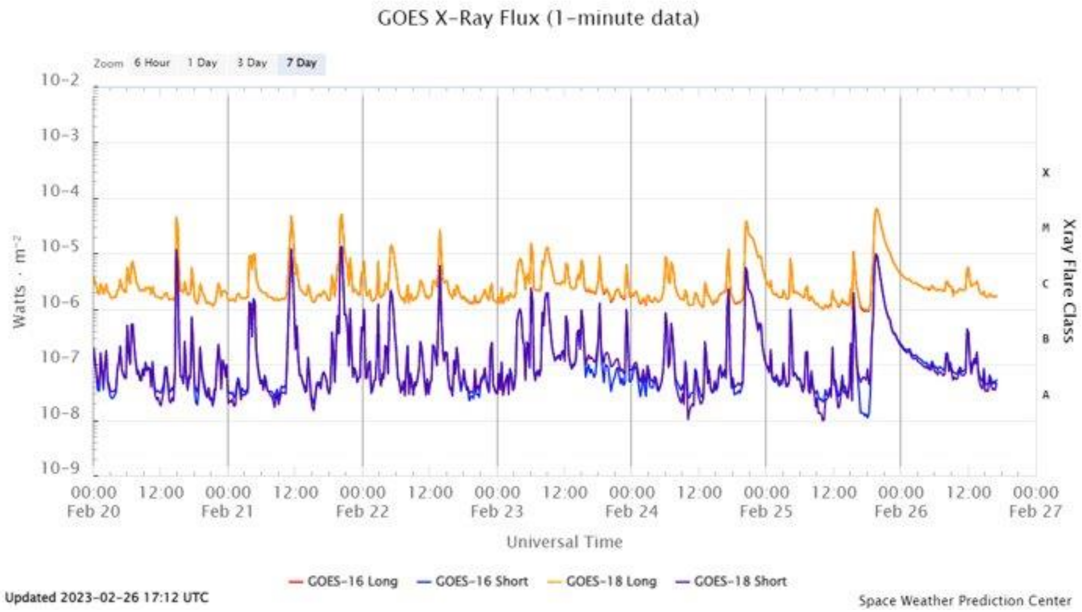
SPACE WEATHER EVENTS THAT AFFECTS AVIATION

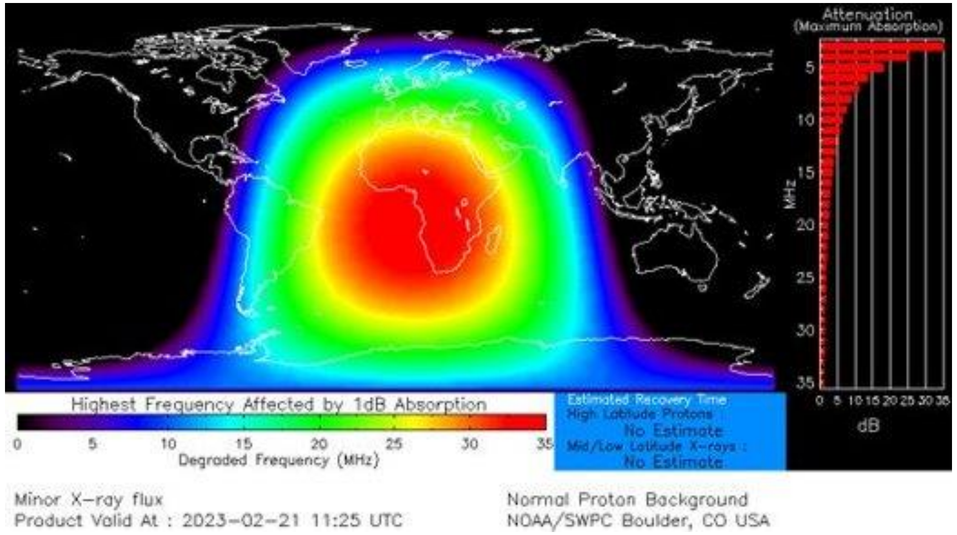
SOLAR EVENT	Solar Flare				CME		Solar Wind	Galactic Cosmic Rays	
SECONDARY EFFECT	X-Ray Emissions	Ultraviolet emissions	Radio Bursts	Solar Energetic Protons (SEPs)	Plasma	Solar Energetic Protons (SEPs)	Enhances Radiation Belts		
EFFECT ON EARTH SYSTEM	Increase Ionosphere Density	Ionospheric disturbances			Geo-magnetic Storms		Aurora	Radiation	Ionospheric Scintillation
AVIATION-RELATED SYSTEMS									
Passengers/Crew (Biological)				X	X	X		X	
Avionics				X		X		X	
HF Communication	X	X		X	X	X			
GPS/WAAS	X	X	X	X	X	X	X		X
Satellites (Navigation, Communication)	X	X	X	X	X	X	X	X	X
Low Frequency Communication	X		X		X				
ATC facilities		X			X				

- ❑ Communication and navigation form the key functions in modern air traffic management(ATM) they are cornerstones that ensure the safety and efficiency in air traffic.
- ❑ Either the degradation or interruption of communication or navigation, whether on the air routes or near the airports are common reasons for flight delays.
- ❑ Malfunctions of communication and navigation system could be directly attributed to the geomagnetic field fluctuations and ionospheric disturbances driven by SWEs.

https://doi.org/10.1051/swsc/2018029
http://dx.doi.org/10.1029/2018SW001932
https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2004GL021467#

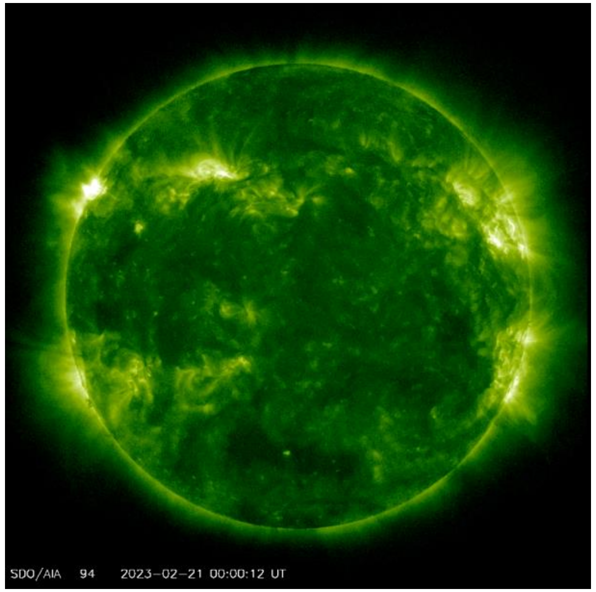
Example of impact on HF communications





- The D-region of ionosphere has largest effect on highest frequency (HF) Comms and low frequency (LF) navigation systems. The map indicates an area of the ionospheric D-region absorption during a solar flare event as well as the estimated recovery time.
- The solar flare on the sunlit side degrade the HF radio communication and this can last anything between few minutes to hours
- In 2017 during the event NOAA reports that high frequency radio, used by aviation, maritime, ham radio, and other emergency bands, was unavailable for up to eight hours. For example, civil aviation reported a 90-minute loss of communication with a cargo plane.
- Many of these flares will produce HF radio wave absorption across the sunlit side of the Earth - strong absorption in the case of X flares

https://sdo.gsfc.nasa.gov/data/



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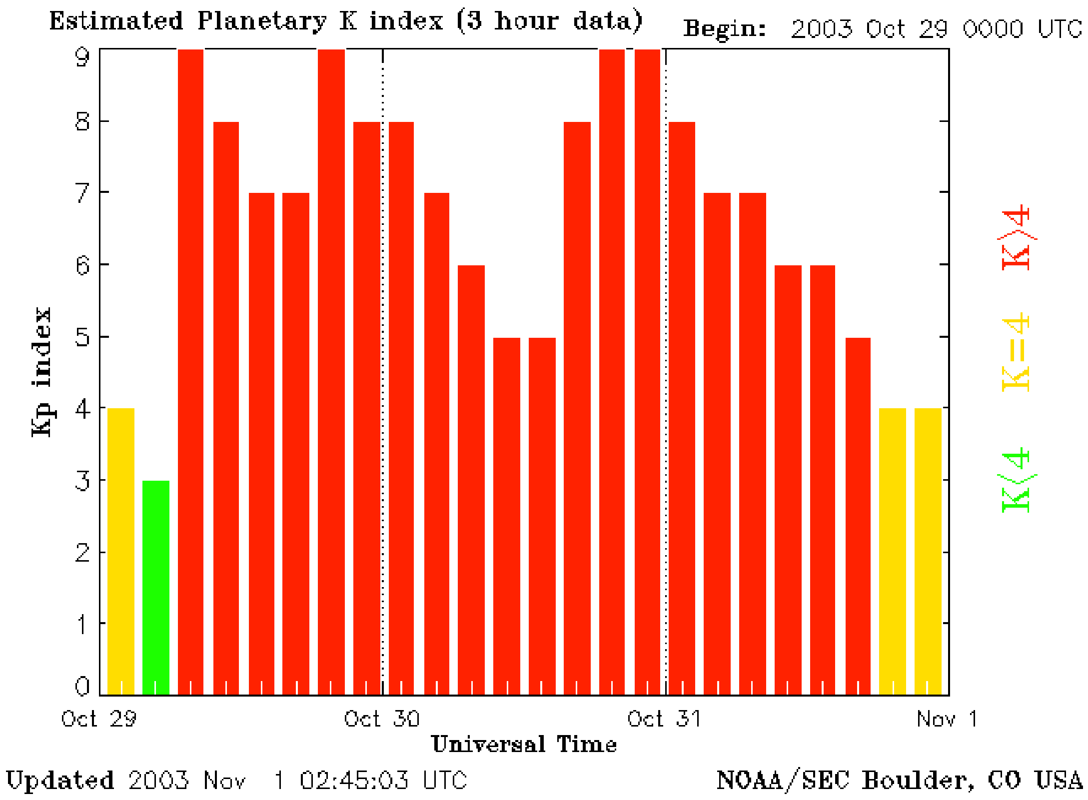
Example of SWx impact on GNSS



- During the storms of 2003, the GNSS Wide Area Augmentation System (WAAS), which operates over North America, lost vertical navigation capability for many hours, and the performance of differential systems was significantly impaired (NSTB/WAAS Test and Evaluation Team, 2004).
- The US Wide Area Augmentation System (WAAS) was affected. For a 15 hour period on the 29 October and an 11 hour period on the 30 October, the ionosphere was so disturbed that the vertical error limit was exceeded and WAAS was unusable for precision approaches.
- 2003 Halloween solar storms During the declining phase of the solar cycle the Sun unexpectedly burst into activity. A number of CMEs and flares resulted from a very large and complex group of sunspots. These resulted in geomagnetic storms that caused outages in high frequency (HF) communication systems, fluctuations in power systems and minor to severe impacts on satellite systems.
- This included two Inmarsat satellites (used by the aviation industry) of which one required manual intervention to correct its orbit and the other went offline due to central processor unit (CPU) failures. These were just two of forty-seven satellites reported to have service interruptions lasting from hours to day.

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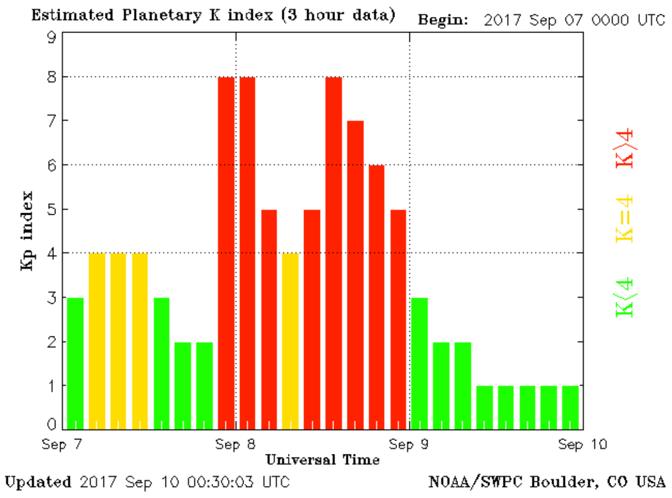
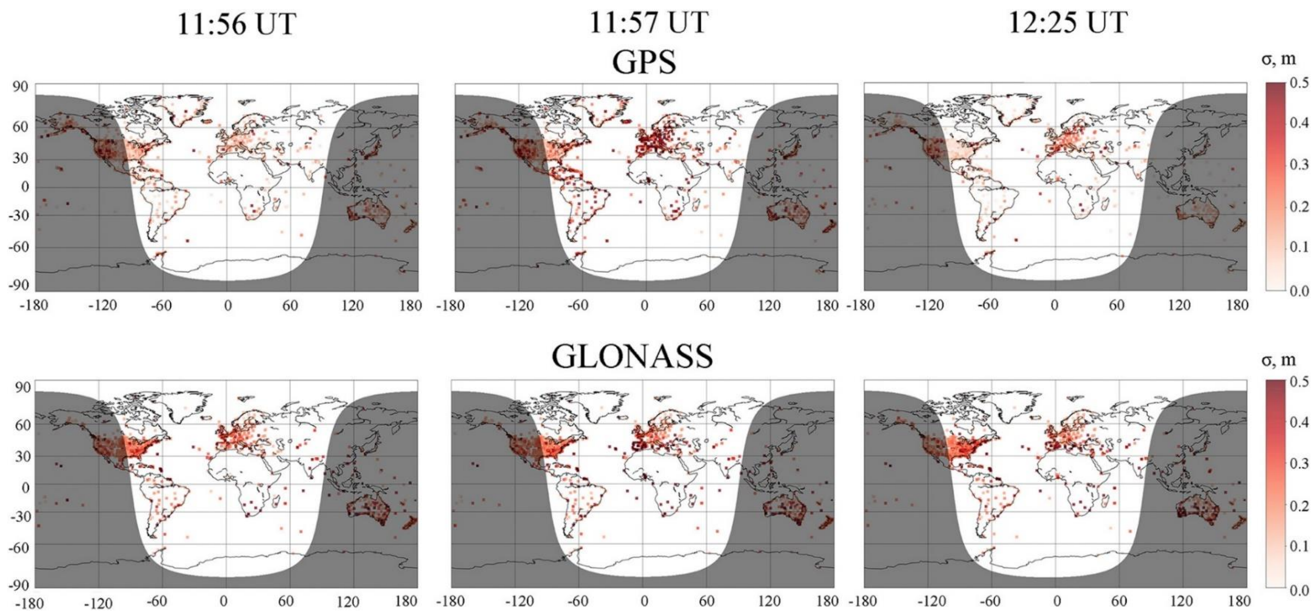
Example of SWx impact on GNSS





- ❑ Air transportation disruptions can be expected with interference in the navigation systems and vehicle tracking systems, creating possible issues during flights but also during landing and taking off operations:
- ❑ Delayed aircraft and stranded passengers at airports
- ❑ Safety issues in landing / flying due to the lack of precision
- ❑ Reduced availability of certain goods and reduced effectiveness of the logistic chain;
- ❑ Note that the dependency on GNSS in air transportation sector is expected to increase in the near future.

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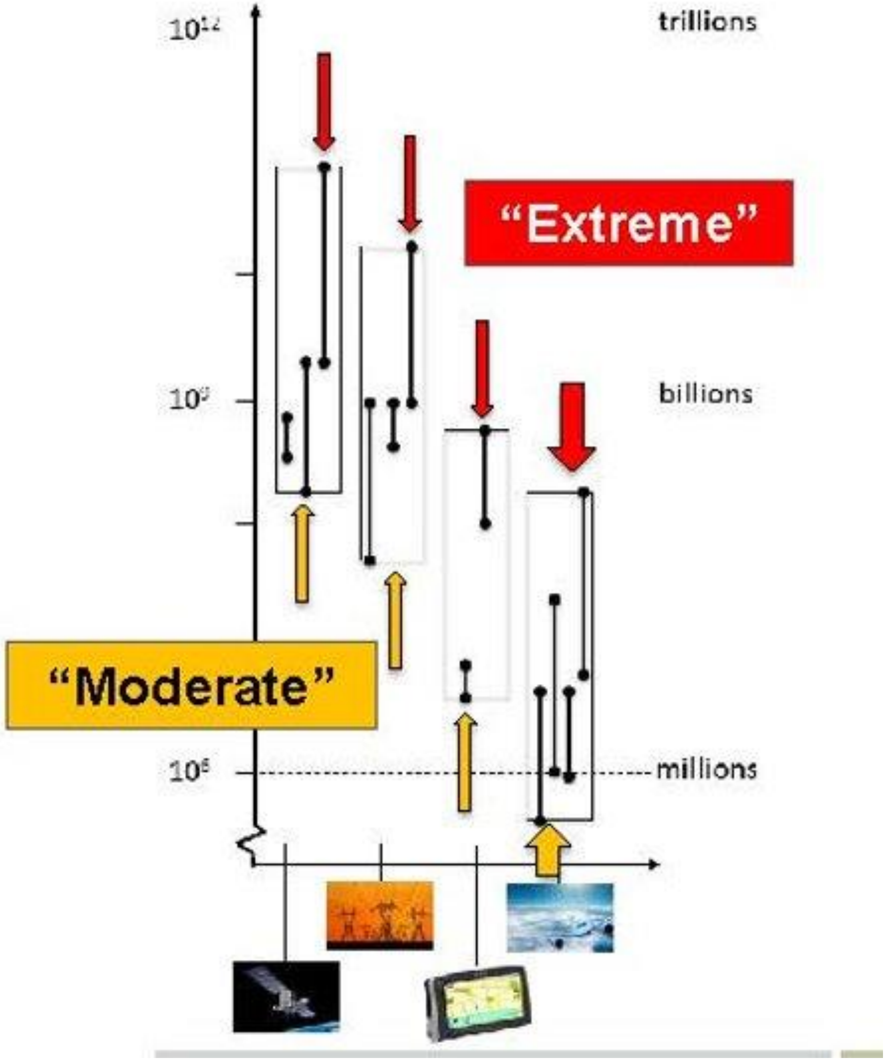
Example of the cost

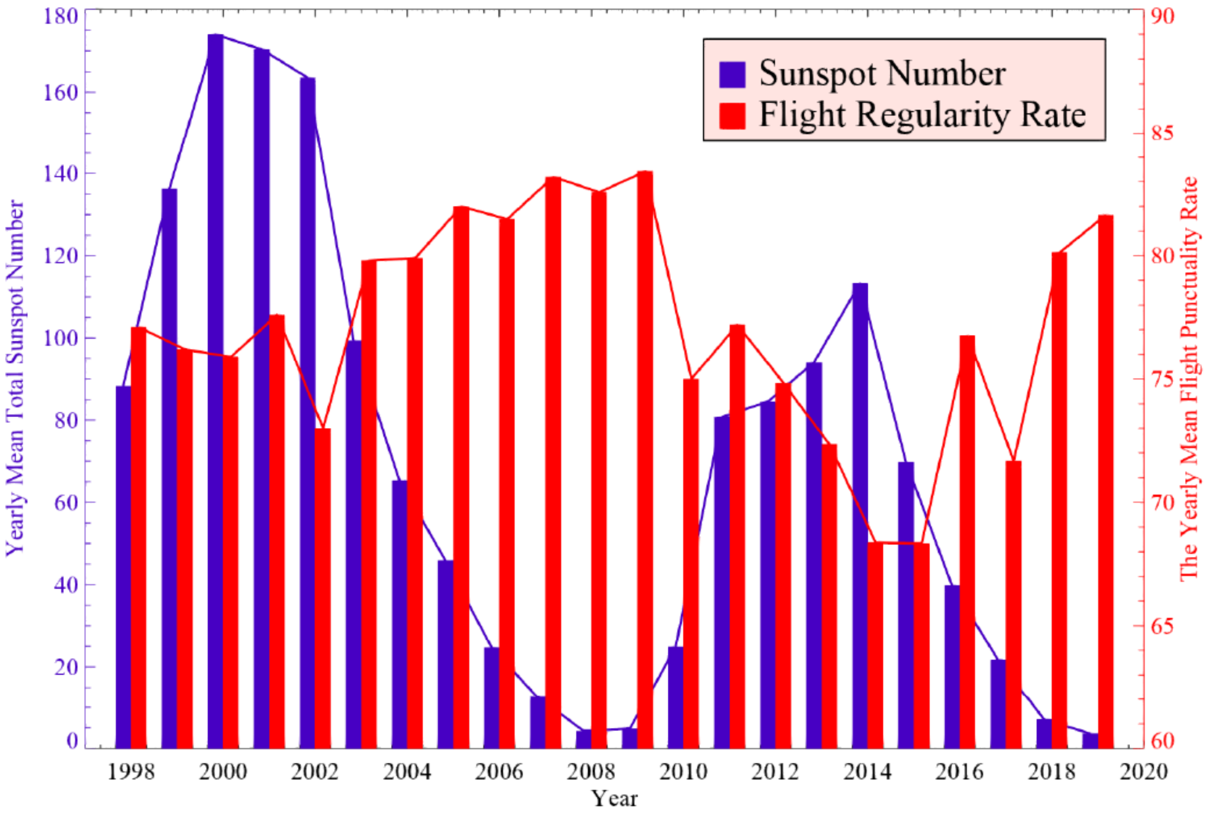


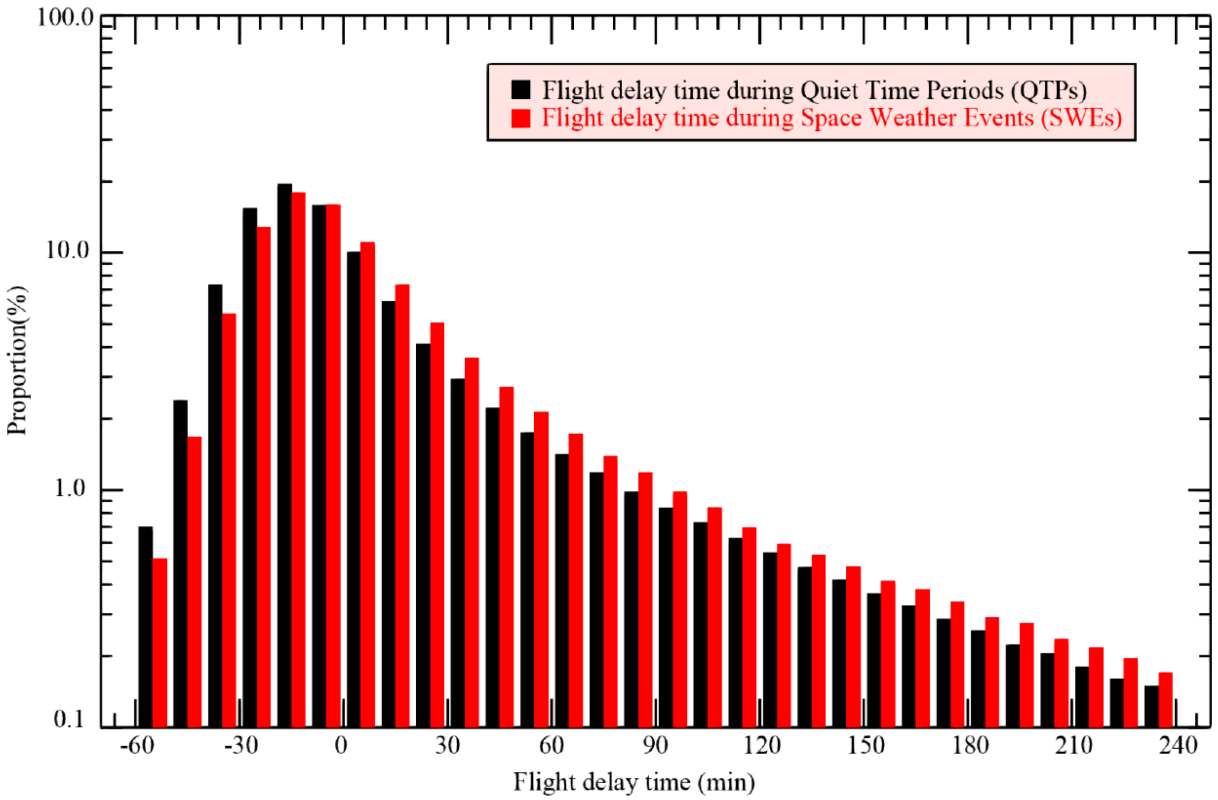
Satellite Technology
- cost of engineering & loss of applications
- Moderate , 1 satellite
- Extreme , 10 – 100 satellites

Communication & Navigation
- Loss of GNSS capability
- GNSS outage could cost $1 billion / day

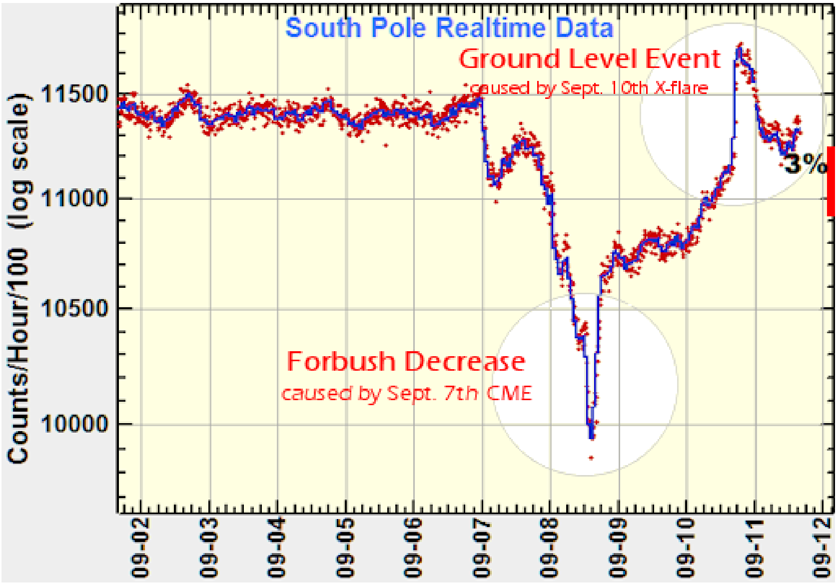
Transport
- **Aviation**, rail, maritime
- Severe economic repercussions

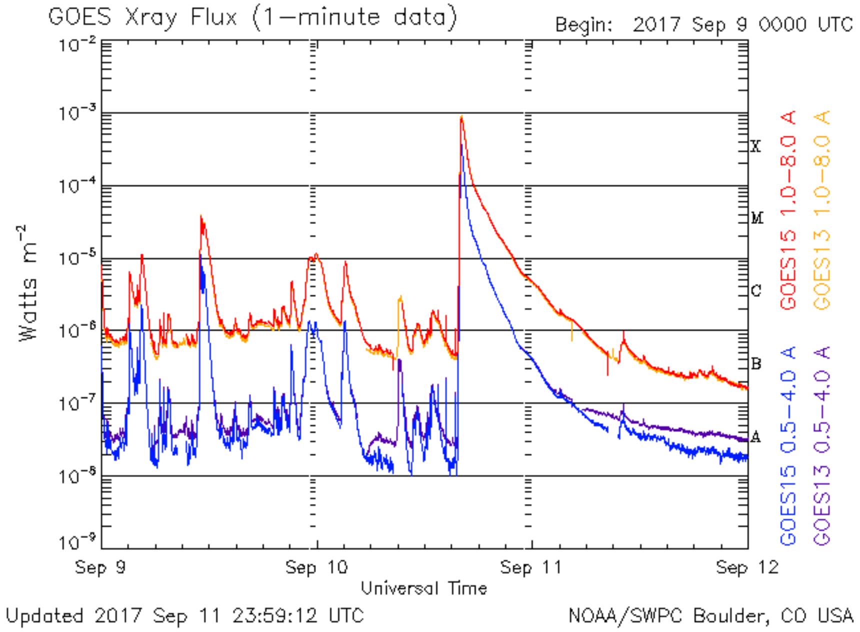
SWx impact on flight operation: flight delays



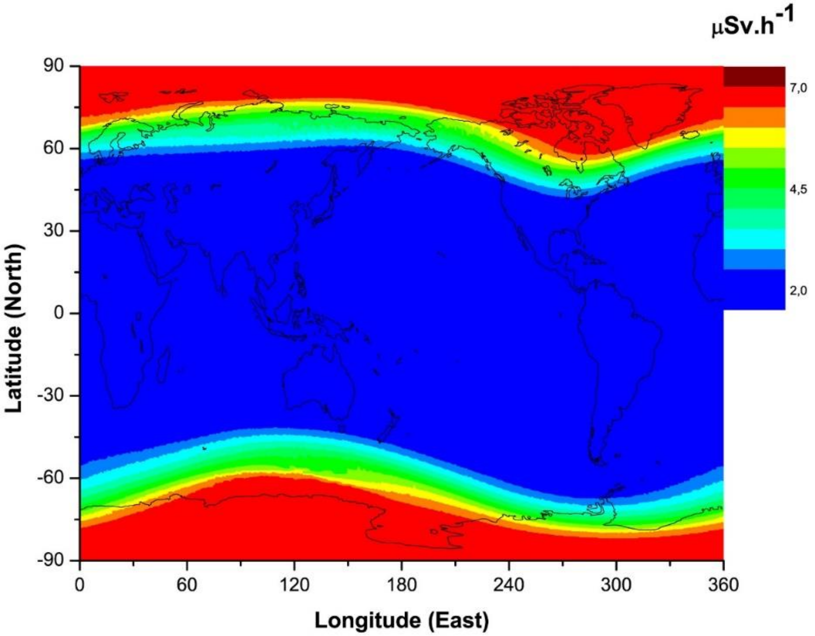


DOI: 10.48550/arXiv.2209.07700





Assessment of the Radiation Environment at Commercial Jet-Flight Altitudes During GLE 72 on 10 September 2017 Using Neutron Monitor Data. Radiation levels jumped about 6%," reports Clive Dyer, a visiting Professor at the University of Surrey Space Centre. "In historical terms, it was a relatively small one -- only about one thousandth as strong as the event of 23 Feb 1956, which is the largest measured."
Nevertheless, it could have made itself felt at aviation altitudes. Dyer says that "passengers flying on high-latitude routes at 40,000 feet could have absorbed an extra 10 microsievert of radiation," approximately doubling the usual dose on such a flight.



In the worst-case scenario, in which the airplanes took off close to the onset of the GLE and maintained a high cruise altitude of 40,000 feet (12 kilometers), passengers on a flight from Helsinki, Finland, to Osaka, Japan, would have received a roughly 90-microsievert dose of radiation, the team found. A flight from Helsinki to New York would have received a slightly higher dose, around 110 microsievert.
Such levels are far below an average American's annual radiation exposure of 1 millisievert. But they remain above typical background radiation and could pose a cumulative health risk for aircraft crew and pilots, who already receive roughly triple the average yearly dose of radiation. Radiation can also upset or damage the sensitive electronics aboard commercial aircraft, underscoring the importance of preparing for severe space weather. (*Space Weather*, https://doi.org/10.1029/2018SW001946, 2018)

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International Commission on Radiological Protection (ICRP) 2016 recommendation for air crew

- More recently, the International Commission on Radiological Protection (ICRP) have made specific recommendations for air crew (ICRP, 2016)
- At typical commercial flight altitudes, the dose rate is generally in the range of 2–10 mSv h1 , depending primarily on latitude, altitude, and level of solar activity (ICRU, 2010).
- In addition, this publication affirms that exposure of aircraft crew to cosmic radiation is occupational, and thus employers have a role to play in protection, even if options are limited in this case.
- **For aircraft crew (**recommendations for air crew (ICRP, 2016)**)**, the Commission recommends that the operating management:

(i) inform the aircraft crew individually about cosmic radiation through an educational programme;

(ii) assess the dose of aircraft crew;

(iii) record the individual and cumulative dose of aircraft crew. These data should be made available to the individuals and should be kept for a reasonable period of time that is, at a minimum, comparable with the expected lifetime of the individuals; and 13

(iv) adjust the flight roster when appropriate, considering the selected dose reference level and after consultation with the concerned aircraft crew.

- The Commission also recommends that national authorities or airline companies disseminate information to raise awareness about cosmic radiation and support informed decisions among all concerned stakeholders, and foster a radiological protection culture for occupationally exposed individuals

Space weather mitigation aspects :

- The topical challenge for effective mitigation of significant space weather events is to forecast or detect such events in due time and to provide the relevant information in the right form to the right persons at the right time
- Satellite failure and GNSS-based applications: A back-up to satellite communication and navigation should remain available.
- Depending on the flight phase, area and aircraft equipment, this back-up could be HF/VHF/SATCOM voice communication, ground based navigation, radar vectoring, inertial navigation, etc.
- Power failure: Air traffic control centers have alternate power generation in case of power failure to ensure the safety of air navigation.
- Increase in the radiation level: As the radiation dose is higher at higher altitude and latitude, a possible solution is to decrease the aircraft altitude and latitude. However, the geographic and altitude limit are difficult to determine. Currently, airlines are not flying polar routes when a radiation storm is in progress.
- In accordance with the 'right to know' principle, which states that people have the right to be informed about the potential risks that they may be exposed to in their daily life, and the underlying ethical values of autonomy, justice, and prudence, the Commission encourages national authorities, airline companies, consumer unions, and travel agencies to disseminate general information about cosmic radiation associated with aviation.
- This information must be easily accessible and should present Radiological protection from cosmic radiation in aviation the origins of cosmic radiation; the influence of altitude, latitude, and solar cycle; and indicate typical doses associated with a set of traditional flight routes and the potential of receiving unexpected exposure in the case of a rare but intense GLE (ICRP, 2016).

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