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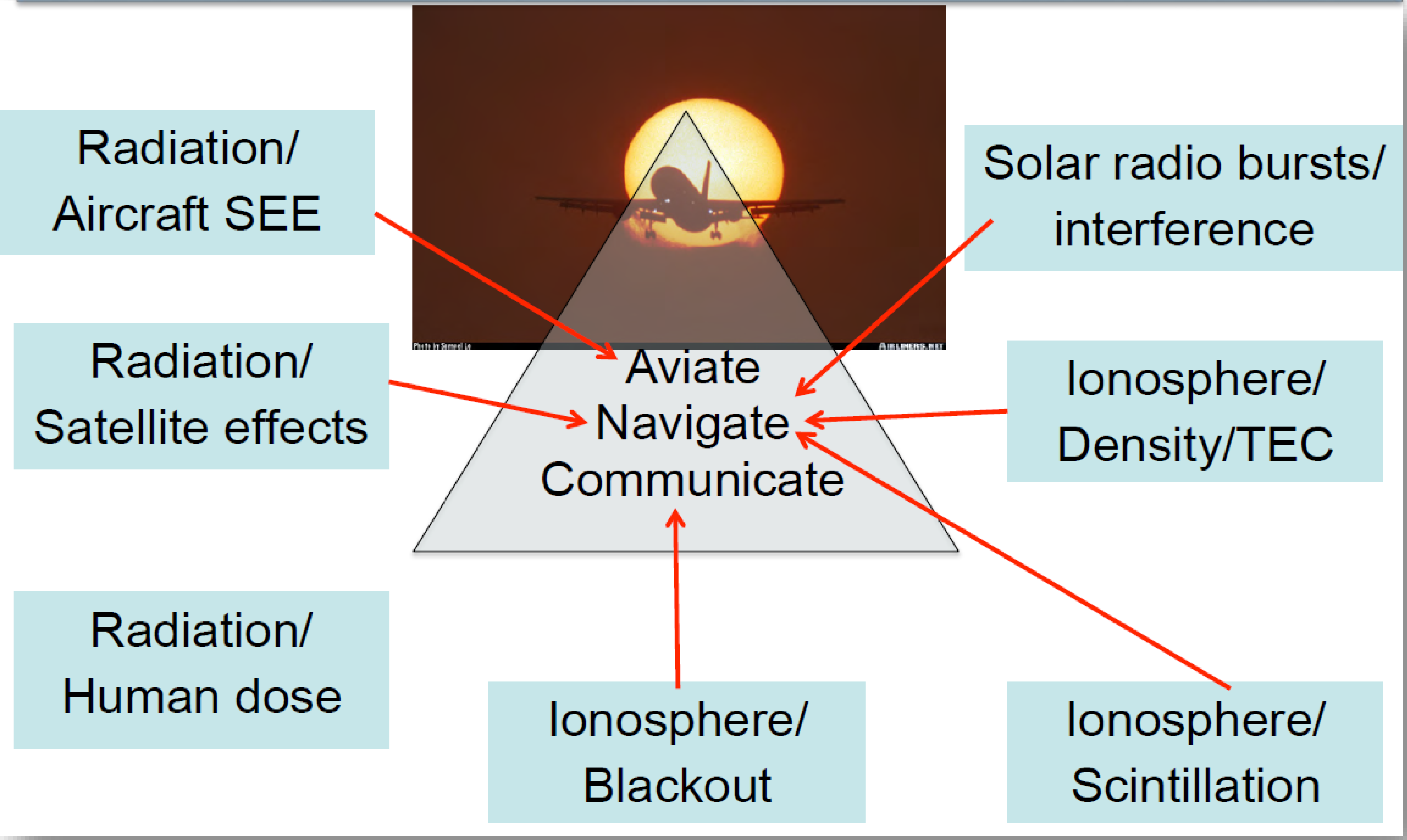
Impact of Space Weather Impact on Aviation: PPT 03

Virtual Meeting/28 July 2021

outline

- Why must Aviation care about space weather?
- Space Weather events that affects Aviation
- Impact on HF communications
- Impact on navigational aids
- Radiation exposure

Why Aviation (Airlines) must care about Space Weather



The International Civil Aviation Organization (ICAO) is the UN organization to foster safe and orderly air travel. 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:

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

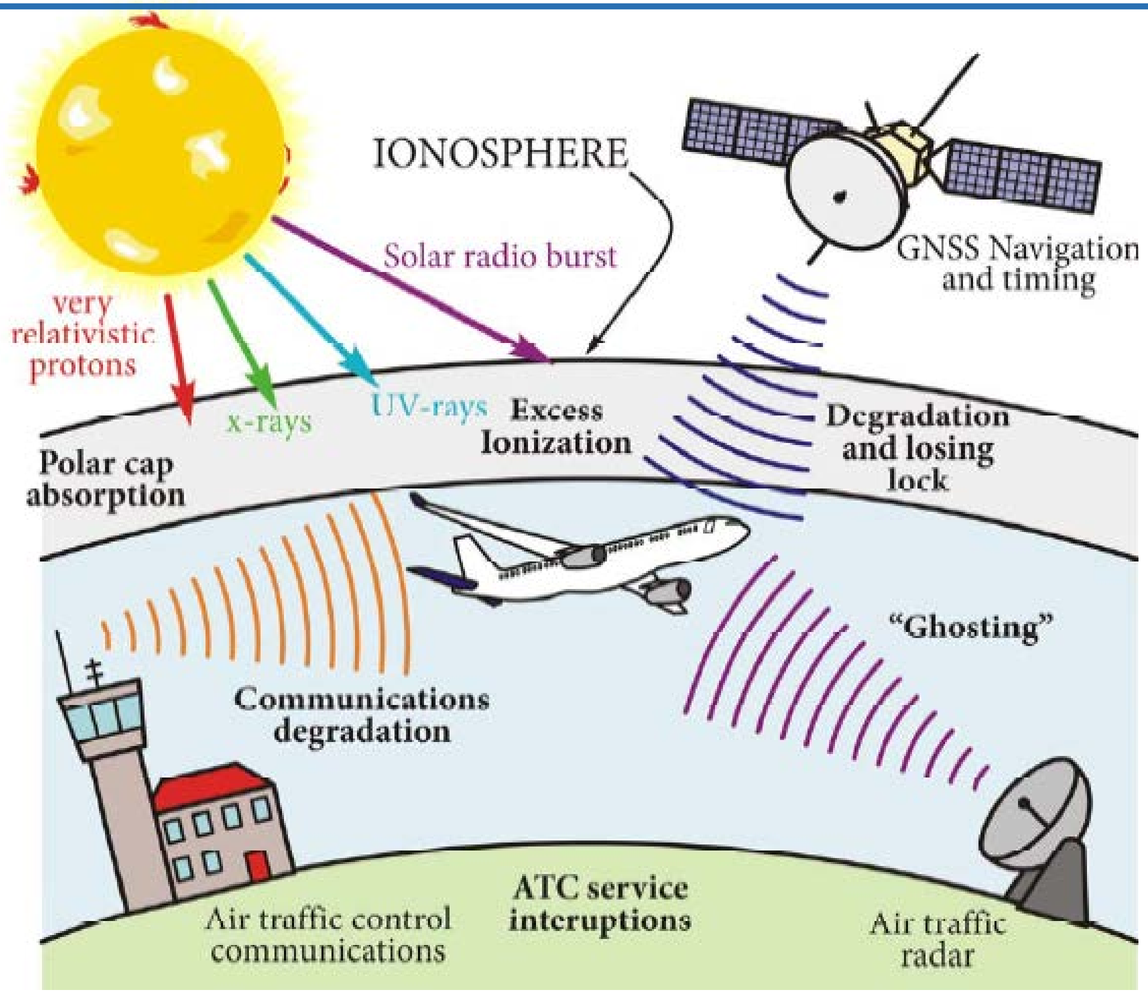
SPACE WEATHER EVENTS THAT AFFECTS AVIATION

	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				

courtesy of https://www.gwu.edu

- unexpected loss of communications; HF voice and data link, i.e., controller pilot data link communications (CPDLC), on routes where that manner of communications is used
- Poor or unusable performance in satellite communications;
- Degraded performance of navigation and surveillance that rely on GNSS and Automatic dependent surveillance – broadcast (ADS-B) and/or automatic dependent surveillance – contract (ADS-C) anomalies;
- Sporadic loss-of-lock of GNSS, especially near the equator and post-sunset;
- Unanticipated non-standard performance of on-board electronics resulting in reboots and anomalies; u Issues related to radiation exposure by aircrew and passengers

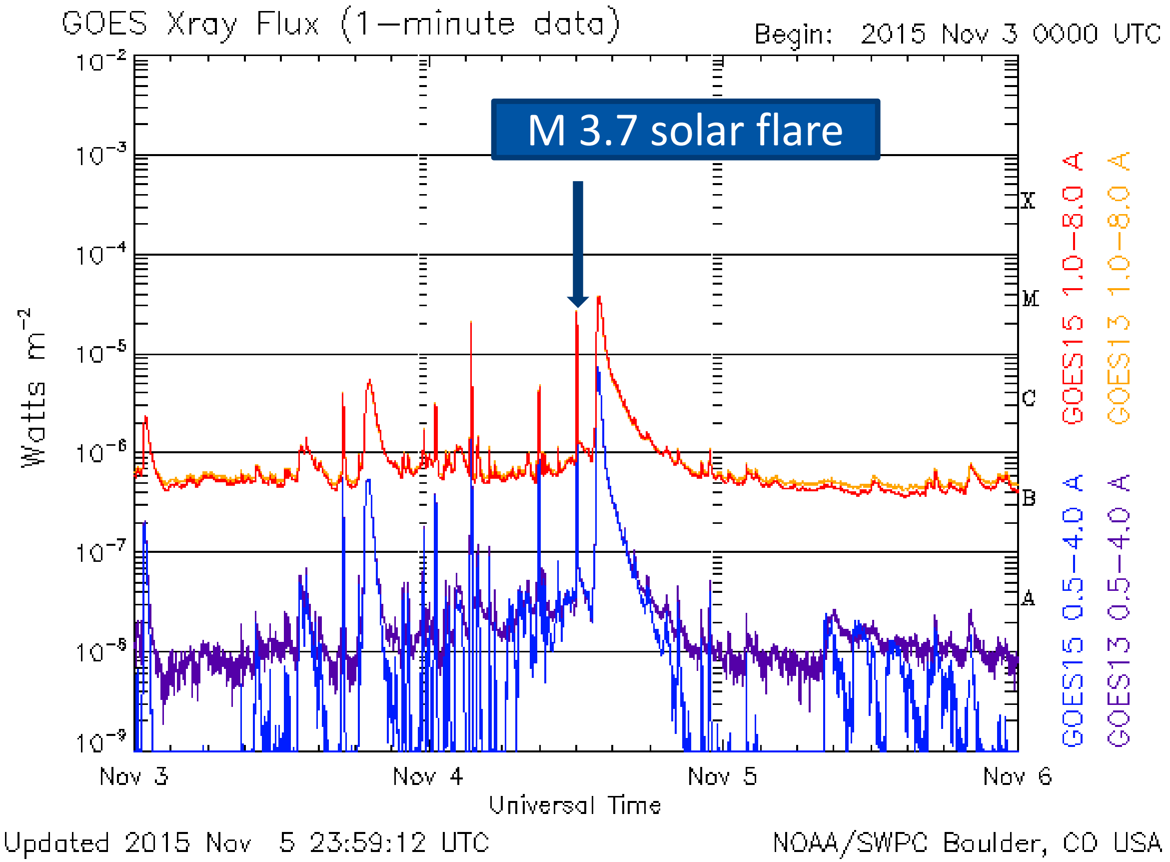
Overview of the multiple routes by which space weather events can impact aviation.



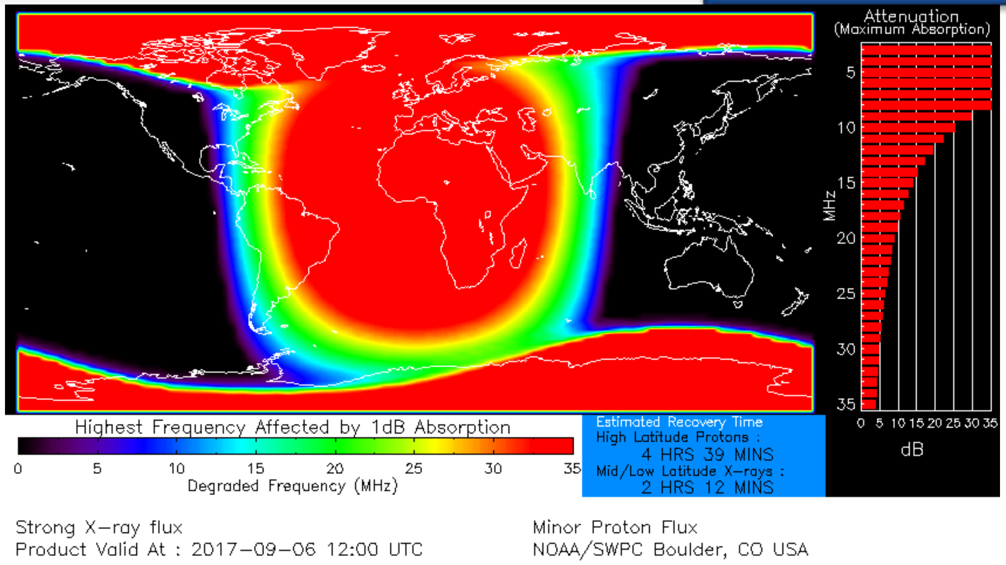
Example of Impacts on Radar system

- On November 4th, 2015, several European air traffic authorities reported issues with operations of secondary air traffic radar systems at or near local sunset
- Belgocontrol, the air traffic authority in Belgium, reported issues with a secondary A/C radar.
- False echoes, representing non-existing planes, were observed only in the direction of the Sun during two periods of time: disruptions of the air traffic over the southern part of Sweden occurred on that day resulting in a de facto partial closure of the airspace and delayed arrivals and departures according to reports in the media (The Local, 2015).
- Based on publicly available information from the Swedish air traffic authority (Luftfartsverket; hereafter LFV), ATC secondary surveillance radar systems could not display proper information to the air traffic controllers, which lead the authorities to reduce aircraft movements for safety reasons (**Luftfartsverket, 2015**).
- **A.J. Andersson, 2017** indicates that for this event that a simultaneous series of ATC radar disturbances occurred at several sites in Sweden starting around 14:19 UT.
- On November 4th, 2015, an Air Greenland plane landing at Thule Airbase in Greenland at 14:49 UT experienced technical issues above 4000 feet altitude with a conflicting report between an ILS localizer (at 109.5 MHz) indicating a correct alignment with the runway and the autopilot being unable to hold on that same position information. The landing went without further complications. After the flight the ILS equipment's were checked for malfunction but were cleared of any defect.

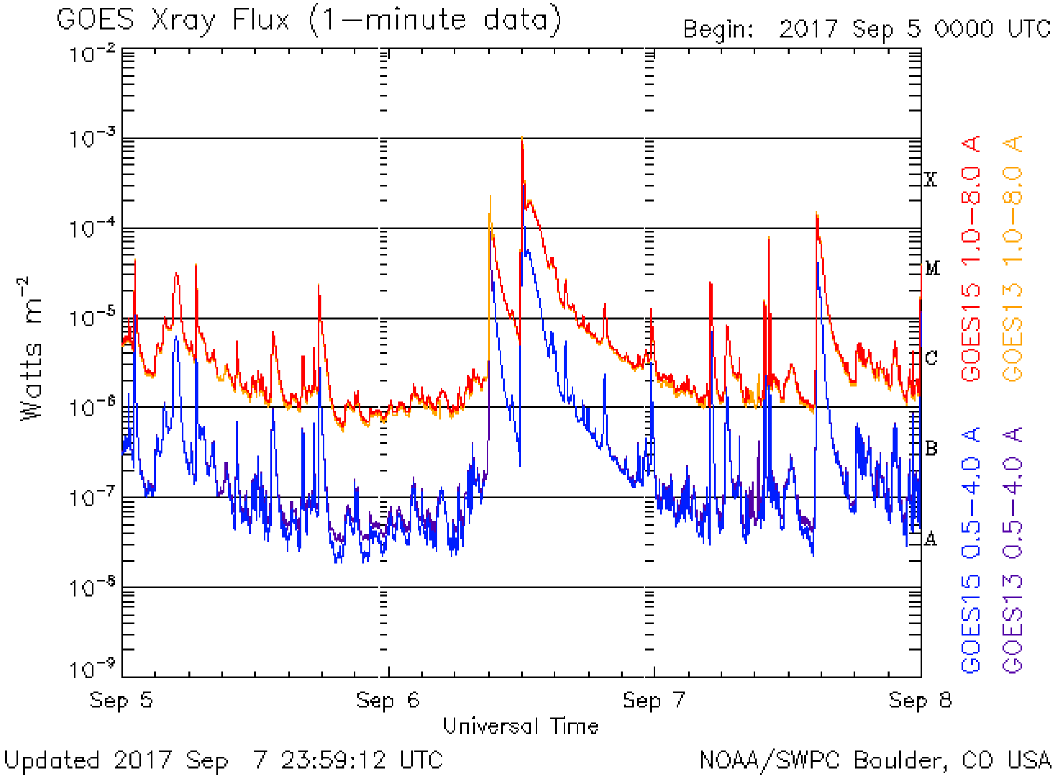
https://doi.org/10.1051/swsc/2018029



Impacts on HF Communications



- Example of X9.3 –class solar flare observed on the 6th September 2017 at ~ 12:04 UT. This is ~15:04 local time. The example shows strong radio blackout over Europe, Africa and the Atlantic Ocean.



D-region absorption (D-RAP)

- 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

- Ionospheric scintillation is the rapid modification of radio waves caused by small scale structures in the ionosphere (tens of m to tens of km). Scintillation events are linked to geomagnetic storms, but the relationship is complex!
- Severe scintillation conditions can prevent a GPS receiver from locking on (i.e., position and timing information lost).
- If loss of lock occurs on sufficient satellites, then the positioning service will also be lost. **Conker at al. (2003)**
- Less severe scintillation conditions reduce the position accuracy and can also impact Ultra High Frequency (UHF) satellite communication systems.

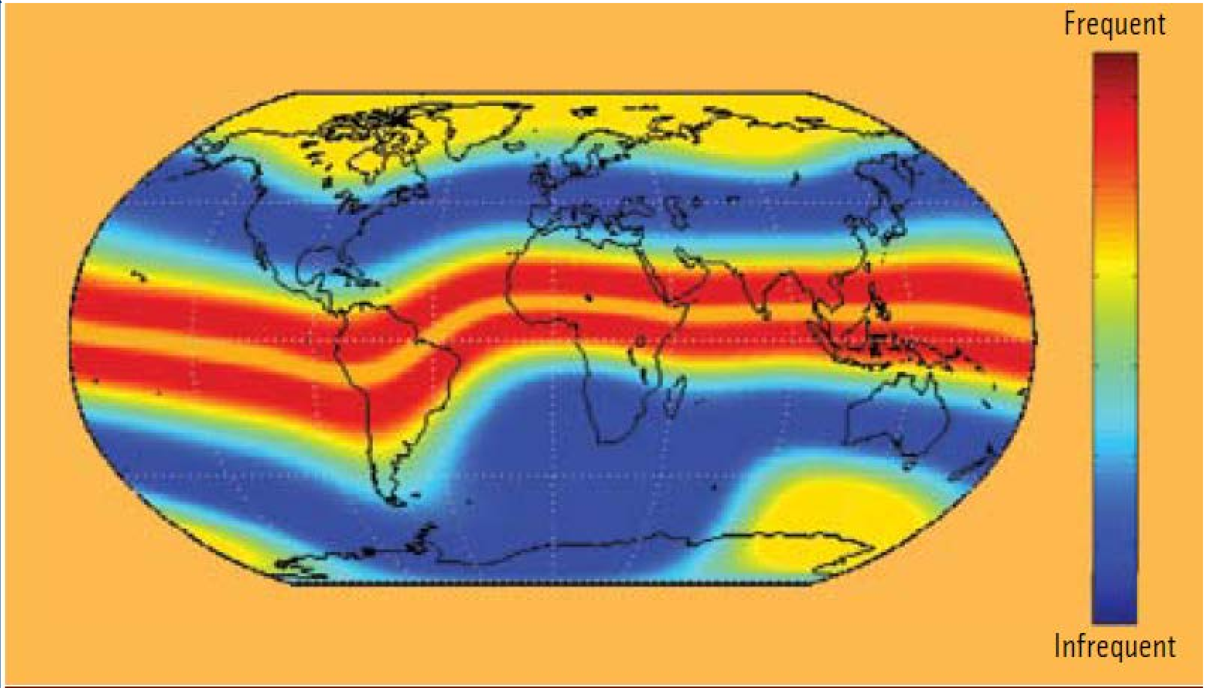
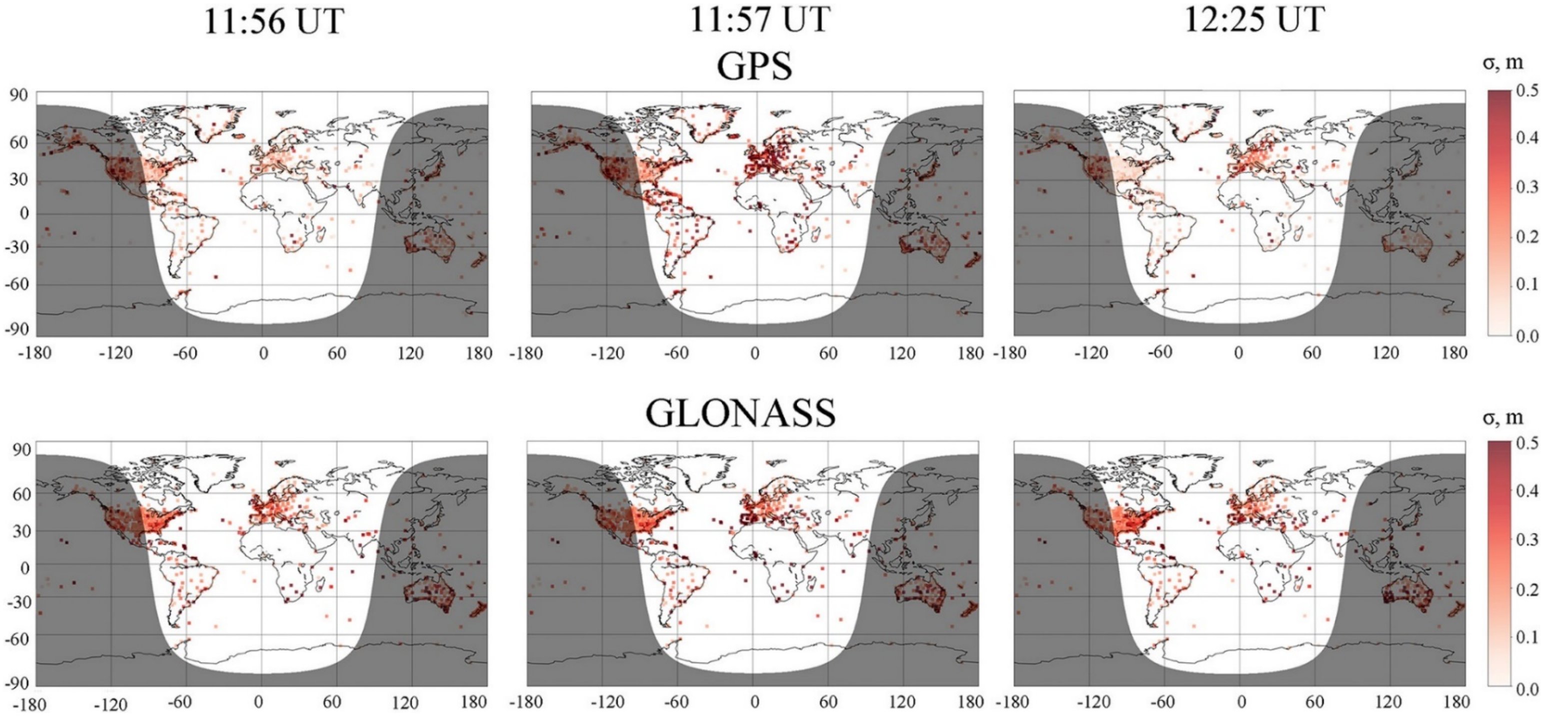
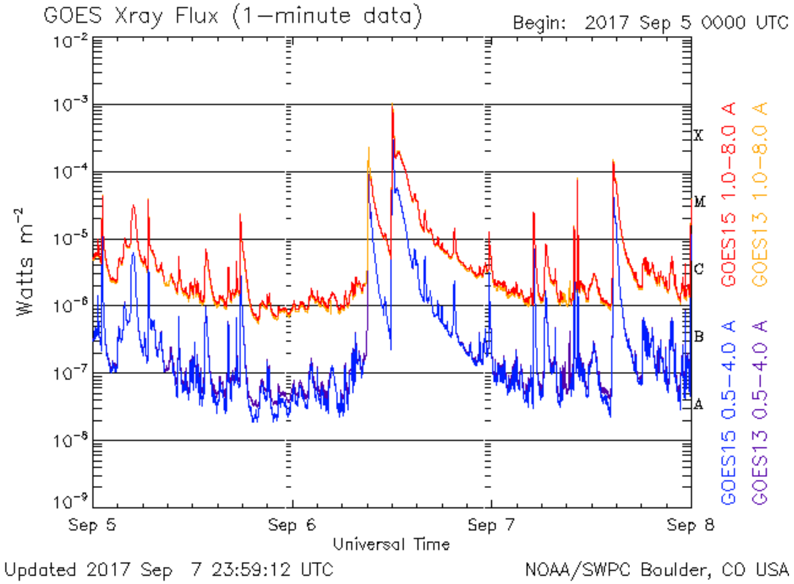


FIGURE 1 Scintillation map showing the frequency of disturbances at solar maximum. Scintillation is most intense and most frequent in two bands surrounding the magnetic equator, up to 100 days per year. At poleward latitudes, it is less frequent and it is least frequent at mid-latitude, a few to ten days per year.

Kintner et al., Inside GNSS, Aug. 2009

Example of position error in GPS due to solar flare of 6 september 2017





- Figure 11 shows the global distribution of positioning error σ during the X9.3 flare. One can see that during the SF the positioning error increased for both GPS and GLONASS systems. Such an effect is observed on the sunlit part of the Earth: on the major part of Africa and Europe, and also (but less pronounced) in South and North America. At 11:56 UT, before the flare, the mean PPP errors over the area of (−30:30°N, −30:60°E) were ~0.17 and ~0.47 m for GPS and GLONASS, respectively. These values sharply increased up to 0.46 and 0.56 m after the SF onset. Such worsening of the positioning lasted for ~30 min until ~12:25 UT. The averaged PPP errors during this period of time over the area of (−30:30°N, −30:60°E) reached ~0.57 and ~0.56 m, for GPS and GLONASS. Overall, our results show that the positioning quality for GPS decreased by ~3 times during the flare.
- During this period of time, the GPS PPP error 3 times exceeded the background level.

https://doi.org/10.1029/2018SW001932

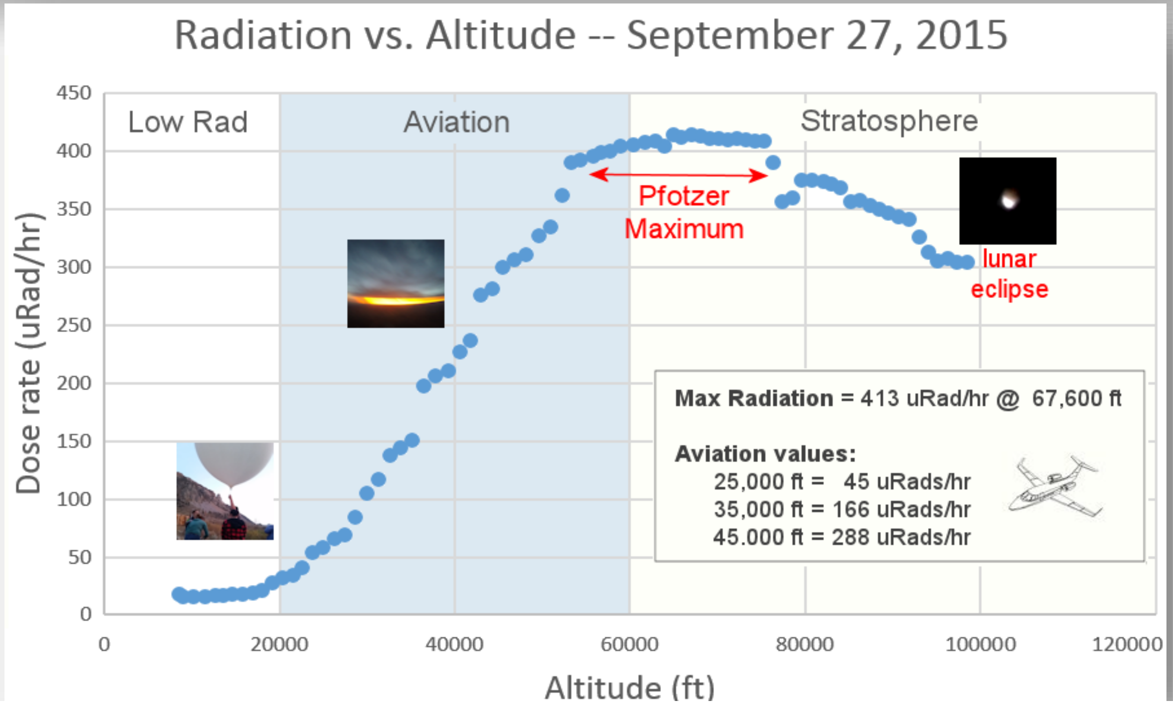
Example of impact on Global navigation satellite systems:

- 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.

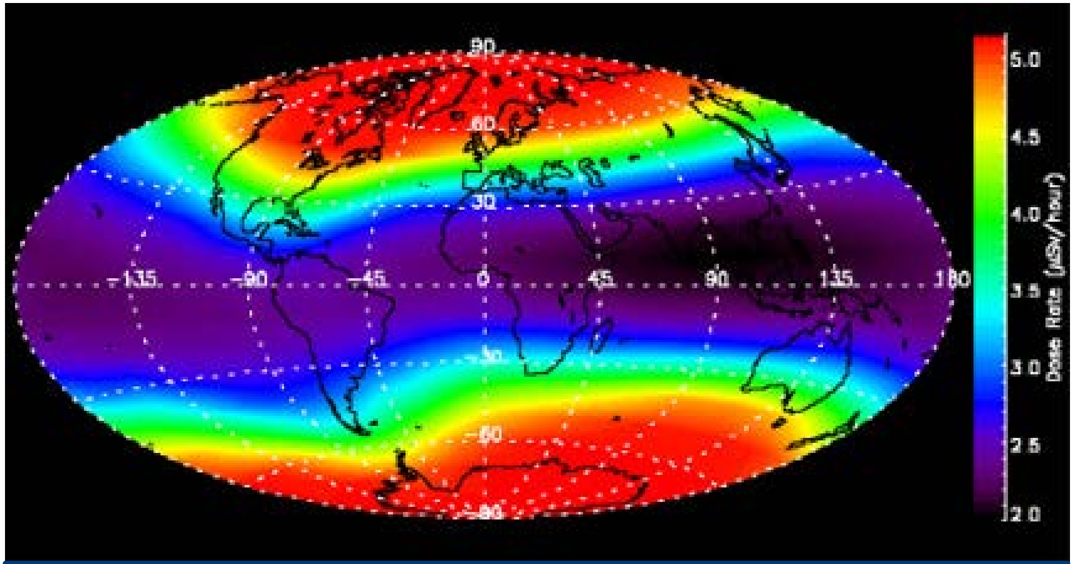
10.1029/2020SW002593

ICAO

Radiation exposure: impact on human health and avionics

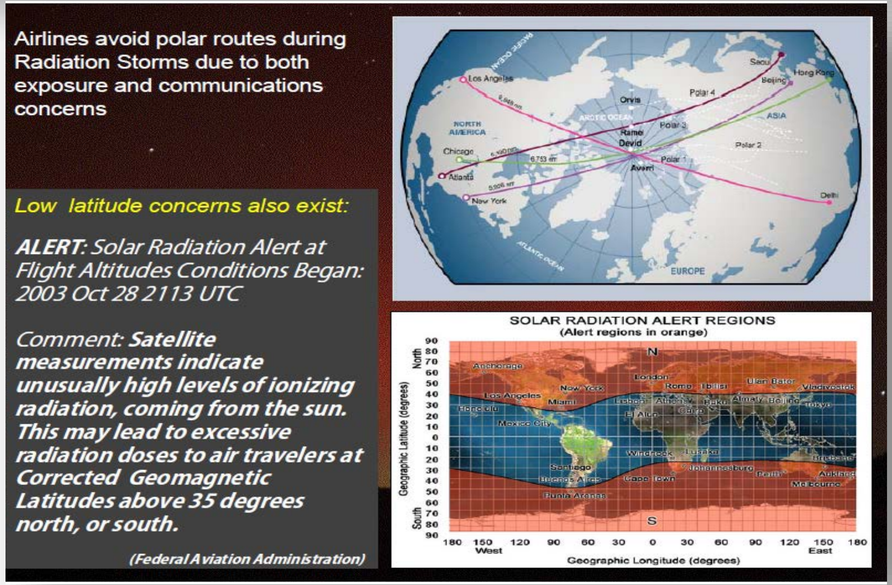


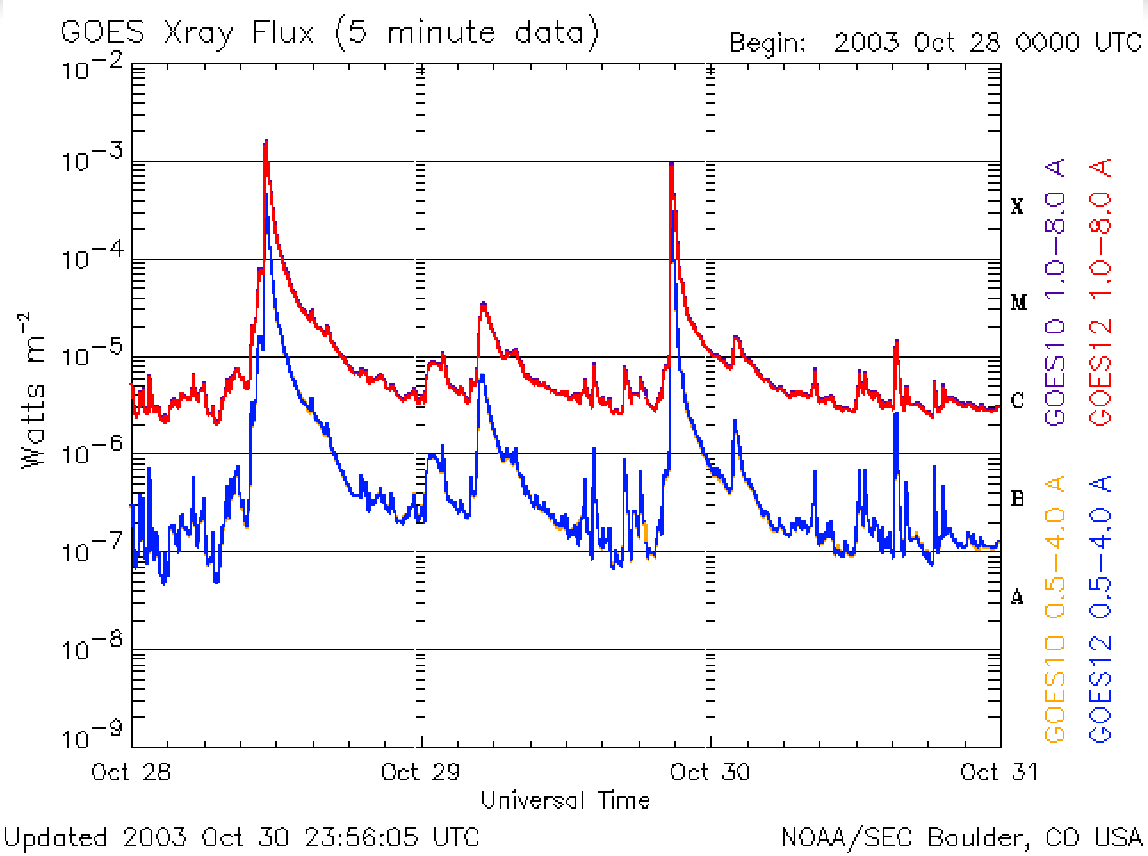
ALTITUDE (feet)	HOURS AT LATITUDE 60 N	HOURS AT EQUATOR
27,000	630	1330
30,000	440	980
33,000	320	750
36,000	250	600
39,000	200	490
42,000	160	420
45,000	140	380
48,000	120	350



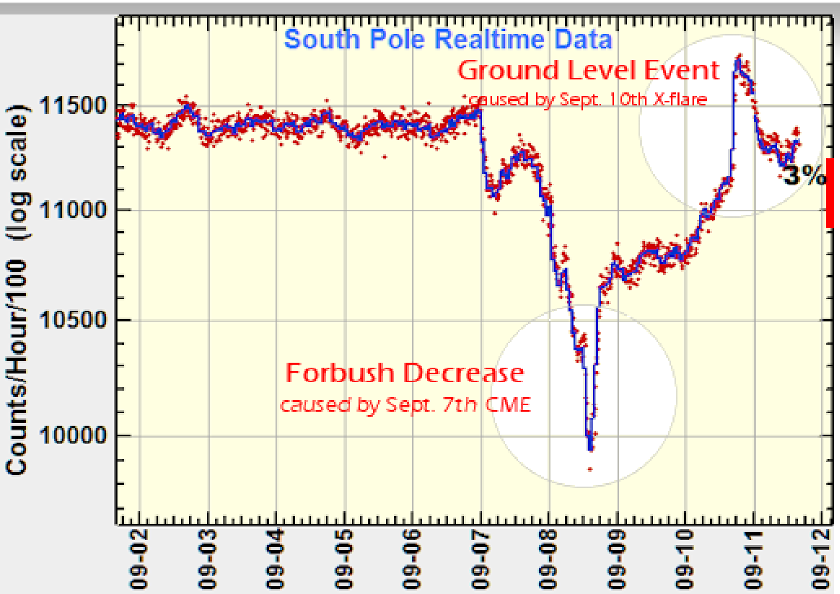
Typical background radiation dose: courtesy of 19hubbl01

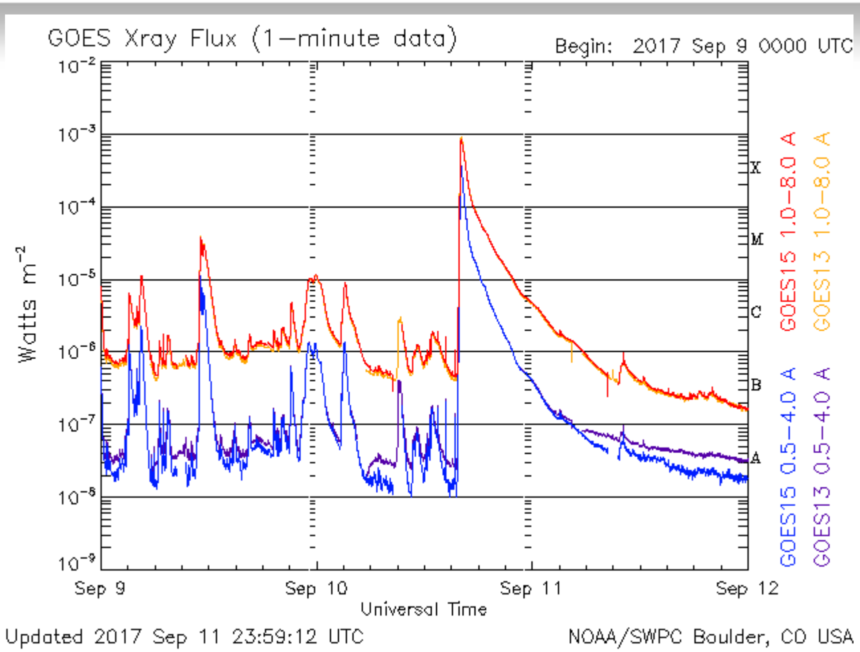
- The radiation dose at the poles, with normal solar activity is about 3 to 5 times greater than in in equatorial latitudes.
- For practical purposes, Table 2 presents estimates for the number of flying hours per year required to reach an effective dose of 1 mSv for a given flight level and latitude.





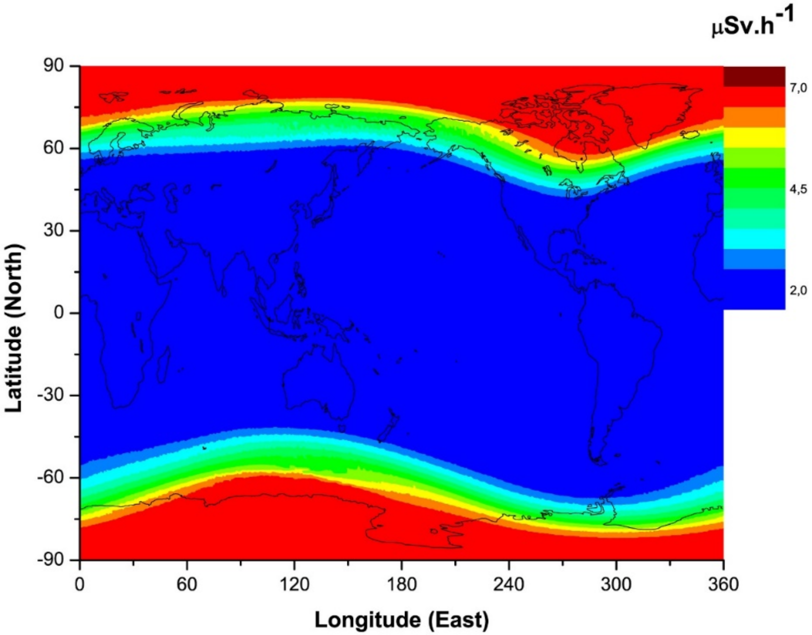
- The electronic system within the aircraft is subjected to high levels of ionizing radiation which can generate transients causing operating errors that can affect system functions and data.
- The most common effect is the so-called single event effect (SEE), which is caused by the high neutron flux at the cruising altitude and single event upset (SEUs) caused by ionizing radiation from galactic cosmic rays.





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)

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

Ref: ICRP, 2016. Radiological Protection from Cosmic Radiation in Aviation. ICRP Publication 132. Ann. ICRP 45(1), 1–48.

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).

References

1. ICRP, 2016
2. ICRU, 2010
3. https://doi.org/10.1029/2018SW001946, 2018)
4. FAA 2003
5. **10.1029/2020SW002593**
6. courtesy of 19hubbl01
7. **https://doi.org/10.1029/2018SW001932**
8. **Conker at al. (2003)**
9. Kintner et al., Inside GNSS, Aug. 2009
10. ***courtesy of https://www.gwu.edu***
11. **https://doi.org/10.1051/swsc/2018029**

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Thank you

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