Space Weather Impact on Aviation systems

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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.

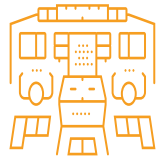
How space weather impacts African aviation

For commercial airlines, space weather carries **operational, commercial,** and **reputational risk**:

High-frequency (HF) radio used for long-range communications can be weakened or lost during solar events.

Satellite navigation systems (GNSS), which are crucial for routing and positioning decisions, can become less accurate.

Crews and frequent flyers may be exposed to higher levels of radiation at cruising altitude.



Sensitive **avionics and onboard computer systems** can be degraded.

Aviation-related systems and Space Weather

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				

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

- 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; Issues related to radiation exposure by aircrew and passengers
- Communication and navigation form the key functions in modern air traffic management(ATM) they are cornerstones that ensure the safety and efficiency of 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 systems could be directly attributed to the geomagnetic field fluctuations and ionospheric disturbances driven by space weather events (SWEs).

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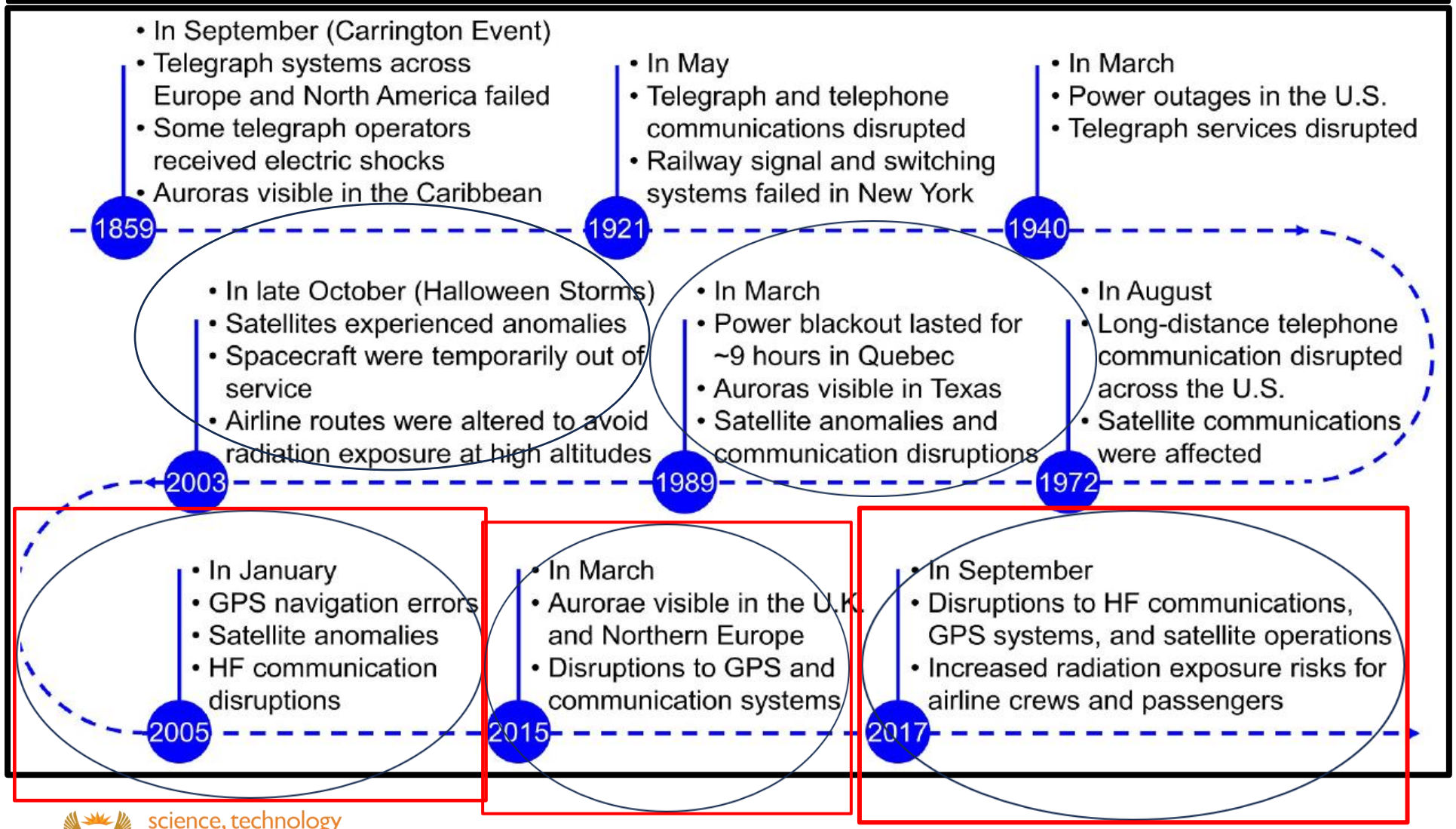
Several notable historical space weather events and their most significant effects on communications, navigation, radiation, and power grids.



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Cases of Large (GNSS) Positioning Errors Caused by Space Weather Events that impacted aviation: Satellite-Navigation Based Air Traffic Management

Time	Geographical location	Condition	Minimum Dst	Positioning errors
September 2002 to April 2003	13.7°N and 100.8°E	S4 (~0.6)	−181 nT	Exceed 10 m at KMLT, Thailand
January to December 2001	19.6°N and 99.5°E	S4 (>0.7)	−387 nT	Reach 14 m in longitude and 22 m in latitude at Chiang Rai, Thailand
April 2004	3.0°S and 40.2°E	Severe ionospheric scintillation	−117 nT	Reach 4 m in vertical components at Malindi, Kenya
7 to 8 September 2017	78.2°N and 16.0°E	Intense geomagnetic condition	−122 nT	Increase from 2 to 6 m at Longyearbyen, Norway

https://doi.org/10.1016/j.asr.2005.07.030
https://doi.org/10.1007/s10291-010-0197-1
https://doi.org/10.1029/2018SW001940
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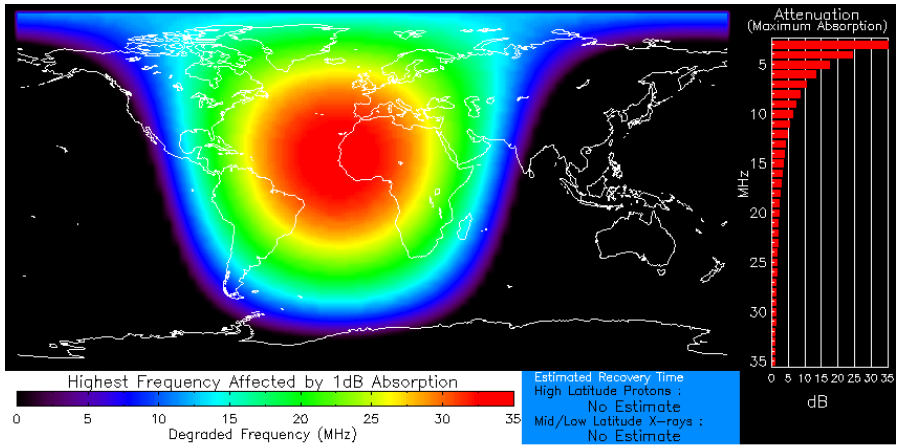
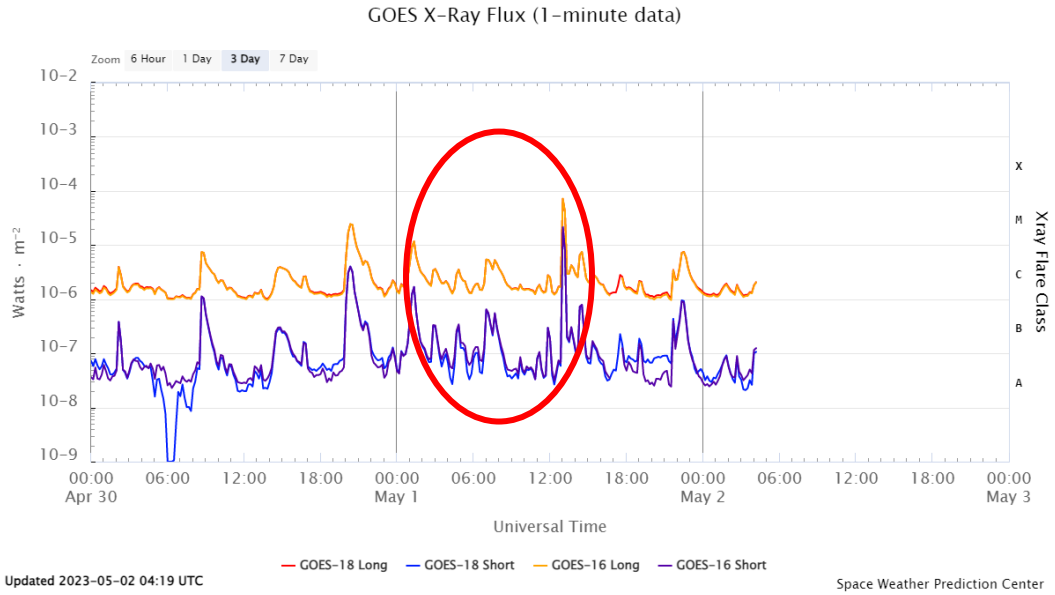


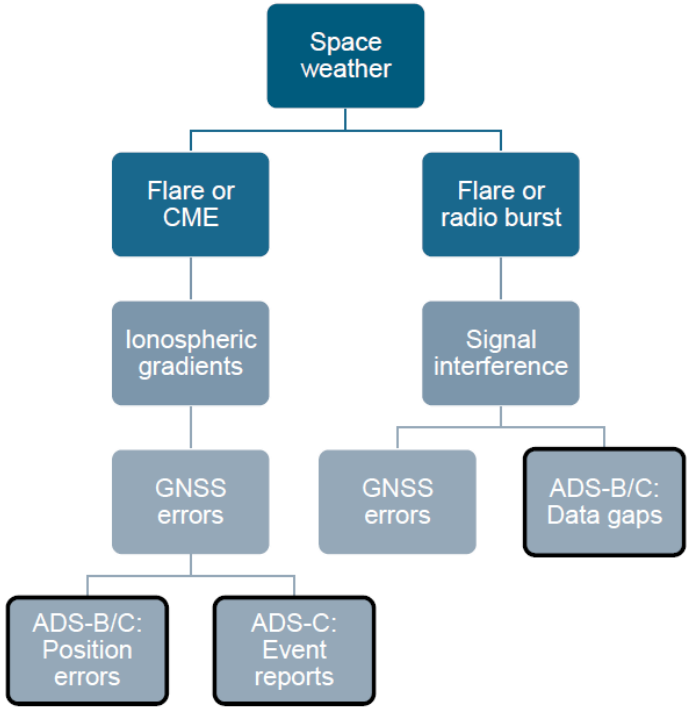
Minor X-ray flux
Product Valid At : 2023-05-01 13:09 UTC

Normal Proton Background
NOAA/SWPC Boulder, CO USA

When ADS-B and radar fail:

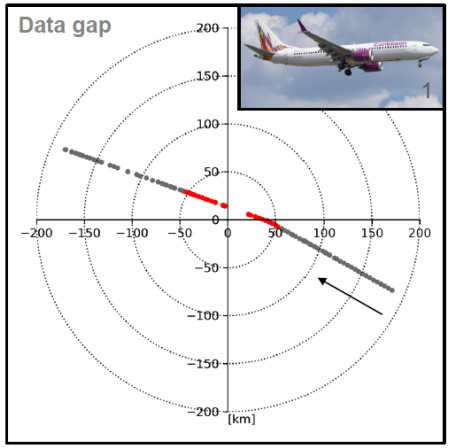
- ✓ Reduce airspace capacity due to increased separation requirements
- ✓ Put strain on ATC personnel

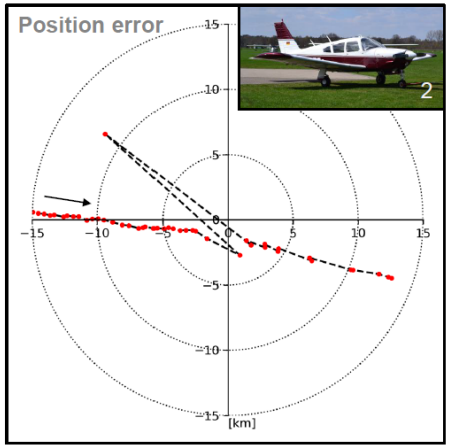




Space weather impacts on ADS-B

First results: Solar flare May 1st 2023





Red dots (●): ADS-B messages during flare (13:02-13:09)
Arrow (➔): Flight direction

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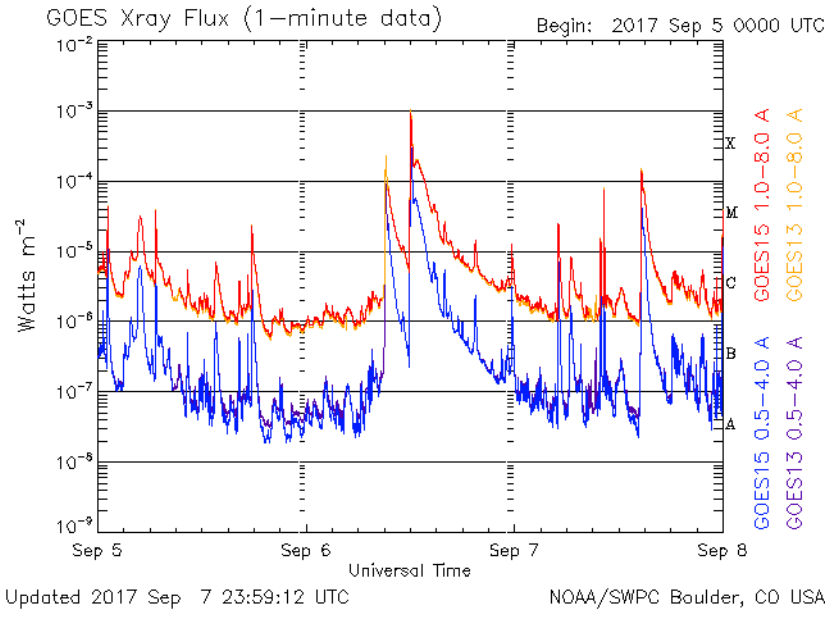

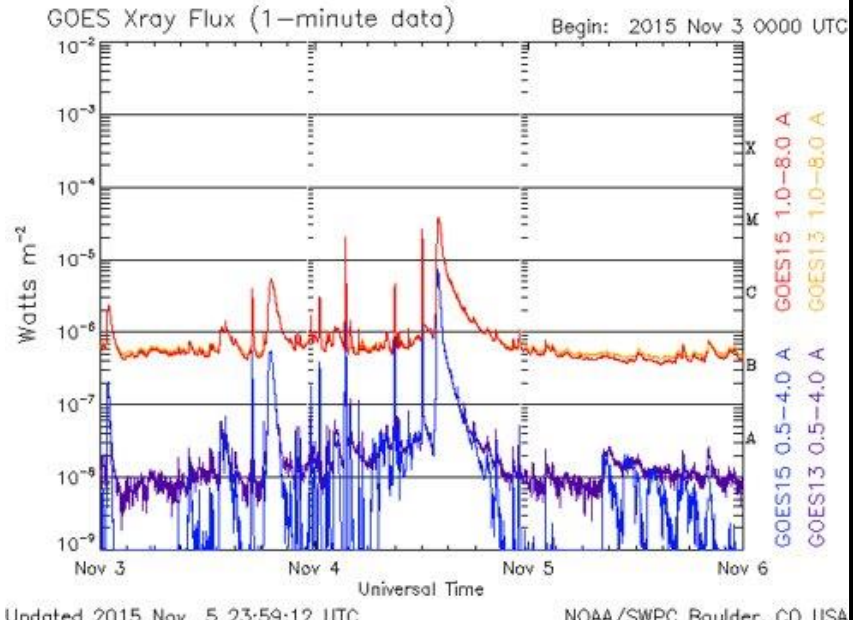

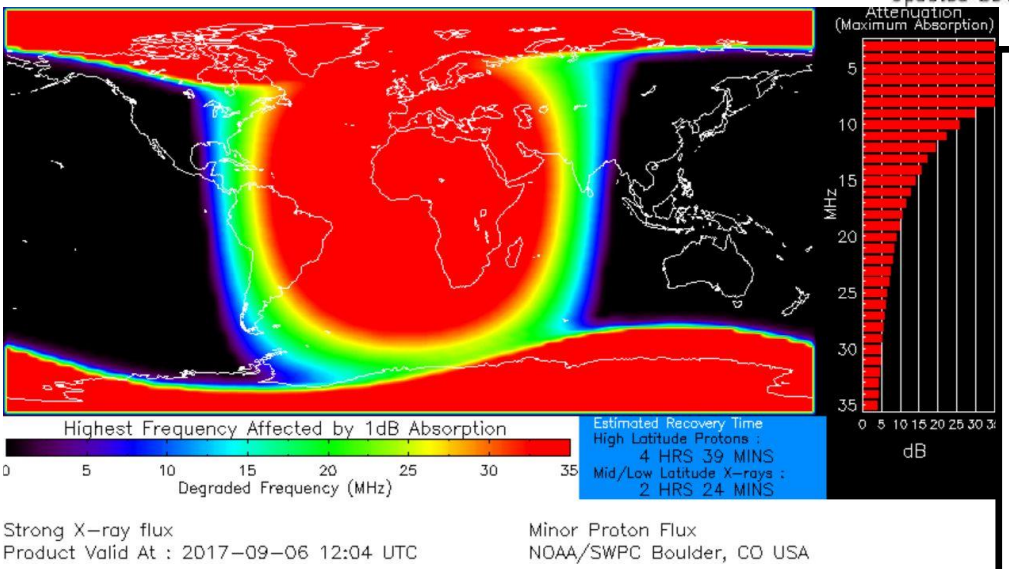

- ✓ In 2017 during the event NOAA reported that high-frequency radio, used by **aviation**, maritime, ham radio, and other emergency bands, **was unavailable for up to eight hours**. For example, **civil aviation reported a 90-minute loss of communication with a cargo plane.**
- ✓ Many of these flares will produce HF radio wave absorption across the sunlit side of the Earth - strong absorption in the case of X flares.
- ✓ Additionally, French civil aviation authorities reported a 90-min loss of HF radio contact with an aircraft lacking CPDLC equipment, occurring off the coasts of Brazil and French Guiana (Rutledge & Desbios, 2018).

- ✓ The D-region of the ionosphere has the 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 degrades the HF radio communication and this can last anything between few minutes to hours.
- ✓ **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 led the authorities to reduce aircraft movements for safety reasons (Luftfartsverket, 2015).**

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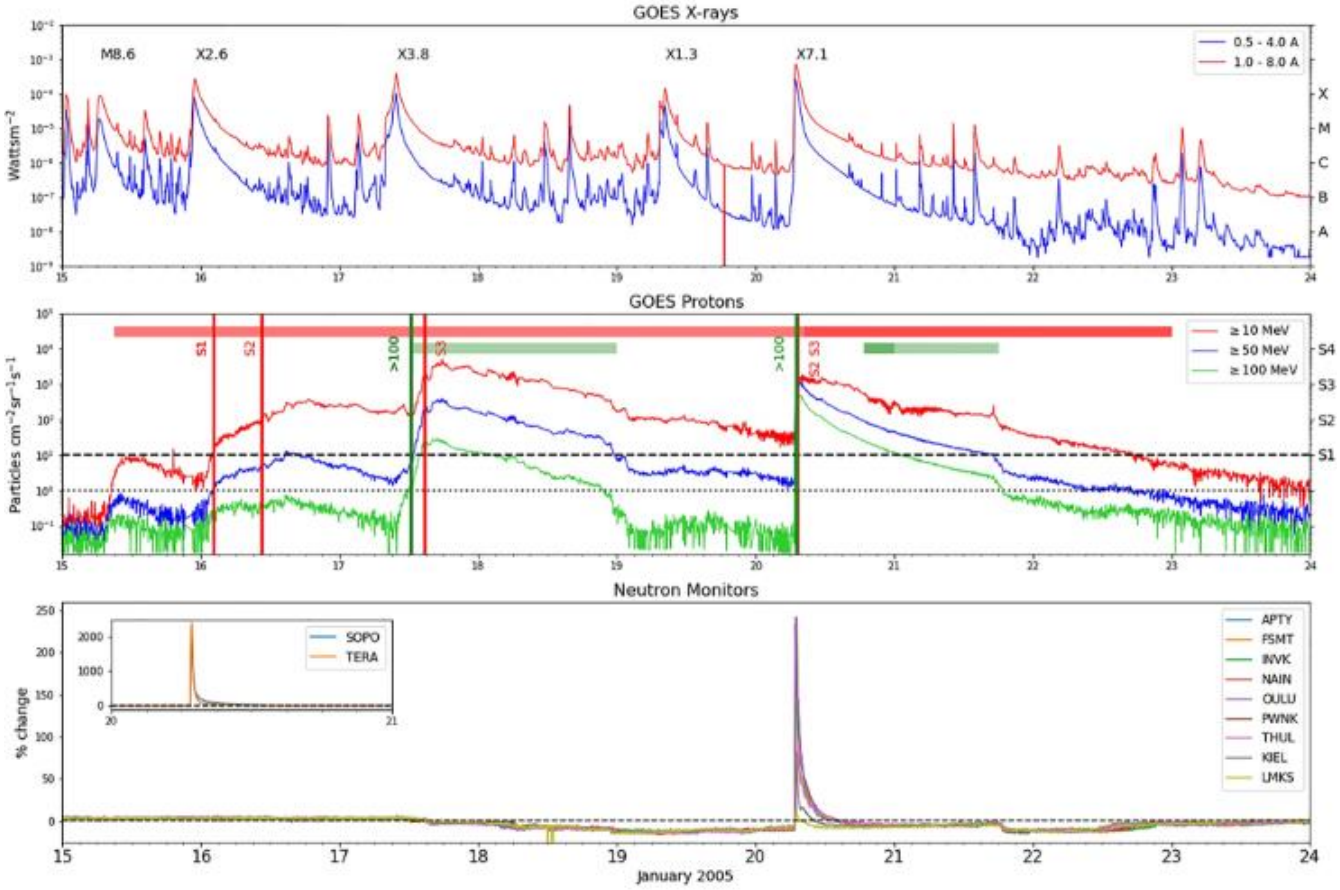
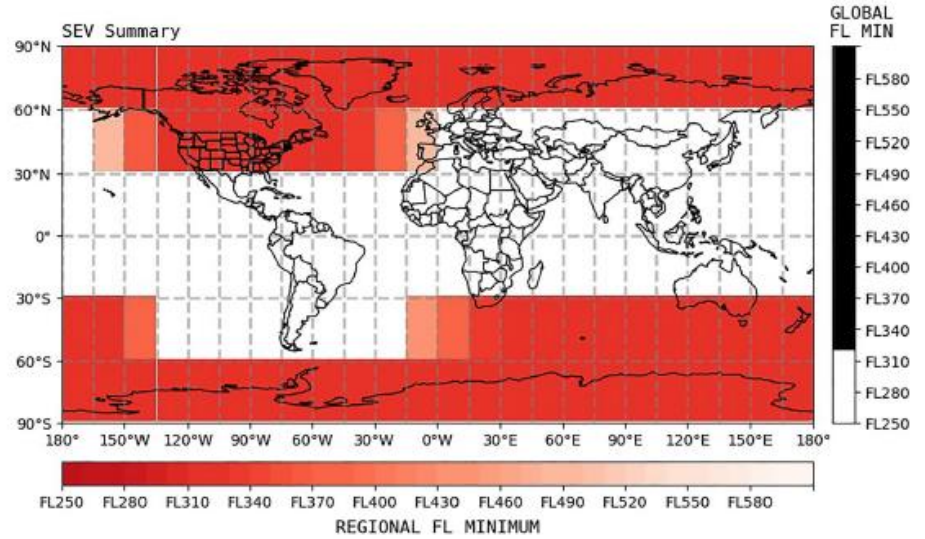
Radiation impact example





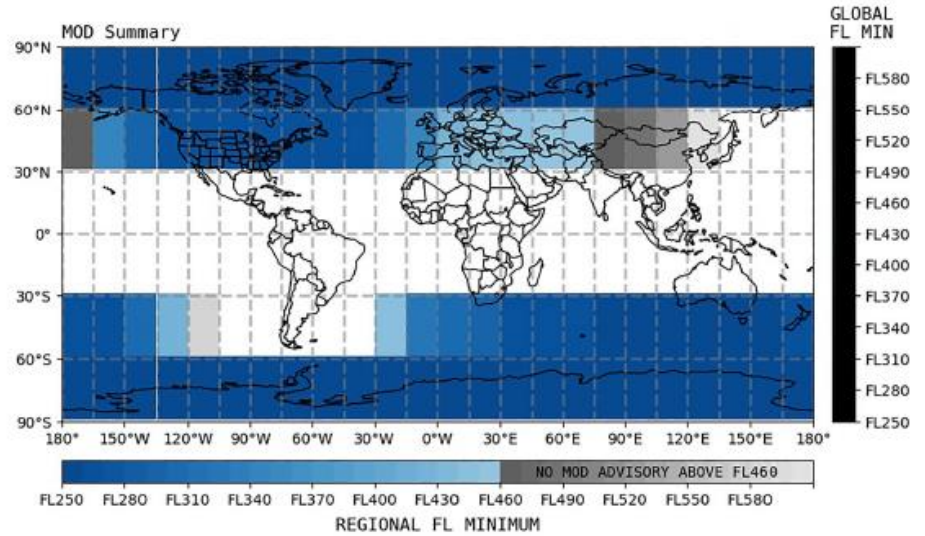


Table 4
ICAO Radiation Advisories for GLE69 on the 20th of January 2005

Issue time (UT)	Advisory	Latitude	Longitude	Flight levels
2005-01-20 06:55	SEV	HNH MNH MSH HSH	E180–W180	ABV FL320
2005-01-20 06:55	MOD	HNH MNH MSH HSH	E180–W180	ABV FL250
2005-01-20 07:25	SEV	HNH MNH MSH HSH	E180–W180	ABV FL410
2005-01-20 07:25	MOD	HNH MNH MSH HSH	E180–W180	ABV FL320
2005-01-20 08:00	SEV	HNH MNH MSH HSH	E180–W180	ABV FL470
2005-01-20 08:25	MOD	HNH MNH MSH HSH	E180–W180	ABV FL390
2005-01-20 10:15	SEV	HNH MNH MSH HSH	E180–W180	ABV FL540
2005-01-20 11:05	MOD	NO SWX EXP		
2005-01-20 12:20	SEV	HNH MNH MSH HSH	E180–W180	ABV FL600
2005-01-20 13:30	SEV	NO SWX EXP		

Figure 3. CARI-7A radiation summary maps thresholded to show regions exceeding the SEV (top:red) and MOD (bottom:blue/gray) ICAO thresholds. Shaded gray cells in the MOD summary map (bottom) show regions ≤FL460 where the radiation effective dose rate has surpassed the MOD threshold, but for which an advisory is not required. Horizontal regional FL Minimum colorbar indicates the minimum flight level reached in each individual region. The vertical global FL minimum colorbar shows the lowest flight level reached globally. The inclusion of MOD and SEV advisories at mid geographic latitudes, due to the tilt of the geomagnetic pole, is discussed Section 6.

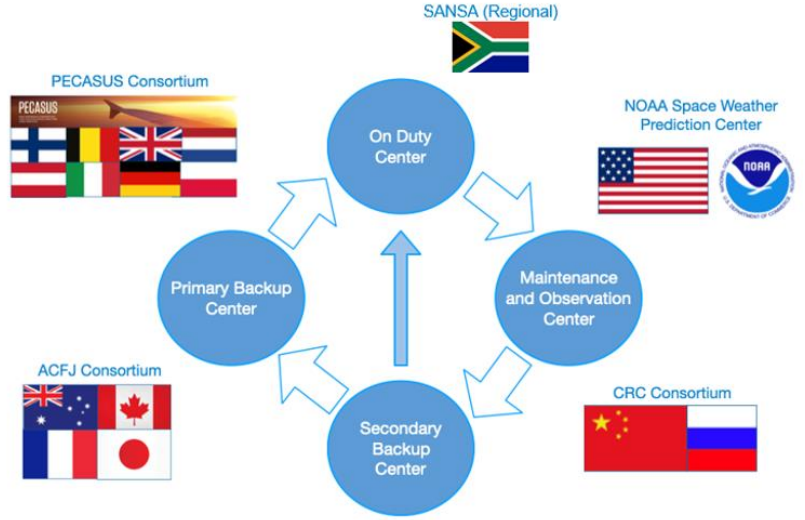
https://doi.org/10.1029/2022SW003346

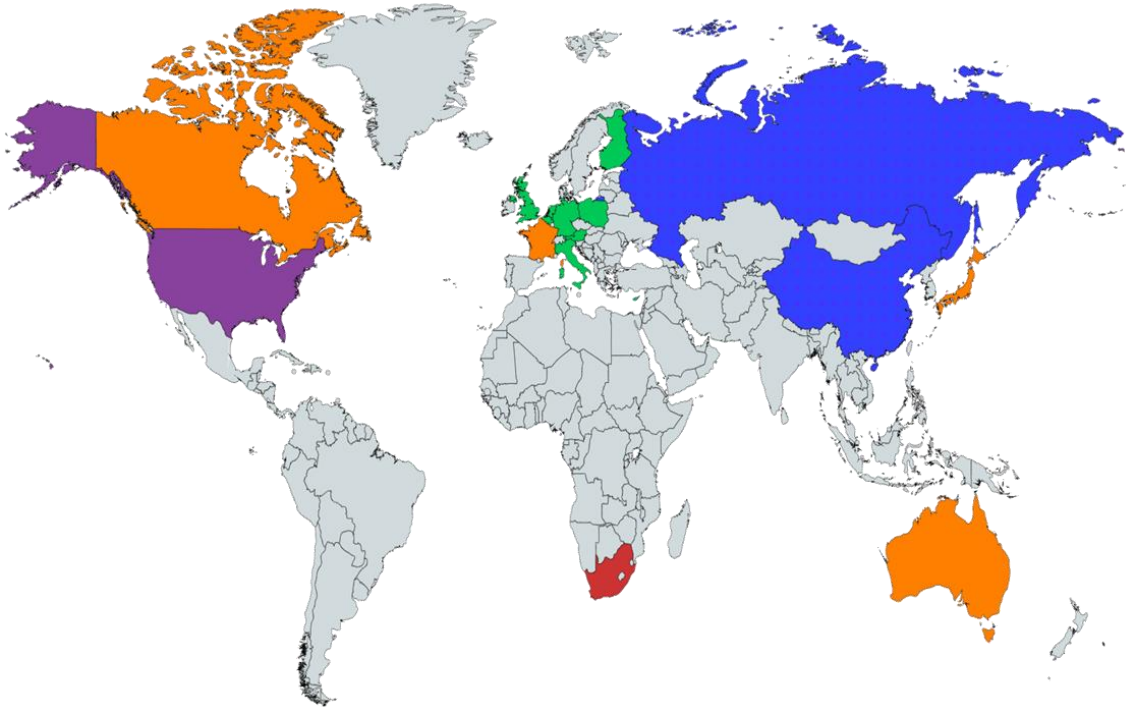
ICAO-designated centres

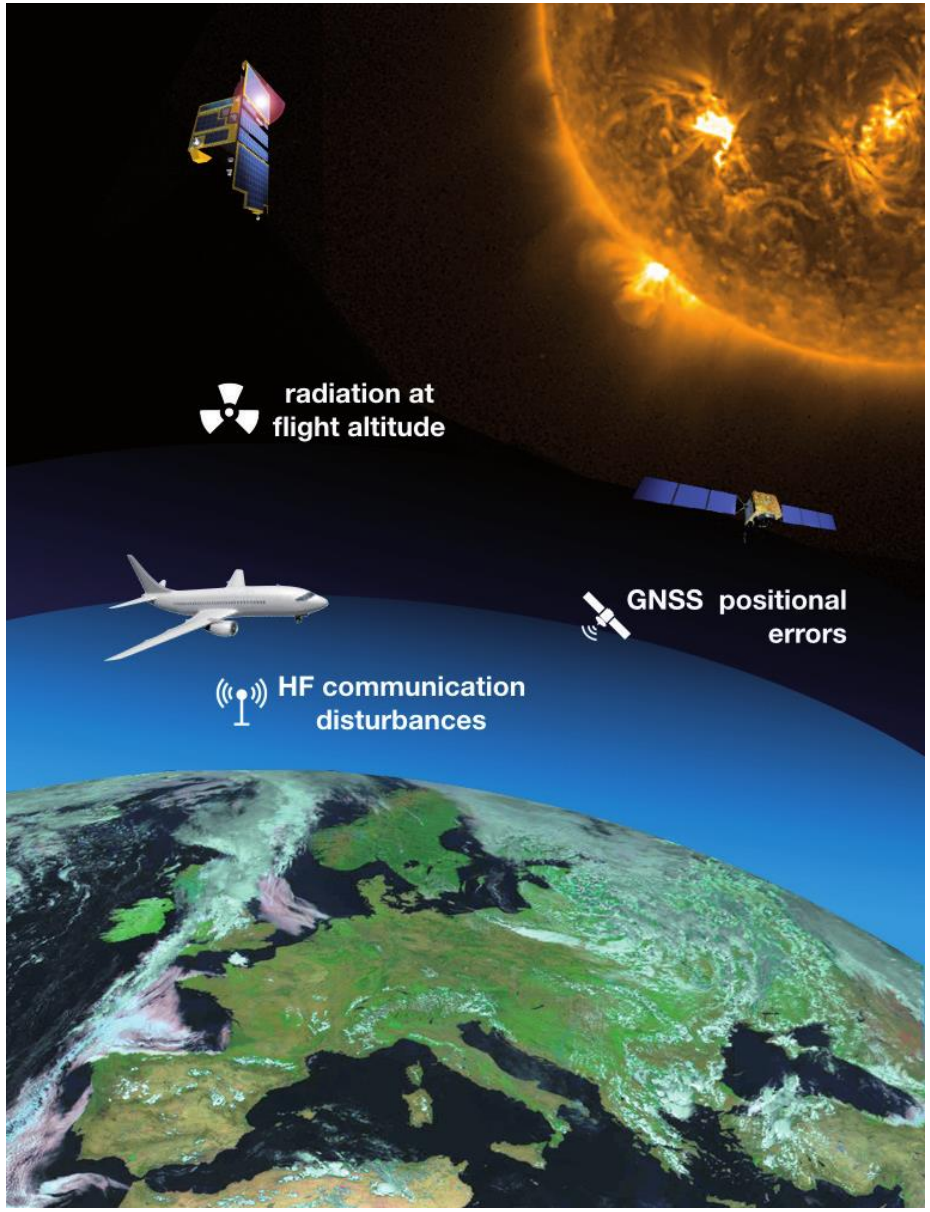
Four global warning centres

- **PECASUS:** Austria, Belgium, Cyprus, Finland, Germany, Italy, Netherlands, Poland, United Kingdom
- **ACFJ**: Australia, Canada, France, Japan
- **SWPC:** United States
- **CRC:** China, Russia

- One regional center
  - **South Africa**







ICAO SWx Information

- International Civil Aviation Organisation (ICAO) has organised a 24/7 global space weather advisory service for international aviation.
- GNSS
  - vertical total electron content (vTEC)
  - scintillations
- HF COM
  - shortwave fadeout
  - auroral absorption
  - polar cap absorption (PCA)
  - post storm depression (PSD)
- Radiation Exposure
  - human health
  - avionics

ICAO SWx Information Service

Objective: To provide situational awareness and advise aviation users when SWx events are expected to cause a moderate or severe impact

- ✓Deterioration or loss of satellite navigation
- ✓Deterioration or loss of HF communications (HF COM)
- ✓Enhanced radiation exposure at specific flight levels

Actionable information:

- ✓Inform pre-flight planning (e.g. route selection, altitude selection, fuel loading)
- ✓Real-time warning of space weather events
- ✓In-flight route or altitude deviations

- Disseminated through ICAO's standard communication channels.
  - ✓TAC and IWXXM formats with different WMO headers

Example of SWx Advisory

FNXX01 LFPW 150043
SWX ADVISORY
DTG: 20240115/0043Z
SWXC: ACFJ
ADVISORY NR: 2024/23
SWX EFFECT: GNSS MOD
OBS SWX: 15/0015Z EQN EQS W105 – 2000
FST SWX +6 HR: 15/0700Z NOT AVBL
FCST SWX +12 HR: 15/1300Z NOT AVBL
FCST SWX +18 HR: 15/1900Z NOT AVBL
FCST SWX +24 HR: 16/0100Z NOT AVBL
RMK: SWX EVENT (SCINTILLATION) INPR POSSIBLY IMPACTING GNSS PER. COULD LEAD TO DEGRADATION OF TIMING AND POSITIOINING PER. INTST GENERALLY STRONGER ON THE NIGHTSIDE.
NXT ADVISORY: 20240115/0700Z=

issuing centre

type, magnitude

latitude bands

observed conditions

longitude extent

forecast conditions

remarks

Example SWx Advisory

FNXX02 EFKL 251127

SWX ADVISORY

DTG: 20251127/1210Z

SWXC: DONLON

ADVISORY NR: 2025/313

NR RPLC: 2025/311 2025/312

SWX EFFECT: GNSS

OBS SWX: 27/1200Z SEV N80E000-N80E090-N60E090-N60E000-N80E000 MOD S60E000-S60E090-S80E090-S80E000-S60E000

FCST SWX +6 HR: 27/1800Z MOD N80E000-N80E090-N60E090-N60E000-N80E000 SEV S60E000-S60E090-S80E090-S80E000-S60E000

FCST SWX +12 HR: 28/0000Z NO SWX EXP

FCST SWX +18 HR: 28/0600Z NO SWX EXP

FCST SWX +24 HR: 28/1200Z NO SWX EXP

RMK: THIS IS A SAMPLE GNSS SPACE WEATHER ADVISORY BASED ON POLYGONS. PLEASE DISREGARD

NXT ADVISORY: WILL BE ISSUED BY 20251127/1800Z=

issuing centre

type

polygons (with magnitude)

observed conditions

forecast conditions

remarks

3 possible entries

affected region

NO SWX EXP

NOT AVBL

SWx – region impacted

- Latitude bands
  - 30˚ resolution in latitude
  - 15˚ resolution in longitude

HNH	60˚ to 90˚	HSH	-60˚ to -90˚
MNH	30˚ to 60˚	MSH	-30˚ to -60˚
EQN	00˚ to 30˚	EQS	-00˚ to -30˚

- DAYLIGHT SIDE (extent of the planet in daylight)
- Polygon
  - multiple vertices
  - 5˚ x 5˚ resolution in latitude and longitude for the corner points
- For radiation
  - MOD issued for FL250 to FL460
  - SEV issued above FL250

SWx – region impacted

HNH

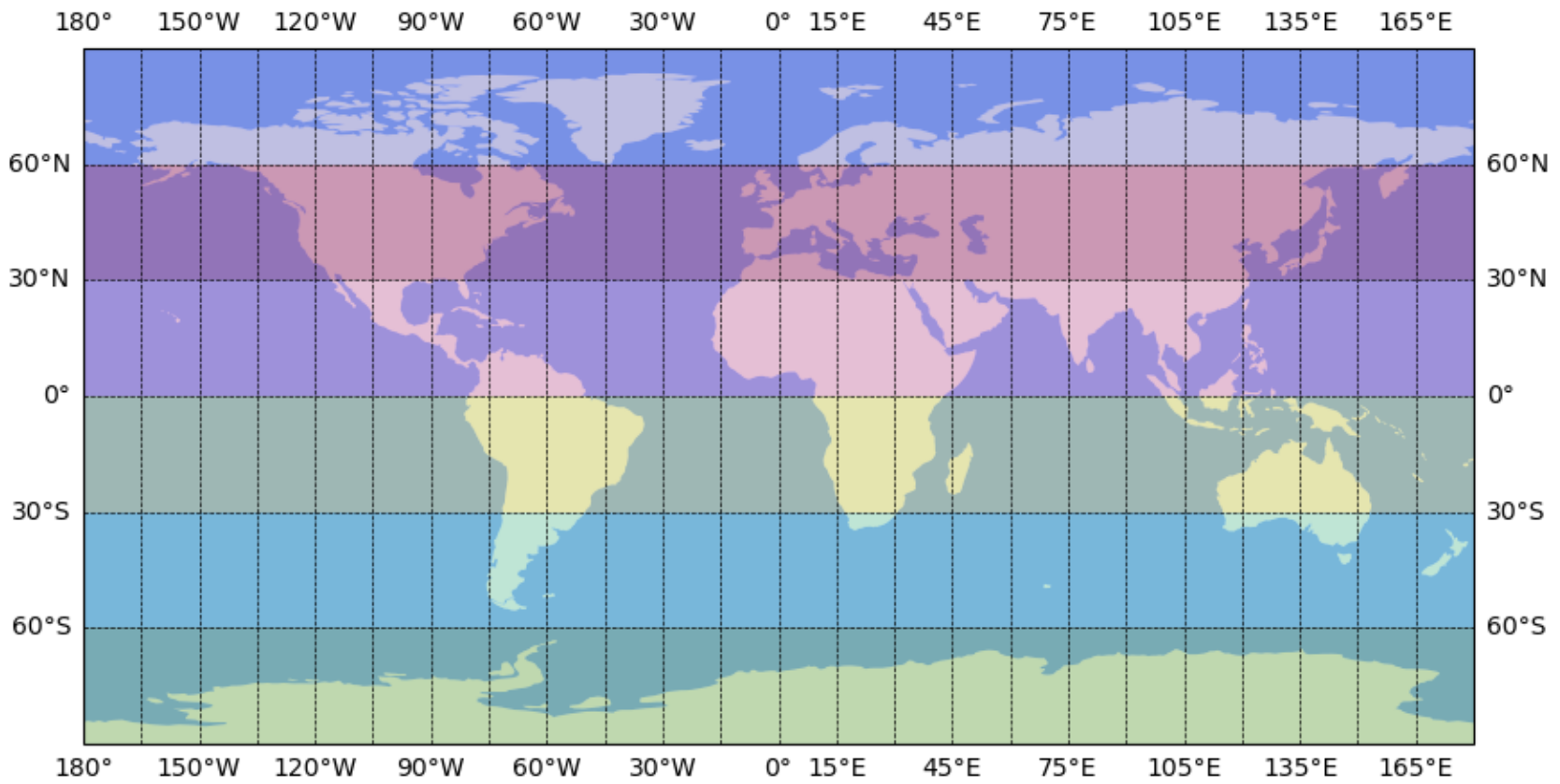
MNH

EQN

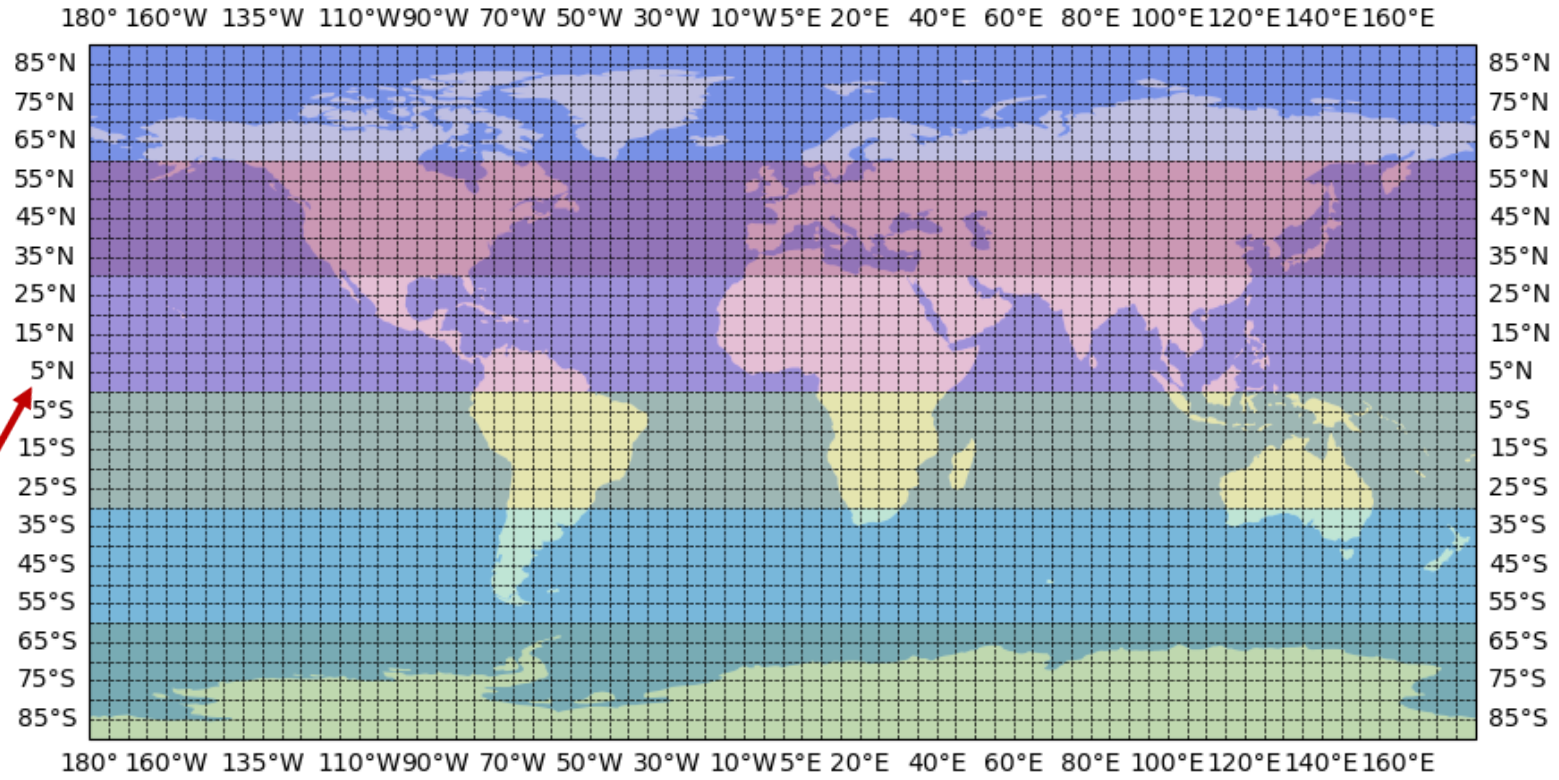
EQS

MSH

HSH



SWx – region impacted



5˚ resolution

How airlines can manage space weather risks

Awareness – Making pilots and flight planners aware that they receive space weather information and alerts through SAWIS bulletins.

Training – Space weather information can be highly technical, so airlines need practical guidance on what alerts mean operationally and what actions may be required. Turning scientific data into clear operational decision-making is a critical part of building resilience.

Planning – Airlines need clear response plans for severe space weather events, including how they conduct impact assessments, explain the issue to customers and crew, reroute flights, recover from delays, schedule maintenance, etc.

The potential cost of space weather

- ✓ **Flight safety,** especially on long-haul and remote routes that depend heavily on satellite navigation and long-range communications
- ✓ **Crew rotations,** particularly as airlines pay closer attention to radiation exposure for pilots and cabin crew who fly frequently.
- ✓ **Flight schedules**, as airlines may need to reroute, delay, or cancel flights during major solar storms.
- ✓ **Airline finances**, as disruptions can lead to grounded aircraft, stranded crews, lost revenue, higher fuel costs, missed connections, and reputational damage
- ✓ **Aircraft availability and maintenance**, if planes need additional checks after disruptions to onboard systems
- ✓ **For airlines already operating on tight margins**, even a short period of disruption can have a noticeable impact on operations and profitability.

How SANSA supports the African aviation industry

SANSA is home to a **24/7 Space Weather Centre** that provides real time geophysical data on the near-Earth space environment as well as forecasts and early warnings of adverse space weather.

SANSA is the International Civil Aviation Organization's (ICAO) **designated regional space weather centre**; fully integrated into global centres in November 2025 and is responsible for supporting global centres through co-operation and provision of regional space weather information

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Conclusions

- ✓ Space weather is the **study of how the Sun** and events in space **impact the near-Earth environment**.
- ✓ For aviation, the risks include **degraded HF radio communications**, **GNSS inaccuracies**, **damage to avionics**, and the potential for increased **radiation exposure.**
  - ✓ The aviation industry can manage these risks through raising **awareness**, **training** crews on how to respond, and **planning** for disruption.
  - ✓ The South African National Space Agency (SANSA) supports the sector through space weather **monitoring, alerts and training**, and is **on-hand to assist** the African aviation industry.

THANK YOU

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