ICAO Space Weather Center Provisions

Presented to: ICAO MID Workshop on formulating a space weather exercise

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to U.S. Member of the ICAO MET Panel

Date: 15-16 November 2023

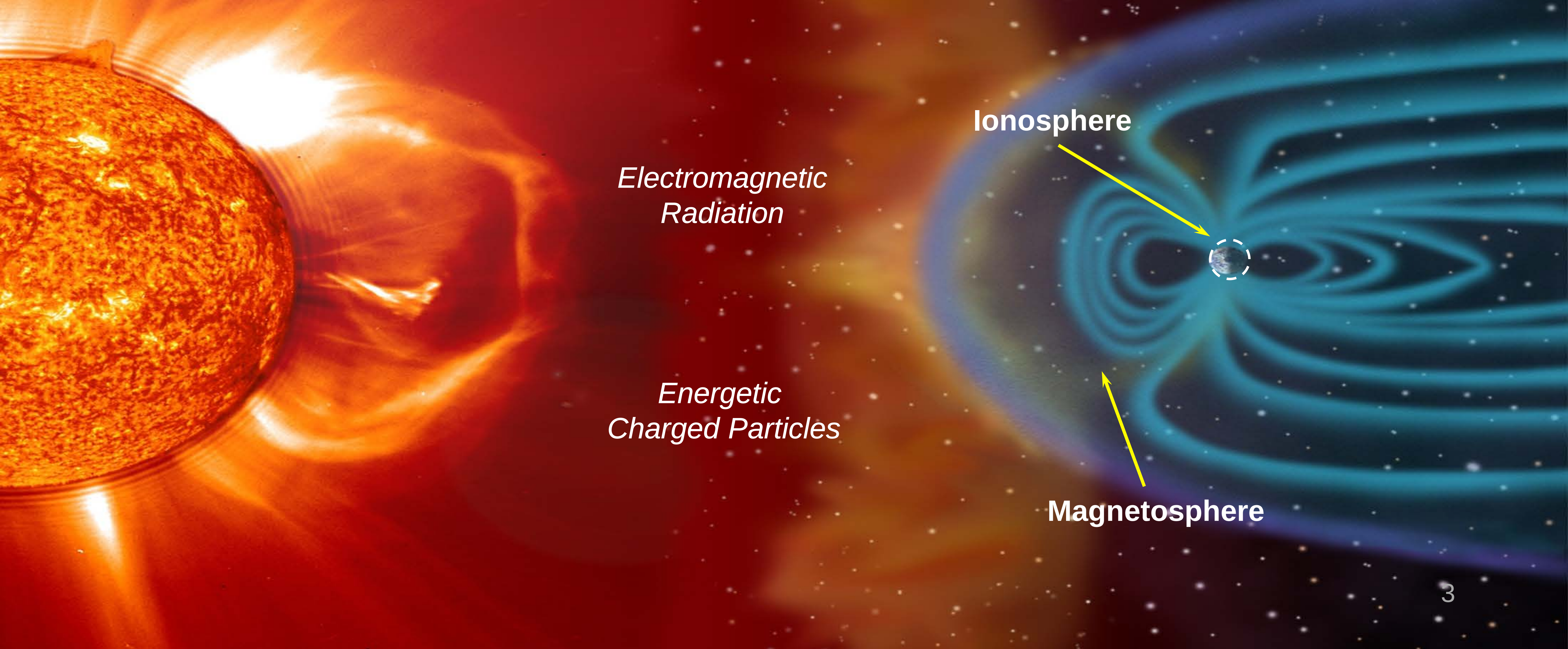
Federal Aviation
Administration

Overview

- What is “Space Weather”
- Space Weather Phenomena
  - Solar Flares
  - Radiation Storms
  - Geomagnetic Storms
- Impacts to Aviation
- Services in ICAO

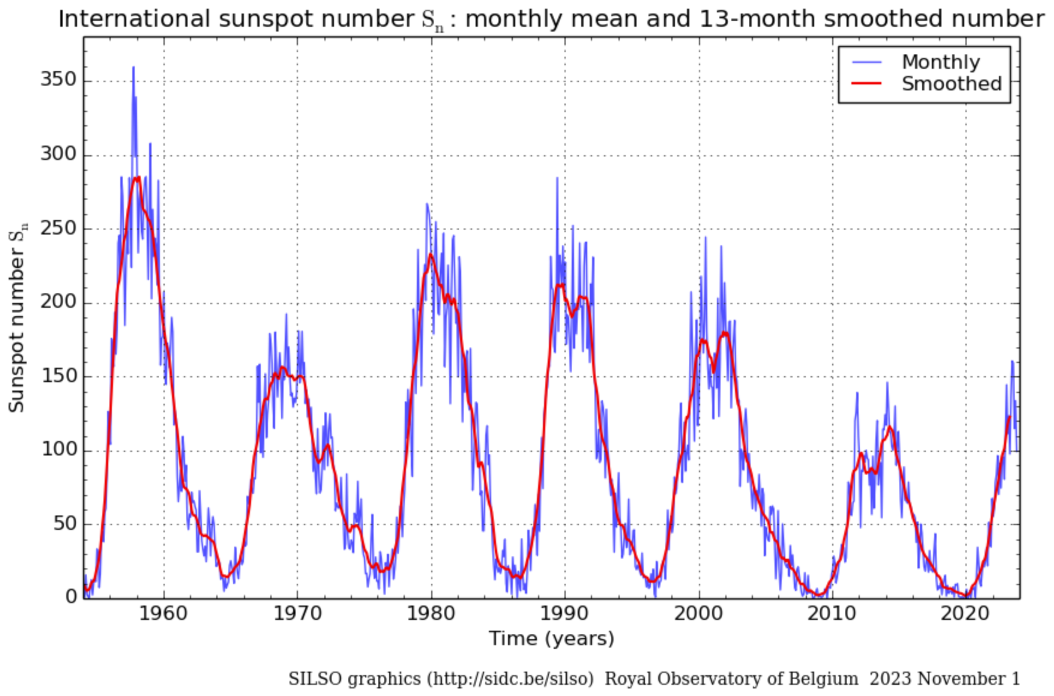
What is Space Weather?

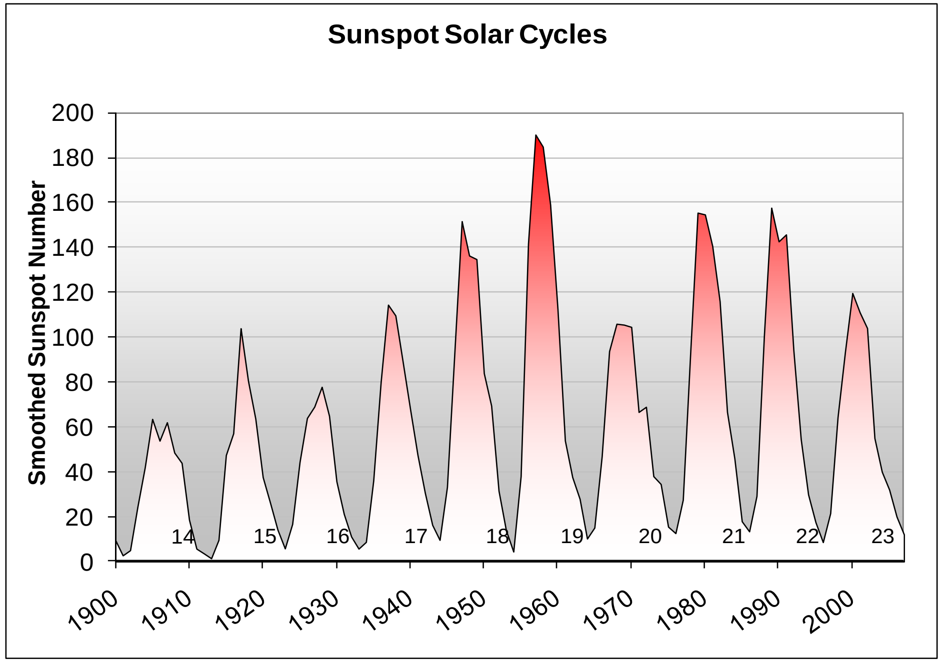
Space weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of space and ground-based technological systems, as well as endanger human health.



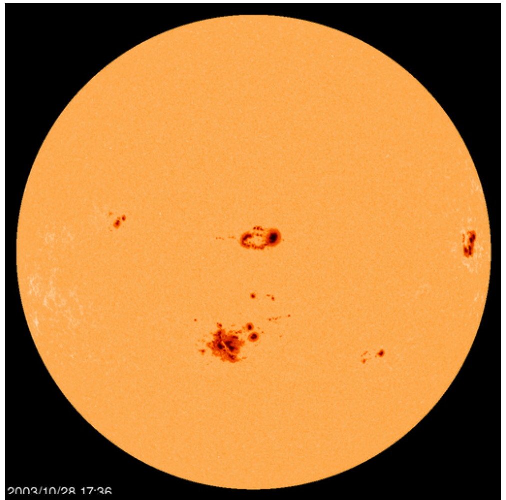
Solar Cycle Update

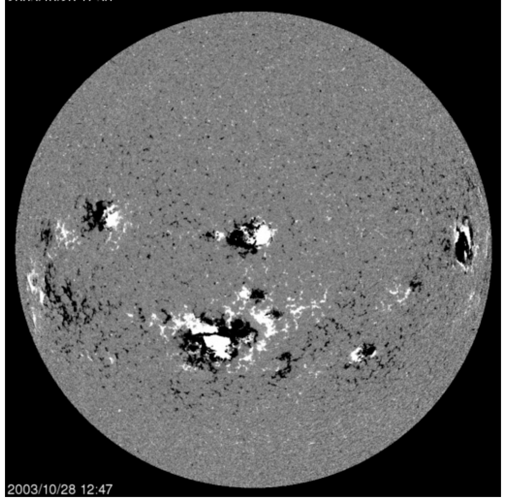
- Space weather impacts more prominent during high points of cycle
- New Cycle 25 is approaching maximum
- Severity of impact loosely correlated with cycle size



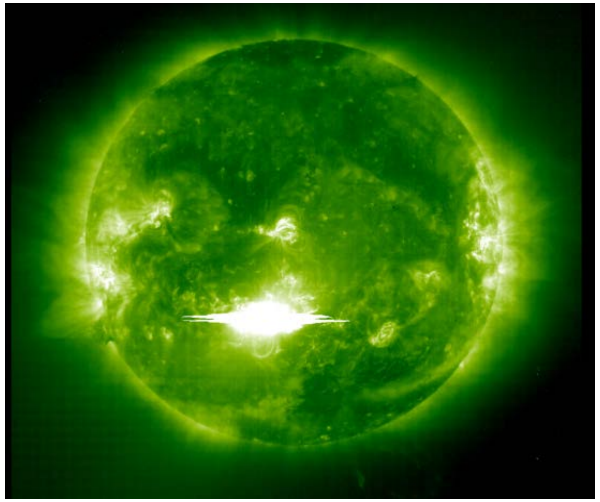


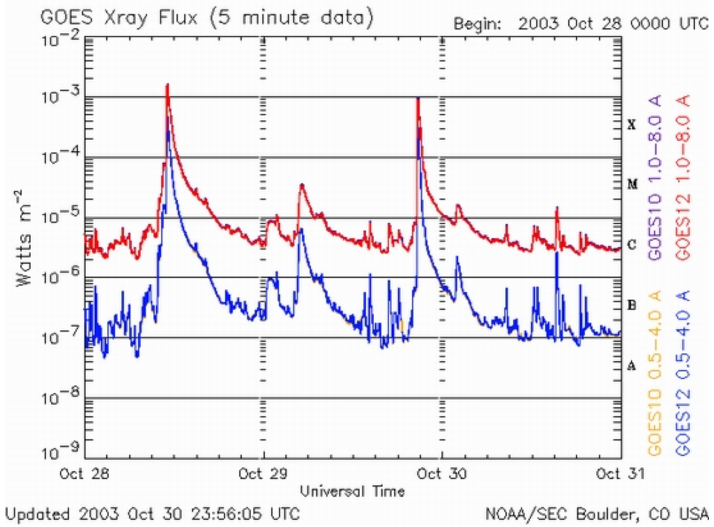
Sequence of Events



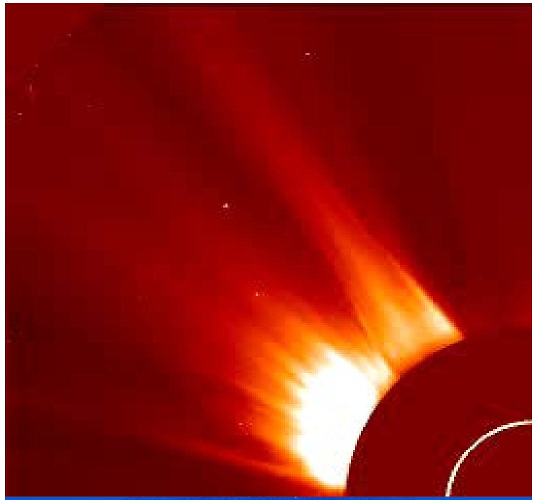


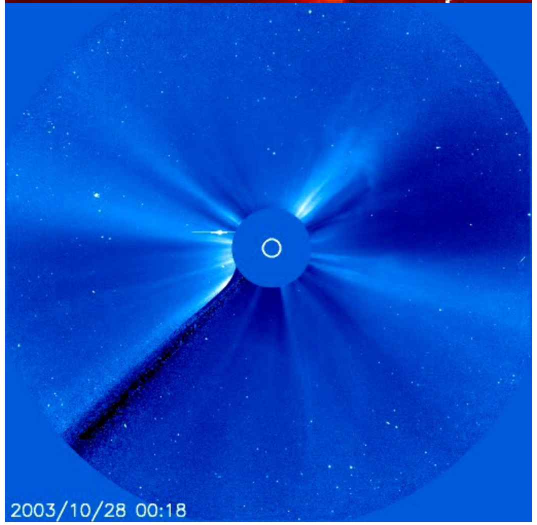
Conditions are Favorable for Activity
(Probabilistic Forecasts)





Event Occurs





Coronal Observations

Aviation Space Weather / Impacts

- **High Frequency (HF) Communications:**
  - No advance warning
  - Effects lasts for 10’s of minutes to several hours
  - Impacts HF communication on the sunlit side of the Earth
  - First indication significant radiation and Performance Based Communication and Surveillance (PBCS) activity may be possible
- **Radiation:**
  - Warnings possible on the minutes to hours time scale
  - Elevated levels can persist for several days
  - Impacts High Frequency communication in the polar regions, affecting commercial airline operations
- **Global Navigation Satellite System (GNSS):**
  - Advance notice possible given coronal mass ejection (CME) transit times from Sun to Earth range from just under a day to several days (CMEs being the main driver of significant storms)
  - In extreme storms, impacts to power grid operations and stability
  - Driver of aurora; severe to extreme storms may cause aurora to be visible over most of the mid-latitudes

Current Capability

- **Communications**
  - HF blackout can be nowcast and forecast probabilistically
  - Limited skill in satellite communications, both in nowcast and forecast phases
  - Longer range forecasts remain challenging, both pre-eruption and when awaiting commencement of a storm as well
- **GNSS**
  - Nowcasting fairly mature where observational data is available
  - Skill improving in short-term forecasting (10's of minutes)
  - Longer range forecasts remain challenging, both pre-eruption and when awaiting commencement of a storm

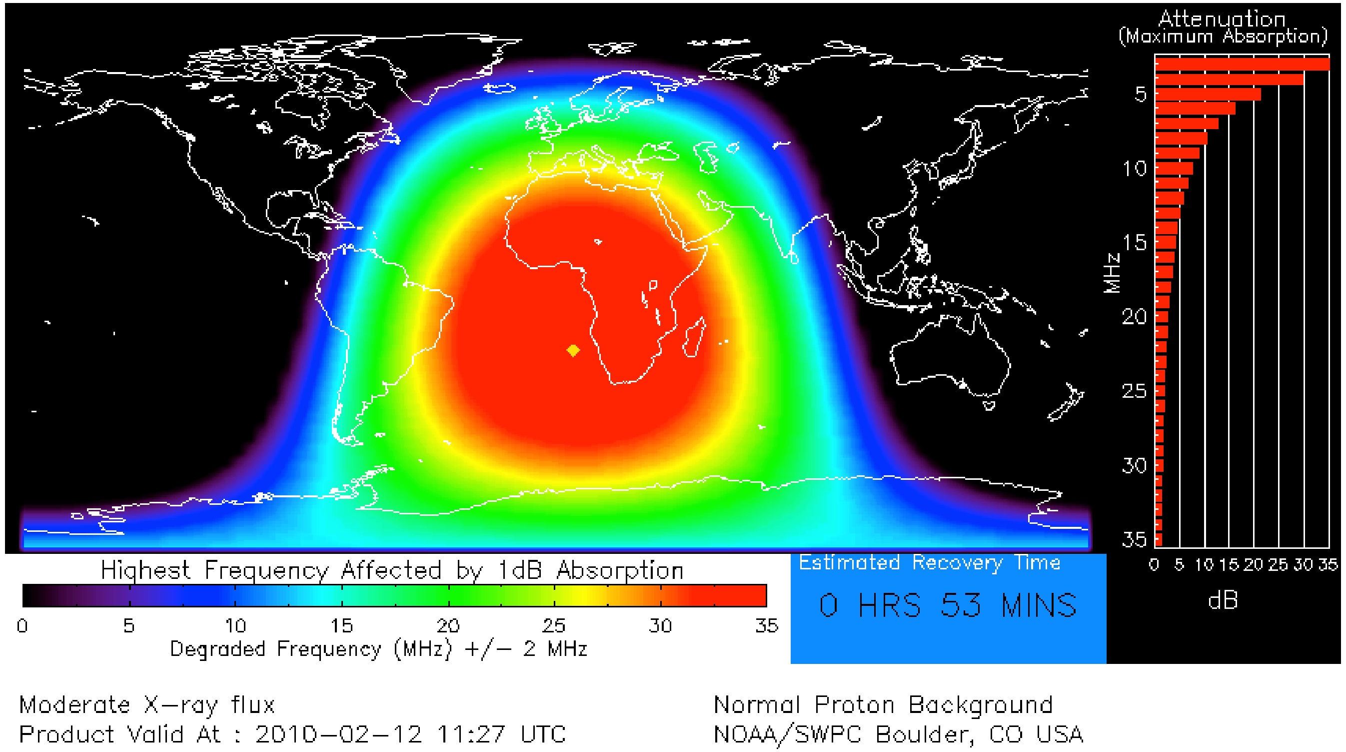
Evolution of Services and Future Needs

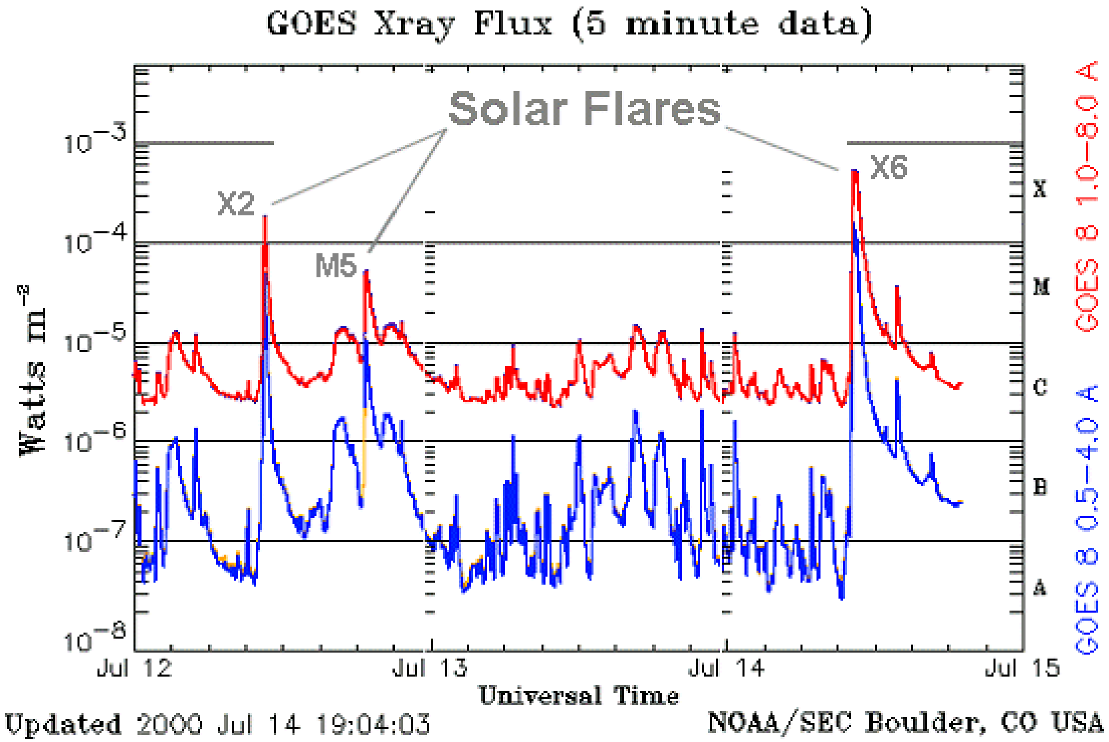
- **Radiation**
  - As aircraft fly farther and longer, exposures will increase
  - In situ observations will help with model validation, data assimilation, and operational decision making
- **GNSS**
  - Additional GNSS frequency adoption can largely eliminate ionospherically-induced position errors
  - Engineers with time and money can engineer around some challenges, but some will remain
  - Scintillation will likely remain the primary issue
- **Communications**
  - Application of HF is changing. HF datalink use still increasing…
  - Geosynchronous and low Earth orbit (LEO)-based satellite communications evolving

- Short-term forecasting gains are coming in the 3-5-year timeframe. However, no paradigm shifts in longer-term forecasting are likely in the foreseeable future.

- Given the chaotic, eruptive nature of the phenomena, space weather may never be like weather, but we can try…

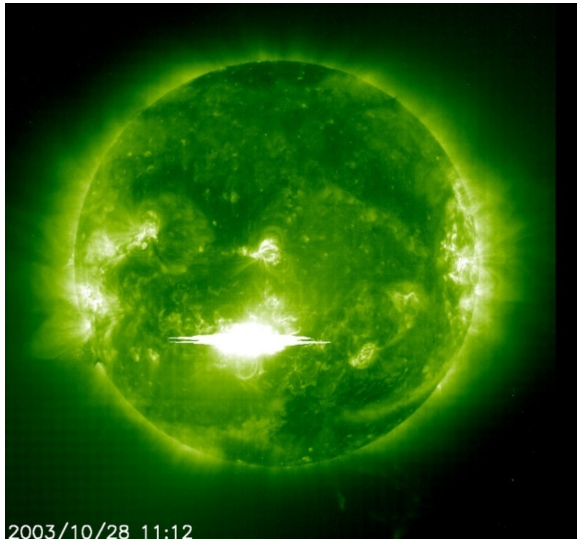
HF Impacts Caused by Solar Flares

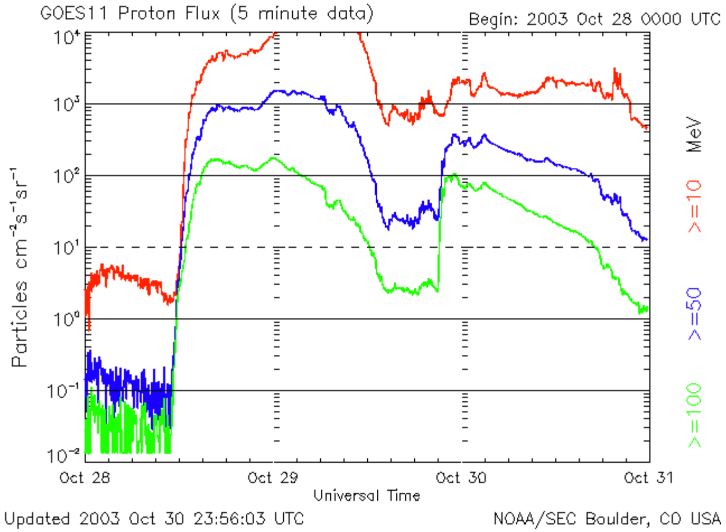


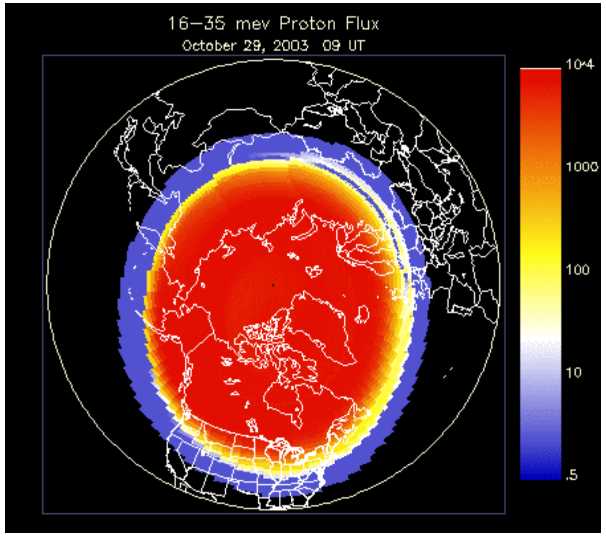


- Duration: Minutes to 3 hours
- Daylight-side impacts

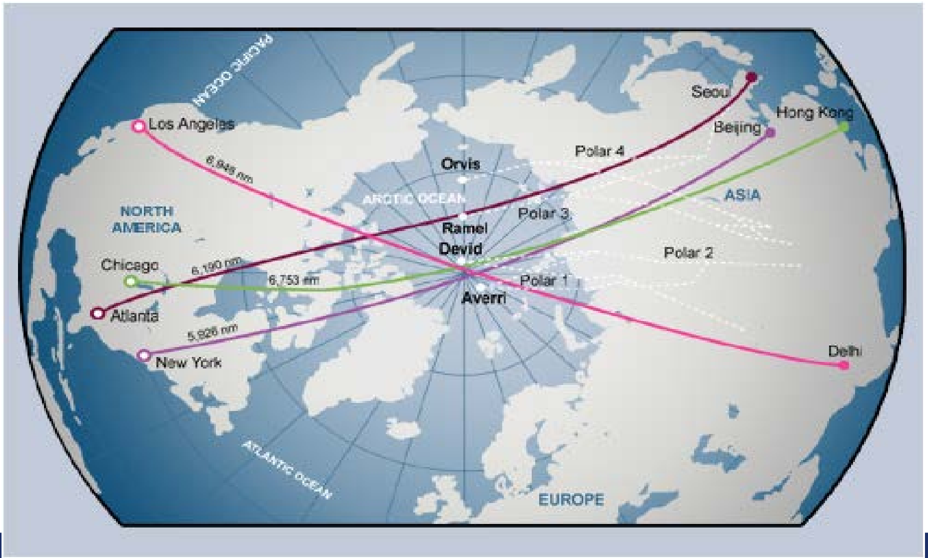
Radiation





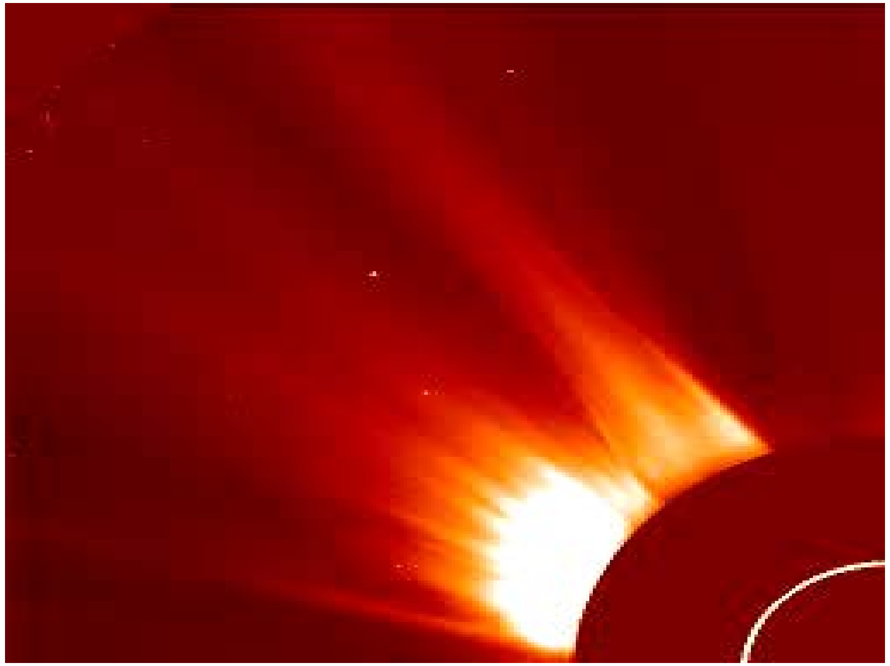


- Arrival: 10’s of minutes to several hours
- Duration: hours to days
- Short-term warning

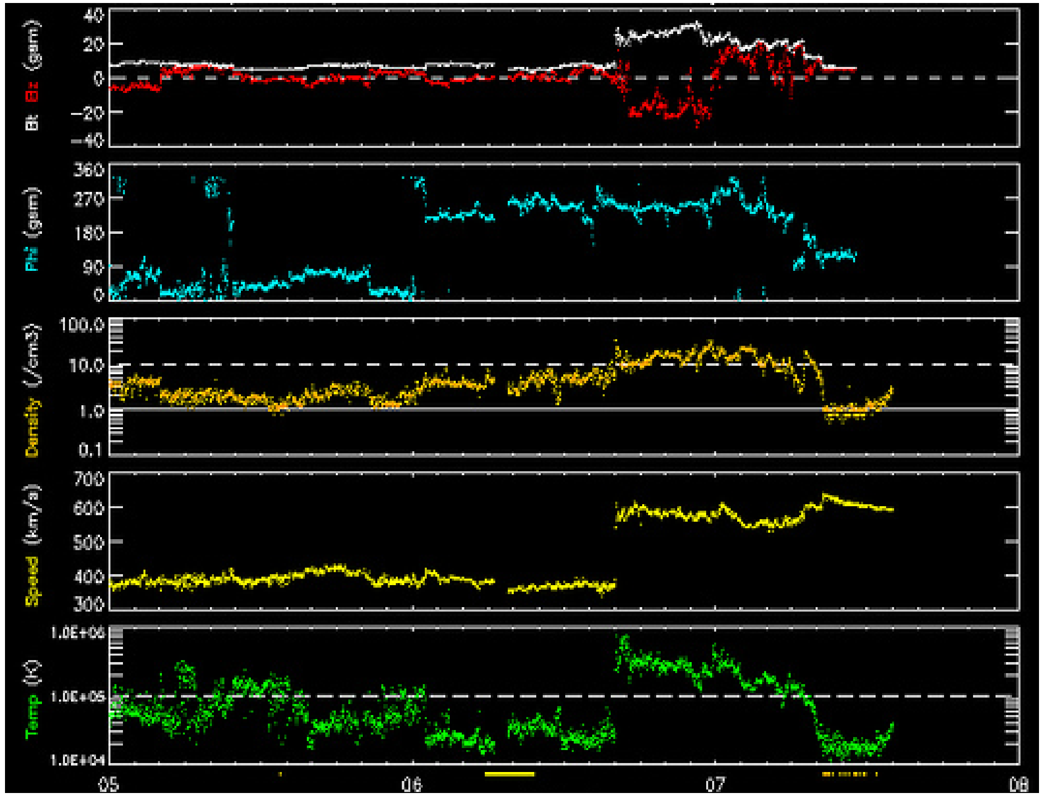


Performance Based Communication & Surveillance (PBCS)

Affected by Geomagnetic Storms



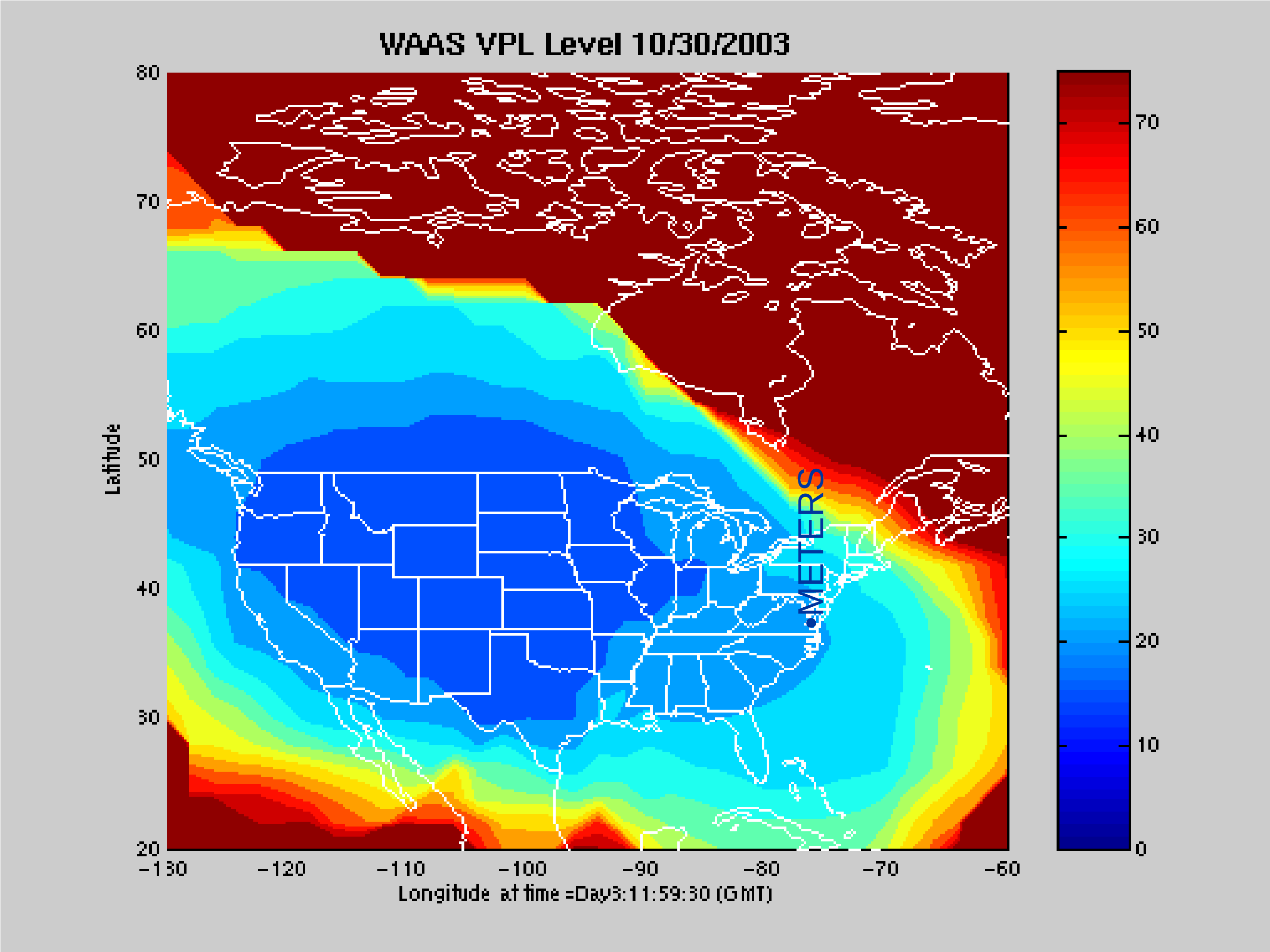
- CMEs create geomagnetic storms
- Arrival: ~18 – 96 hours
- Duration: Hours to a day or two
- Creates ionospheric storms, geomagnetically induced currents, aurora



- 1-2 Day watch products based on coronagraph observations and modeling (Highest Expected K)
- Short-term (15-60 min) warnings based on measurement between Sun/Earth

GPS IMPACT – U.S. Federal Aviation Administration (FAA) Wide Area Augmentation System (WAAS)

- Intense geomagnetic and ionosphere storms occurred on 29 and 30 October 2003
- Acceptable vertical error limits were exceeded for 15 and 11-hour periods



Polar Region: Space Weather Above

- The geomagnetic field converges at the poles, creating a focal point for solar energetic particles
- As geomagnetic activity increases, the Aurora gets brighter, more active, and moves equatorward

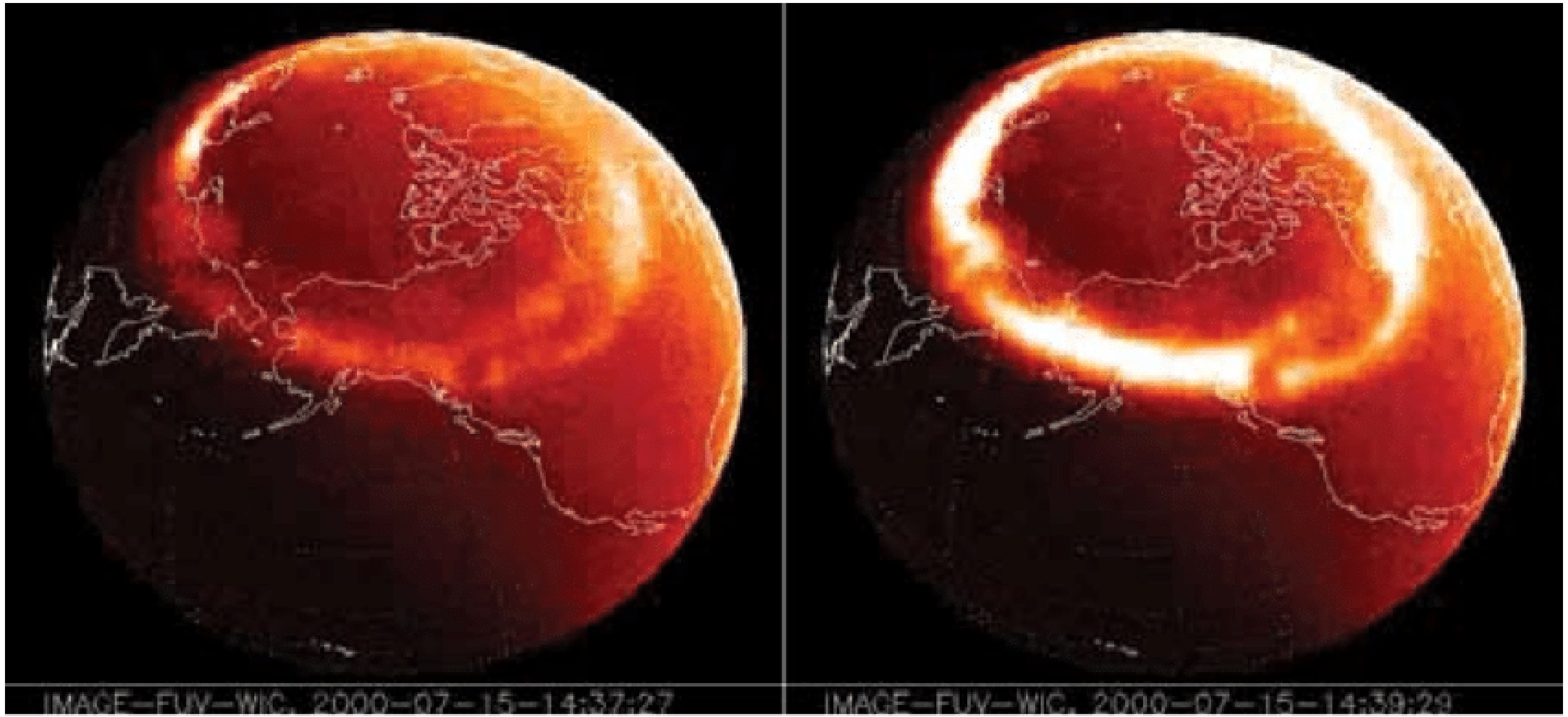
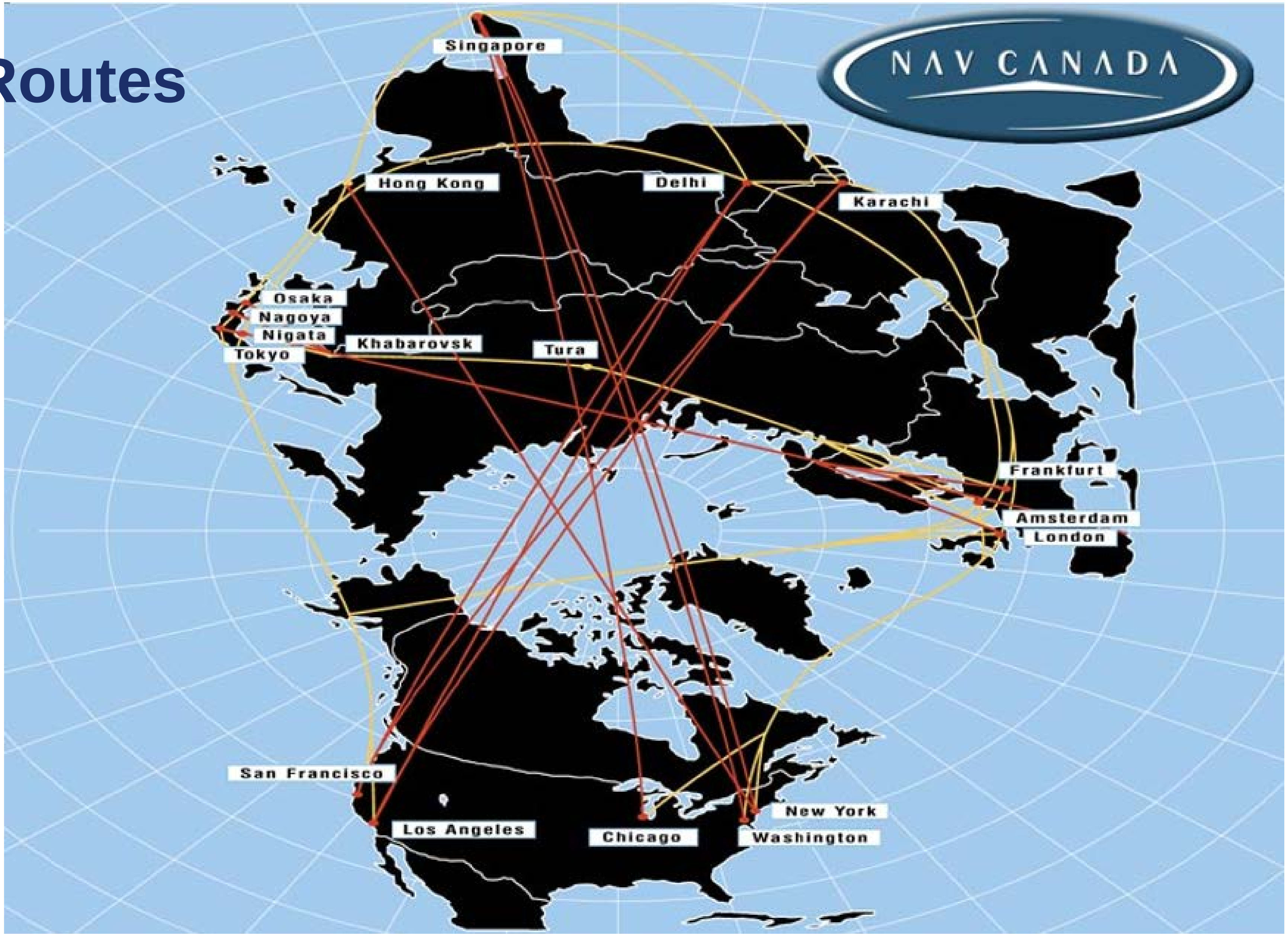


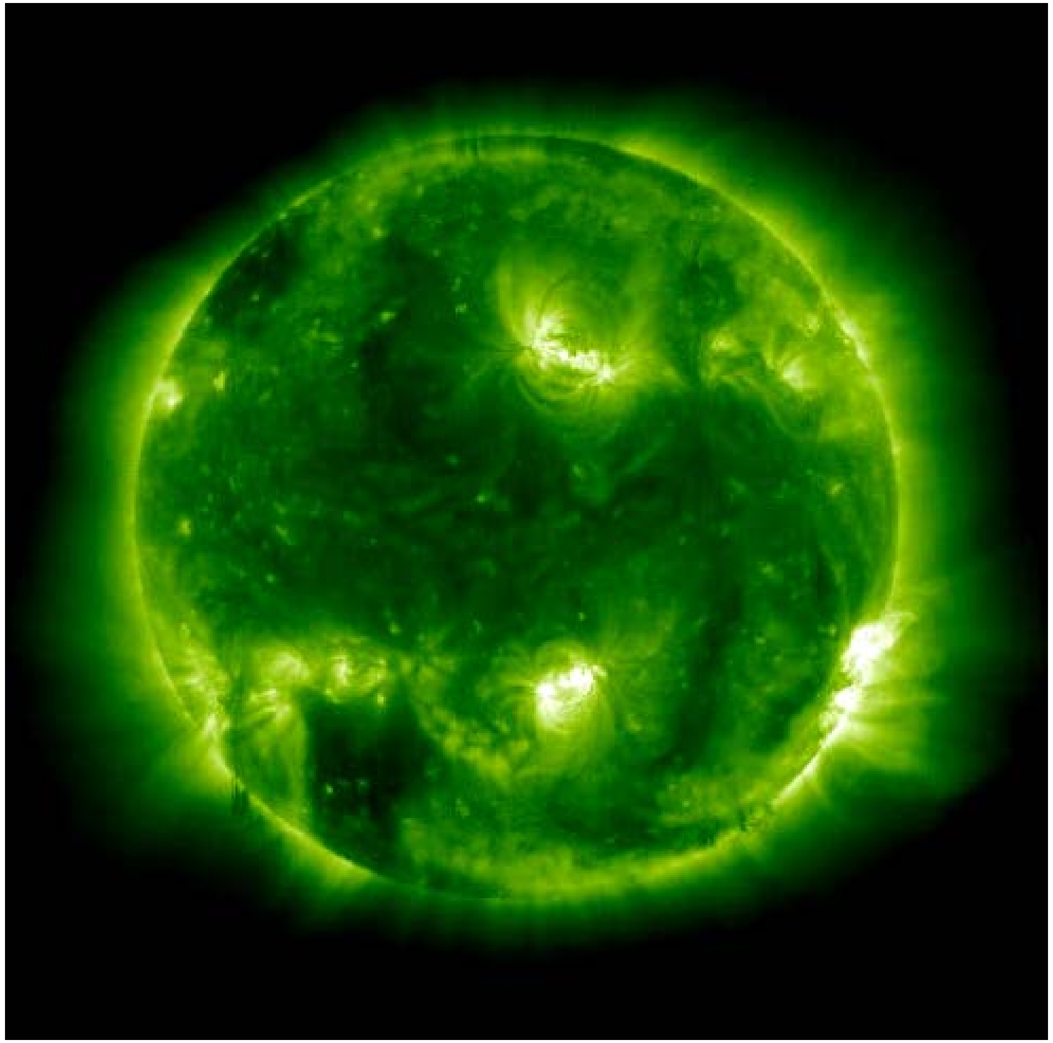
Image from NASA IMAGE Satellite

Polar Routes



Space Weather Storms – Timing and Consequences

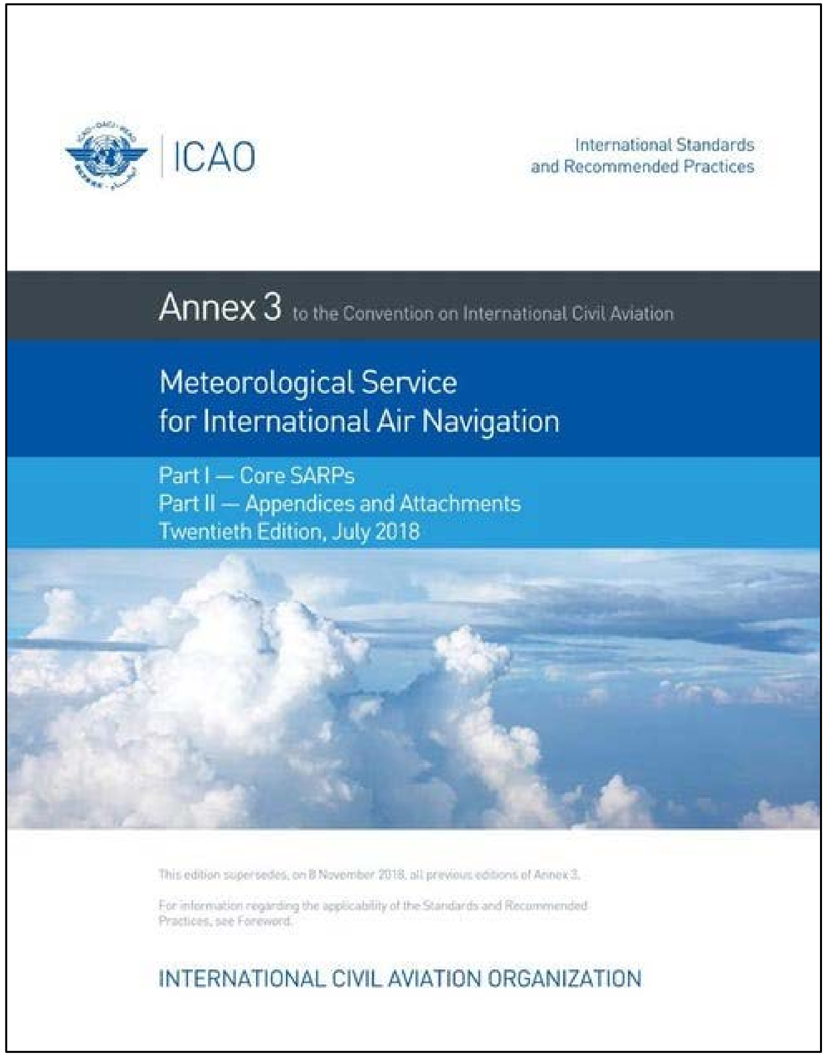
- A Flare and/or CME erupts from the Sun
- 8 minutes later: First blast of extreme ultraviolet (EUV) and X-ray light increases the ionospheric electron density
  - Radio (HF) communications are lost
- 30 to 1000 minutes later: Energetic Particles arrive
  - Astronauts are impacted
  - Satellites are impacted
  - Polar flights are impacted
- 1 to 4 days later: CME passes and energizes the magnetosphere and ionosphere
  - Electric Power is affected
  - Navigation Systems are affected
  - Radio Communications are affected



From NASA SOHO Satellite

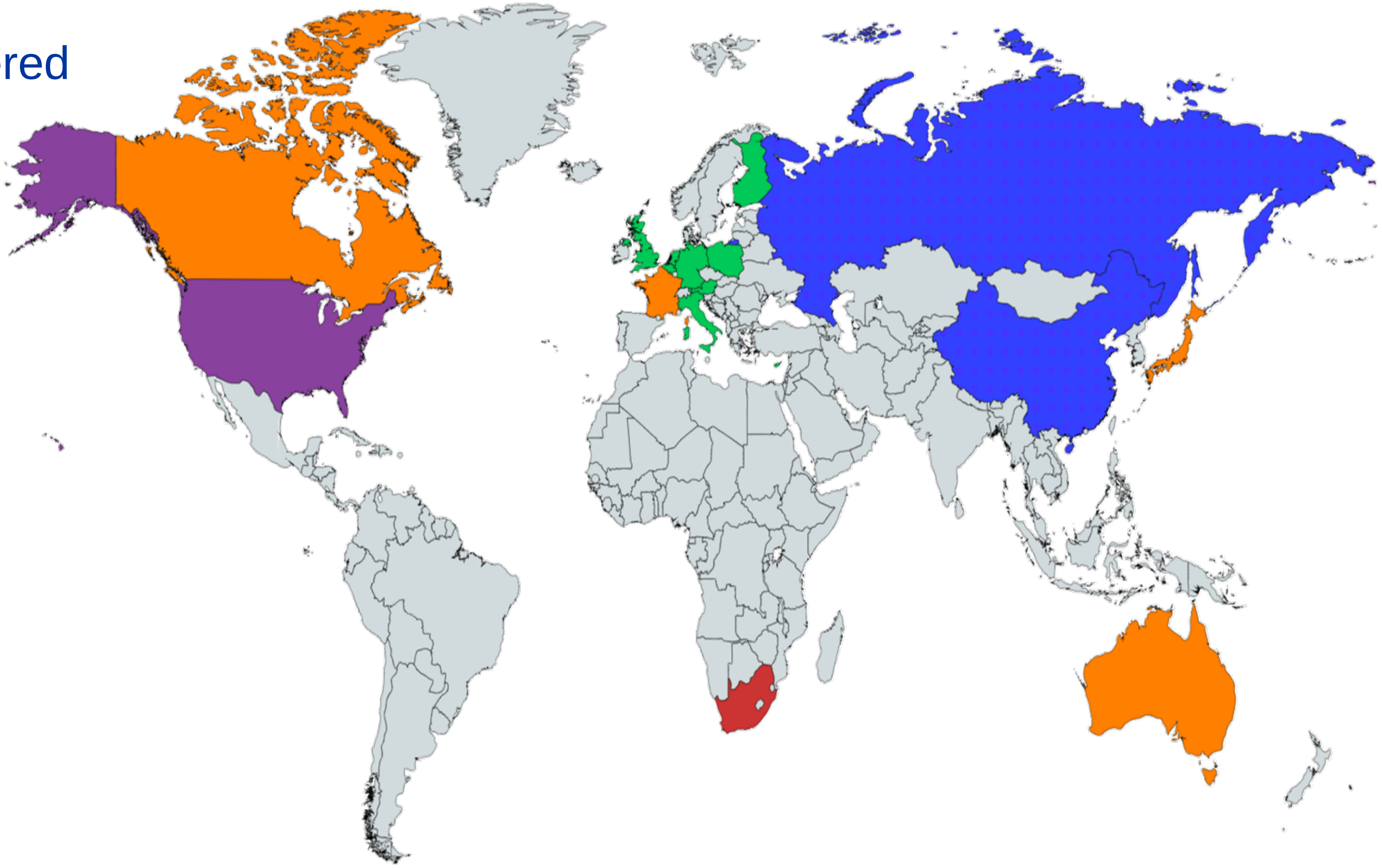
ICAO Annex 3 – *Meteorological Service for International Air Navigation*

- Space weather introduced in Amendment 78 (2018)
  - Advisories issued for
    - HF Voice/Data & Satellite Communications
    - Radiation Exposure to Crew & Passengers
    - GNSS Based Navigation & Surveillance
- Minor changes made to the content of the advisory in Amendment 79 (2020)
- Additional changes to the format and content planned for Amendment 81 (2024)



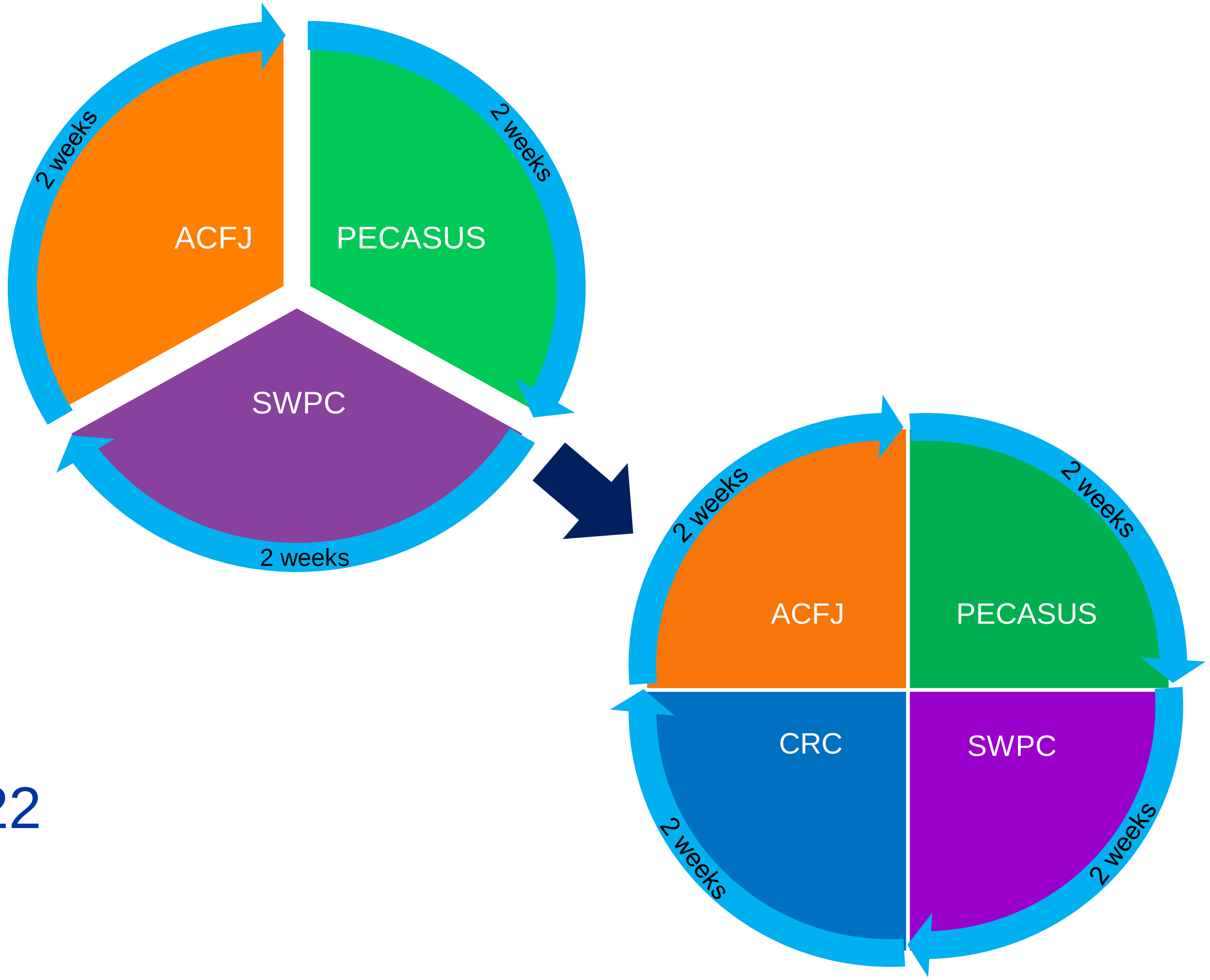
ICAO Space Weather Centers

- Designated ICAO Centers
  - Four Global – Consortiums are considered one center
    - PECASUS (European consortium lead by Finland)
      - Finland, United Kingdom
      - Germany, Austria
      - Poland, Italy
      - Netherlands, Belgium
      - Cyprus
    - ACFJ (Australia, Canada, France, Japan)
    - NOAA SWPC (United States)
    - China/Russia Consortium
  - One Regional
    - South Africa



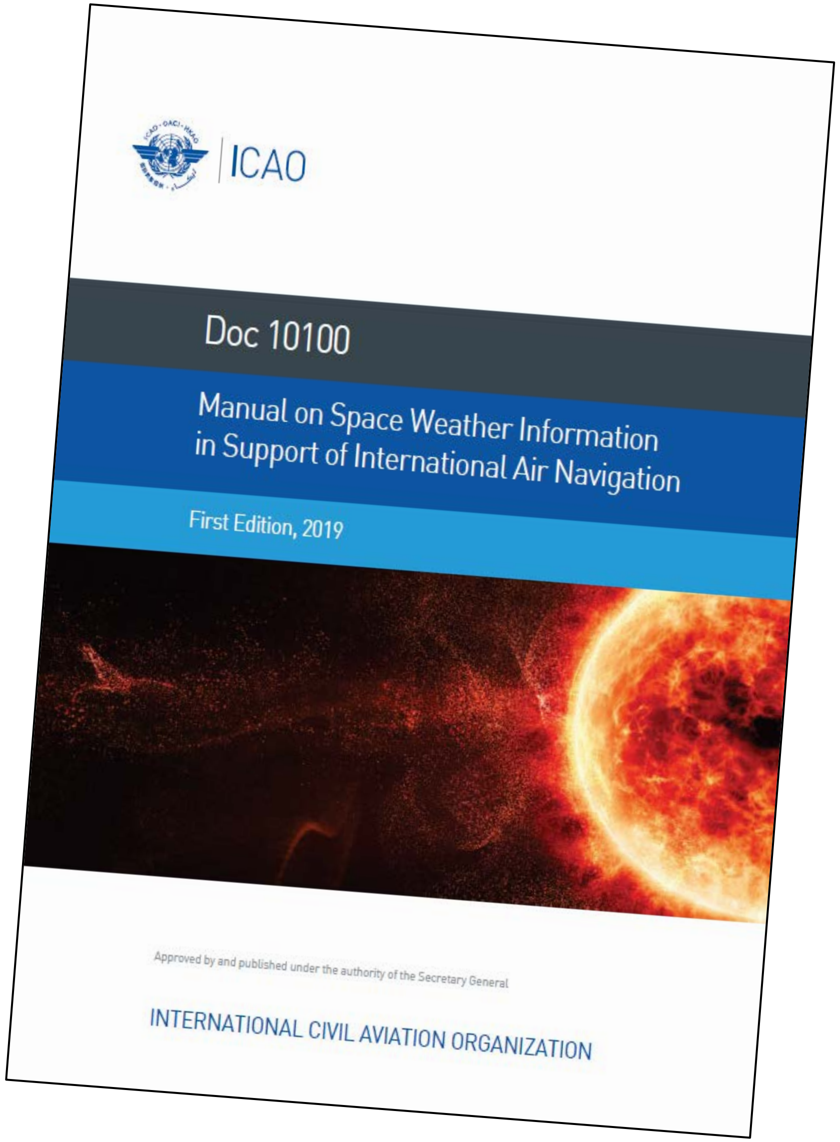
ICAO Space Weather Centers – cont.

- Global Centers working to meet Annex 3 Global provision → operational **7 November 2019**
- One 'On Duty' Center at any given time
  - Two-week rotation
  - 'On Duty' Center issues all advisories
  - Centers coordinate and collaborate continually
  - China-Russia Consortium became operational in 2021
- Regional Center operational by 2022
  - Sooner if feasible



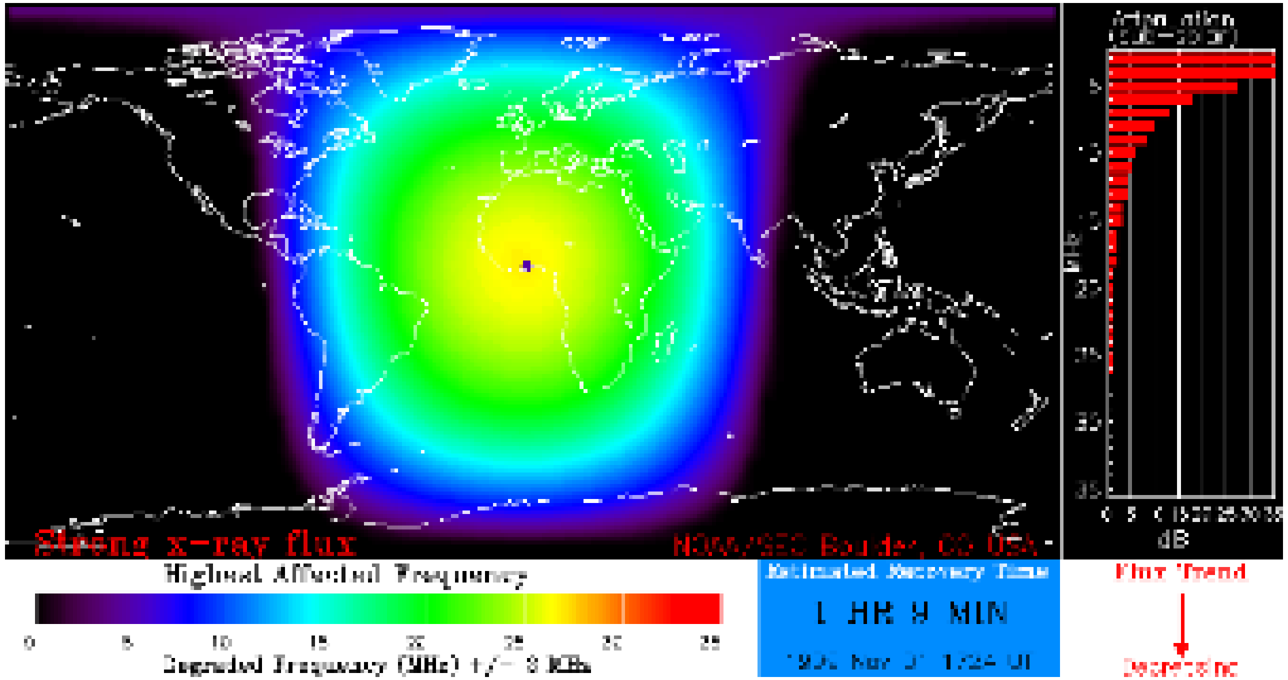
ICAO Space Weather Manual

- First published October 2019, updated for 2024
  - Manual on Space Weather Information in Support of International Air Navigation
- Other Guidance Material
  - Center Rotation & Operations
  - Advisory Interpretation and Use



Description of Advisories

- Issue advisories for:
  - HF Voice/Data & Satellite Communications (HF *most mature*, SATCOM *tbd*)
  - Radiation Exposure to systems, crew & passengers
  - GNSS Based Navigation & Surveillance (newest addition)



Use of the Space Weather Advisory

- Primarily intended for pre-flight planning decisions (e.g., route selection, altitude selection, fuel loading)
- Provides real-time warnings for some SWX events
- May be used for in-flight route or altitude deviations
- Promotes common situational awareness among aviation decision-makers

ICAO Space Weather Advisory

- **Issued for moderate (MOD) and severe (SEV) events**
  - For radiation events,
    - MOD is issued for radiation between FL 250 and FL 460
    - SEV is issued above FL 250.
- **The advisory depicts the affected region in one of three ways:**
  - one or more pre-defined latitude bands of width 30° shown in the table, followed by a longitude range in 15° increments;
  - the term DAYLIGHT SIDE, meaning the extent of the planet that is in daylight; or
  - a polygon using latitude and longitude coordinates

Title of the latitude bands	Ranges of the latitude bands
High latitudes northern hemisphere (HNH)	N90 to N60
Middle latitudes northern hemisphere (MNH)	N60 to N30
Equatorial latitudes northern hemisphere (EQN)	N30 to equator
Equatorial latitudes southern hemisphere (EQS)	Equator to S30
Middle latitudes southern hemisphere (MSH)	S30 to S60
High latitudes southern hemisphere (HSH)	S60 to S90

Sample ICAO SWX Advisory

```
FNXX01 YMMC 020100
SWX ADVISORY
DTG:                20190202/0100Z
SWXC:               ACFJ
ADVISORY NR:        2019/10
SWX EFFECT:         HF COM MOD
OBS SWX:            02/0100Z DAYLIGHT SIDE
FCST SWX + 6 HR:    02/0700Z DAYLIGHT SIDE
FCST SWX + 12 HR:   02/1300Z DAYLIGHT SIDE
FCST SWX + 18 HR:   02/1900Z NO SWX EXP
FCST SWX + 24 HR:   03/0100Z NO SWX EXP
RMK:                LOW END OF BAND HF COM DEGRADED
                    ON SUNLIT ROUTES. NEXT 12 HOURS
                    MOST POSSIBLE, DECLINING THEREAFTER.
NXT ADVISORY:       20190202/0700Z=
```

ICAO Space Weather Advisory Thresholds

		Moderate	Severe
GNSS			
	Amplitude Scintillation (S4)(dimensionless)	0.5	0.8
	Phase Scintillation (Sigma-Phi)(radians)	0.4	0.7
	Vertical TEC (TEC Units)	125	175
RADIATION			
	Effective Dose Rate (micro-Sieverts/hour)*	30	80
HF			
	Auroral Absorption (Kp)	8	9
	PCA (dB from 30MHz Riometer data)	2	5
	Solar X-rays (0.1 - 0.8 nm)($W\text{-}m^{-2}$)	$1X10^{-4}$ (X1)	$1X10^{-3}$ (X10)
	Post-Storm Depression (MUF)**	30%	50%

Dissemination

- User's can obtain the Space Weather Advisory (SWXA) through their National (Operational Meteorological) OPMET Centre (NOC), their State Aeronautical Information Service (AIS) or the secure internet services: The Secure Aviation Data Information Service (SADIS) and the World Area Forecast (WAFS) Internet File Service (WIFS)
- The World Meteorological Organization (WMO) message headers (TTAAii CCCC) for the text and IWXXM Advisories and Administration messages are given in the table below
  - *Note*: *ACJF Consortium will issue advisories from two locations*

Dissemination – cont.

	WMO Headers	
	TAC Advisory	IWXXM Advisory
ACFJ – Australia	FNXX01 YMMC	LNXX01 YMMC
ACFJ – France	FNXX01 LFPW	LNXX01 LFPW
PECASUS – Finland	FNXX01 EFKL	LNXX01 EFKL
PECASUS – UK	FNXX01 EGRR	LNXX01 EGRR
CRC – China	FNXX01 ZBBB	LNXX01 ZBBB
CRC – Russia	FNXX01 UUAG	LNXX01 UUAG
SPWC – USA	FNXX01 KWNP	LNXX01 KWNP

01 = GNSS

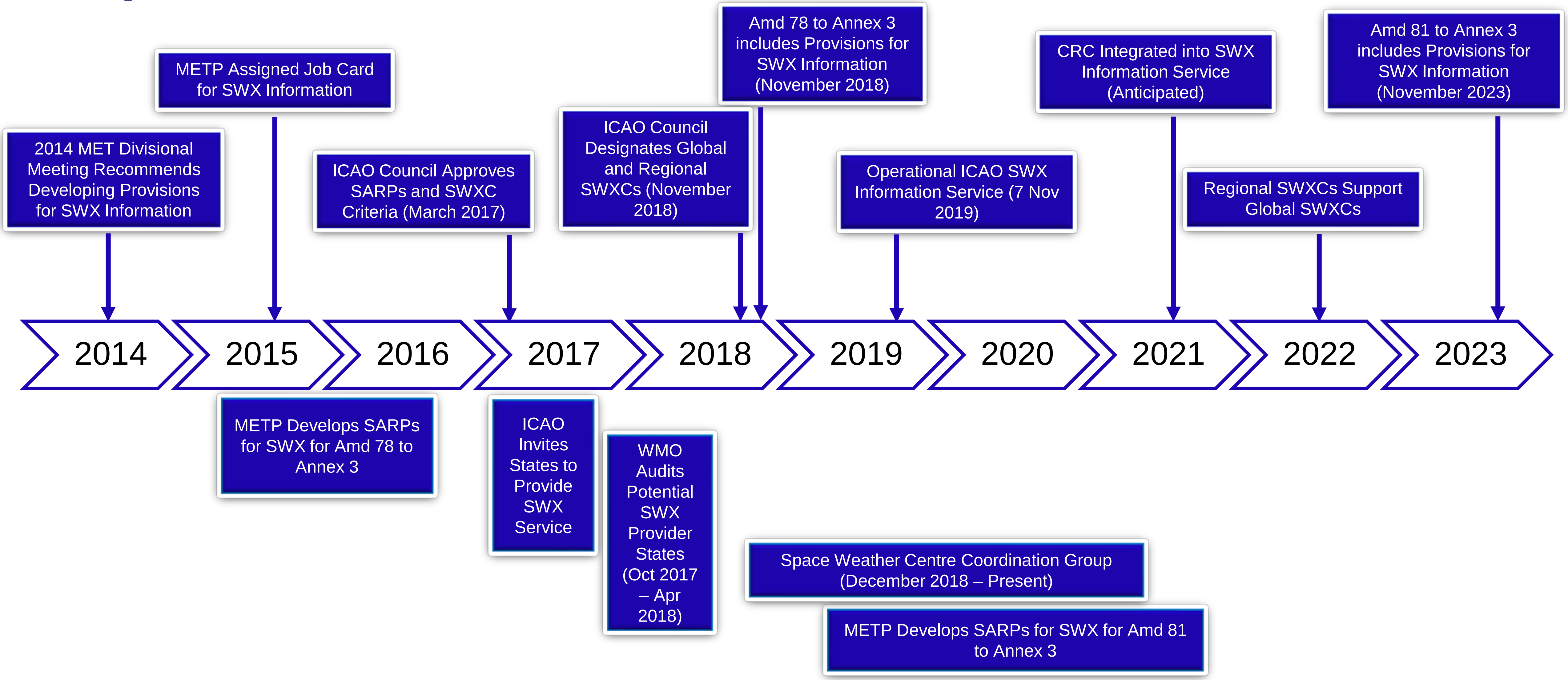
02 = HF COM

03 = RADIATION

04 = SATCOM

Backup Slides

Space Weather Information Service



Background

- Phases to designate ICAO Space Weather Provider(s)/Center(s)
  - ICAO issued State Letter AN 10/1-IND/17/11 on June 9, 2017 requesting States to provide a formal expression of interest in providing the space weather information service
  - WMO conducted an audit of all States and consortia that indicated a formal interest
    - Audit against criteria developed by MET Panel (accepted by ANC)
    - Did not assess the ‘quality’ of meeting criteria
    - Did not make a judgment (e.g., ranking) of States - only reported results of States’ meeting or not meeting the identified criteria

International Civil Aviation Organization | Organisation de l’aviation civile internationale | Organización de Aviación Civil Internacional | Международная организация гражданской авиации | منظمة الطيران المدني الدولي | 国际民用航空组织

Tel.: +1 514-954-8219 ext. 6717

Ref.: AN 10/1-IND/17/11 — 9 June 2017

Subject: Request for interest in providing a space weather information service

Action required: Comments to reach Montréal by 8 September 2017

Sir/Madam,

1. I have the honour to inform you that the Air Navigation Commission, at the tenth meeting of its 204th Session held on 9 March 2017, considered proposals developed by the second meeting of the Meteorology Panel (METP/2) to amend Annex 3 — *Meteorological Service for International Air Navigation*. The Commission authorized their transmission to Member States and appropriate international organizations for comment. The consultation process has already started through SL AN 10/1-17/41, related to proposals for amendment of Annex 3 and consequential amendments to Annex 15 — *Aeronautical Information Services, Procedures for Air Navigation Services — ICAO Abbreviations and Codes* (PANS-ABC, Doc 8400) and the *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444).

2. One of the above proposals refers to the introduction of a space weather information service to support international air navigation, which is intended for implementation in November 2018. An essential element of the implementation is the designation of space weather information providers. In this regard, the Air Navigation Commission endorsed METP/2 Recommendation 4/4, which is reproduced below:

> **Recommendation 4/4 – Guidance on the process for selecting space weather information providers**
>
> That to assist in the process of selection of space weather information providers, the guidance on the process for establishing the global space weather information capability, including the schedule to complete the said process (Appendix I) be endorsed by the ANC.

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Background – cont.

- ICAO Council selects/designates States to provide Space Weather Annex 3 products in Nov 2018
  - Considered ‘optimum number’ recommended
    by METP
  - Based on WMO audit results
  - Based on ‘other’ considerations