METEOROLOGY PANEL

Space Weather and ICAO Space Weather Information Service Overview

Mark Gibbs
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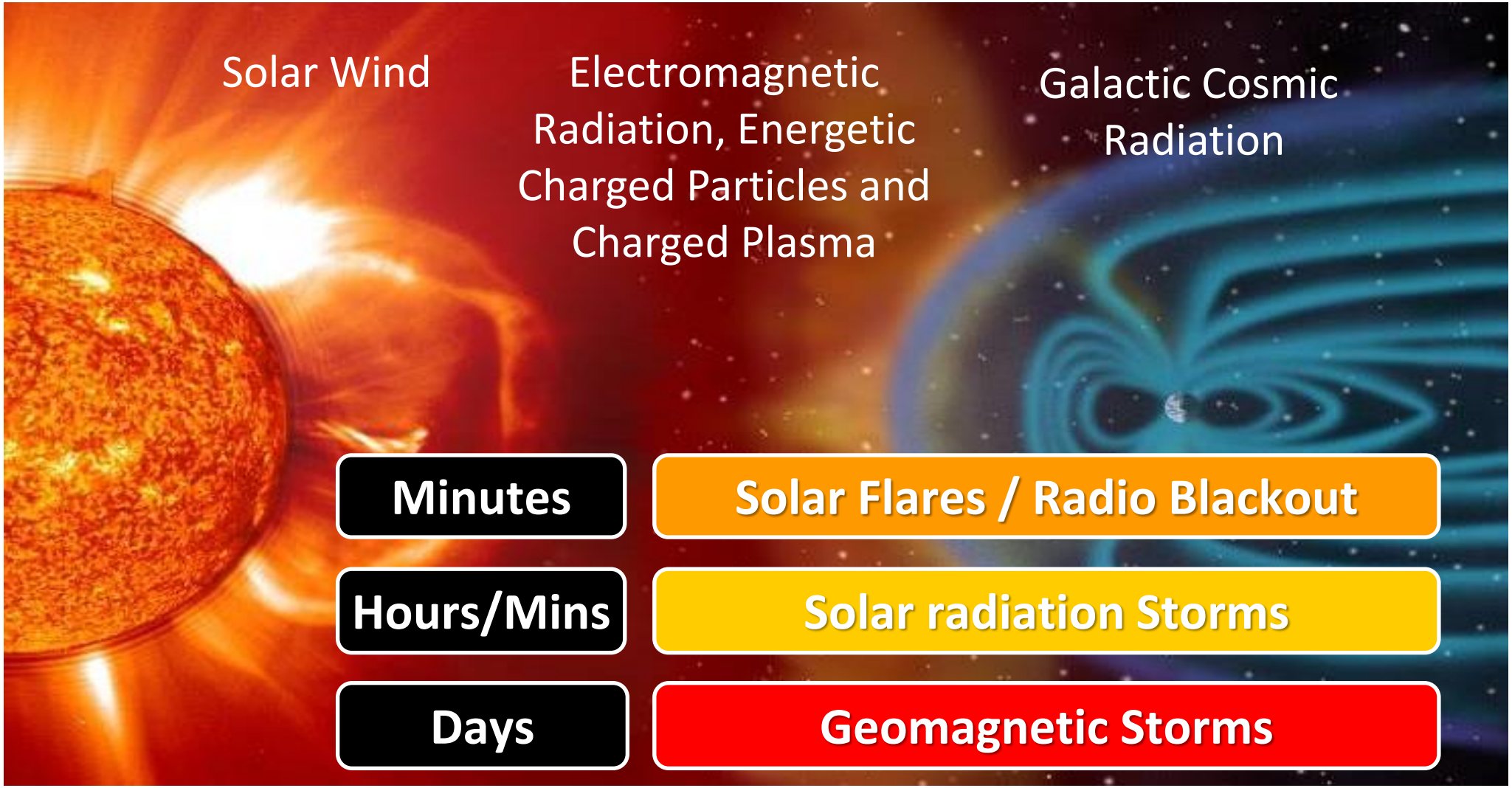
on behalf of SWXCCG

Space Weather

What is it and what are the impacts?

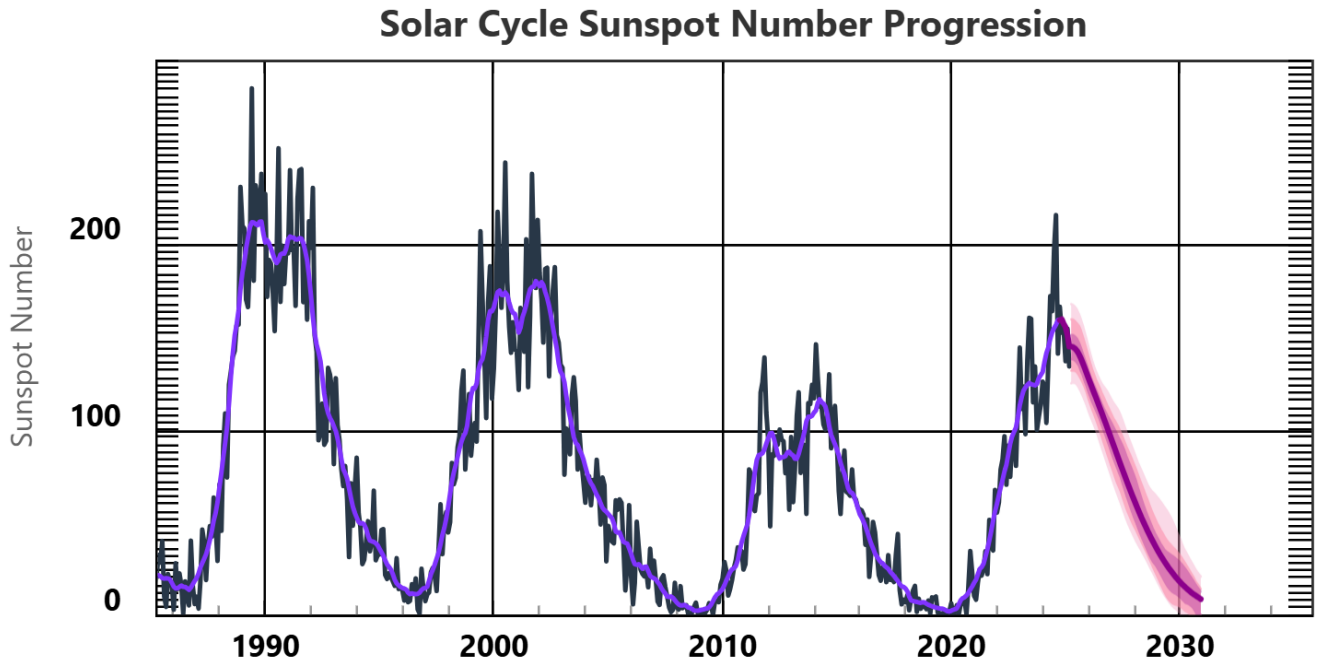
Space Weather

Space Weather Types and Arrival Times from Sun



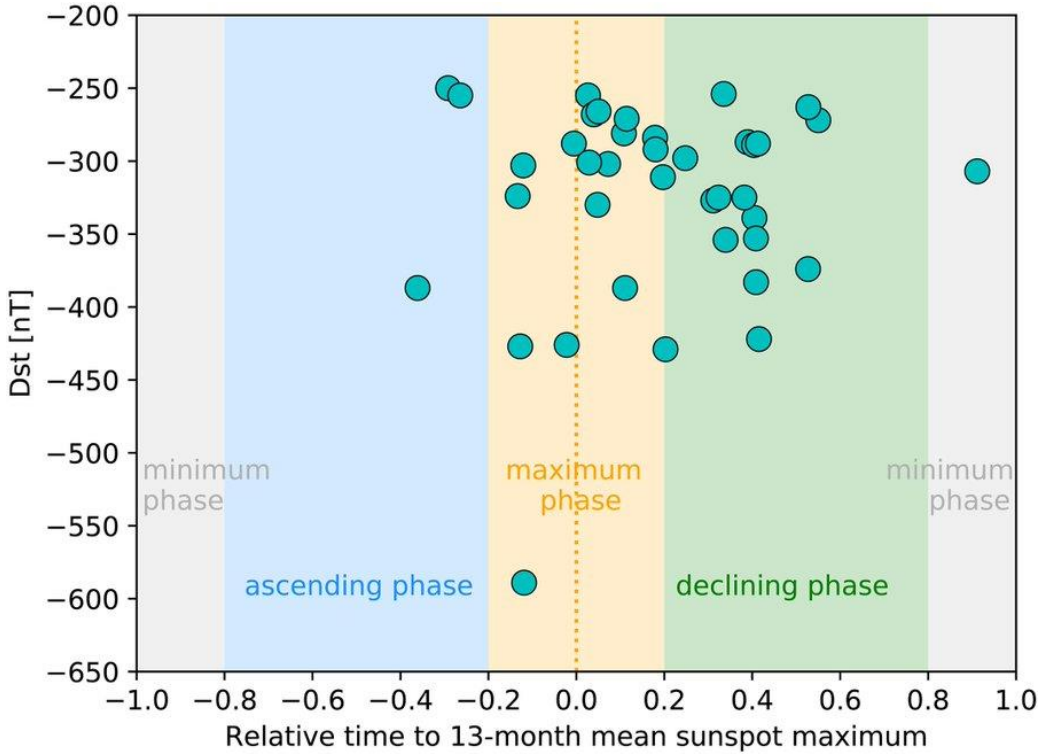
The Solar Cycle

We may have just passed solar maximum?



…but we must not be off our guard

large events are more common during the declining phase and have occurred close to solar minimum in the past.



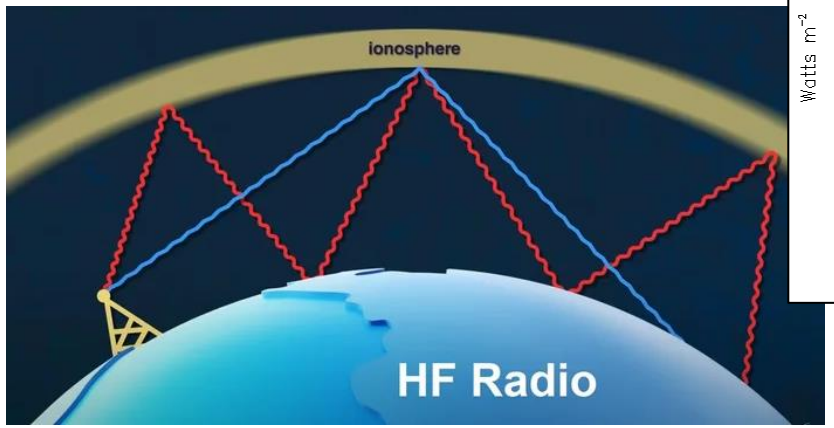
Solar Flares & Radio Bursts

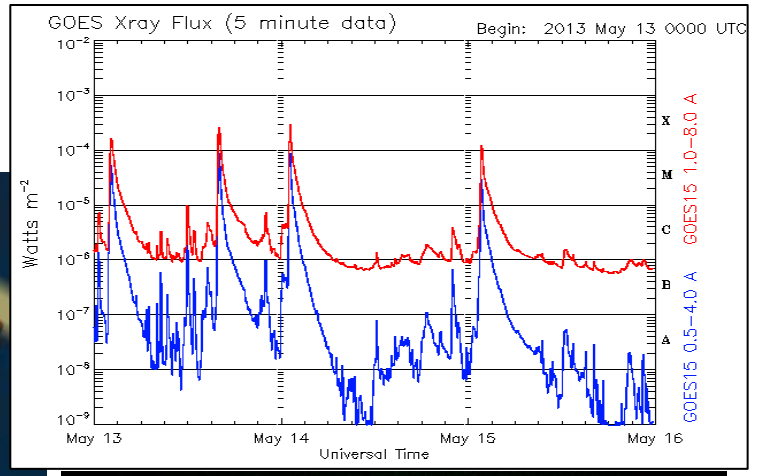
Electromagnetic Radiation

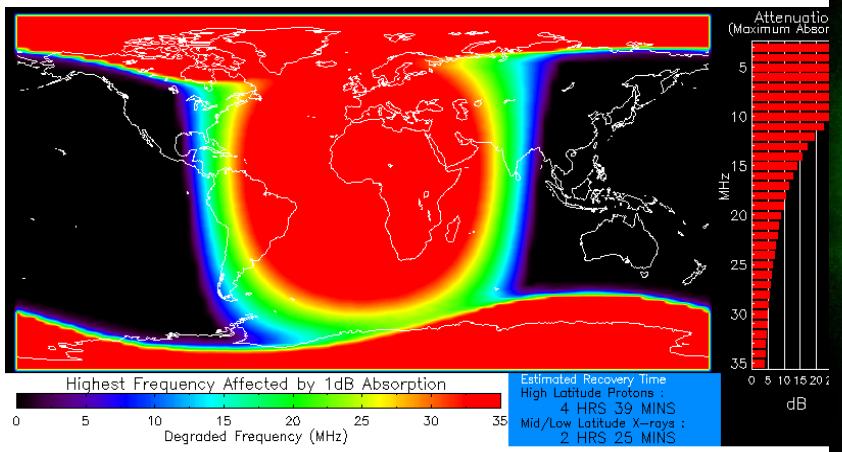
- Arrival: 8 min
- Typical duration: 1-3 Hours

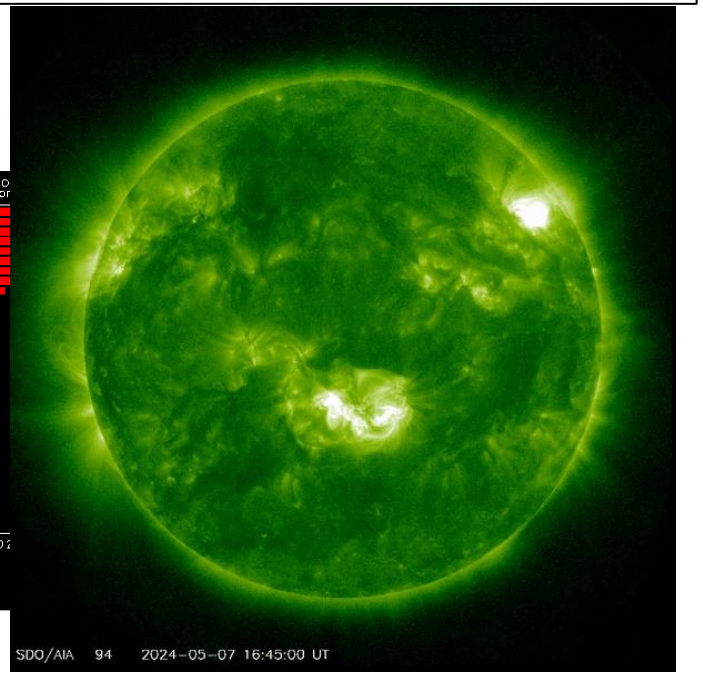
• Effects (Sunlit earth)

- VLF-HF Radio degradation or blackout
- SATCOM interference
- Radar interference
- Satellite orbit decay
- GNSS errors (Geo-location)









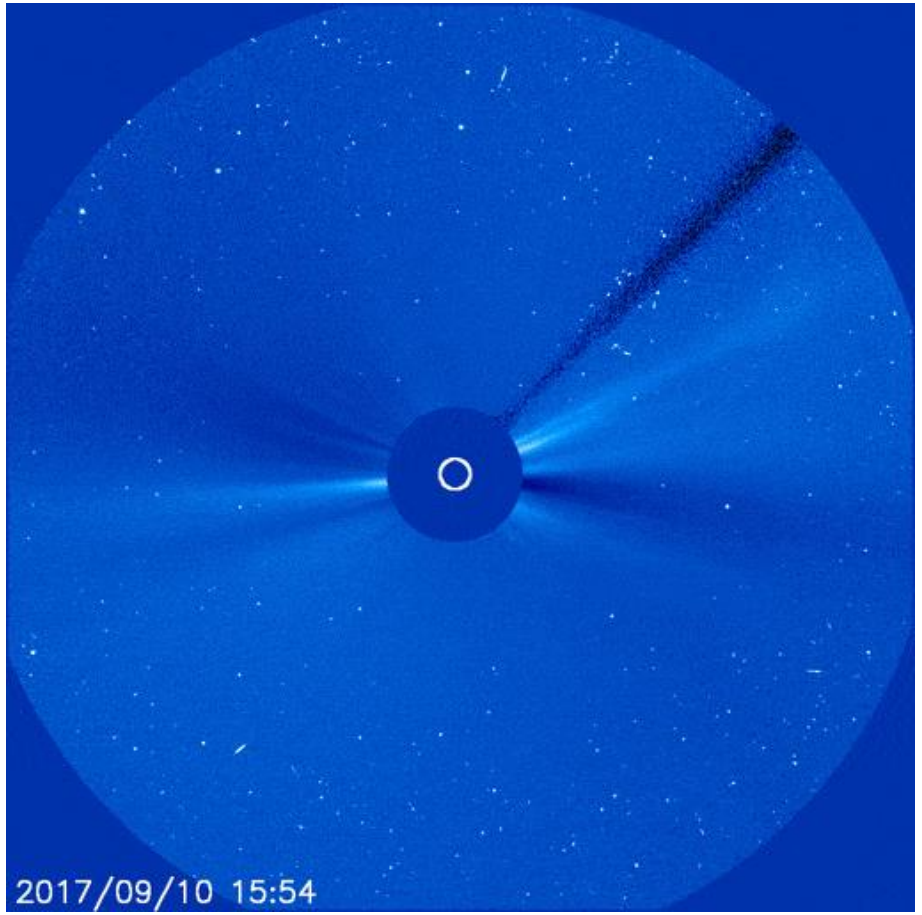
6th Sept 2017

Solar Radiation Storms

High Energy Charged Particles

- Arrival: ~10 Minutes to few hours
- Typical duration: Few days

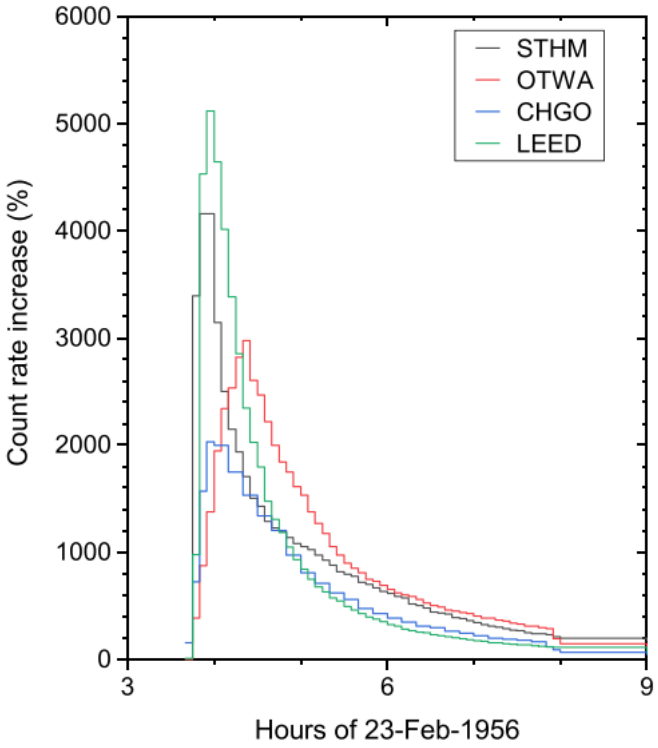
- Effects
  - High-latitude VLF-HF Radio degradation or blackout
  - Satellite disorientation
  - Spacecraft damage
  - High-altitude Radiation exposure
  - Upsets to avionics and ground-based electronics

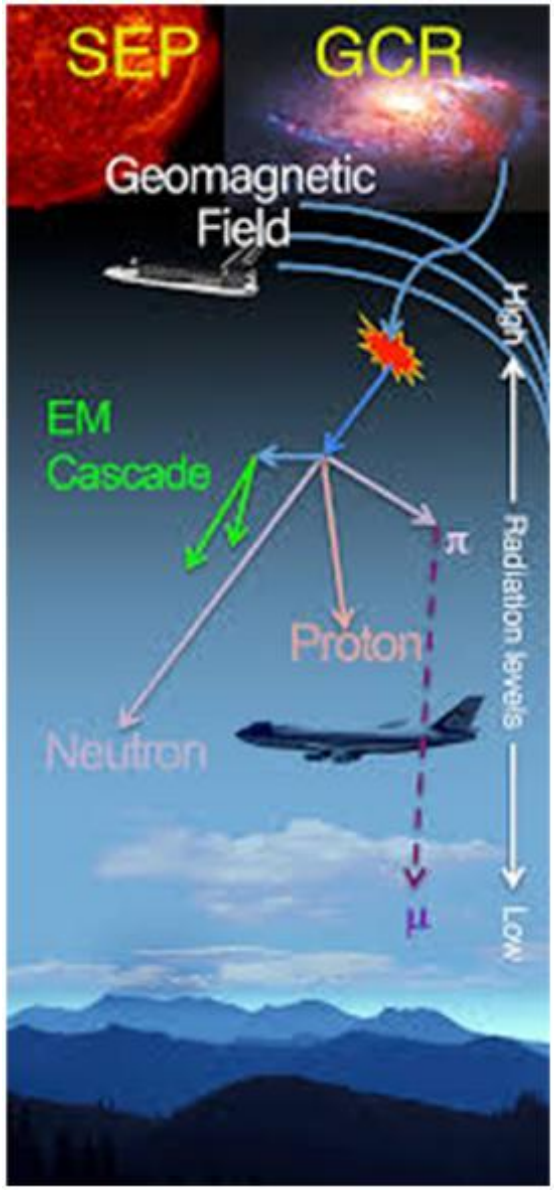


Solar Radiation Storms

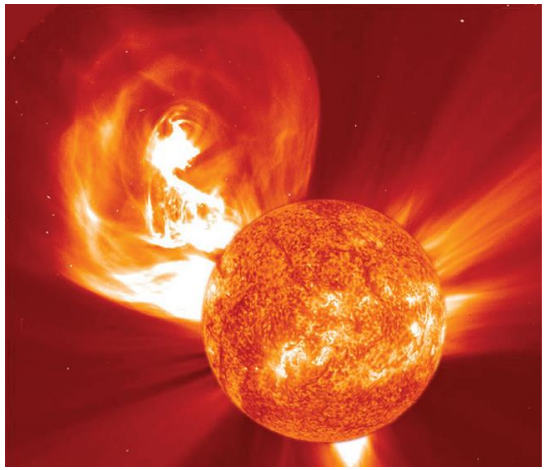
Ground Level Events (GLEs)

- Human radiation dose
- Potential to disrupt aircraft avionics
- Potential to disrupt electronic ground-based systems





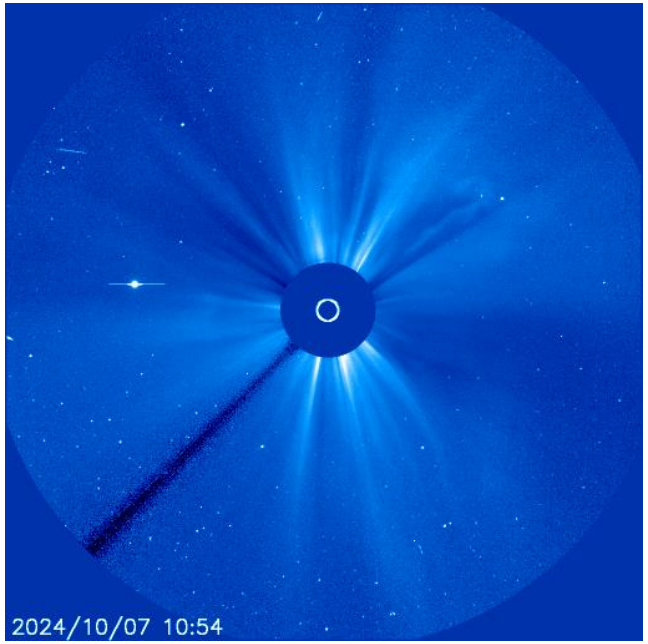
Geomagnetic Storms



Electrically charged plasma

- Arrival: 14 hours to 3 days
- Typical duration: Few days

- Effects
  - Degraded VLF-HF radio and SATCOM
  - Spacecraft charging/damage
  - Radar interference/false targets
  - GNSS location/timing errors or loss
  - Spacecraft orbit decay
  - Induced currents in long conductors
  - Power Grid Failures



Historic Events and Impacts

- **Carrington event – 1859**
  - Telegraph lines across Europe & US were seen to spark and equipment caught fire

- **Geomagnetic storms 1989 & Oct/Nov 2003**
  - Quebec 1989 - 6m people lost power for 9 hours
  - Malmo 2003 - complete power blackout
    - 47 satellites temporary outages

- **9-11 May 2024 Storm**
  - Mitigative actions taken by power companies in North America and New Zealand
  - Impacts to HF comms, GNSS, and satellite systems

Identifying the Risk – Extreme Space Weather

From UK Expert Community

- The longest interval of severe space weather is likely to be **of the order of two weeks.**

- It is **extremely difficult to predict the order, size, and duration of individual space weather phenomena.**

- **Different systems could experience adverse impacts (a) simultaneously, (b) sequentially, or (c) unpredictably (i.e., effectively randomly).** Furthermore, it is highly likely that these system failures will interact with each other to cause cascading failure modes that are fundamentally difficult to predict.

METEOROLOGY PANEL

ICAO Space Weather Information Service (SWIS)

ICAO space weather advisories

- Annex 3 to the Convention on International Civil Aviation (known as the Chicago Convention).
- Space Weather requirements first included in Amendment 78 (applicability Nov 2018)
- Service went live Nov 2019
- Complimented by Doc 10100
- Requirements:
  - Safety
    - Radiation dose to aircrew
    - Maintain communication for safe navigation / separation
  - Minimise disruption
    - Loss of communications
    - Loss of GNSS precision approaches

ICAO space weather advisories

- Targets three impact areas for aviation:
  - HF Communications (HF COM)
  - GNSS-based navigation and surveillance (GNSS)
  - Radiation impacts on human health (RAD)

- Issued at two intensity thresholds, MOD and SEV, as defined in ICAO Doc 10100
  (Manual on Space Weather Information in Support of International Air Navigation)

Impact	Parameter	MOD	SEV
RAD	Effective dose	30 µSievert/h	80 µSievert/h
GNSS			
Ampl. Scint.	S_4	0.5	0.8
Phase Scint.	σ_ϕ	0.4 rad	0.7 rad
Total el. Cont.	TECU	125	175
HF COM			
Auroral Abs.	Kp	8	9
Pol. Cap. Abs.	Riometer abs.	2 dB	5 dB
Shortwave Fadeout	Solar X-rays	10^{-4}W/m^2 (X1)	10^{-3}W/m^2 (X10)
Post Storm Depr.	MUF	30%	50%

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SWX ADVISORY
DTG:                20200930/0415Z
SWXC:               ACFJ
ADVISORY NR:        2020/33
SWX EFFECT:         HF COM MOD
OBS SWX:            30/0352Z HNH E000 - E075
FCST SWX +6 HR:     30/1000Z NO SWX EXP
FCST SWX +12 HR:    30/1600Z NO SWX EXP
FCST SWX +18 HR:    30/2200Z NO SWX EXP
FCST SWX +24 HR:    01/0400Z NO SWX EXP
RMK:                SPACE WEATHER EVENT (MAXIMUM USABLE FREQUENCY
DEPRESSION) IN PROGRESS IMPACTING HIGHER HF COM
FREQUENCY BAND. LOWER FREQUENCIES MAY BE LESS
IMPACTED. ISOLATED AREAS OF SEV HF COM DEGRADATION
POSSIBLE.
NXT ADVISORY:       WILL BE ISSUED BY 20200930/1000Z=
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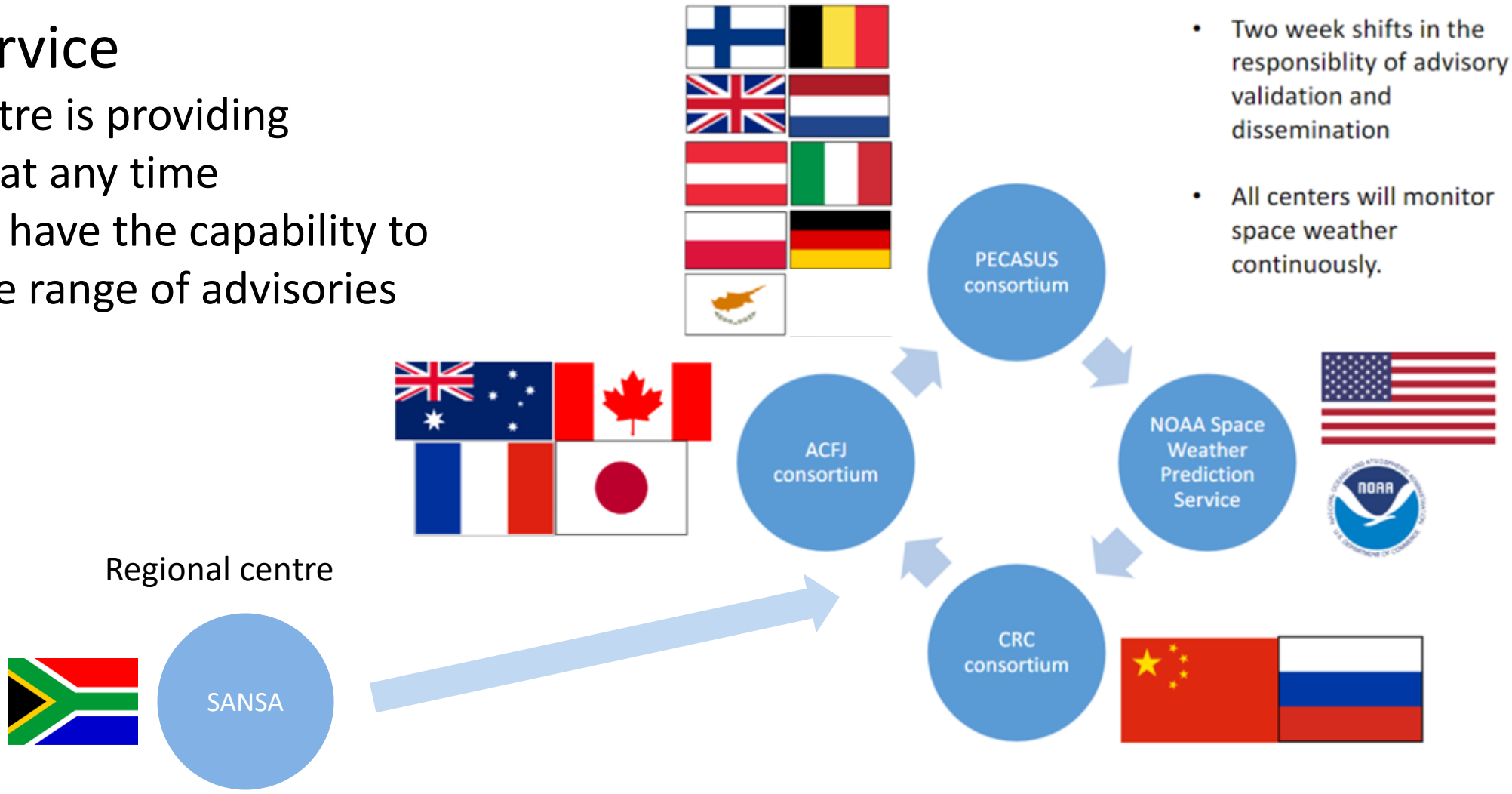
ICAO space weather centres

- A single service
  - Only 1 centre is providing advisories at any time
  - All centres have the capability to provide the range of advisories

Advisories are provided by four global space weather centers



- Two week shifts in the responsiblity of advisory validation and dissemination
- All centers will monitor space weather continuously.

Aviation sector potential impacts

- Communications
  - HF beyond-line-of-sight comms
  - SATCOM

Too many technologies, frequencies, etc

HF COM
Auroral Abs.
Pol. Cap. Abs.
Shortwave Fadeout
Post Storm Depr.

- RADAR
  - Interference
  - Reduced Signal to Noise Ratio

Under investigation – possibly needs local automated alerting

- GNSS loss
  - Position, navigation & timing

GNSS
Ampl. Scint.
Phase Scint.
Total el. Cont.

- Atmospheric radiation / GLE
  - Elevated radiation dose to passengers and aircrew
  - Single Event Upsets (SEU) to avionics

RAD

Vulnerability not well understood

- Electricity impacts

Sources of information

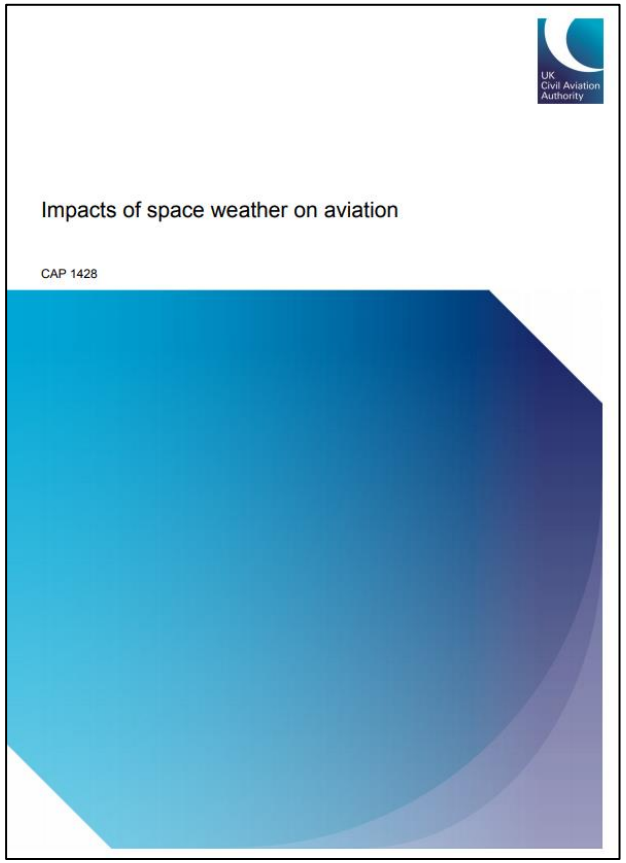
FAA website

InFO (Information For Operators) 20007

Effect	Sub-effect	Parameter used	Thresholds		Impact within advisory area	
			MOD	SEV	MOD	SEV
GNSS	Amplitude Scintillation	S4 (dimensionless)	0.5	0.8	Possible degraded service	Possible unreliable service
GNSS	Phase Scintillation	Sigma-phi (radians)	0.4	0.7		
GNSS	Vertical Total Electron Content (TEC)	TEC units	125	175		
RADIATION		Effective dose rate (micro-Sieverts/hour)	30	80	Possible increased dose rates above normal levels.	
HF COM	Auroral Absorption (AA)	Kp index	8	9	Possible degraded service	Possible unreliable service
HF COM	Polar Cap Absorption (PCA)	dB from 30MHz riometer data	2	5		
HF COM	Shortwave Fadeout (SWF)	Solar X-rays (0.0-0.8 nm) ($W-m^{-2}$)	$1x10^{-4}$ (X1)	$1x10^{-3}$ (X10)		
HF COM	Post-Storm Depression	Maximum usable frequency (MUF)	30%	50%		
SATCOM	No threshold has been set for this effect				Possible degraded service	Possible unreliable service

www.pecasus.eu

Sources of information



http://www.caa.co.uk/CAP1428

- Provides further information about impacts of space weather on aviation, including the probability of occurrence, forecasting and observing space weather, safety risk assessments and recommendations

Category	Space weather scale	Aviation Impact	Probability (outside of solar min)
Solar Superstorm	Extreme G5	• GNSS positioning and timing degraded for up to three days, due to signal fading and uncharacterised signal delays (EGNOS unlikely to help). • HF communication will be impossible or at best difficult to manage for one to two days, due to fading and unusual propagation conditions. • Aircraft SATCOMS lost or poor at most latitudes due to fading; worst for polar flights. • Contribution to loss of 10% of the satellite infrastructure. • Potential disruption to the electricity network due to ground induced currents (GICs), with possible consequences for air traffic control infrastructure.	~ 1 in 100 years
Significant	G5 Kp=9	• GNSS positioning and timing degraded for hours, due to signal fading and uncharacterised signal delays. • HF communication will be impossible or at best difficult to manage for one to two days, due to fading and unusual propagation conditions. • Aircraft SATCOMS poor at most latitudes due to fading, worst for polar flights. • Contribution to loss of one or two of the satellite fleet.	~4 to 6 days per year
Routine	G4 Kp=8	• HF communications need managing. • Otherwise, no significant effect.	~100 days per year

Thank You