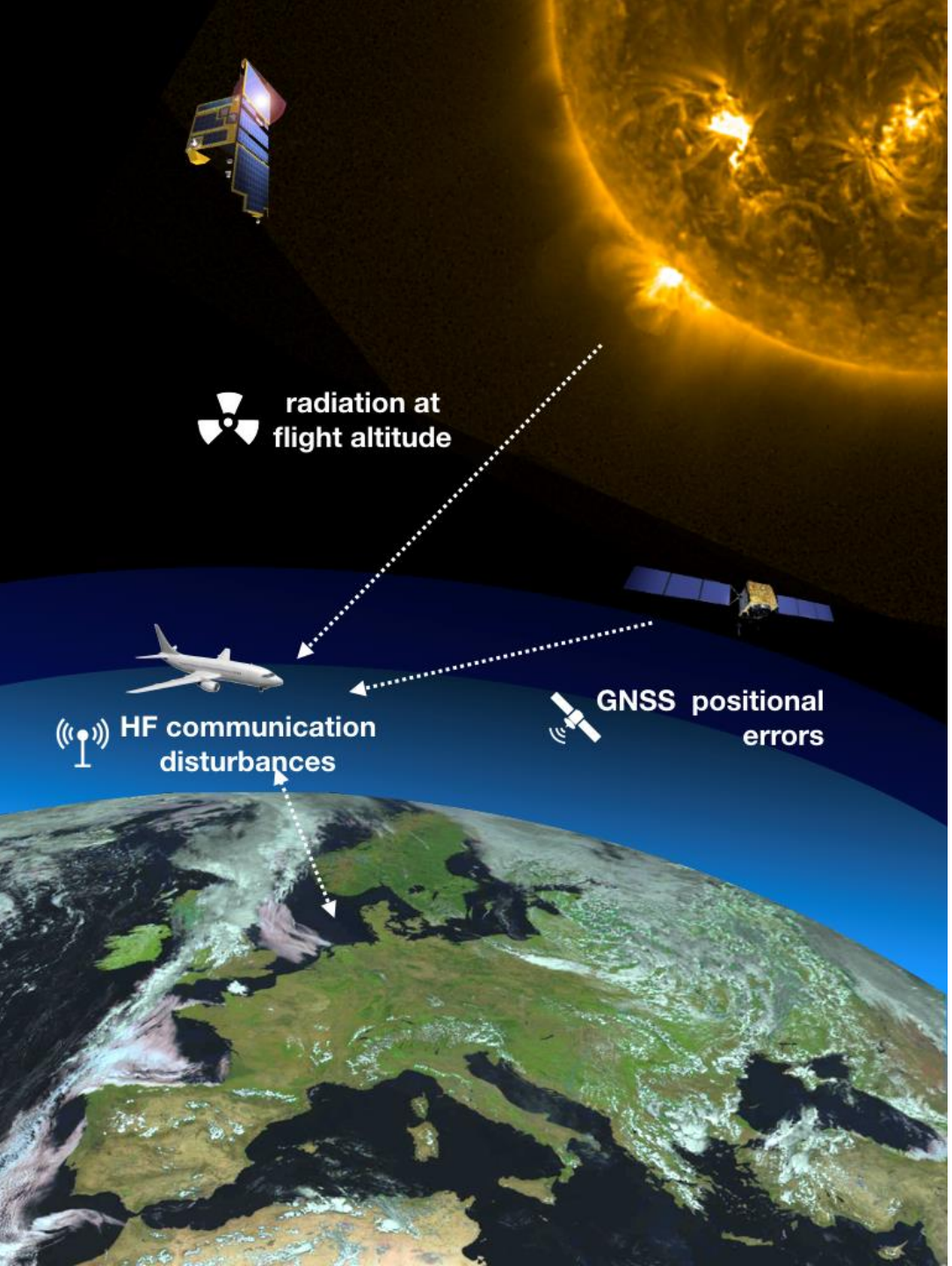


Space Weather impacts on Aviation

Course by the
Solar-Terrestrial Centre of Excellence

March 2024

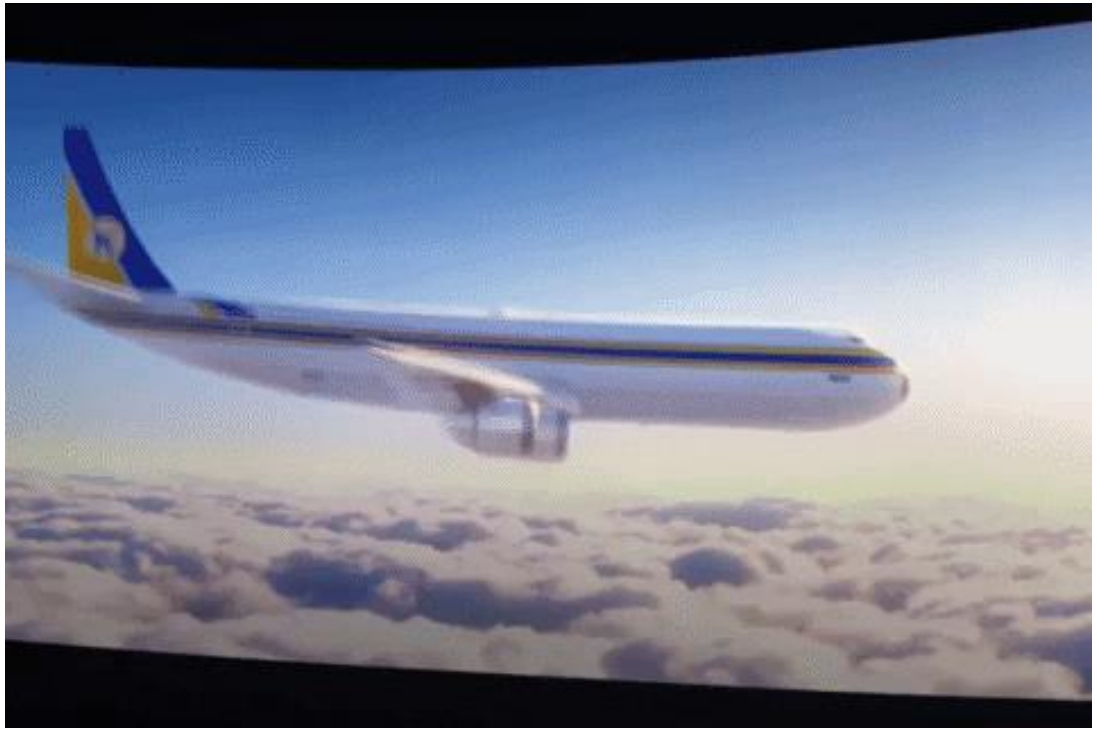
Space Weather impacts on Aviation

Disturbances seen in GNSS, HF Com and Radiation at FL

Jan Janssens

Contents

- Drivers of disturbed SWx
- SWx impacts on aviation
  - Diagram
  - Historical events
    - HF Com
    - Radiation
    - GNSS



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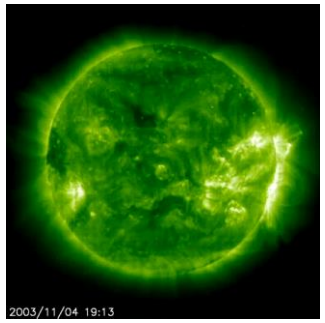
Drivers of disturbed SWx

Solar eruptions

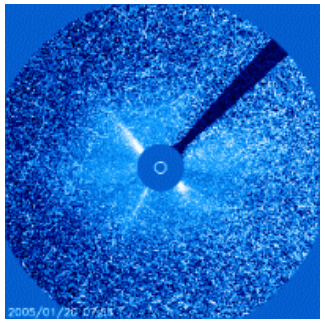
Electromagnetic Radiation

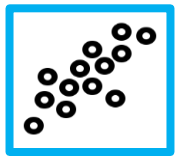
Particles

Solar flares

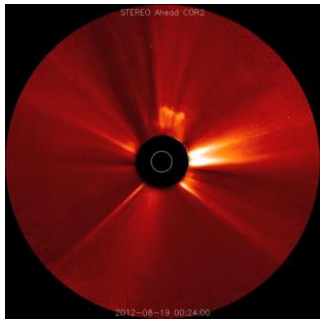


Proton events





Coronal Mass Ejections



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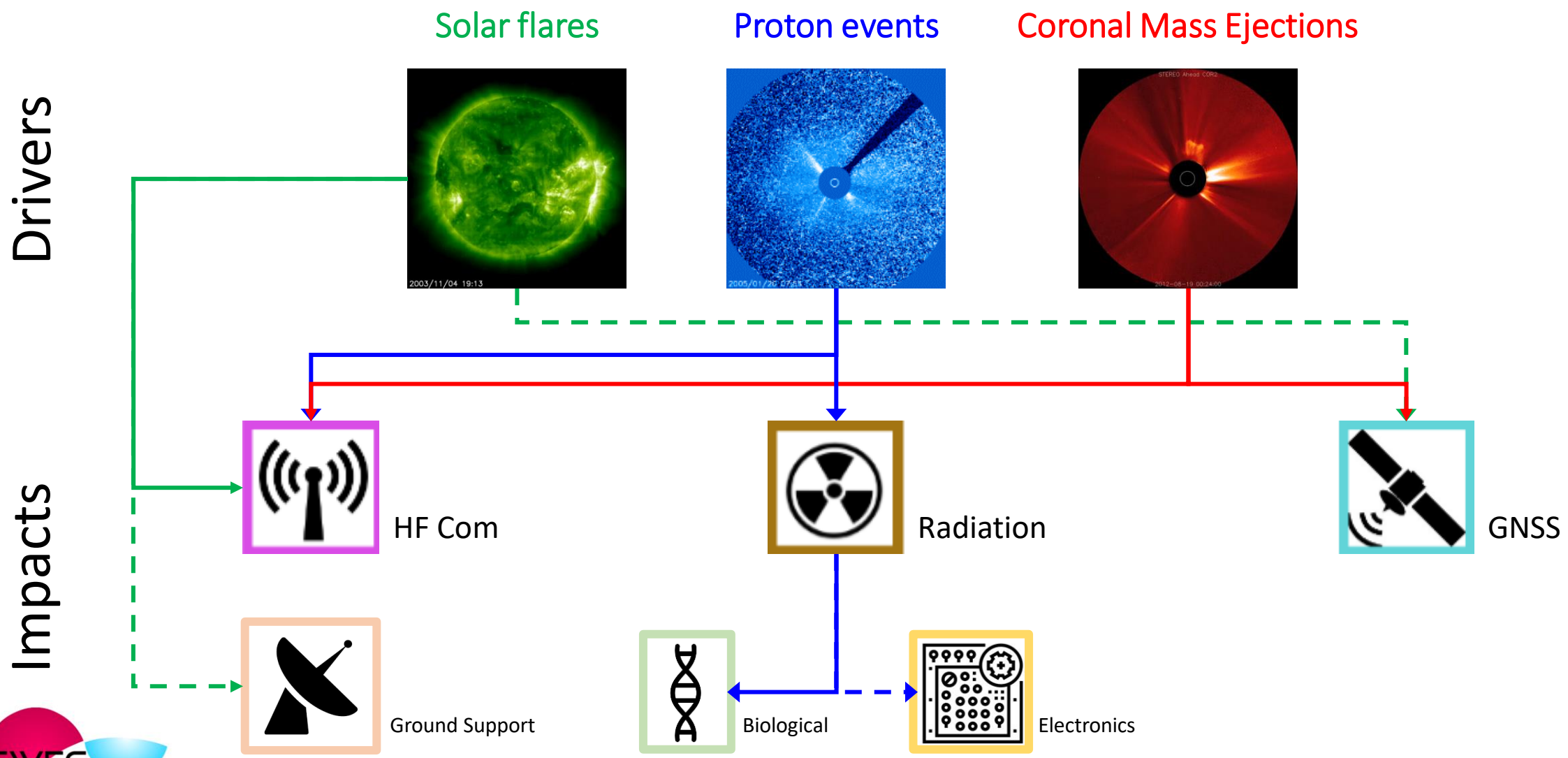
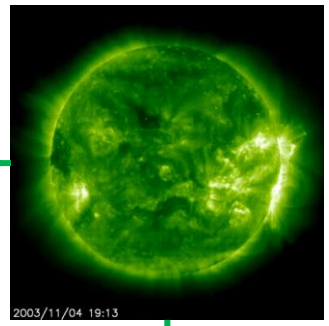
SWx impacts on aviation



HF Com: High Frequency Communications (3-30 MHz) ; GNSS: Global Navigation Satellite Systems (GPS, Galileo,,…) **Currently NOT covered by SWx advisories for ICAO**

SWx impacts from solar flares on aviation

Solar flares



HF Com

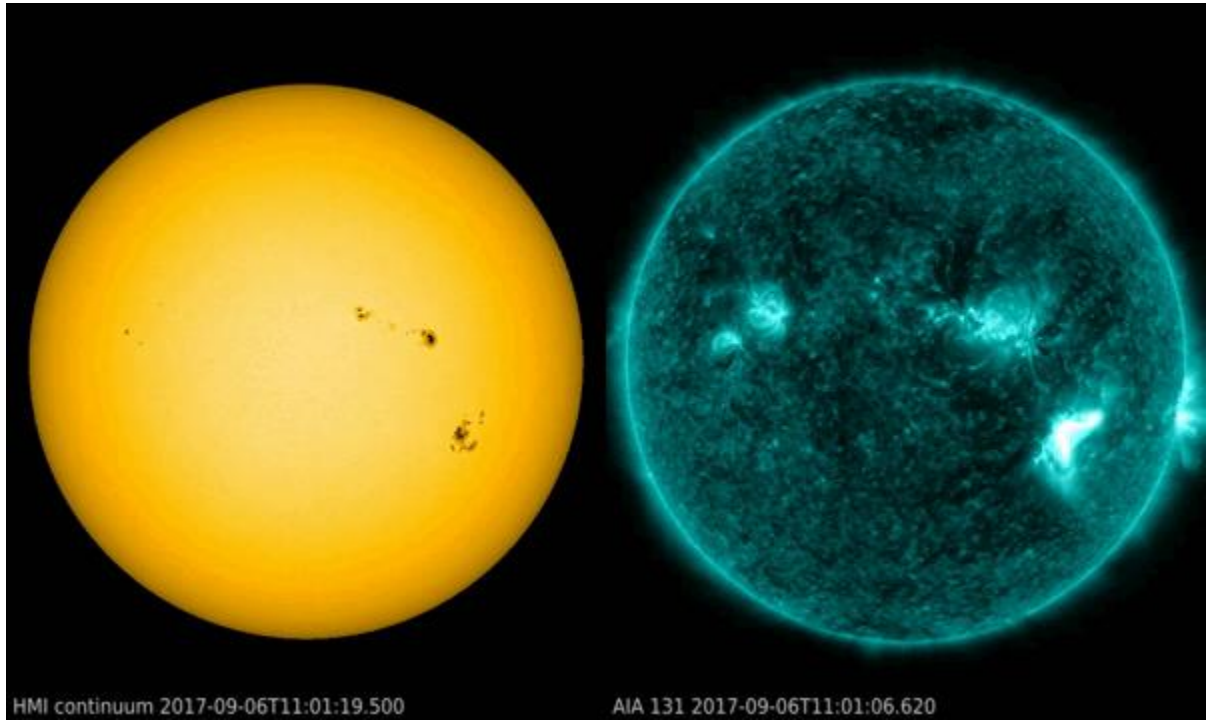
GNSS

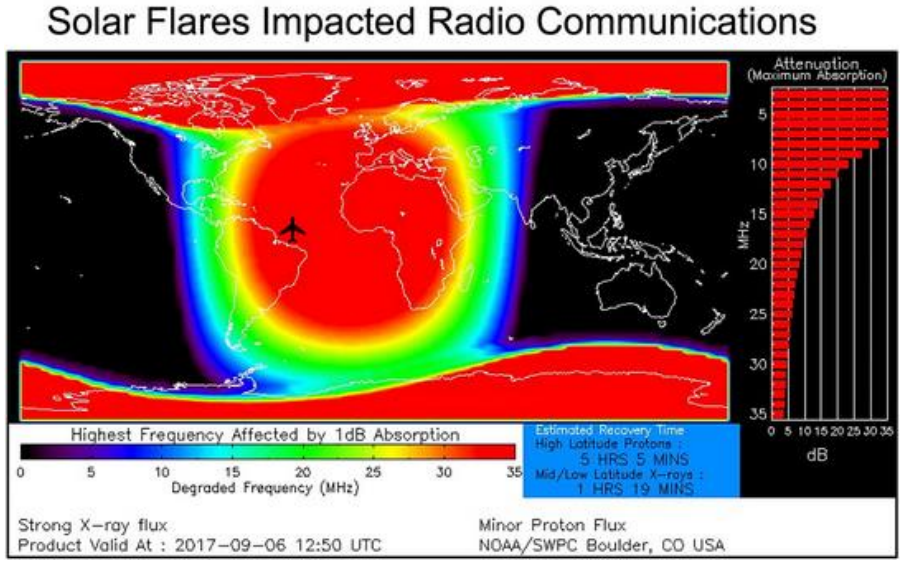
Ground Support

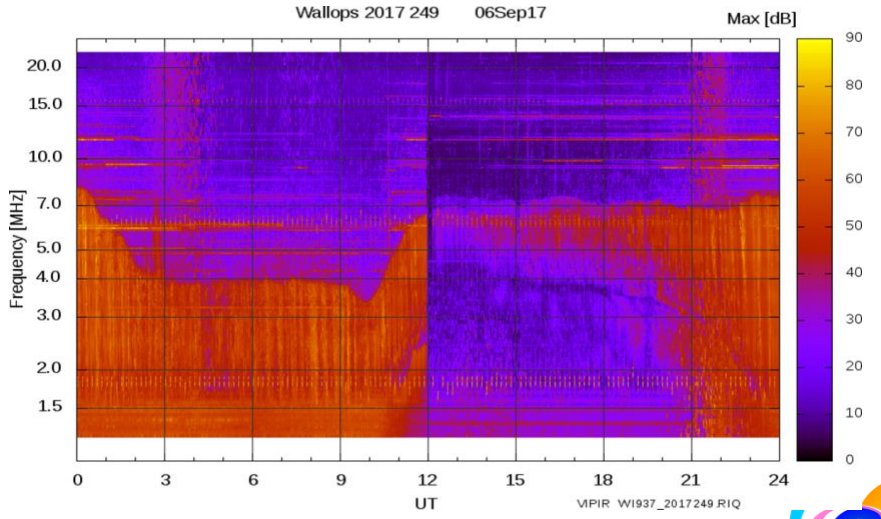
HF Com: High Frequency Communications (3-30 MHz) ; GNSS: Global Navigation Satellite Systems (GPS, Galileo,,…) — — — Currently NOT covered by SWx advisories for ICAO

SWx impacts from solar flares on HF Com

- From EUV and x-rays
  - Short-wave fadeout (SWF)





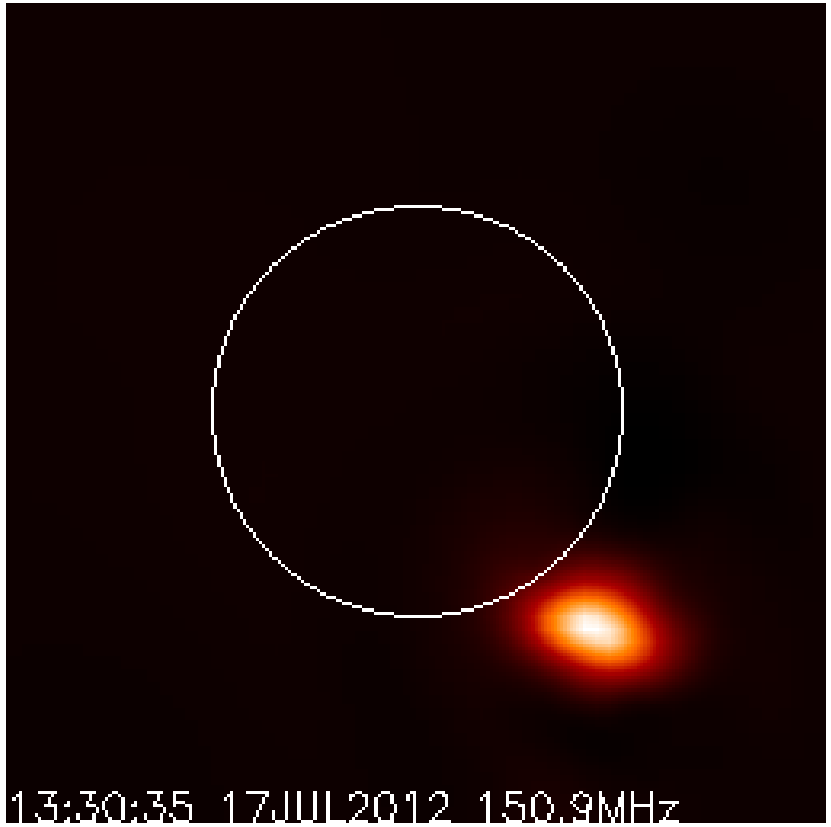


Courtesy of CIRES, Terry Bullett

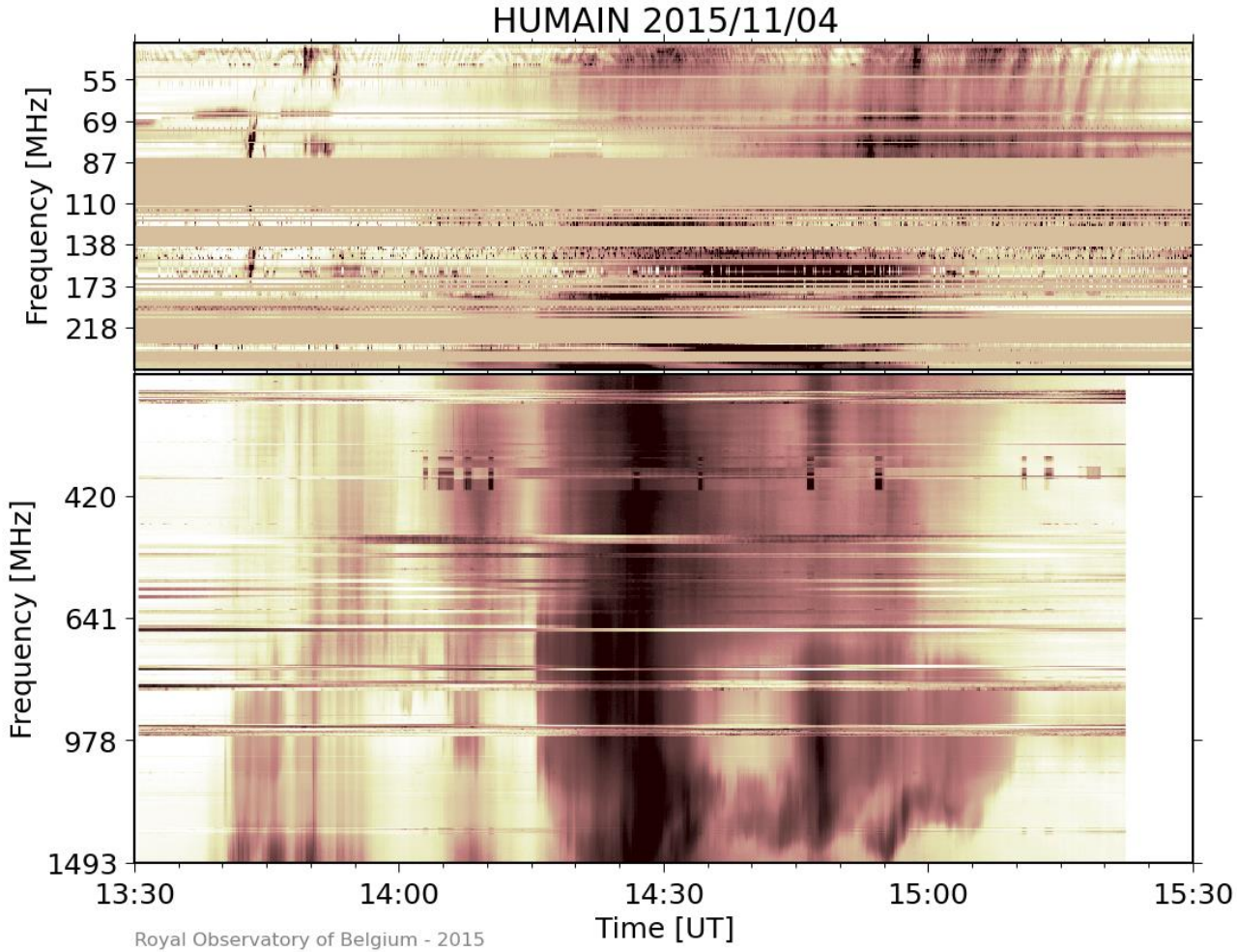
HF Com: High Frequency Communications (3-30 MHz) ; EUV: Extreme Ultraviolet

SWx impacts from solar flares on Ground Suppor

- From radio emission
  - Solar Radio Burst (SRB)



Nançay Radioheliograph

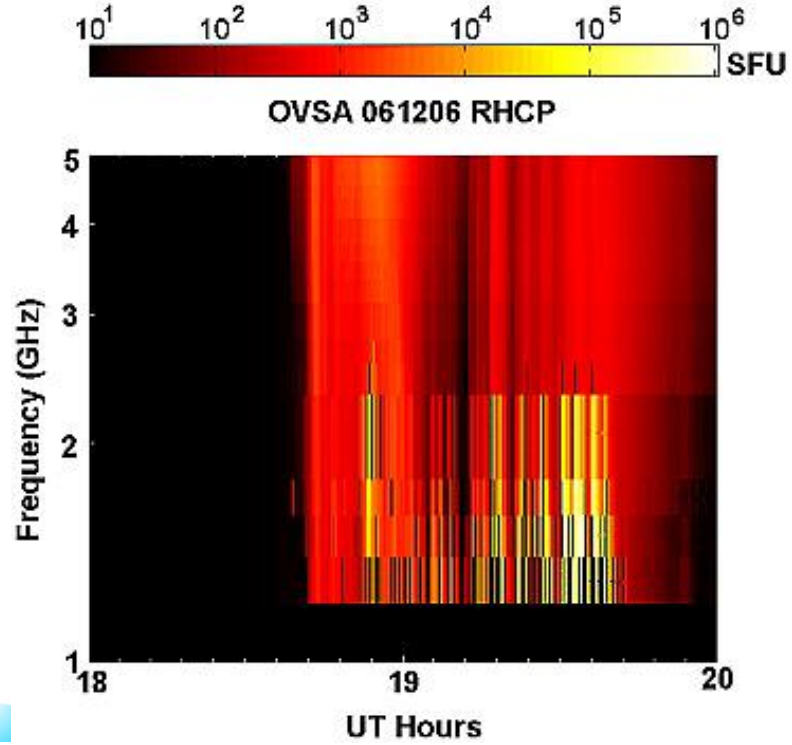


SXR: soft x-rays ; GHz: gigahertz ; MHz: megahertz

Currently NOT covered by SWx advisories for ICAO

SWx impacts from solar flares on GNSS

- From radio emission @ GNSS frequencies
  - Solar radio burst (SRB)
- 6 December 2006



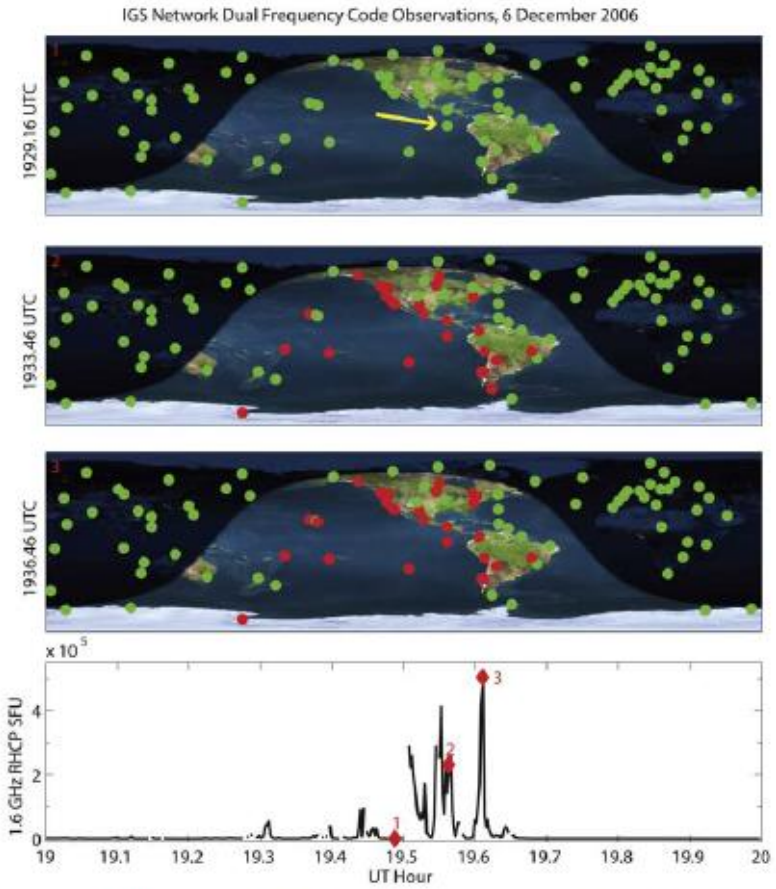


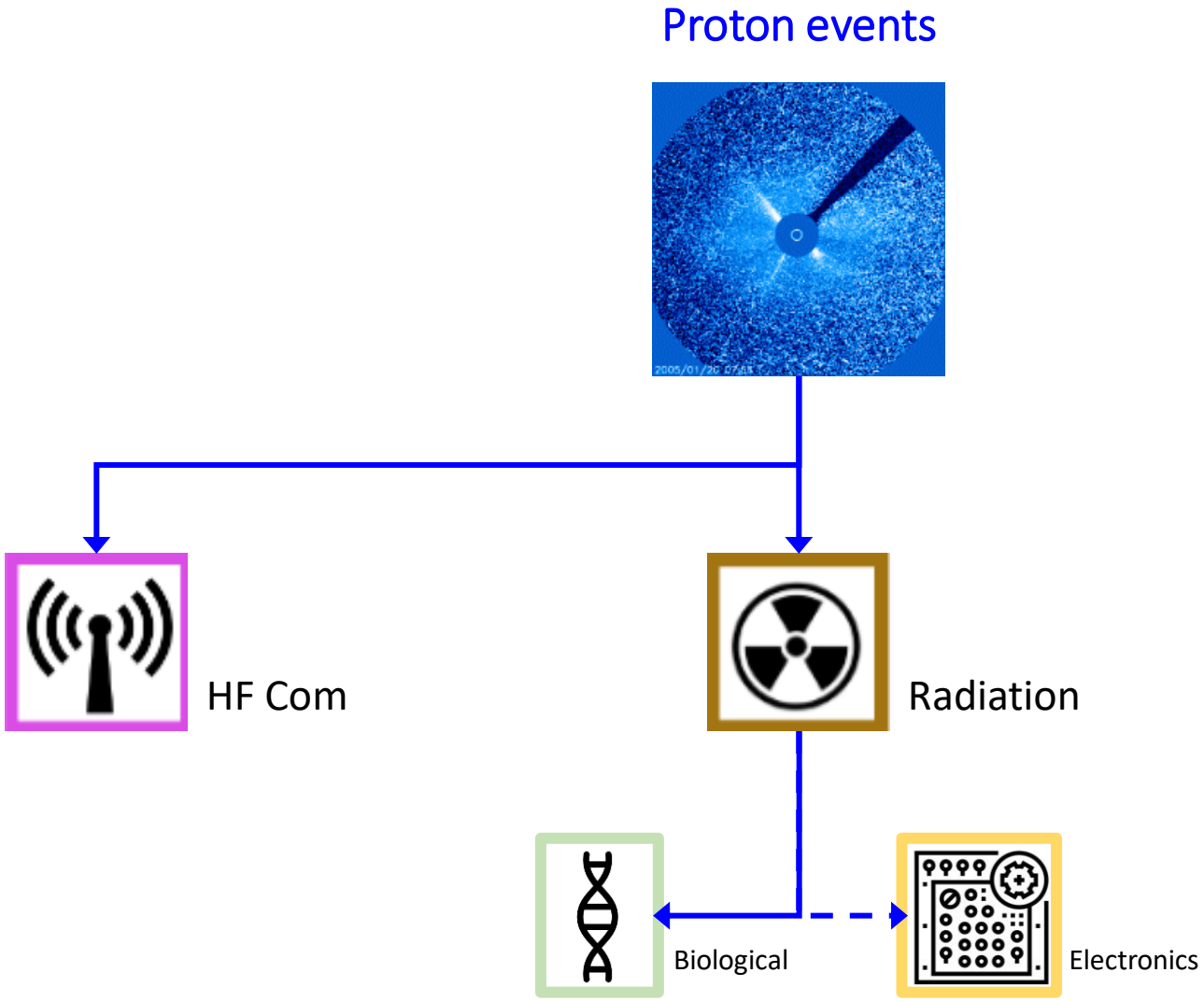
Figure 6. Receivers in the Global GPS Network that were analyzed during the solar radio burst. Green indicates the normal number of satellites being tracked. (fourth panel) During the burst (power at 1.6 GHz), several sunlit receivers tracked fewer than the four satellites needed for a full positioning solution (marked in red). (Image of Earth from the The Living Earth, 1996 and is used here by permission of the publisher. Day/night overlay created using Earth Viewer by J. Walker.)

Credits: Cerruti et al. (2008)

GNSS: Global Navigation Satellite Systems (GPS, Galileo,,…) ; sfu: solar flux units ; GHz: gigahertz ; IGS: International GNSS service

Currently NOT covered by SWx advisories for ICAO

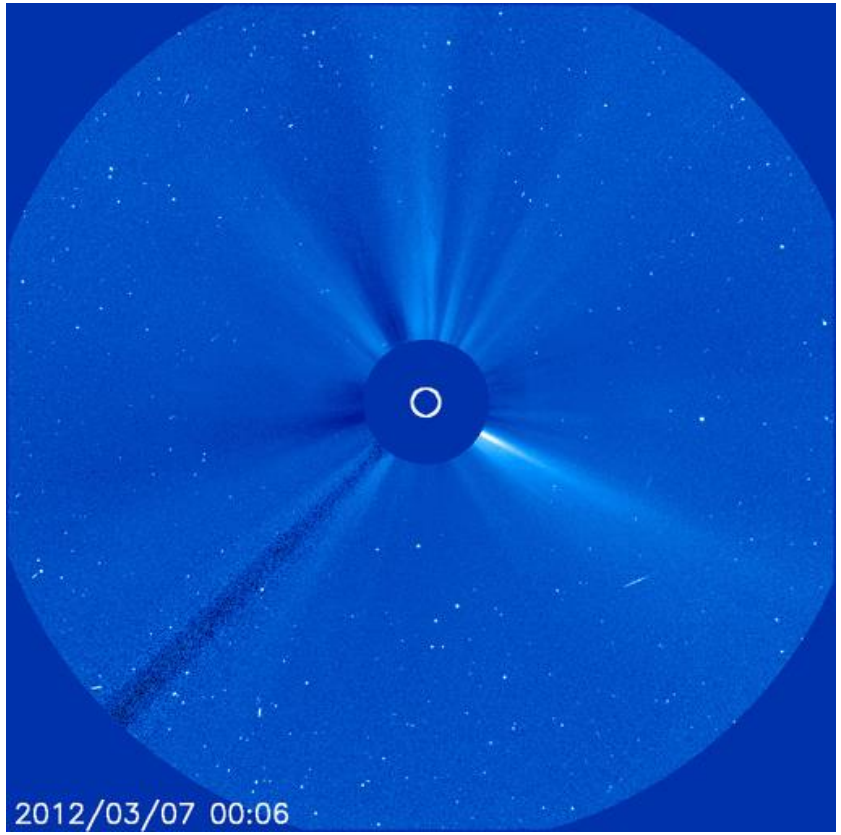
SWx impacts from proton events on aviation

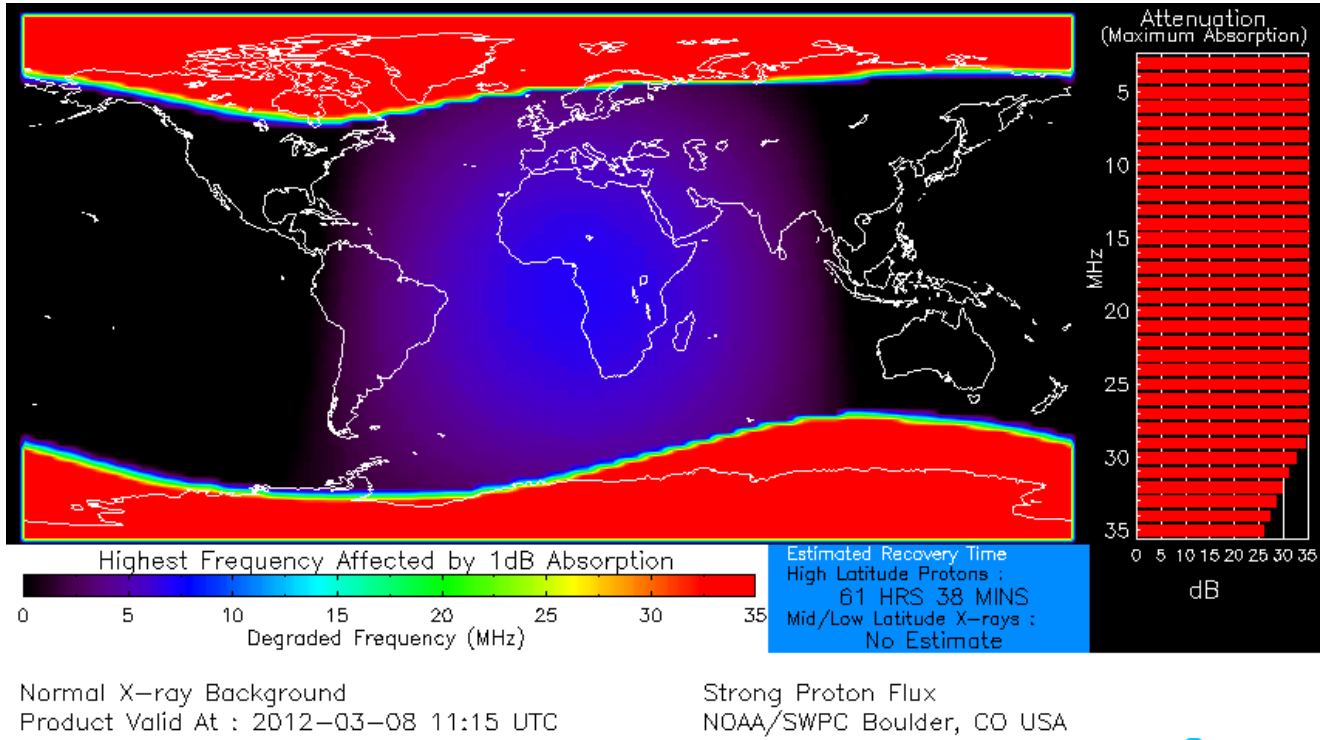


HF Com: High Frequency Communications (3-30 MHz) — — — **Currently NOT covered by SWx advisories for ICAO**

SWx impacts from proton events on HF Com

- Polar Cap Absorption (PCA)
  - From 10 MeV proton flux
  - 7-8 March 2012

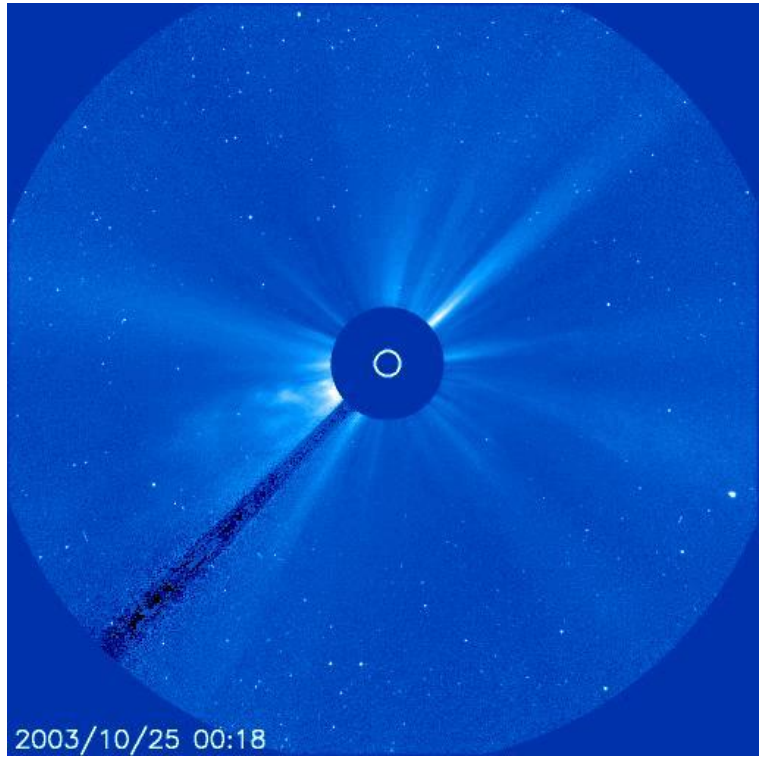


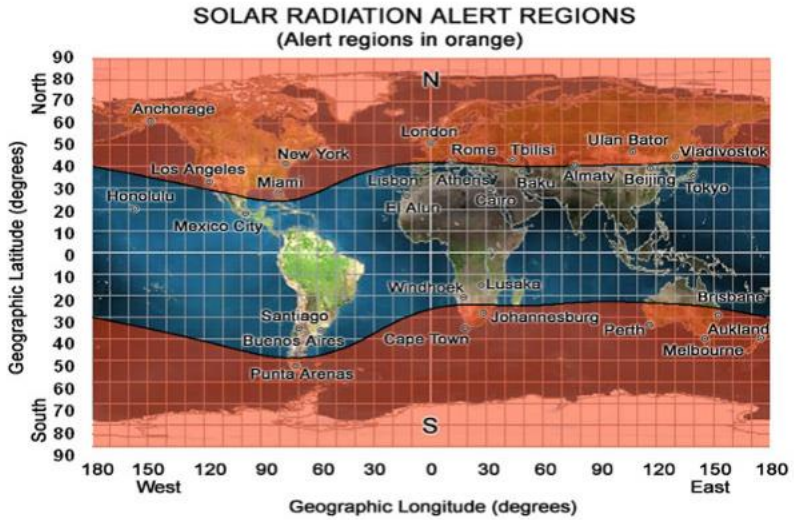


MeV: megaelectronvolt ; MF: magnetic field ; HF Com: High Frequency Communications (3-30 MHz) ; pfu: proton flux units ; dB: decibel

SWx impacts from proton events : Biological

- Energetic particles (GCR ; SEP)
  - Can damage DNA and cause cancer & reproductive problems
- Halloween storms October 2003





Space Weather Message Code: ALTPAV Issue Time: 2003 Oct 28 2123 UTC
ALERT: Solar Radiation Alert at Flight Altitudes
Conditions Began: 2003 Oct 28 2113 UTC

Comment:
Satellite measurements indicate unusually high levels of ionizing radiation, coming from the sun. This may lead to excessive radiation doses to air travelers at Corrected Geomagnetic (CGM) Latitudes above 35 degrees north, or south.

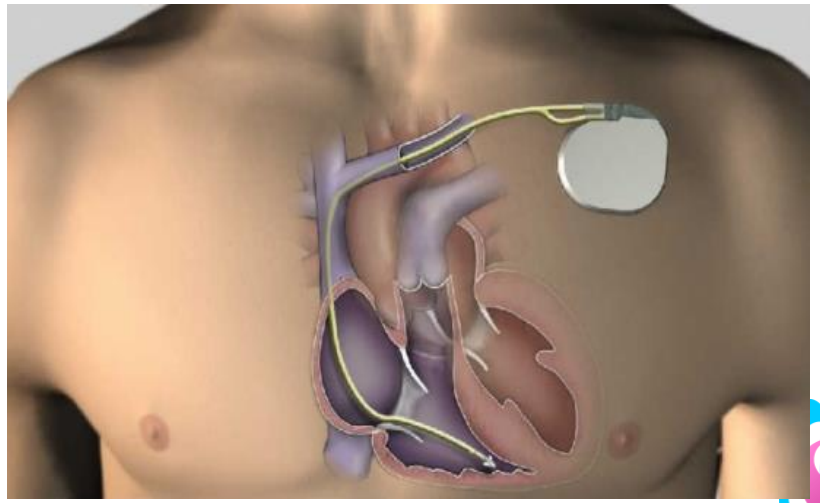
Avoiding excessive radiation exposure during pregnancy is particularly important.

Reducing flight altitude may significantly reduce flight doses. Available data indicates that lowering flight altitude from 40,000 feet to 36,000 feet should result in about a 30 percent reduction in dose rate. A lowering of latitude may also reduce flight doses but the degree is uncertain. Any changes in flight plan should be preceded by appropriate clearance.

GLE: Ground Level Enhancement ; µSv/h: microsievert per hour ; mSv: millisievert ; FL: Flight Level (100 feet) ; pfu: proton flux units ; GCR: Galactic Cosmic rays ; SEP: Solar Energetic Particles

SWx impacts from proton events : Electronics

- Single Event Effects (SEE)
  - Direct hit of an electronic component by an energetic particle (GCR, SEP) resulting in an anomaly
    - Phantom commands, attitude control systems, satellite failure,…
- Ground Level Enhancement (GLE)
  - Sharp increase #neutrons @ ground
  - Main source
    - Strong SEPs ~500 MeV per nucleon
      - => RARE!! (about 1 per year)
  - Impacts
    - Computer glitches, servers,…
    - Pacemakers, defibrillators, and other medical devices,…
    - Difficult to prove connection!

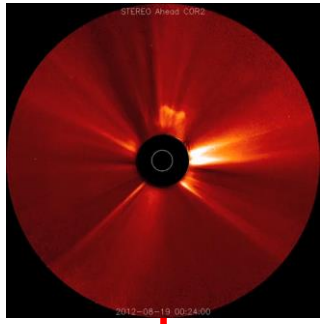


SEP: Solar Energetic Particles ; GCR: Galactic Cosmic Rays ; MeV: megaelectronvolt

Currently NOT covered by SWx advisories for ICAO

SWx impacts on aviation

Coronal Mass Ejections



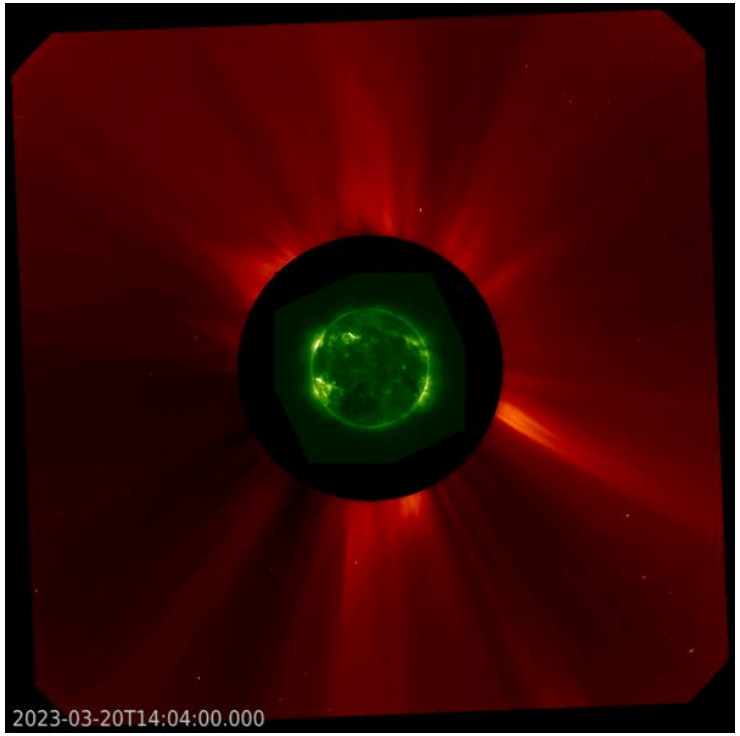
HF Com

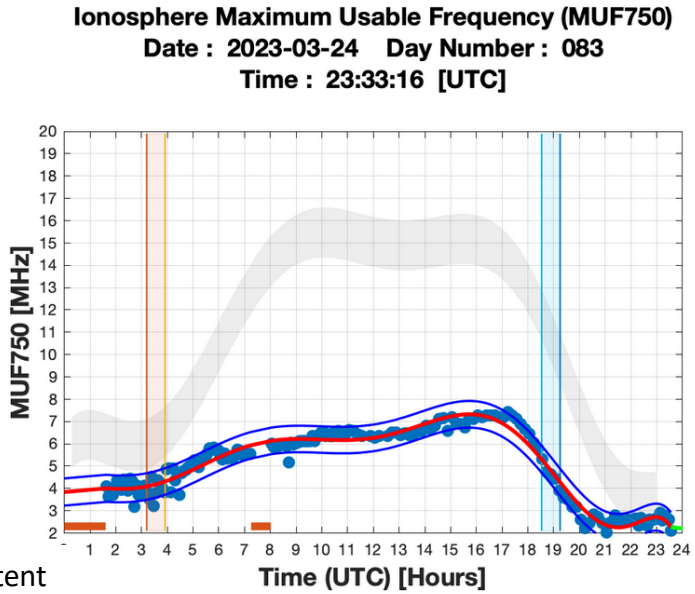
GNSS

HF Com: High Frequency Communications (3-30 MHz) ; GNSS: Global Navigation Satellite Systems (GPS, Galileo,,…)

SWx impacts from ICMEs on HF Com

- Auroral Absorption (AA)
  - Aurora affecting lower ionosphere
- Post-Storm Depression (PSD)
  - Negative phase ionospheric storm

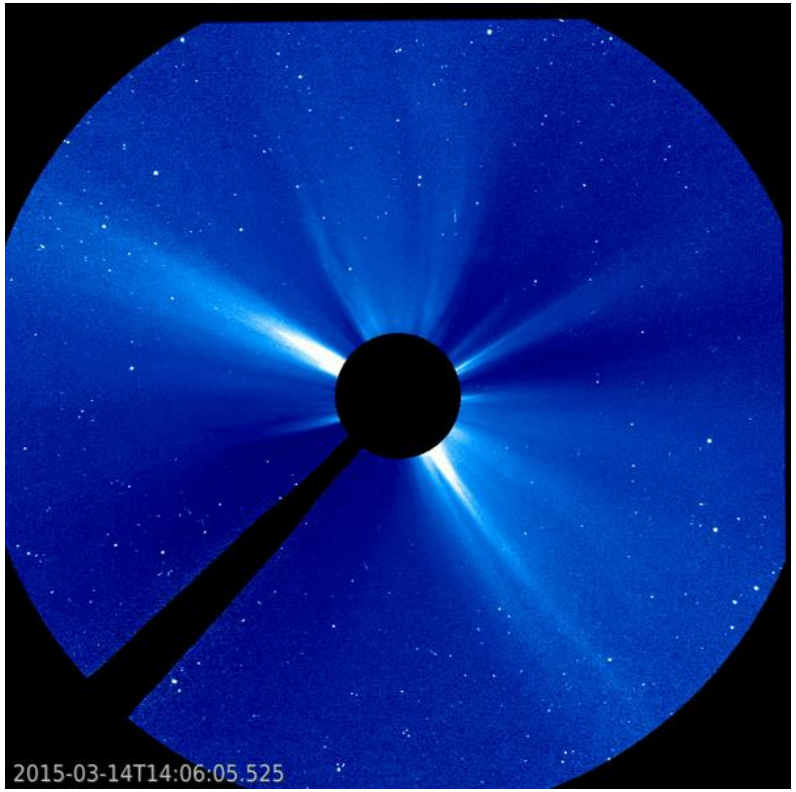


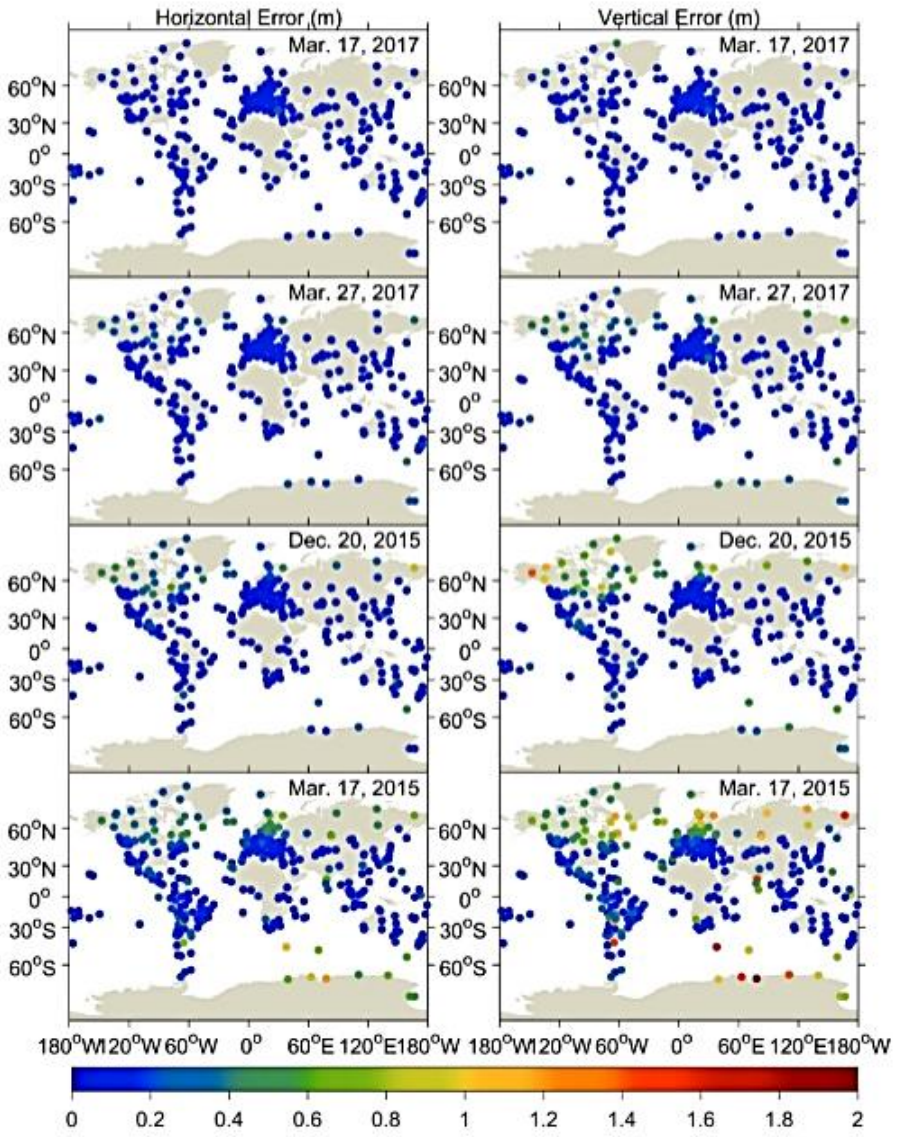


HF Com: High Frequency Communications (3-30 MHz) ; ICME: Interplanetary coronal mass ejection ; TEC: Total Electron Content

SWx impacts from ICMEs on GNSS

- Ionospheric storm
  - VTEC based



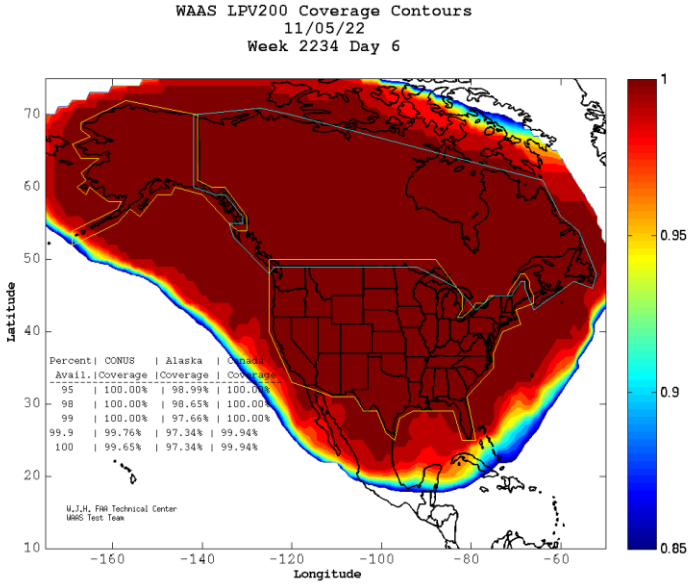


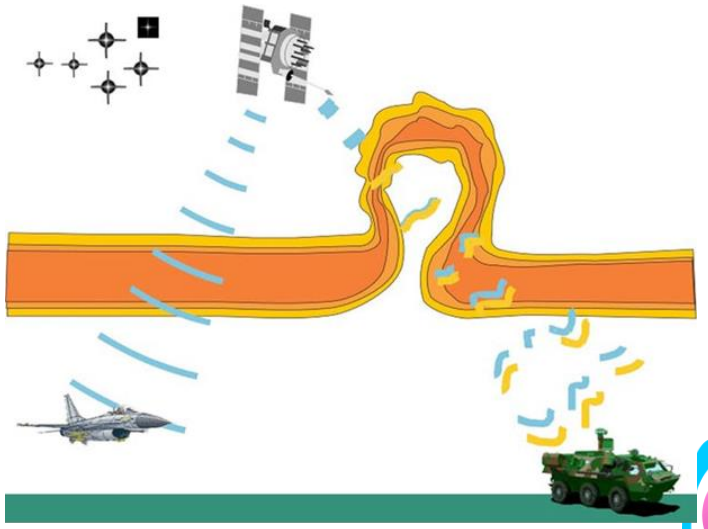
Credits: Luo et al. (2018)

DF: Dual Frequency ; ICME: Interplanetary coronal mass ejection ; VTEC: Vertical Total Electron Content ; nT: nanotesla ; Dst: Disturbance storm time ; TECu: TEC units

SWx impacts from ICMEs on GNSS

- Ionospheric scintillations
  - Small-scale density variations in ionosphere
    - Affect GNSS signals
  - 7 November 2022
    - Kp = 5o ; Dst = -89 nT
  - Also in February, March, April and November 2023
  - Reminder
    - Also when geomagnetic activity is quite low
      - Battle of Takur Ghar! (2002)

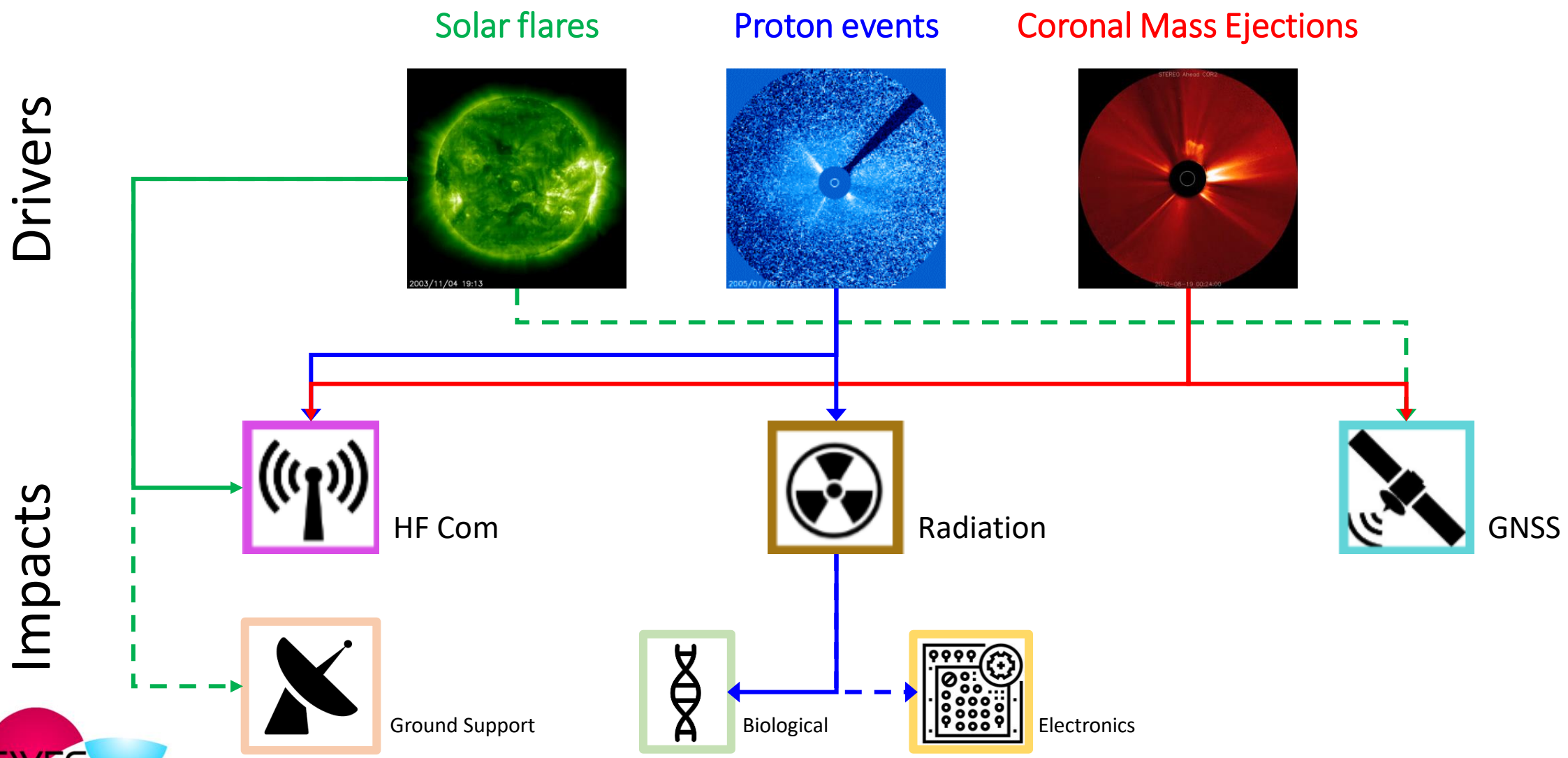




GNSS: Global Navigation Satellite Systems (GPS, Galileo,,…) ; ICME: Interplanetary coronal mass ejection ; nT: nanotesla ; Dst: Disturbance storm time ; dB: decibel

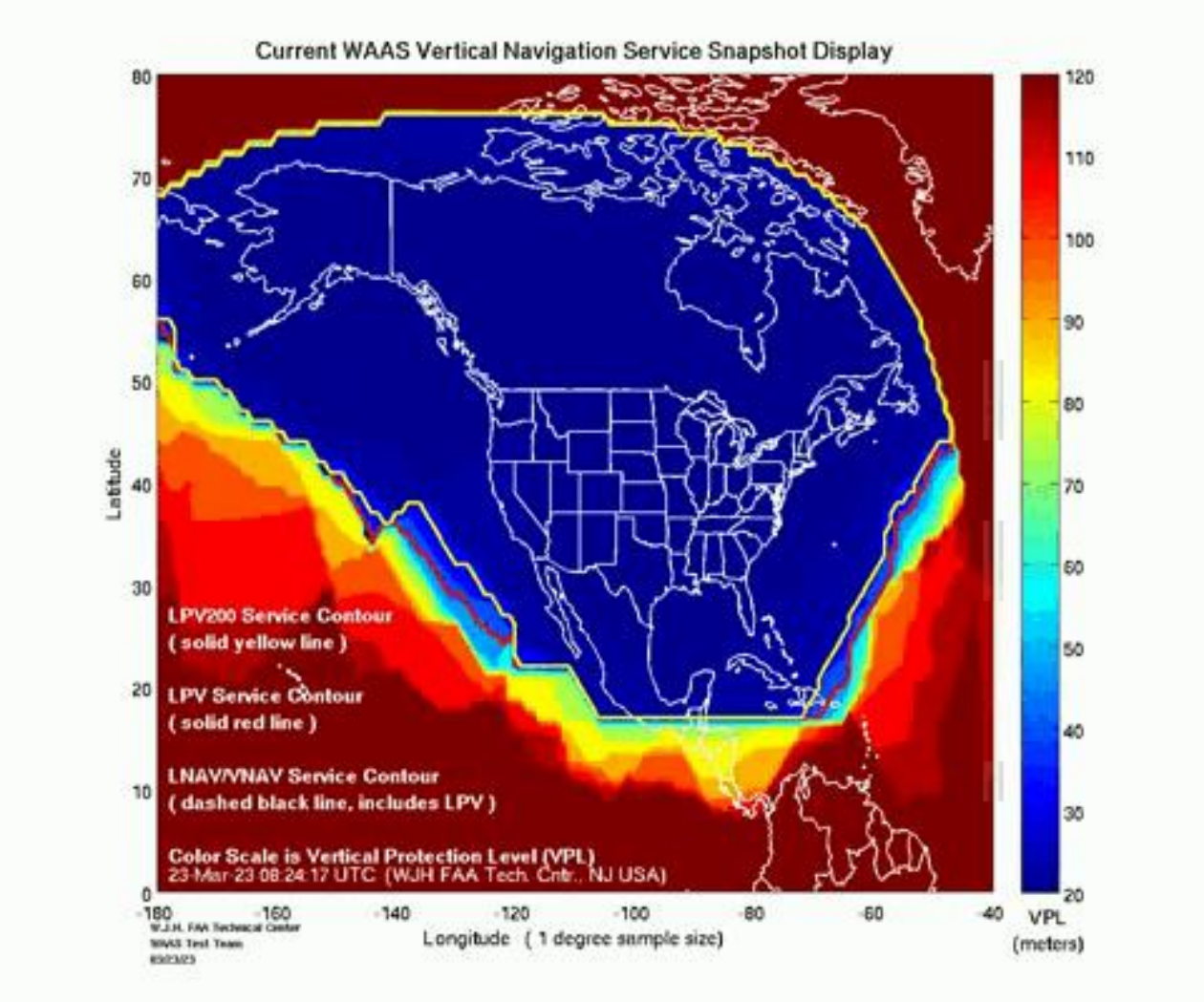
Credits: US Air Force Research Laboratory

SWx impacts on aviation



HF Com: High Frequency Communications (3-30 MHz) ; GNSS: Global Navigation Satellite Systems (GPS, Galileo,,…) **Currently NOT covered by SWx advisories for ICAO**

Questions?



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