Space Weather Service Operations: Lab activity

Y. Maneva (yana.maneva@oma.be), P. Vanlommel
and the STCE's SWOP team

Royal Observatory of Belgium

Solar Influences Data analysis Centre
www.sidc.be

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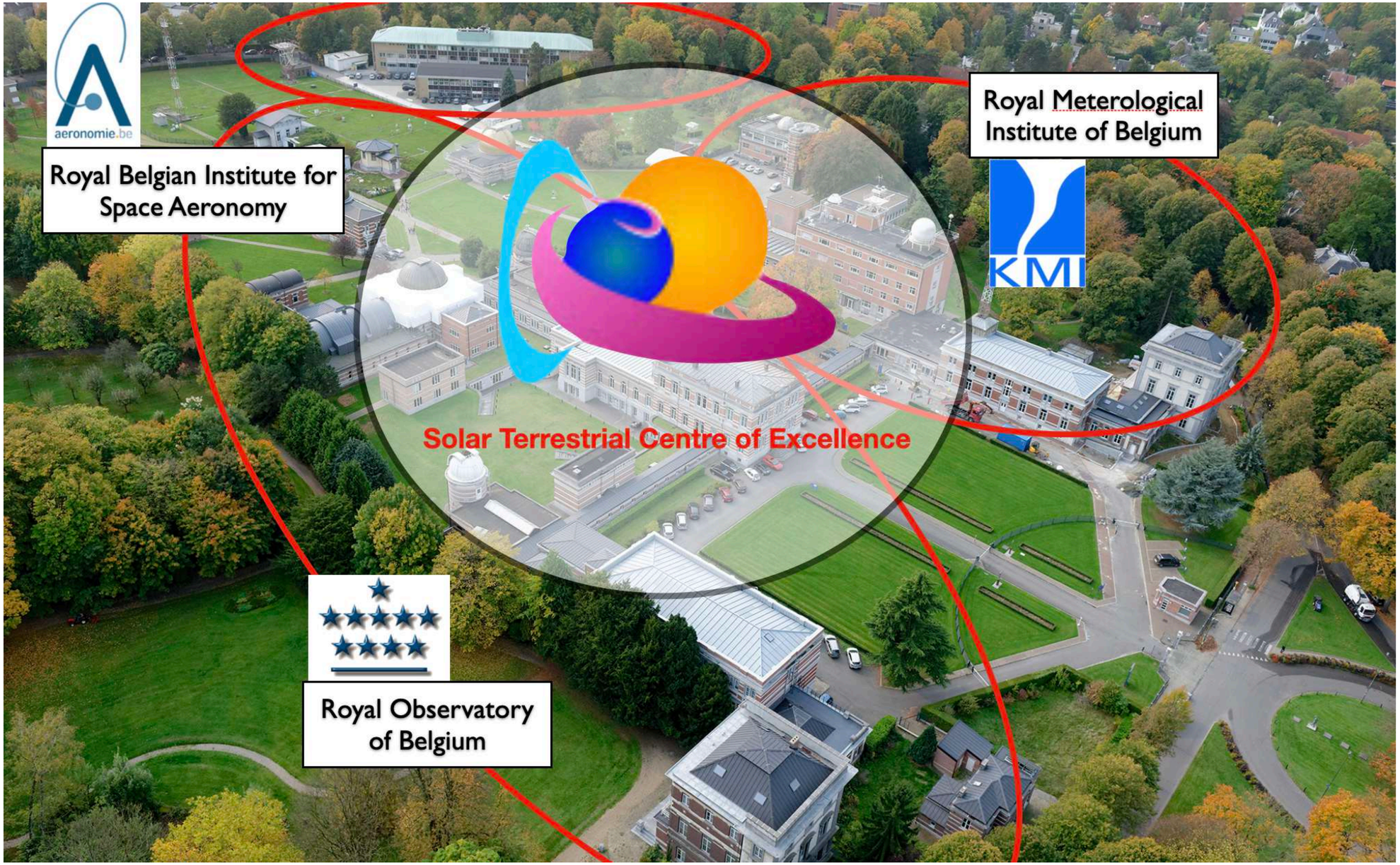
Space Weather Services at STCE/ROB



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USET sunspot observations

- 16 cm Grubb refracting telescope in ops since 1940 (drawings)

- White-light
- H-alhpa
- Call-K

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Space Weather Services on sidc.be

Supporting Observations

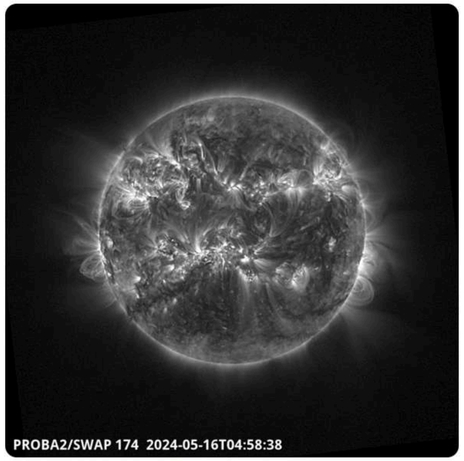
Royal Observatory *of* Belgium

Solar Influences Data Analysis Center

Home | Observations | Services | Research | Activities

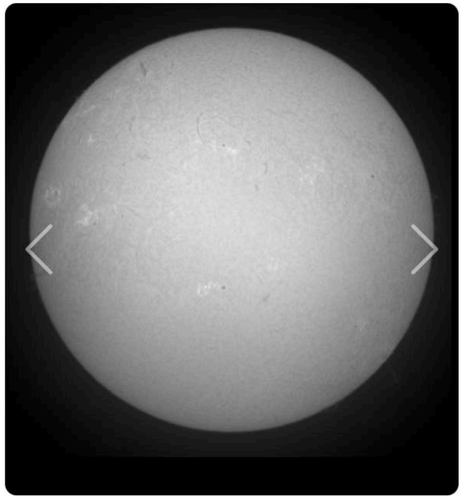
Observations

Space Based Imaging



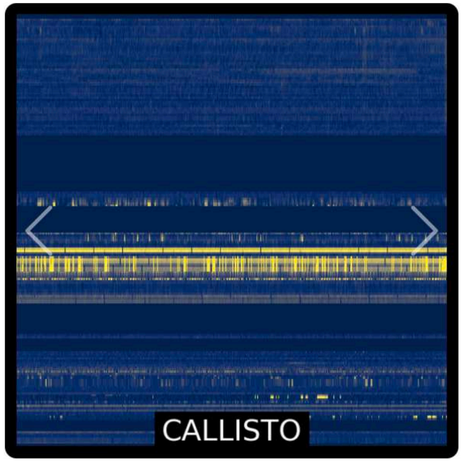
More data: SWAP, EUI

Ground Based Imaging



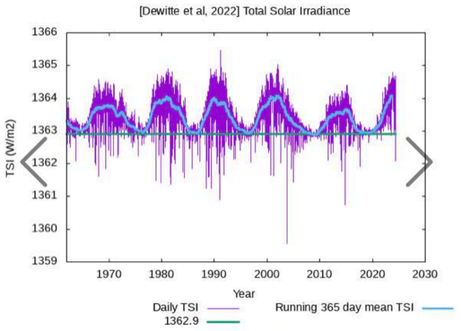
More: H-α, WL, Ca-IIK, Drawings

Ground Based Radio



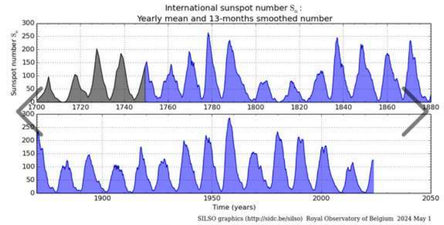
More: ARCAS+HSRS, CALLISTO

Space Based Timelines



More data: LYRA, TSI

WDC Sunspot Index



More data: SILSO

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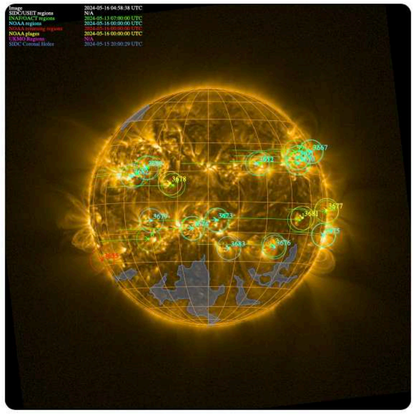
Space Weather Services

Detections

Solardemon
2024-05-16 07:54 B2 flare

CACTus
2024-05-15 16:24 436km/s

Solar Map



Latest Alerts

Presto 2024-05-15

An X3.0 flare was registered by GOES-16 as peaked today at 14:38 UTC. The source was an

Flaremail 2024-05-15

A class X2.9 solar X-ray flare occurred on 2024/05/15 with peak time 14:38UT

CACTus Halo 2024-05-16

A halo or partial-halo CME was detected with the following characteristics: t0 | dt0|

Forecasts

Flare:	M-class flares (≥50%)
Protons:	Event in progress (>10 MeV)
Geomagnetic:	Active conditions (A>=20 or K=4)
All quiet:	False
Provisional SSN:	212

Solar Activity

URSIgram 2024-05-15

Solar flaring activity was high during the last 24 hours with three X-class flares detected during the last 24 hours. The brightest flare was a long-lasting X8.7 emited from NOAA Active Region (AR) 3664 (magnetic configuration Beta-Gamma-Delta, Catania sunspot group 86) yesterday at 16:51 UTC. The same AR produced the rest of the X-class flare activity, namely an X3.4 that peaked today at

Solar Wind

URSIgram 2024-05-15

Geomagnetic conditions were both globally and locally unsettled to quiet (NOAA Kp 3- to 1 and K BEL 3 to 2) during the past 24 hours. In the next 24 hours they are expected to reach active levels as a result of the expected arrival of a Coronal Mass Ejection (CME). The Solar Wind (SW) conditions are gradually returning to the slow SW regime during the past 24 hours. The SW speed dropped from

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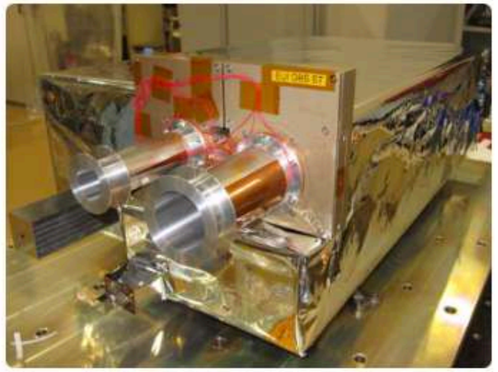
Ground Observations

The SIDC monitors the level of solar activity from the photosphere to the corona with ground based instruments located in Uccle and Humain.

Read more

Space Instruments



To avoid the disturbing or blocking effect of the Earth atmosphere, EUV observations of the solar corona need to be made from space...

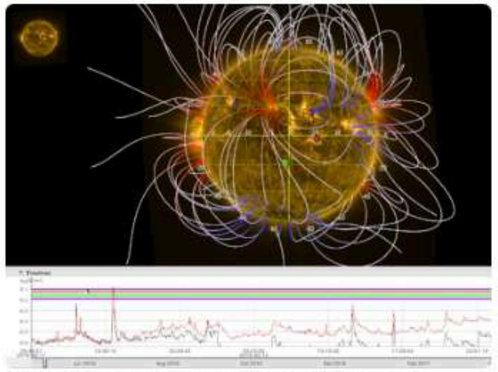
Read more

Space Weather & Climate

We monitor and forecast solar variability to provide information services to society and industry about the influence of space weather and climate.

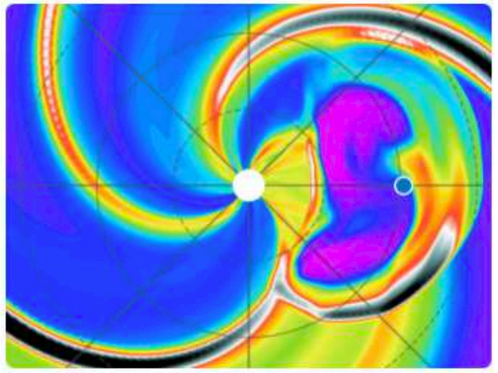
Read more

Data Processing & Distribution



Data processing is necessary to extract

Modeling



Modelling of Solar phenomena allows scientists to test theories and to predict Space Weather phenomena and their impact

Supporting Research

The SIDC shares and expands its expertise through interaction with both upcoming and experienced researchers.

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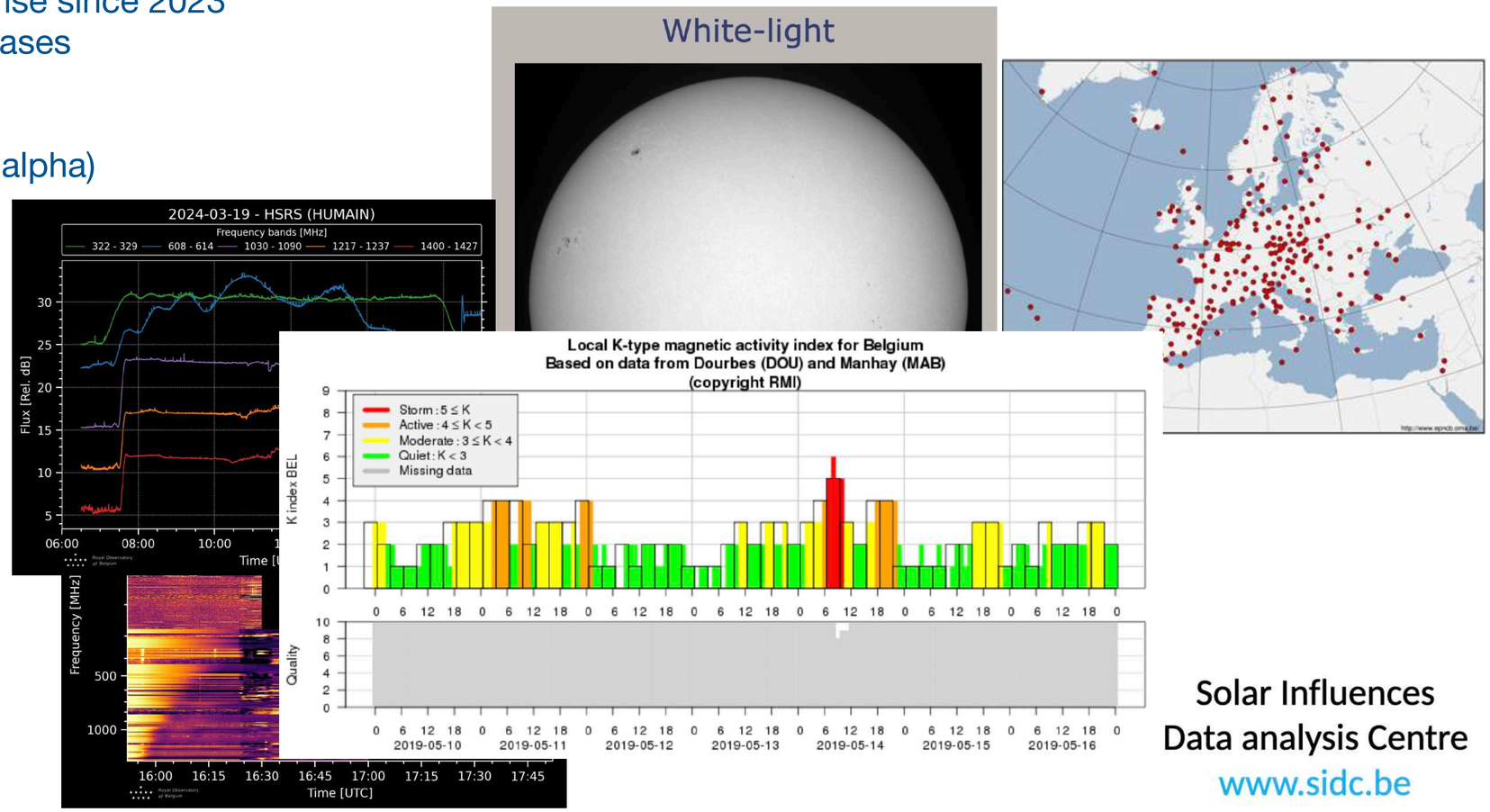
SWOP services at STCE Belgium

- SILSO WDC since 1981
- daily SW bulletins and warnings since 2000
- ESA/SWESNET: SSCC, S-ESC 2010
- SWEC since 2017
- SW services to civil Aviation (PECASUS) since 2019
- Agreement with Belgian Ministry of Defense since 2023
- STCE Trainings, Newsletter & News Releases

RWC Belgium (24 years)

Solar Influences Data Analysis Center

- Existing Assets for SW Services:
  - USET observations (white light, Ca, H-alpha)
  - Humain radio data
  - PROBA 2
  - PROBA 3
  - Solar Orbiter (EUI)
  - Vigil
  - Solar C
  - Belgium K indices: Dourbes, Manhay
  - Dourbes ionosonde
  - GNSS network
  - NM Dourbes



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Lab work Outline

PART 1

What is Space Weather (SWX) - summary of the week
- Exercise on basic terminology

PART 2

Operational Space Weather Tools
- Exercise on Space Weather Impacts reporting

PART 3

Space Weather Service to Aviation and Operational Challenges
- Exercise on sending out Advisories (Petra)

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PART 1: What is Space Weather?

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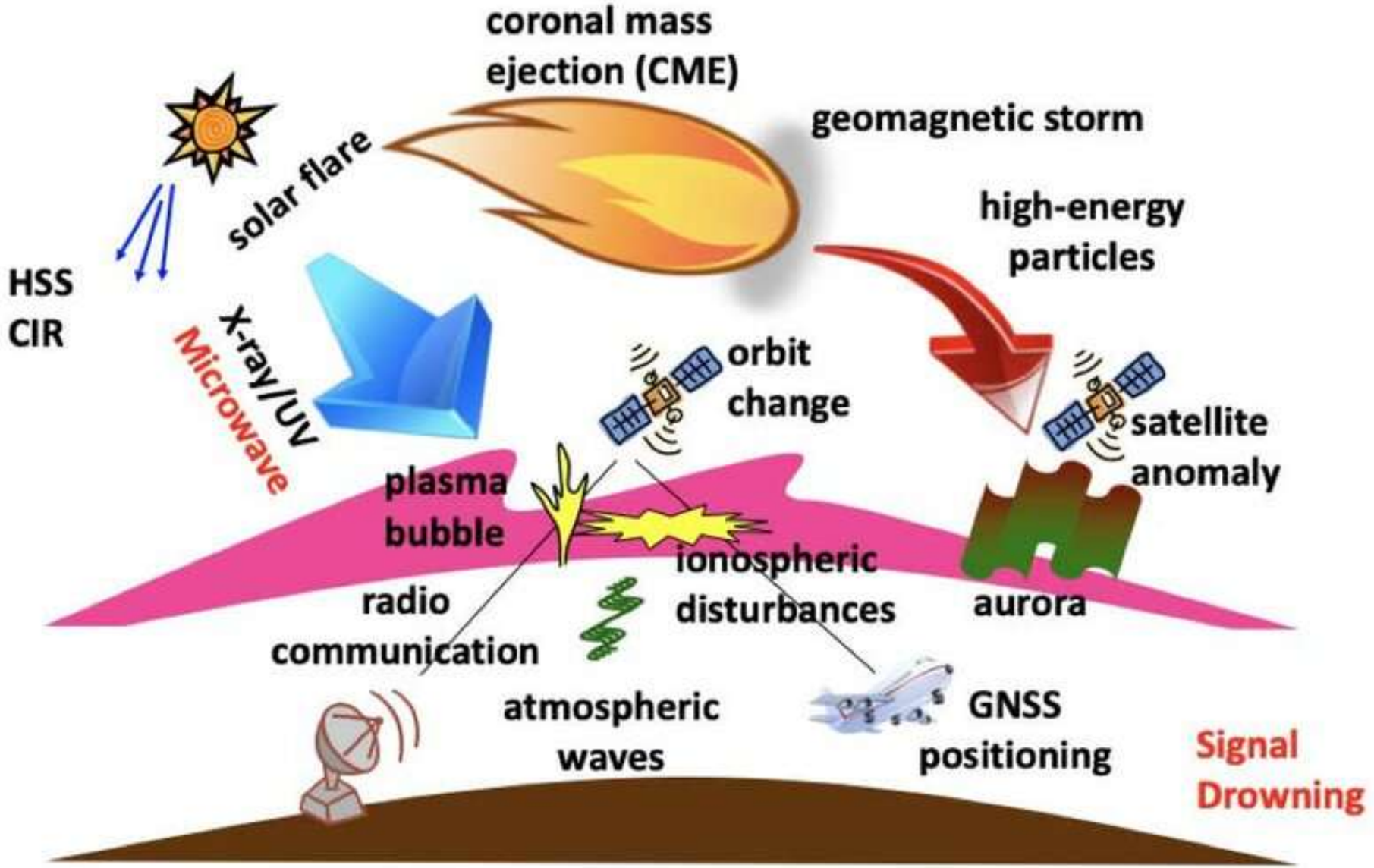
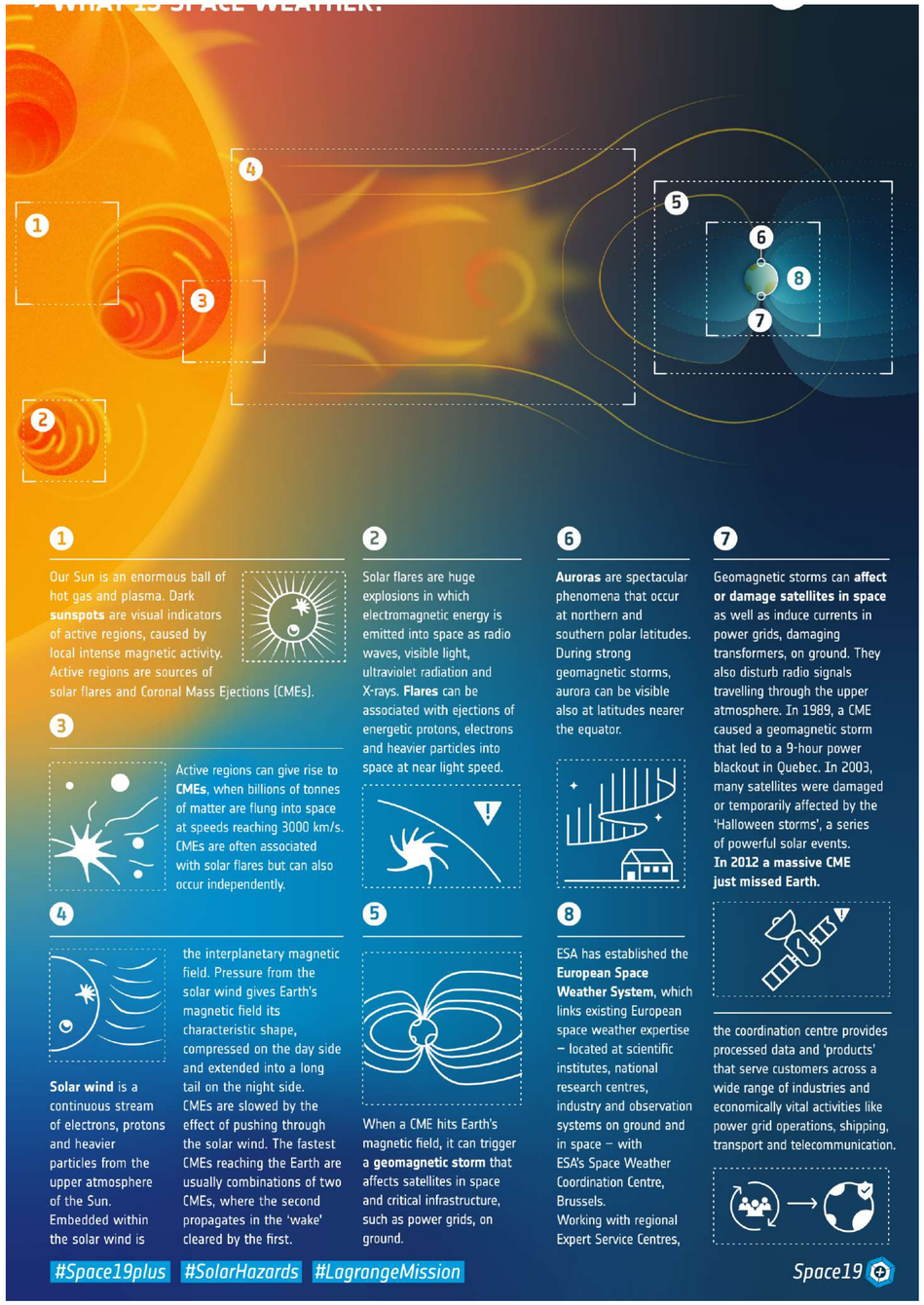
Space Weather Kitchen



SCOSTEP/PRESTO

ESA's SPACE WEATHER DEFINITION



DRIVERS:

SUN
- CMEs (& SEPs)
- Flares (& SEPs)
- CHs (CIR, HSS)

Others
- GCRs
- Meteorites,
- Asteroids
- Commets
- Space junk

AREA:

- Interplanetary space
- Magnetosphere
- Exosphere
- Ionosphere
- Atmosphere
- Ground

IMPACTS:

- Geo storms (K, Kp)
- Radiation storms
- Radio Blackouts
- Loss of Lock
- AS/PS
- Deviations in VTEC
- PSD
- PCA
- Auroral Absorption
- Radiation at FLs (cabin crew safety)
- GLEs
- Spacecraft orbit
- Satellite drag
- Electronics (SEU, …)
- Solar Panels
- Astronauts safety
- Power grids
- Long railways
- Telecom cables
- …

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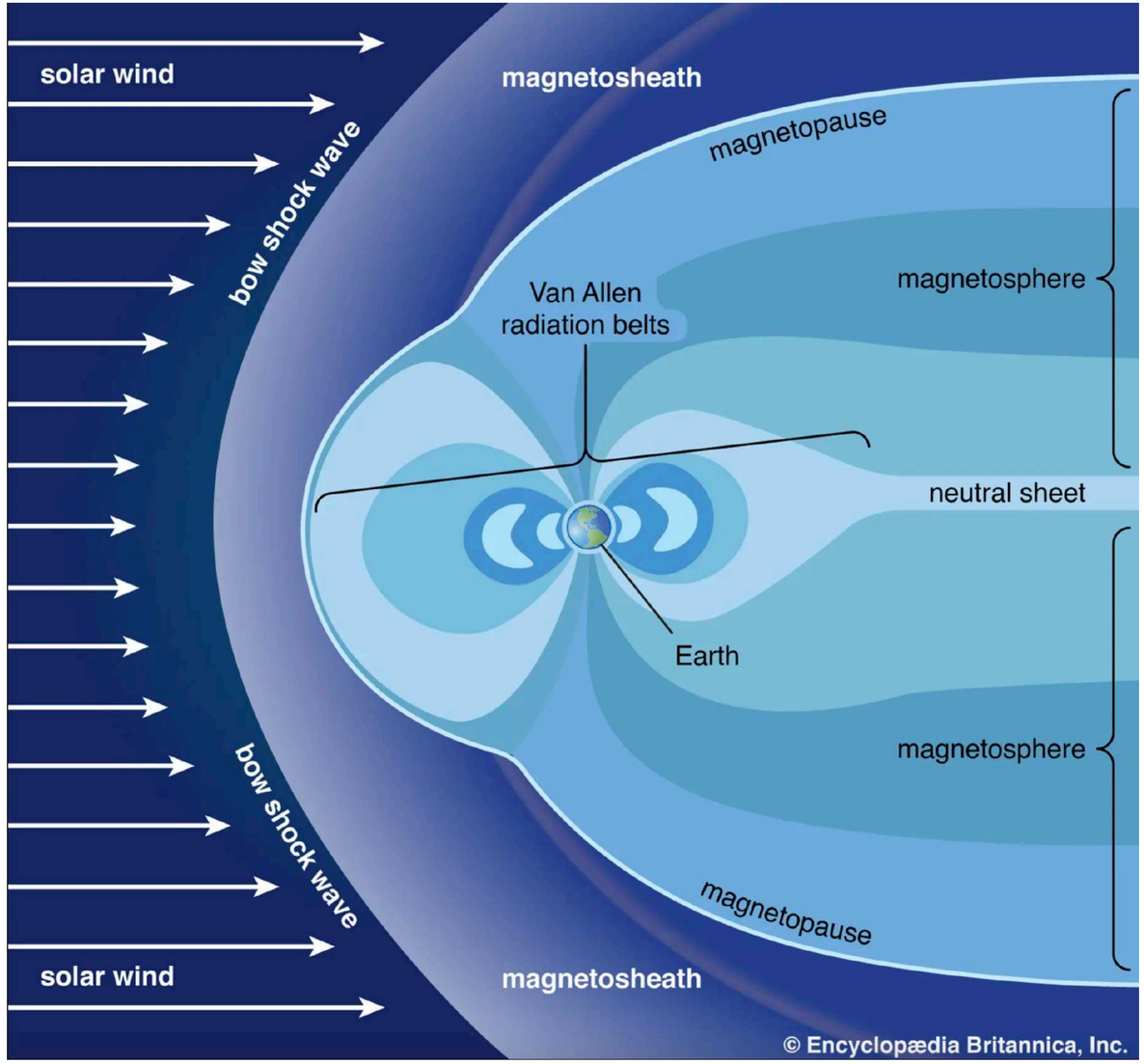
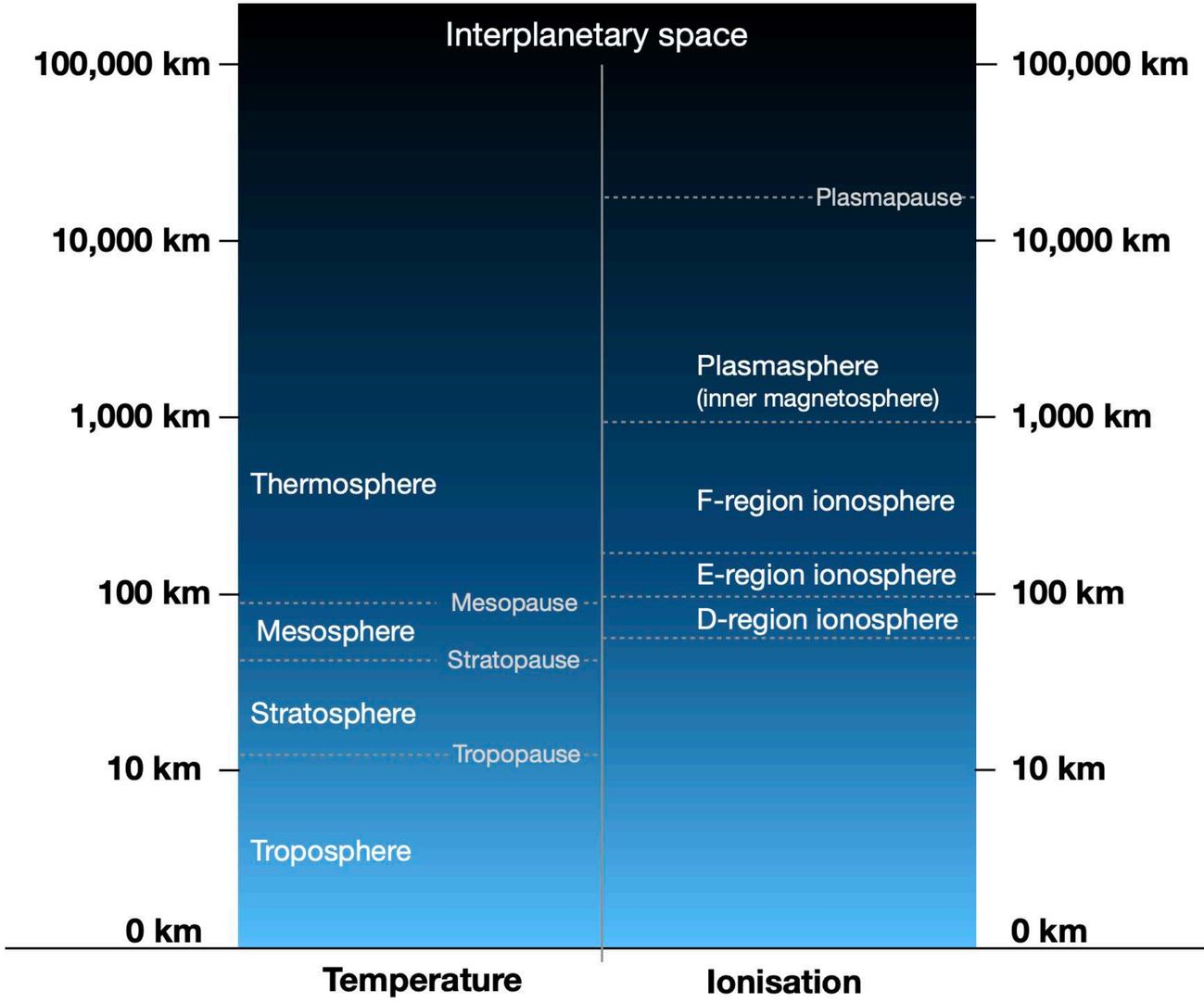
Space Weather Impact Area





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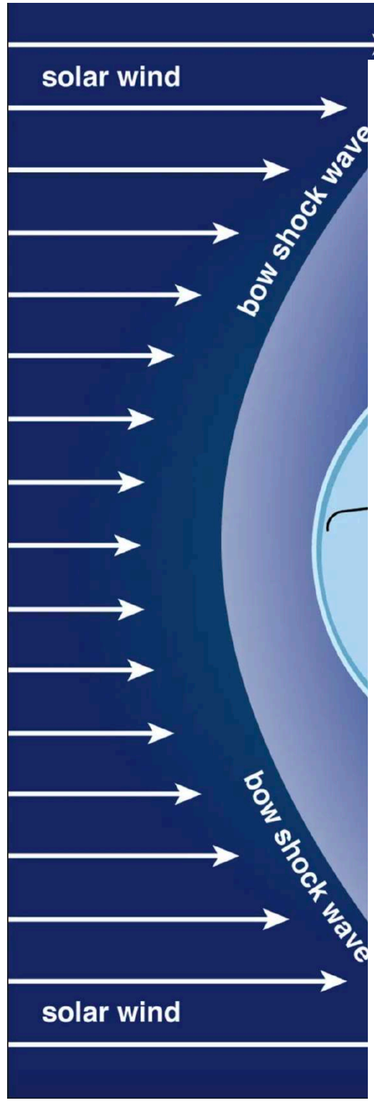
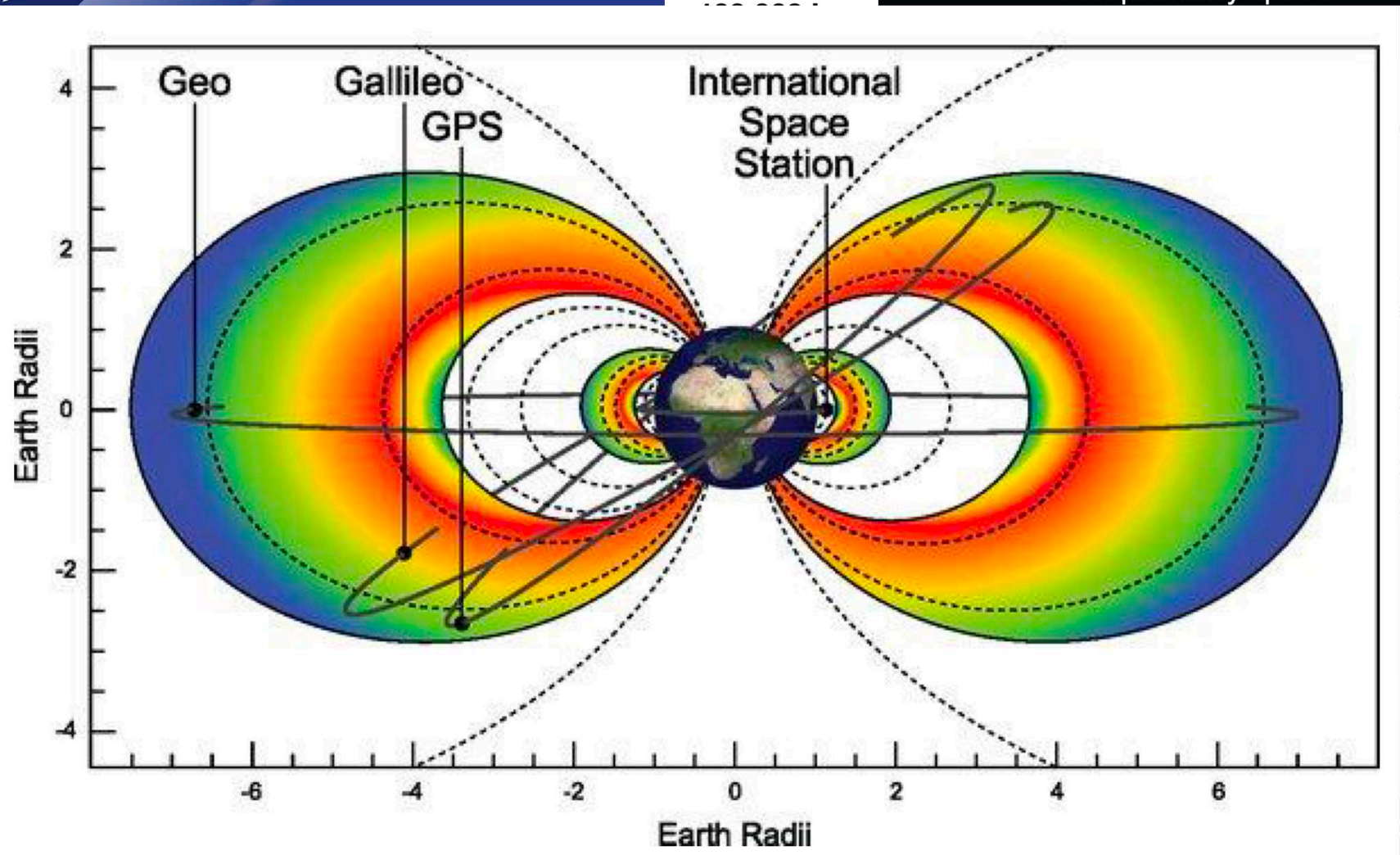
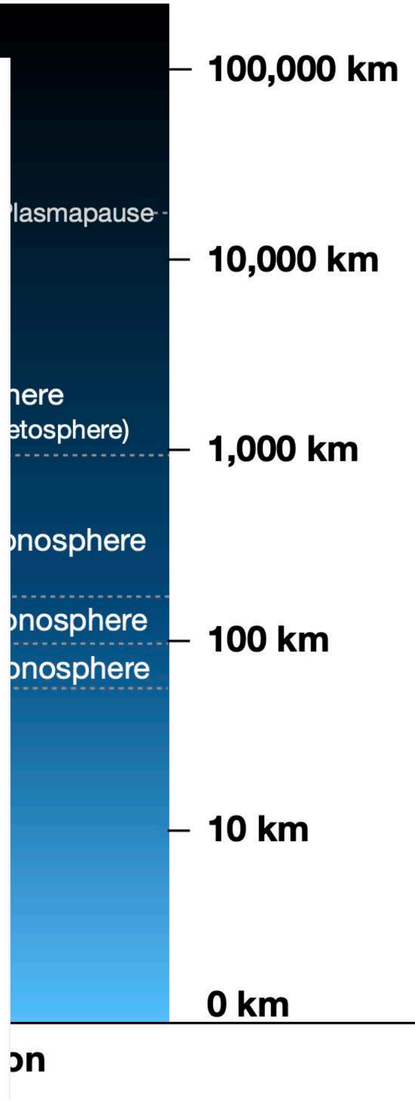
Space Weather Impact Area







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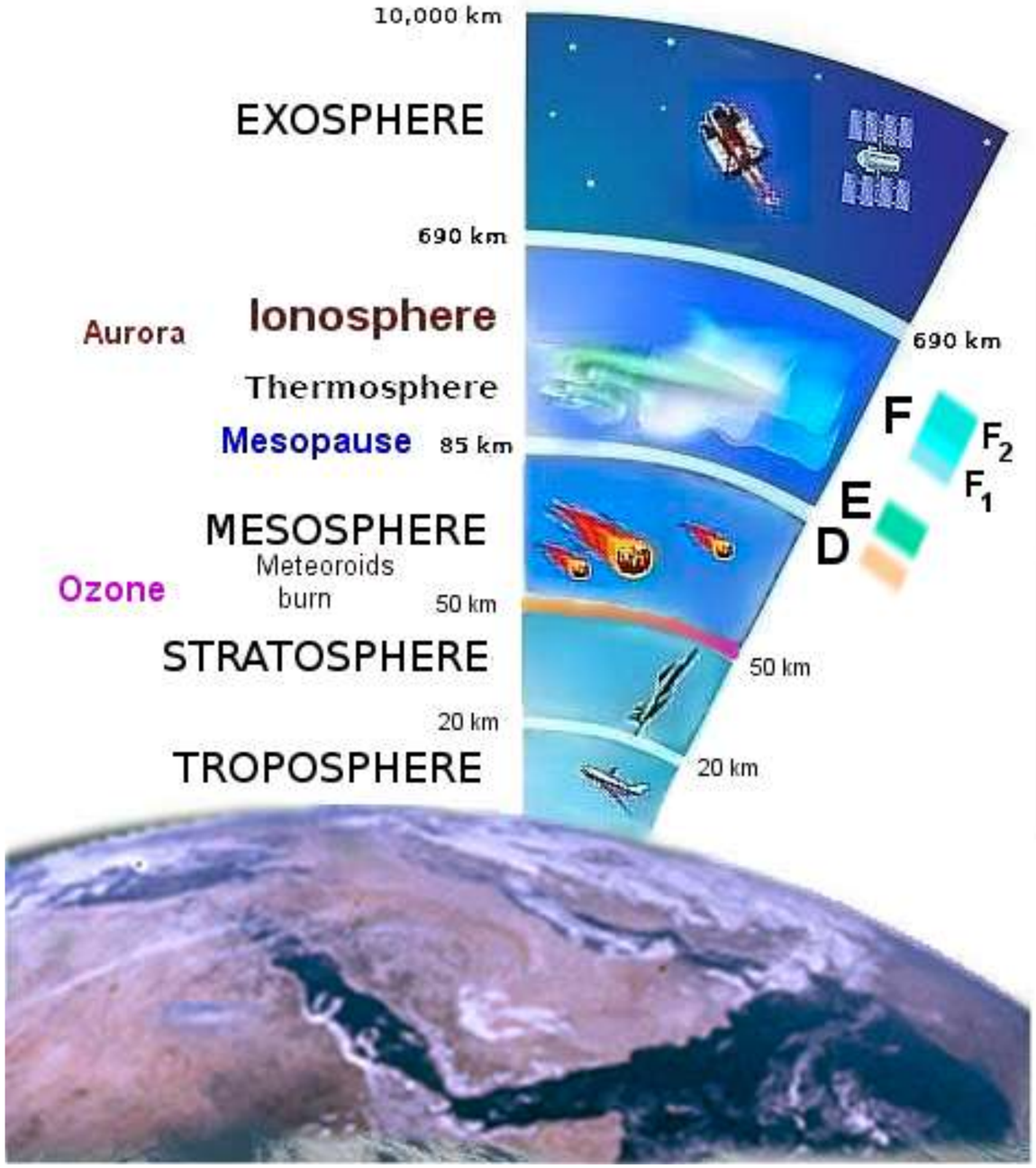

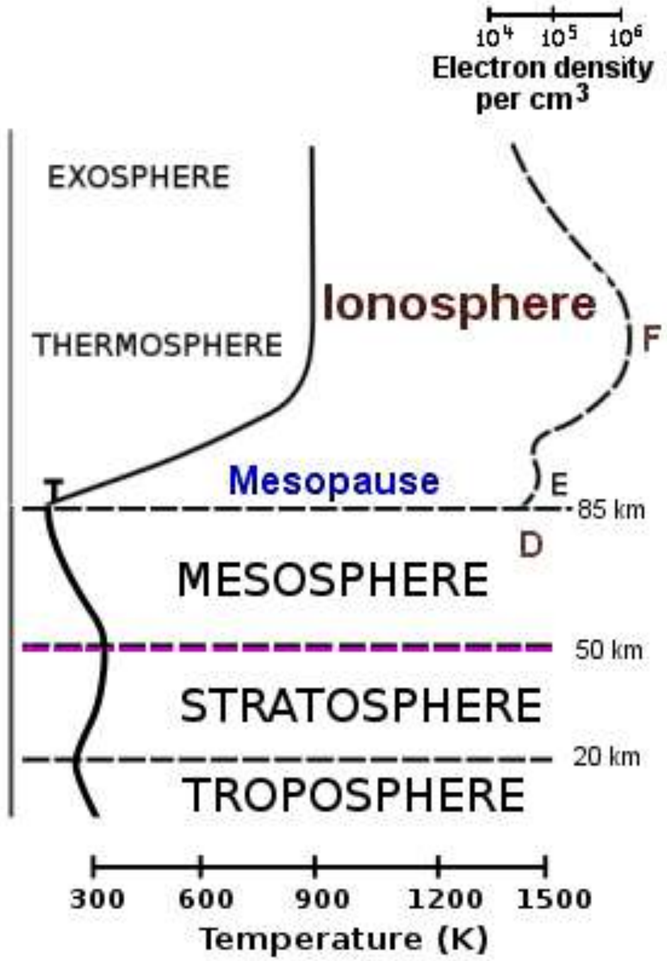

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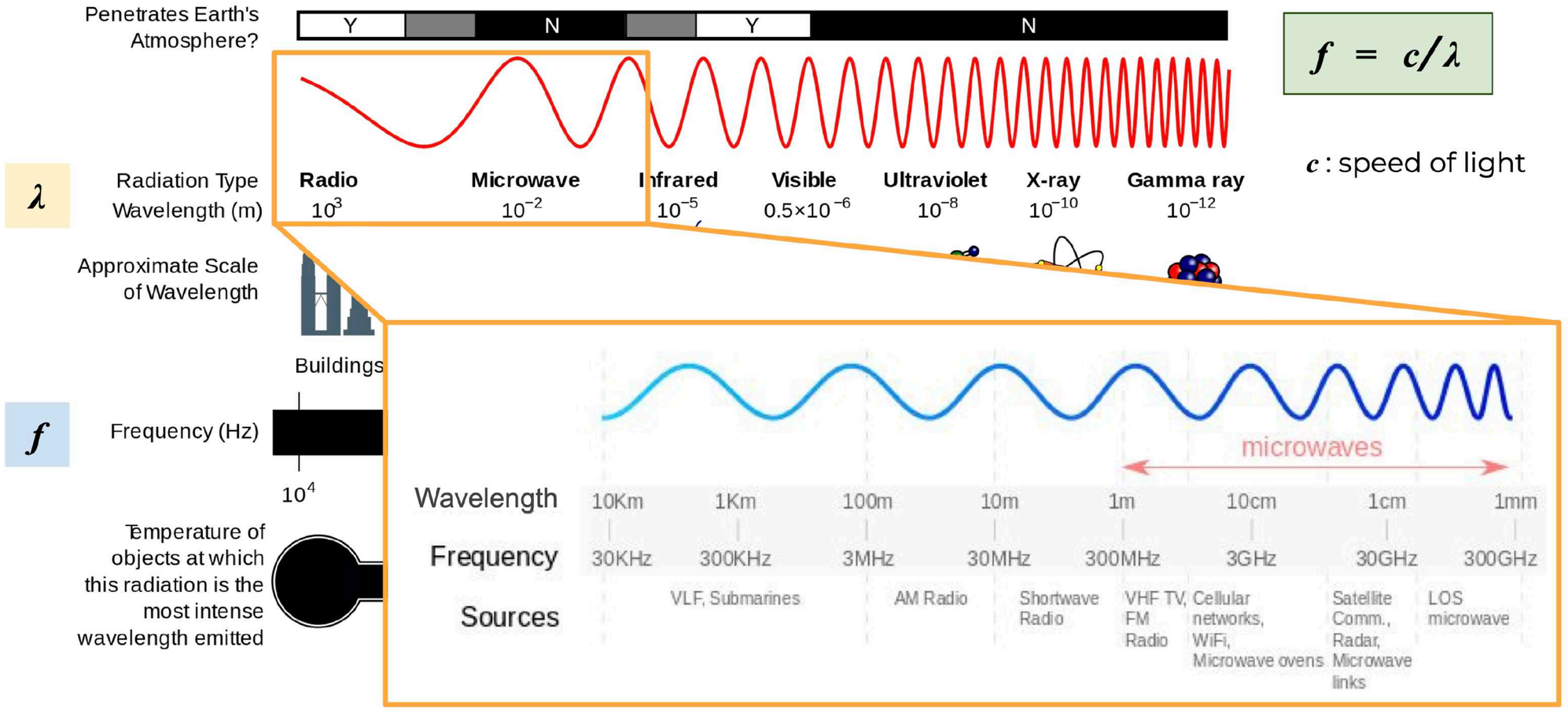
Scales and frequencies of interest

Electromagnetic spectrum



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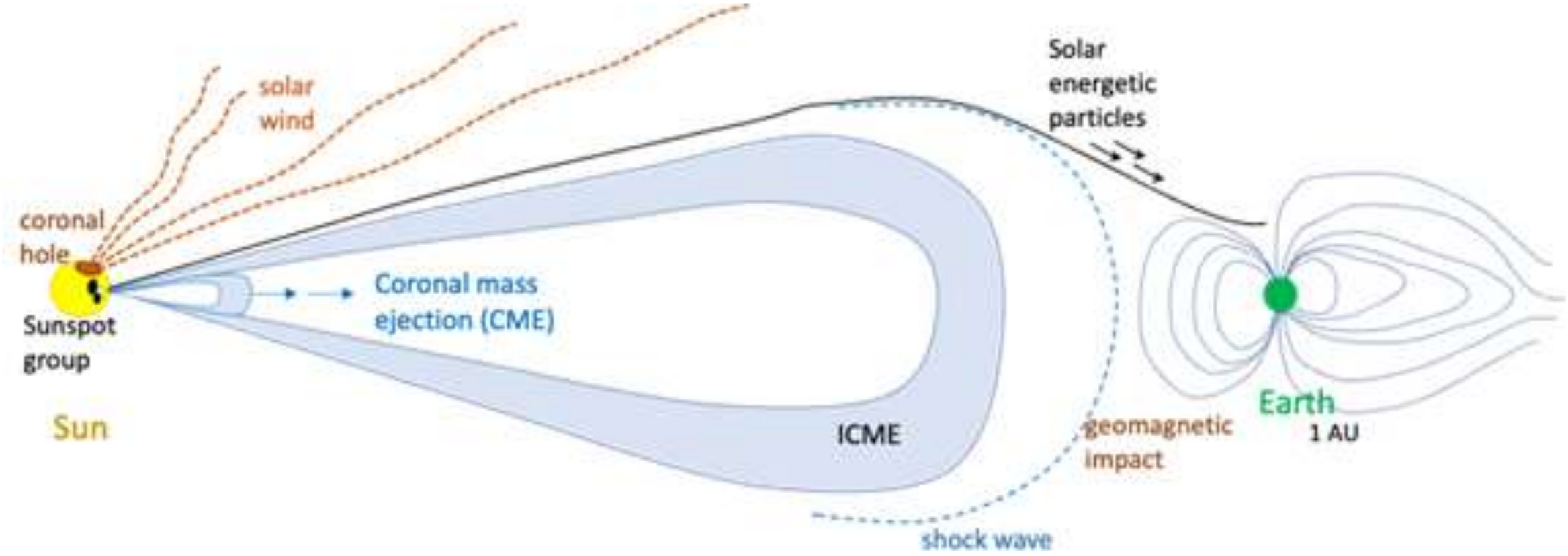
Sun-Earth Event Chains schema: sketch with some of the major components



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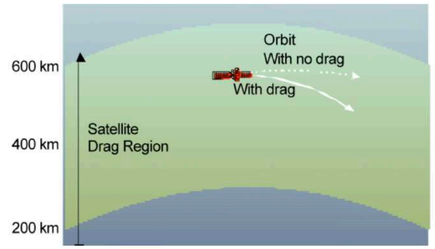
Event chain with CH as a SWX driver

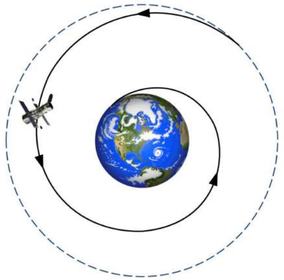
Coronal hole

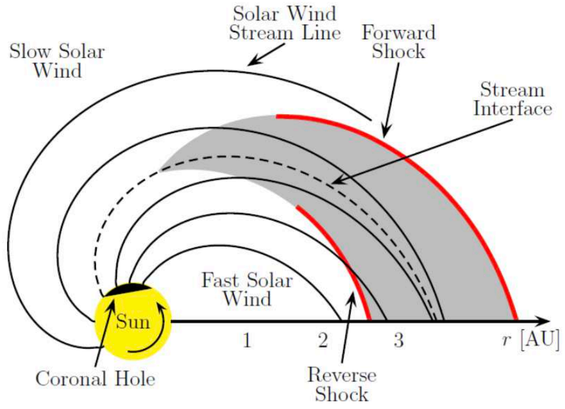
Co-rotating Interaction Region (CIR)

SW shock

High Speed Stream







Scintillation

Geomag. storm (K/Kp)

e- flux

Post-storm depression

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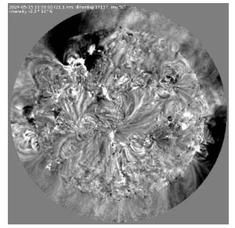
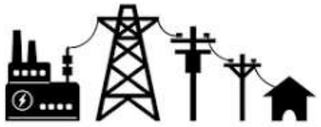
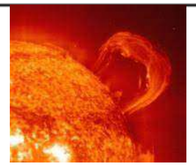
Event chains with AR and Filament as drivers





prominence, filament erption



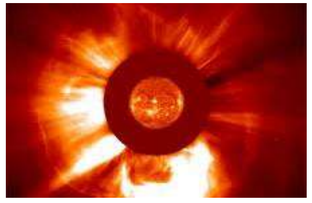
EIT, EUV, Moreton Waves

dimmings (appear after CME is lauched, but observed sometimes before CME observations in LASCO)

EIT waves propagating from source AR

prominence filament eruption

CME



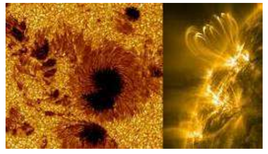
radio shocks WL shocks SEPs

SpW impact on: Kp, Dst, e- flux, p+ flux, Polar cap absorption, post storm depression, ...

GLEs

sunspot

active regions

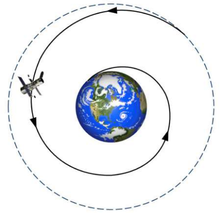


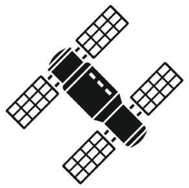
WL flares EUV flares Xray flares

H alpha

radio shocks SEPs

ICME + shocks





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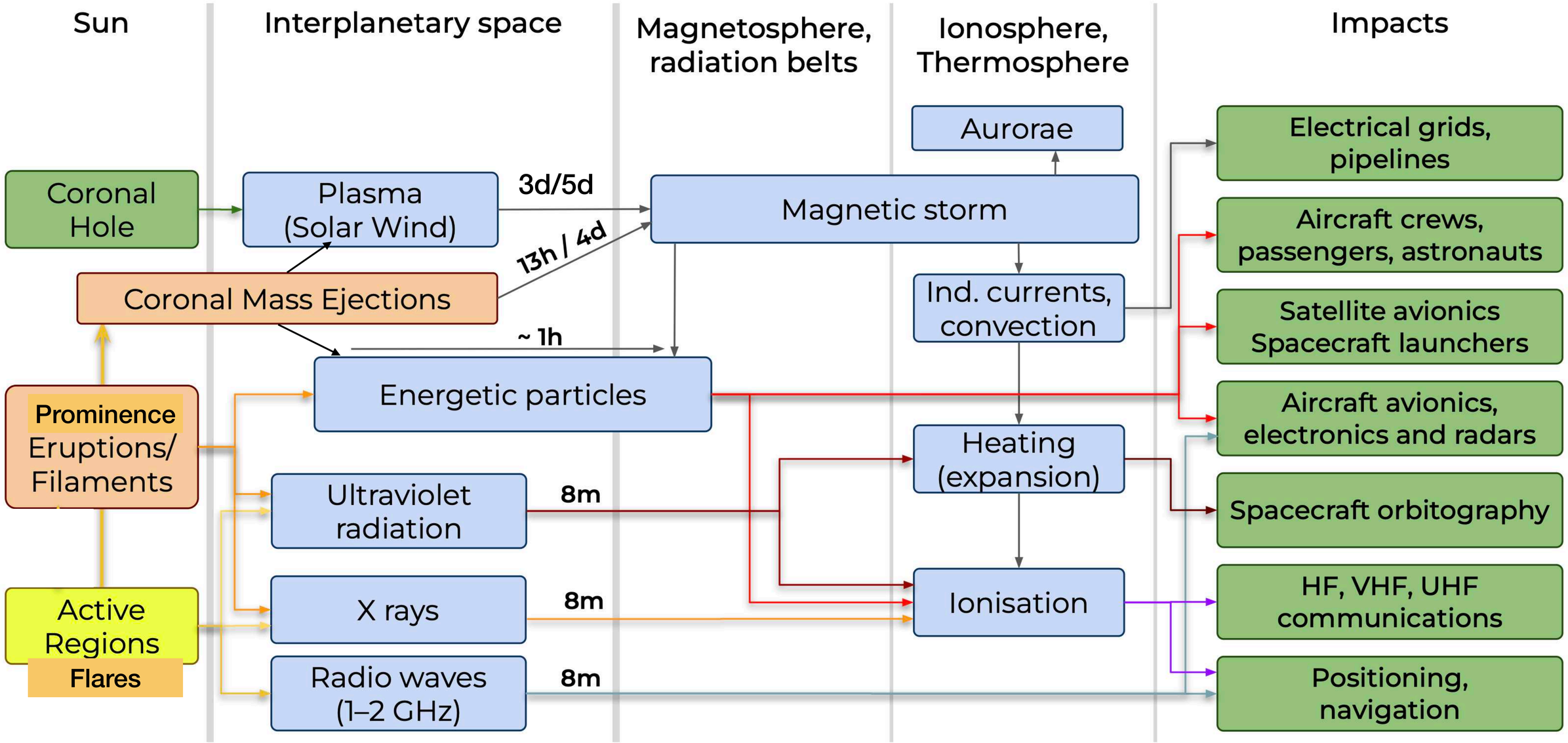
Space Weather Processes & Impacts



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What is Space Weather according to BOM?

https://www.sws.bom.gov.au/vid/Space%20Weather%20Impacts%20and%20Extremes.mp4
Or https://www.sws.bom.gov.au/Educational

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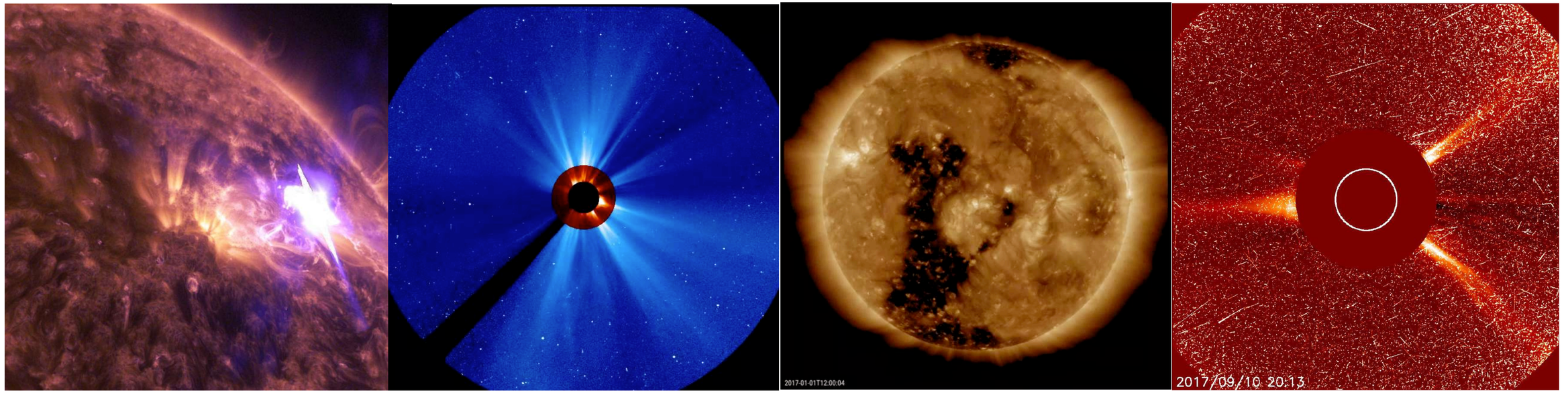
Space Weather Drivers and Impact Timescales

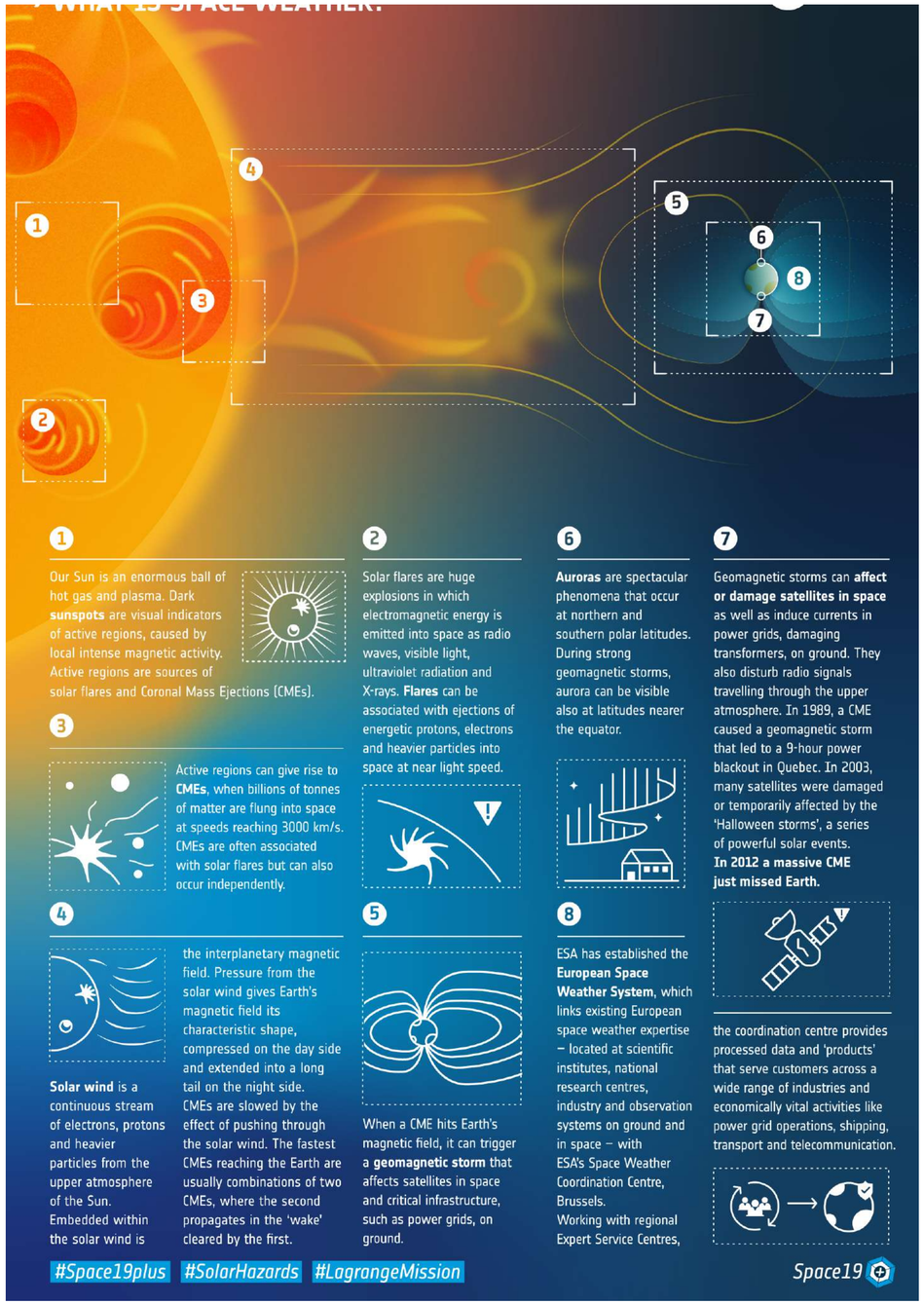


8.3 MIN

CME: 1-4 DAYS
HSS: 3-5 DAYS

MINS - HOURS

ESA's SPACE WEATHER DEFINITION



OBSERVABLES:

- Dst index
- A, Ap index
- K, Kp index
- AE index
- F10.7 flux
- SW properties at L1
- Radio observations (light curves)
- GNSS measurements
  - S4, sigma, VTEC, TEC grad, ROTI, …
- HF comm impacts
  - FoF2, MUF
- SEP fluxes
- Electron flux
- Aurora
- Polar cap and auroral cap absorption
- Magnetospheric waves
- Ground induced currents
- Riometer absorption
- End user anomalies reports:
  - Spacecraft orbit
  - Satellite drag
  - Electronics (SEE)
  - Solar Panels
  - Loss of lock
  - Lost of radio
  - Lost navigation
  - Power outage
- Neutron monitor counts (on ground, in air)
- …

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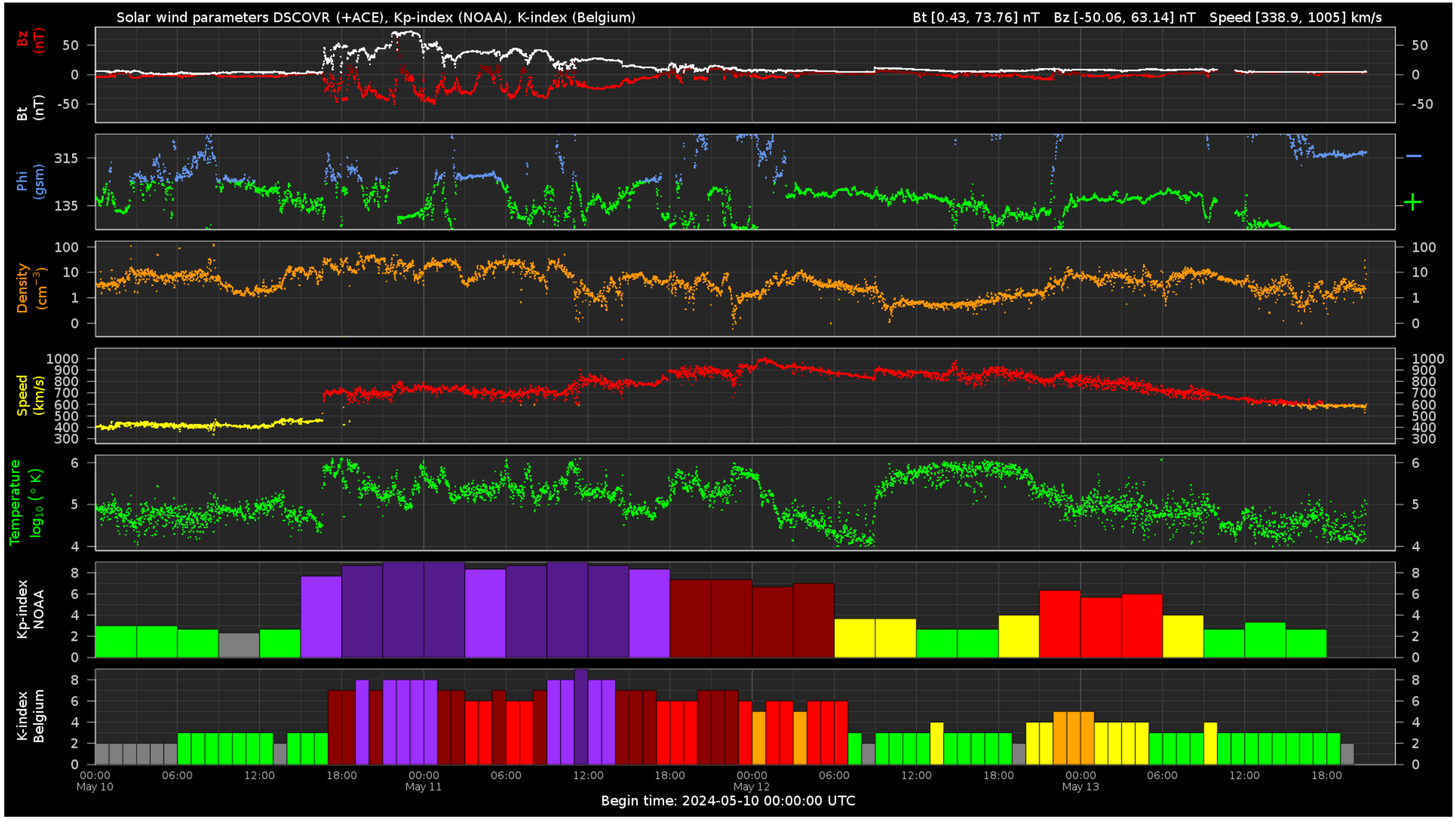
How to measure Space Weather (SWX) Impacts?



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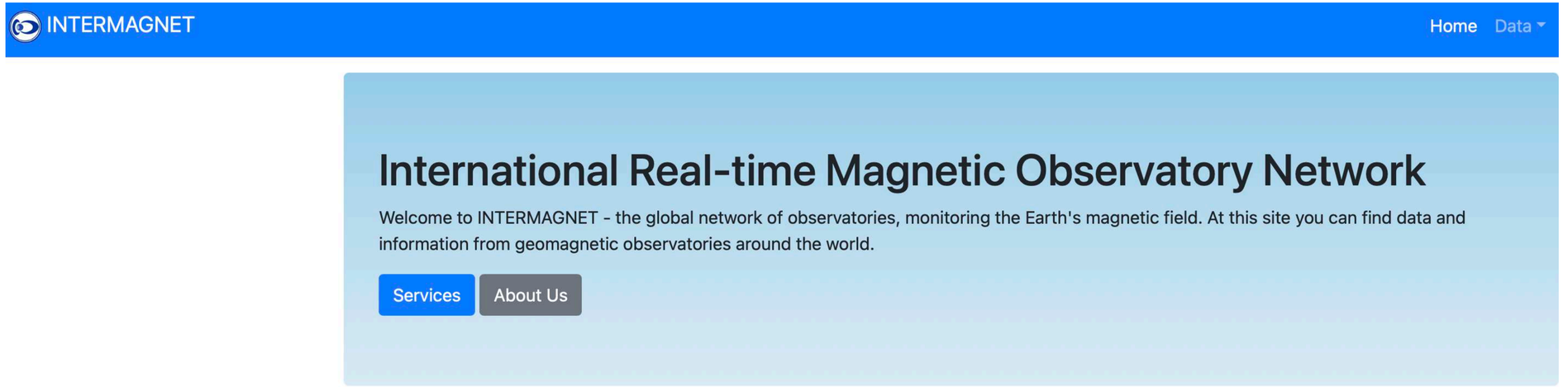
How to measure Space Weather Impacts? (GIC proxy)



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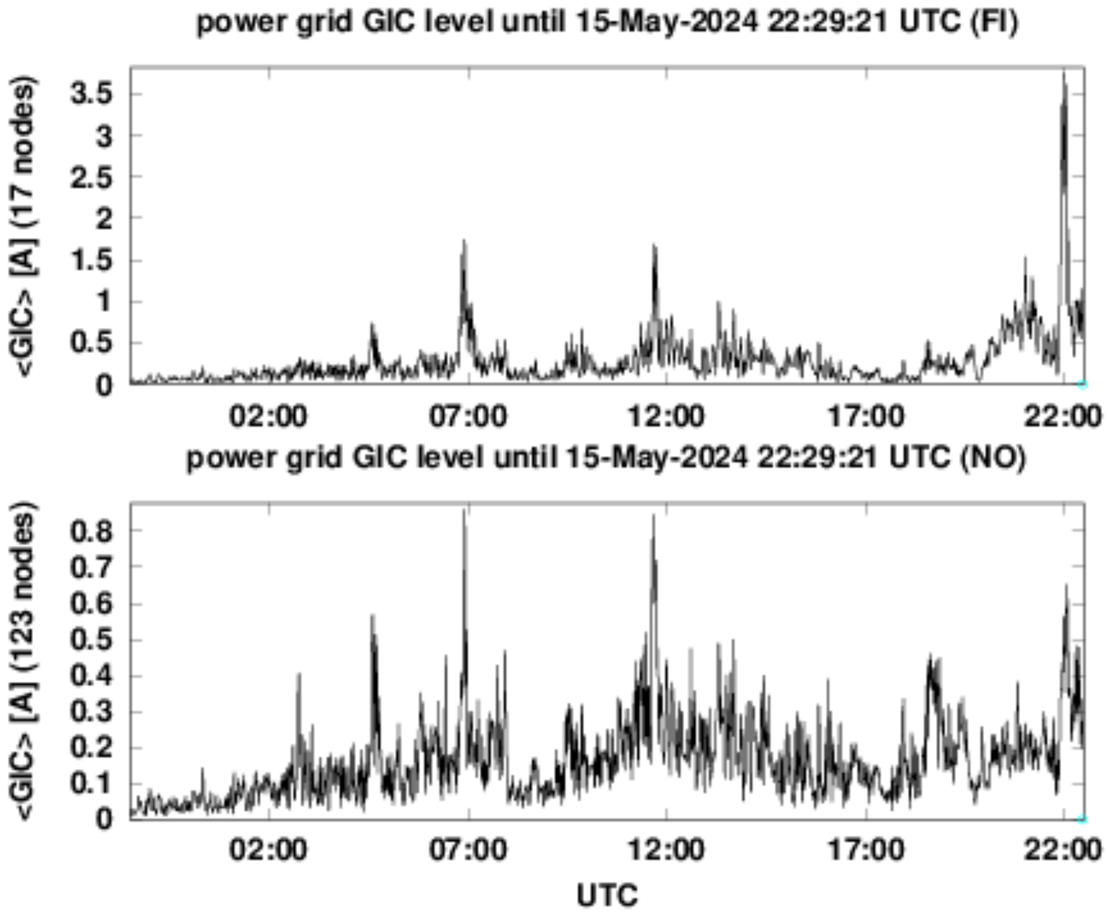
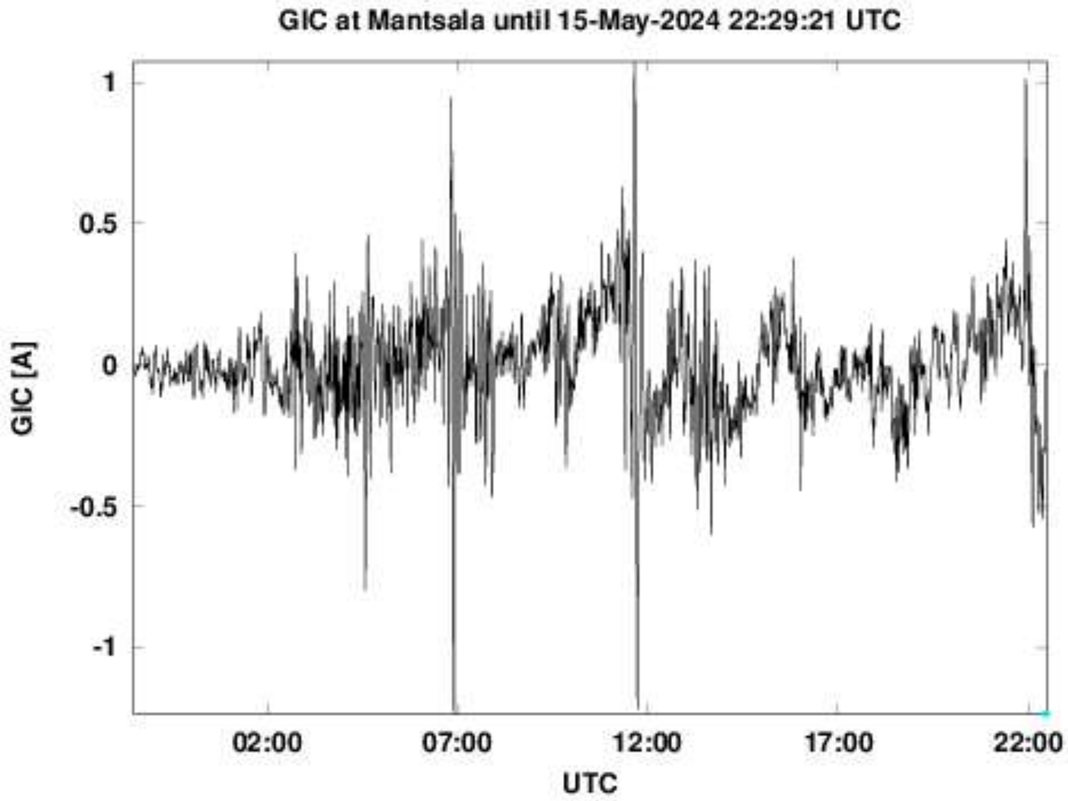
How to measure SWX Impacts? (GIC)

Power Grid



Pipelines



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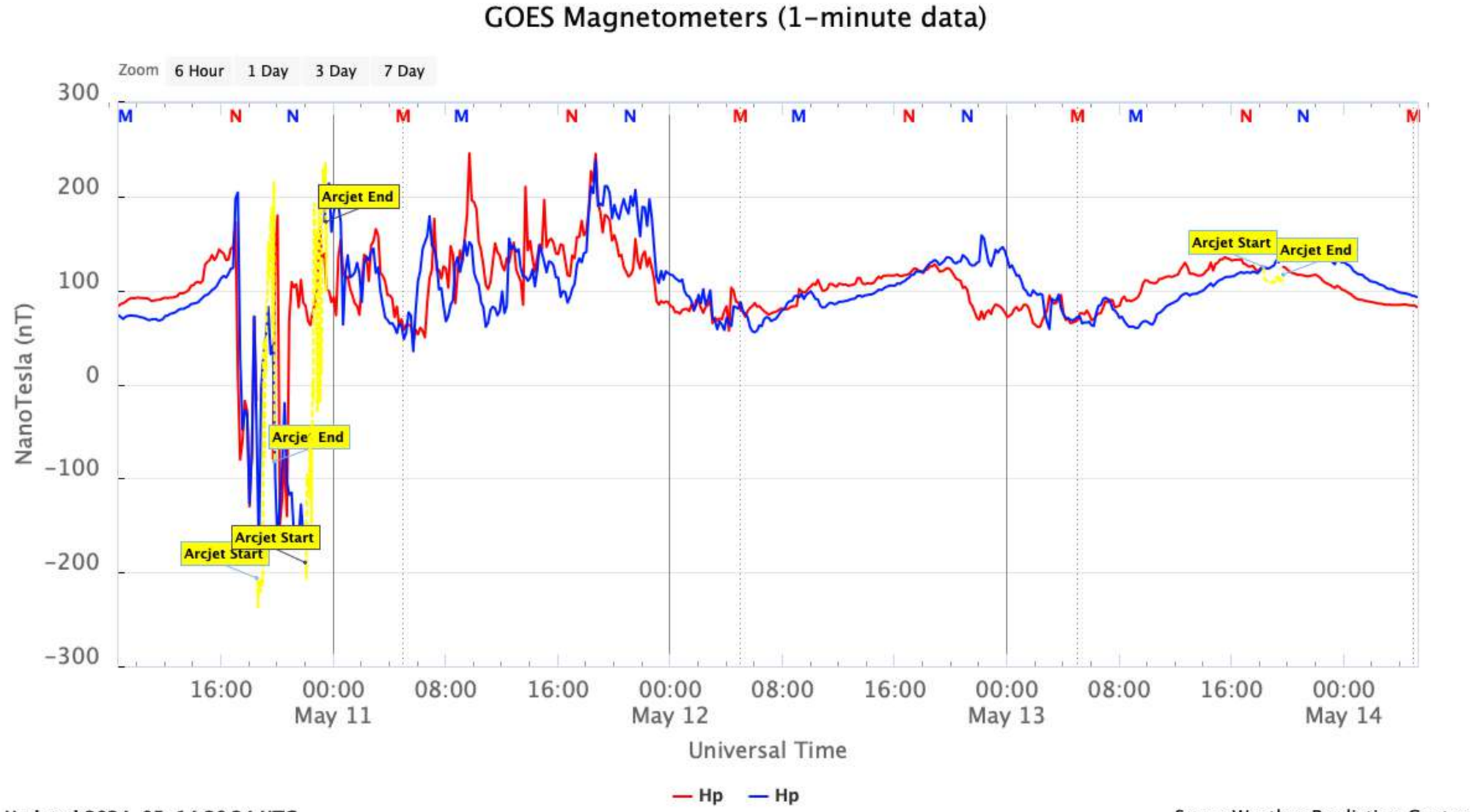
How to measure Space Weather Impacts?



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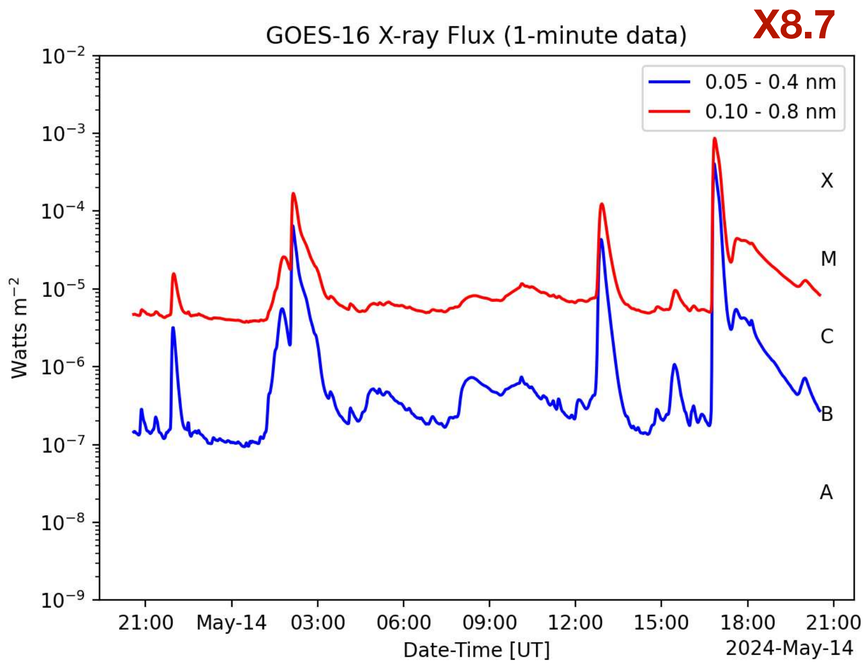
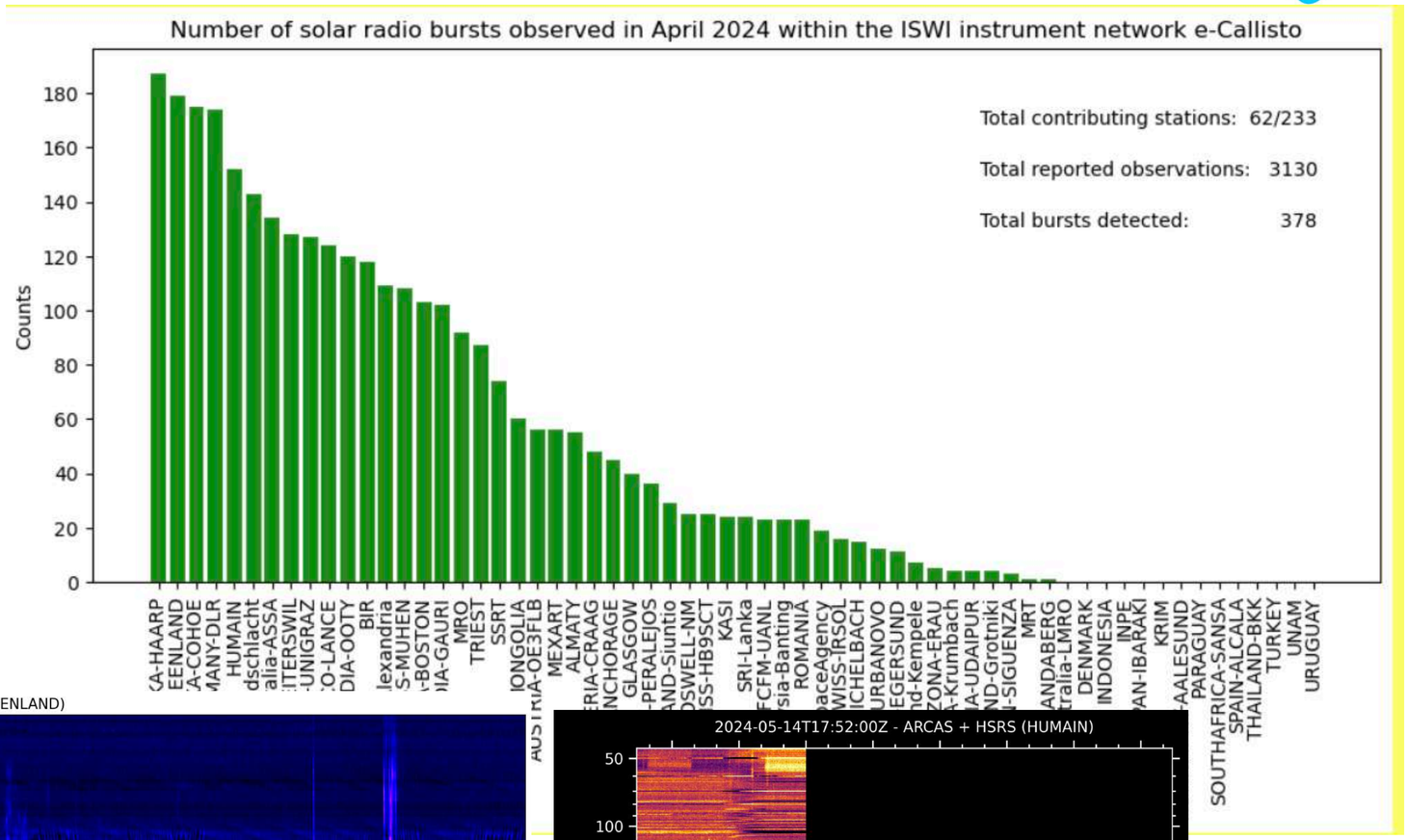
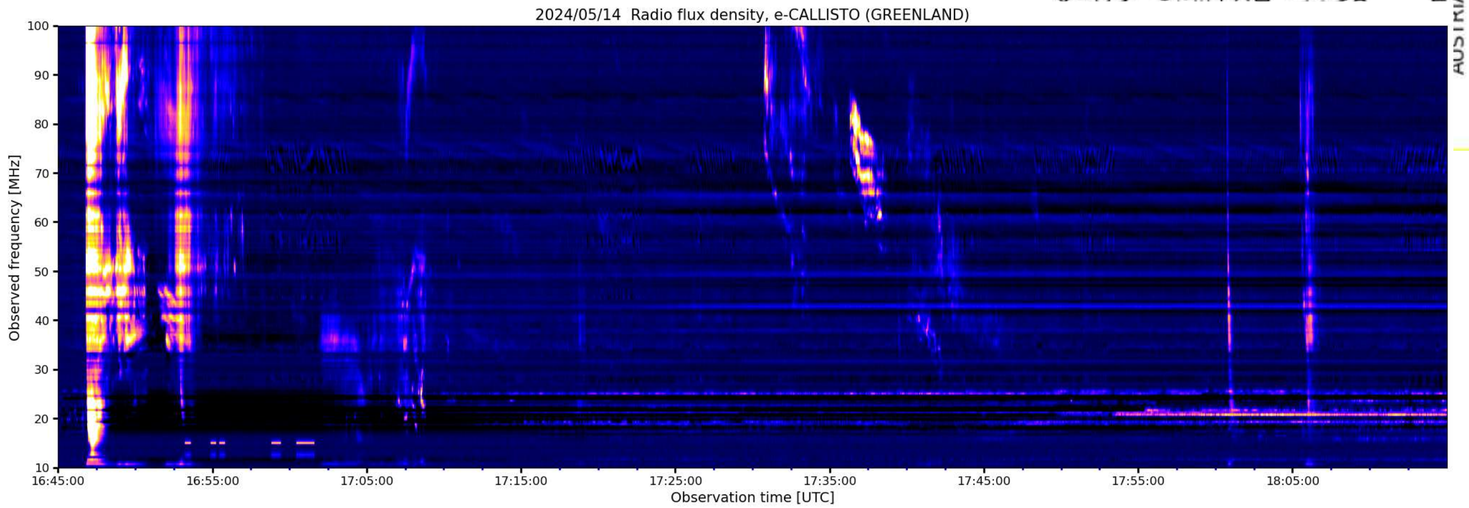
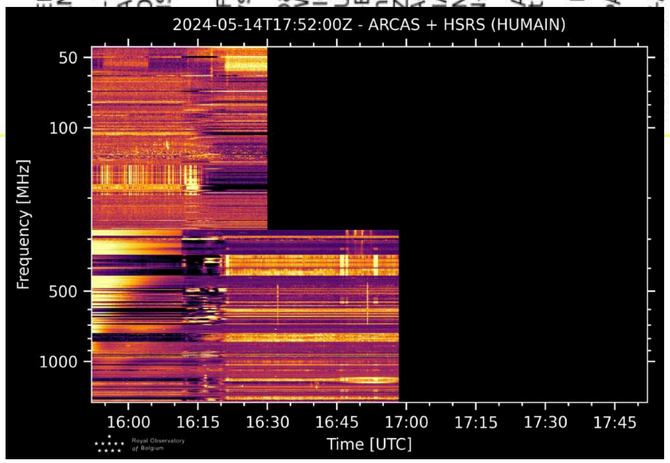
How to measure SWX Impacts? (Radio, GNSS)









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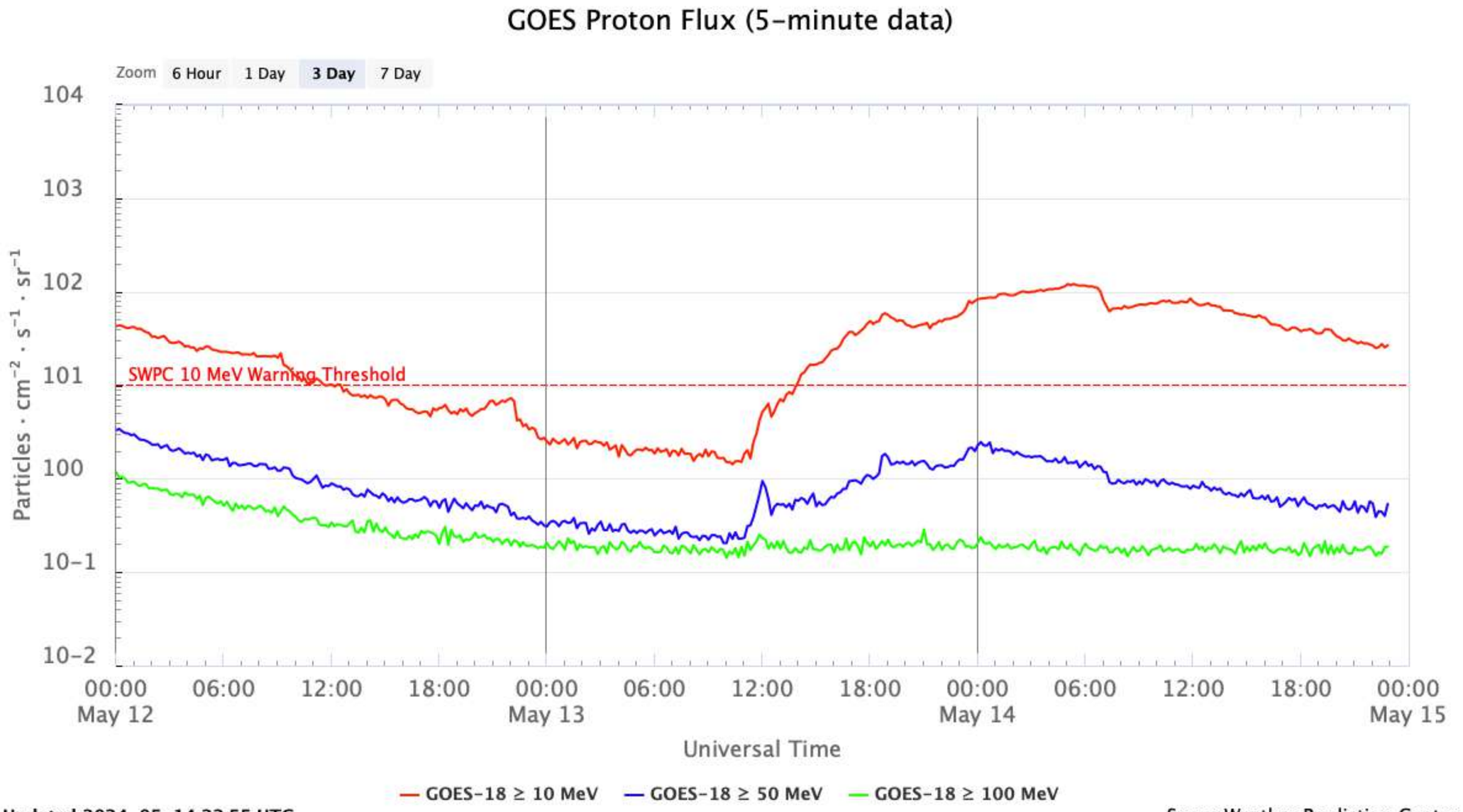
How to measure SWX Impacts? (RAD, HF COM, SEU)



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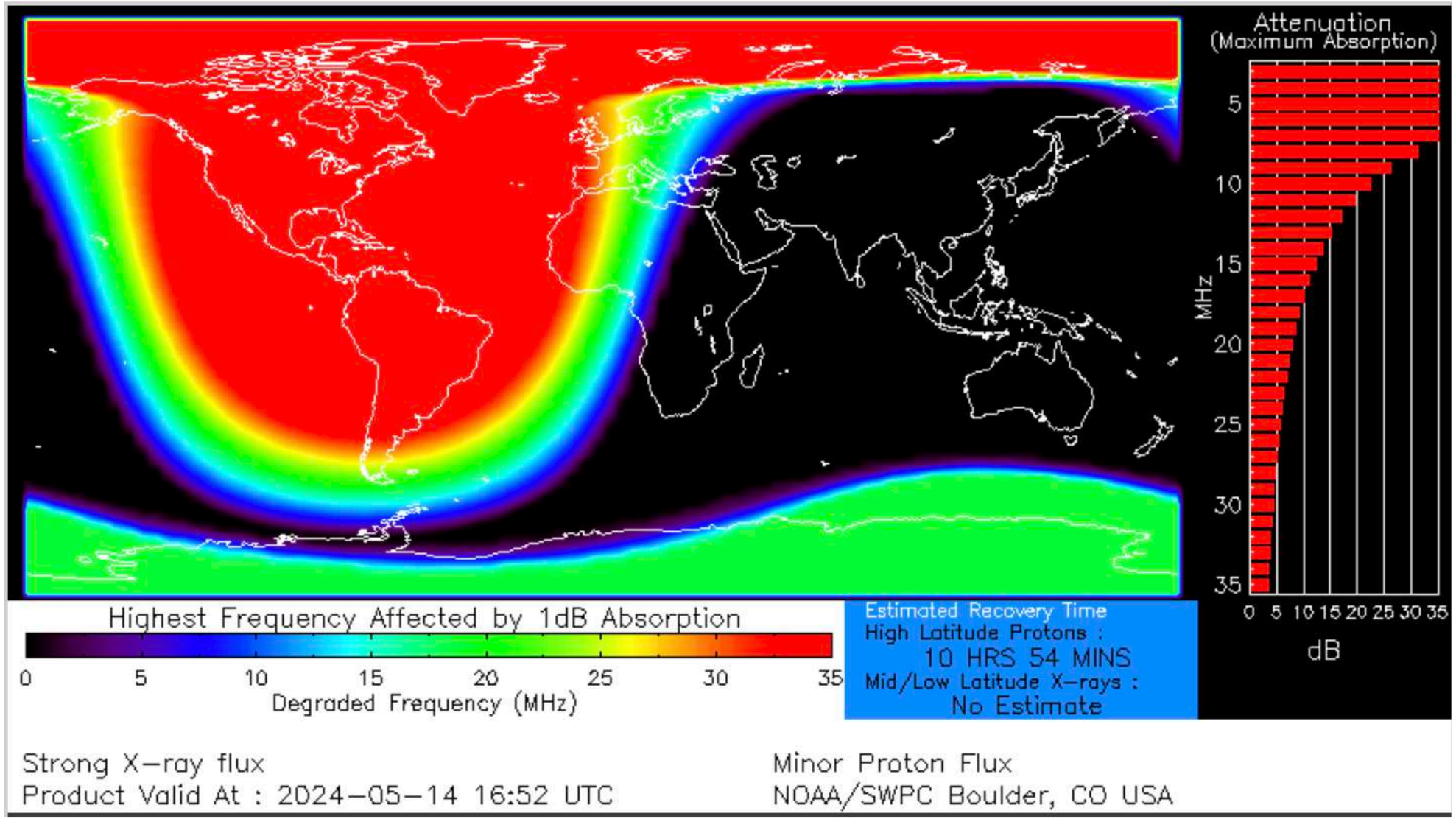
How to quantify Space Weather Impacts? (HF COM)



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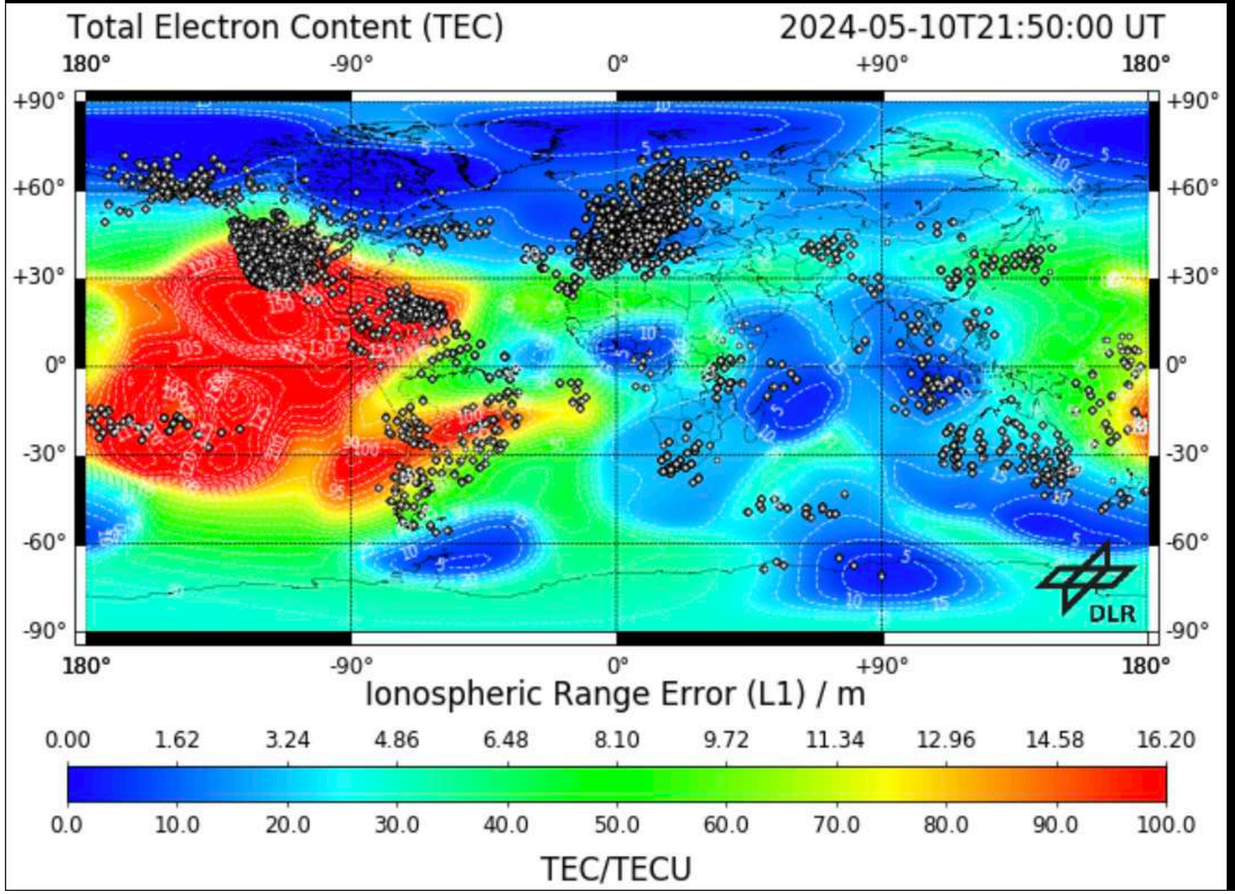
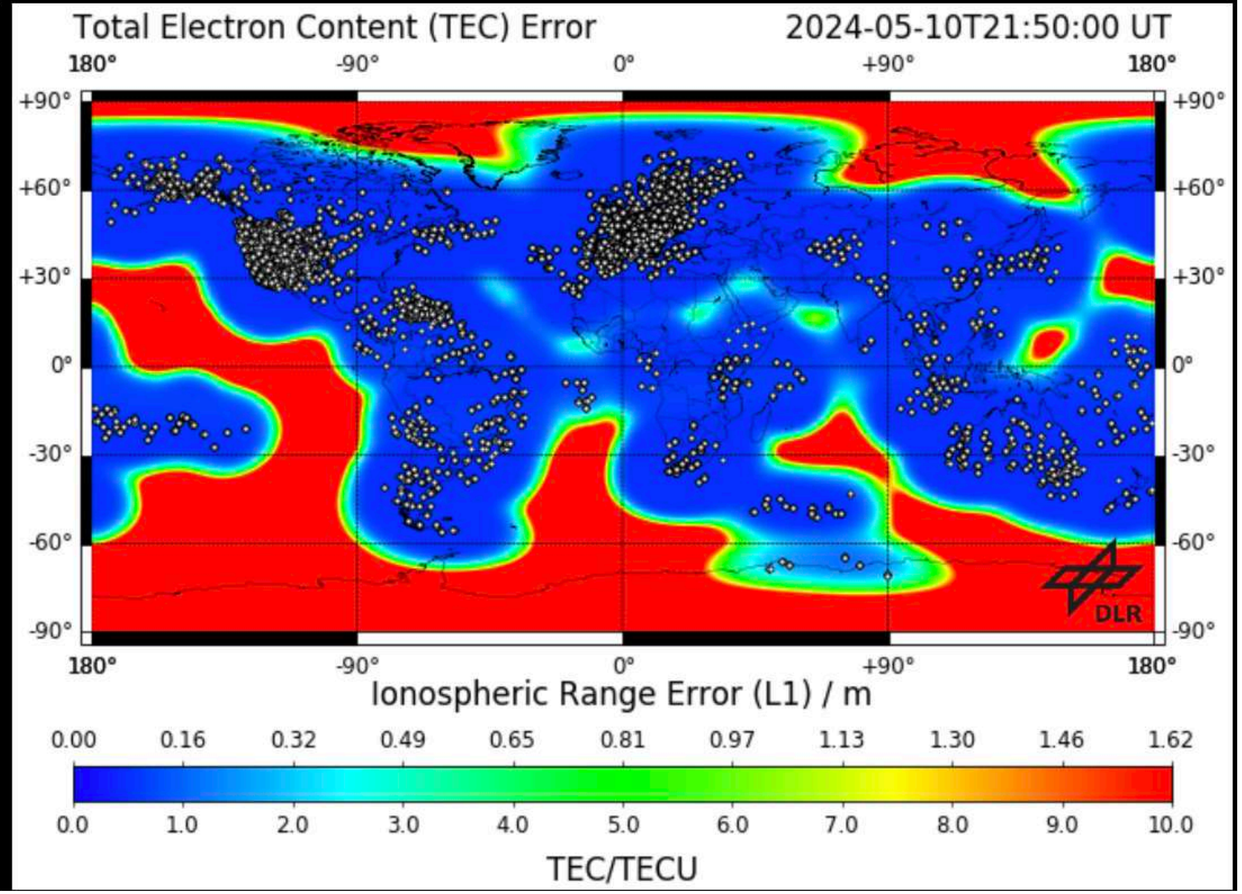
How to quantify Space Weather Impacts? (GNSS)

GNSS/Vertical TEC Map Nowcast - DLR



GNSS/Vertical TEC Error Map - DLR



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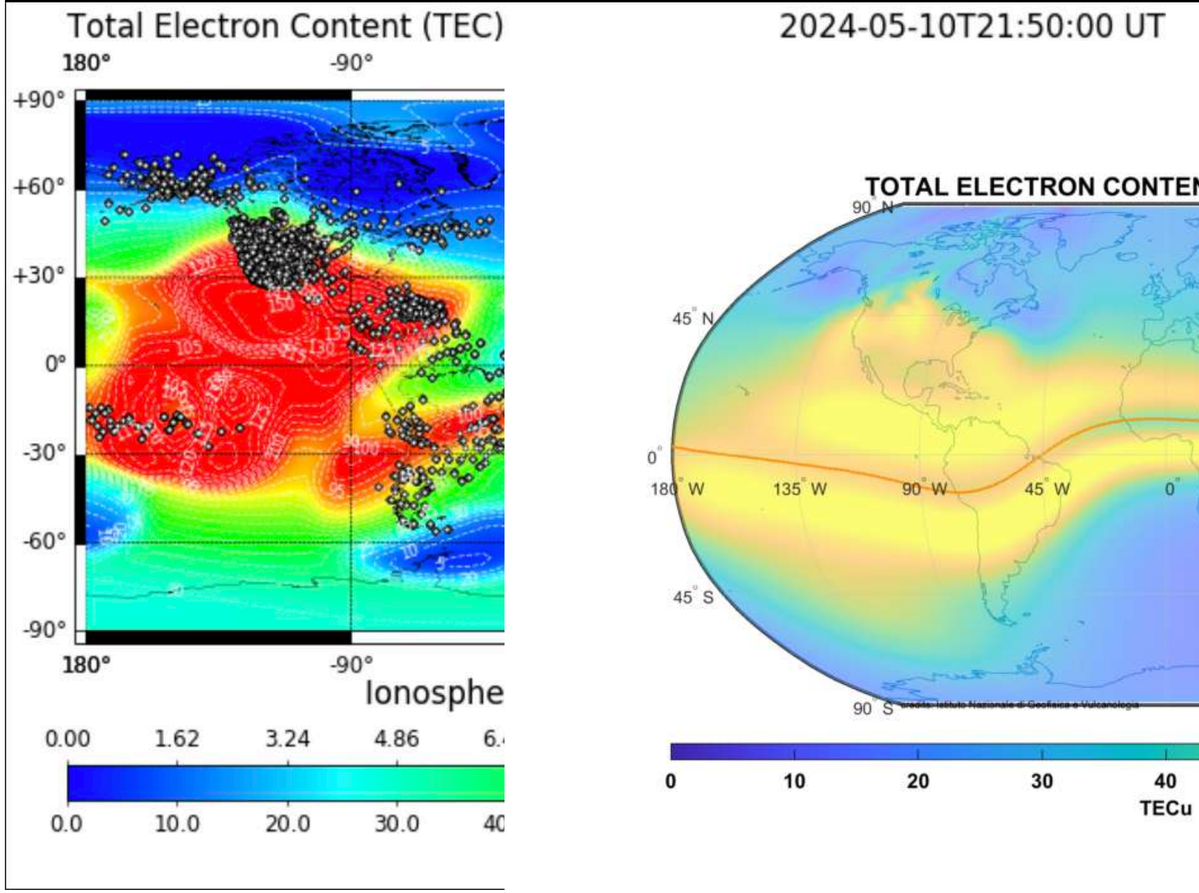
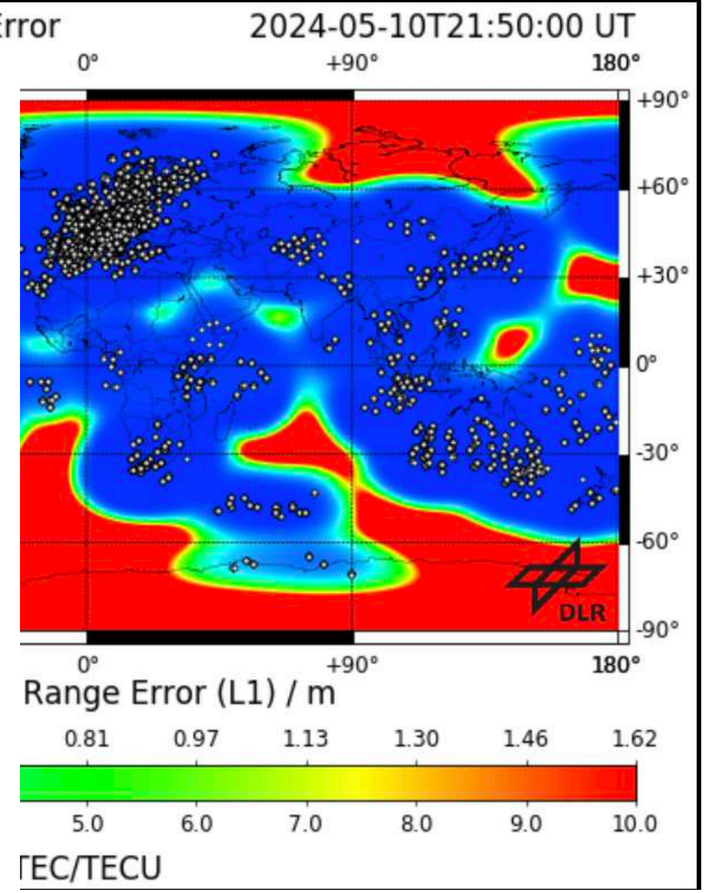
How to quantify Space Weather Impacts? (GNSS)

GNSS/Vertical TEC Map Nowcast - DLR



GNSS/Vertical TEC Error Map - DLR



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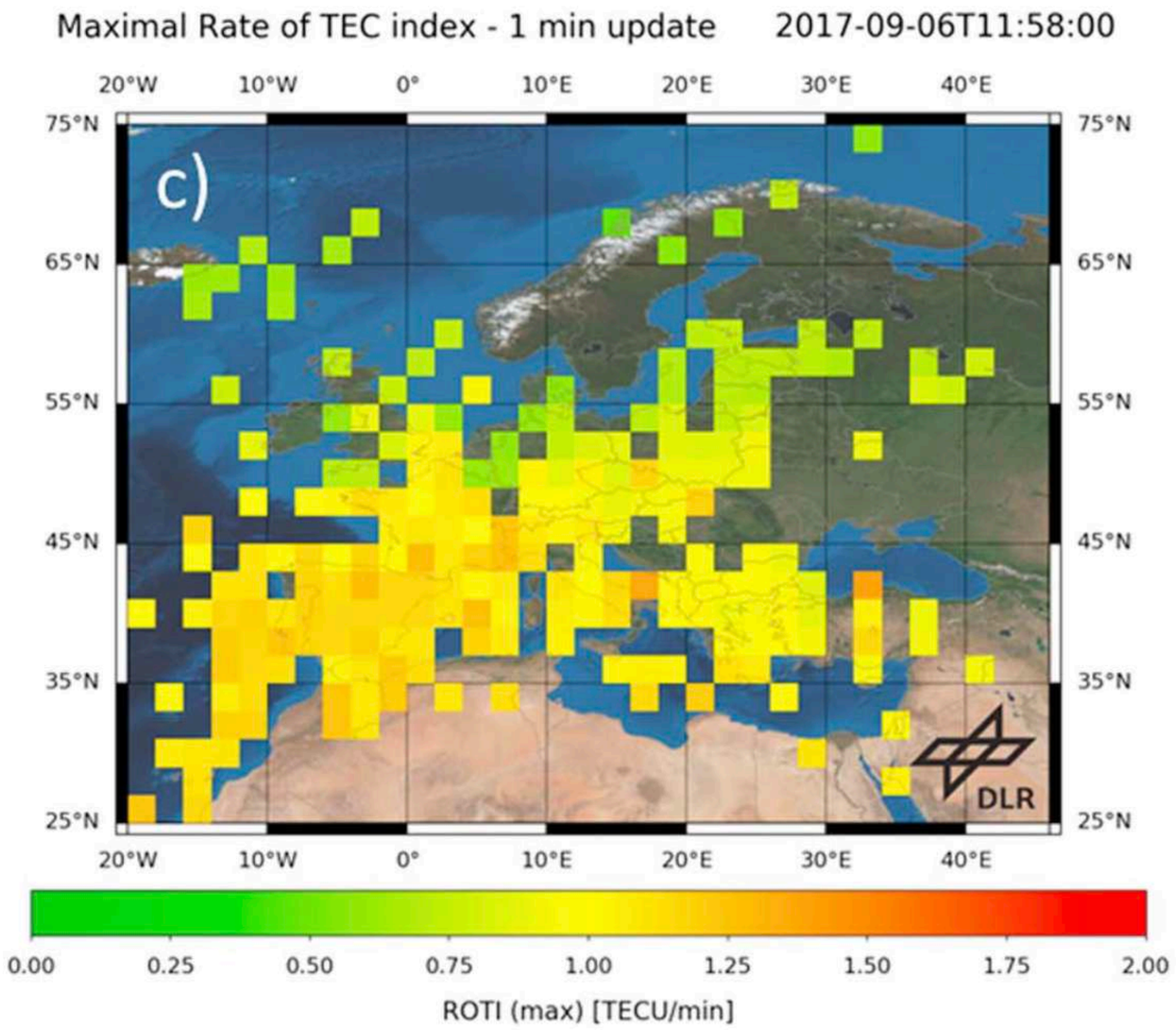
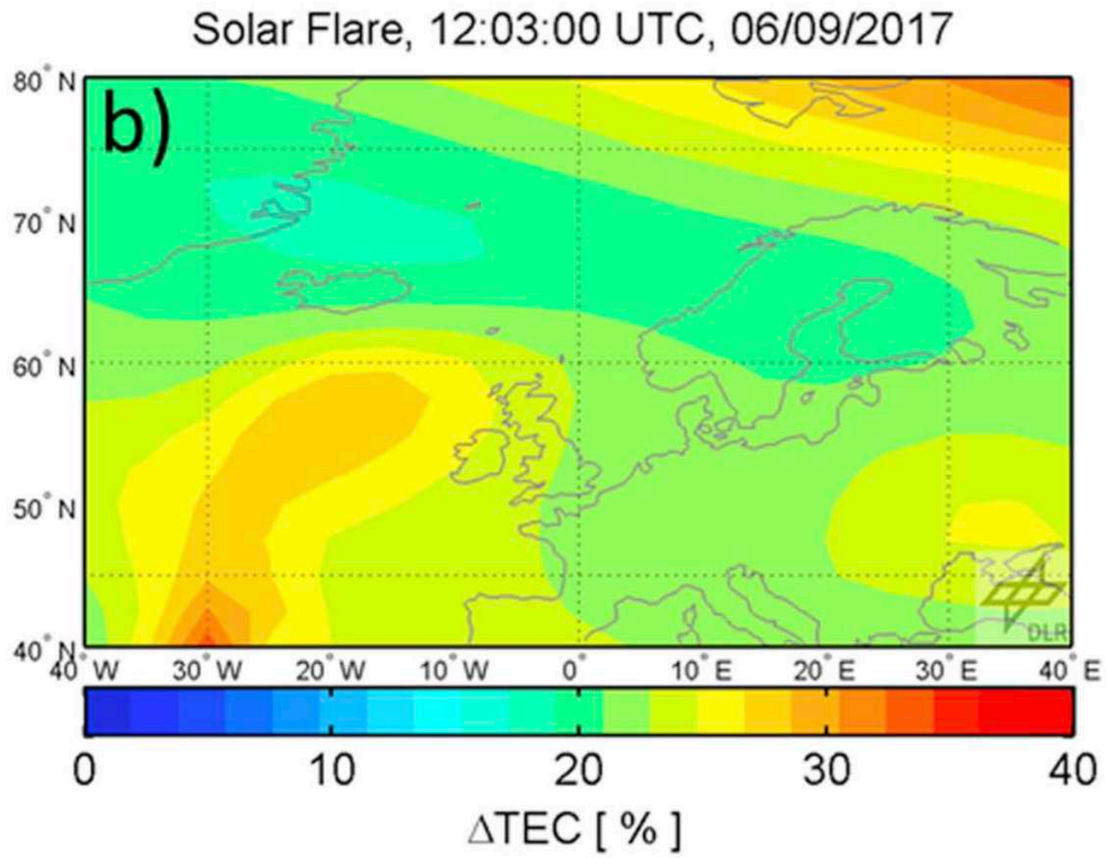
How to quantify Space Weather Impacts? (GNSS)





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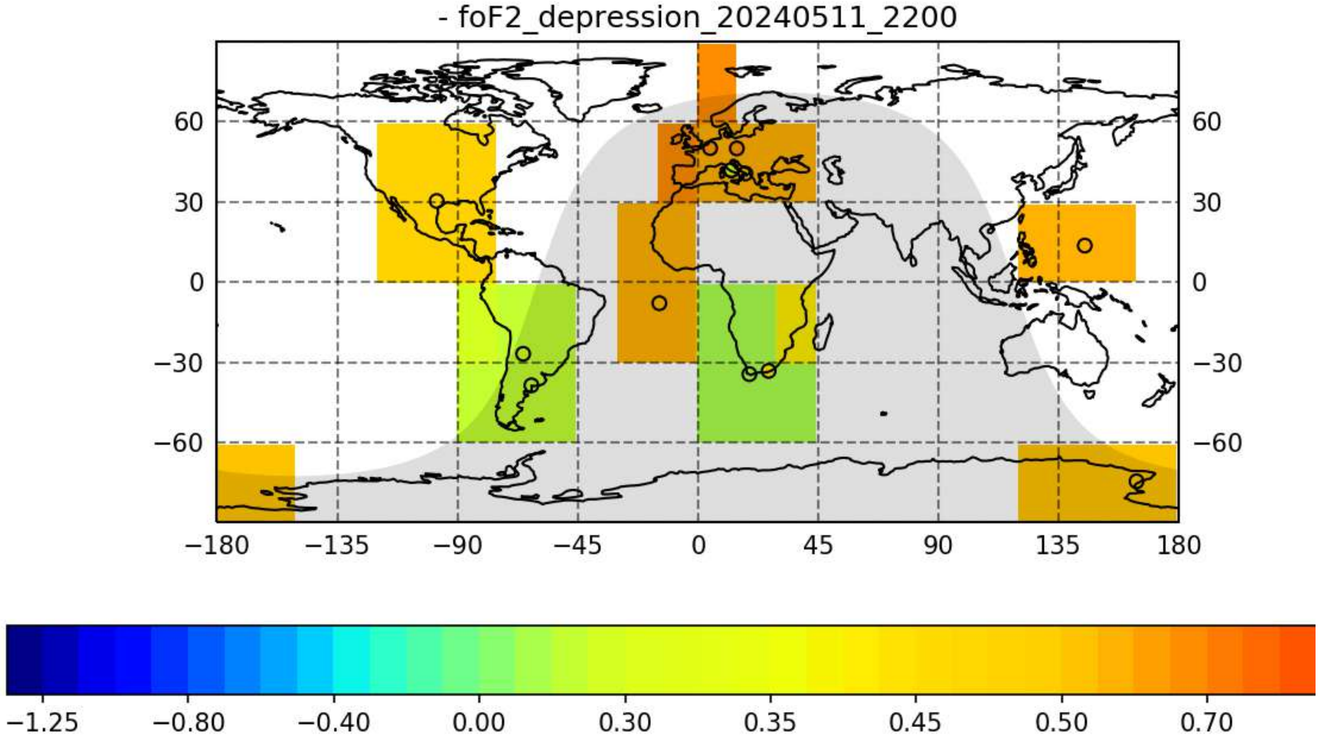
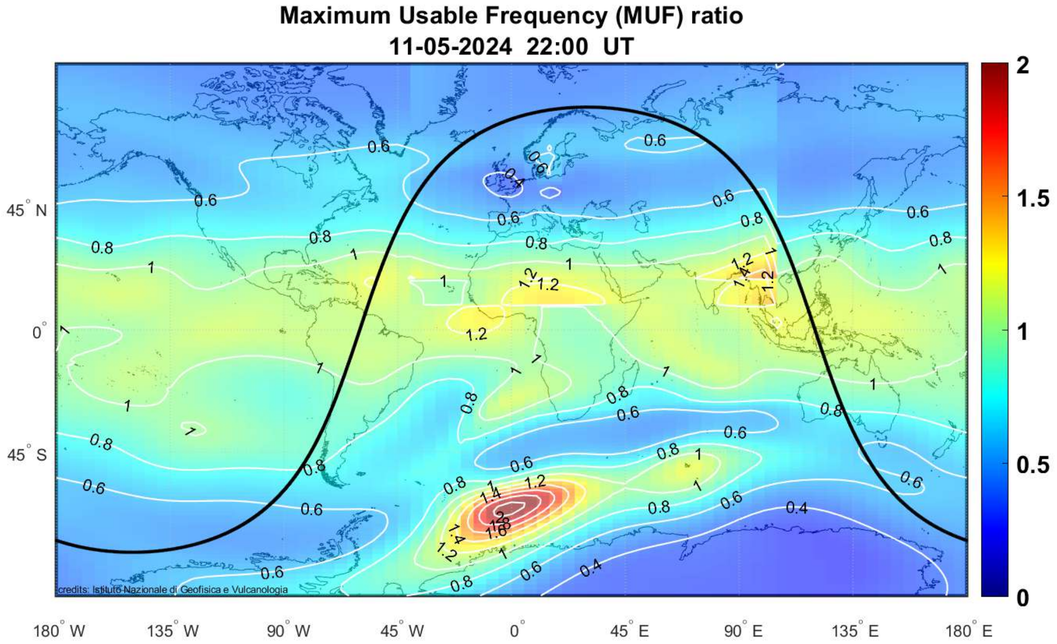
How to quantify Space Weather Impacts? (HF COM)





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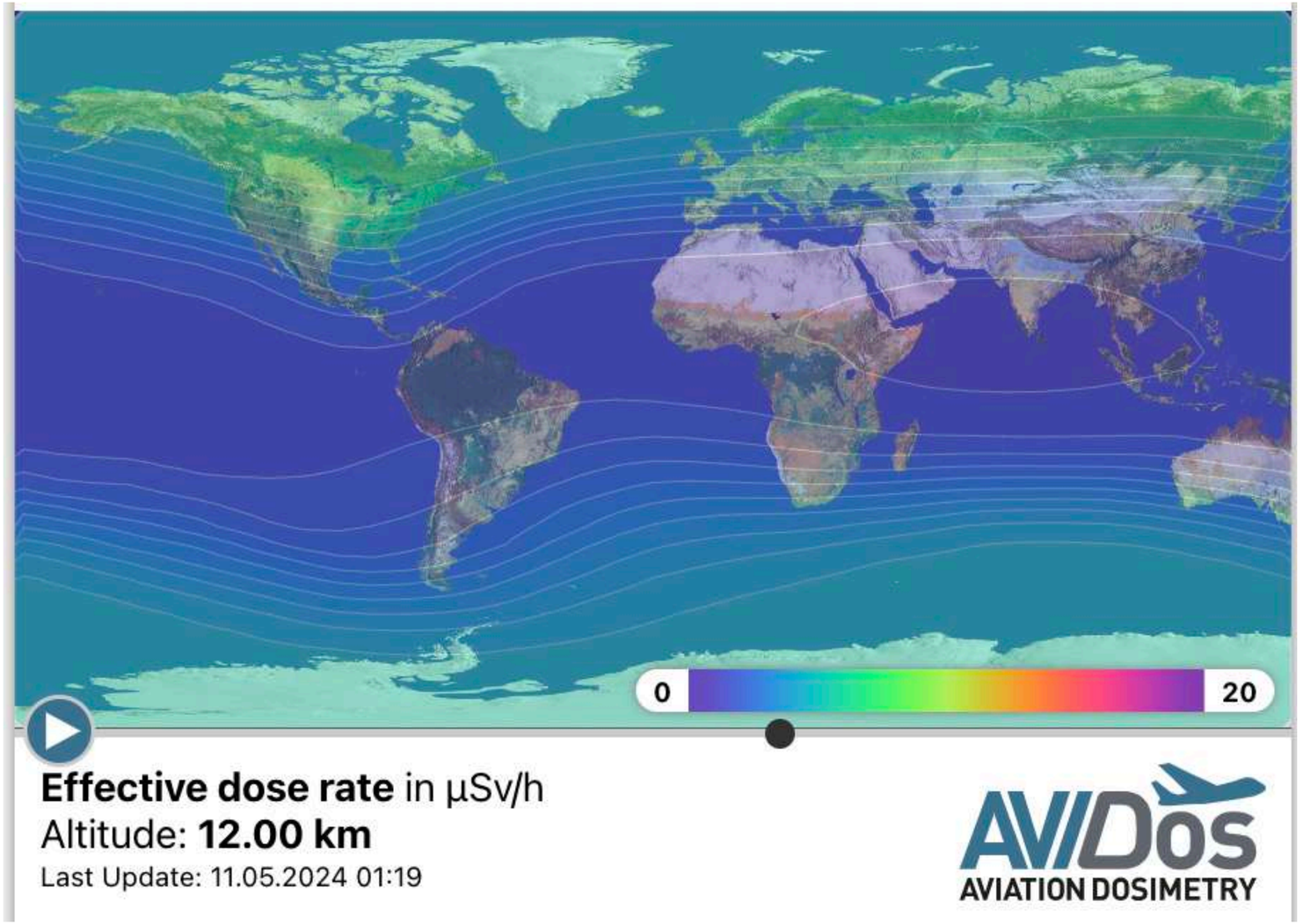
How to quantify Space Weather Impacts? (RAD)



https://swe.ssa.esa.int/nso_air_dashboard

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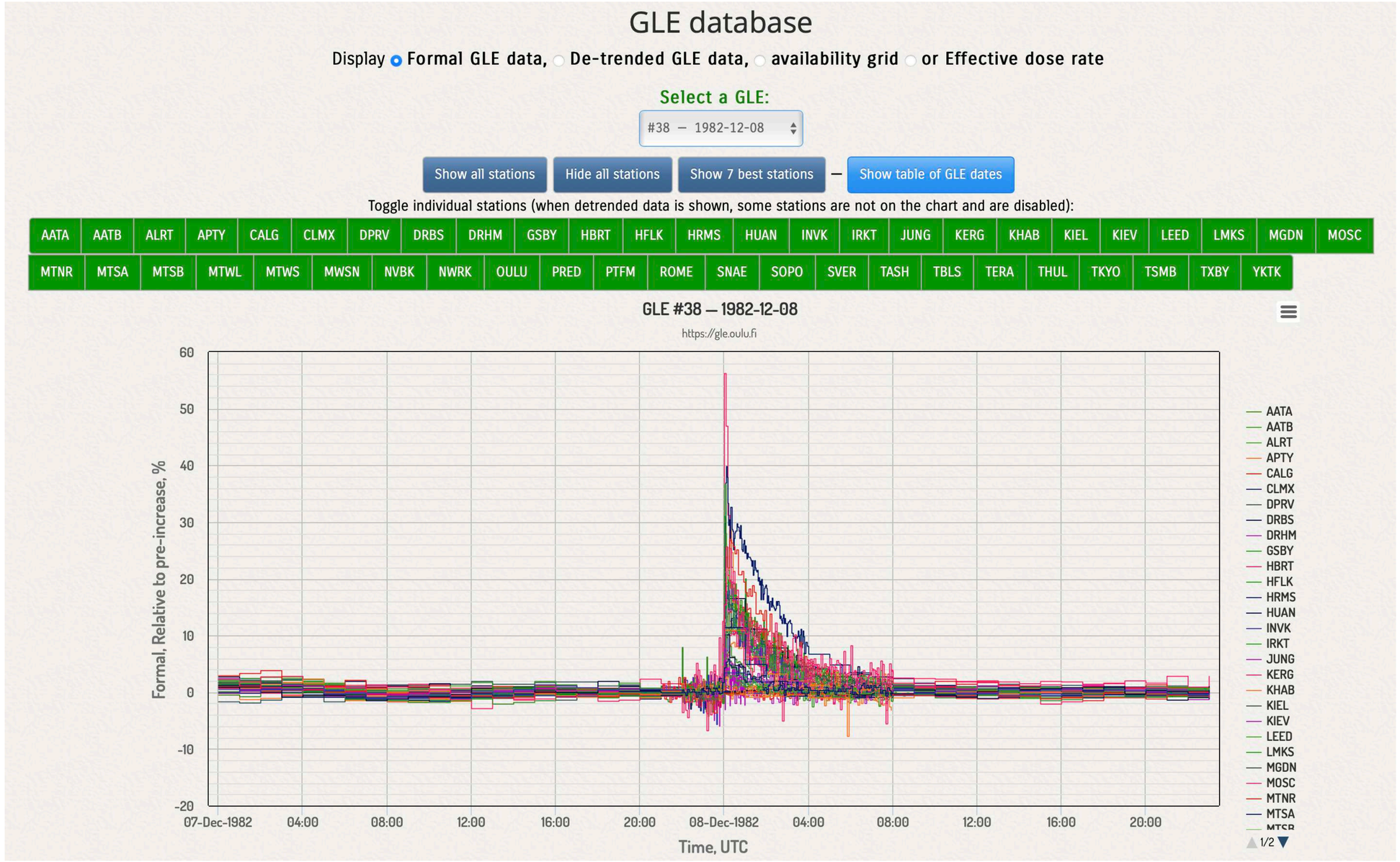

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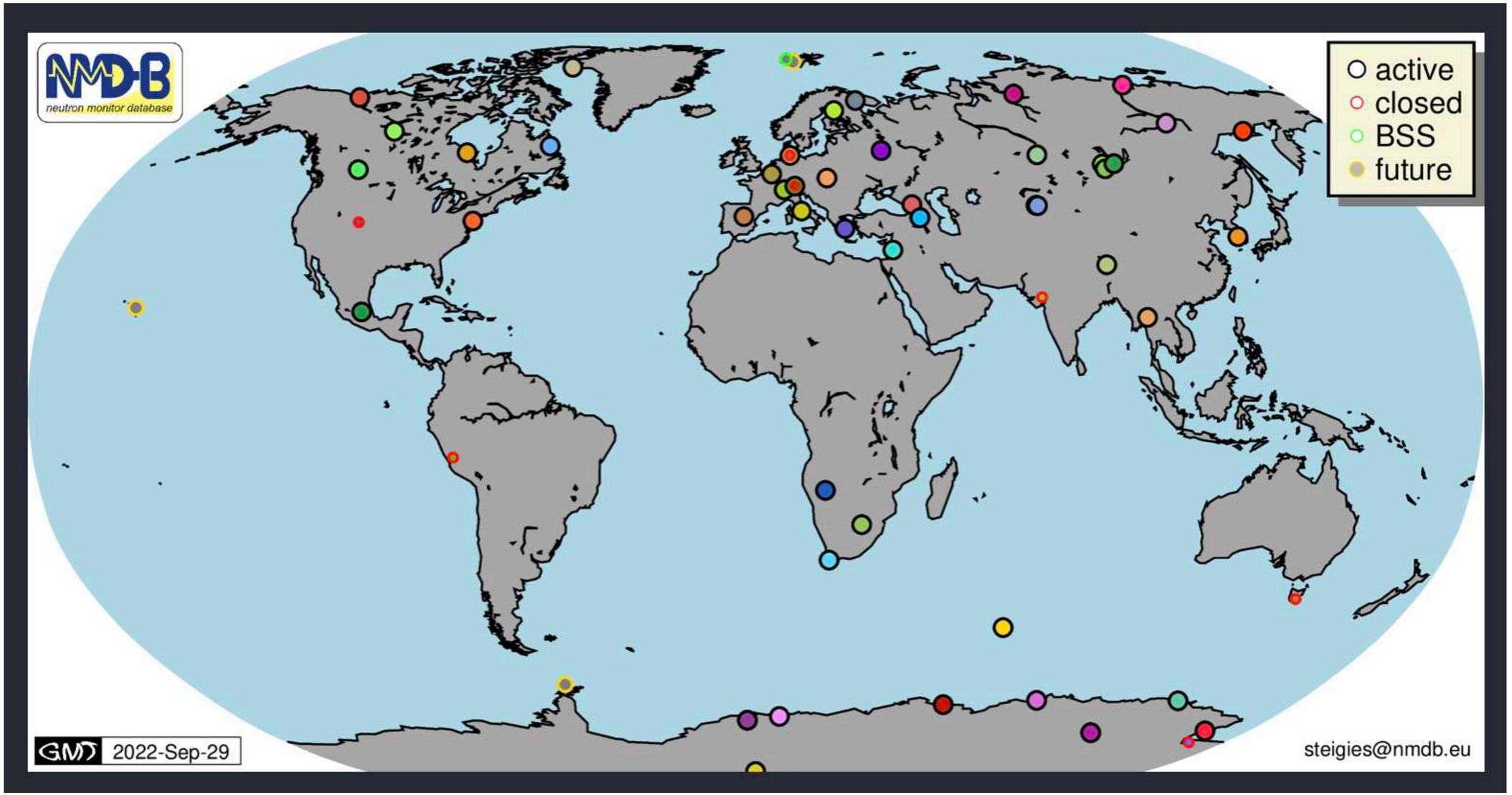
How to measure Space Weather Impacts?



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How to measure Space Weather Impacts?

GLOBAL IONOSPHERE RADIO OBSERVATORY

with Real-Time & Retrospective HF Ionospheric Sounding Data from Lowell DIDBase

UMASS LOWELL

The Lowell GIRO Data Center (LGDC) implements a suite of technologies for post-processing, modeling, analysis, and dissemination of the acquired and derived data products:

IRTAM

IRI-based Real-time Assimilative Model, "IRTAM", that builds and publishes every 15-minutes an updated "global weather" map of the peak density and height in the ionosphere, as well as a map of deviations from the classic IRI climate;

GAMBIT

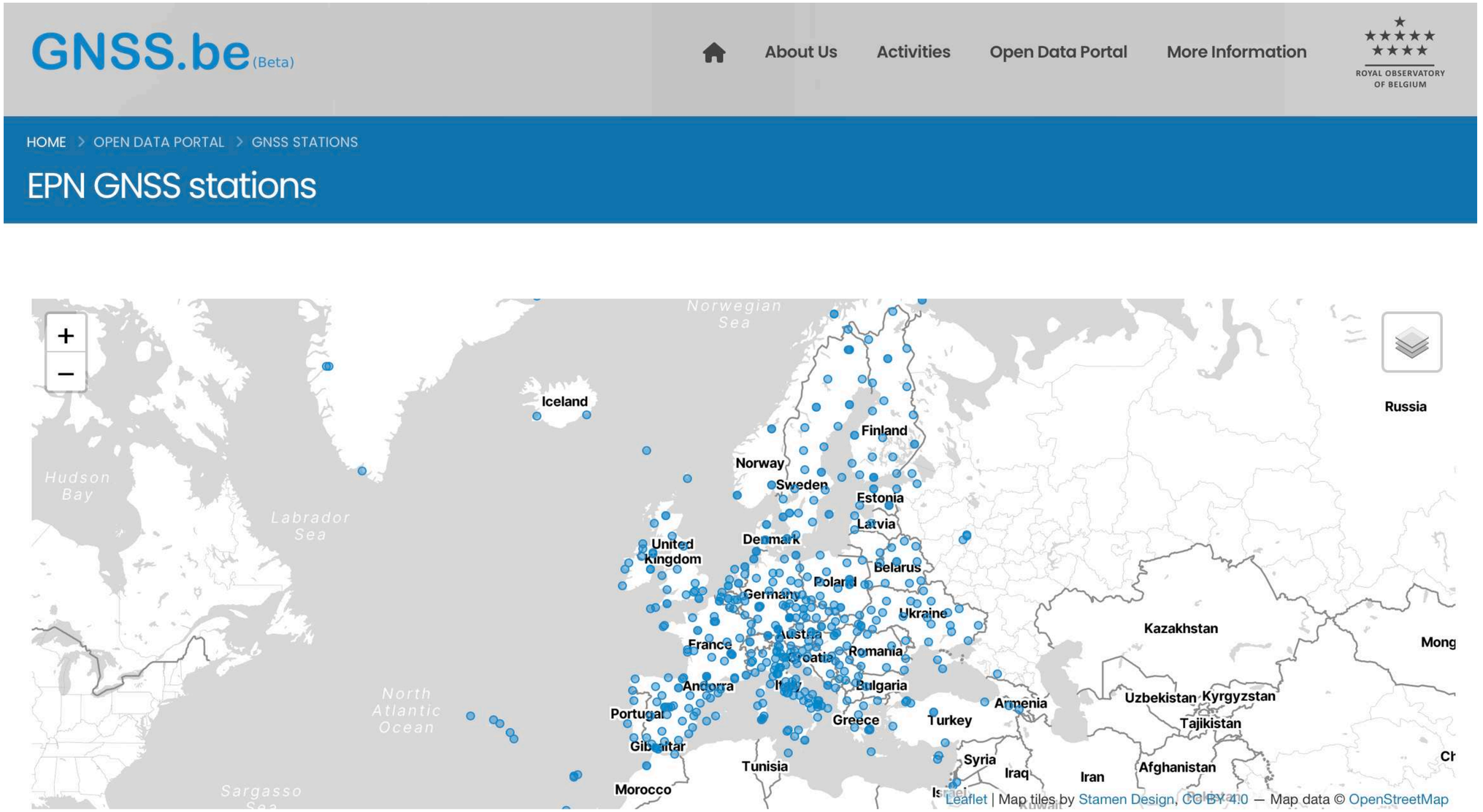
Global Assimilative Model of Bottomside Ionosphere Timelines (GAMBIT) Database and Explorer holding 15 years worth of IRTAM computed maps at 15 minute cadence;.

ALL OPERATING AND UPCOMING GIRO SITES:

Current and prospective sites with inputs to assimilative models

ROYAL OBSERVATORY OF BELGIUM

How to measure Space Weather Impacts?



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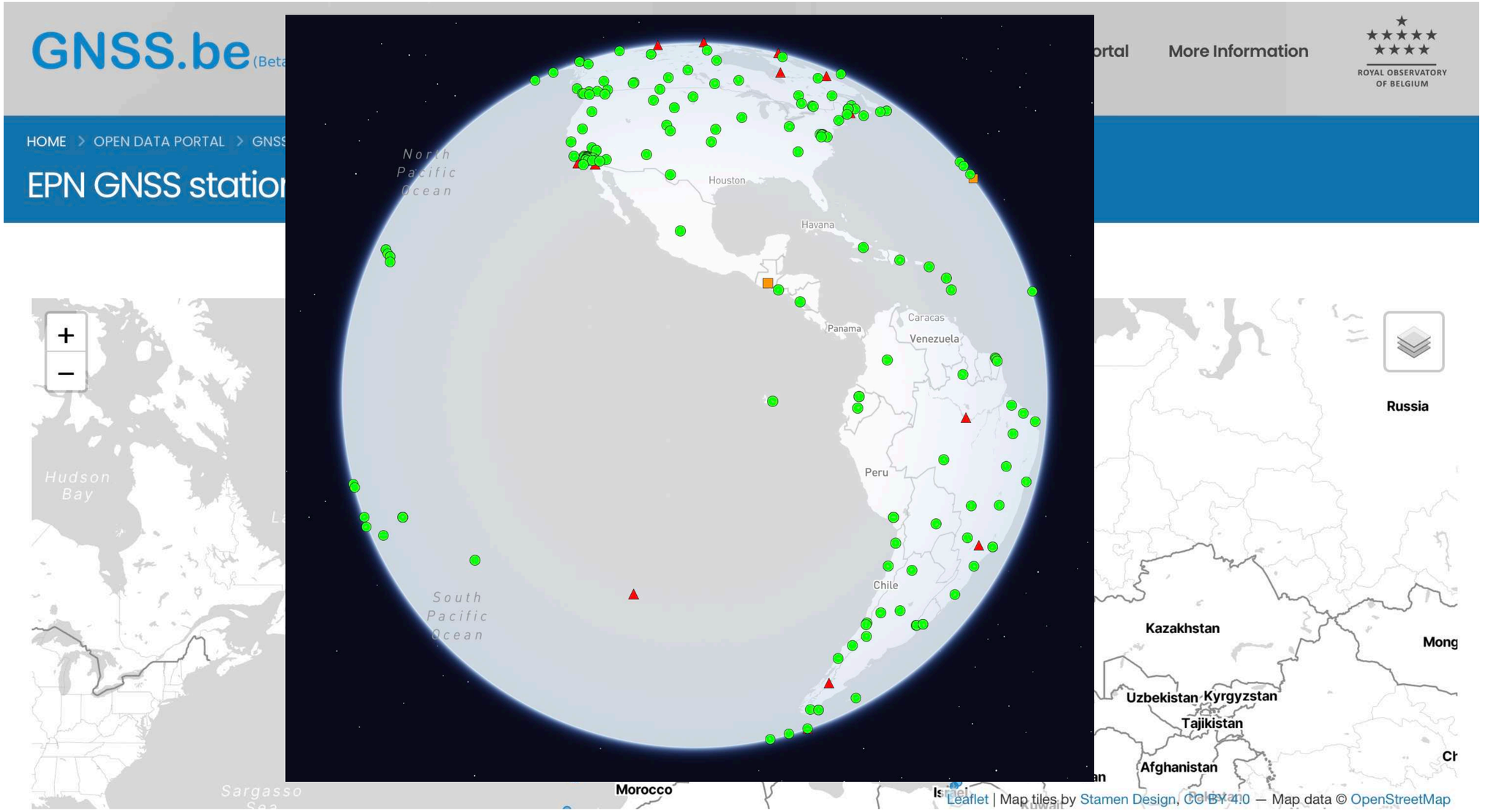

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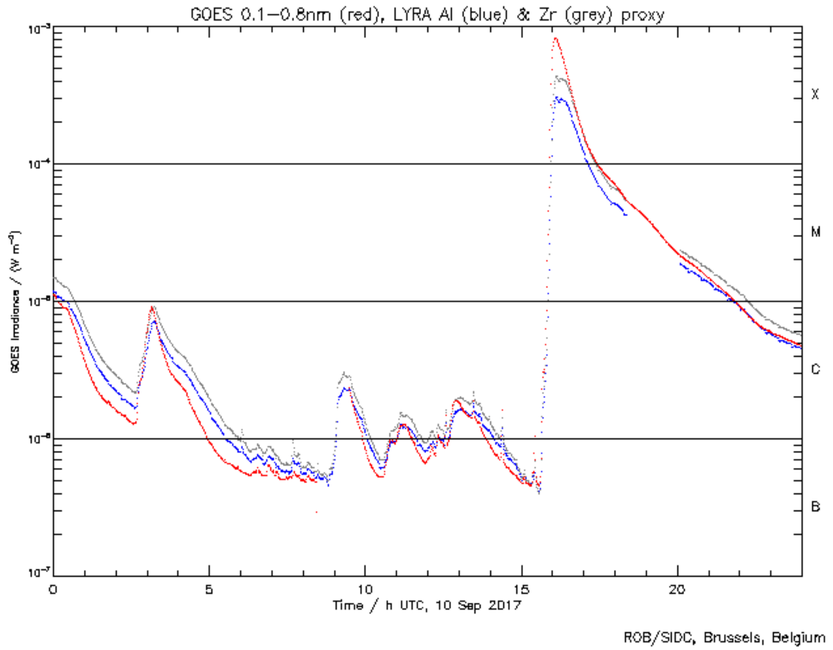
More ionospheric data sources

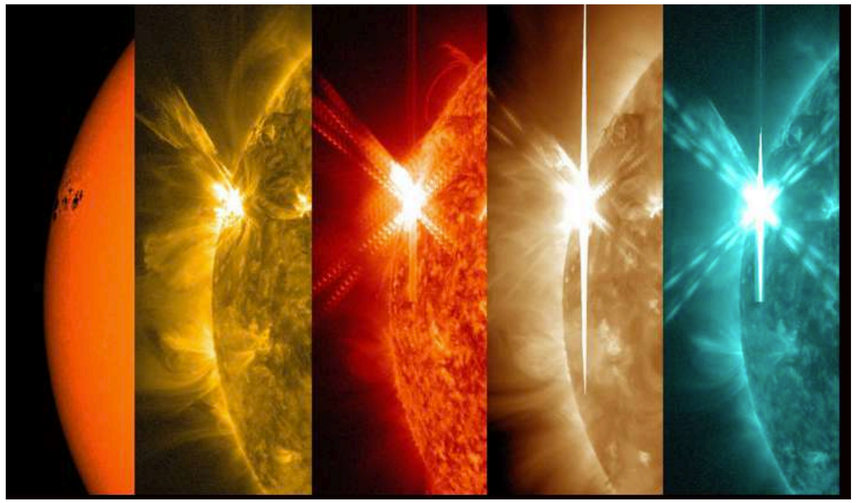
Auroral visible imaging	Obtain from all-sky imagers. Reuse of imaging systems such as the Finnish Meteorological Institute (FMI) realtime auroral cameras
Ionosphere	Sourced from ionospheric sounders such as the European Digital Upper Atmosphere Server (DIAS) network. Obtain complete global coverage through international cooperation agreements.
Ionospheric scintillation	Dedicated GNSS receivers for scintillation monitoring. Detectors capable of sampling at the frequency required for scintillation measurement are less widely available and further deployment at high and low latitudes should be considered.
Ionospheric electric field	Inchoherent/coherent radar network such as the Super Dual Auroral Radar Network (SuperDARN) and from the European Incoherent SCATter Scientific Association (EISCAT)
Ionospheric radio absorption	From riometer networks. Reuse existing assets such as AAR/AIRS in Norway, IRIS in Finland and NORSTAR in Canada

ROYAL OBSERVATORY OF BELGIUM

How to link SWX drivers and impacts?

Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 ($2x10^{-3}$)	Fewer than 1 per cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)





NOAA scales

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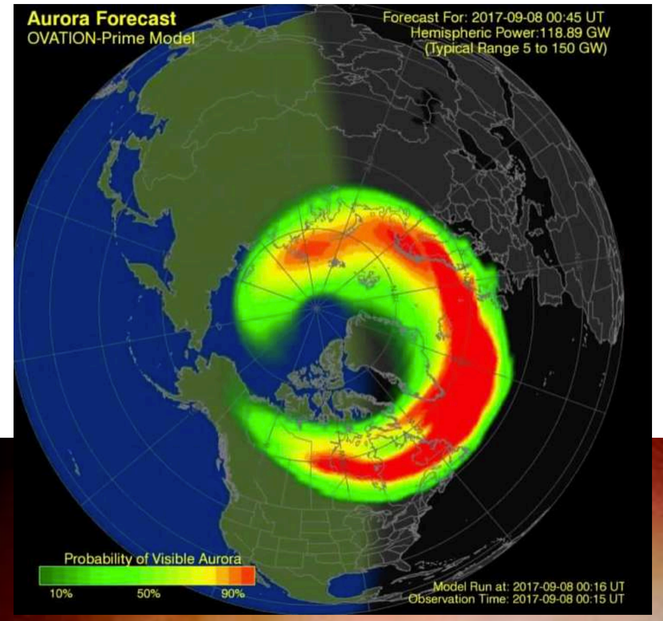
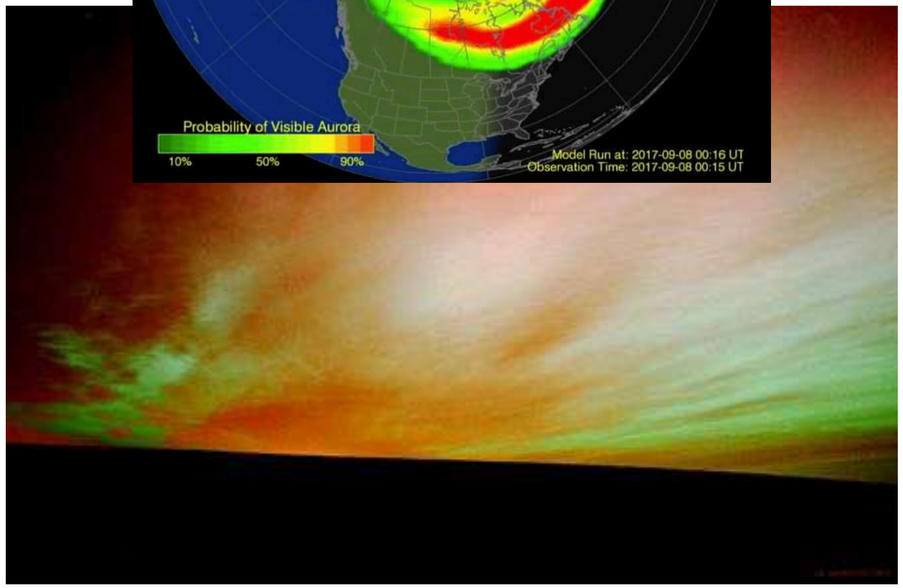
How to link SWX drivers and impacts?

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**.	Kp=9	4 per cycle (4 days per cycle) **Carrington 1959 Bastille Day 2000 Halloween 2003 Mother's day 2024**
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.)**.	Kp=8, including a 9-	100 per cycle (60 days per cycle) **2017 Event A few in 2023**
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**.	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**.	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**.	Kp=5	1700 per cycle (900 days per cycle)

Possible Impacts of Geomagnetic storms on Earth





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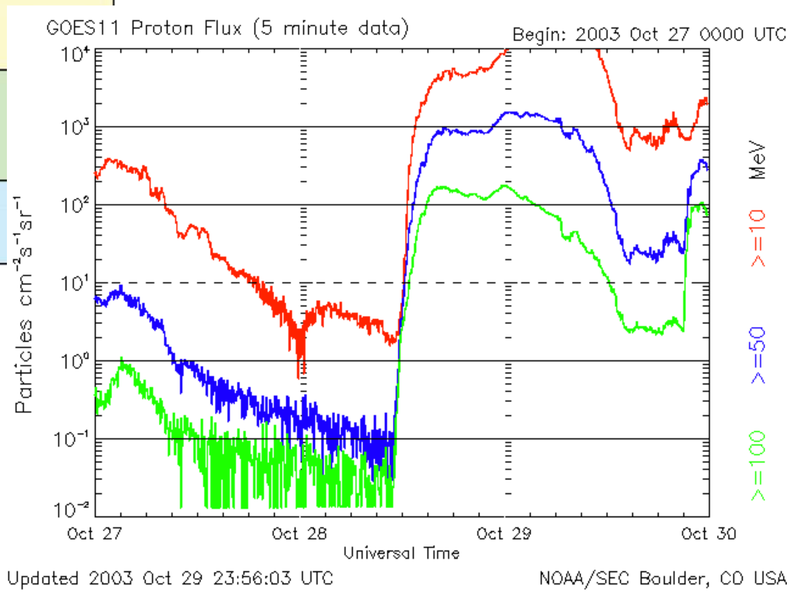
How to link SWX drivers and impacts?

Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); high radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 100 chest x-rays) is possible. Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle **Halloween 2003**
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; elevated radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 10 chest x-rays) is possible. Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in commercial jets at high latitudes may receive low-level radiation exposure (approximately 1 chest x-ray). Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: none. Satellite operations: infrequent single-event upsets possible. Other systems: small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle **April 23rd 2023** **April, May 2024**
S 1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

Halloween 2003



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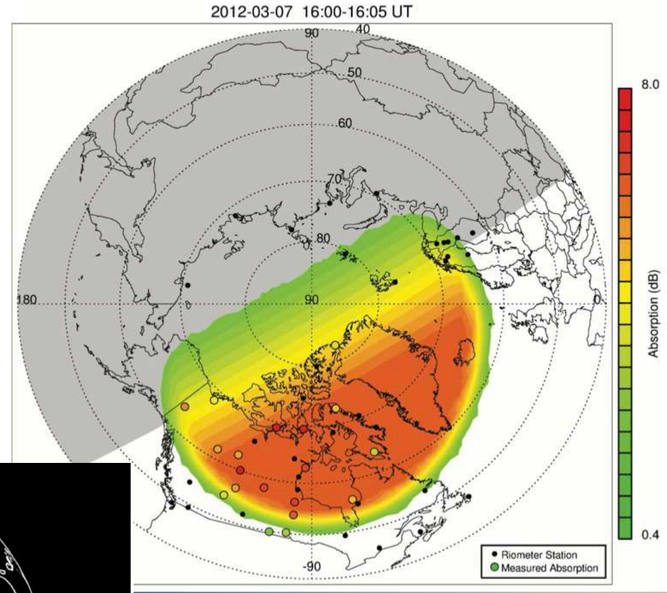
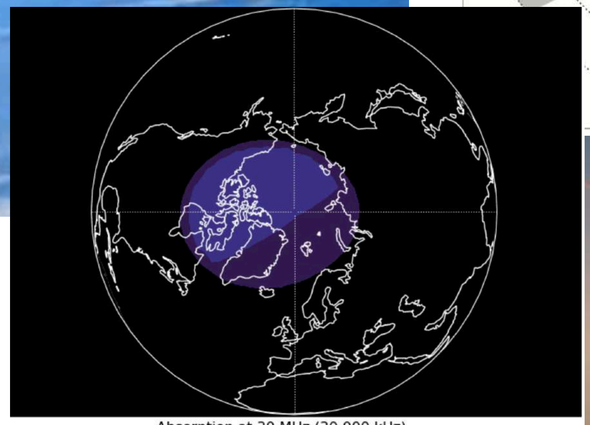
Impacts of Solar Energetic Particles





- Satellite malfunction (SEE)
- Satellite loss
- HF com PCA
- Increased radiation exposure
- Astronaut radiation exposure

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EXERCISE 1: Understanding of SWX Terminology

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EXERCISE 1

MUF, FoF2, AS/PS, TEC (STEC, VTEC), ROTI, Kp, SWF, AA, PCA, GLE, GIC, SEP, SRB

- Definiton
- Which SWX driver it relates to?
- Relation to SWX impacts
- Where it occurs/impacts?
- How do we measure/quantify?
- Units
- Other