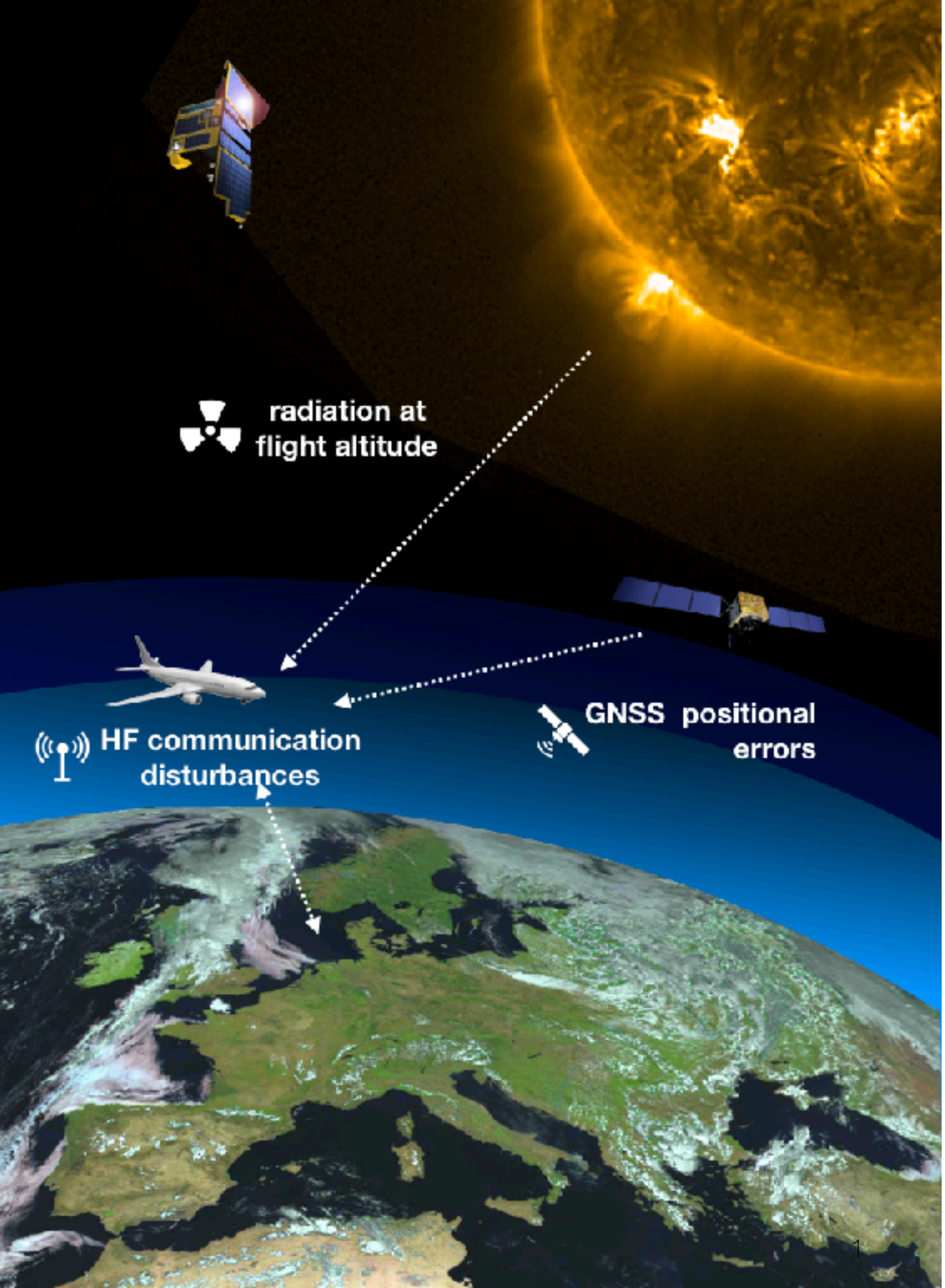

SWx for aviation

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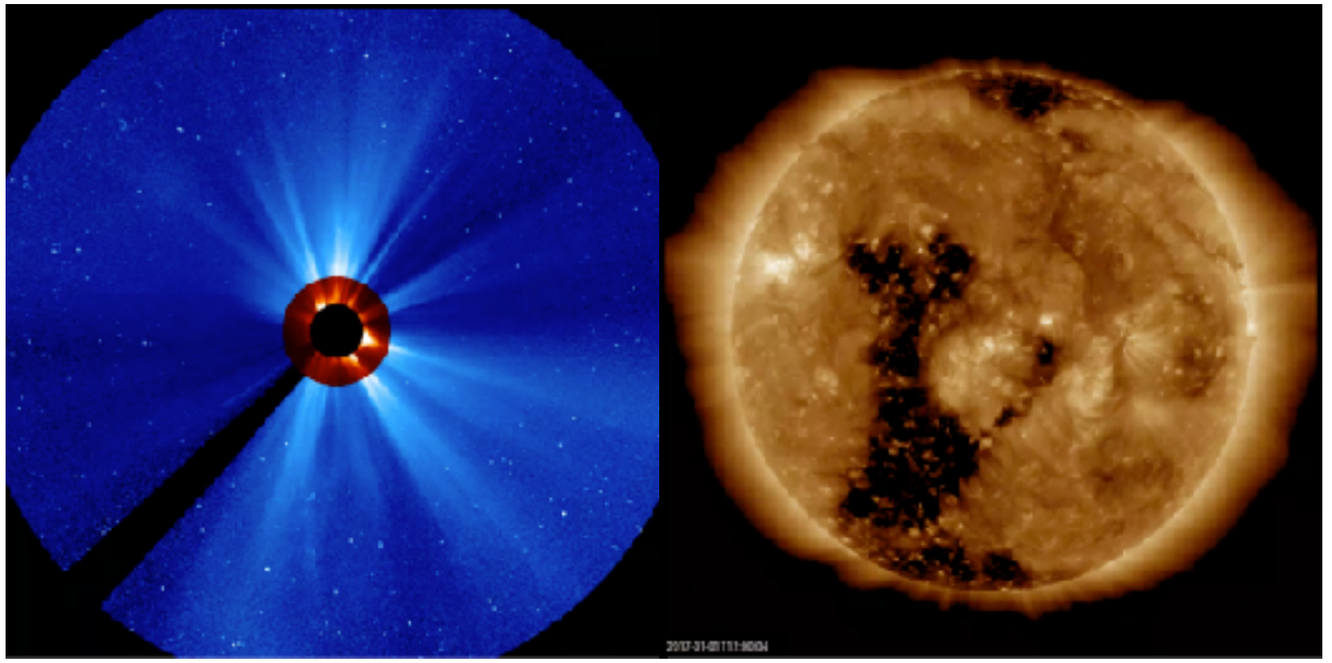
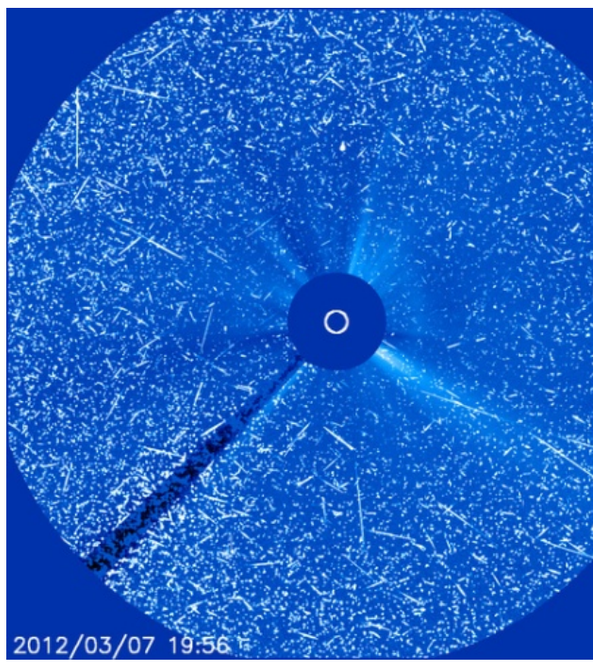
SOLAR STORMS

At a certain moment, energy might be released on a shorter time scale. Space weather is the change that occur on the Sun or in the space environment. This chance might be in an abrupt, impulsive and brutal way (flare, Coronal Mass Ejection, proton storm) or in a non-eruptive manner (Coronal Hole).





FLARE

SOLAR WIND DISTURBANCES

PARTICLE STORM

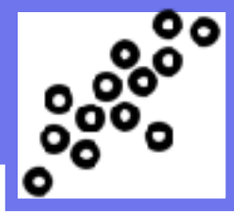
SPACE WEATHER

Our atmosphere and magnetosphere can respond in a dramatic way to solar storms. A solar storm can initiate space weather processes in our atmosphere and magnetosphere who can respond in a dramatic way. This impact is measured near or on Earth and results in 3 sorts of space weather storms.

Radio blackout

Geomagnetic storm

Solar radiation storm



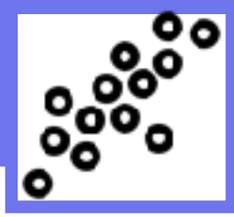
AREA OF IMPACT

Note that the solar wind can change the geomagnetic field by reconnection processes. This is because the solar wind is magnetised. Charged particles follow simply the magnetic highways.

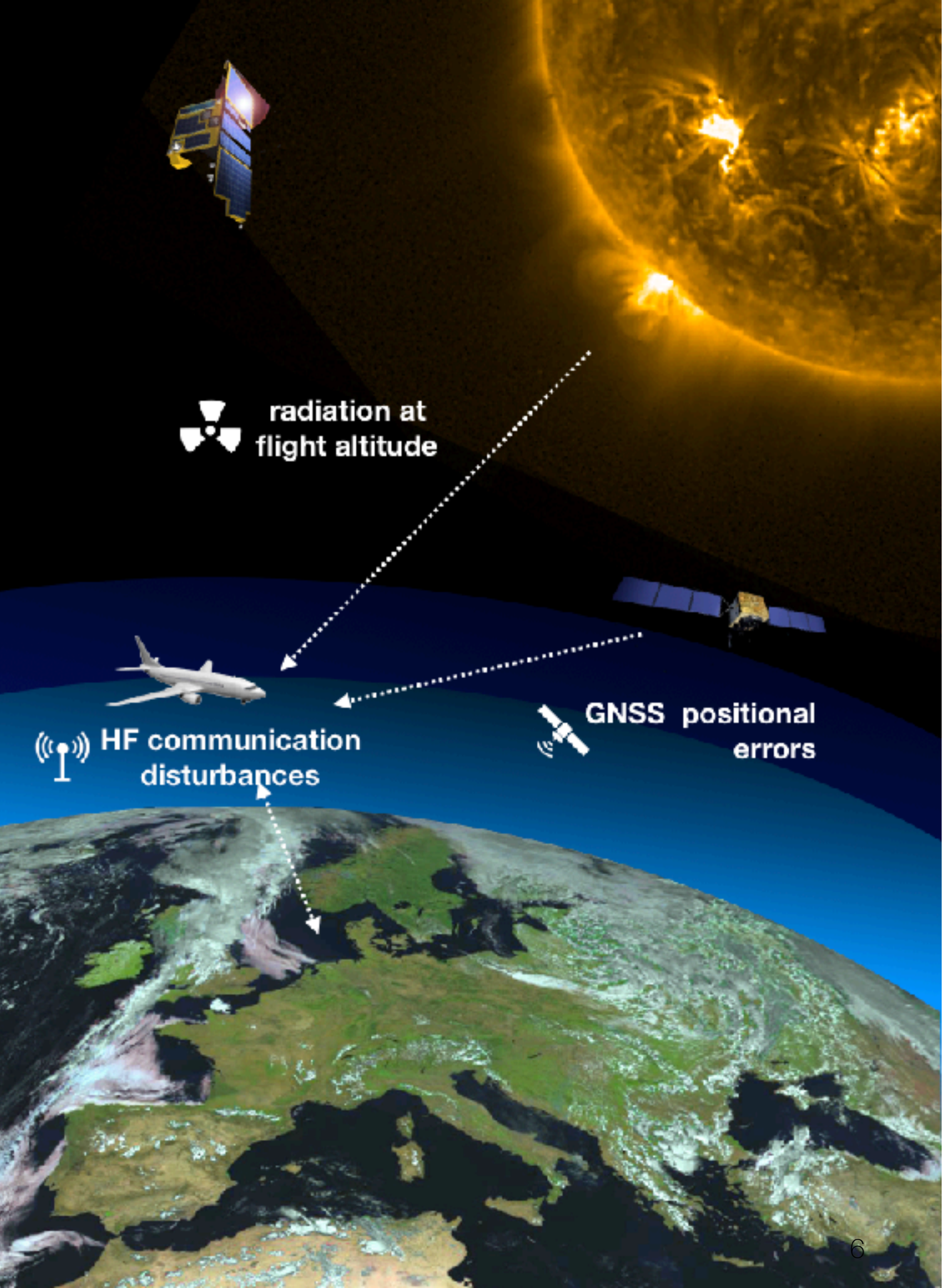
Illuminated area

Latitude

Altitude




PECASUS
FOR ICAO



Storm parameters

Thresholds

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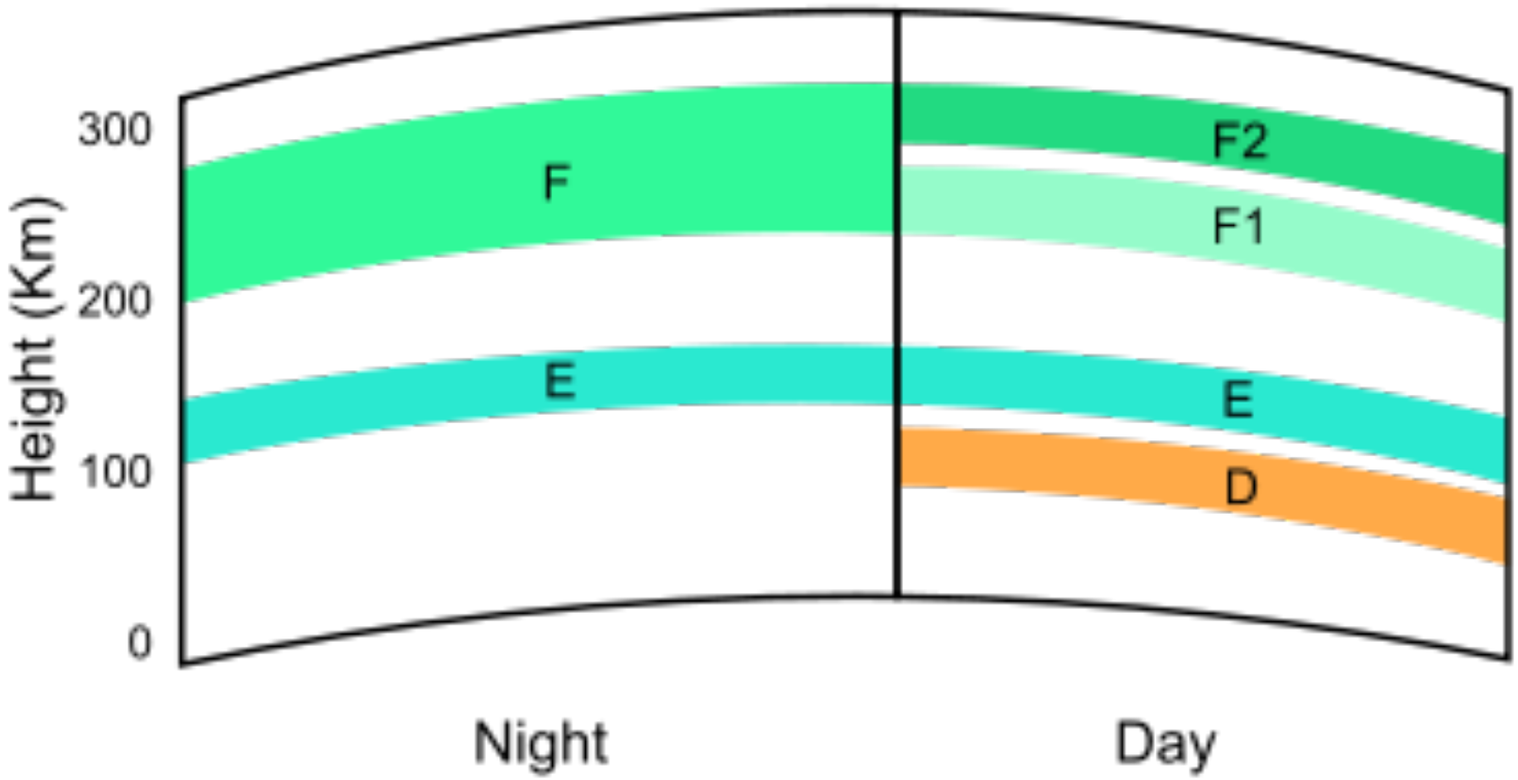
IONOSPHERE

Atmospheric layer with free electrons.

Ionization by solar x-ray and extreme ultraviolet radiation.

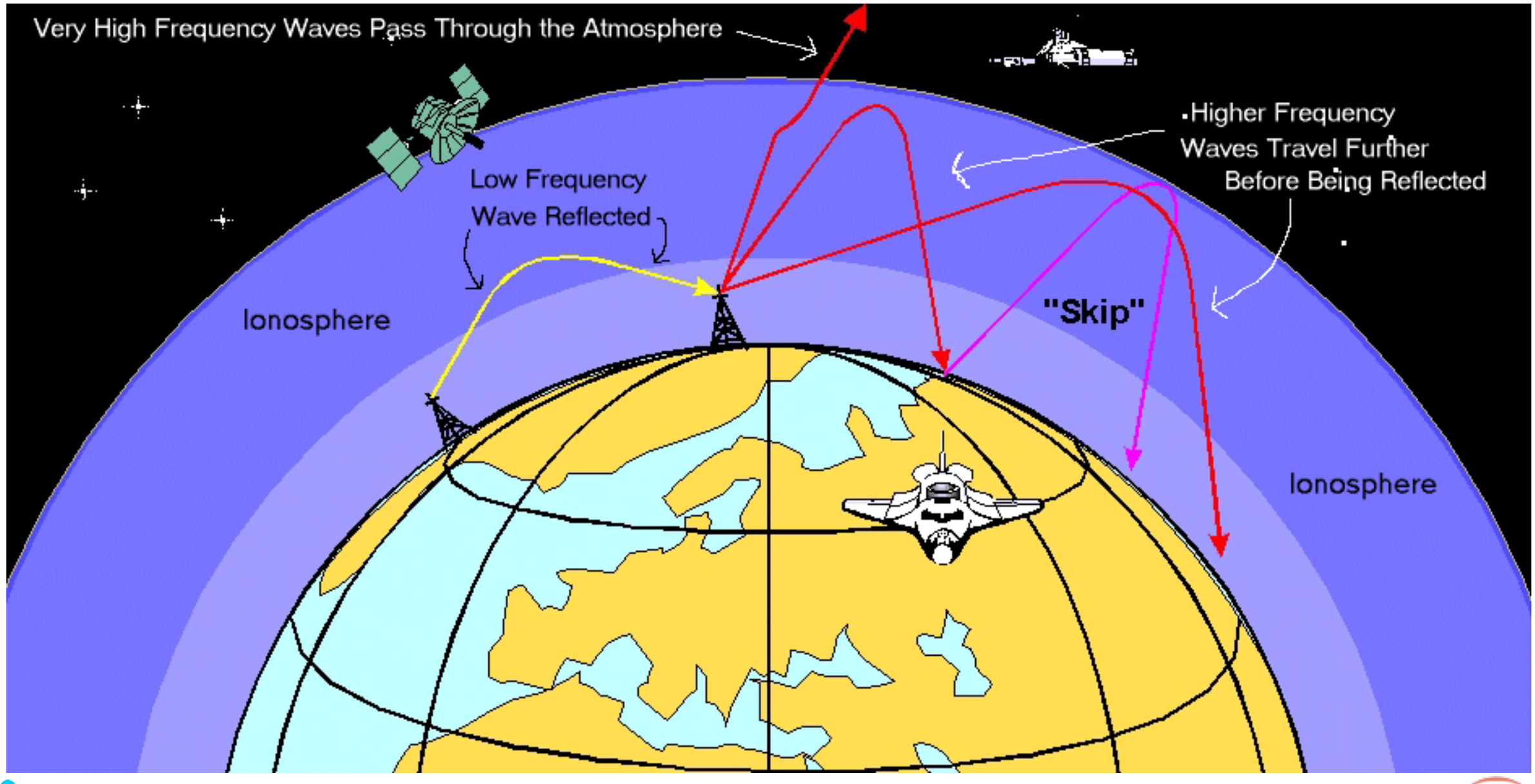
RADIO WAVES AND IONOSPHERE

The electron content of each layer defines a characteristic frequency which in turn affects the refractive index of the medium. Each layer will reflect or absorb radio waves depending on their frequencies.The reflection is used for long distance communications

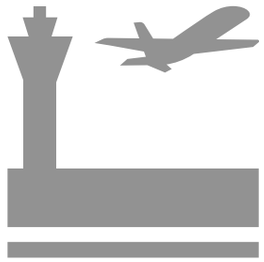


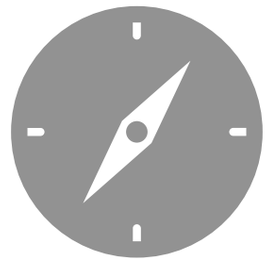
RADIO WAVES & IONOSPHERE

The ionosphere seems to be the key-layer for HF communication and GNSS performance: or radio waves are reflected at, or pass through the ionosphere.



FREQUENCIES USED IN AVIATION

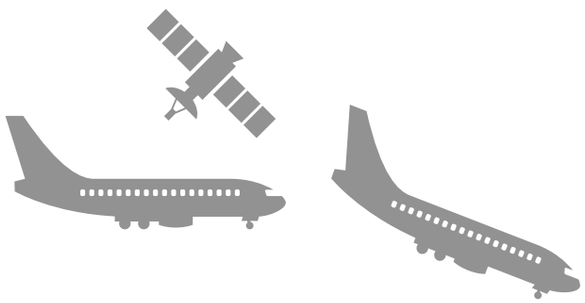




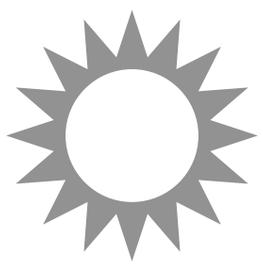
Surveillance
SSR 1030 - 1090 MHz
PSR 1215 -1350 MHz
2700 - 2900 MHz

Communications
118 - 137 MHz
226 - 400 MHz
410 - 450 MHz

GNSS
GPS
GALILEO
GLONASS
1164 - 1610 MHz



Solar activity
Solar radio bursts



Navigation
960 - 1215 MHz
329 - 335 MHz
108 - 118 MHz
75 MHz

Solar activity
Solar Xray flares
Geomagnetic storms
Proton events

Long distance communication & data link
2.8 - 22 MHz

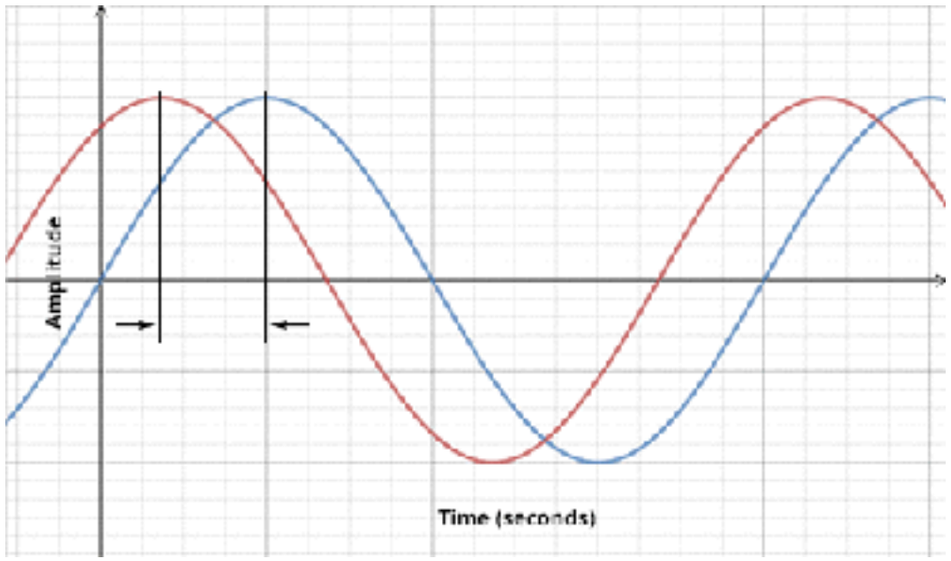
GNSS - GLOBAL NAVIGATION SATELLITE SYSTEM

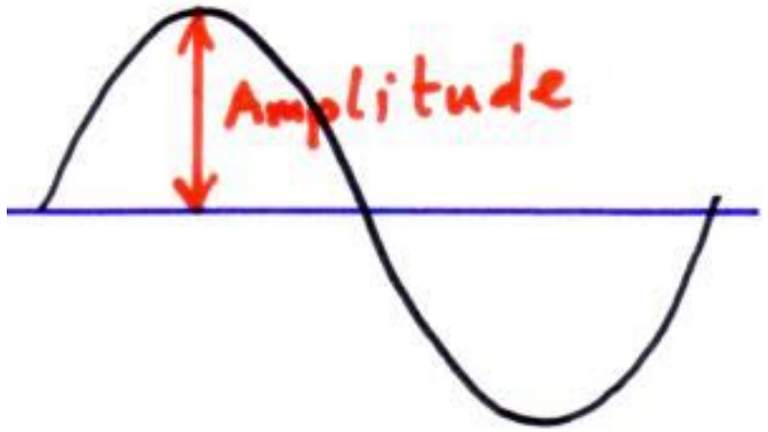
GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
Amplitude Scintillation	0.5	0.8	2020-10-12 14:15	0.25	QUIET		0.35	QUIET
Phase Scintillation	0.4	0.7	2020-10-12 14:15	0.13	QUIET		0.14	Q
Vertical TEC	125	175	2020-10-12 14:15	61.92	QUIET		61.93	QUIET

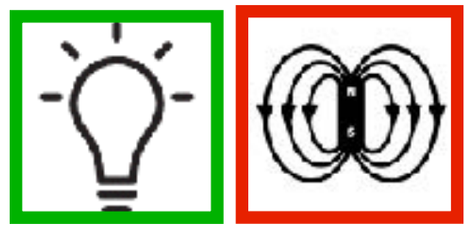
RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
Effective Dose FL≤460	30	80	2020-10-12 14:20	0	QUIET		0	QUIET
Effective Dose FL > 460	/	80	2020-10-12 14:20	0	QUIET		0	QUIET

HF COM	Moderate	Severe	Time UTC	Values/Flags	Status	Alert	Max-3h values	Max-3h status
Auroral Absorption (AA)	8	9	2020-10-12 14:16	3.0	QUIET		3.0	QUIET
Polar Cap Absorption (PCA)	2	5	2020-10-12 14:20	0.00	QUIET		0.00	QUIET
Shortwave Fadeout (SWF)	x1.0	x10.0	2020-10-12 14:17	< M.5-flare	QUIET		< M.5-flare	QUIET
Post-Storm Depression (PSD)	30%	50%	2020-10-12 14:15	0	QUIET		0	QUIET

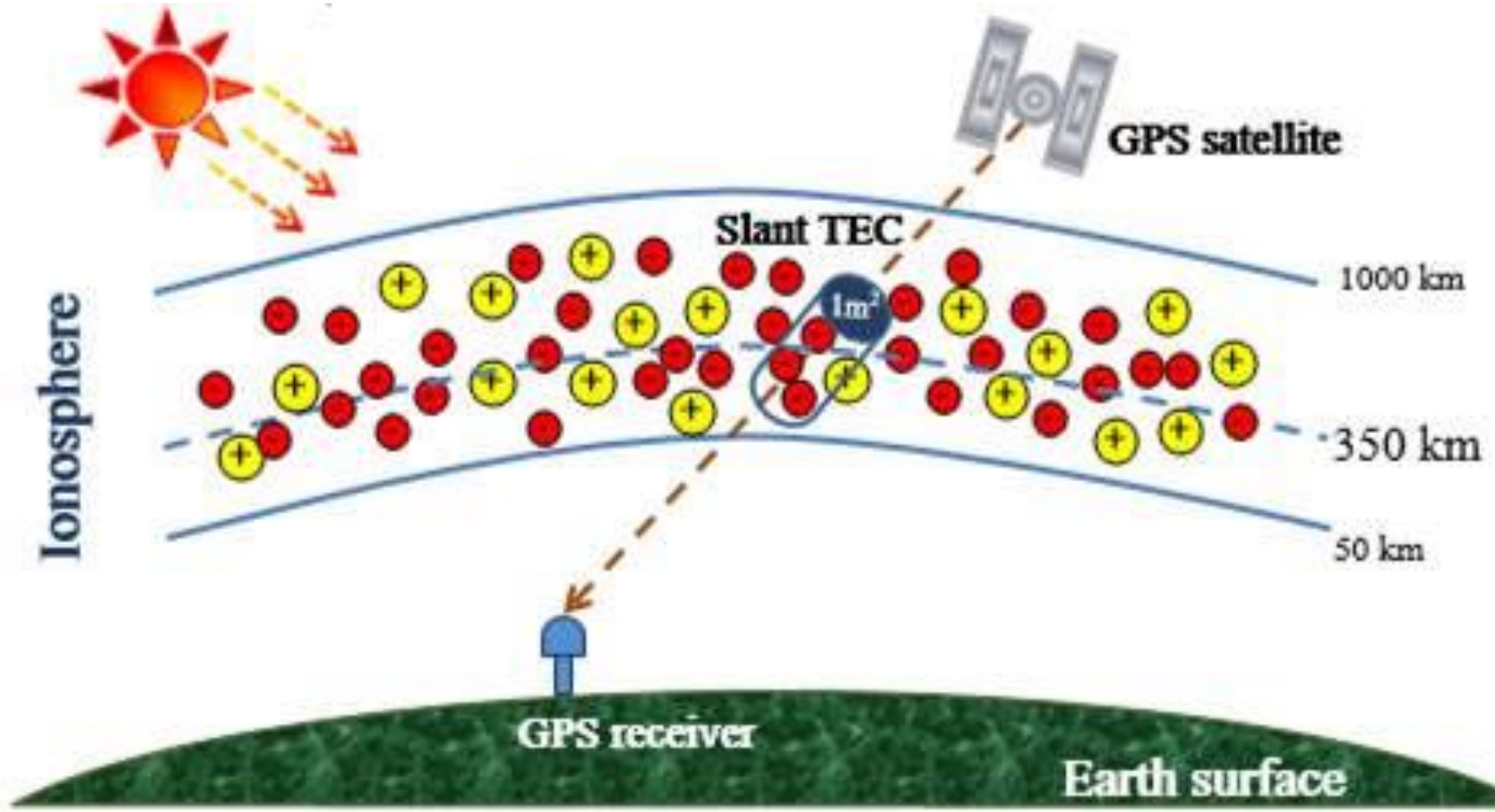
IONOSPHERIC SCINTILLATION

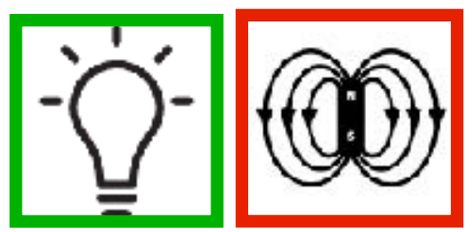


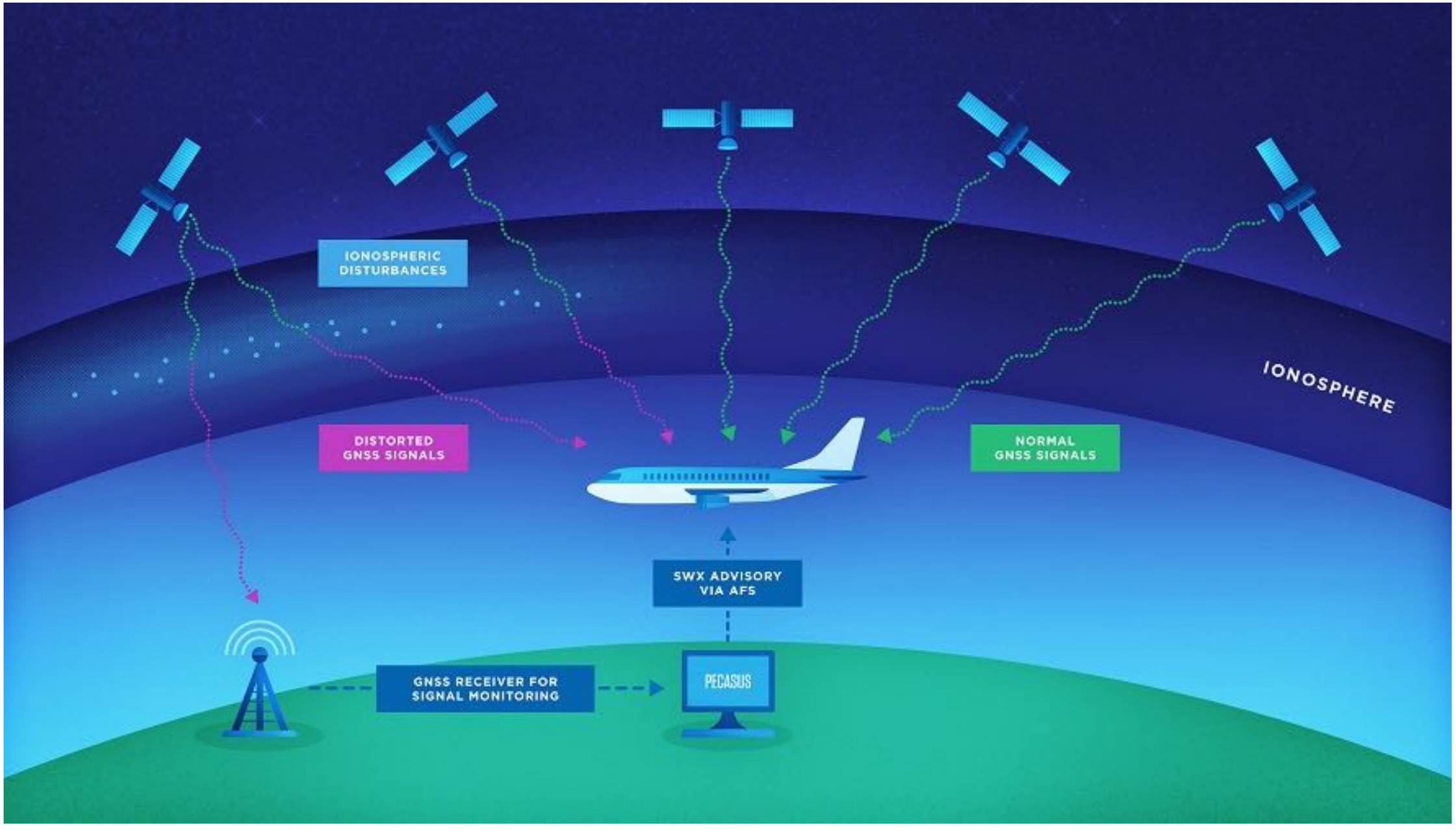




VERTICAL TEC






IONOSPHERIC
DISTURBANCES
IONOSPHERE
DISTORTED
GNSS SIGNALS
NORMAL
GNSS SIGNALS
SWX ADVISORY
VIA AFS
GNSS RECEIVER FOR
SIGNAL MONITORING
PECASUS

RADIATION

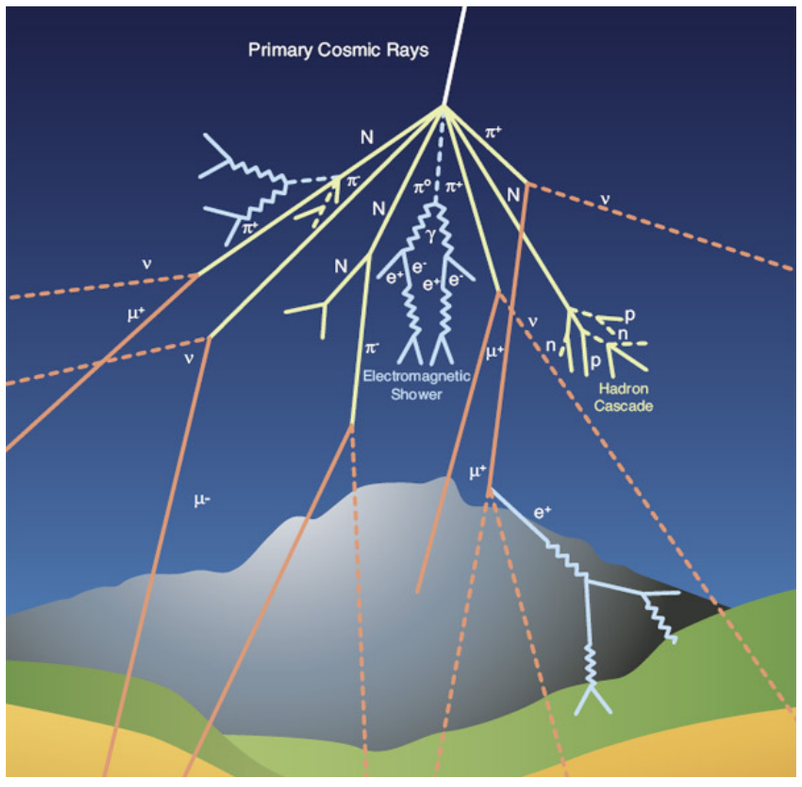
GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
Amplitude Scintillation	0.5	0.8	2020-10-12 14:15	0.25	QUIET		0.35	QUIET
Phase Scintillation	0.4	0.7	2020-10-12 14:15	0.13	QUIET		0.14	QUIET
Vertical TEC	125	175	2020-10-12 14:15	61.92	QUIET		61.93	QUIET

RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
Effective Dose FL≤460	30	80	2020-10-12 14:20	0	QUIET		0	QUIET
Effective Dose FL > 460	/	80	2020-10-12 14:20	0	QUIET		0	QUIET

HF COM	Moderate	Severe	Time UTC	Values/Flags	Status	Alert	Max-3h values	Max-3h status
Auroral Absorption (AA)	8	9	2020-10-12 14:16	3.0	QUIET		3.0	QUIET
Polar Cap Absorption (PCA)	2	5	2020-10-12 14:20	0.00	QUIET		0.00	QUIET
Shortwave Fadeout (SWF)	x1.0	x10.0	2020-10-12 14:17	< M.5-flare	QUIET		< M.5-flare	QUIET
Post-Storm Depression (PSD)	30%	50%	2020-10-12 14:15	0	QUIET		0	QUIET

ATMOSPHERIC RADIATION ENVIRONMENT

The radiation environment at aviation altitudes is shaped mainly by Galactic Cosmic Radiation (GCR) and occasional Solar Radiation Storm (SEP - Solar Energetic Particles), both phenomena comprised of high energetic particles.



Galactic Cosmic Rays (GCR) → Background radiation
- Always present
- Protons + heavy ions
- Global

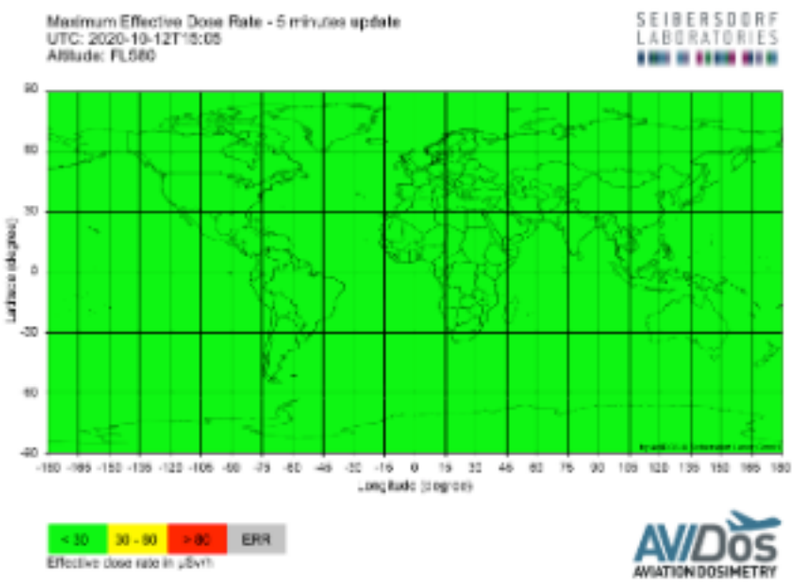
Solar Energetic Particles (SEP) → Increased radiation exposure !!
- Sporadic (solar storms)
- Mainly protons
- High latitude regions

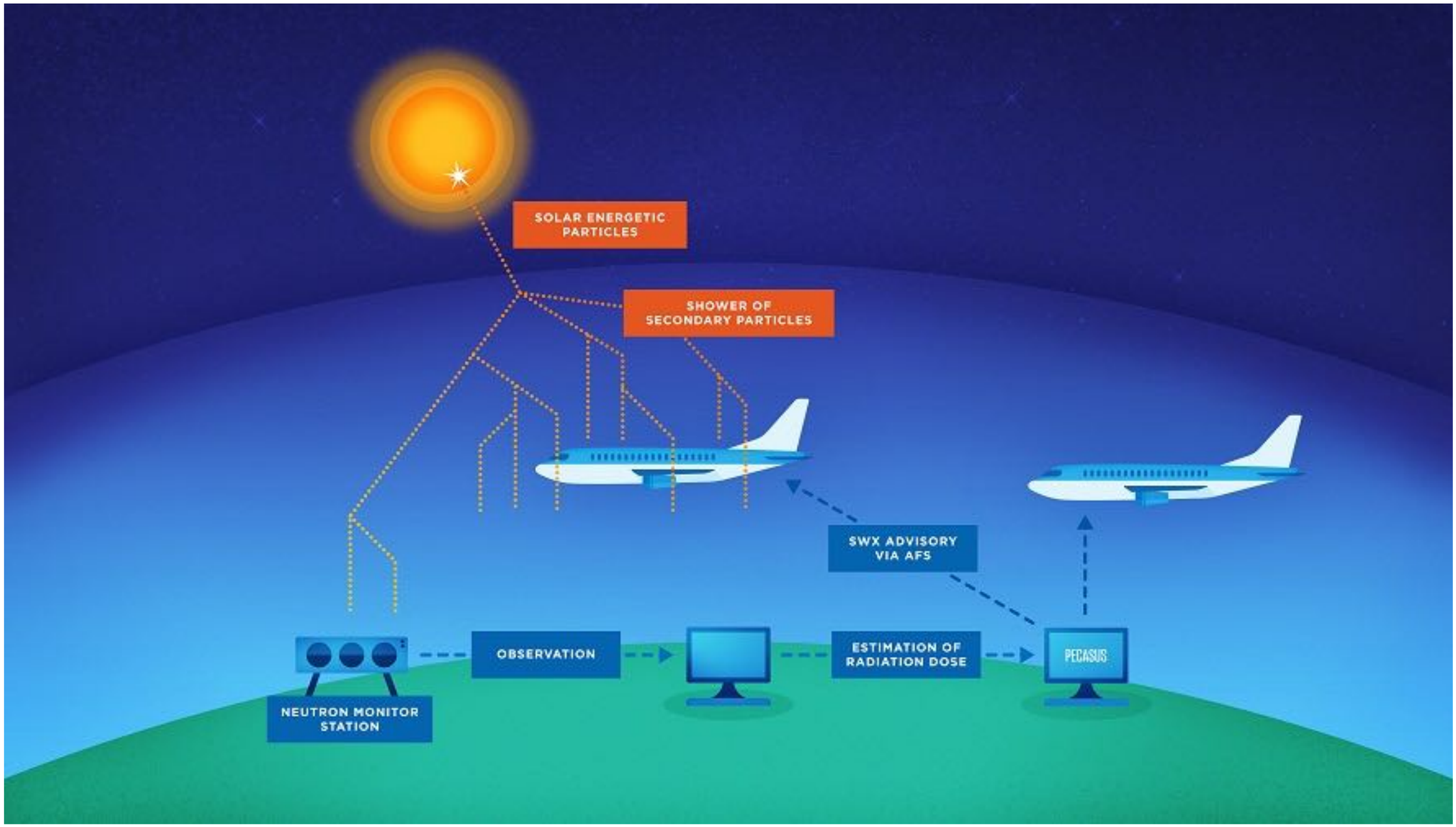
Secondary particles:
- **Neutrons**
- Protons
- Muons
- Pions
- Photons
- Electrons/positrons

RADIATION -$\mu Sv/h$

During a strong Solar Radiation Storm, a Ground Level Enhancement (GLEs) may occur. A GLE is sudden increase in the cosmic ray intensity recorded by ground based detectors. Radiation at FLV in particular latitude bands will increase.

What?	Strong Solar Radiation Storm
Consequences	Increased radiation
What to monitor	micro-Sieverts/hour




SOLAR ENERGETIC PARTICLES
SHOWER OF SECONDARY PARTICLES
SWX ADVISORY VIA AFS
NEUTRON MONITOR STATION
OBSERVATION
ESTIMATION OF RADIATION DOSE
PEGASUS

HF COM

GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
Amplitude Scintillation	0.5	0.8	2020-10-12 14:15	0.25	QUIET		0.35	QUIET
Phase Scintillation	0.4	0.7	2020-10-12 14:15	0.13	QUIET		0.14	QUIET
Vertical TEC	125	175	2020-10-12 14:15	61.92	QUIET		61.93	QUIET

RADIATION	Moderate	Severe	Time UTC	Flags	Status	Alert	Max-3h flags	Max-3h status
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HF COM	Moderate	Severe	Time UTC	Values/Flags	Status	Alert	Max-3h values	Max-3h status
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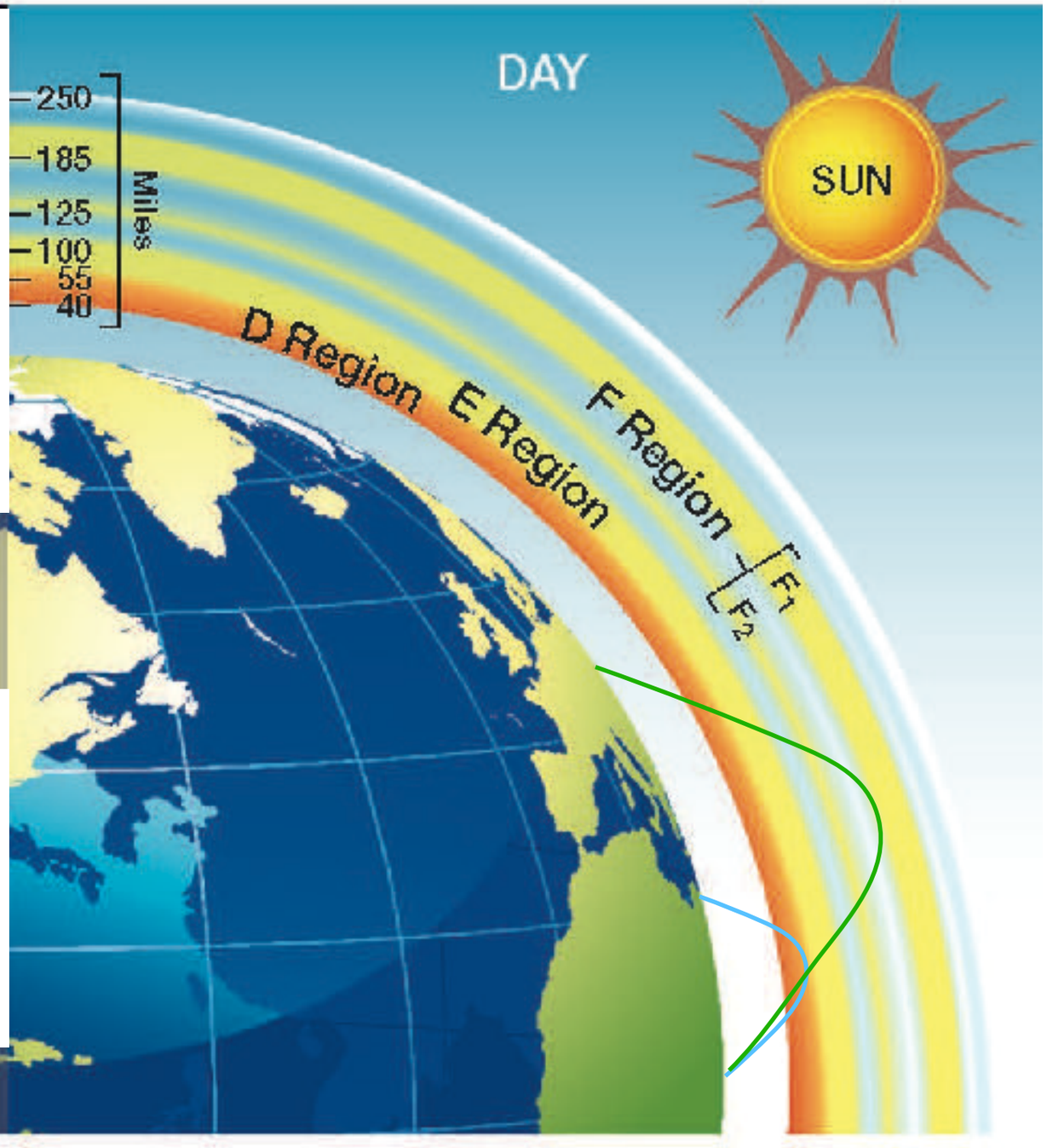
Post-Storm Depression (PSD)	30%	50%	2020-10-12 14:15	0	QUIET		0	QUIET

Radio Waves & Ionosphere

The electron content of each layer defines a critical frequency which in turn affects the refractive index of the medium

$$f_p \propto \sqrt{n}_o \qquad n = \sqrt{1 - \frac{f_p^2}{f^2}}$$

Each layer will reflect or absorb or let pass radio waves depending on their frequencies and on the characteristic frequency.



AURORAL ABSORPTION - KP

During geomagnetic storms, energetic particles will enter the polar regions of the ionosphere and trigger excess ionisation, triggering radio absorption, called an auroral absorption.

What?	Strong geomagnetic storms Kp>8
Consequences	radio fade out in both polar region
What to monitor	Kp indices

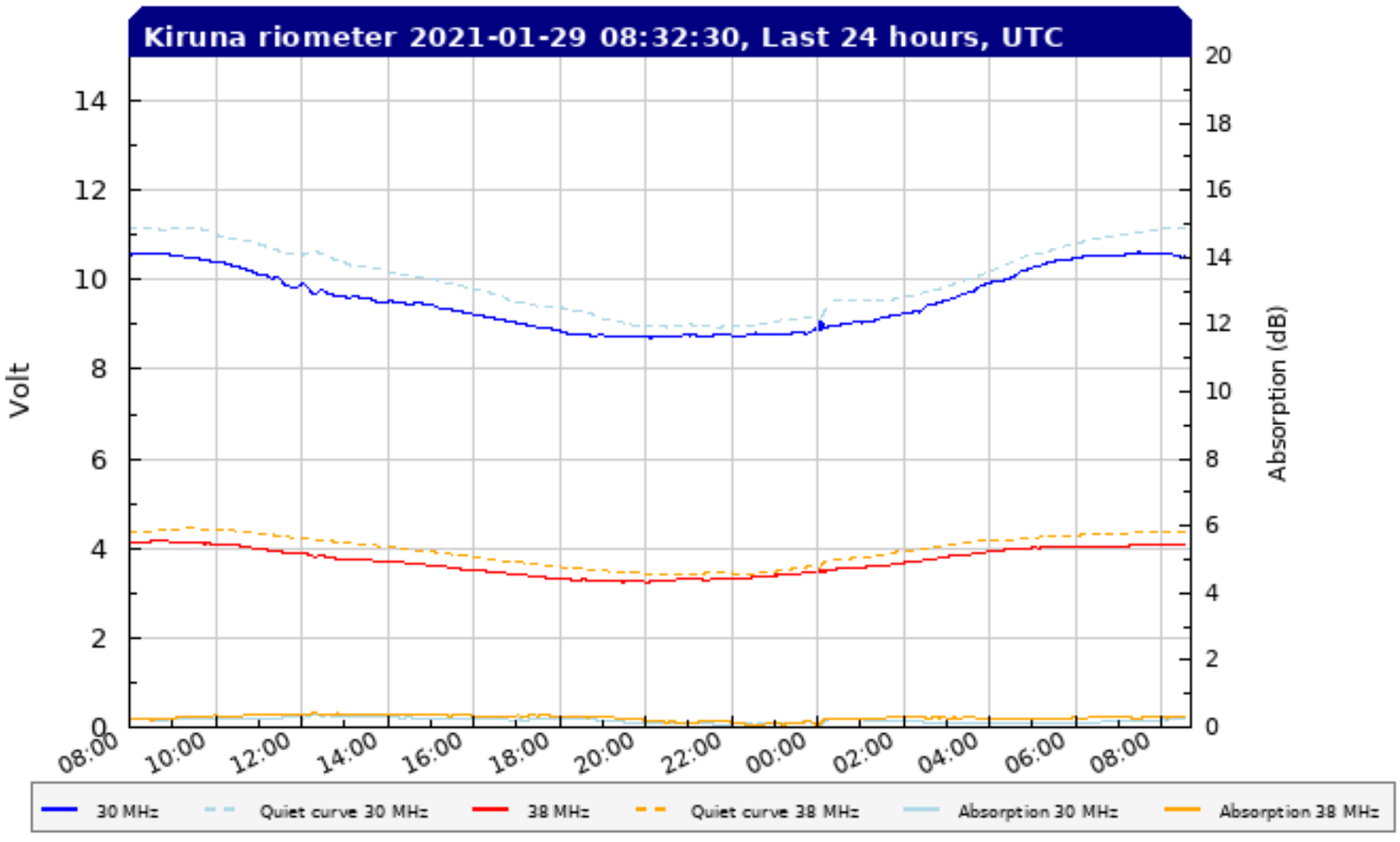
https://www.swpc.noaa.gov/products/planetary-k-index

Polar Cap Absorption

During proton events or solar radiation storms, energetic particles from the Sun will trigger extra ionisation of the D-layer in the polar regions inducing a radio fade out, called a Polar Cap Absorption.

What?	Solar radiation storm
Consequences	radio fade out in both polar regions
What to monitor	Absorption >2 dB

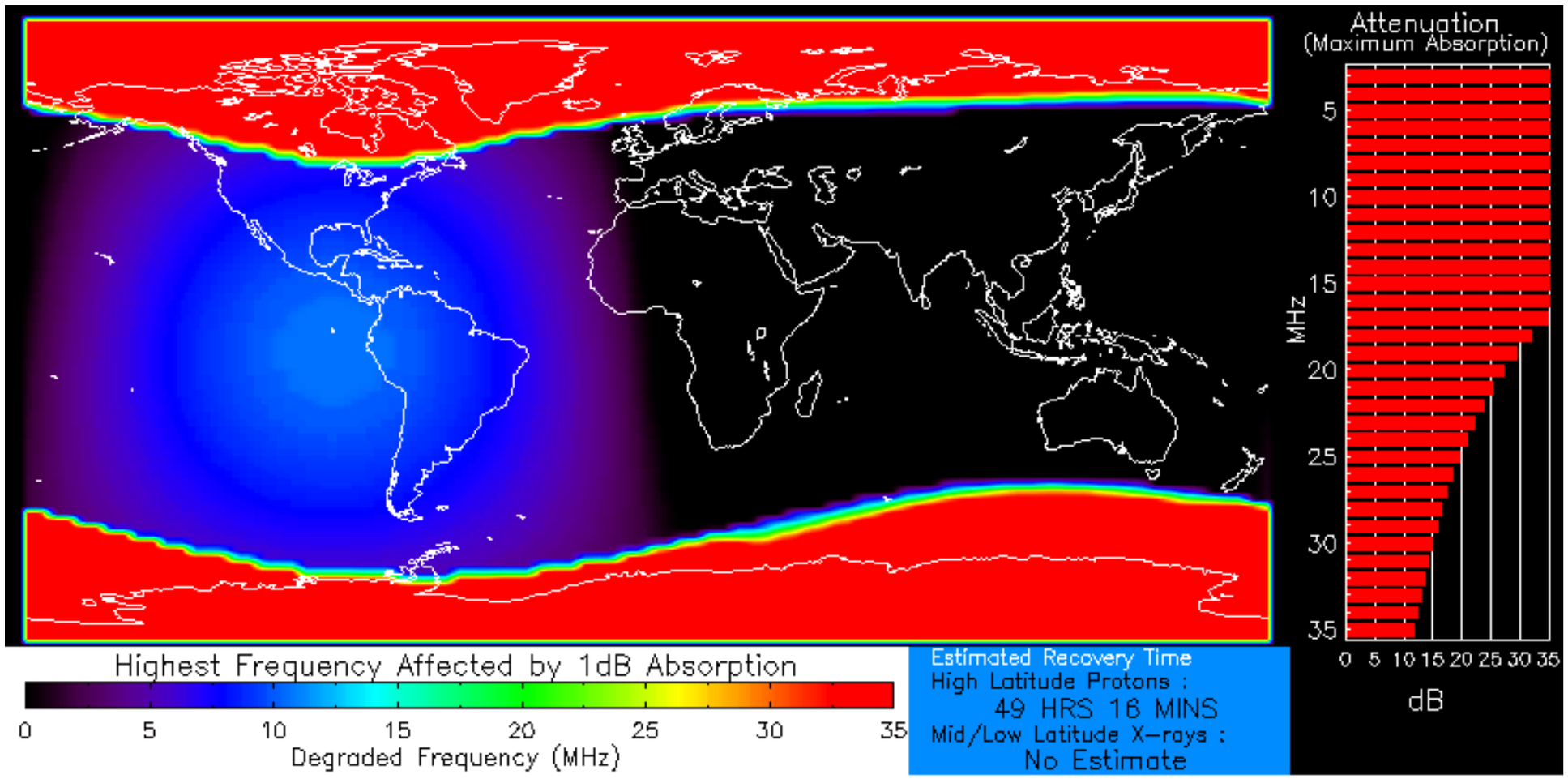
PCA - RIOMETERS



http://pecasus.stce.be/dashboards/pecaDashboard_HF_PCA.php?&time=2020-10-12+15:06

PCA - D-RAP MODEL

Conditions in the D-region of the ionosphere have a dramatic effect on HF communications. The global D-Region Absorption Predictions (D-RAP) depicts the D-region at high latitudes where it is driven by particles as well as low latitudes, where photons cause the prompt changes.



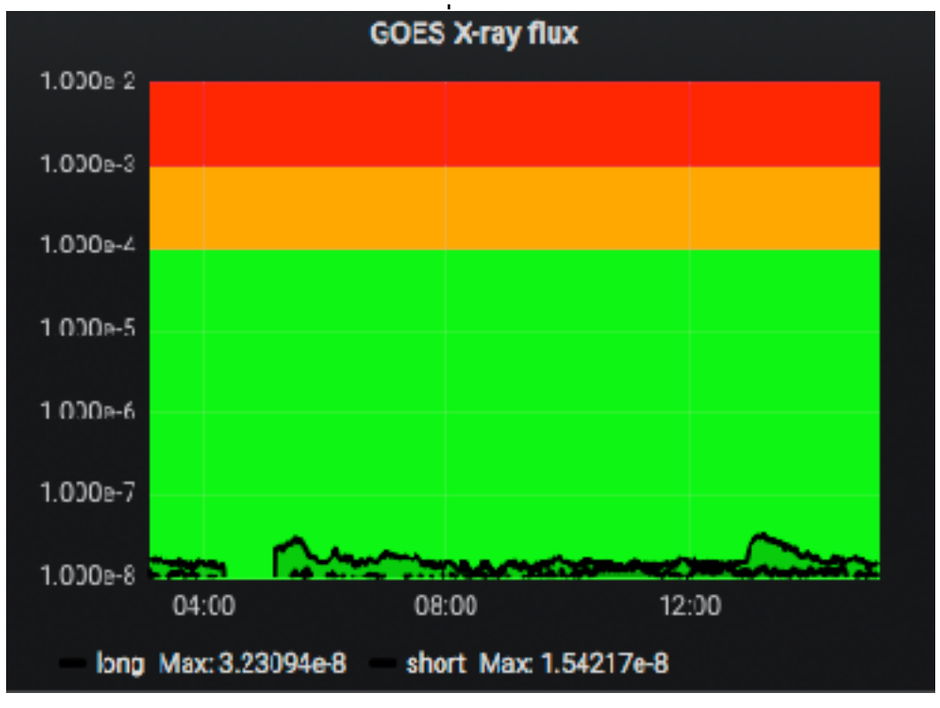
Normal X-ray Background
Product Valid At : 2012-03-07 18:00 UTC

Strong Proton Flux
NOAA/SWPC Boulder, CO USA

SHORT WAVE FADE OUT

The soft Xray flux increase will induce an excess ionisation of the D layer triggering an absorption of low HF frequencies (fade out).

What?	Strong flares (>X1)
Consequences	radio fade out in the Sun-lit hemisphere
What to monitor	GOES soft Xray flux



https://www.swpc.noaa.gov/products/goes-x-ray-flux

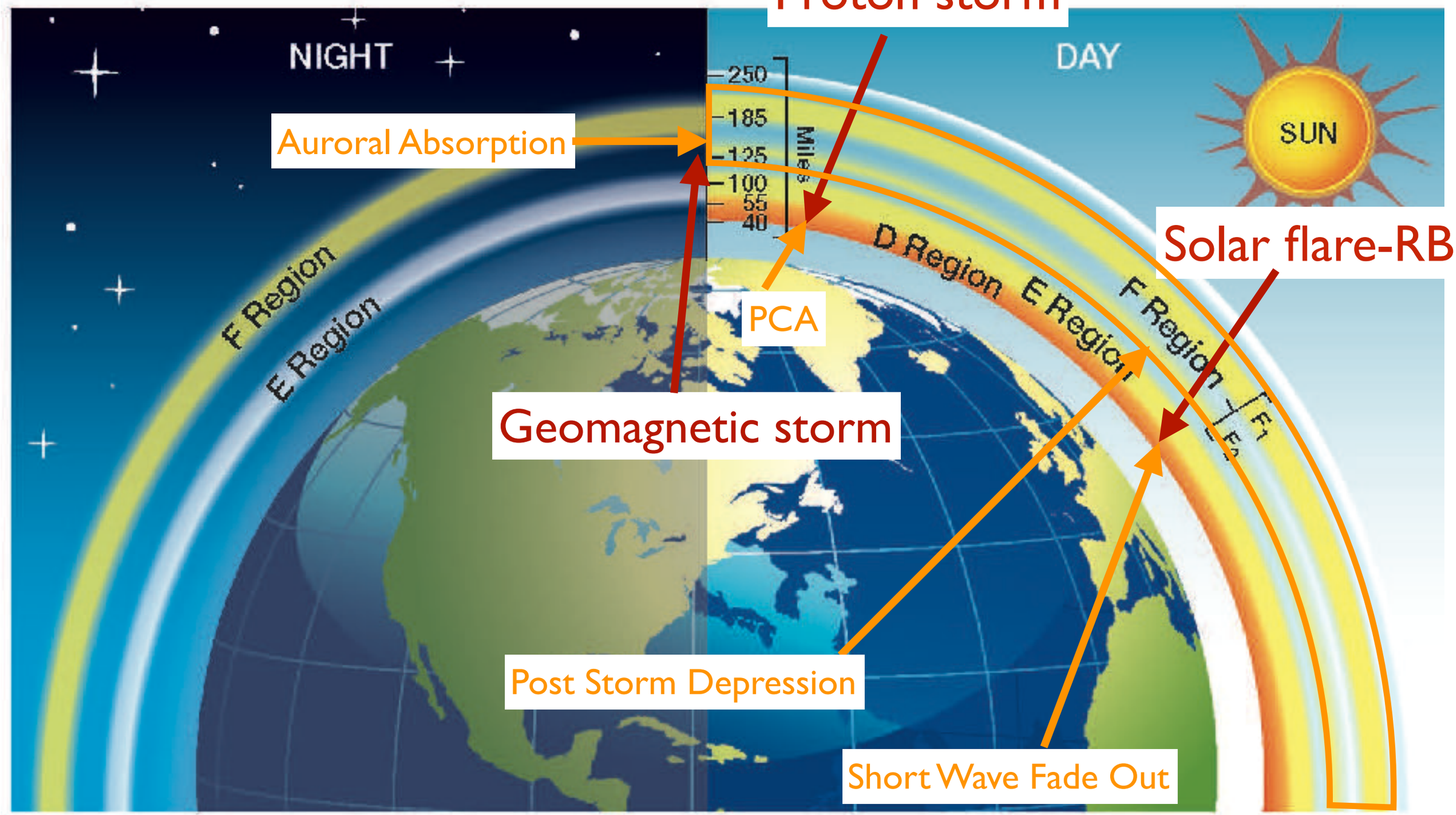
Post Storm Depressions

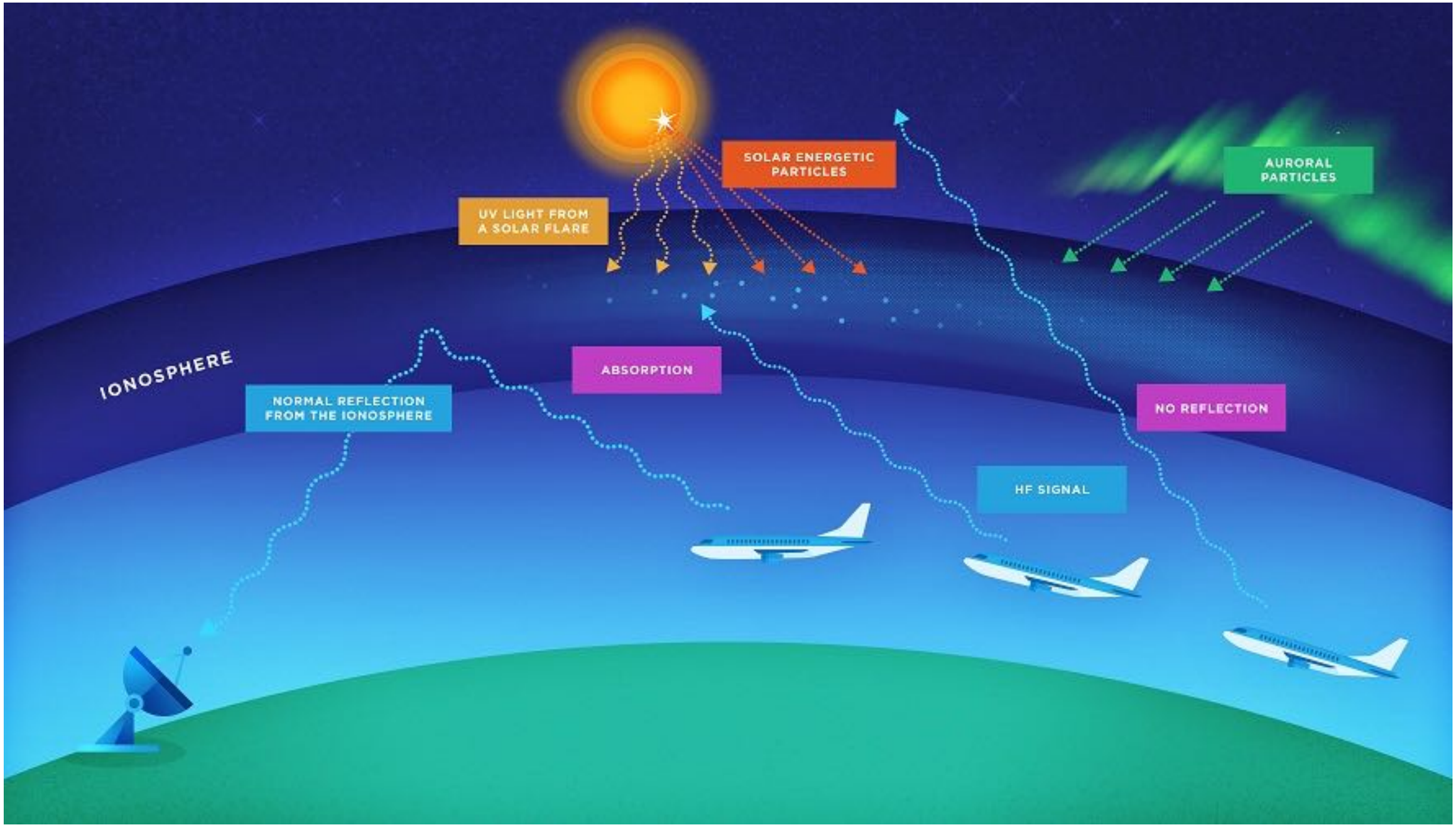
The maximum usable frequency (MUF) for a given communication path is the highest HF radio frequency that can be used for communication via reflection. In the late phases of ionospheric storms, the ionosphere remains in an unsettled state, triggering disturbances in long range radio communications. The MUF varies with respect to their undisturbed values.

What?	ionospheric disturbances
Consequences	Global radio communication troubles
What to monitor	$\frac{MUF}{median_{30days}(f_oF_2)}$ % decrease

$$f_oF_2 \equiv f_p \propto \sqrt{n}_o \qquad MUF \equiv \frac{f_oF_2}{\cos\theta}$$

PECAHF


Proton storm
NIGHT
DAY
Auroral Absorption
250
185
125
100
55
40
Miles
SUN
F Region
E Region
D Region
E Region
F Region
F1
F2
E
Solar flare-RBO
PCA
Geomagnetic storm
Post Storm Depression
Short Wave Fade Out


SOLAR ENERGETIC PARTICLES
UV LIGHT FROM A SOLAR FLARE
AURORAL PARTICLES
IONOSPHERE
ABSORPTION
NORMAL REFLECTION FROM THE IONOSPHERE
NO REFLECTION
HF SIGNAL