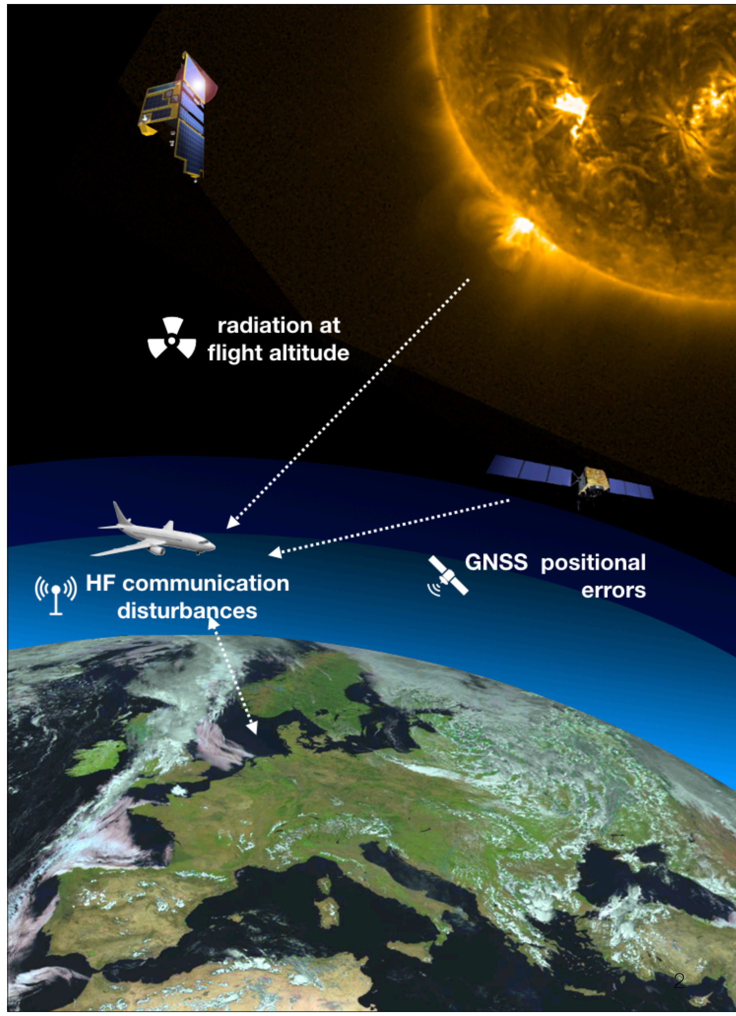
PECASUS
For civil aviation

FIRST TRAINING DAY
For MeteoWing Operators

Oct 22/Nov 5 2019



Storm parameters

Thresholds

Petra.Vanlommel@oma.be

PECASUS DASHBOARDS

GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h Values	Max-3h Status
Amplitude Scintillation (S4) (dimensionless)	0.5	0.8	**2019-11-04 09:30**	**0.185941**	**QUIET**		**1.12889**	**SEVERE**
Phase Scintillation (Sigma-Phi)(radians)	0.4	0.7	**2019-11-04 09:30**	**0.058812**	**QUIET**		**1.32625**	**SEVERE**
Vertical TEC (TEC Units)	125	175	**2019-11-04 09:30**	**30.6949**	**QUIET**		**30.6949**	**QUIET**

RADIATION	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
Effective Dose (micro-Sieverts/hour)	30	80	**----**	**----**	**----**		**----**	**----**

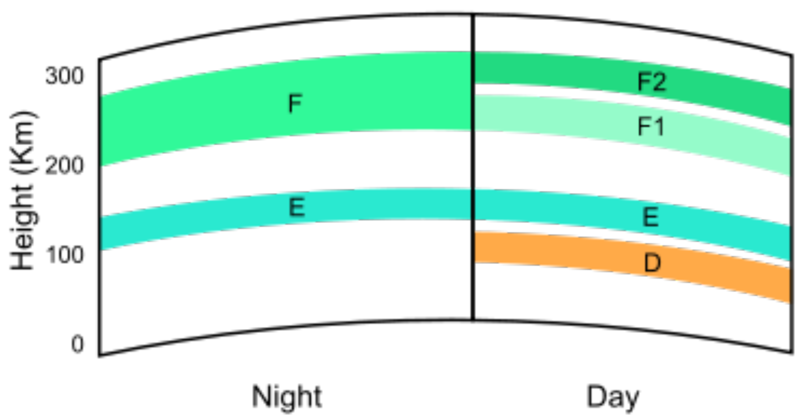
HF COM	Moderate	Severe	Time UTC	Values	Status	Alert	Max-9h values	Max-9h status
Auroral Absorption (Kp-NOAA)	8	9	**2019-11-04 09:33**	**2**	**QUIET**		**2**	**QUIET**
PCA (dB from 30MHz Riometer data)	2	5	**2019-11-04 09:32**	**0.0**	**QUIET**		**0.0**	**OUTDATED**
Solar X-rays (0.1 - 0.8 nm) (W/mÂ²)	X1.0	X10.0	**2019-11-04 09:33**	**< M.5-flare**	**QUIET**		**< M.5-flare**	**QUIET**
Post-Storm Depression (MUF)	30%	50%	**-----**	**-----**	**NOT OPERATIONAL**		**-----**	**-----**

IONOSPHERE

Exists because of ionising solar e.m. radiation

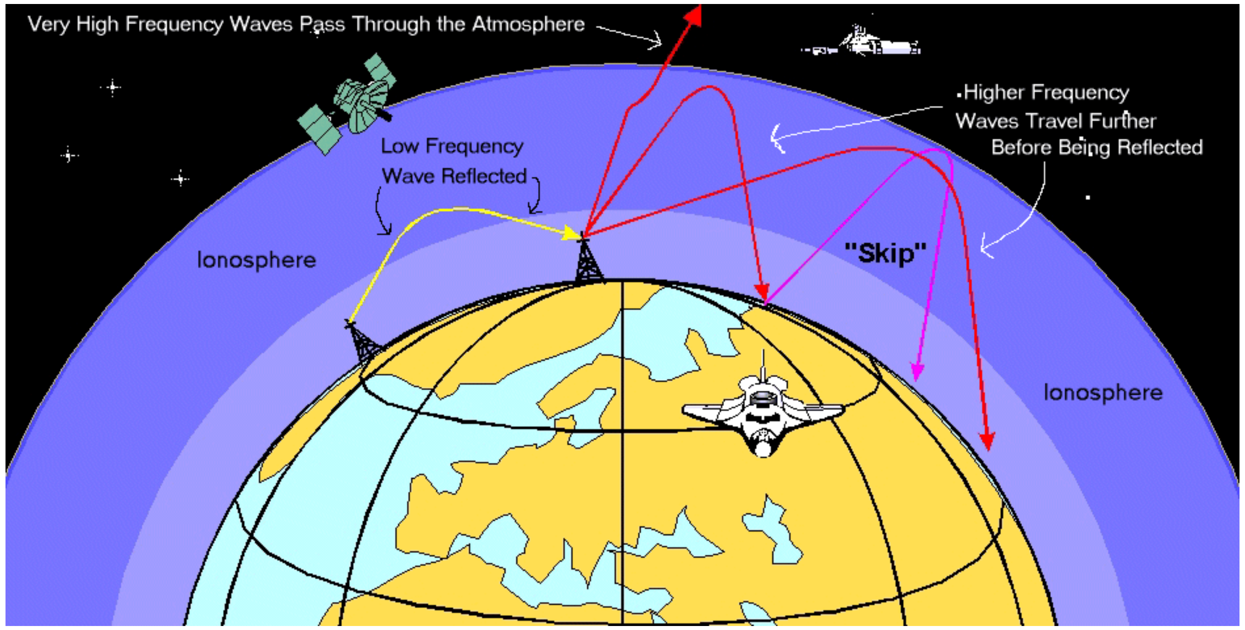
RADIO WAVES AND IONOSPHERE

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



The ionosphere (/aɪˈɒnəˌsfɪər/[1][2]) is the ionized part of Earth's upper atmosphere, from about 60 km (37 mi) to 1,000 km (620 mi) altitude, a region that includes the thermosphere and parts of the mesosphere and exosphere. The ionosphere is ionized by solar radiation. It plays an important role in atmospheric electricity and forms the inner edge of the magnetosphere. It has practical importance because, among other functions, it influences radio propagation to distant places on the Earth.[3]

The Total Electron Content (TEC) is the integrated total number of electrons present along a path between a radio transmitter and receiver.

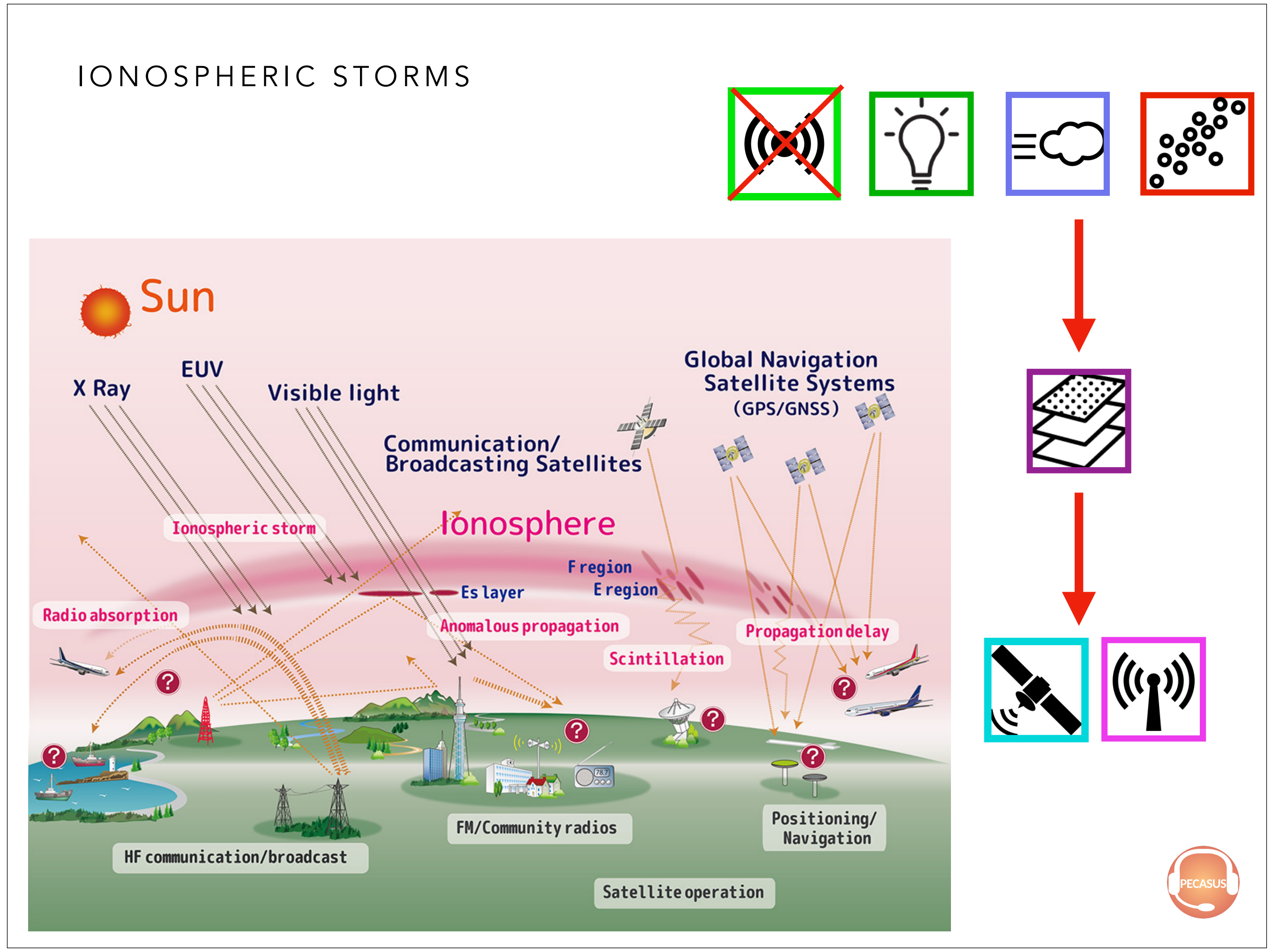


The ionosphere has the ability to reflect radio waves. If the degree of ionisation would be zero, no radio waves would be reflected and all would pass.

Ionisation can change over time.
Ionisation is not the same everywhere.

HF goes through
LF are reflected

During the night, the ionisation decreases – the skill to reflect drops.
—> also LF goes through —> Maximum Usable Frequency, MUF decreases.



How the ionosphere behaves has an impact on HF communication and navigation

Ionospheric storms primarily affect the equatorial regions but can also extend into the middle latitudes and affect GNSS navigation.

An ionospheric storms impacts the signal itself -> radio signal delay ->signal reception

X-rays: sudden ionospheric disturbances (SID)[edit]
When the Sun is active, strong solar flares can occur that hit the sunlit side of Earth with hard X-rays. The X-rays penetrate to the D-region, releasing electrons that rapidly increase absorption, causing a high frequency (3-30 MHz) radio blackout. During this time very low frequency (3-30 kHz) signals will be reflected by the D layer instead of the E layer, where the increased atmospheric density will usually increase the absorption of the wave and thus dampen it. As soon as the X-rays end, the sudden ionospheric disturbance (SID) or radio black-out ends as the electrons in the D-region recombine rapidly and signal strengths return to normal.

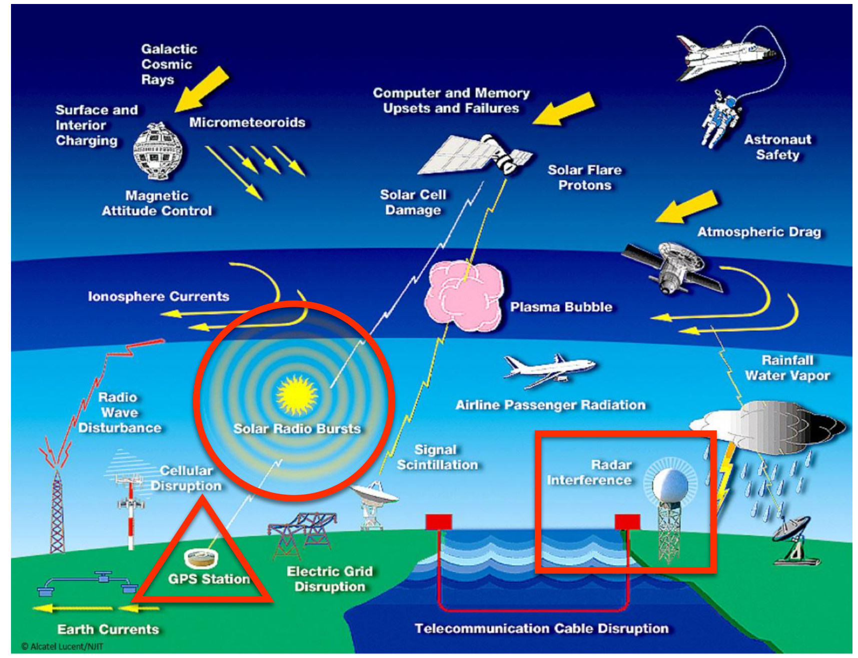
Protons: polar cap absorption (PCA)[edit]
Associated with solar flares is a release of high-energy protons. These particles can hit the Earth within 15 minutes to 2 hours of the solar flare. The protons spiral around and down the magnetic field lines of the Earth and penetrate into the atmosphere near the magnetic poles increasing the ionization of the D and E layers. PCA's typically last anywhere from about an hour to several days, with an average of around 24 to 36 hours. Coronal mass ejections can also release energetic protons that enhance D-region absorption in the polar regions.

Geomagnetic storms[edit]
A geomagnetic storm is a temporary intense disturbance of the Earth's magnetosphere.

During a geomagnetic storm the F_2 layer will become unstable, fragment, and may even disappear completely.
In the Northern and Southern pole regions of the Earth aurorae will be observable in the sky.

CONTRARY TO SOLAR RADIO BURSTS

Noise increase - the ionosphere is not impacted but the signal itself. The noise of the Sun is too loud, the GPS receiver can't hear the satellite signal clear enough. Or the radar interprets the radio waves coming from the Sun as being a plane.



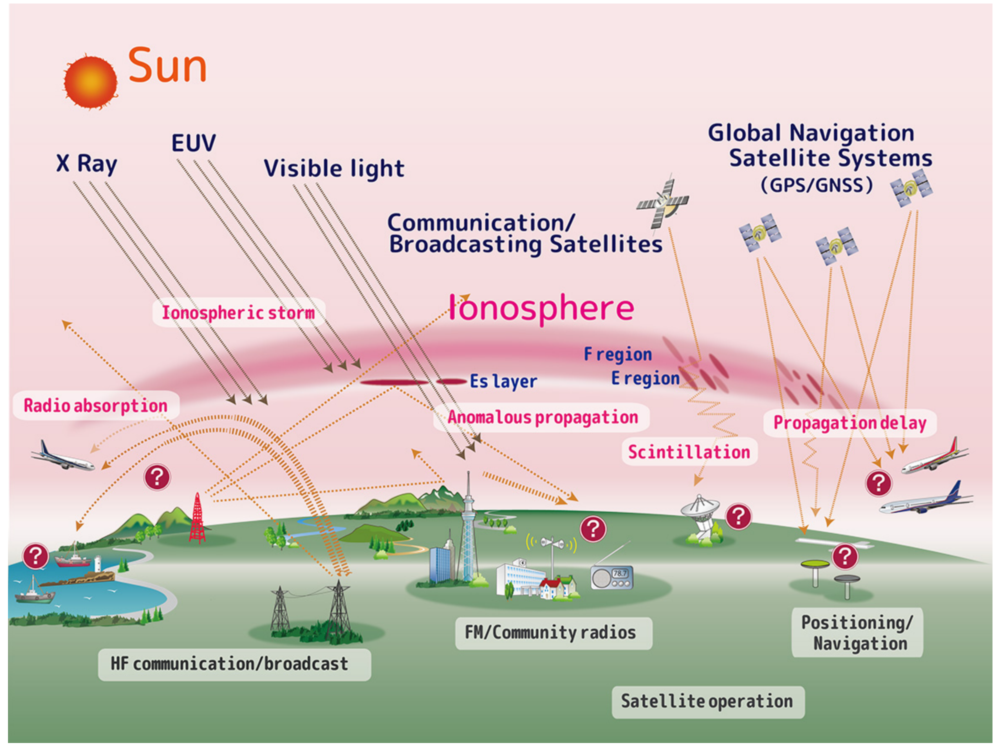
Impact of SRB itself
Noise increase – the ionosphere is not impacted but the signal itself

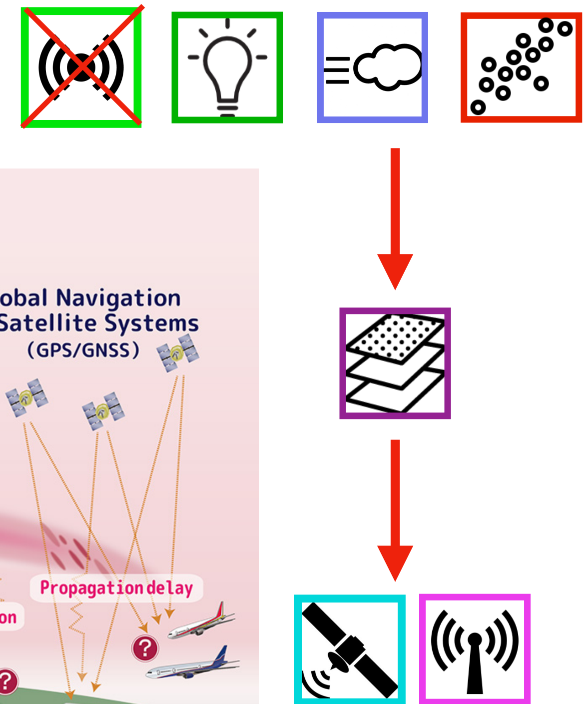
GPS station
Signal/noise – signal is from the satellite. GPS receivers are designed to be sensible to the signal above them, not at the horizon.
When there is a strong **radio burst** – in the typical GPS frequencies – the **noise increases**.
GPS receiver ontvangt signalen die niet van een satelliet komen maar van de Zon. De GPS ontvanger maakt geen onderscheid tussen solar noise en satelliet signaal.

Radar interference
Radars are monitoring the planes near the horizon – descending and ascending planes.
Radar 'ziet' vliegtuigen door de reflectie van radio-signaal. Radio-signalen van de zon kunnen geïnterpreteerd worden als 'spook'-vliegtuigen: vliegtuigen die je ziet op het radar-scherm maar er in werkelijkheid niet zijn.

SRB can impact HF communication (no feedback from industry) and navigation

IONOSPHERIC STORMS





How the ionosphere behaves has an impact on HF communication and navigation

Ionospheric storms primarily affect the equatorial regions but can also extend into the middle latitudes and affect GNSS navigation.

An ionospheric storms impacts the signal itself -> radio signal delay ->signal reception

X-rays: sudden ionospheric disturbances (SID)[edit]
When the Sun is active, strong solar flares can occur that hit the sunlit side of Earth with hard X-rays. The X-rays penetrate to the D-region, releasing electrons that rapidly increase absorption, causing a high frequency (3–30 MHz) radio blackout. During this time very low frequency (3–30 kHz) signals will be reflected by the D layer instead of the E layer, where the increased atmospheric density will usually increase the absorption of the wave and thus dampen it. As soon as the X-rays end, the sudden ionospheric disturbance (SID) or radio black-out ends as the electrons in the D-region recombine rapidly and signal strengths return to normal.

Protons: polar cap absorption (PCA)[edit]
Associated with solar flares is a release of high-energy protons. These particles can hit the Earth within 15 minutes to 2 hours of the solar flare. The protons spiral around and down the magnetic field lines of the Earth and penetrate into the atmosphere near the magnetic poles increasing the ionization of the D and E layers. PCA's typically last anywhere from about an hour to several days, with an average of around 24 to 36 hours. Coronal mass ejections can also release energetic protons that enhance D-region absorption in the polar regions.

Geomagnetic storms[edit]
A geomagnetic storm is a temporary intense disturbance of the Earth's magnetosphere.

During a geomagnetic storm the F_2 layer will become unstable, fragment, and may even disappear completely.
In the Northern and Southern pole regions of the Earth aurorae will be observable in the sky.

GNSS - GLOBAL NAVIGATION SATELLITE SYSTEM

GNSS	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h Values	Max-3h Status
Amplitude Scintillation (S4) (dimensionless)	0.5	0.8	**2019-11-04 09:30**	**0.185941**	**QUIET**		**1.12889**	**SEVERE**
Phase Scintillation (Sigma-Phi)(radians)	0.4	0.7	**2019-11-04 09:30**	**0.058812**	**QUIET**		**1.32625**	**SEVERE**
Vertical TEC (TEC Units)	125	175	**2019-11-04 09:30**	**30.6949**	**QUIET**		**30.6949**	**QUIET**

IONOSPHERIC SCINTILLATION

What

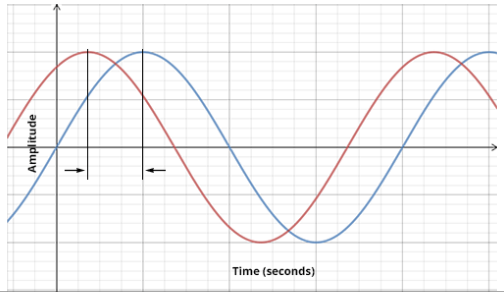
Ionospheric scintillation is the rapid modification of radio waves caused by small scale structures in the ionosphere. Scintillation of radio waves impacts the power and phase of the radio signal. Scintillation is caused by small-scale (tens of meters to tens of km) structures in the ionospheric electron density along the signal path and is the result of interference of refracted and/or diffracted (scattered) waves.

Consequences

Severe scintillation conditions can prevent a GPS receiver from locking on to the signal and can make it impossible to calculate a position. Less severe scintillation conditions can reduce the accuracy and the confidence of positioning results.

What to monitor

Scintillation is usually quantified by two indexes: S4 for amplitude scintillation and σφ (sigma-phi) for phase scintillation.



PECASUS

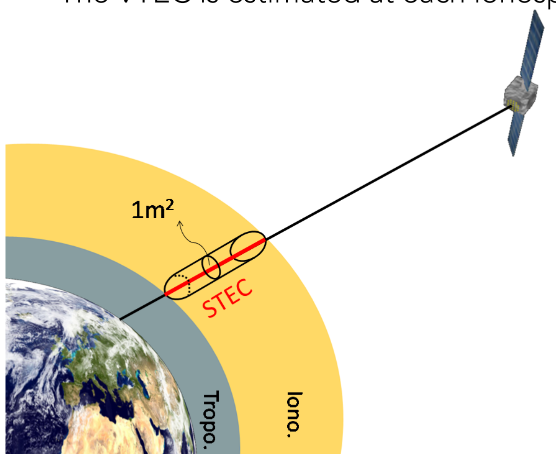
the phase of a periodic function F of some real variable t is the relative value of that variable within the span of each full period.

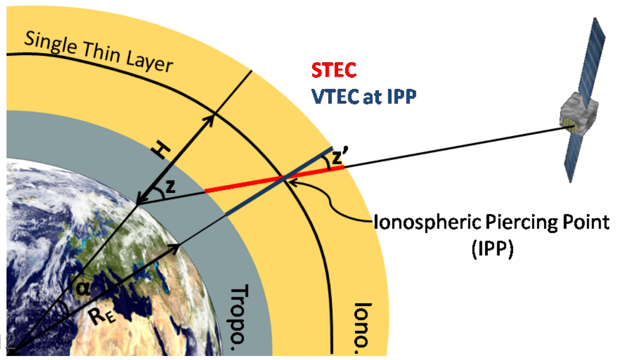
The phase is typically expressed as an angle ϕ(t), in such a scale that it varies by one full turn as the variable t goes through each period (and F(t) goes through each complete cycle). Thus, if the phase is expressed in degrees, it will increase by 360° as t increases by one period. If it is expressed in radians, the same increase in t will increase the phase by

2 π.

VERTICAL TEC

TEC is the total number of electrons integrated between two points, along a tube of one meter squared cross section, i.e., the electron columnar number density. It is often reported in multiples of the so-called TEC unit, defined as TECU=10^16 electrons/m^2.
The STEC depends on the length of the signal's path trough the ionosphere and is consequently dependant on the satellite elevation. To correct for this effect, an estimation of the Vertical TEC (VTEC) above a given point on the Earth surface is necessary. To determine this, the Single Thin Layer Model is usually employed. This model assumes that all the free electrons are concentrated in a layer of infinitesimal thickness located at the altitude *H*.
The VTEC is estimated at each ionospheric Pierce Point (IPP)





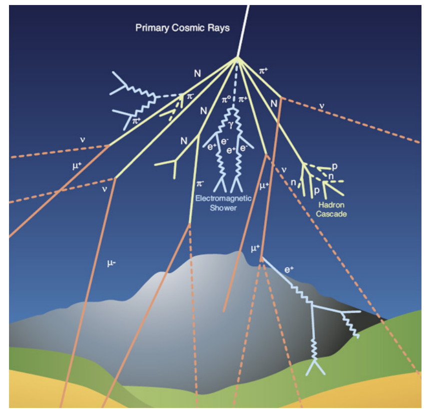
RADIATION

RADIATION	Moderate	Severe	Time UTC	Values	Status	Alert	Max-3h values	Max-3h status
Effective Dose (micro-Sieverts/hour)	30	80	----	----	----		----	----

Micro = 10^-6
Sieverts = J/kg

Atmospheric radiation environment

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



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

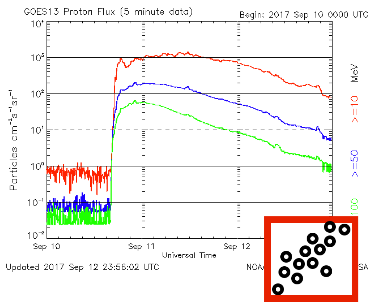
Solar Energetic Particles (SEP) → Increased radiation exposure !!
- Sporadic (solar storms)
- Mainly protons
- High latitude regions

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



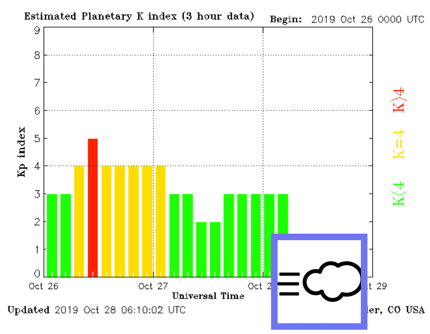
HF COM

HF COM	Moderate	Severe	Time UTC	Values	Status	Alert	Max-9h values	Max-9h status
Auroral Absorption (Kp-NOAA)	8	9	**2019-11-04 09:37**	**2**	**QUIET**		**2**	**QUIET**
PCA (dB from 30MHz Riometer data)	2	5	**2019-11-04 09:38**	**0.0**	**QUIET**		**0.0**	**OUTDATED**
Solar X-rays (0.1 - 0.8 nm) (W/mÂ²)	X1.0	X10.0	**2019-11-04 09:33**	**< M.5-flare**	**QUIET**		**< M.5-flare**	**QUIET**
Post-Storm Depression (MUF)	30%	50%	**-----**	**-----**	**NOT OPERATIONAL**		**-----**	**-----**

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.

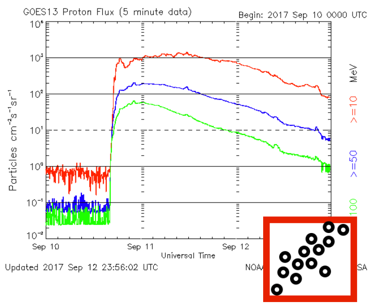
What?	Strong geomagnetic storms Kp>8
Consequences	radio fade out in both polar region
What to monitor	Kp indices



POLAR CAP ABSORPTION

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

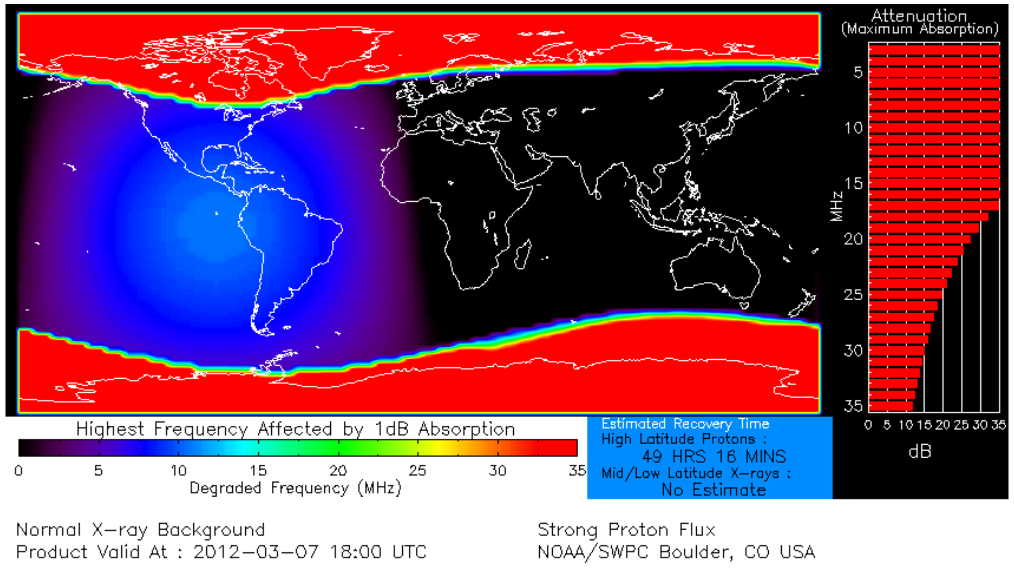
What?	Solar radiation storm
Consequences	radio fade out in both polar regions
What to monitor	Riometer data D-RAP model Absorption >2 dB



A condition in the polar ionosphere where HF and VHF radio waves are absorbed and LF and VLF radio waves are reflected at lower altitudes than normal. PCA events usually originate from major solar storms that launch energetic protons that reach our outer atmosphere quickly and cause excess ionization that distorts the normal refractive properties of the polar ionosphere.

POLAR CAP ABSORPTION

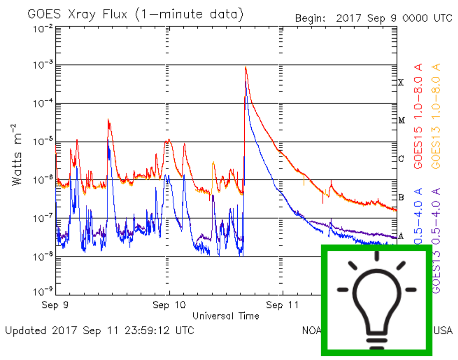
During proton events or solar radiation storms, energetic particles from the Sun will trigger extra ionisation in the polar regions inducing a radio fade out, called a Polar Cap Absorption.



Solar Xray - Flares

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



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

In the late phases of magnetic storms, the ionosphere remains in an unsettled state, triggering disturbances in long range radio communications. The MUF and the critical frequency vary with respect to their undisturbed values.

The maximum usable frequency (MUF) for a given communication path is the highest HF radio frequency that can be used for communication via reflection. A depression of the MUF prohibits aircraft from accessing the highest frequencies normally available.