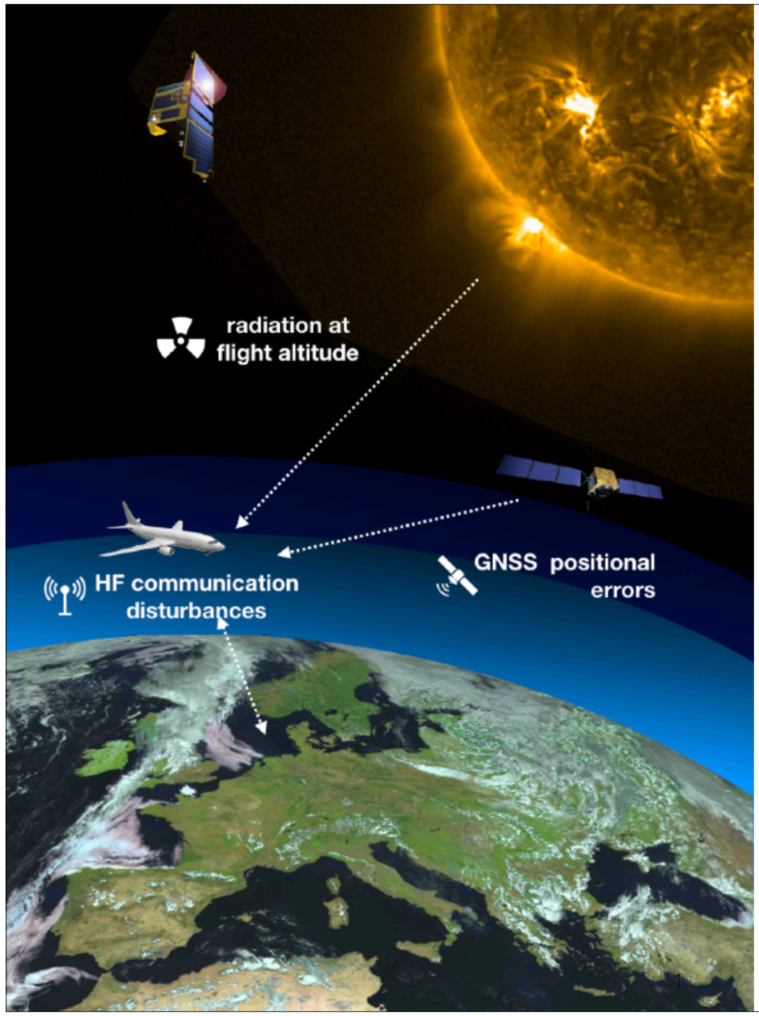
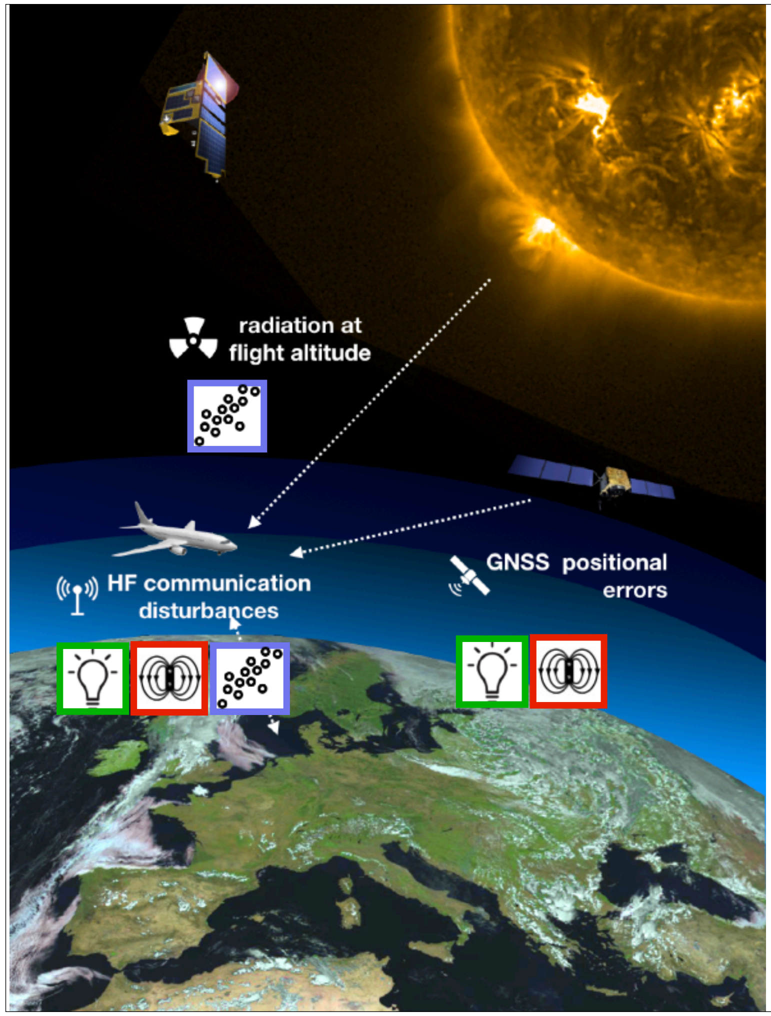


SWx for aviation

Petra.Vanlommel@oma.be

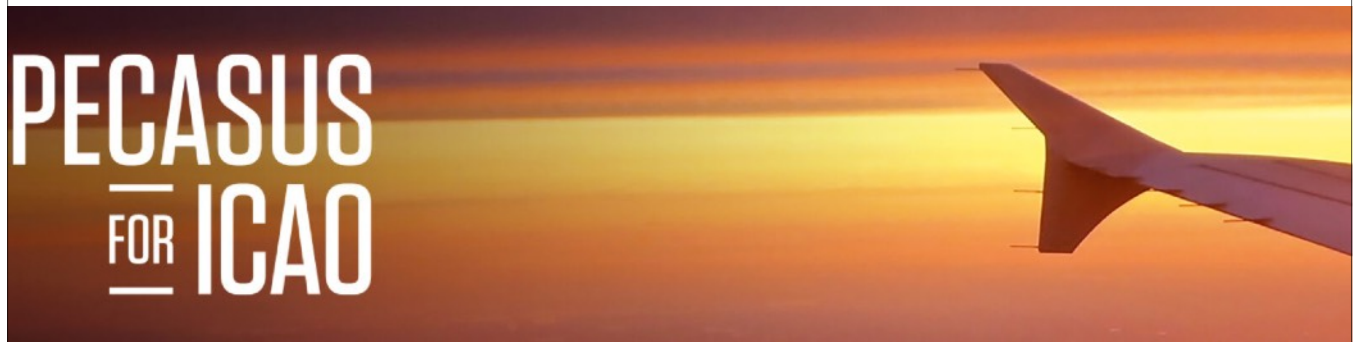
PECASUS



SOLAR STORMS IMPACTING AVIATION

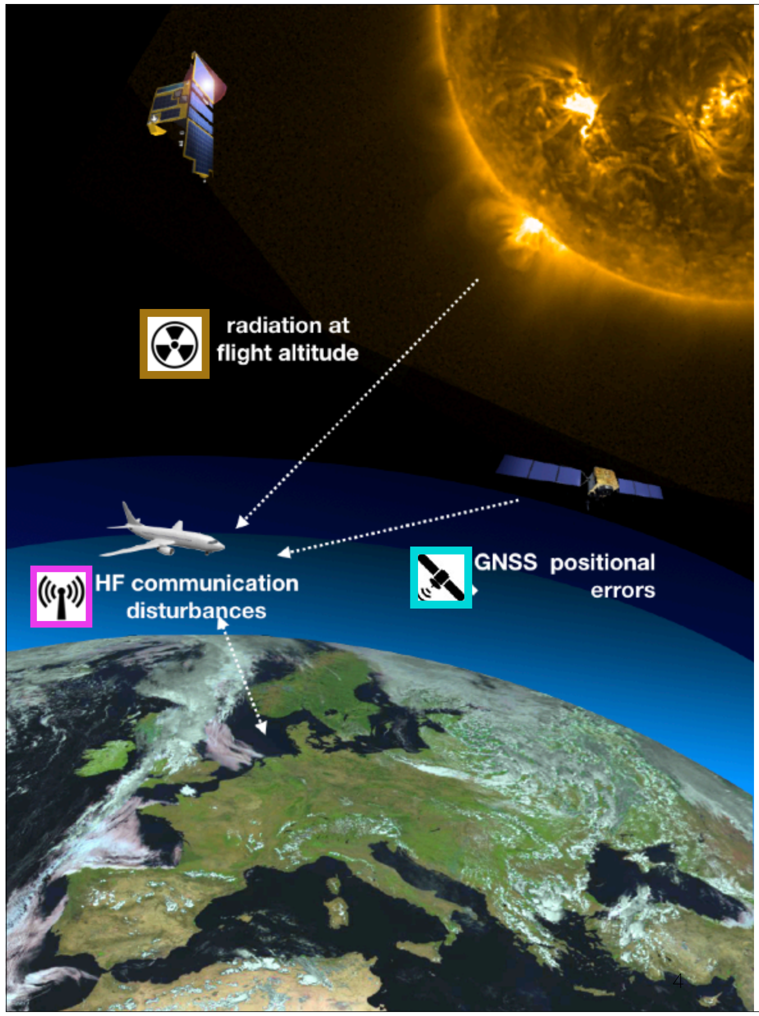
A solar storm initiates space weather processes which impact our navigation and radio communication systems and can cause an increase of radiation levels at flight altitude.

A solar storm initiates space weather processes which impact our navigation and radio communication systems and can cause an increase of radiation levels at flight altitude.



PECASUS: pan-europeans consortium for aviation space weather user services
SWPC
ACFJ
Russia and China

International Civil Aviation Organization



Storm parameters

Thresholds

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PECASUS

IONOSPHERE

Atmospheric layer with free electrons.

Ionization by solar x-ray, extreme ultraviolet radiation and particle radiation.

https://www.ngdc.noaa.gov/stp/iono/ionointro.html

The ionosphere is that part of the upper atmosphere where free electrons occur in sufficient density to have an appreciable influence on the propagation of radio frequency electromagnetic waves. This ionization depends primarily on the Sun and its activity. ionospheric structures and peak densities in the ionosphere vary greatly with time (sunspot cycle, seasonally, and diurnally), with geographical location (polar, auroral zones, mid-latitudes, and equatorial regions), and with certain solar-related ionospheric disturbances.

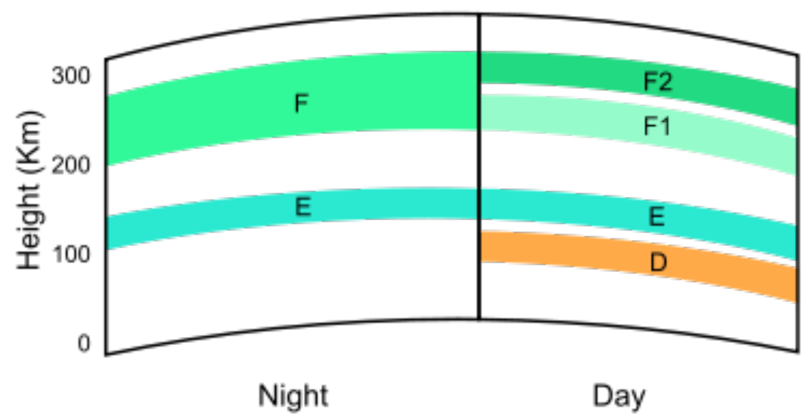
The major part of the ionization is produced by solar X-ray and ultraviolet radiation and by corpuscular radiation from the Sun. The most noticeable effect is seen as the Earth rotates with respect to the Sun; ionization increases in the sunlit atmosphere and decreases on the shadowed side. Although the Sun is the largest contributor toward the ionization, cosmic rays make a small contribution. Any atmospheric disturbance affects the distribution of the ionization.

The ionosphere is a **dynamic system controlled by** many parameters including **acoustic motions of the atmosphere, electromagnetic emissions, and variations in the geomagnetic field**. Because of its extreme sensitivity to atmospheric changes, the ionosphere is a very sensitive monitor of atmospheric events.

The most accurate way of measuring the ionosphere is with a ground-based ionosonde, which records data as ionograms.

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.



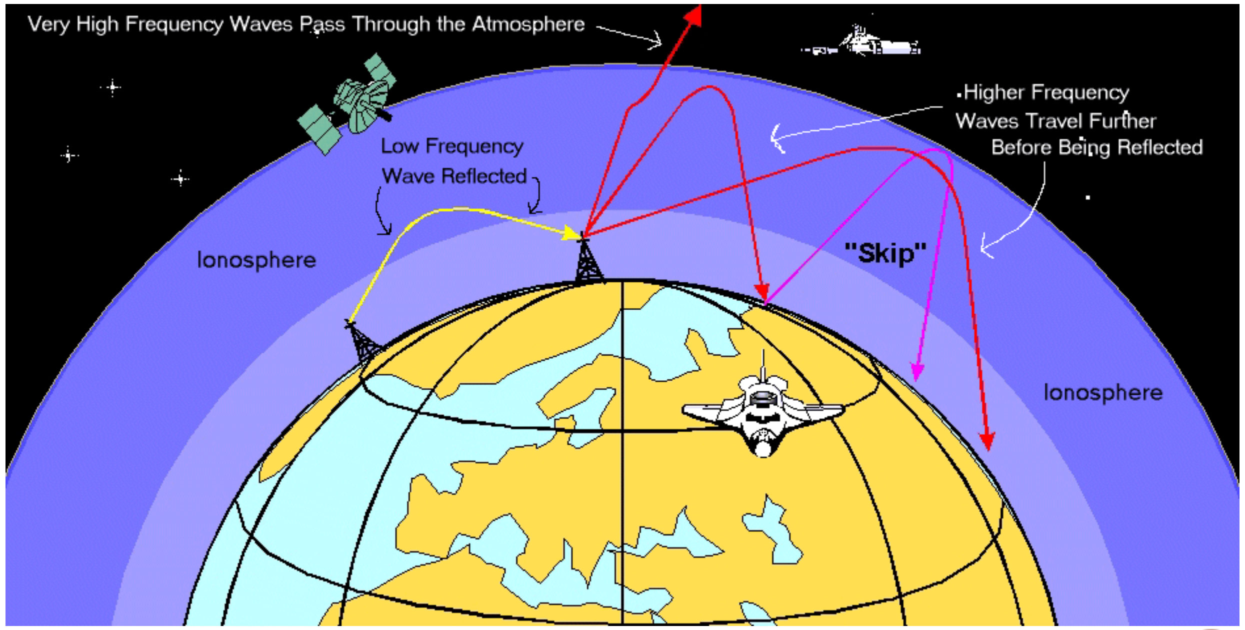
The ionosphere (/aɪˈɒnəˌsfɪər/[1][2]) is the ionized part of Earth's upper atmosphere, from about 60 km (37 mi) to 1,000 km (620 mi) altitude, a region that includes the thermosphere and parts of the mesosphere and exosphere. The ionosphere is ionized by solar radiation. It plays an important role in 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]

Especially the F-layer reflects the radio waves, up to around 38 Mhz

Only the E, F1 and F2 regions refract HF waves. The D region, through which an HF sky wave must pass to reach the refracting region, absorbs the energy of the wave and reduces signal strength

https://www.sws.bom.gov.au/Educational/5/2/2
The most important feature of the ionosphere for HF sky wave communications is its ability to refract radio waves. However, only a certain range of frequencies is refracted. At a certain location at a particular time, some of the higher HF frequencies will penetrate the ionosphere while some of the lower HF frequencies will be absorbed by the D region during the day.

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.



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.

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

PECASUS

DASHBOARDS

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
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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

Ionosphere is not needed, it’s an inconvenient layer where the satellite signal has to go through.

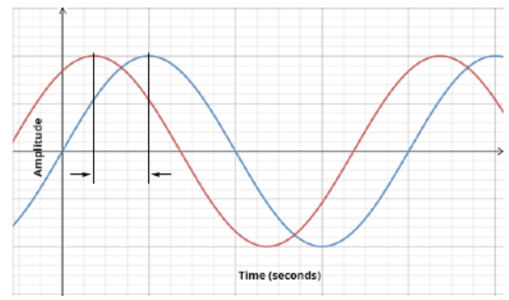
One of the largest sources of error in Positioning Navigation and Timing (PNT) signals from GNSS satellites is due to the passage of the satellite signal through the relatively dense electron environment of the upper atmosphere. These errors are compensated for by GPS receivers that use an ionospheric delay correction model. During ionospheric storms, or periods where the ionosphere deviates significantly from normal conditions, these models may be inadequate and lead to uncorrected positioning errors. Precision navigation systems that autocorrect for the ionosphere, such as differential GPS, or GPS augmentation systems such as the Satellite-Based Augmentation System (SBAS) or Ground-Based Augmentation System (GBAS) are still susceptible to errors during severe ionospheric storms. GNSS positioning is also susceptible to interference from solar radio bursts in the ultra-high-frequency (UHF) range, leading to significant loss of satellite tracking for up to tens of minutes in severe cases.

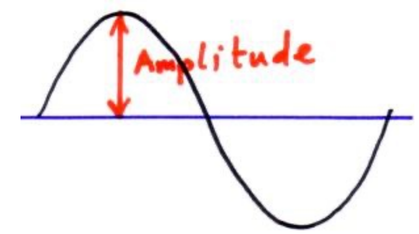
https://www.swpc.noaa.gov/impacts/space-weather-and-gps-systems

There are several ways in which space weather impacts GPS function. GPS radio signals travel from the satellite to the receiver on the ground, passing through the Earth’s ionosphere. The charged plasma of the ionosphere bends the path of the GPS radio signal similar to the way a lens bends the path of light. **In the absence of space weather, GPS systems compensate for the “average” or “quiet” ionosphere, using a model to calculate its effect on the accuracy of the positioning information.** But when the ionosphere is disturbed by a space weather event, the models are no longer accurate and the receivers are unable to calculate an accurate position based on the satellites overhead.

In calm conditions, single frequency GPS systems can provide position information with an accuracy of a meter or less. During a severe space weather storm, these errors can increase to tens of meters or more. Dual frequency GPS systems can provide position information accurate to a few centimeters. In this case the two different GPS signals are used to better characterize the ionosphere and remove its impact on the position calculation. But when the ionosphere becomes highly disturbed, the GPS receiver cannot lock on the satellite signal and position information becomes inaccurate.

IONOSPHERIC SCINTILLATION





rapid modification of radio waves caused by small scale structures (tens of meters to tens of km) in the ionosphere along the signal path and is the result of interference of refracted and/or diffracted (scattered) waves.

Loss of lock
—
S4 is a normalised standard deviation of C/NO = carrier-to-noise ratio
Sigma-phi is expressed in radians.
— —
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.
— —
Can be induced by solar flare, by geomagnetic storm
— —
Scintillation involves fluctuation in the phase and amplitude of GNSS signals. In extreme cases, scintillation can cause loss of signal tracking (i.e. cycle slips). It is important to note that the effects of scintillation are not removed by dual-frequency observations. Trimble has setup a global ionospheric scintillation sounding network, which detects scintillation effects and is able to give up to date warning information on scintillation effects in different parts of the world.

Typically scintillation occurs in equatorial regions after sunset for several hours. In polar regions, scintillation can occur at any time. Mid-latitude regions are sometimes affected by Travelling Ionospheric Disturbances (TIDs). A map showing the current ionospheric scintillation activity can be found here http://www.trimbleionoinfo.com/Images.svc/SCINTI
— —-
https://www.swpc.noaa.gov/phenomena/ionospheric-scintillation

Ionospheric scintillation is the rapid modification of radio waves caused by small scale structures in the ionosphere. 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.

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) structure in the ionospheric electron density along the signal path and is the result of interference of refracted and/or diffracted (scattered) waves. Scintillation is usually quantified by two indexes: S4 for amplitude scintillation and $\sigma\phi$ (sigma-phi) for phase scintillation. The indexes reflect the **variability of the signal over a period of time,** usually one minute. Scintillation is more prevalent at low and high latitudes, but mid-latitudes, such as the United States, experience scintillation much less frequently. Scintillation is a strong function of local time, season, geomagnetic activity, and solar cycle but it also influenced by waves propagating from the lower atmosphere.

https://www.sws.bom.gov.au/Satellite/6/3

A Station connects with many satellites.

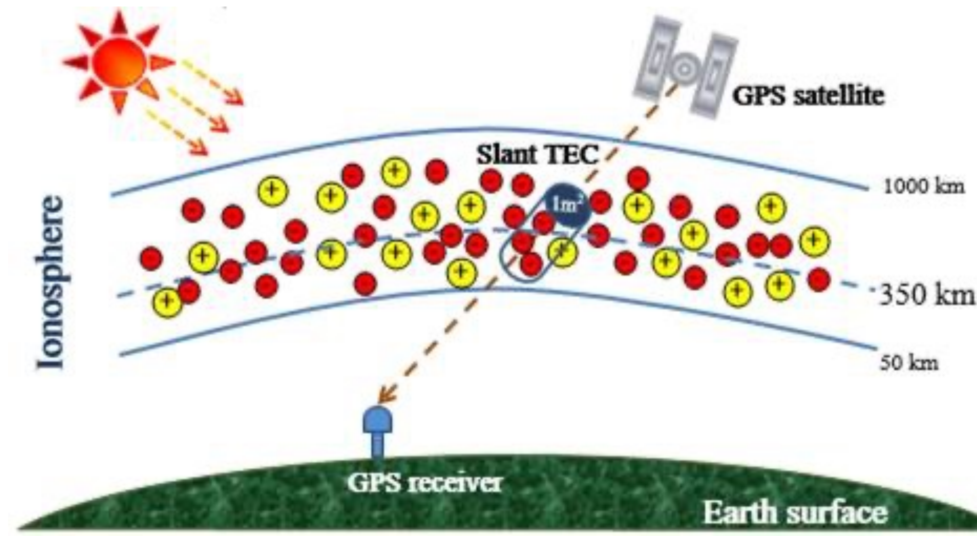
IPP are concentrated in the area of the station.

Scintillation is a localised phenomenon.

A green/orange/red dot are 15 dots on top of each other: last 15 min data, the max is the top dot.

Stations without green dots: station doesn't provide data - data outage.

VERTICAL TEC



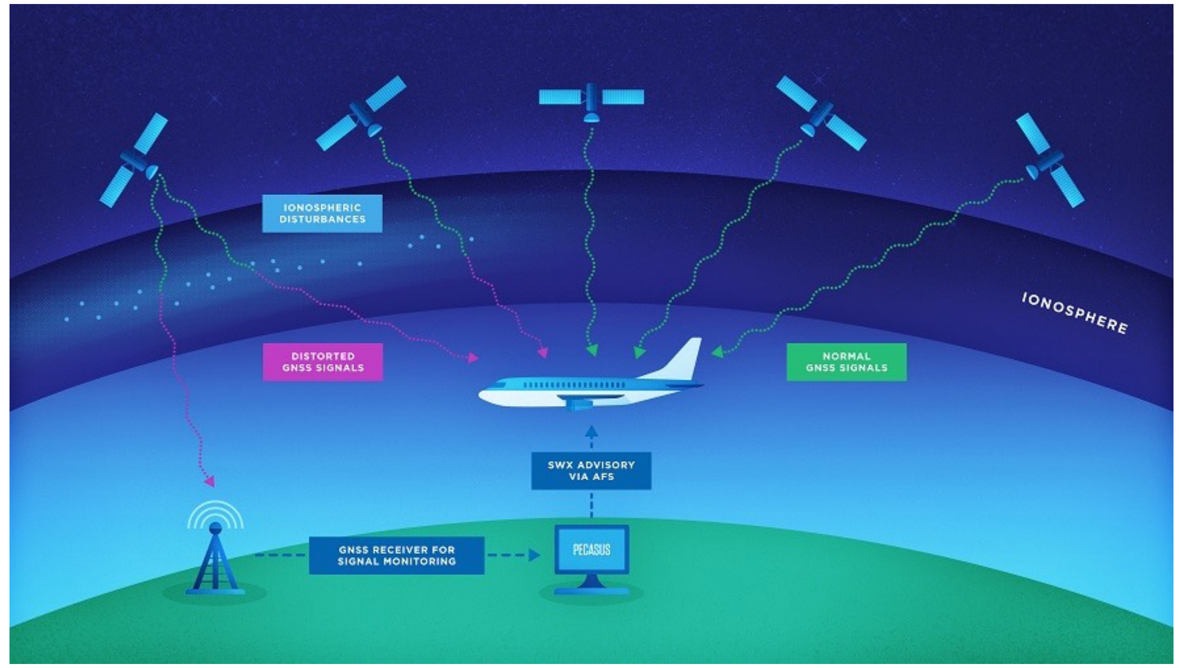
Change in the path and velocity

http://www.trimbleionoinfo.com/Library/IonosphericEffects.htm
Ionospheric Signal Delay
An important descriptive quantity in describing the effect of the ionosphere on the GNSS signal is the total electron content (or TEC). TEC is the total number of electrons present along a path between the satellite and the receiver on earth, with units of electrons per square meter, where 1016 electrons/m^2 = 1 TEC unit (TECU).

The relationship between TECU and the group delay of a GNSS signal is described in the first approximation by

https://www.swpc.noaa.gov/impacts/space-weather-and-gps-systems
Geomagnetic storms create large disturbances in the ionosphere. The currents and energy introduced by a geomagnetic storm enhance the ionosphere and increase the total height-integrated number of ionospheric electrons, or the Total Electron Count (TEC). GPS systems cannot correctly model this dynamic enhancement and errors are introduced into the position calculations. This usually occurs at high latitudes, though major storms can produce large TEC enhancements at mid-latitudes as well.
——
https://www.swpc.noaa.gov/phenomena/total-electron-content
The TEC in the ionosphere is modified by changing solar Extreme Ultra-Violet radiation, geomagnetic storms, and the atmospheric waves that propagate up from the lower atmosphere. The TEC will therefore depend on local time, latitude, longitude, season, geomagnetic conditions, solar cycle and activity, and troposphere conditions. The propagation of radio waves is affected by the ionosphere. The velocity of radio waves changes when the signal passes through the electrons in the ionosphere. The total delay suffered by a radio wave propagating through the ionosphere depends both on the frequency of the radio wave and the TEC between the transmitter and the receiver. At some frequencies the radio waves pass through the ionosphere. At other frequencies, the waves are reflected by the ionosphere.

The change in the path and velocity of radio waves in the ionosphere has a big impact on the accuracy of satellite navigation systems such as GPS/GNSS. Neglecting changes in the ionosphere TEC can introduce tens of meters of error in the position calculations. The Global Positioning System (GPS), the US part of GNSS, uses an empirical model of the ionosphere, the Klobuchar model, to calculate and remove part of the positioning error caused by the ionosphere when single frequency GPS receivers are used. When conditions deviate from those predicted by the Klobuchar model, GPS/GNSS systems will have larger positioning errors. I



The ionosphere plays also a crucial role in satellite navigation. The signal sent by the satellite has to pass through the ionosphere to reach the receiver. **Solar storms can introduce small scale structures** in the ionosphere. When the signal encounters these obstacles, its amplitude and phase can alter very rapidly. Similarly, when the number of electrons in the ionosphere increases dramatically due to a solar storm, positioning errors are introduced in satellite navigation.

Solar wind disturbances and solar flares can create structures of tens of meters to tens of kms in the ionosphere. These structures form obstacles for the satellite signals that pass through the ionosphere. A radio wave can undergo rapid modification in its amplitude or phase. Scintillation can prevent a receiver from locking on to the signal and as such make it impossible to calculate its position.

The velocity and the path of radio waves changes when the signal passes through the electrons in the ionosphere. The total delay suffered by a radio wave propagating through the ionosphere depends both on the frequency of the radio wave and the TEC between the transmitter and the receiver. At some frequencies the radio waves pass through the ionosphere. At other frequencies, the waves are reflected by the ionosphere.

RADIATION

GNSS	Moderate	Severe	Time UTC	Values	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

Micro = 10^-6
Sieverts = J/kg
Effective dose = Micro Sievert / hour

https://nl.wikipedia.org/wiki/Sievert
De sievert (symbool Sv) is de SI-eenheid voor de equivalente dosis ioniserende straling waaraan een mens in een bepaalde periode is blootgesteld, en is gelijk aan 1 J/kg. De sievert is afhankelijk van de biologische effecten van straling. Dit in tegenstelling tot de natuurkundige effecten van straling, waarvoor de grootheid geabsorbeerde dosis wordt gebruikt, uitgedrukt in de eenheid gray, symbool Gy.

During solar eruptive events, large numbers of energetic particles may be released from the sun and travel to earth. The particles travel along earth's magnetic field lines, collide with air molecules and produce showers of secondary particles in the atmosphere. These particles are ultimately stopped by the relatively dense lower atmosphere of the earth. In the equatorial and mid-latitude regions, the earth's near-horizontal magnetic field acts as a shield. In the polar regions however, where the magnetic field is closer to vertical, the energetic particles can cascade down to lower altitudes or even reach the ground, increasing radiation exposure for people in the vicinity. As these particles are weakened (slowed and absorbed) by passage through the atmosphere, higher altitudes are exposed to higher levels of radiation. The radiation exposure of flight crew and passengers can significantly increase during these solar energetic particle events, particularly on polar or near-polar flights.

Effective dose takes the sort of radiation into account, the human body, the tissue and the organs being radiated and tells you what the effect is at the end.

It says something about the chance, probability to develop cancer.

It is not about dropping death because of a sudden increase of radiation. This is the absorbed dose.

Effective dose is a dose quantity in the International Commission on Radiological Protection (ICRP) system of radiological protection.[1]

It is the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the human body and represents the stochastic health risk to the whole body, which is the probability of cancer induction and genetic effects, of low levels of ionising radiation.[2][3] It takes into account the type of radiation and the nature of each organ or tissue being irradiated, and enables summation of organ doses due to varying levels and types of radiation, both internal and external, to produce an overall calculated effective dose.

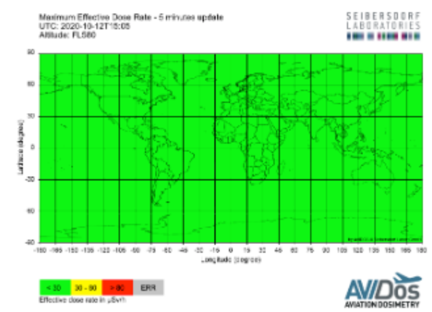
The SI unit for effective dose is the sievert (Sv) which represents a 5.5% chance of developing cancer.[4] The effective dose is not intended as a measure of deterministic health effects, which is the severity of acute tissue damage that is certain to happen, that is measured by the quantity absorbed dose.[5]

http://pecasus.stce.be/dashboards/AVIDOS_maps_Manon.php
The stuff with the triangles, maximum over all FL < 460 and all FL >= 460 - The “up” triangles indicate FL >= 460 and the down triangles indicate FL < 460
The thing below the triangles is the max over all latitudes

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



Micro = 10^-6
Sieverts = J/kg
Effective dose = Micro Sievert / hour

In Belgium, FANC estimates the mean natural background radiation to be 2,5 mSv/year, this is around 0.2 micro Sv/h
Chest X-ray —> 0,1 mSv (Sv = J/kg) = 0,1 10^3 Micro Sv = 100 Micro Sv

30 and 80 Micro Sv/h
https://nl.wikipedia.org/wiki/Sievert
De sievert (symbool Sv) is de SI-eenheid voor de equivalente dosis ioniserende straling waaraan een mens in een bepaalde periode is blootgesteld, en is gelijk aan 1 J/kg. De sievert is afhankelijk van de biologische effecten van straling. Dit in tegenstelling tot de natuurkundige effecten van straling, waarvoor de grootheid geabsorbeerde dosis wordt gebruikt, uitgedrukt in de eenheid gray, symbool Gy.

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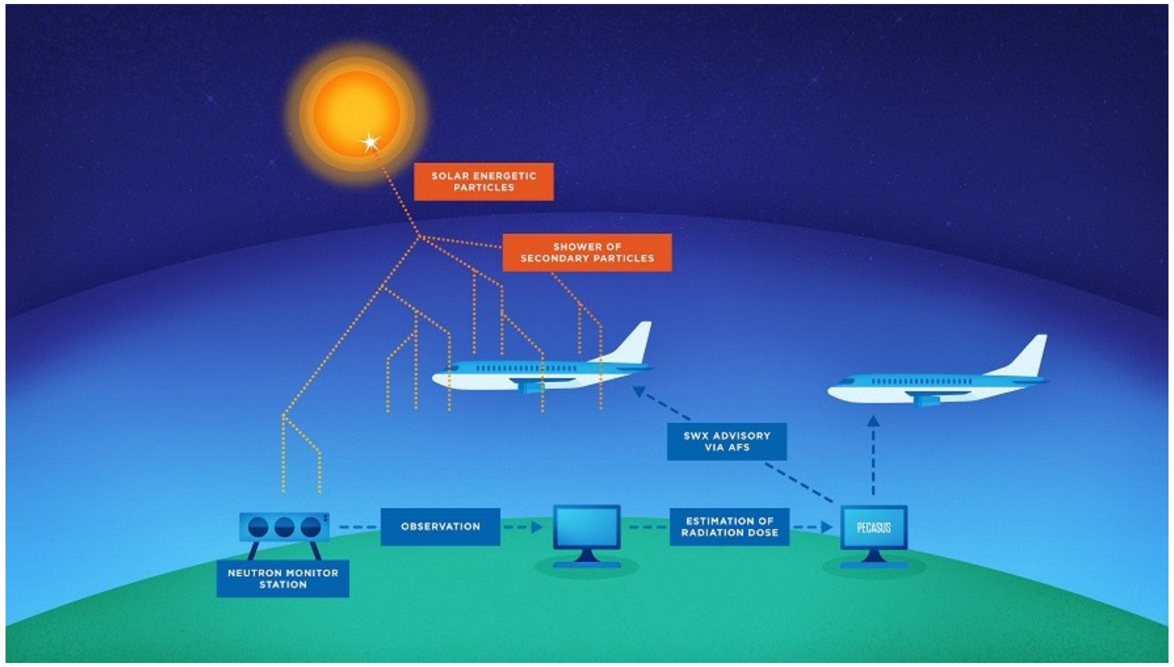

During solar storms, solar particles like protons can suddenly be accelerated, heading into space at great speed. When they arrive at Earth, these energetic particles can penetrate the atmosphere at the magnetic poles. They bombard atmospheric particles and create a shower of particles possibly reaching the Earth's surface. When this happens, crew and passengers onboard airplanes are more vulnerable to this harmful radiation. The effect is stronger at high altitudes and latitudes.

Neutron monitors are detectors on the Earth surface that measure Galactic Cosmic Rays (GCR). This is the background radiation from outside the heliosphere. The variation of GCR is negligible when it comes to human health. During a strong Solar Radiation Storm, energetic particles bombard our atmosphere and create secondary particles that are 'seen' by neutron monitors. When more than 3 stations measure an increase in radiation, we determine it as a Ground Level Event which also implies an extra dose of radiation on airplanes in flight. The impact depends on altitude and latitude: the higher the altitude and/or latitude, the stronger the impact.

AFS = Aeronautical Fixed Service

HF COM

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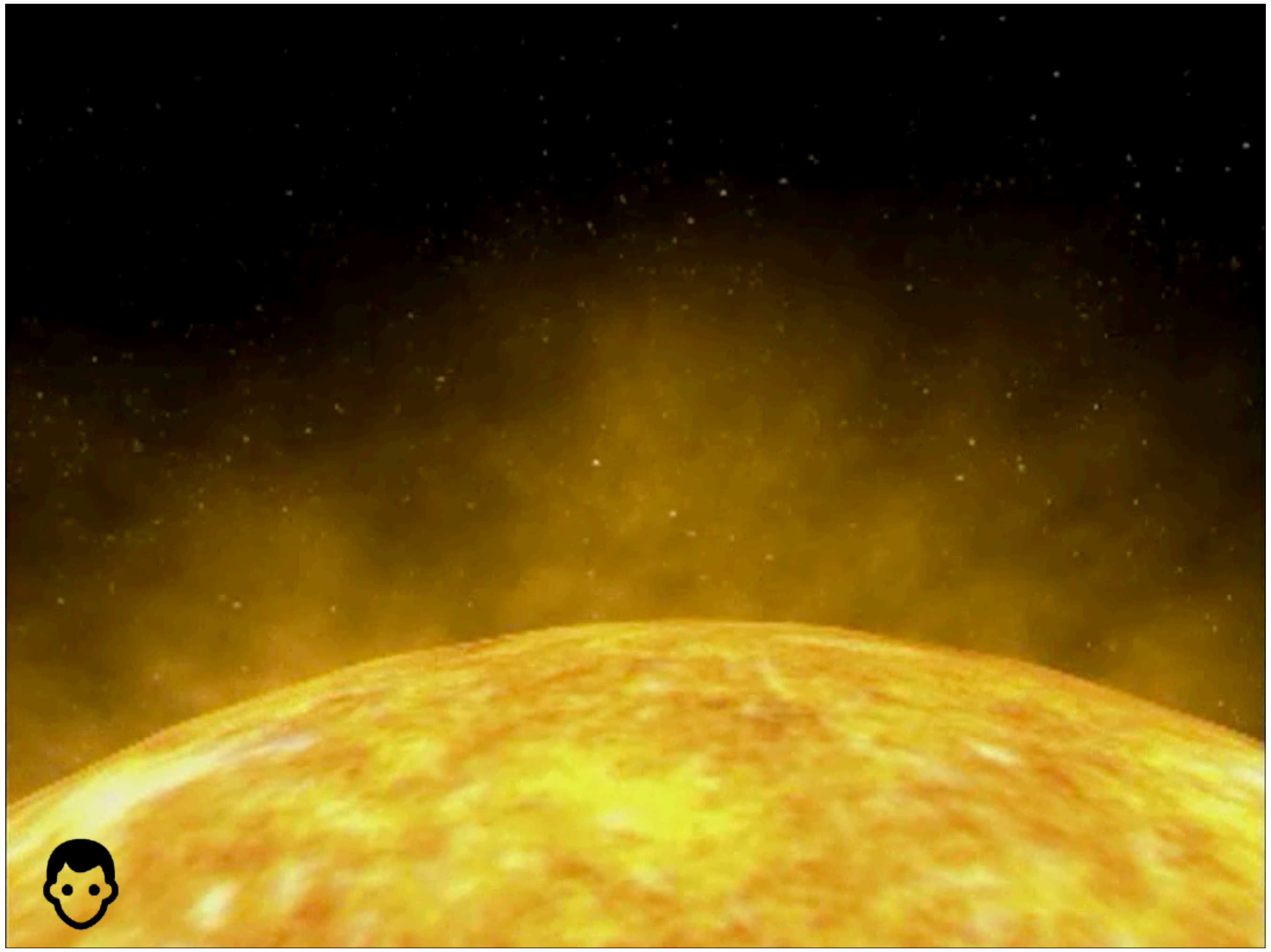
Ionosphere is needed for long distance HF communication which makes use of the reflective capability of the ionosphere. The ionosphere acts as a mirror.

AA, PCA, SWF are absorption events
PSD reduces the range of frequencies available.



Precipitating electrons coming from the tail

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

Energetic precipitation on the morning sector

During auroral displays, the **precipitating electrons** can enhance other layers of the ionosphere and have similar disrupting and blocking effects on radio communication. This occurs mostly **on the night side of the polar regions of Earth where the aurora is most intense and most frequent.**

The auroral absorption is an indicator of the high-energy electrons intrusion in the lowest ionosphere layer D.

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2000RS002550
The high variability of radio wave propagation in the polar regions is especially challenging to geophysicists and radio engineers. Propagation effects include polar cap absorption (PCA), which lasts for one to several days following solar proton events, and auroral absorption, which occurs almost all the time and varies on shorter timescales. Except when a PCA event is ongoing, auroral absorption is the most significant effect on high-latitude propagation. Auroral absorption occurs primarily in the D region of the Earth's ionosphere, where electron-neutral collisions dissipate the energy of electromagnetic waves passing through the medium. The collision frequency depends on electron density, which in the nighttime auroral D region is provided primarily by electron impact ionization by auroral electrons, leading to a close correlation between the absorption and auroral activity.

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

Riometer data
D-RAP model

Attenuation
10 * log (P1/P2) met P1 in en P2 out —- log (P1/P2)=y —> P1/P2=10^y

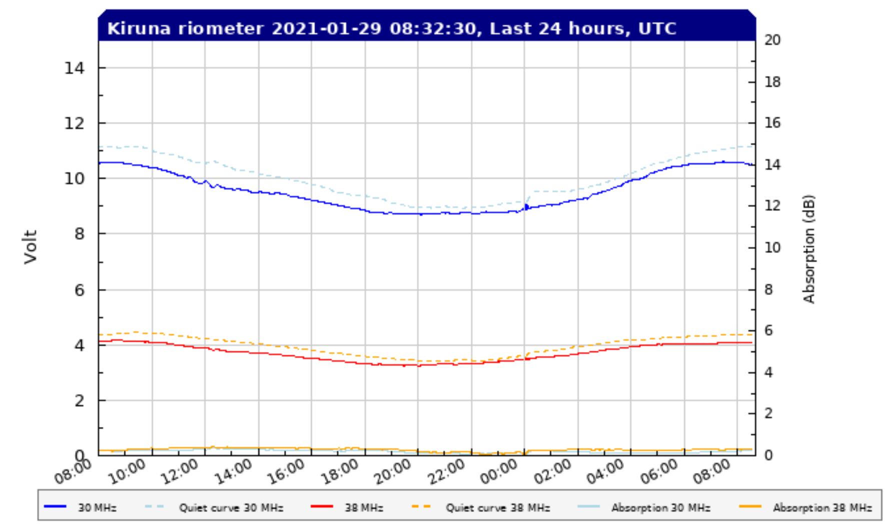
1dB attenuation -> out = in
10dB attenuation —> out = 10 times less strong - P2 = 10^-1 P1
20 dB attenuation —> out =100 times less strong - P2 = 10^-2 P1
30 dB attenuation —> out = 1000 times less strong - P2 = 10^-3 P1

1dB attenuation -> in = out
2,3,4,5,6,7,8,9
10dB attenuation —> in = 10 times stronger than out - P1 = 10^1 P2
20,30,40,50,60,70,80,90
20 dB attenuation —> in = 100 times stronger than out - P1 = 10^2
200,300,
30 dB attenuation —> in = 1000 times stronger than out - P1 = 10^3

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.

Radio waves are reflected at the F2 layer. The radio waves pass through the D-layer where they can be absorbed.
>2dB for 30 Mhz

PCA - RIOMETERS



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

A riometer is an instrument used to quantify the amount of electromagnetic-wave ionospheric absorption in the atmosphere.
"opacity" of the ionosphere to radio noise emanating from cosmic origin.

In the **absence of any ionospheric disturbance**, this radio noise, averaged over a sufficiently long period of time, forms a **quiet-day curve**.

Increased ionization in the ionosphere will cause absorption of radio signals (both terrestrial and extraterrestrial), and a departure from the quiet-day curve. The **difference between the quiet-day curve and the riometer signal** is an **indicator of the amount of absorption**, and is measured in decibels.

Riometers are generally passive radio antenna operating in the VHF radio frequency range (~30-40 MHz).

https://www.oulu.fi/sgoenglish/node/19549
Riometer (Relative ionospheric opacity meter) **measures cosmic radio noise absorption** (CNA) in the D-region of ionosphere. Frequencies used for the measurement are reserved for the military communication, so time to time local transmitters can saturate the receiver. One of the strongest radio sources on the sky is Cygnus α.

Kiruna riometer: http://www2.irf.se/riographs/rtkirplot2_rio_filtered_24.png

A riometer (commonly relative ionospheric opacity meter, although originally: Relative Ionospheric Opacity Meter for Extra-Terrestrial Emissions of Radio noise[1]) is an instrument used to quantify the amount of electromagnetic-wave ionospheric absorption in the atmosphere.[2] As the name implies, a riometer measures the "opacity" of the ionosphere to radio noise emanating from cosmic origin. In the absence of any ionospheric absorption, this radio noise, averaged over a sufficiently long period of time, forms a quiet-day curve. Increased ionization in the ionosphere will cause absorption of radio signals (both terrestrial and extraterrestrial), and a departure from the quiet-day curve. The difference between the quiet-day curve and the riometer signal is an indicator of the amount of absorption, and is measured in decibels. Riometers are generally passive radio antenna operating in the VHF radio frequency range (~30-40 MHz). Electromagnetic radiation of that frequency is typically Galactic synchrotron radiation and is absorbed in the Earth's D region of the ionosphere.

Rioters are put on the ground

https://web.archive.org/web/20130404234726/http://www.haarp.alaska.edu/haarp/Rio.html
What is a riometer?

A riometer is a passive scientific instrument used to observe ionospheric absorption, particularly absorption at altitudes less than 110 km caused by electron precipitation. The word riometer stands for Relative Ionospheric Opacity Meter

How does a Riometer Work?

Riometers measure the strength of radio noise originating from stars or galaxies and arriving at the earth after passing through the ionosphere. The sky is filled with stars and galaxies that emit a broad spectrum of radio noise and the noise is strong enough to be picked up using sensitive receiving equipment. Because some regions of the sky are noiser than others, this noise varies on a predictable basis as the Earth rotates. Although noise due to stars or galaxies may change over very long time frames, it is constant enough to be considered a repeatable function of Local Sidereal Time.
Depending on the amount of ionization present, radio signals passing through the ionosphere may suffer losses (or become weaker) in a process called absorption. Imagine the ionosphere as a set of louvers. If it is disturbed, the louvers close and signals arriving from outside of the earth's vicinity do not pass through very well. If the ionosphere is "quiet," the louvers are open fully and signals pass through easily.

If there were no sources of absorption in the earth's atmosphere, the cosmic noise measured by the riometer would be exactly the same at corresponding times during each successive Sidereal day. The "Quiet Day Curve" is this expected, or "no-absorption" diurnal noise level. (In this context,"quiet" means that the ionosphere is undisturbed by solar events.) Any difference between the actual measurement and the Quiet Day Curve is attributed to ionospheric absorption.

The riometer uses a sensitive receiver which is typically tuned to a frequency near the lower end of the Very High Frequency (VHF) region. The frequency is chosen to be high enough that radio waver are not reflected by the ionosphere but pass through it. At the same time, ionospheric absorption gets less as the frequency is increased, so the frequency should not be too high if good measurement resolution is desired. Traditionally, frequencies in the 21 to 40 MHz range have been used. A large number of riometers world wide including the one at HAARP use a common frequency, 30 MHz.

The riometer is intended to measure the ionospheric absorption directly above its location. Medium to high gain antennas pointed at the zenith are used. Such antennas also suppress interfering, man made radio signals that may propagate into the location at low angles.

In operation, the riometer listens to the background cosmic radio noise throughout the day. If that noise is the same as the expected (or quiet day curve) noise, we know that it is not being affected by the ionosphere before it reaches the earth's surface. **If the received noise is less than the quiet day curve, we know the ionosphere has absorbed some of the noise signal.** The riometer uses a conversion algorithm to calculate an estimate of the amount of absorption thus observed. A simple relation can be used to determine the amount of absorption that would be caused at other frequencies.

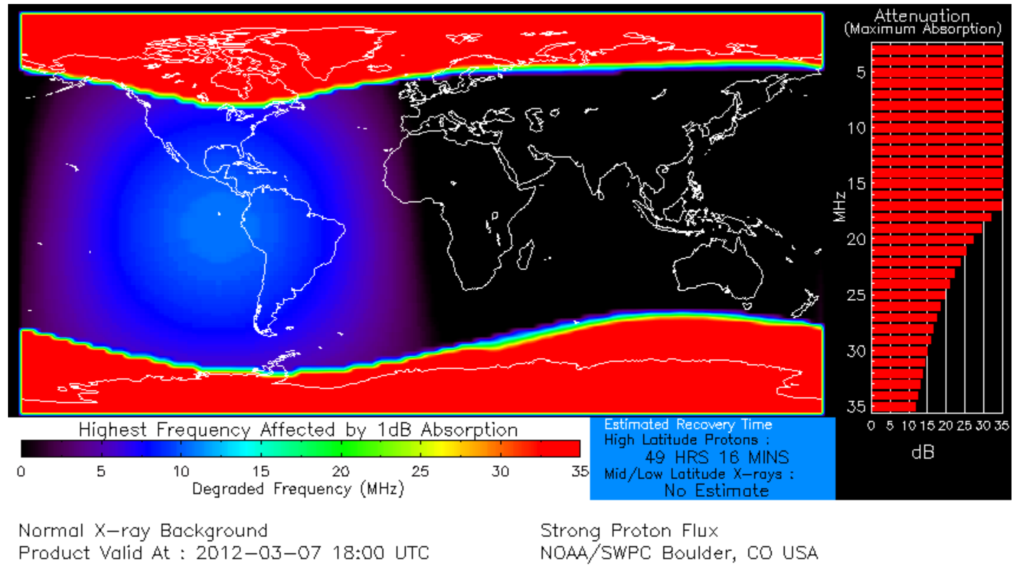
How is the riometer used scientifically?

Riometers are most sensitive to ionospheric absorption occurring at altitudes between 50 and 110 km. Absorption at these altitudes can be caused in several ways. During daylight hours, for example, the sun causes ionization in the "D layer" at altitudes near 80 km. This ionization occurs each day throughout the year and is a predictable function of the sun's zenith angle. This regular and periodic absorption is accounted for in the "quiet day curve."
Another type of absorption event is caused by high energy electrons precipitating into the earth's atmosphere from the magnetosphere as a result of a disturbance in the solar wind, for example. The altitude to which these particles penetrate depends on their initial energy. Auroral precipitation, commonly observed at high latitudes, produces absorption at altitudes of 90 - 100 km. Riometers are capable of observing auroral precipitation events that would not necessarily be visible optically.

Absorption events shown by riometers are very frequently (but not always) associated with poor HF sky-wave propagation conditions. When the sun is above the horizon, an energetic solar flare will cause nearly instantaneous increases in the ionization of the D and E layers, producing an abrupt short wave fade-out. Riometers will clearly indicate these transient events that are common during the active portion of the solar cycle.

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.



D-Region Absorption Predictions
Map giving info on spatial extend and freq impact

HF radio communication
Another type of space weather, the Radiation Storm caused by energetic solar protons, can also disrupt HF radio communication. The protons are guided by Earth's magnetic field such that they collide with the upper atmosphere near the north and south poles. The fast-moving protons have an affect similar to the x-ray photons and create an enhanced D-Layer thus blocking HF radio communication at high latitudes.

https://www.swpc.noaa.gov/products/d-region-absorption-predictions-d-rap
D-region absorption product addresses the operational impact of the solar X-ray flux and SEP events on HF radio communication. Long-range communications using high frequency (HF) radio waves (3 - 30 MHz) depend on reflection of the signals in the ionosphere. Radio waves are typically reflected near the peak of the F2 layer (~300 km altitude), but along the path to the F2 peak and back the radio wave signal suffers attenuation due to absorption by the intervening ionosphere.

The D-Region Absorption Prediction model is used as guidance to understand the HF radio degradation and blackouts this can cause.
Conditions in the D-region of the ionosphere have a dramatic effect on high frequency (HF) communications and low frequency (LF) navigation systems. 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. This product merges all latitudes using appropriate displays, and is useful to customers from a broad base that includes emergency management, aviation and maritime users.

The D-Region Absorption Map is composed of four dynamic components: a global map of the highest frequency affected by absorption of 1 dB due to either solar X-ray flux or SEP events or a combination of both, an attenuation bar graph, status messages, and an estimated recovery clock. All of the components update continuously, driven by one-minute GOES X-ray flux data and by five-minute GOES proton flux data. To complement the global frequency map, polar projection maps of the highest frequency affected by absorption of 10 dB due to primarily to SEP events are also available by clicking on the North Pole and South Pole links. The Tabular Values link displays numeric values of the frequency map in 5-degree latitude and 15-degree longitude increments. A more complete discussion of the product can be found in the Global D-Region Absorption Prediction documentation.

https://www.swpc.noaa.gov/content/global-d-region-absorption-prediction-documentation

Attenuation = verzwakking

10 * log (P1/P2) met P1 in en P2 out —- log (P1/P2)=y —> P1/P2=10^y

1dB attenuation -> out = in
10dB attenuation —> out = 10 keer minder sterk - P2 = 10^-1 P1
20 dB attenuation —> out =100 keer minder sterk - P2 = 10^-2 P1

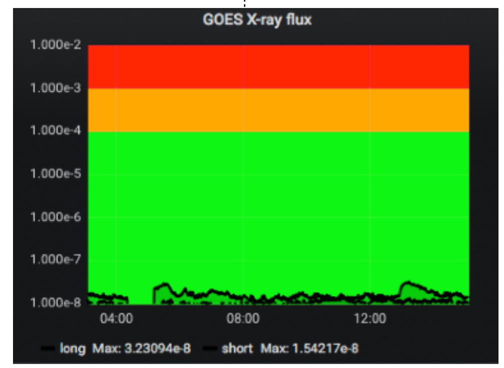
30 dB attenuation —> out = 1000 keer minder sterk – P2 = 10^–3 P1

1dB attenuation –> in = out
2,3,4,5,6,7,8,9
10dB attenuation —> in = 10 keer sterker dan out – P1 = 10^1 P2
20,30,40,50,60,70,80,90
20 dB attenuation —> in = 100 keer sterker dan out – P1 = 10^2
200,300,
30 dB attenuation —> in = 1000 keer sterker dan out – P1 = 10^3

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

advise: higher HF might be less impacted

http://www.astro.gla.ac.uk/users/eduard/cesra/?p=2198&utm_source=dlvr.it&utm_medium=facebook

Both Figure 1 and Figure 2 show how quickly and dramatically a solar flare can impact HF communications. Radio blackouts are particularly difficult because they are generally impossible to predict. Since the flare X-ray energy travels at the speed of light, we can only know the flare has occurred once it has already arrived. Fortunately, the recombination time of the D region is relatively fast, and communications can resume within just a few hours. Also, solar flares primarily affect only the dayside ionosphere; Frissell et al. (2019) shows a corresponding figure to Figure 2 that shows United States communications were barely affected by the flares because the US was on the dawn flank.

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

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

foF2= critical frequency

N

Ionosonde: The most widely used instrument for ionospheric measurement is the ionosonde. The ionosonde is essentially a high frequency radar which sends short pulses of radio energy into the ionosphere. If the radio frequency is not too high, the pulses are reflected back to earth.

1- MUF/median 30 days —> negative when MUF increases, 0 wanneer het zoals verwacht is, positive when MUF is decreased

It is negative when MUF> median

MUF is lower during night, but doesn't fade away because the reflective capability of the ionosphere is not gone over 1 night.

foF2=vertical signal
https://www.sws.bom.gov.au/HF_Systems/6/5
A feature of the ionosphere is its ability to reflect radio waves. However, only radio waves within a certain frequency range will be reflected and this range varies with a number of factors.

——————

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.

In radio transmission maximum usable frequency (MUF) is the highest radio frequency that can be used for transmission between two points via reflection from the ionosphere (skywave or "skip" propagation) at a specified time, independent of transmitter power. This index is especially useful in regard to shortwave transmissions.

In shortwave radio communication, a major mode of long distance propagation is for the radio waves to reflect off the ionized layers of the atmosphere and return diagonally back to Earth. In this way radio waves can travel beyond the horizon, around the curve of the Earth. However the refractive index of the ionosphere decreases with increasing frequency, so there is an upper limit to the frequency which can be used. Above this frequency the radio waves are not reflected by the ionosphere but are transmitted through it into space.

The ionization of the atmosphere varies with time of day and season as well as with solar conditions, so the upper frequency limit for skywave communication varies on an hourly basis. MUF is a median frequency, defined as the highest frequency at which skywave communication is possible 50% of the days in a month, as opposed to the lowest usable high frequency (LUF) which is the frequency at which communication is possible 90% of the days, and the Frequency of optimum transmission (FOT).

Typically the MUF is a predicted number. Given the maximum observed frequency (MOF) for a mode on each day of the month at a given hour, the MUF is the highest frequency for which an ionospheric communications path is predicted on 50% of the days of the month.

On a given day, communications may or may not succeed at the MUF. Commonly, the optimal operating frequency for a given path is estimated at 80 to 90% of the MUF. As a rule of thumb the MUF is approximately 3 times the critical frequency.[1]

MUF=critical frequency/cos θ[2]

where the critical frequency is the highest frequency reflected for a signal propagating directly upward and Θ is the angle of incidence.[3]

advise: lower frequencies might be less impacted
—-
https://en.wikipedia.org/wiki/High_frequency
The dominant means of long-distance communication in this band is skywave ("skip") propagation, in which radio waves directed at an angle into the sky refract back to Earth from layers of ionized atoms in the ionosphere.[3] By this method HF radio waves can travel beyond the horizon, around the curve of the Earth, and can be received at intercontinental distances. However, suitability of this portion of the spectrum for such communication varies greatly with a complex combination of factors:

Sunlight/darkness at site of transmission and reception
Transmitter/receiver proximity to solar terminator
Season
Sunspot cycle
Solar activity
Polar aurora
At any point in time, for a given "skip" communication path between two points, the frequencies at which communication is possible are specified by these parameters

Maximum usable frequency (MUF)
Lowest usable high frequency (LUF) and a
Frequency of optimum transmission (FOT)
The maximum usable frequency regularly drops below 10 MHz in darkness during the winter months, while in summer during daylight it can easily surpass 30 MHz. It depends on the angle of incidence of the waves; it is lowest when the waves are directed straight upwards, and is higher with less acute angles. This means that at longer distances, where the waves graze the ionosphere at a very blunt angle, the MUF may be much higher. The lowest usable frequency depends on the absorption in the lower layer of the ionosphere (the D-layer). This absorption is stronger at low frequencies and is also stronger with increased solar activity (for example in daylight); total absorption often occurs at frequencies below 5 MHz during the daytime. The result of these two factors is that the usable spectrum shifts towards the lower frequencies and into the Medium Frequency (MF) range during winter nights, while on a day in full summer the higher frequencies tend to be more usable, often into the lower VHF range.[citation needed]

When all factors are at their optimum, worldwide communication is possible on HF. At many other times it is possible to make contact across and between continents or oceans. At worst, when a band is "dead", no communication beyond the limited groundwave paths is possible no matter what powers, antennas or other technologies are brought to bear. When a transcontinental or worldwide path is open on a particular frequency, digital, SSB and Morse code communication is possible using surprisingly low transmission powers, often of the order of milliwatts, provided suitable antennas are in use at both ends and that there is little or no man-made or natural interference.[4] On such an open band, interference originating over a wide area affects many potential users. These issues are significant to military, safety[5] and amateur radio users of the HF bands.

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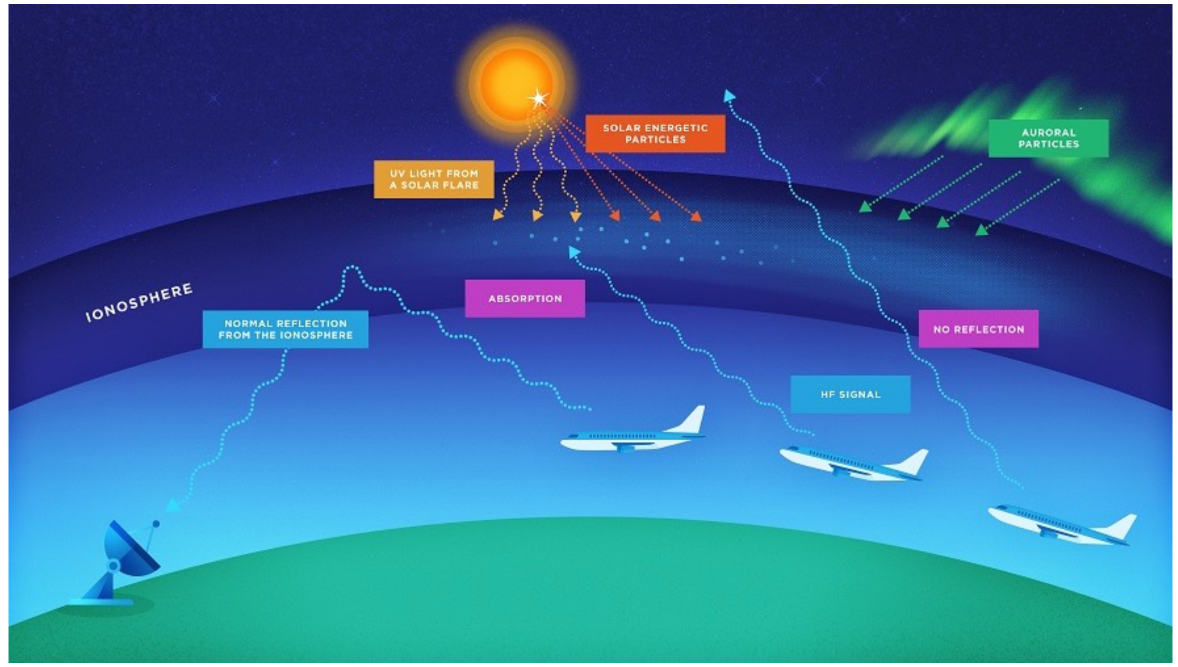

AA - auroral absorption - precipitating electrons - F-layer
PCA - protons trigger extra ionisation - D-layer
Flare - extra ionisation - D-layer
PSD - ionospheric storm

The ionosphere is a layer at the top of our atmosphere which is ionised due to sunlight (at ultraviolet and x-ray wavelengths). Because the layer is ionised, it has the ability to reflect HF radio waves allowing long distance radio communication, which is crucial for aviation. HF radio waves have frequencies between 3 and 30 MHz.
However, during solar storms, extra energy is deposited into the ionosphere, introducing additional ionisation and irregularities. HF radio waves can be absorbed or reflected in unforeseen ways, causing a radio communication failure. This malfunctioning can happen near the Earth's poles or on the day-light side of the Earth, depending on the sort of solar storm and associated energy input.

A geomagnetic storm disturbs the Earth's magnetic field allowing an increased transport of energy from the magnetotail towards the auroral zones. Typically, a geomagnetic storm is more intense at higher latitudes.
Solar energetic protons can penetrate the Earth at the magnetic poles and cause extra ionisation making radio communication impossible for hours and days. A so-called Polar Cap Absorption is localised near the Earth's magnetic poles and depends on latitude and impacts the lower frequencies of the HF band.
During a solar flare, extra ionising solar radiation indents on the ionosphere on the day-side of Earth and impacts HF communication. The impact of a solar flare lasts as long as the flare, ranging from minutes to hours.
These three space weather storms impact the ionosphere. These impacts are labelled as an 'ionospheric storm' and result in a Post Storm Depression. The parameter used describes in percentages how much the frequency usable for HF radio communication is lowered.