PECASUS

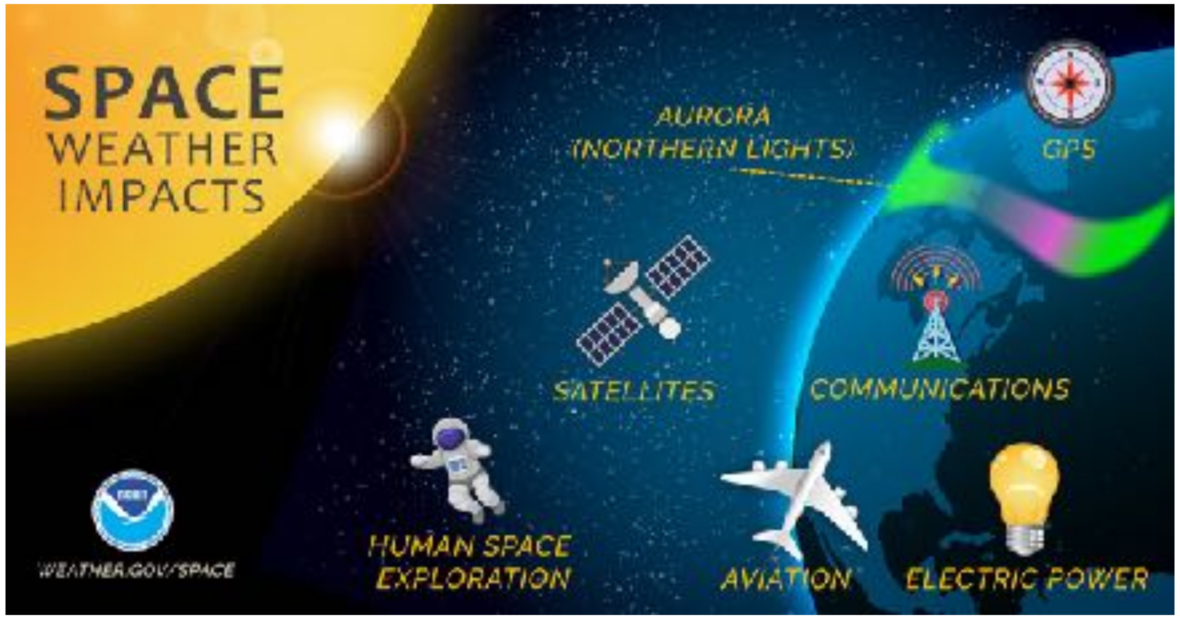
For civil aviation

SPACE WEATHER INTRODUCTORY COURSE

For space weather operators

4TH PART

You need information on solar weather, heliopsheric weather, Galactic Cosmic Rays and ionospheric weather to make an advisory for civil aviation. We need to check the impact of space weather on Radiation at FLV, HF communication and GNSS effects.

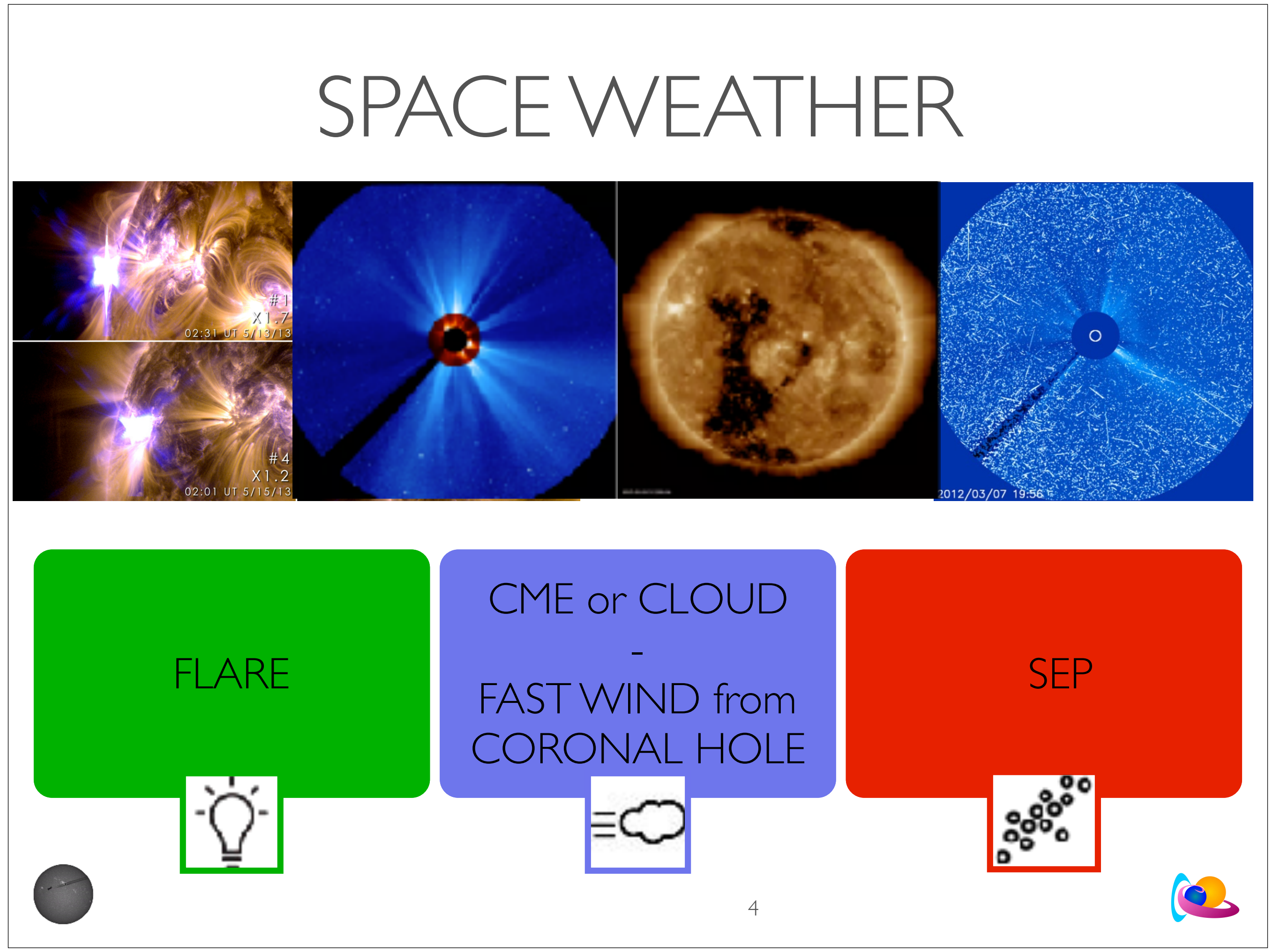


Rehearsal + SRB + GCR + Ionospheric storms

An ursigram exercise

Visit of the STCE GNSS headquarters

Visit of the STCE Radiation headquarters



Magnetic reconnection triggers a sudden release of energy in the form of a flare, CME, particle event.

Space weather is the change that occur in the space environment.

A Flare is a sudden strong increase of the solar e.m. radiation. The light flash is localised on the solar surface.
SDO/AIA

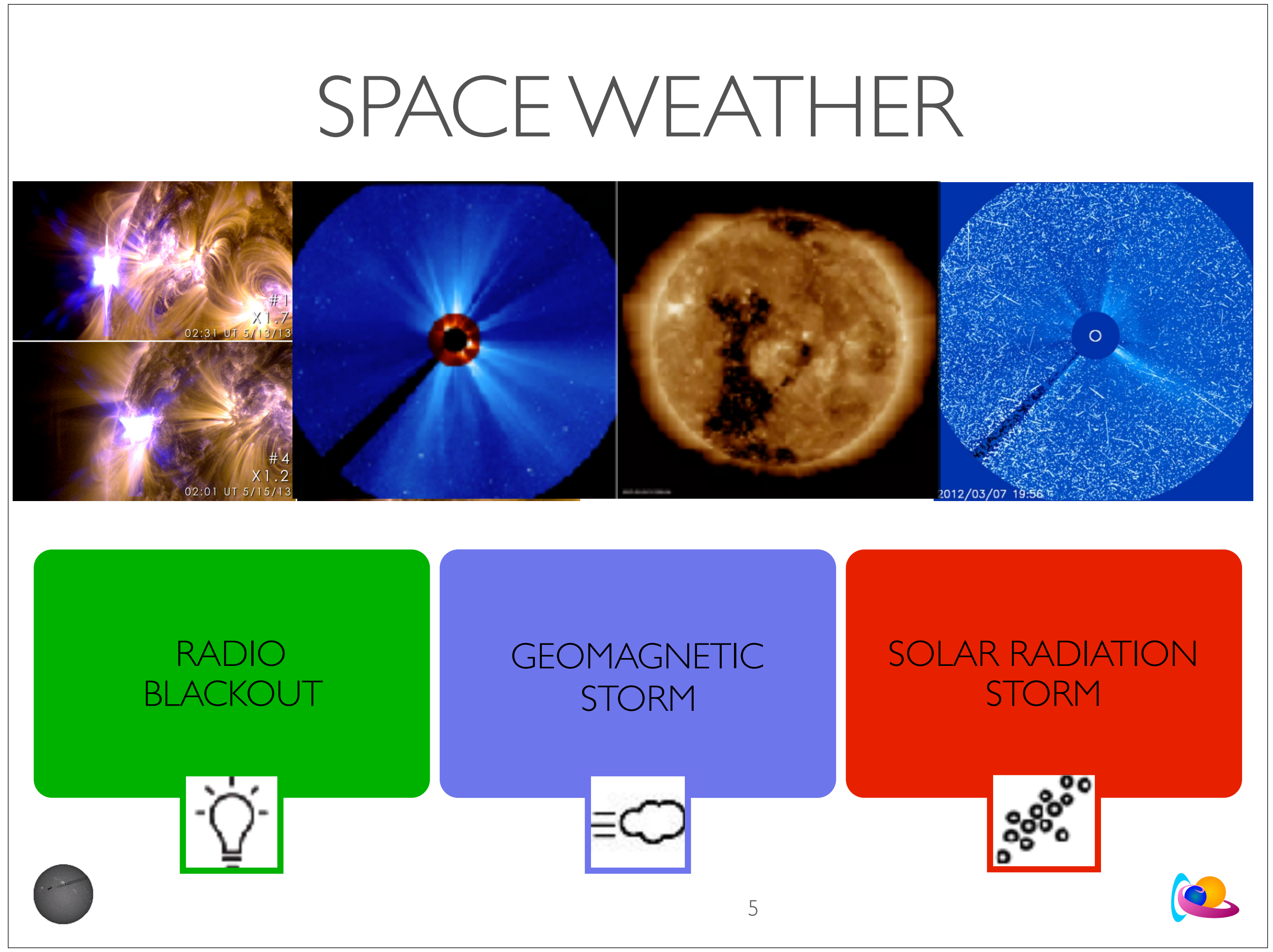
A Coronal Mass Ejection is a plasma cloud that is ejected into space. You consider it as a cloud and not as a bunch of individual particles. It is superimposed on the background solar wind. You can see a CME as a complex magnetic bag with different magnetic layers with plasma in it that travels as a tsunami through space. It can go faster/as fast as/slower than the background solar wind. When it is faster, you will see a shock in front of the cloud. This is exactly the same as the shock you see in front of a speed boat.
A CME is visible as a white cloud in corona graphic images like the one on the slide. A coronagraph is a telescope that creates an artificial eclipse and makes pictures in the visible light of the region around the sun.
SOHO/LASCO C2 (red) and LASCO C3 (blue)

A coronal hole is a structure in the solar corona that you see as a black area in the EUV. It looks black because there is less plasma present that radiates in the EUV. The magnetic field lines are open, i.e. fan out into space. There are no magnetic loops above a coronal hole. The solar wind emanating from a CH is faster compared to the usual solar wind.
SDO/AIA

A particle storm is a bunch of electrically charged particles that circle around the IMF lines into space. They may impact telescopes. They are seen as white stripes and dots: this are particles that fall into the lens and blind the pixel(s). During that particular moment, the telescope can't see anymore through the impacted pixels. You can say that the dots and stripes represent a sort of in situ measurement.

In situ means that you measure a parameter local. Remote sensing means that you look at something from a distance.

Near Earth, the IMF still controls the solar wind and its movement. If we would go much much further, the CME magnetic bag with solar plasma would be almost empty (all the solar material is spread over an immense volume) and the magnetic bag would have evaporated. But, this doesn't matter for us. We are at 1AU and at 1AU the IMF and solar plasma make space weather in a normal way, in an extreme way.



Impact on Earth environment according to the NOAA space weather scales

Radio blackout
Impact on navigation & radio communication

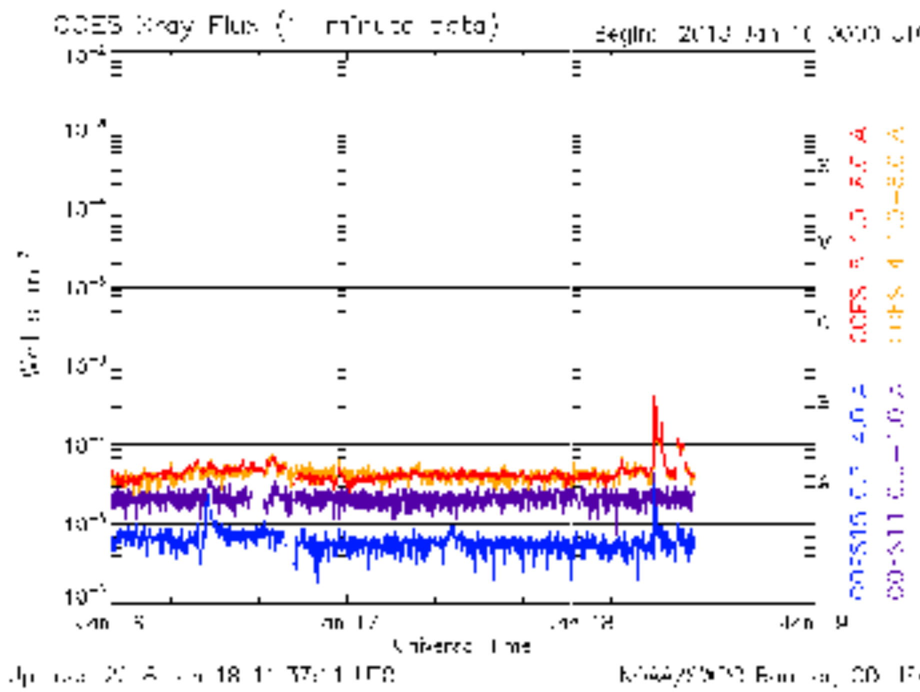
Geomagnetic storm
Radio communication, HF and LF
Satellite operations
Power systems, e.g. GIC
Aurora

Solar radiation storm
Biological impact
Satellite operations
HF communication in the polar regions – degradation or black out (PCA)
Navigation

Flare

X-RAY FLUX

A flare is identified by its x-ray flux. Flares are put into logaritmisch categories.



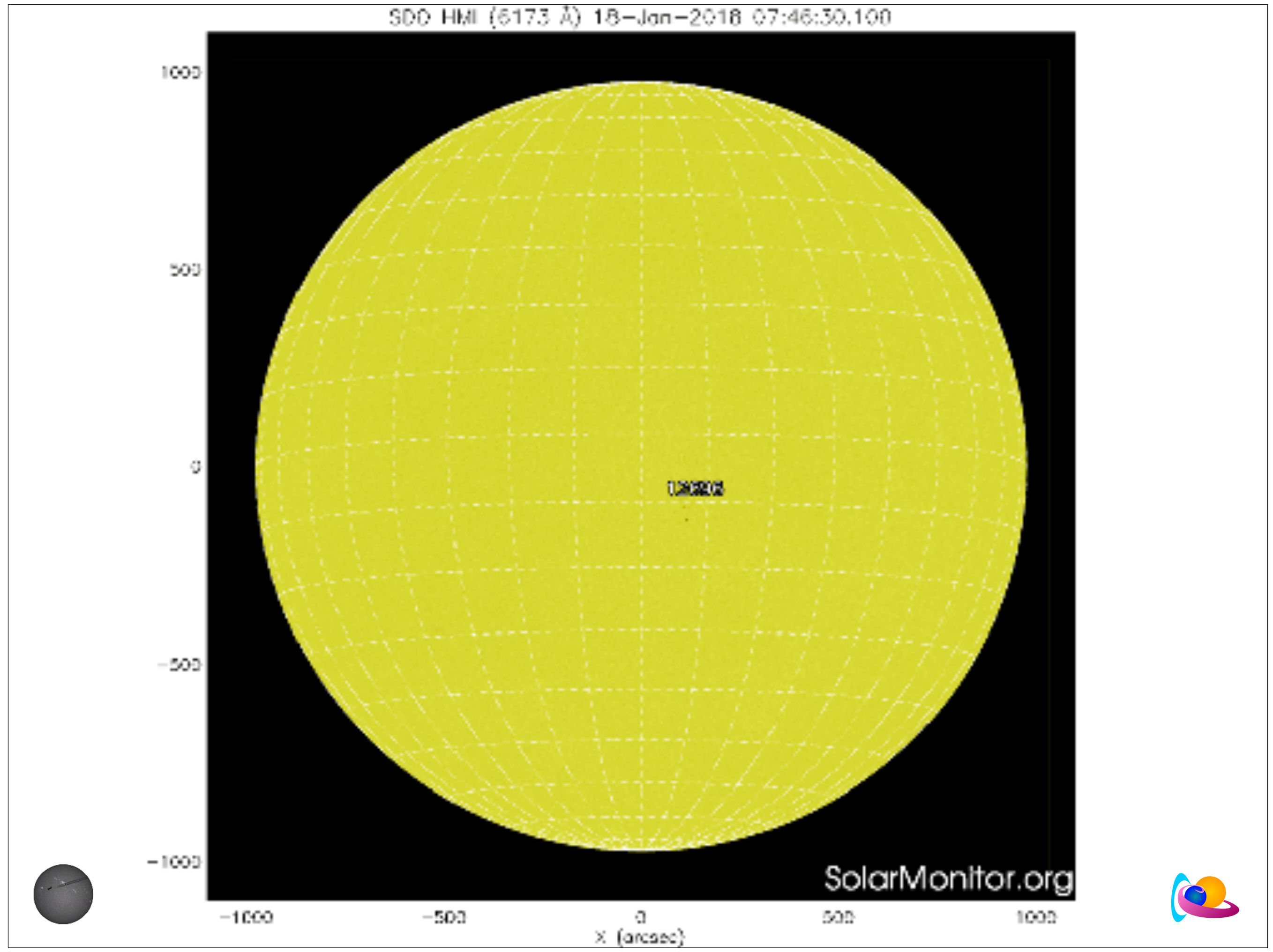
GOES satellite, geostationary
http://www.swpc.noaa.gov/products/goes-x-ray-flux

During a flare, magnetic energy is transformed into e.m. waves.

GOES measures the full disk e.m. radiation (Energy per second per square meter) in a particular X-ray wavelength every minute. The more intense, the higher the curve.

Flares are put into X-ray flux categories. The X-ray flux is measured by GOES (meteo-satellites of NOAA). The classes are based on the enlargement factor of the X-flux in the spectral range 1 to 8 Å - logarithmic. This enlargement factor can go up to 10 000, typically between 10 and 100.

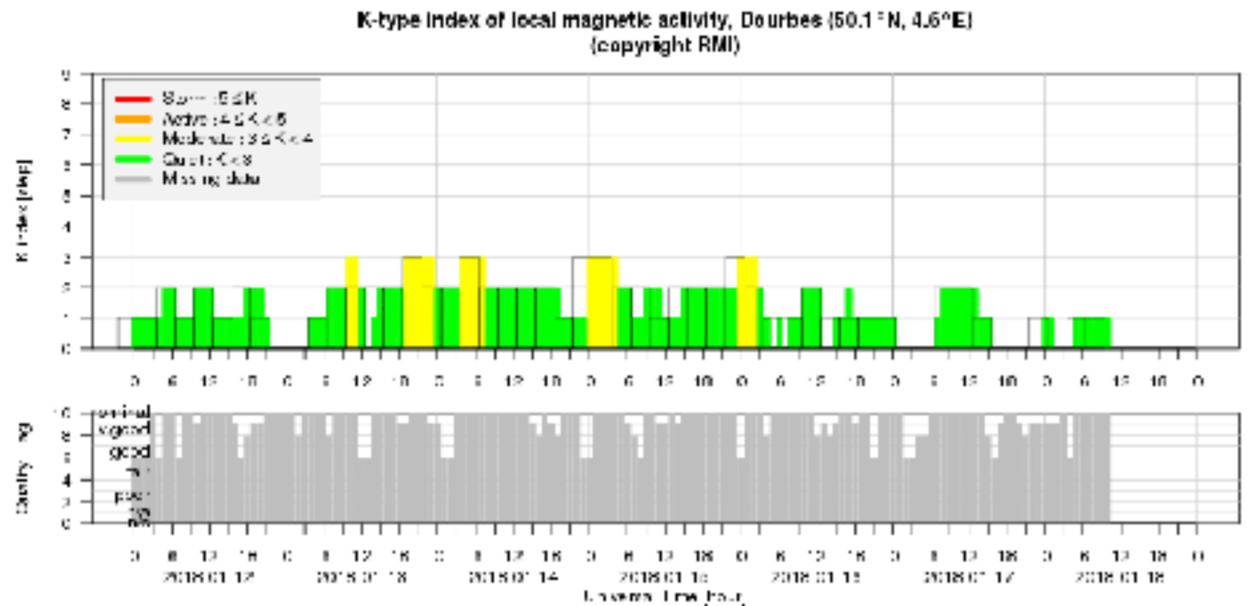
A flare can be a simple peak in the X-ray curve or a long duration event.


SDO HMI (6173 Å) 18-Jan-2018 07:46:30.100
1000
500
0
−500
−1000
−1000
−500
0
500
1000
X (arcsec)
SolarMonitor.org

Solar wind

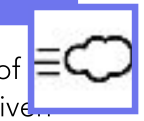
GEOMAGNETIC STORM

Magnetic reconnection between the solar wind magnetic field and the magnetic field of the Earth introduces magnetic disturbances. The strength of a geomagnetic storm is given by a local K of the planetary Kp index.



GEOMAGNETIC STORM

Solar wind



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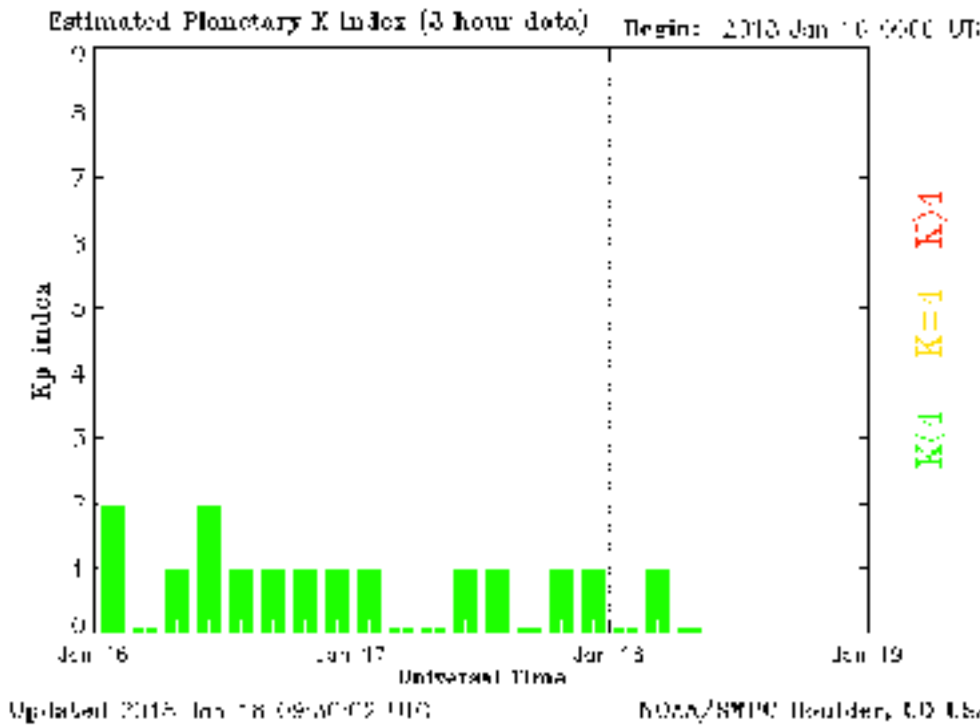
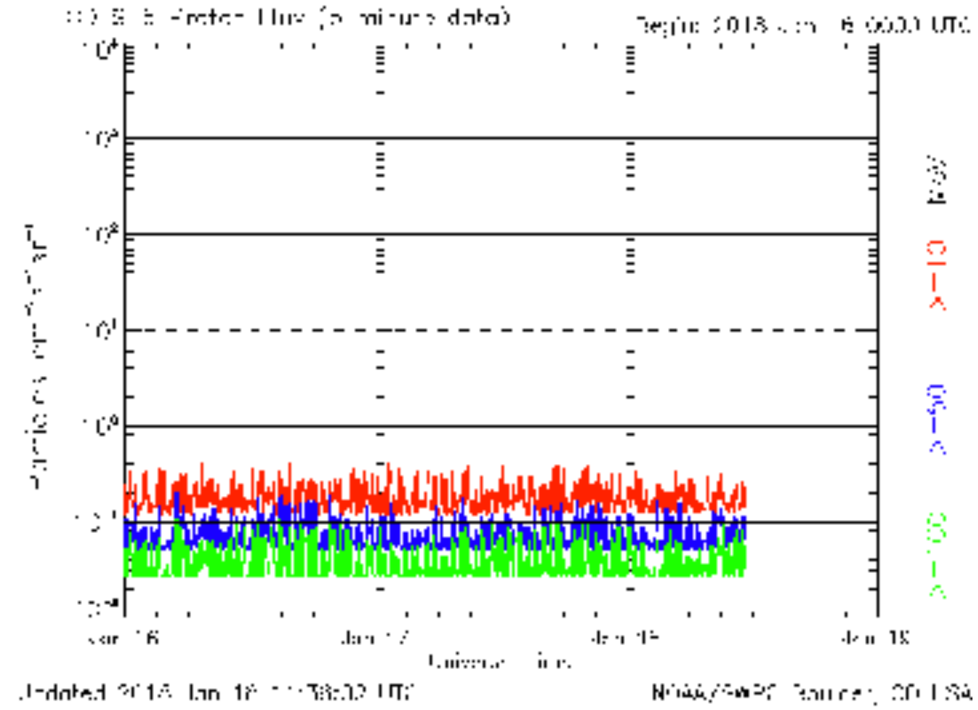
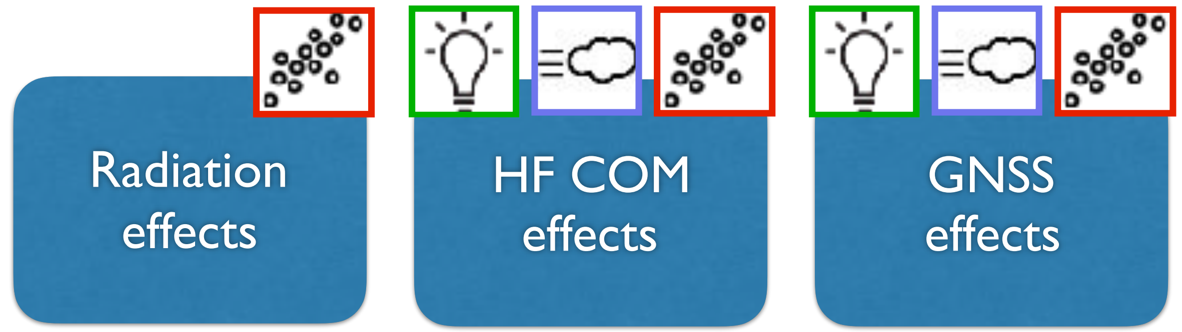


PROTON FLUX NOW



IMPACT ON TECHNOLOGY

Nevertheless, our technology is impacted. PECASUS concerns impacts on aviation operations.



Monitoring & forecasting space weather should result in 3 advisory messages.

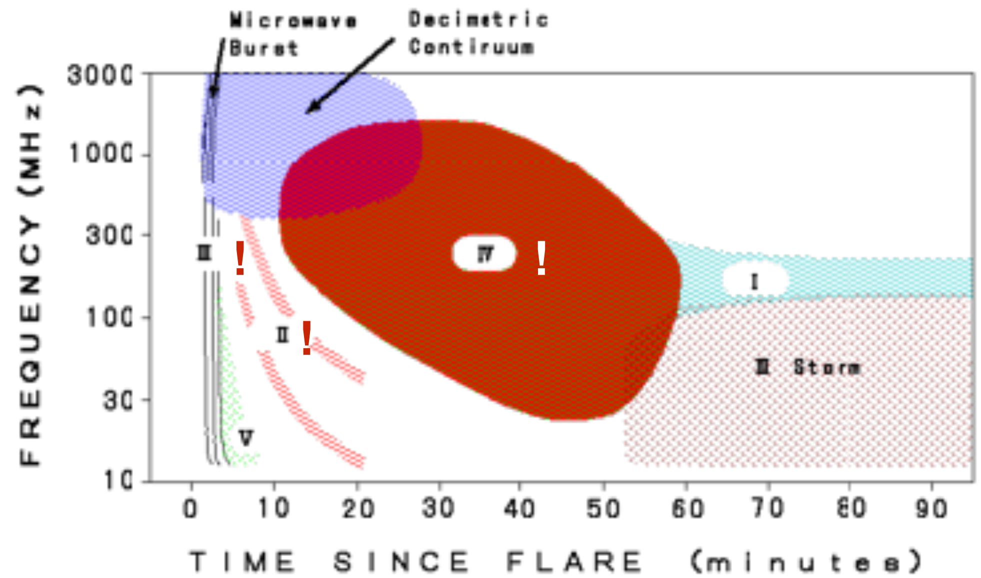
NOTAM = NOtice To AirMen

Radiation exposure at flight levels
High Frequency radio communication
GNSS-based navigation and surveillance

Solar Radio Bursts

Ionospheric storms

Galactic Cosmic Rays



SOLAR RADIO BURSTS

Detected by measuring e.m. waves in the radio wavelength
Type II, III and IV are important for space weather.
Indication

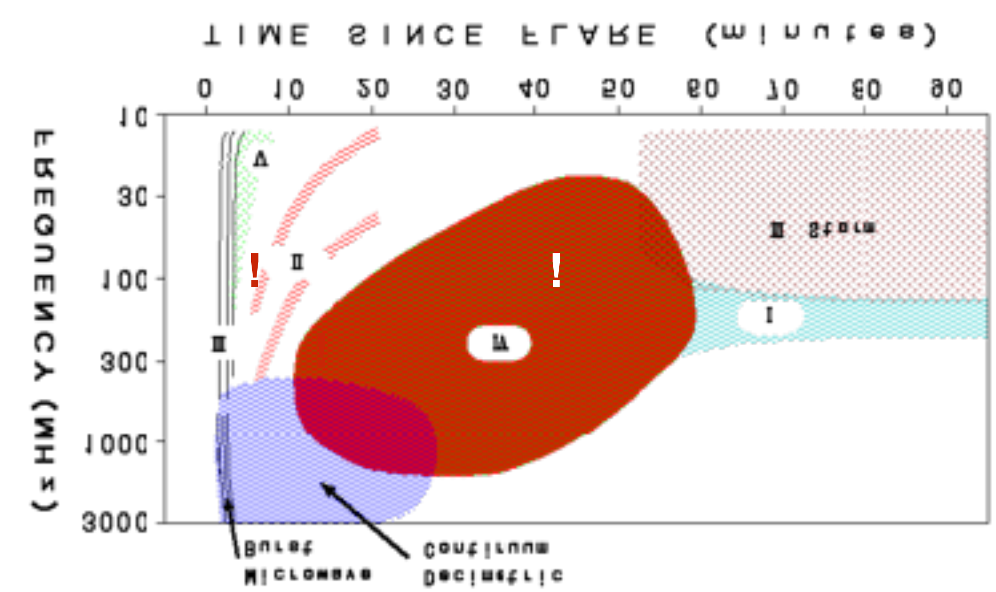
We can measure the **solar e.m. radio output and put it into a spectrogram.**
At low frequencies, **5 types** of radio wave bursts are seen, **each with a unique signature in frequency and time.**

These bursts are triggered by a solar event.

Mind the orientation of the vertical axis! Other figures may have a reversed direction. As the frequency is proportional to the square root of the density, and the density decreases with increasing distance from the Sun, a decreasing frequency means locations higher up in the solar atmosphere.

The ionospheric cut-off frequency is around 15MHz (due to too low frequency and so reflected by ionosphere). In order to observe radio disturbances below this frequency, one has to use satellites (above the earth atmosphere) such as STEREO/SWAVES or WIND. Radio bursts at low frequencies (< 15 MHz) are of particular interest because they are associated with energetic CMEs that travel far into the interplanetary (IP) medium and affect Earth's space environment if Earth-directed. Low frequency radio emission needs to be observed from space because of the ionospheric cutoff.
Example: https://stereo-ssc.nascom.nasa.gov/browse/2017/01/16/insitu.shtml

Coronal Mass Ejections and solar radio emissions, N. Gopalswamy
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.708.626&rep=rep1&type=pdf
Gopalswamy: The three most relevant to space weather radio burst types are type II, III, and IV. Three types of low-frequency non-thermal radio bursts are associated with coronal mass ejections (CMEs): Type III bursts due to accelerated electrons propagating along open magnetic field lines, type II bursts due



SOLAR RADIO BURSTS

F — density ^1/2

100 - 10
16 - 4
4 - 2
1 - 1

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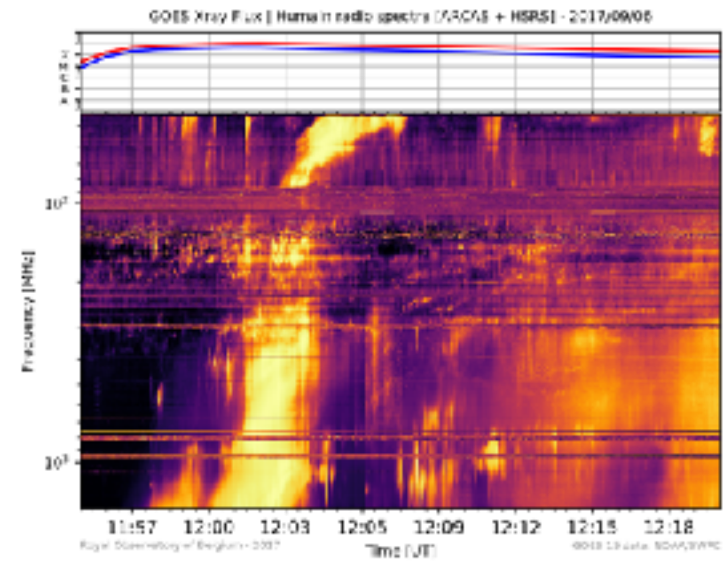
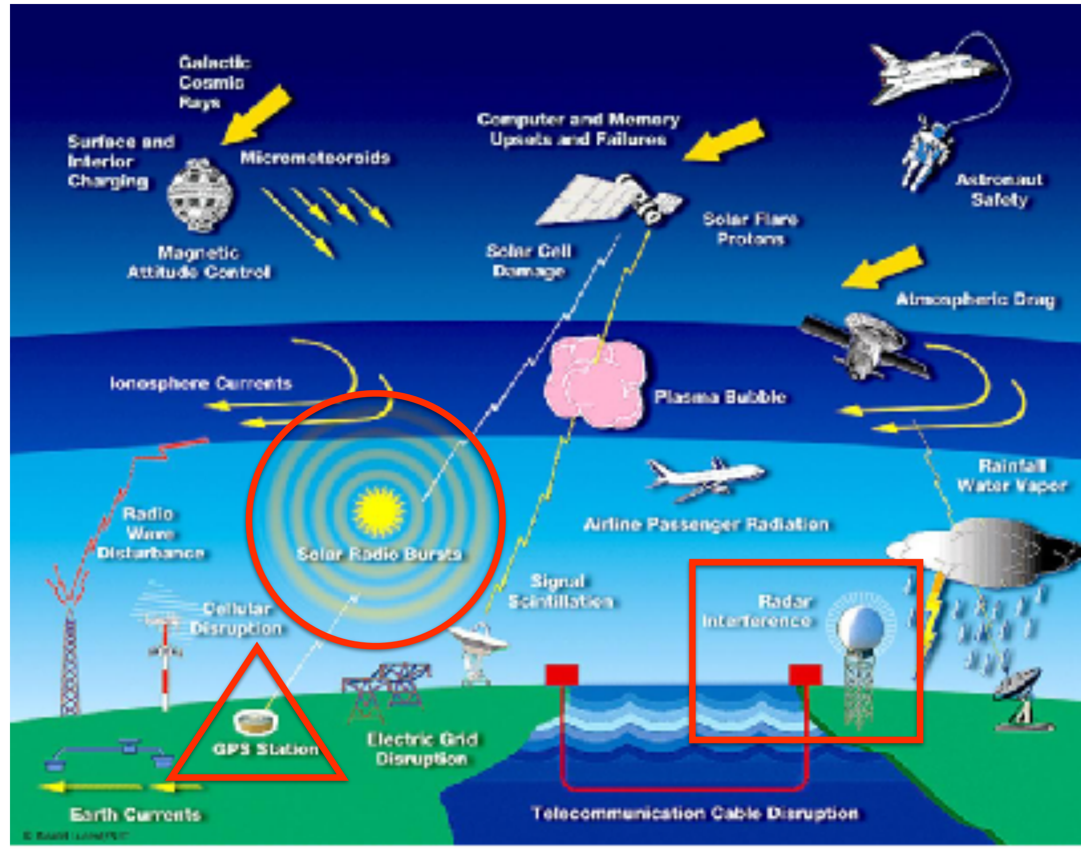
SOLAR RADIO BURSTS

SRB are produced by energetic electrons accelerated by solar eruptive events, like flares, filament eruptions, coronal mass ejections. Their radial signature - how it looks like in a spectrogram - tells something about the fate of these electrons.

- Type I: trapped in loops above A.R.
- Type II: accelerated by shock waves
- Type III: beams accelerated along open magnetic field lines
- Type IV: trapped in post-flare loops



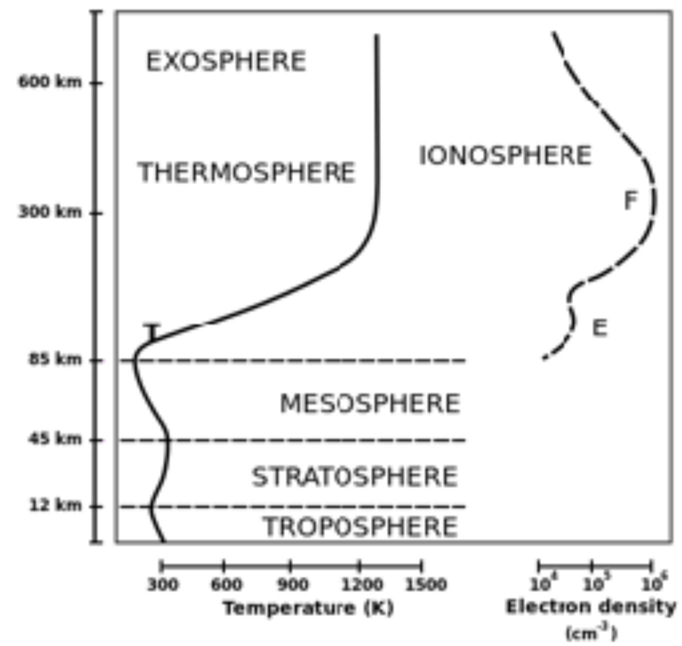
Radar interference
Signature of presence of a CME, flare

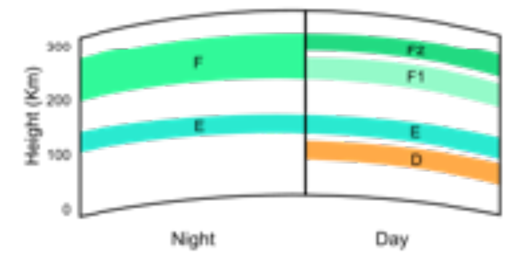


GPS station
Signal/noise – signal is from the satellite. GPS receivers are designed to be sensible to the signal above them, not at the horizon.
When there is a strong radio burst – in the typical GPS frequencies – the noise increases.

Radar interference
Radars are monitoring the planes near the horizon – descending and ascending planes

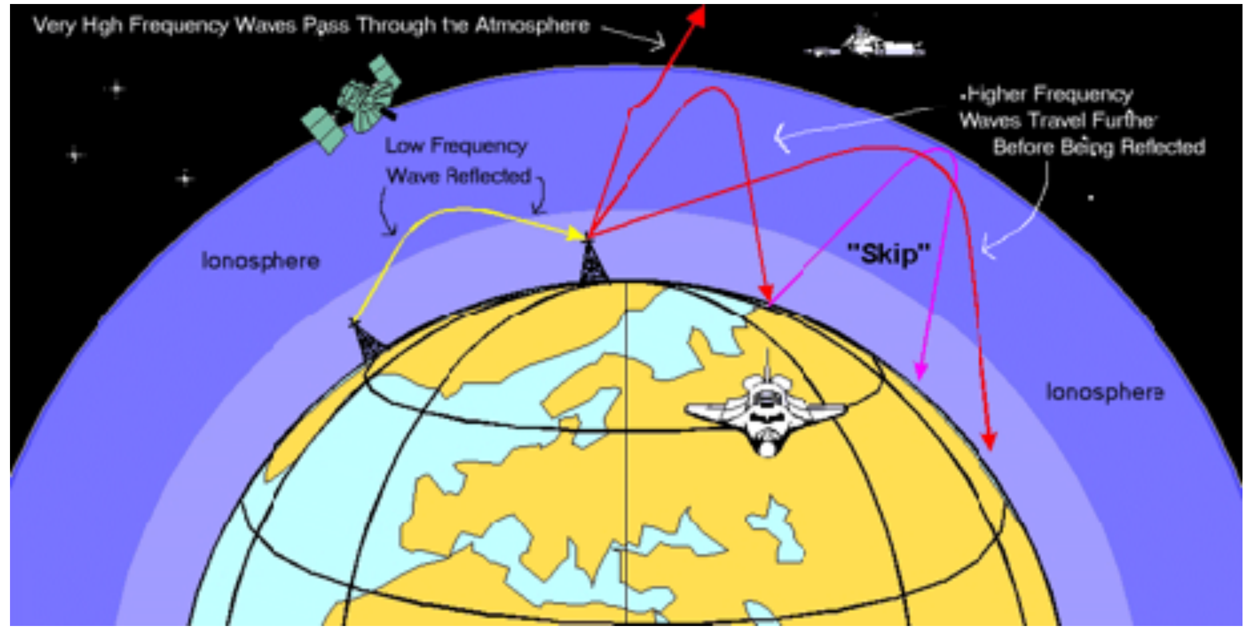
SRB can impact HF communication (no feedback from industry) and navigation





IONOSPHERE

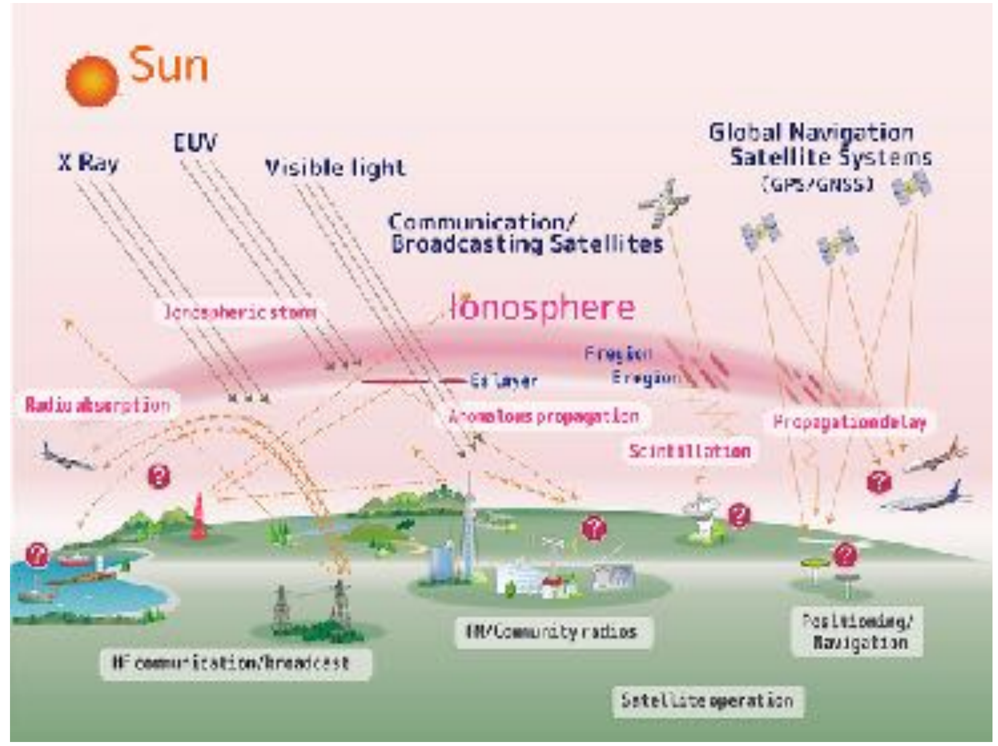
The ionosphere (/aɪˈɒnəˌsfɪər/[1][2]) is the ionized part of Earth's upper atmosphere, from about 60 km (37 mi) to 1,000 km (620 mi) altitude, a region that includes the thermosphere and parts of the mesosphere and exosphere. The ionosphere is ionized by solar radiation. It plays an important role in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



RADIO WAVES

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.



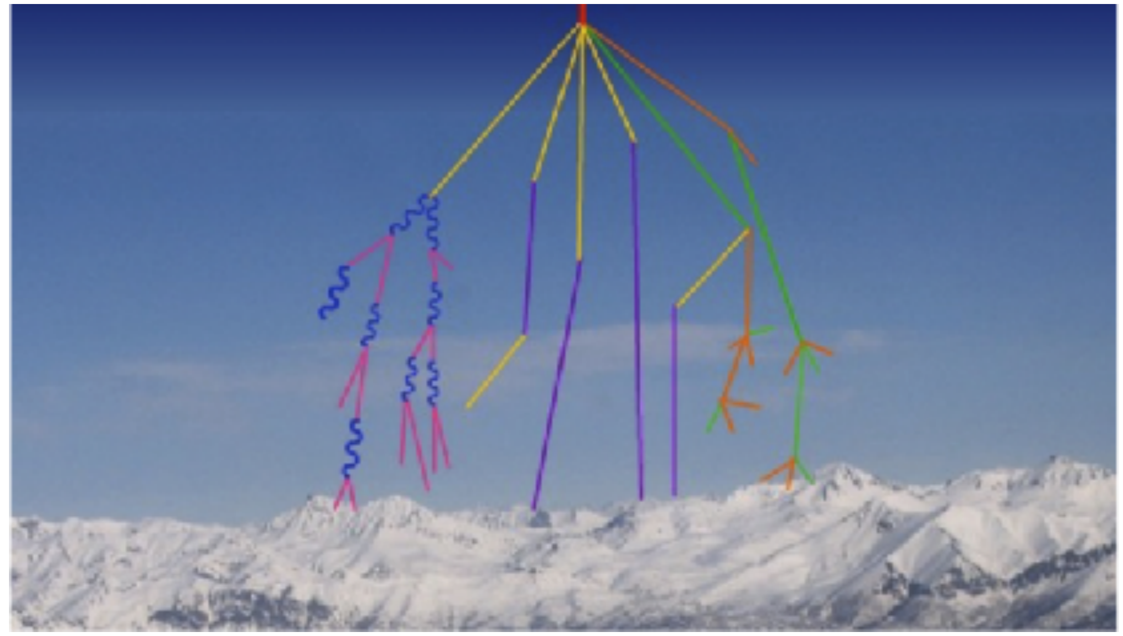
IONOSPHERIC ACTIVITY

Impact on HF communication and navigation

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

GALACTIC COSMIC RAYS

Galactic Cosmic Rays (GCR) are the slowly varying, highly energetic background source of energetic particles that constantly bombard Earth. GCR originate outside the solar system and are likely formed by explosive events such as supernova.



Neutron monitors:
They measure energetic particles at the earth surface. It measures the background radiation - which is always present and are in fact the GCR. This background radiation is modulated by solar activity, they are in anti-phase: high solar activity/strong solar wind corresponds to less GCR on earth.

The neutron monitors can measure a Ground Level Event, GLE. There will be a peak on top of the background GCR.
You can have a GLE in case of a strong Solar Energetic Proton storm.

http://www.swpc.noaa.gov/phenomena/galactic-cosmic-rays

Galactic Cosmic Rays (GCR) are the slowly varying, highly energetic background source of energetic particles that constantly bombard Earth. GCR originate outside the solar system and are likely formed by explosive events such as supernova. These highly energetic particles consist of essentially every element ranging from hydrogen, accounting for approximately 89% of the GCR spectrum, to uranium, which is found in trace amounts only. These nuclei are fully ionized, meaning all electrons have been stripped from these atoms. Because of this, these particles interact with and are influenced by magnetic fields. The strong magnetic fields of the Sun modulate the GCR flux and spectrum at Earth.
Over the course of a solar cycle the solar wind modulates the fraction of the lower-energy GCR particles such that a majority cannot penetrate to Earth near solar maximum. Near solar minimum, in the absence of many coronal mass ejections and their corresponding magnetic fields, GCR particles have easier access to Earth. Just as the solar cycle follows a roughly 11-year cycle, so does the GCR, with its maximum, however, coming near solar minimum. But unlike the solar cycle, where bursts of activity can change the environment quickly, the GCR spectrum remains relatively constant in energy and composition, varying only slowly with time. (See Forbush decrease for short-term changes of GCR related to space strong solar events)
These charged particles are traveling at large fractions of the speed of light and have tremendous energy. When these particles hit the atmosphere, large showers of secondary particles are created with some even reaching the ground. These particles pose little threat to humans and systems on the ground,

IMPACT ON TECHNOLOGY

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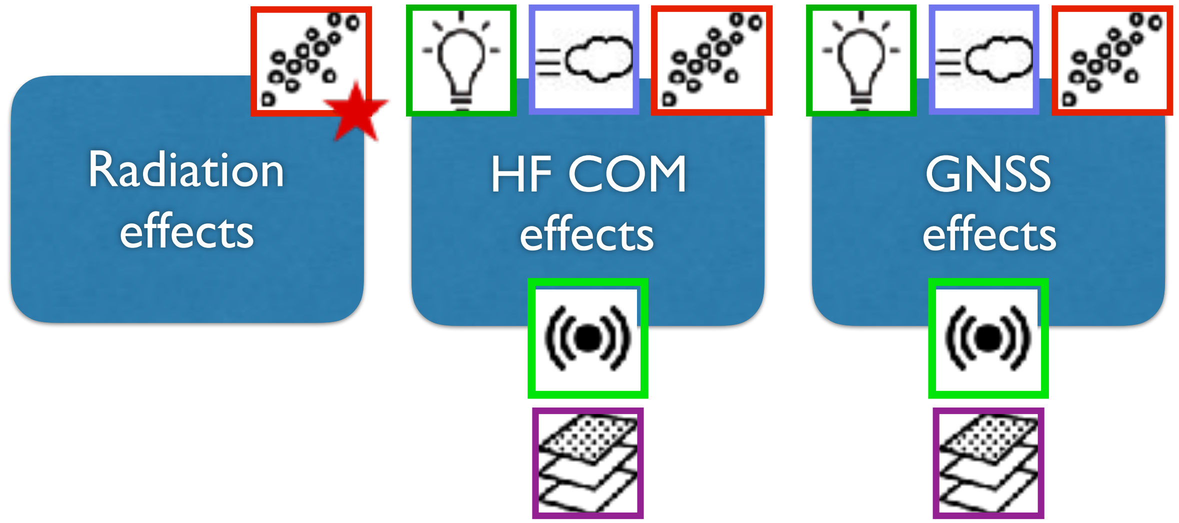

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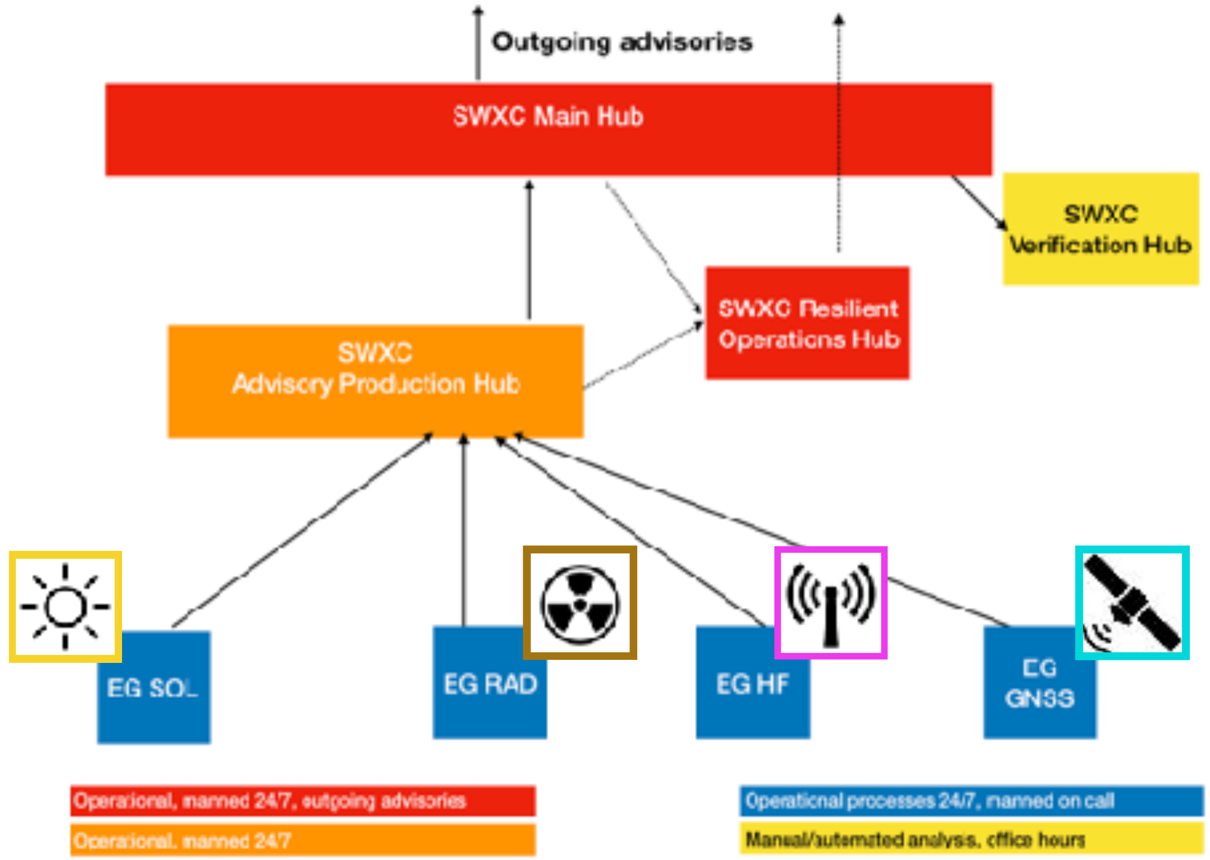
Outgoing advisories
SWXC Main Hub
SWXC Verification Hub
SWXC Resilient Operations Hub
SWXC Advisory Production Hub
EG SOL
EG RAD
EG HF
EG GNSS
Operational, manned 24/7, outgoing advisories
Operational, manned 24/7
Operational processes 24/7, manned on call
Manual/automated analysis, office hours

Visit of STCE GNSS headquarters

Visit of STCE Radiation headquarters