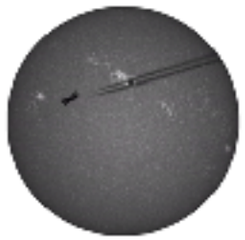


PECASUS
For civil aviation

SPACE WEATHER INTRODUCTORY COURSE
For space weather operators

5TH PART

What does an operator of the space weather bureau have to do when space weather gets crazy? Which procedures should be followed? How are the data you need presented? Where to find and how will you get this data?

"This is Matt with your five-day forecast, on location."

Short Rehearsal

Advisories + Concept of Operations + EGs

PECASUS live

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

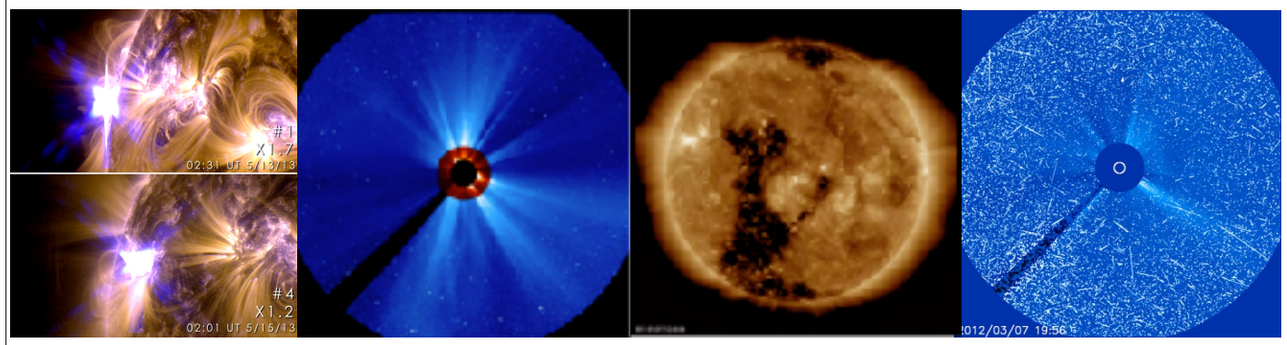
Radiation exposure at flight levels
High Frequency radio communication
GNSS-based navigation and surveillance

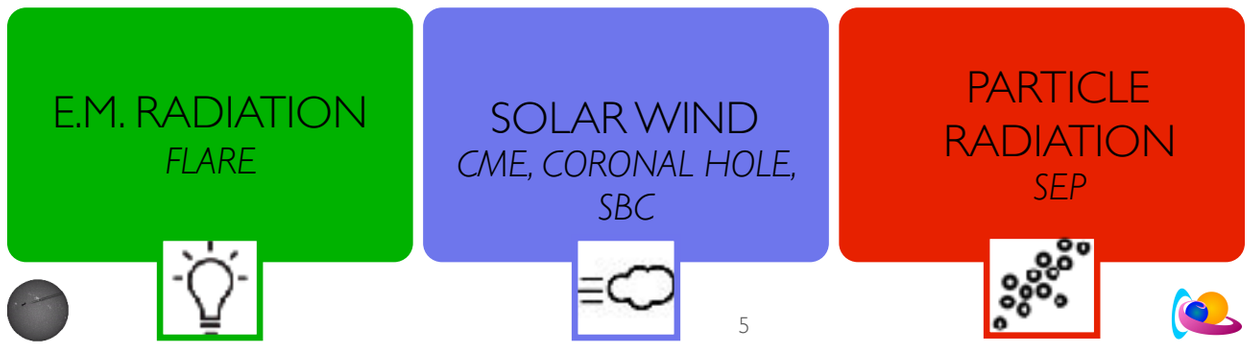
Note: for geomagnetic storm
If an event were strong enough to produce moderate degradation in the equatorial regions, it would likely be severe in the middle and high regions. In this case, there would be two advisories issued, one for the severe event affecting HNH, HSN, MNH and MSH and a second advisory for the moderate event affecting EQN and EQS.

Note for Radiation storm
Solar radiation may be severe above a certain altitude and moderate below. This requires 2 advisories.

SPACE WEATHER

The sun expels continuously energy. We put the energy in 3 categories: e.m. radiation, solar wind flow of magnetised mass, particle radiation. Space weather concerns the (non-)eruptive energy releases that come on top of these continuous processes.





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

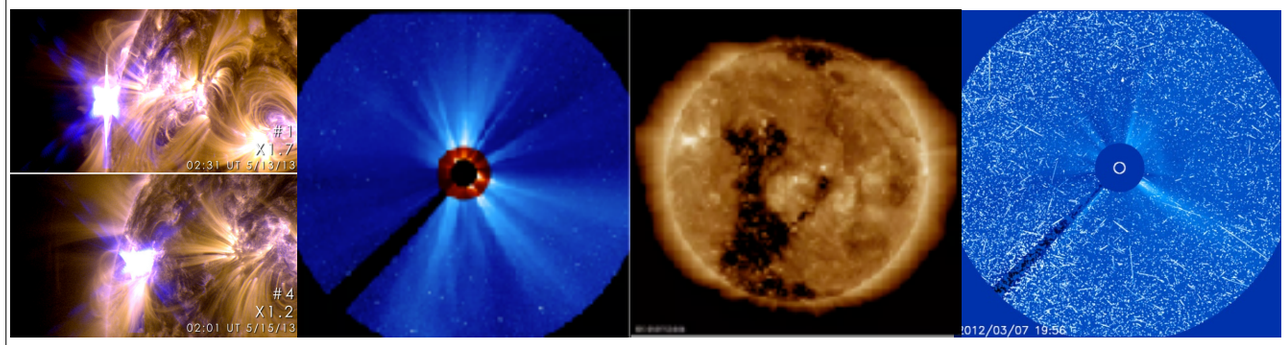
A particle storm is a bunch of electrically charged particles that circle around the IMF lines into space. They may impact telescopes. They are seen as white stripes and dots: this are particles that fall into the lens and blind the pixel(s). During that particular moment, the telescope can't see anymore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

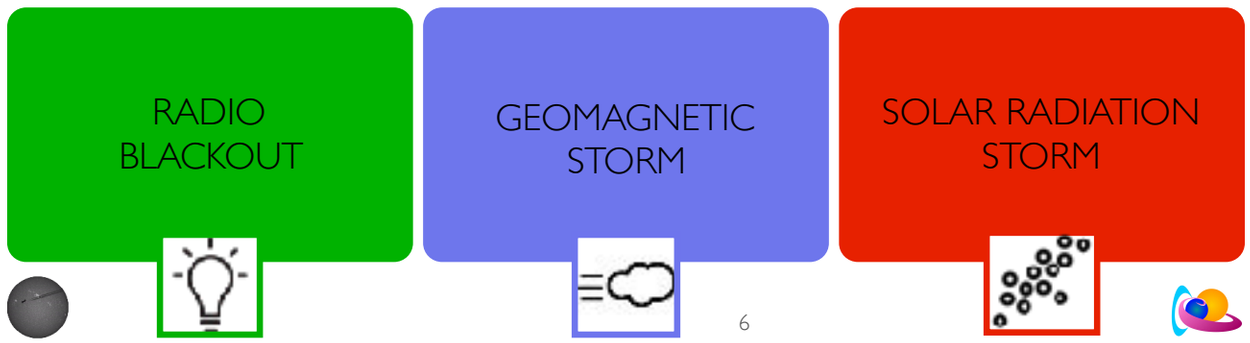
In situ means that you measure a parameter local. Remote sensing means that you look at something from a distance.

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.

SPACE WEATHER

The Earth and its environment reacts on these space weather events. The solar storms that impact earth are called ‘radio blackout’, ‘geomagnetic storm’ or ‘solar radiation storm’.





Impact on Earth environment according to the NOAA space weather scales

Radio blackout
Impact on navigation & radio communication

Affects communications, and on rare occasions GNSS navigation.
Daylight side impact only.
May last from a few minutes to a few hours and are much shorter duration than geomagnetic storms.

Geomagnetic storm
Radio communication, HF and LF
Satellite operations
Power systems, e.g. GIC
Aurora
—> affect communication and GNSS navigation in the HNH and HSH regions and sometimes include MNH and MSH regions. EQN and EQS may be affected during the worst storms.

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

SPACE WEATHER

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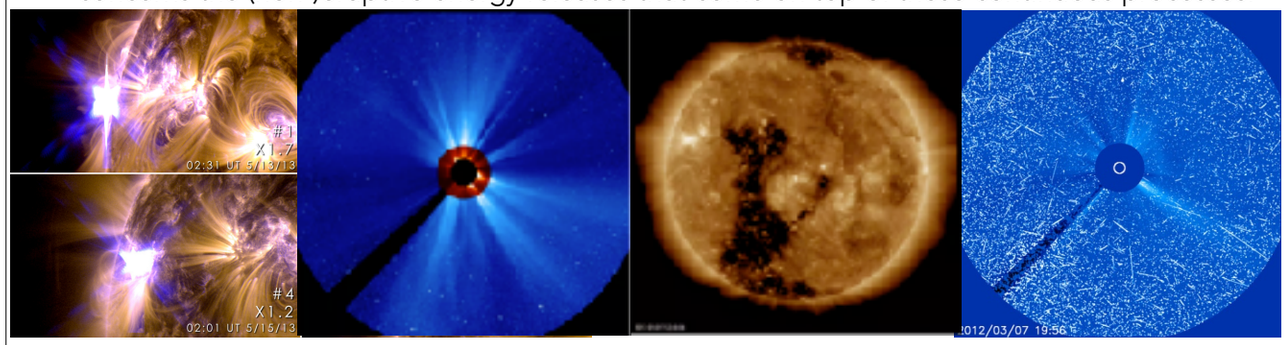

RADIO BLACKOUT

GEOMAGNETIC STORM

SOLAR RADIATION STORM

Impact on Earth environment according to the NOAA space weather scales

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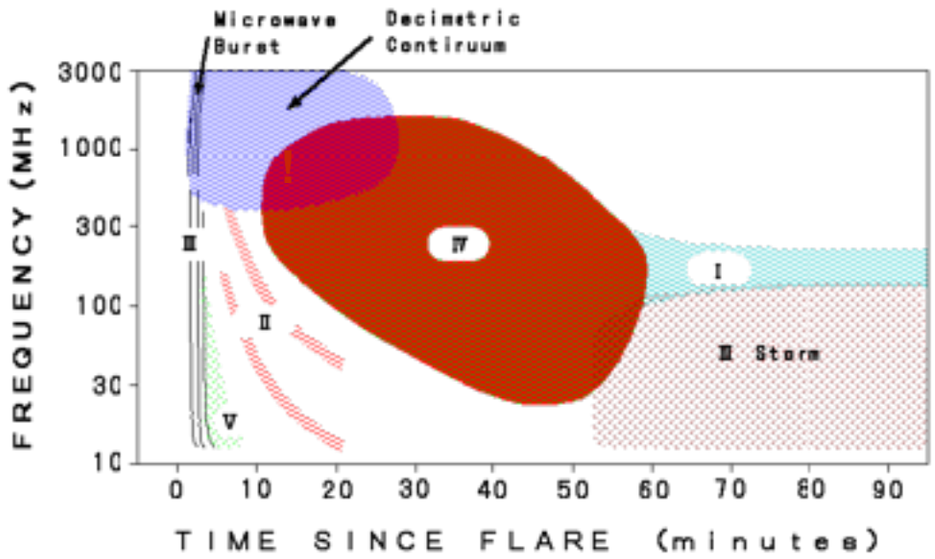
Solar radiation storm
Biological impact
Satellite operations
HF communication in the polar regions - degradation or black out (PCA)
Navigation

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.



These bursts are triggered by a solar event.
Signature of presence of a CME, flare

****

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

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.**

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.

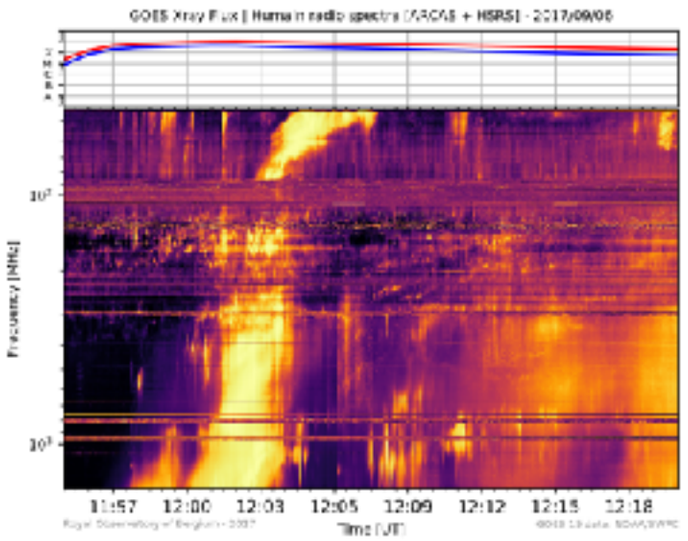
The ionospheric cut-off frequency is around 15MHz (due to too low frequency and so reflected by ionosphere). In order to observe radio disturbances below this frequency, one has to use satellites (above the earth atmosphere) such as STEREO/SWAVES or WIND. Radio bursts at low frequencies (< 15 MHz) are 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

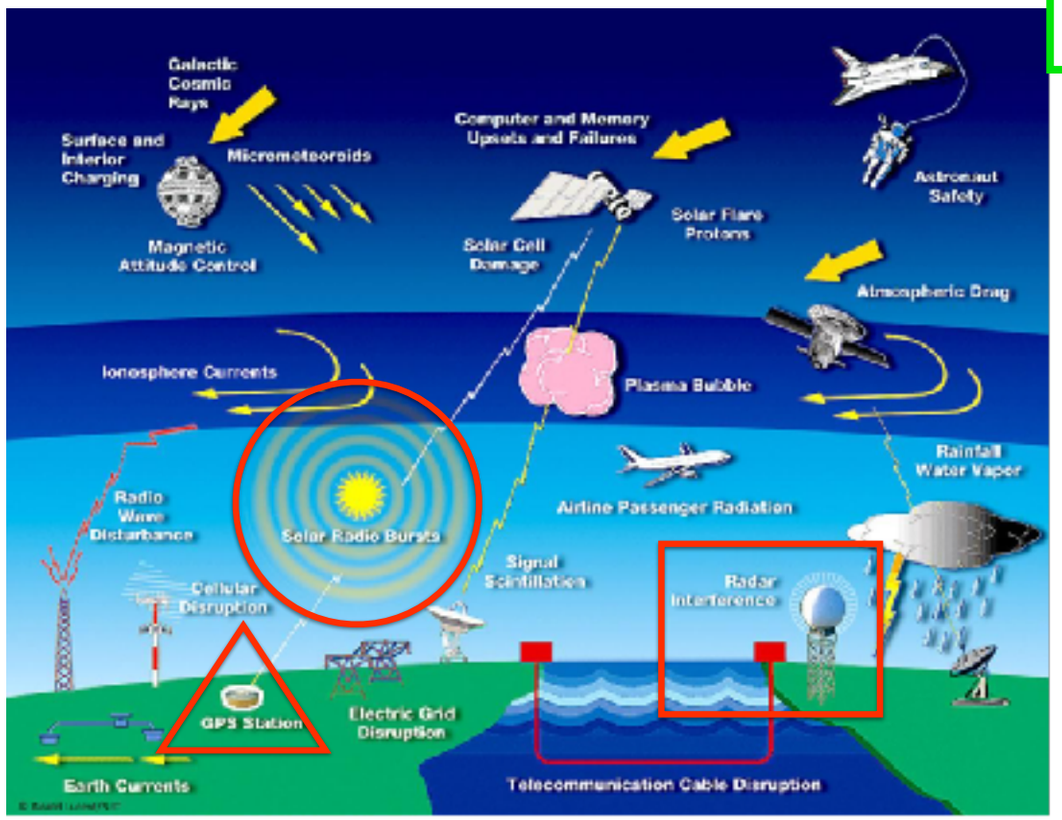
SOLAR RADIO BURSTS

We distinguish between 5 types of solar radio bursts. Not all types are present during an event.

- 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



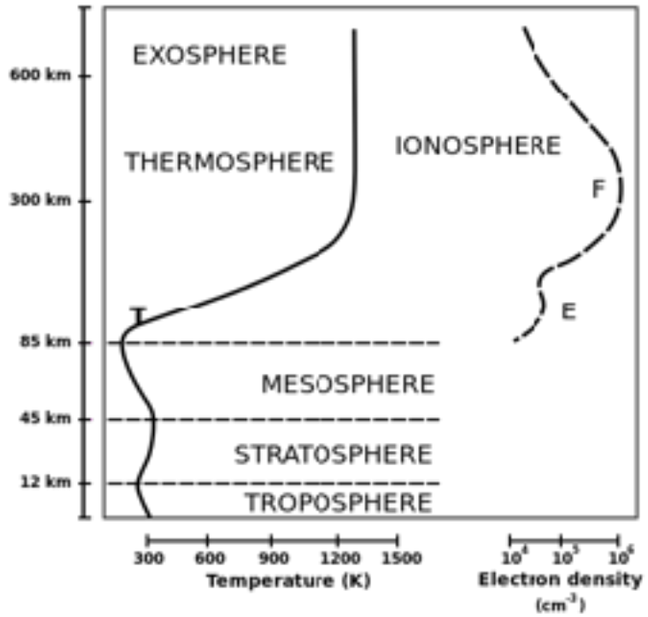
Signature of presence of a CME, flare

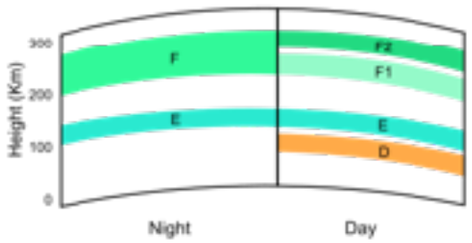


Impact of SRB itself
GPS station
Signal/noise - signal is from the satellite. GPS receivers are designed to be sensible to the signal above them, not at the horizon.
When there is a strong radio burst - in the typical GPS frequencies - the noise increases.
GPS receiver ontvangt signalen die niet van 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

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

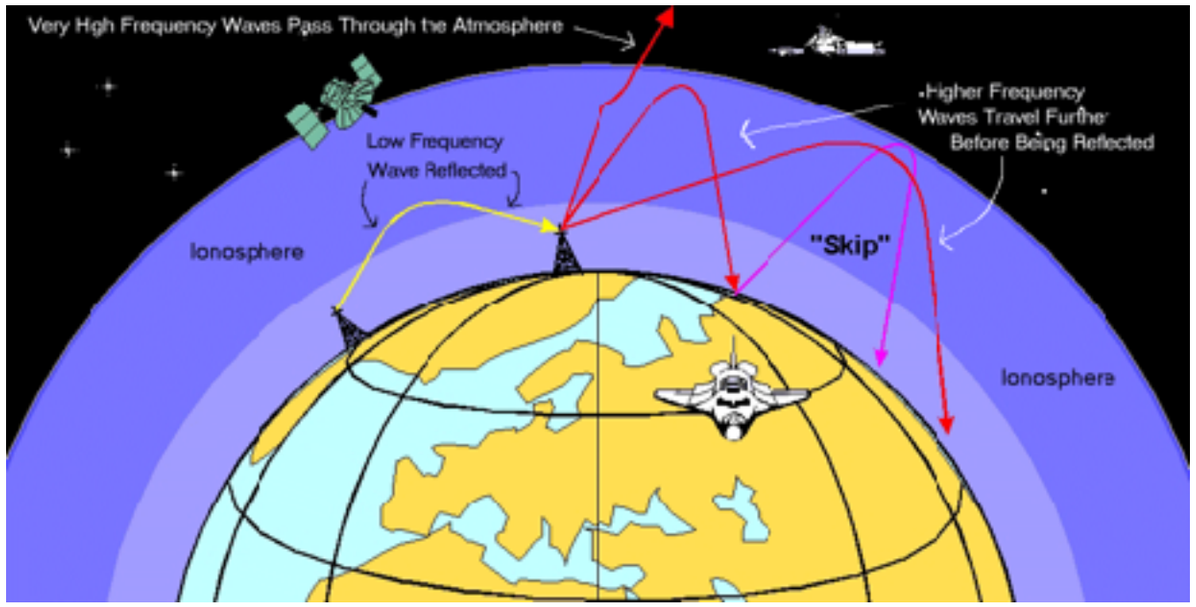




IONOSPHERE

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]

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



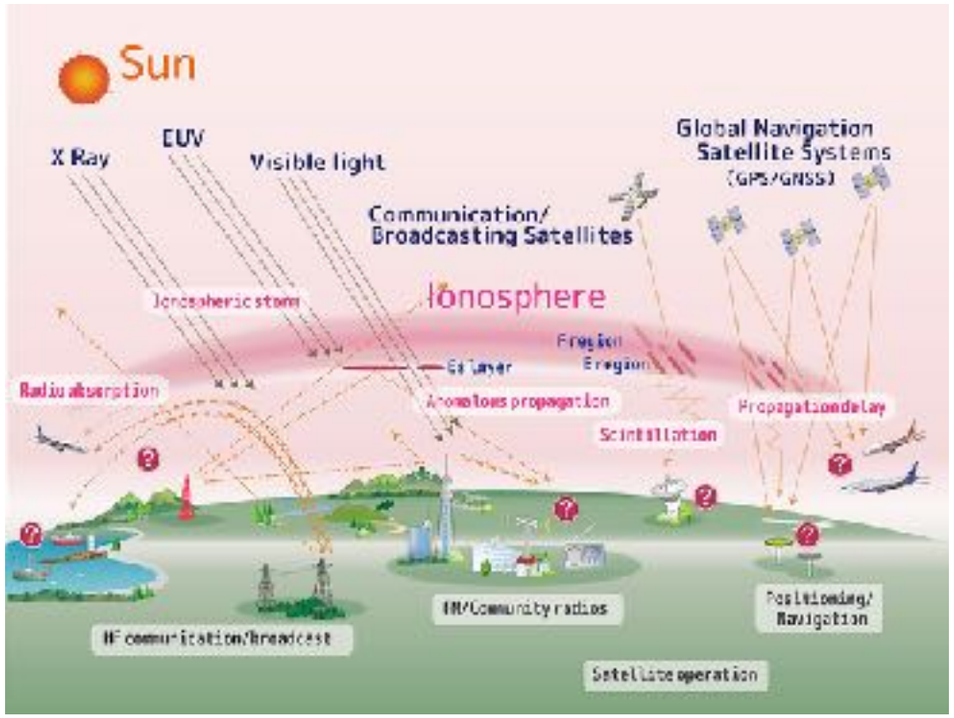
RADIO WAVES

The ionospheric 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.



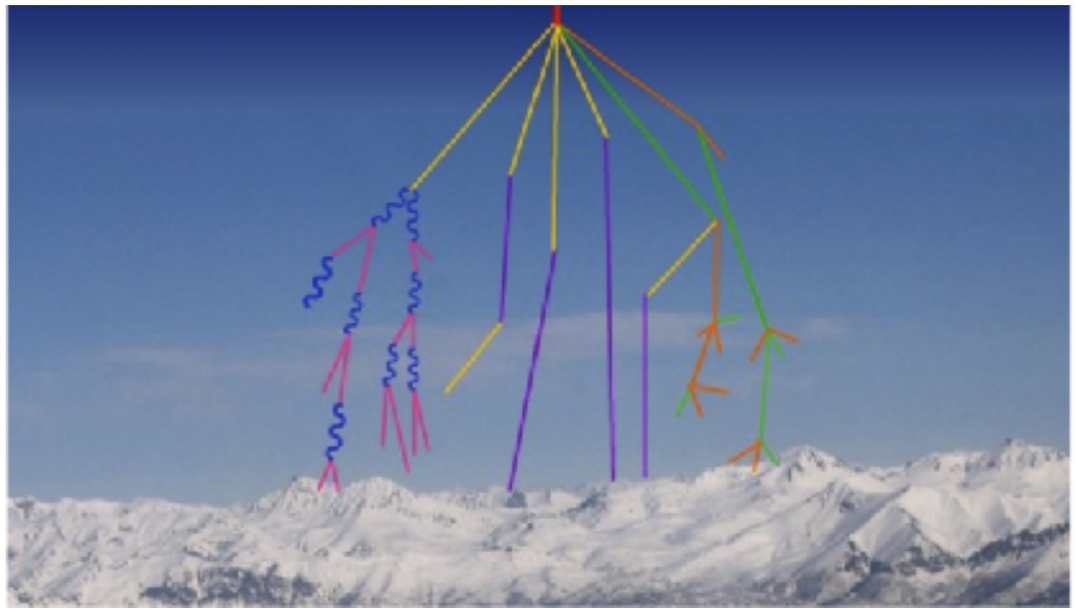
IONOSPHERIC STORMS

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.

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.

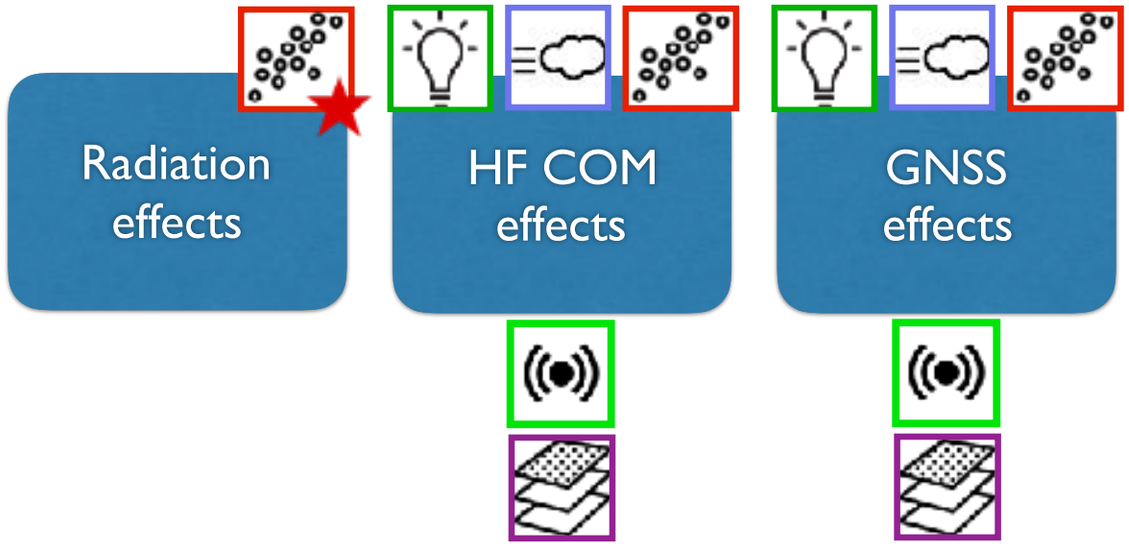
The neutron monitors can measure a Ground Level Event, GLE. There will be a peak on top of the background GCR.
You can have a GLE in case of a strong Solar Energetic Proton storm.

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

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



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

These messages are called ‘NOTAM’ = NOtice To AirMen

Radiation exposure at flight levels concerns increased exposure to radiation

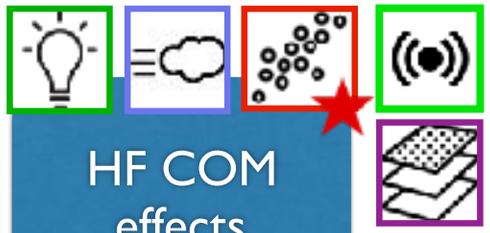
High Frequency radio communication concerns propagation & absorption of radio waves

GNSS-based navigation and surveillance concerns the degradation of the performance of satellite navigation systems.

Short Rehearsal

Advisories + Concept of Operations + EGs

PECASUS live



Space Weather Centre

SEVere or MODerate

Forecasts up to 24 HR

We can use also ‘NIGHTSIDE’

(communication header)	
SWX ADVISORY	
DTG:	20161108/0100Z
SWXC:	(to be determined)
SWX EFFECT:	HF COM SEV
ADVISORY NR:	2016/1
OBS SWX:	20161108/0100Z DAYLIGHT SIDE
FCST SWX +6 HR:	20121108/0700Z DAYLIGHT SIDE
FCST SWX +12 HR:	20161108/1300Z DAYLIGHT SIDE
FCST SWX +18 HR:	20161108/1900Z DAYLIGHT SIDE
FCST SWX +24 HR:	20161109/0100Z DAYLIGHT SIDE
RMK:	PERIODIC HF COM ABSORPTION HAS BEEN OBSERVED AND IS LIKELY TO CONTINUE IN THE NEAR TERM. COMPLETE AND PERIODIC LOSS OF HF ON THE SUNLIT SIDE OF THE EARTH EXPECTED. CONTINUED HF COM DEGRADATION LIKELY OVER THE NEXT 2 DAYS. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY:	20161108/0700Z

OBS SWX
FCST SWC
NO SWX EXP

YYYYMMDD/UTC

Additional info on a web-site

Update provided as necessary but
at least after 6 HR

THE EARTH'S GRID SYSTEM

- Only the city of New Orleans, La., is located at the crossing of the 30th east-west line north of the Equator and the 90th north-south line west of the prime meridian.
- Lines of latitude cross lines of longitude at right angles.
- Although only a few lines of latitude and longitude are shown on globes and maps, their number is infinite.

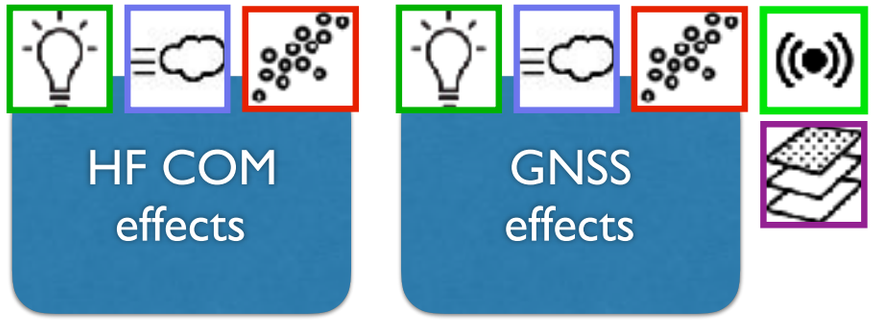
Radiation effects

Element		Range	Resolution
Flight Level		280-600	20
Longitudes for advisories:	[degrees] [minutes]	000 – 180 00	15' 0
Latitude bands for advisories:	High latitudes northern hemisphere (HNH)	N9000 - N6000	30'
	Middle latitudes northern hemisphere (MNH)	N6000 - N3000	
	Equatorial latitudes northern hemisphere (EQN)	N3000 - N0000	
	Equatorial latitudes southern hemisphere (EQS)	S0000 - S3000	
	Middle latitudes southern hemisphere (MSH)	S3000 - S6000	
	High latitudes southern hemisphere (HSH)	S6000 - S9000	

(communication header)	
SWX ADVISORY	
DTG:	20161108/0000Z
SWXC:	(to be determined)
SWX EFFECT:	RADIATION MOD
ADVISORY NR:	2016/2
FCST SWX:	20161108/0100Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +6 HR:	20161108/0700Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +12 HR:	20161108/1300Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +18 HR:	20161108/1900Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +24 HR:	20161109/0100Z NO SWX EXP
RMK:	RADIATION LEVELS HAVE EXCEEDED 100 PERCENT OF BACKGROUND LEVELS AT FL350 AND ABOVE. THE CURRENT EVENT HAS PEAKED AND LEVELS ARE SLOWLY RETURNING TO BACKGROUND LEVELS. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY:	NO FURTHER ADVISORIES

HNH : High latitudes northern hemisphere, i.e. N9000- N6000
MNH : Middle latitudes nothern hemisphere, I.e. N6000- N3000
EQN
EQS
MSH
HSH : High latitudes Southern hemisphere

Solar radiation may be severe above a certain altitude and moderate below. This requires 2 advisories.



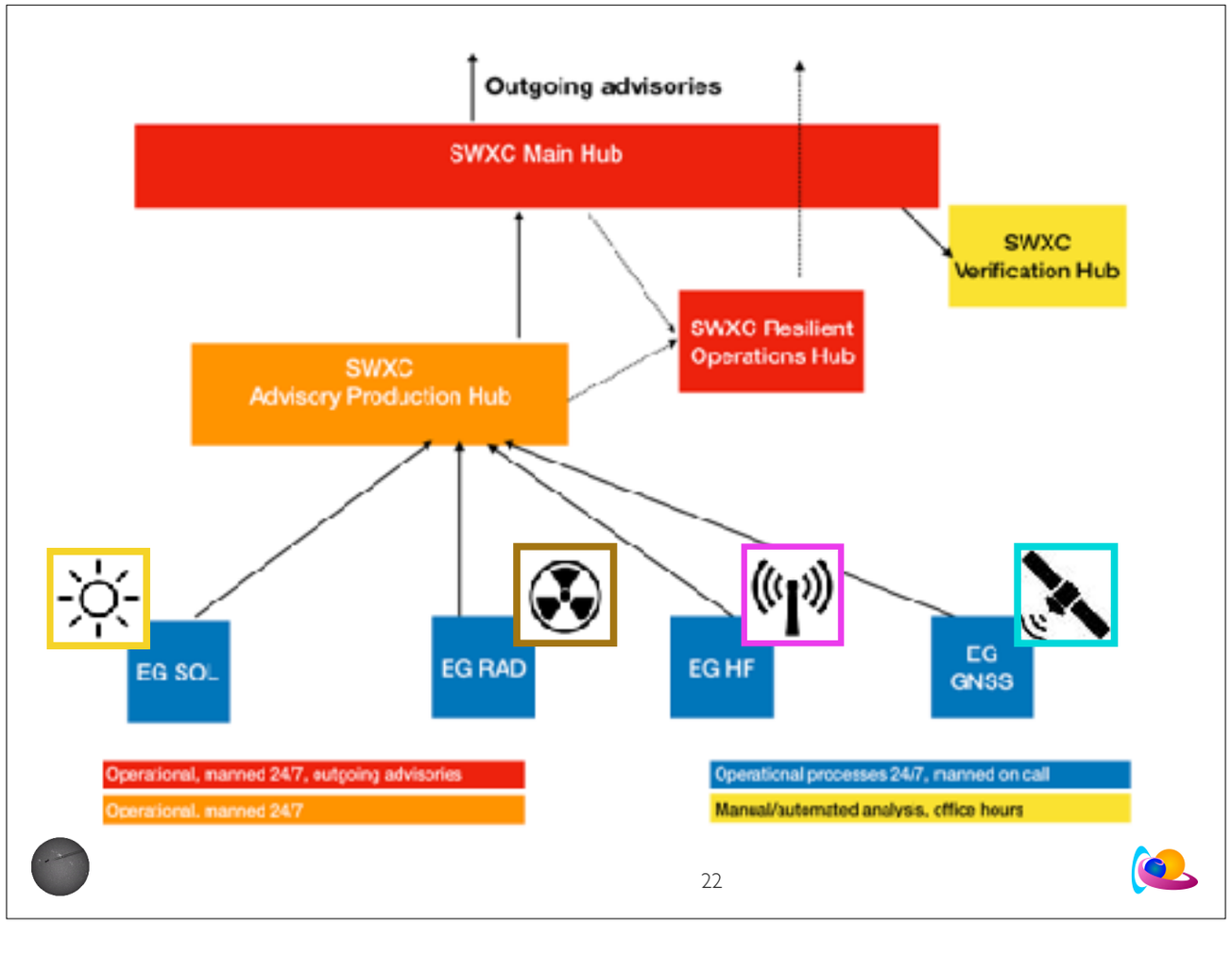
(communication header)	
SWX ADVISORY	
DTG:	20161108/0100Z
SWXC:	(to be determined)
SWX EFFECT:	GNSS MOD AND HF COM MOD
ADVISORY NR:	2016/1
OBS SWX:	20161108/0100Z HNH HSH E18000 – W18000
FCST SWX +6 HR:	20121108/0700Z HNH HSH E18000 – W18000
FCST SWX +12 HR:	20161108/1300Z HNH HSH E18000 – W18000
FCST SWX +18 HR:	20161108/1900Z HNH HSH E18000 – W18000
FCST SWX +24 HR:	20161109/0100Z NO SWX EXP
RMK:	LOW-LEVEL GEOMAGNETIC STORMING IS CAUSING INCREASED AURORAL ACTIVITY AND SUBSEQUENT MOD DEGRADATION OF GNSS AND HF COM AVAILABILITY IN THE AURORAL ZONE. THIS STORMING IS EXPECTED TO SUBSIDE
	IN THE FORECAST PERIOD. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY:	NO FURTHER ADVISORIES

Note for geomagnetic storm
If an event were strong enough to produce moderate degradation in the equatorial regions, it would likely be severe in the middle and high regions. In this case, there would be two advisories issued, one for the severe event affecting HNH, HSN, MNH and MSH and a second advisory for the moderate event affecting EQN and EQS.

Short Rehearsal

Advisories + **Concept of Operations** + EGs

PECASUS live



EG SOL
EG RAD
EG HF
EG GNSS
Gives all the necessary data to make an advisory in case of MOD or SEV conditions.

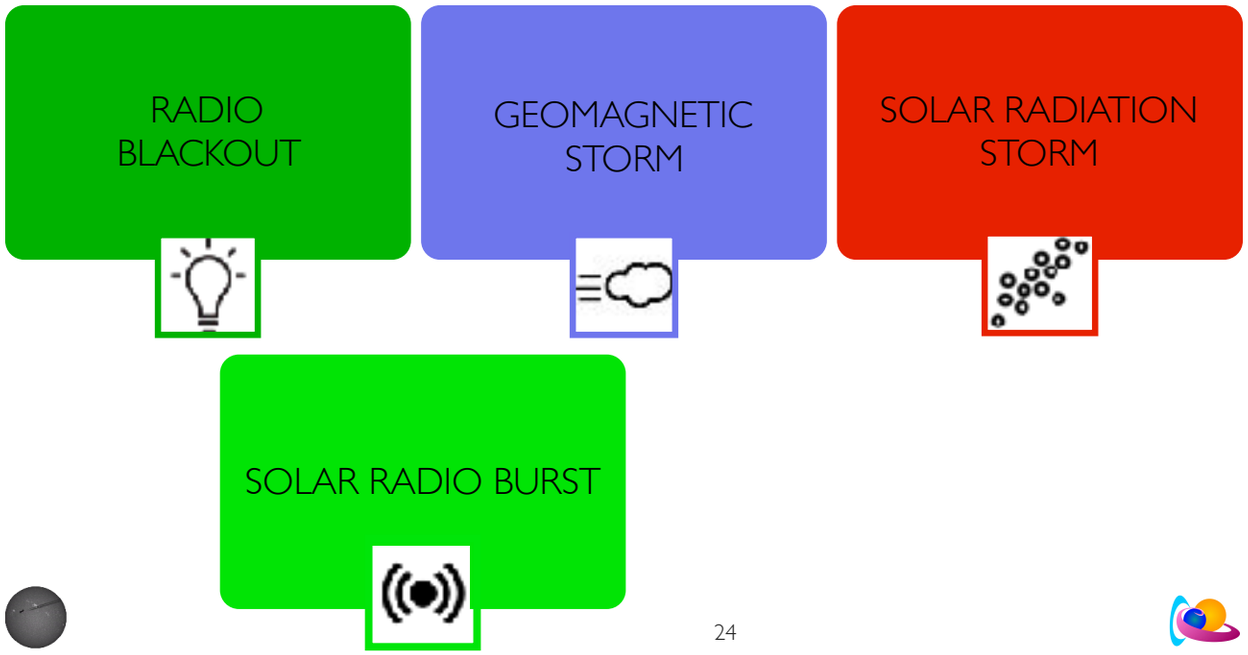
Short Rehearsal

Advisories + Concept of Operations + **EGs**

PECASUS live

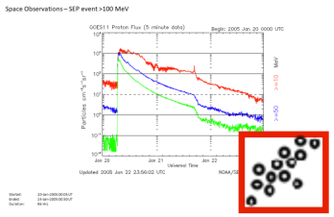
EXPORT GROUP SOL

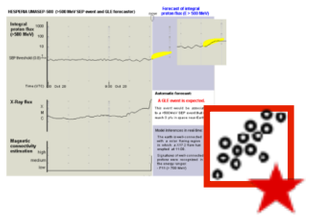
The products of the EG SOL are derived from the services of the Regional Warning Center (RWC). The RWC monitors the Sun, makes space weather bulletins and alerts in case of extreme space weather.

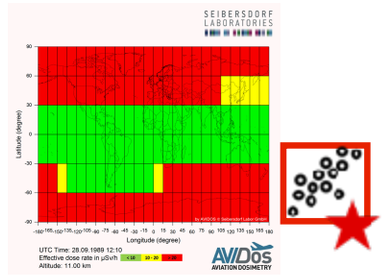


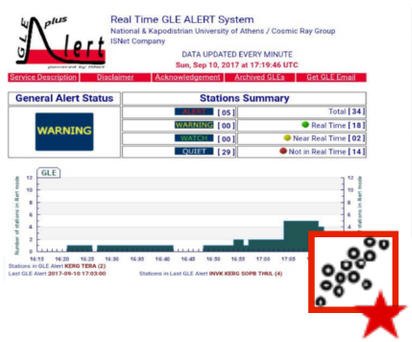
EXPORT GROUP RADIATION

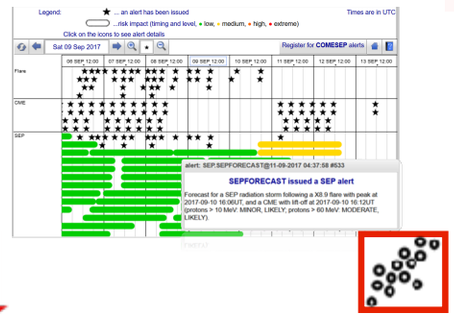
The products of the EG RADIATION are the results of monitoring the SEP and GCR and the calculation by AVIDOS of the radiation impact at flight level.





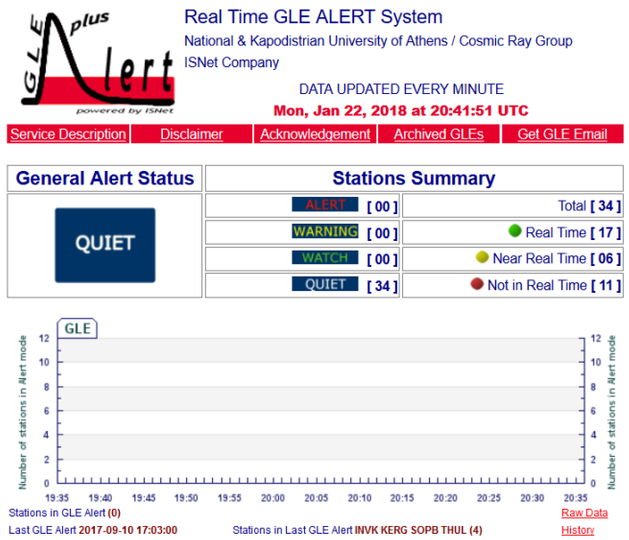






GROUND LEVEL EVENT

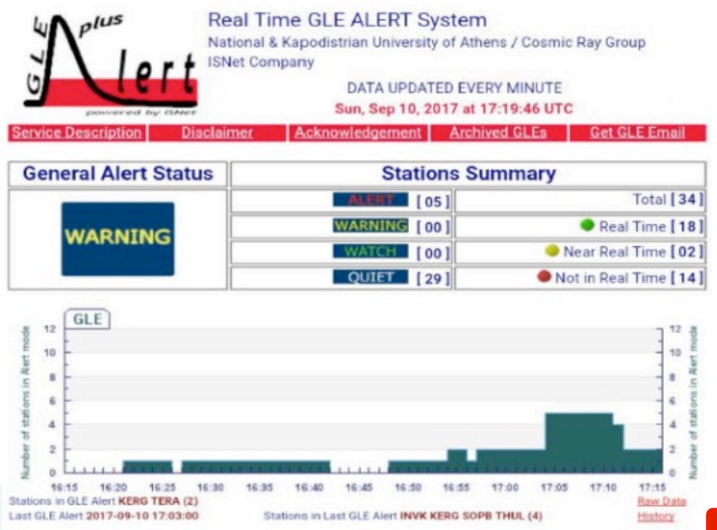
Ground Observations – Nominal situation



Particles

GROUND LEVEL EVENT

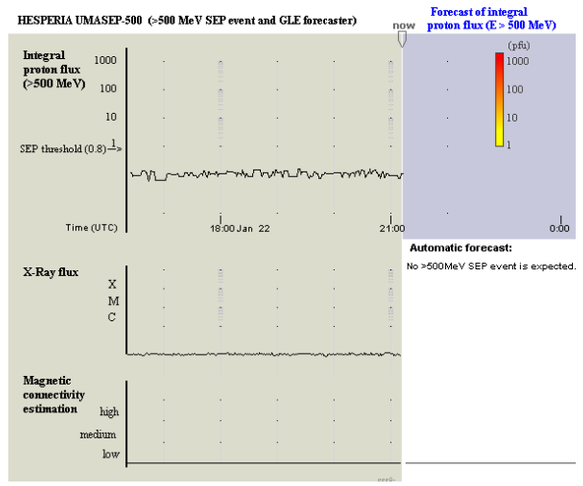
Ground Observations – Warning



Particles

SOLAR ENERGETIC PARTICLES

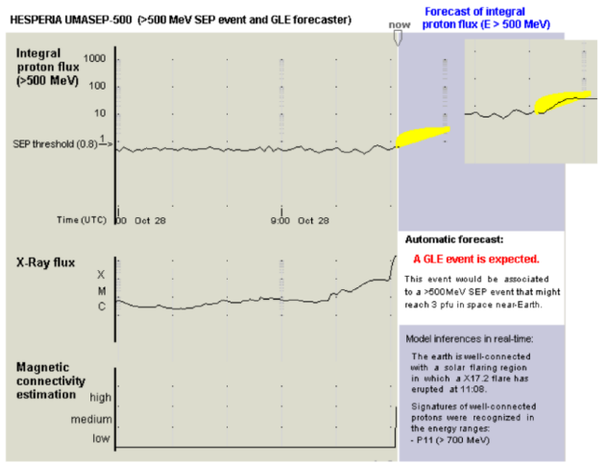
SEP Forecast >500 MeV – Nominal situation



Particles

SOLAR ENERGETIC PARTICLES

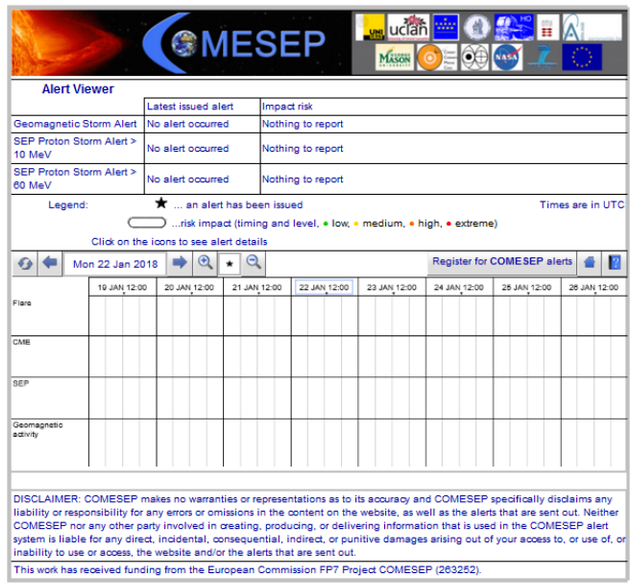
SEP Forecast > 500 MeV – Event expected



Particles

SOLAR ENERGETIC PARTICLES

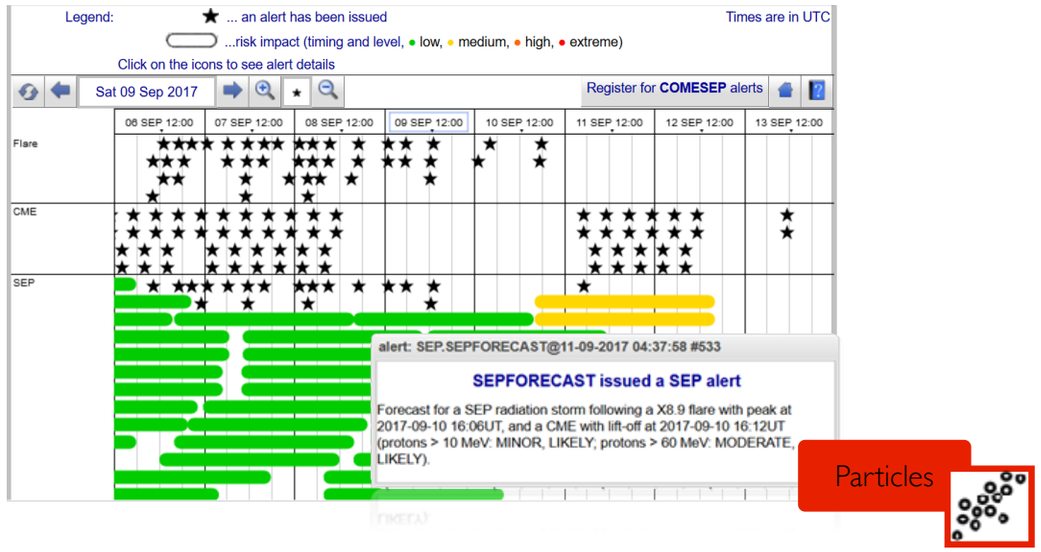
SEP Forecast >10, >60 MeV – Nominal situation



Particles

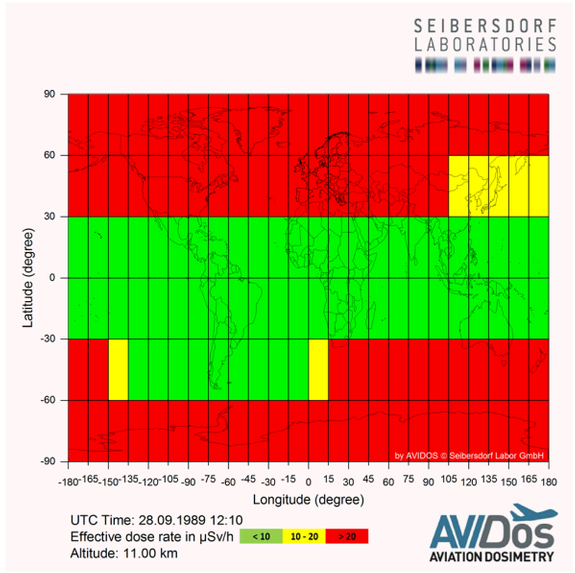
SOLAR ENERGETIC PARTICLES

SEP Forecast >10, >60 MeV – Moderate



Particles

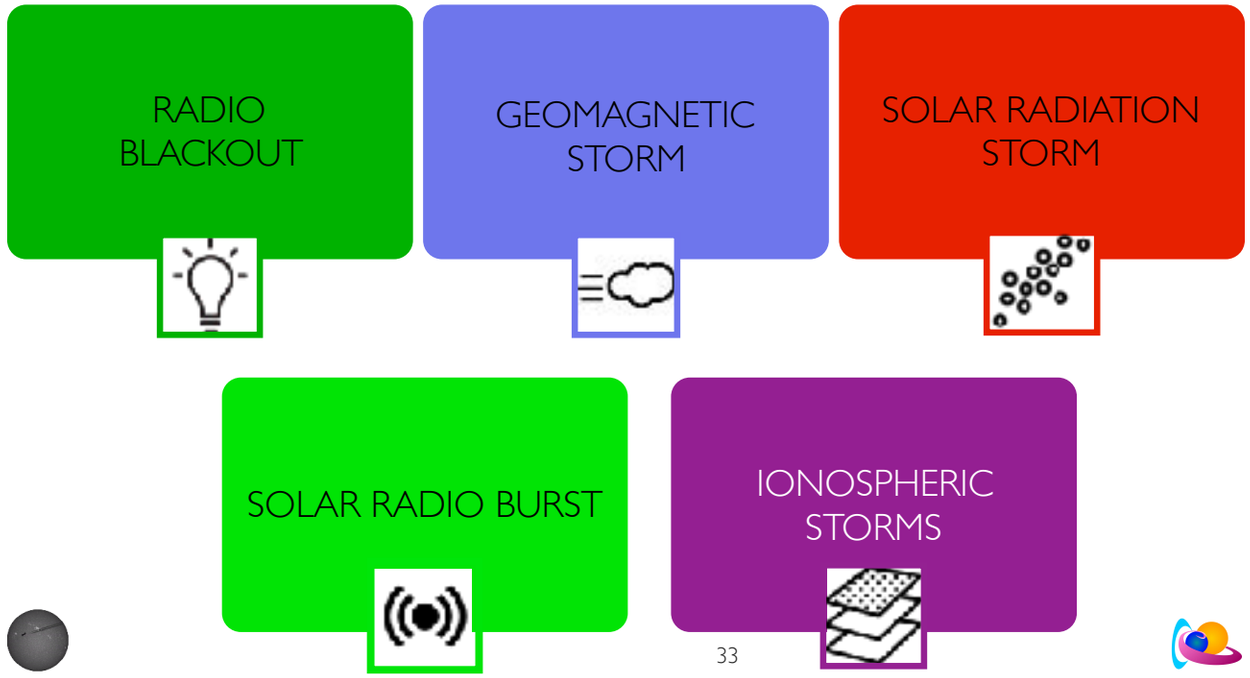
RADIATION ABV FL



Particles

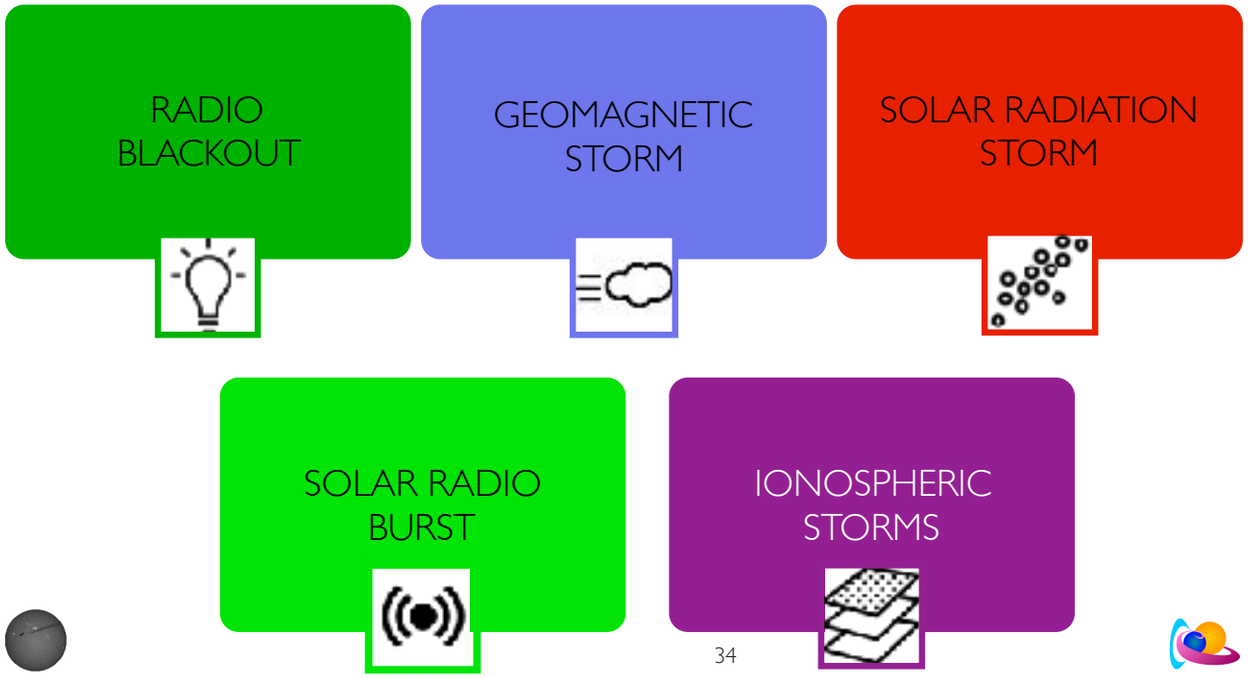
EXPORT GROUP GNSS

The products of the EG GNSS are strongly linked with ionospheric activity and SRB, but also with solar activity. Nicolas will run through all the products.



EXPORT HF COMMUNICATION

The products of the EG HF are strongly linked with ionospheric activity and SRB, but also with solar activity.



Short Rehearsal

Advisories + Concept of Operations + EGs

PECASUS live