Gamma-ray bursts detection capabilities of a sudden ionospheric disturbance (SID) detector.

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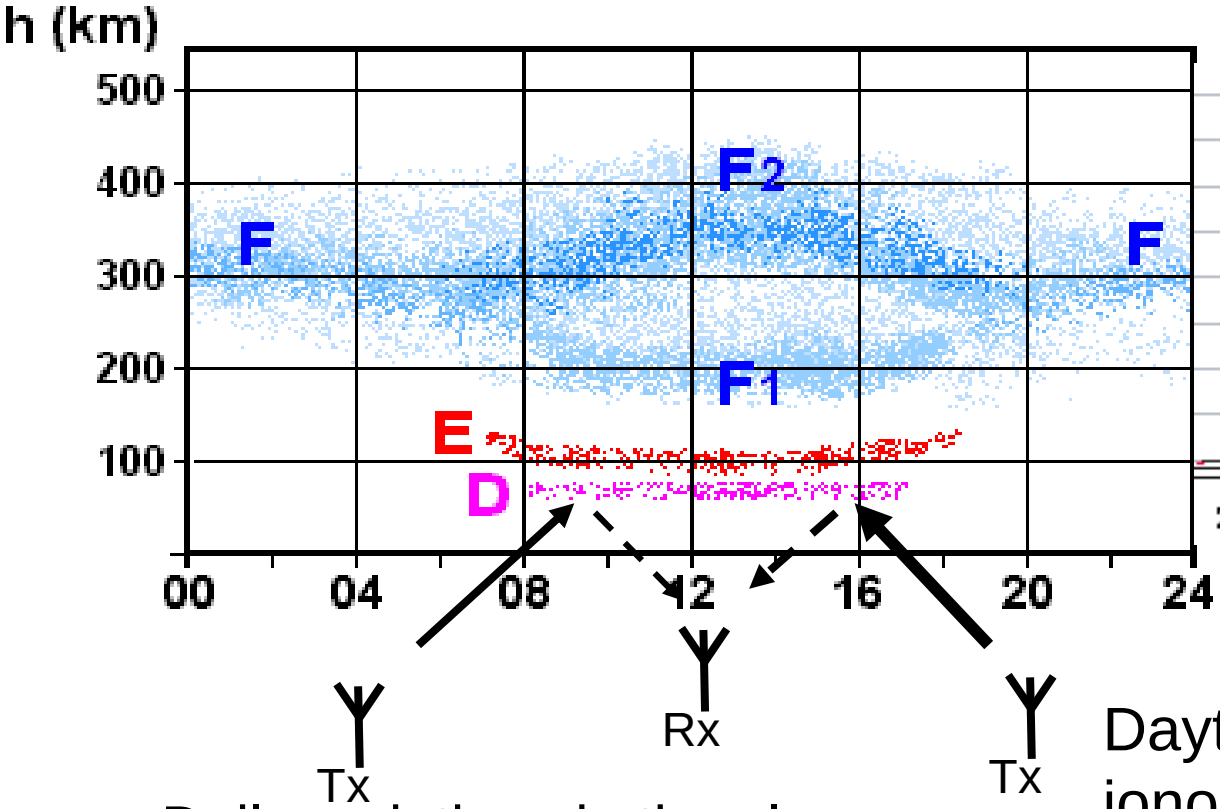
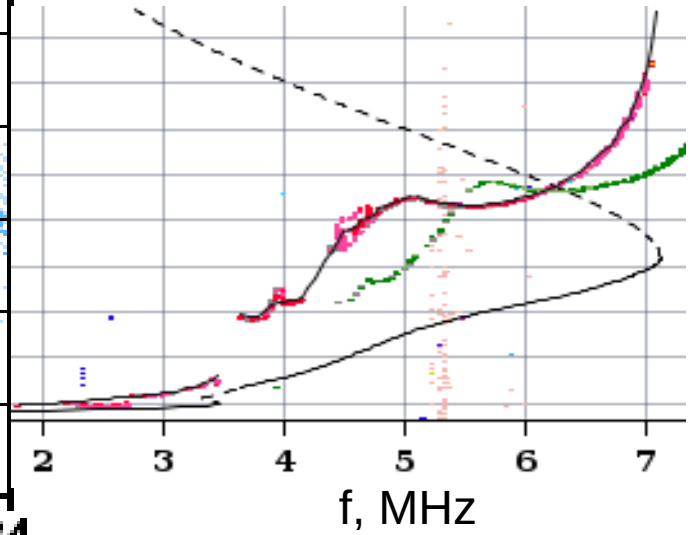
- Potency of SID monitors to detect Gamma Ray Bursts(GRB) – modelling.

Detection of GRB by probing the ionosphere was first demonstrated in 1983 by Fishman and Inan and despite the large detection volume (of the entire D ionospheric layer) was not fully explored.

Sudden Ionospheric Disturbances





Daily variations in the plasma density of the ionosphere and principle of) skywave(img. F5zv)

Daytime ionograp (Dourbes ionosonde)
- Ionospheric layers and Electron Density Profiles

Sudden Ionospheric Disturbances

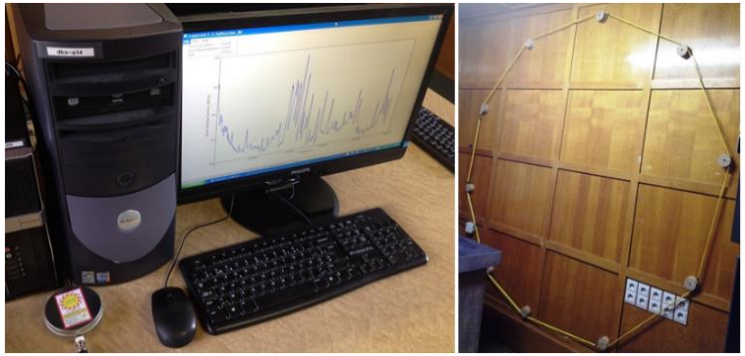
- Sporadic increase in the ionisation and plasma density of the D (70-90 km) and E layers resulting from Solar Flares or other high energy photon sources (also called Mögel-Dellinger effect)

⇒High absorption of Medium and High Frequency signals – blackouts)

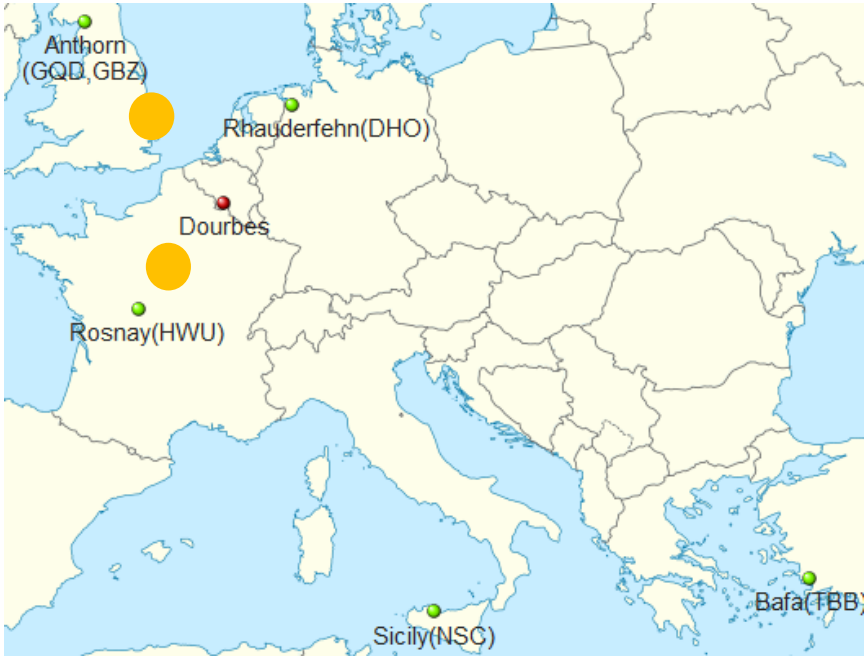
⇒ typically the usable frequency band will vanish)

- Possible to probe it with low frequency waves VLF (3-30 kHz)

The SID monitor

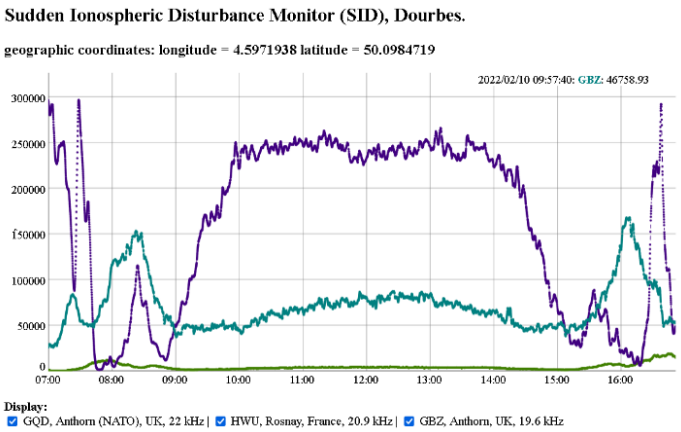


SuperSID monitor and antenna at the Geophysical Center of Dourbes, BELGIUM (SuperSID, DRBS)



Location of the monitor and the VLF transmitters of interest: Anthorn, UK and Rosnay, France

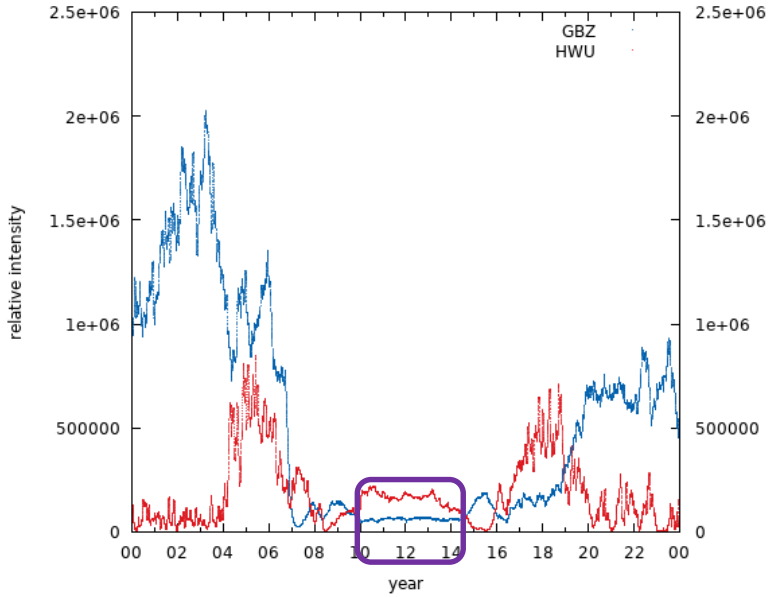
- SID sensitive regions



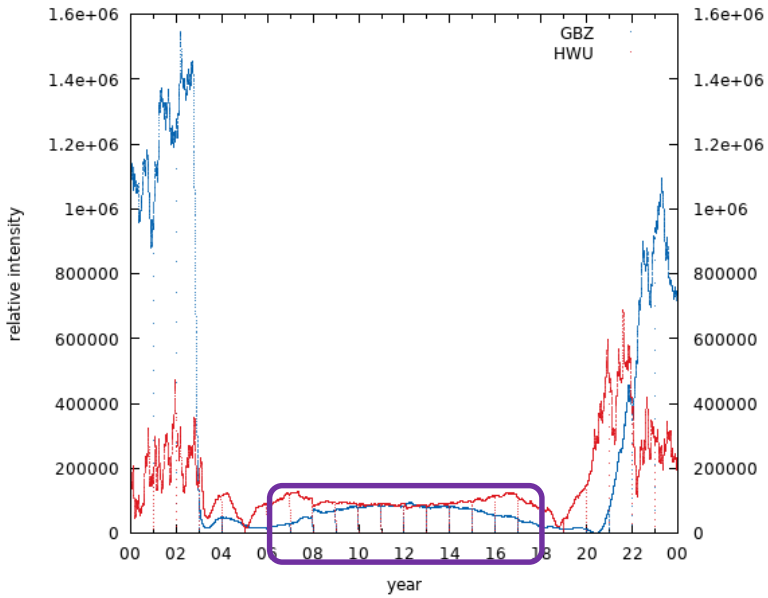
A quiet day signal from the three nearest stations

The SID monitor

Seasonal variations in the SID signal stength – mid latitudes northern hemisphere:



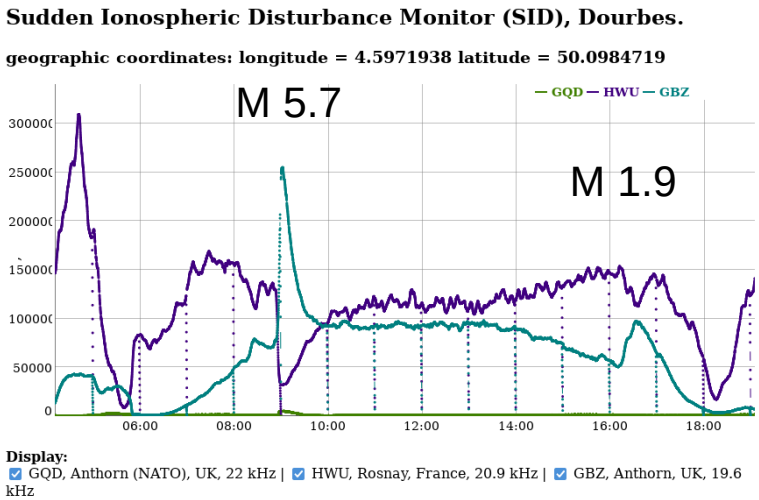
Winter (2022-02-02)

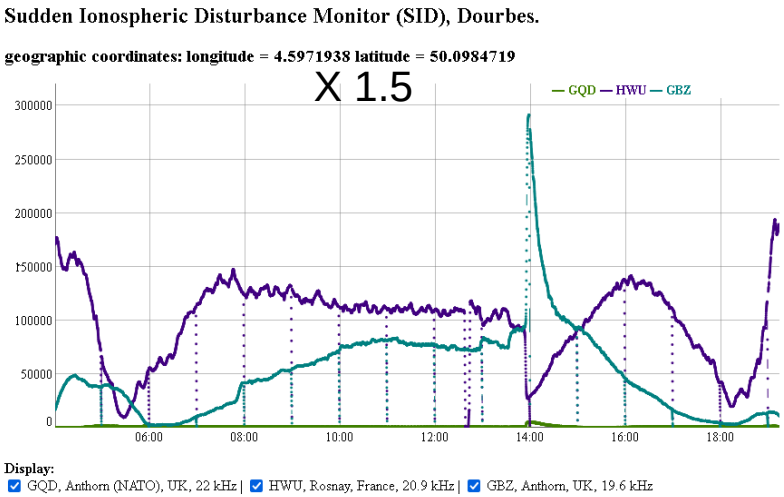


Summer (2022-07-15)

Flare detection is possible when the D and E layers are well established.

Solar Flares seen by the SID monitor



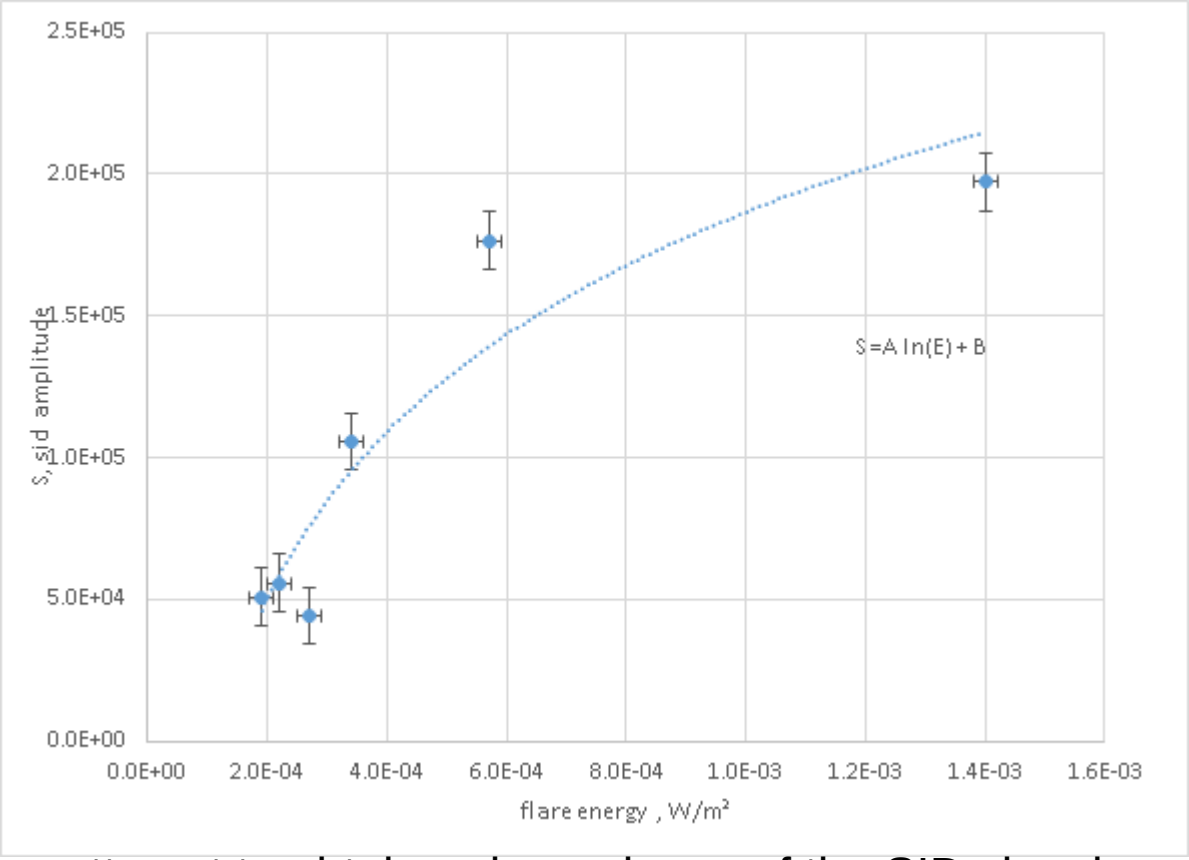


closely spaced with two C class flares
SID data 2022-05-04
daily X-ray

SID data 2022-05-10
daily X-ray

The measured flare peaks are then used to ``calibrate'' the energy dependence of the ionospheric disturbance. From the energy of known GRBs we can deduce then the response of the SID to the latter.

SID measured amplitude vs. Flare energy

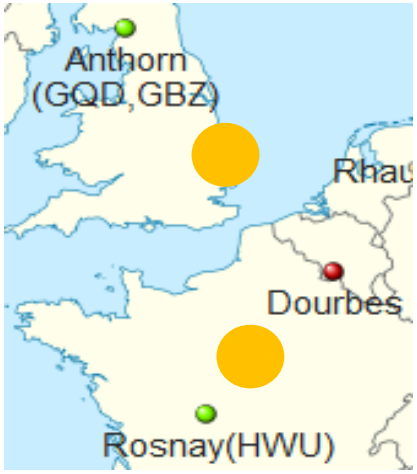


Calibration attempt to obtain a dependence of the SID signal amplitude S on the flare class and energy:

- Large uncertainties and bad fitting. Logarithmic trend-line, E, W/m², A, B respectively 84460, 769970

Ionisation and Electron concertations

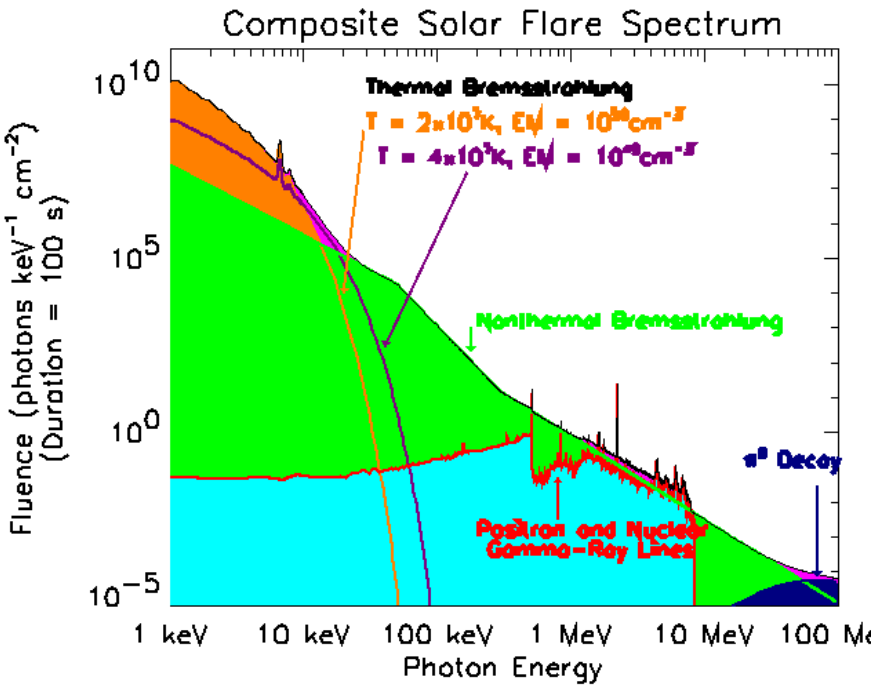
- Determine the baseline electron concentration in the regions of skip (hop) wave reflection
- Calculate (model and simulate) the electron concentration resulting from flares (and GRB)
- Relate to the observed peak amplitude: $S=f(N_e)$

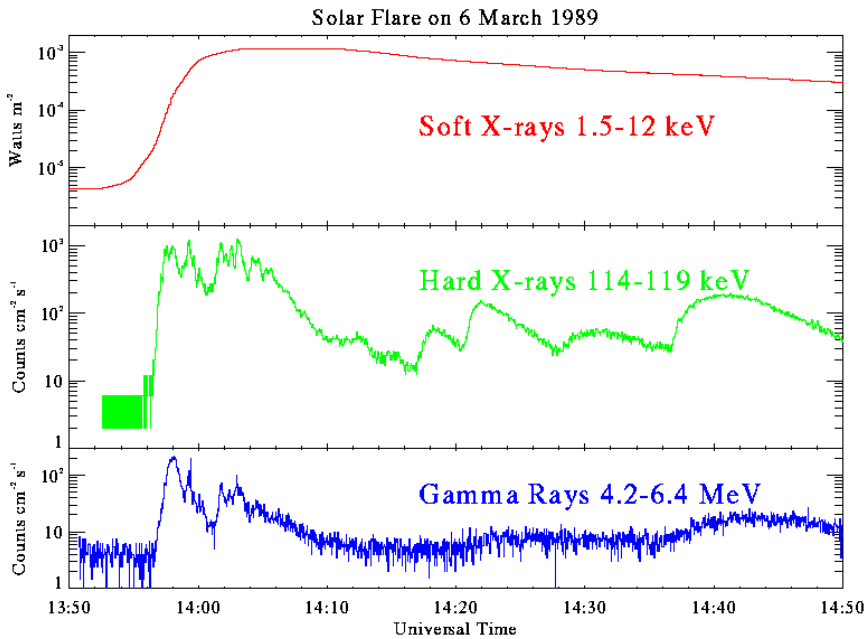


The availability of two VLF transmitters at the same location emitting at different frequencies additionally allows us to determine the baseline e-concentrations.

For the 3 VLF transmitters and the Receiver at Belgium The required electron concentration is of the order: $N_e \sim 0.2 – 0.6\ cm^{-3}$

Solar Flares Composite spectrum





source: https://hesperia.gsfc.nasa.gov/hessi/flares.htm

The available measurements, allow to parametrisize and numerically modell the flare spectrum using several groups and weight factors for sampling.

GRB composite spectrum

- GRBs and Solar Flares share common features (prompt and afterglow)
- We need to model the spectrum in order to evaluate the ionospheric response in terms of electron concentration
- In this work we use the analysis by N. Ohmori et al.* for which we use the proposed cutoff power law spectrum:

$$f_{CPL}(E) = K\left(\frac{E}{100}\right)^{\alpha} exp\left[-\frac{E(2+\alpha)}{E_{peak}}\right]$$

K normalizing constant at 100 keV, *α* photon index and E_{peak} the peak energy of the spectral flux spectrum

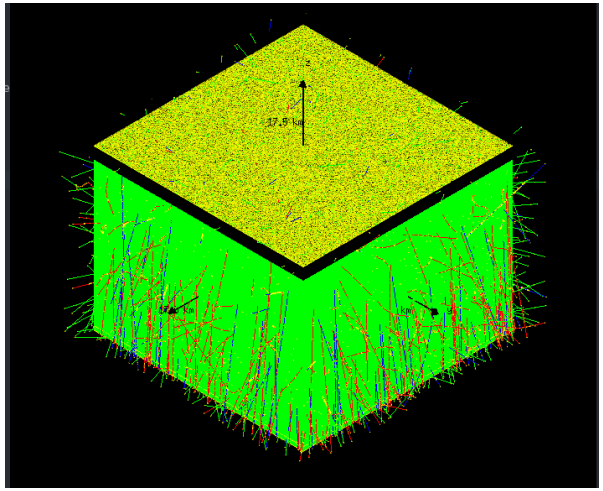
The analysis of the GRB spectra has been used from this work for our modelling.

*doi: 10.1093/pasj/psz054

Calculation of the electron concentrations

- Tool: GEANT4.10.5
- D-ionospheric layer geometry - air density and composition (layered structure)
- Attenuation layer (to account for the atmosphere above 90 km) of equivalent thickness
- Input gamma – fluence 100 s (peak, prompt 1 s)
- Main scorer: e+ and e- at 80 km

3 x 3 x 3 km



D-layer region 30 x 30 x 20 km
Standard US atmosphere

Results

- In this work we obtained a quantitative relation of the observed signal amplitude in function of the electrons concentration (per cm^{-3})resulting from solar flare and an average GRB.

	VLF	f, KHz	base, spring	M	X	GRB
Anthorn	GBZ	19.6	0.21	0.41	0.51	0.76
Anthorn	GQD	22	0.26	0.41	0.51	0.76
Rosnay	HWU	20.9	0.61	1.21	1.52	2.25

The coefficient to obtain the amplitude of the signal will depend on the position of the SID monitor and the VLF transmitters it is listening to.

According to the results and the GRB energy we used for the calculations, we would observe a GRB-peak comparable with a X-class solar flare peak

Summary

- We have analyzed the response of a SuperSID monitor to solar flares
- We propose a method to evaluate the amplitude of the observed SID events taking into account the electron concentrations at the regions of skip reflections
- Taking into account the cataloged energy spectra of past GRBs, we can use the SID monitor and the presented method for detection and analysis of their energy parameters