Studying temporal variations of atmosphere properties at different spatial and temporal scales by VLF radio signals and space geodesy techniques

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Outline

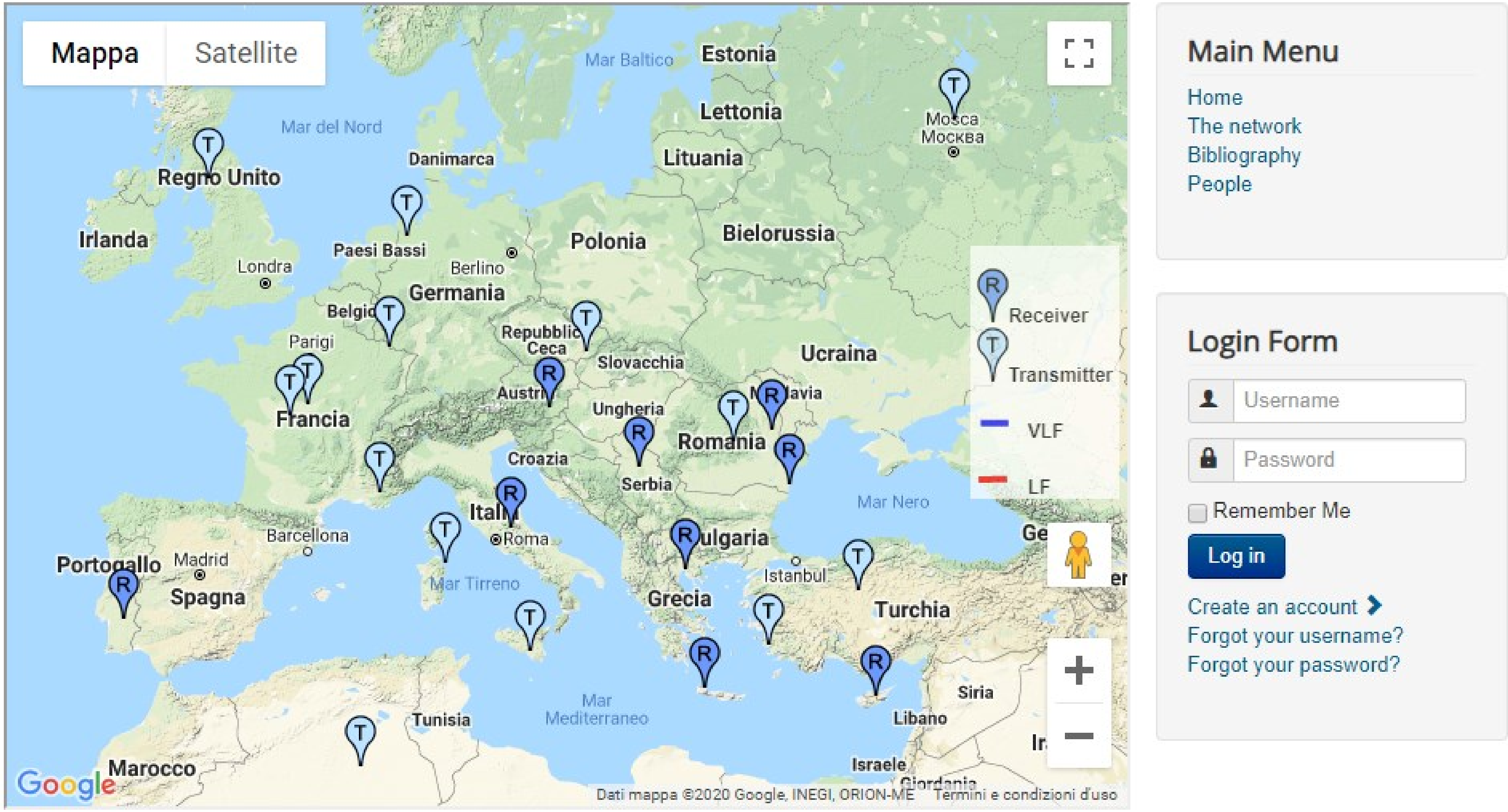
- INFREP network of VLF/LF receivers
- Effects of D-region disturbances on SAR interferometry and GNSS signals
- Effects of D-region disturbances on VLF signals

International Network for Frontier Research on Earthquake Precursors

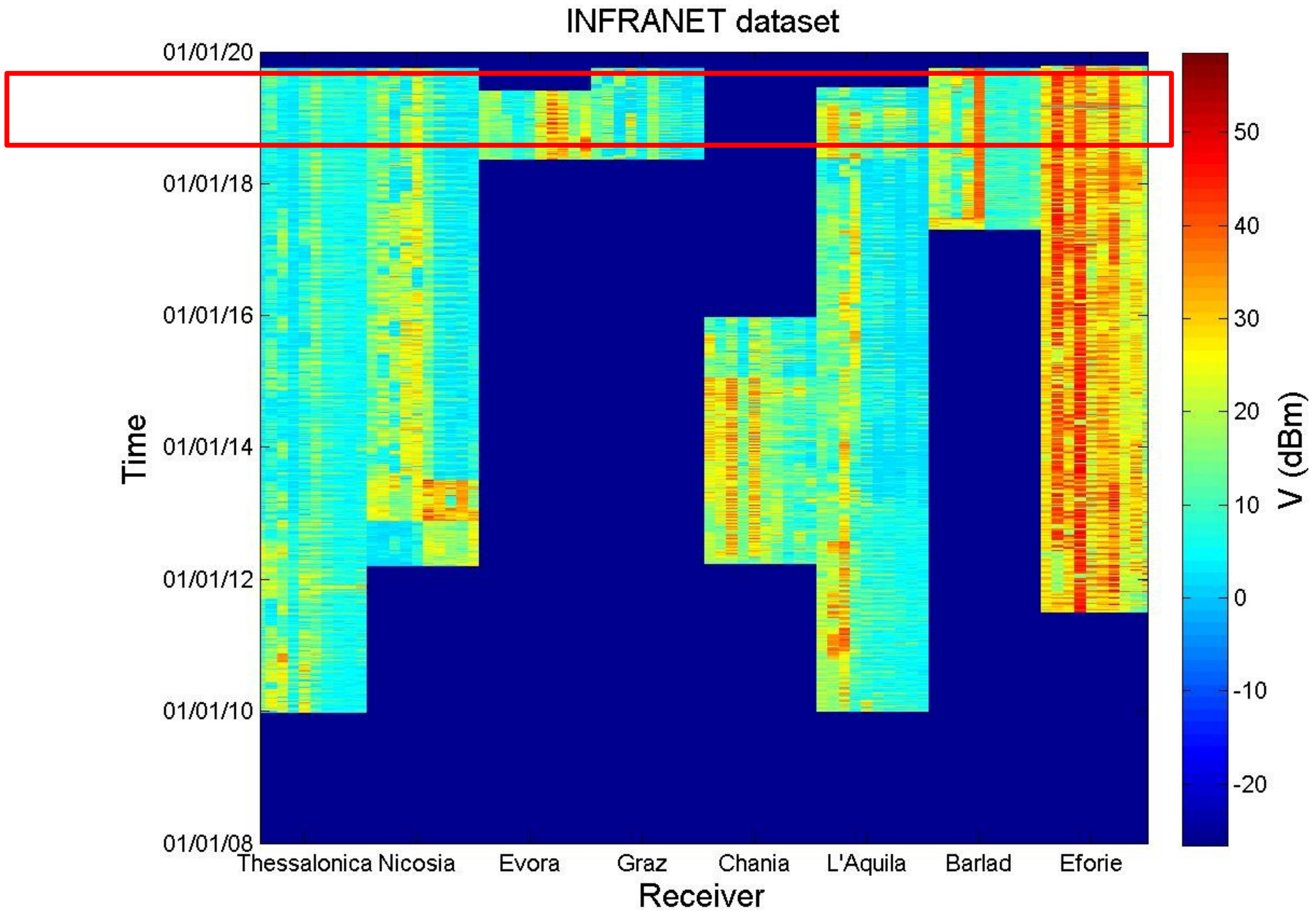
INFREP is a scientific cooperation among different international research teams. The cooperation aims to build up networks for measuring different physical/chemical parameters in order to search and study effects related to the occurrence of earthquakes.

Currently, a network consisting of several receivers able to measure VLF-LF radio signals from different broadcasting stations located throughout Europe is into operation. The data collected are transmitted every day a server and processed. If an anomaly is revealed, a protected warning system is active.

INFREP network (www.infrep-network.eu)



Dataset used for analysis



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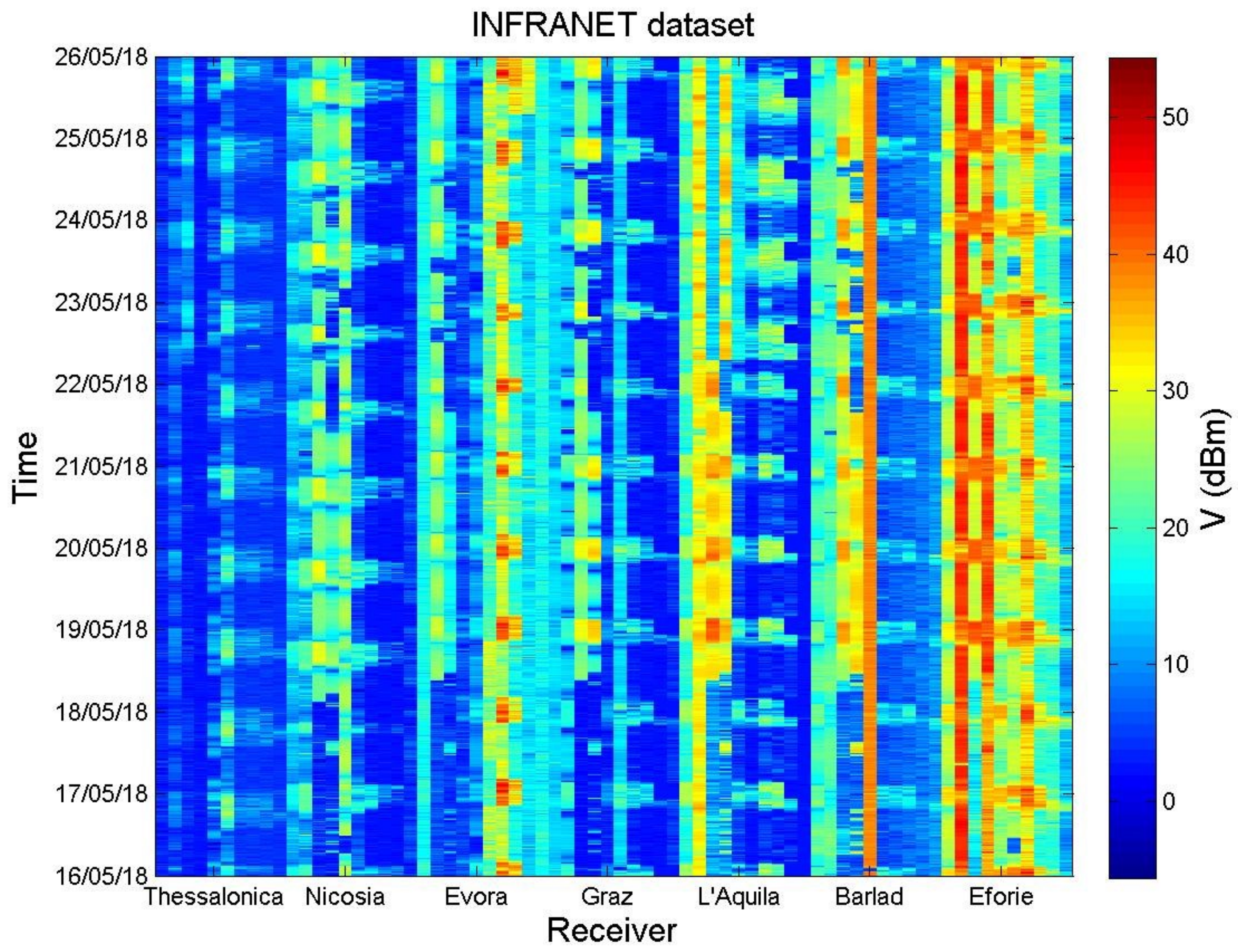

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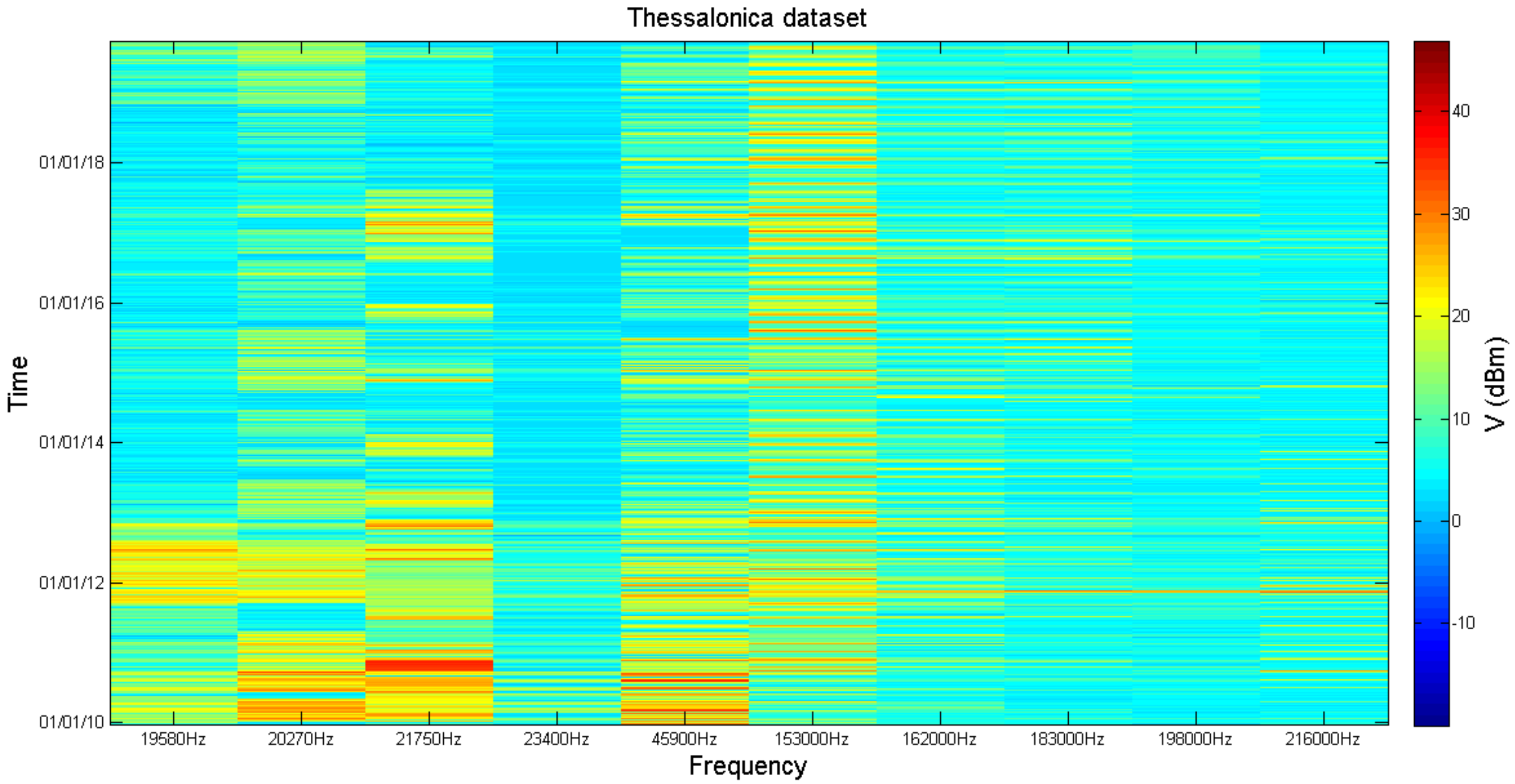
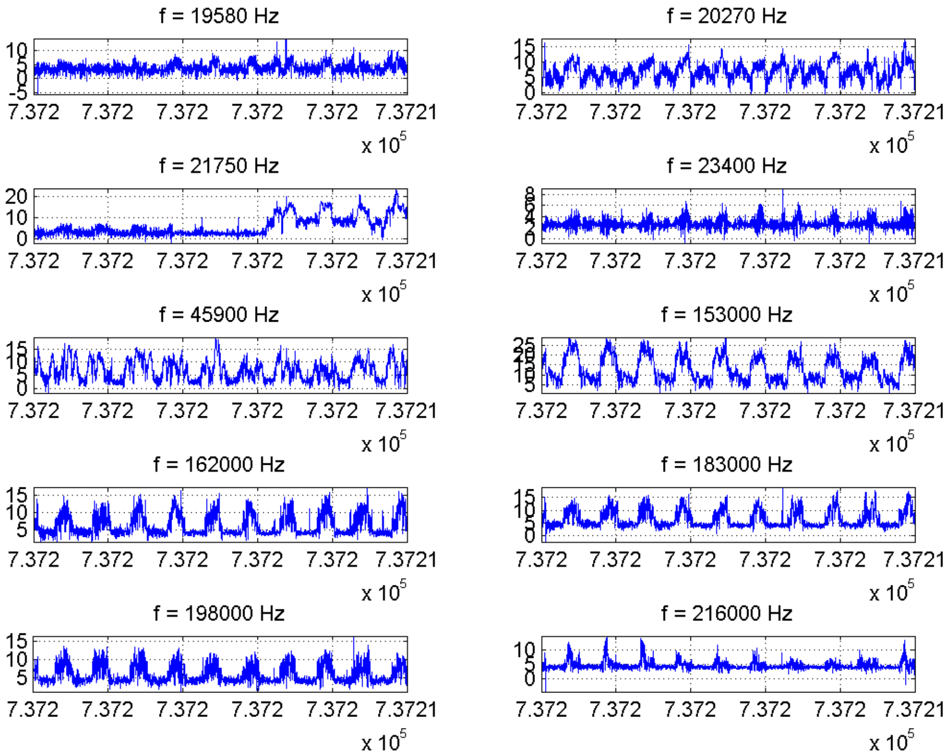
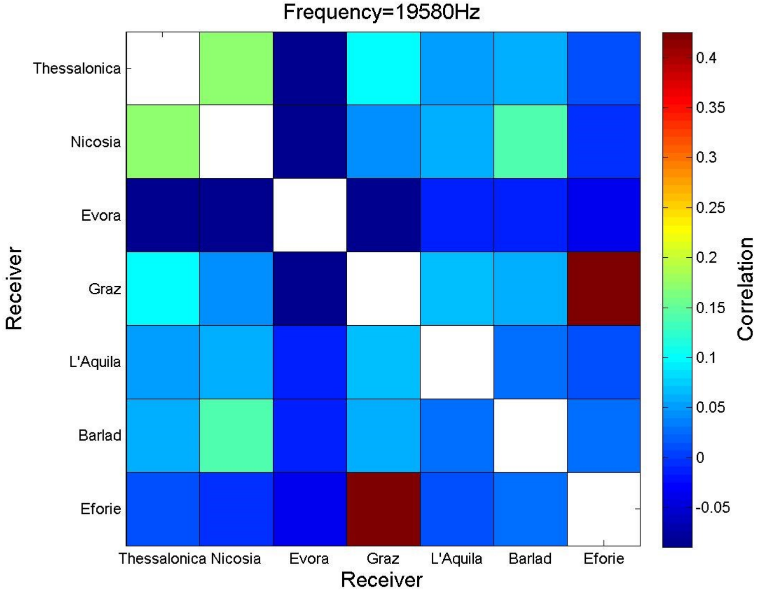
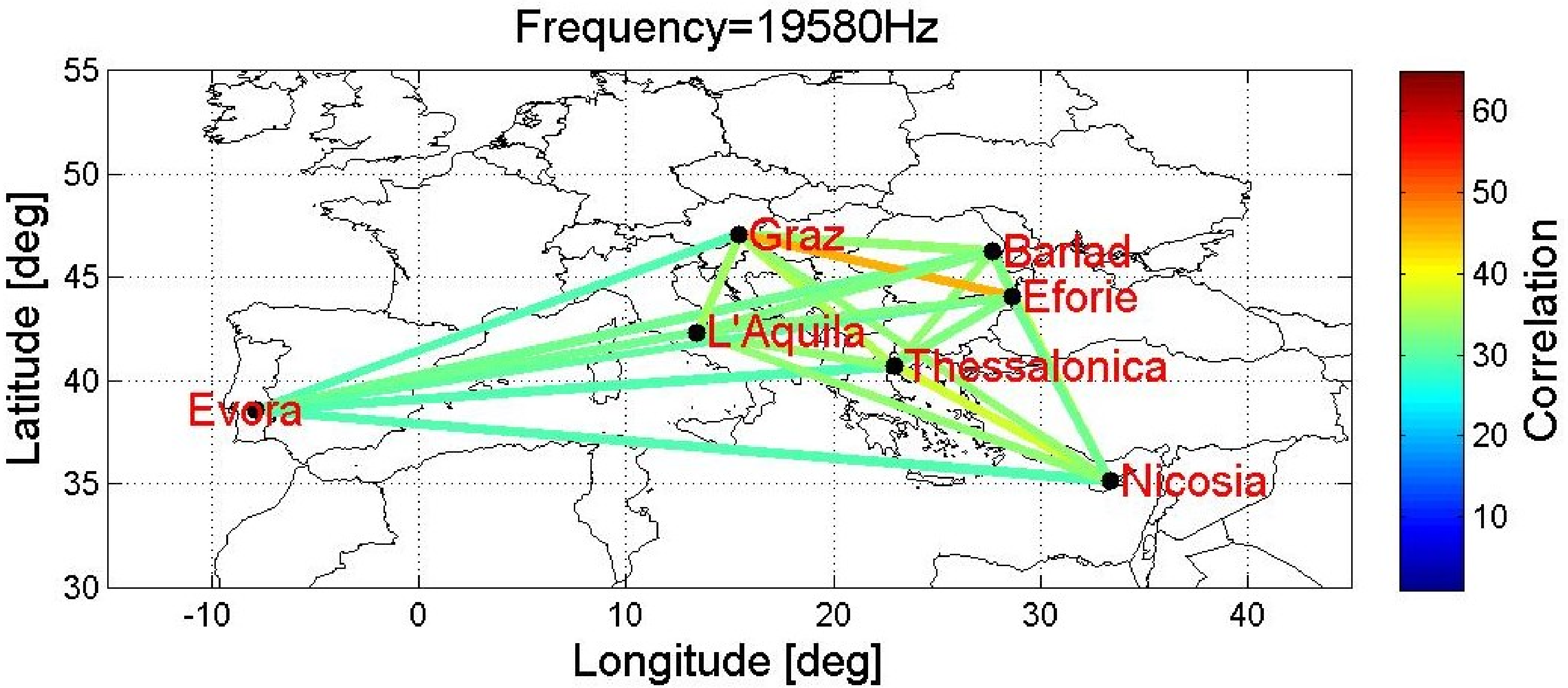




Adjacency matrix and graph analysis (f_1 = 19580 Hz)





Effects of D-region disturbances on space geodesy measurements

The influences of upper ionospheric disturbances on space geodesy technique have been already studied. Here we focus on the influence of D-region disturbances on GNSS and SAR interferometry (InSAR) space geodesy techniques. This lower part of ionosphere can also be studied by VLF signals.

The most important influence on the mid latitude D-region coming from the Sun. However, effects of photons and charged particles are different. Namely, in addition to Ly-α radiation, increased X radiation during solar X-ray flares significantly disturb this atmospheric part, while ionization of the mid latitude D-region by charged particles is not so important.

Determination of ionospheric effects on GNSS and InSAR signals

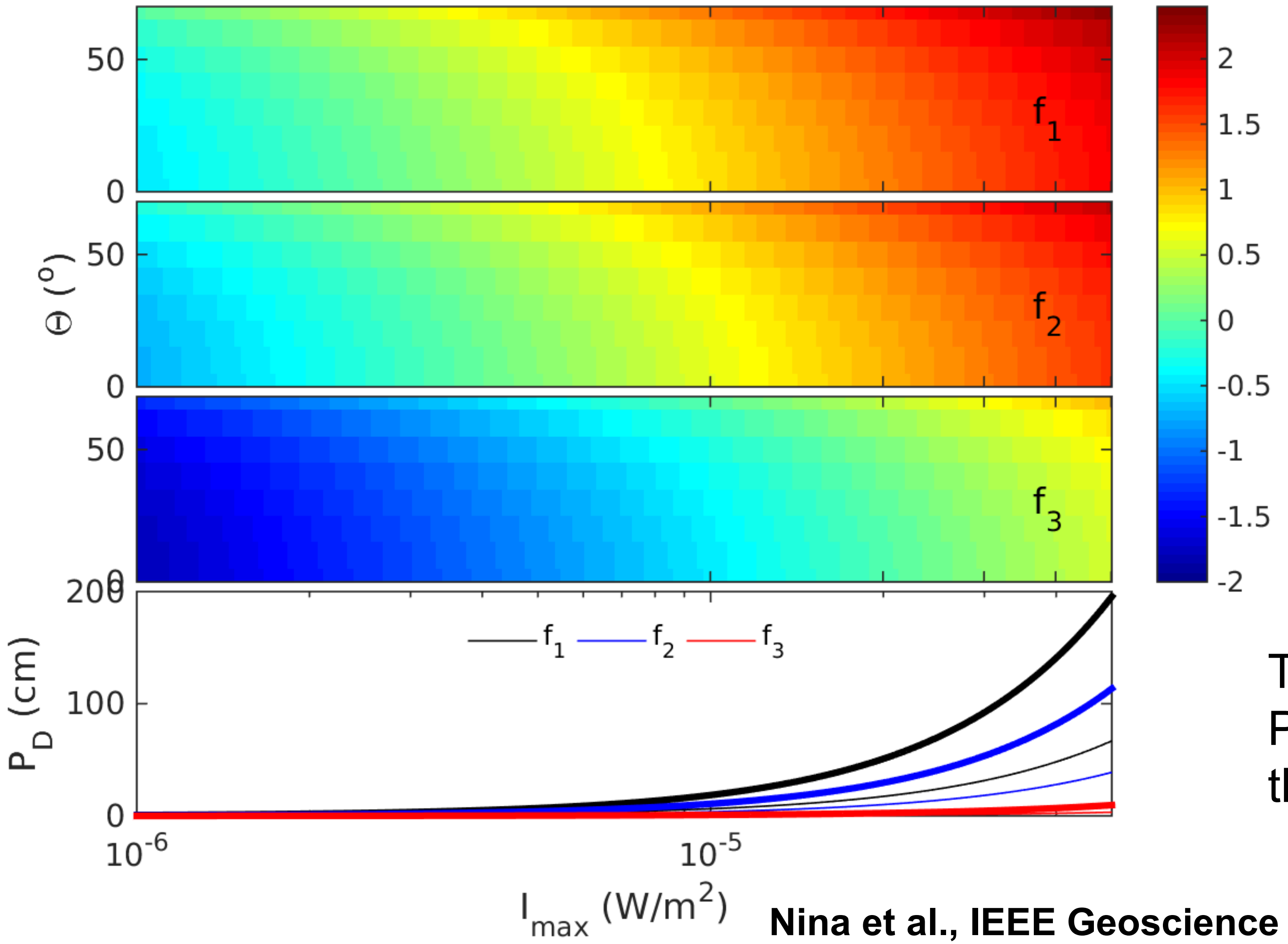
Signal deviation is caused by free electrons. Calculations of ionospheric influences on received signals are based on knowledge of the total electron content (TEC). There are different models for TEC determination. They are based on some approximations whose applications in cases of intense ionospheric disturbances can be questioned and this task is in focus of contemporary research.

The electron density is significantly larger in the upper ionosphere. For this reason, modeling of the ionospheric influences on satellite signals is often based on the analyses for altitudes above 90 km. However, this limitation (applicable to the quiet conditions) opens a question: Can the perturbed low ionosphere sufficiently affect the GNSS and SAR signals so that the inclusion of the D-region (60 km - 90 km) in models becomes necessary for measurements?

Determination of ionospheric effects on GNSS and InSAR signals

- ✓ D-region delays during perturbations can be sufficiently large to cause pronounced impacts on the GNSS and InSAR distance measurements
- ✓ The GNSS/SAR signal incident angle affects the amount of the D-region path delay P_D and duration time when the solar X-ray flare sufficiently alters the signal characteristics
- ✓ The maximum flux of a solar X-ray flare significantly affects the D-region influence on the SAR signals
- ✓ The D-region path delay P_D decreases with the frequency of SAR signals.

Determination of ionospheric effects on GNSS and InSAR signals



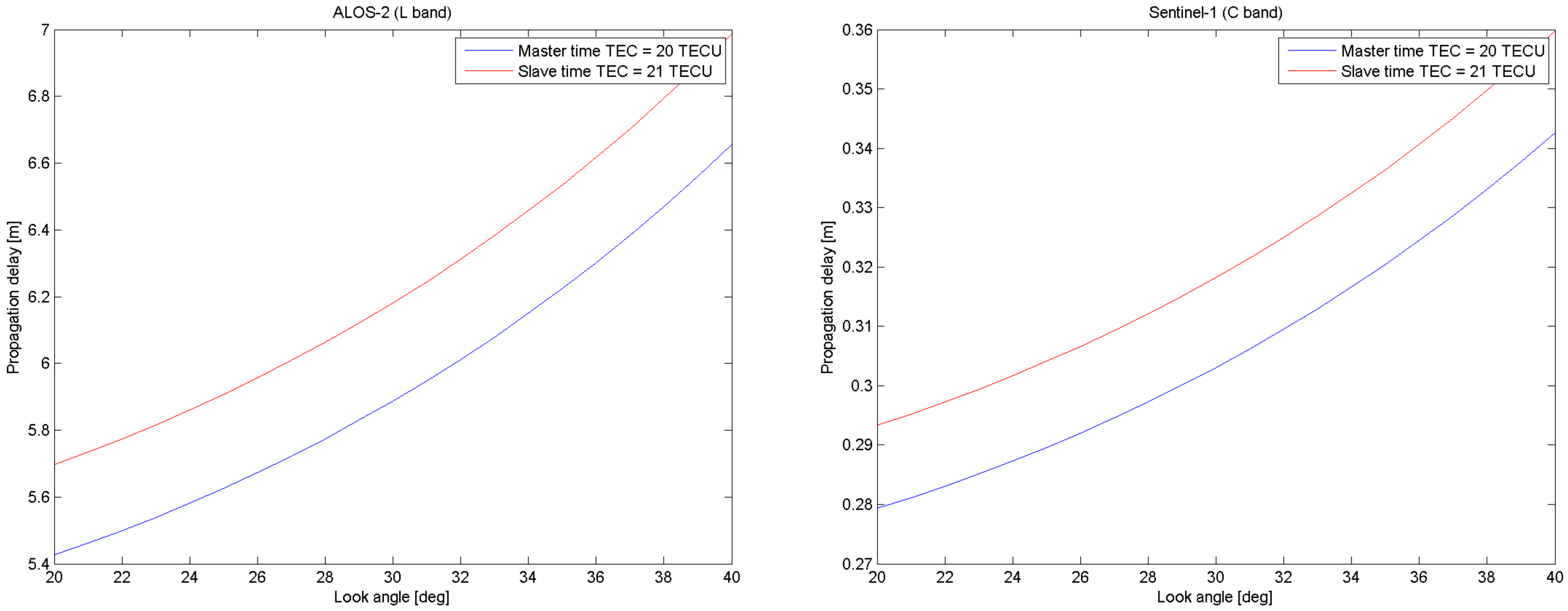
Dependence of the D-region path delay P_D dependence on $I_{ma}x$ for incident angles ϑ_0 in the range 0°--70° and GNSS/InSAR frequencies:

- f1 = 1:20000 GHz
- f2 = 1:57542 GHz
- f3 = 5:40500 GHz

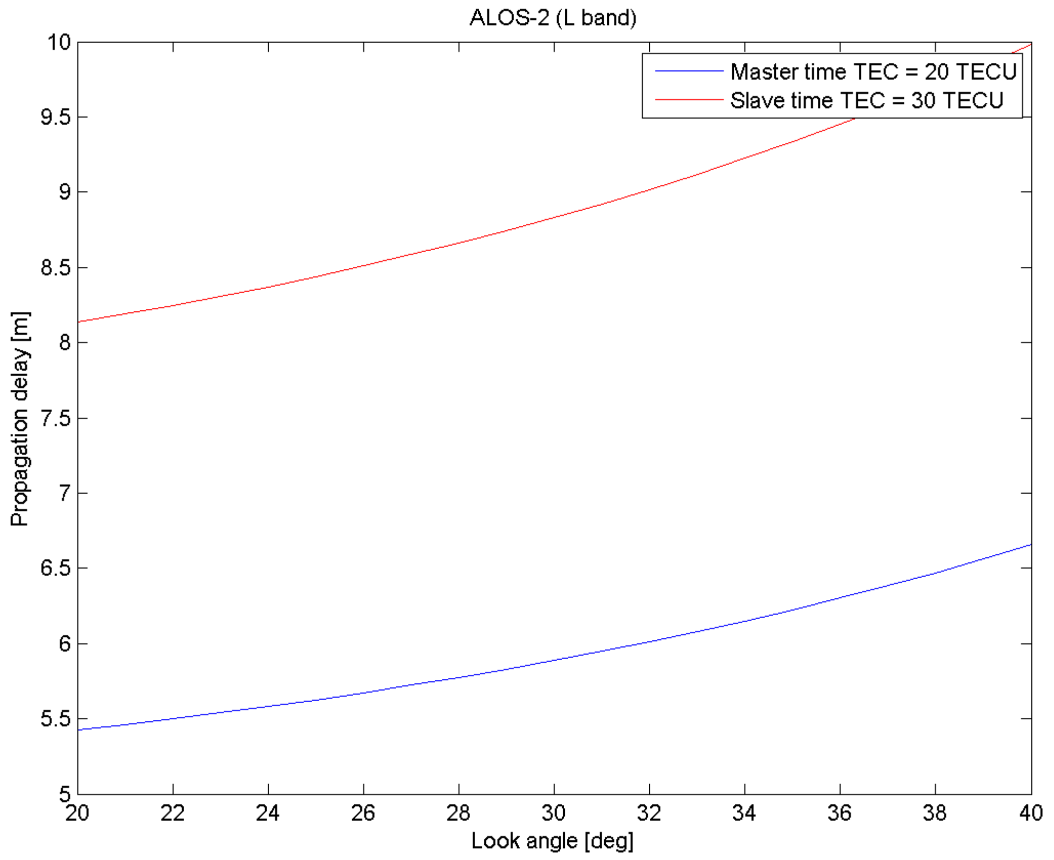
Time evolutions of D-region path delay P_D for the above incident angles and three frequencies.

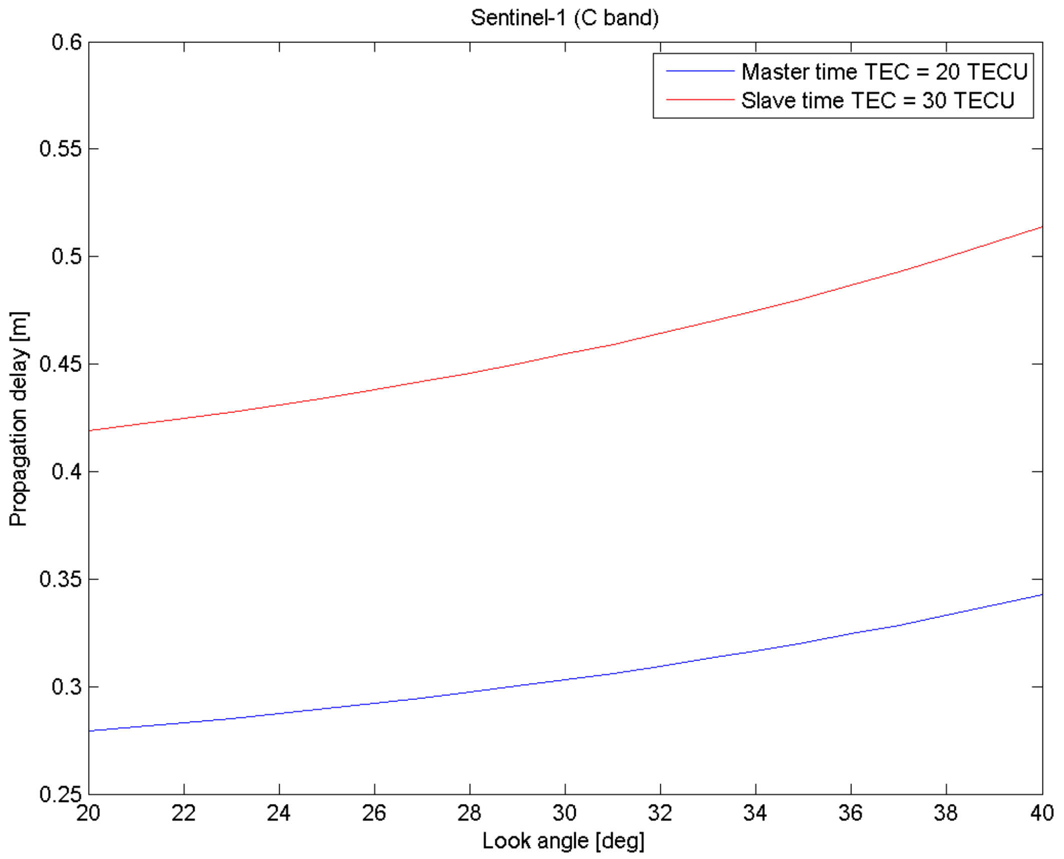
Nina et al., IEEE Geoscience and Remote Sensing Letters, 17(7), 1198-1202, 2020.

Temporal variation of TEC = 1 TECU



Temporal variation of TEC = 10 TECU

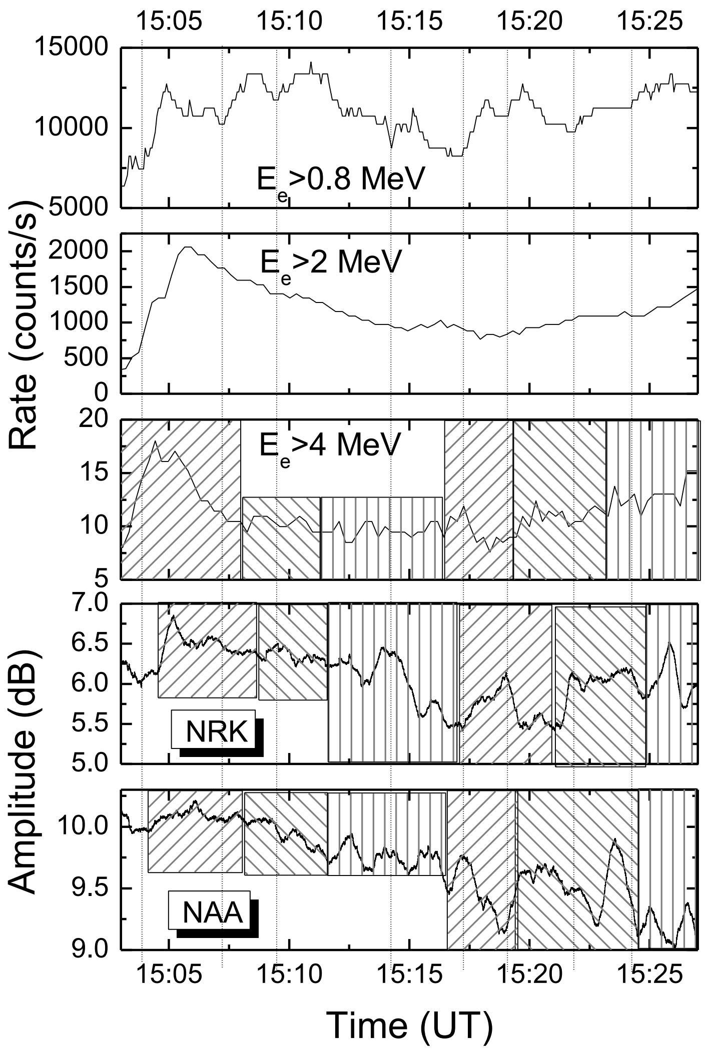




Variations in the D-region properties

Variations in the D-region properties are primary studied at high latitude.

Time evolutions of NRK and NAA VLF signals emitted in Iceland and the USA and received in Belgrade by the AWESOME (Atmospheric Weather Electromagnetic System for Observation Modeling and Education) receiver on 24 January, 2012 when charged particles rates increase due to a coronal mass ejection.
In the three upper panels time evolution of electrons with energies larger than 0.8, 2 and 4 MeV are presented. As one can see, there is not clear similarity in these evolutions.



Conclusions and future Work

In this work we discussed the use of VLF radio signals, GNSS data and InSAR images as a means to study the temporal evolution of physical properties of atmosphere at different temporal and spatial scales.

We focused on the D region of ionosphere since it is the most affected during X-ray flares, the less modeled in GNSS and InSAR applications and the region where the synergy between VLF, GNSS and InSAR data is the most fruitful.

Further work is needed to detect the effects of D-region perturbations in VLF radio signals and image them by means of SAR interferometry.