ULF RADIO MONITORING NETWORK IN A SEISMIC AREA

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1. Abstract

ULF monitoring is a part of a multidisciplinary network (AeroSolSys) located in Vrancea (Curvature Carpathian Mountains). Four radio receivers (100 kHz – microwave) placed on faults in a high seismic area characterized by deep earthquakes detect fairly weak radio waves. The radio power is recorded in correlation with many other parameters related to near surface low atmosphere phenomena (seismicity, solar radiation, air ionization, electromagnetic activity, radon, CO_2 concentration, atmospheric pressure, telluric currents, infrasound, seismo-acoustic emission, meteorological information). We follow variations in the earth's surface propagate radio waves avoiding reflection on ionosphere. For this reason distances between stations is less than 60 km and the main source of emission is near (Bod broadcasting transmitter for long and medium wave radio, next to Brasov city). In the same time tectonic stress affects the radio propagation in air and it could generates ULF waves in ground (LAIC coupling [1]). To reduce the uncertainty is necessary to monitor a location for extended periods of time to outline local and seasonal fluctuations. Solar flares do not affect seismic activity but they produce disturbances in telecommunications networks and power grids [2]. Our ULF monitoring correlated with two local magnetometers does not indicate this so far with our receivers. Our analysis was made during magnetic storms with Kp 8 according to NOAA satellites. To correlate the results we implemented an application that monitors the satellite EUTELSAT latency compared to WiMAX land communication in the same place. ULF band radio monitoring showed that our receiver is dependent on temperature and that it is necessary to introduce a high pass filter in data analysis. ULF data acquisition is performed by Kinemetrics and National Instruments digitizers with a sampling rate of 100 Hz in MiniSEED format and then converted into text files with 1 Hz rate for analysis in very low frequency. In both cases we use spectrum analysis in three bands of frequency with different filters. More results showed that tectonic stress generated by seismicity is more important than effects of solar flares.

We consider two geomagnetic storms with Kp = 8 (NOAA, 17.03.2015, 22.06.2015) and the earthquake with magnitude 5R in Vrancea area (08.02.2017). In these cases we analysis the effects on ULF signals produced by solar explosions and from tectonic stress. We chose the largest Kp and the most important earthquake after the AeroSolSys network was implemented in Vrancea area. Geomagnetic storms major affect Earth' magnetosphere and ionosphere, and solar wind has effects on space environment. There are impacts on space weather, GPS systems and electric power transmission according to NOAA [2].

2. ULF Monitoring Network

The general structure of AeroSolSys multidisciplinary monitoring network is presented in Fig. 1. The geological structure shows that each location is under the effect of a fault [3]. Bod broadcasting radio station is used for many researcher in VLF networks (Fig. 1).

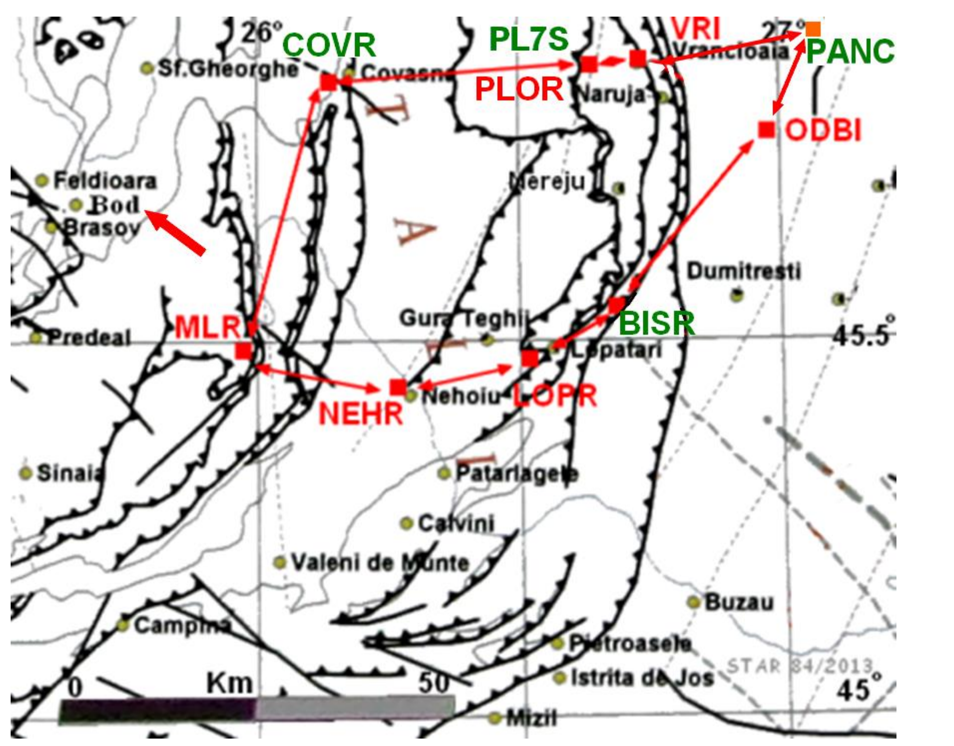

Fig. 1 . Multidisciplinary monitoring network in Vrancea area, main faults (map by C. Dinu, V. Raileanu et al. CEEX 647/2005)

It is received in Cyprus e.g. The geological structure is important for our monitoring of aerosols, ions, radio ULF waves propagation, radon and cloud monitoring. We made geological investigation for every station. Equipment in each station with ULF receivers and magnetometer are presented in Table 1. The geomagnetic storms are recorded by MLR's magnetometer and some times by telluric field in PLOR.

The data are send automatically to NIEP center (National Institute for Earth Physics from Romania) where we save them on servers, display and make a analysis in real time.

Table 1

Station	Location	Sensors
BISR	Bisoca	Seismic velocity-acceleration, acoustic, **radio ULF**, inclinometer, radon, air temperature, pressure and humidity.
COVR	Covasna	Seismic speed-acceleration, **radio ULF.**
PLOR	Plostina	Seismic velocity-acceleration, acoustic, infrasound, meteorological station, ionization, telluric field, air electrostatic field, inclinometer, air -ground – borehole temperature
PL7S	Plostina 7	Seismic velocity-acceleration, **radio ULF**, video camera for clouds, radiometer for solar direct and reflected monitoring (long and short waves).
PANC	Panciu	Seismic velocity-acceleration, **radio ULF.**
MLR	Muntele Rosu	Seismic velocity-acceleration, acoustic, inclinometer, radon, air temperature, pressure and humidity, **magnetic field X, Y, Z.**

Tab. 1. Configuration ULF monitoring stations

3. Equipment and data acquisition

Fig. 2. ULF receiver

The receiver is presented in figure 2. It is a Natural Electromagnetic (EM) Meter manufactured in the USA by AlphaLab, Inc [4]. "The radio/microwave detector is sensitive from 100,000 to 2.5 billion oscillations per second (100 KHz to 3 GHz) and can detect strong or unusual atmospheric electrical activity. Its minimum and maximum detectable signal strengths are 0.01 milliwatt/cm^2 and 1 milliwatt/cm^2 respectively", according to AlphaLab. Our measurements indicate its dependence on temperature. That's why we use a high pass filter to analyze data or we correlate measurements with temperature. The whole energy is concentrated under 1 Hz frequency but the interesting part is over 10 Hz.

Fig. 3 Magnetometer

The three - axis magnetometer (Fig. 3) and Mag-03DAM data acquisition module are from Bartington. The measuring range is ±70μT in low noise version with <6pTrms/√Hz at 1Hz and bandwidth 3 kHz. The software was developed in LabVIEW for a 1 Hz sampling rate and data is saved in EXCEL compatible text files. The ULF receiver has an analogue output that is digitized by Kinematics equipment (Basalt and Obsidian) with 24-bit Delta Sigma converters, one per channel, 8 channels, built-in GPS and work at 100 Hz sample rate in MiniSEED format. The information is saved in real time in a NIEP's data base next to seismic data by SeisComP.

Fig. 4. Equipment for data acquisition

4. Methods and results

Fig. 5. ULF BISR, high pass 1Hz, Butterworth, 16.03.2015

The software developed reads MiniSEED, SAC and text file and has many futures:
- Filters low pass, band pass, band stop: Butterworth, Chebyshev, Inv. Chebyshev, Elliptic, Bessel, Median, Zero Phase (LabVIEW library), reduce spikes;
- Power Spectrum;
- Power Spectrum Density (PSD) [5];
- Evolution in time of Fest (frequency), Power over Frequency, PSD; we use a time window with overlaps;
- Spectrograms: Adaptive, Cone Shaped, Cohen, CWD, Gabor, STFT, WVD and Wavelet (LabVIEW library).

Starting with geomagnetic storm from 17.03.2015 (Kp =8) and using a high pass 1Hz, Butterworth filter, we observe (Fig. 5) that the energy is concentrated below 5 Hz. Applying a median filter for 16, 17, and 18.03.2015 days in BISR station we obtain Fig.6 where there are variation correlated with Kp.

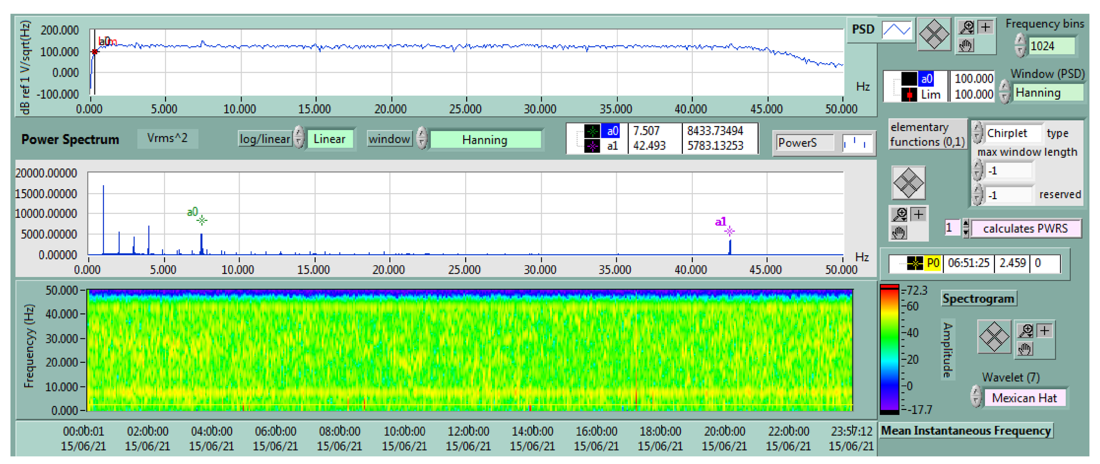

Fig. 8. ULF BISR, high pass 1Hz, Butterworth, 21.06.2015

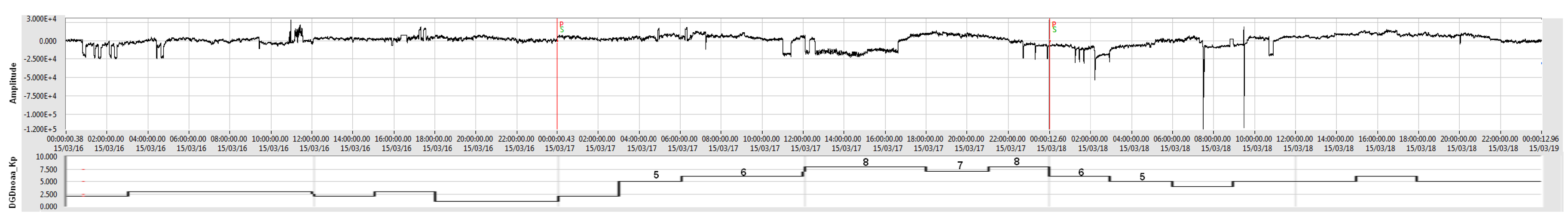

Fig. 6. ULF BISR, Median filter, DGD NOAA Kp, 16 - 18.03.2015 period

We have the same correlation over 10 Hz at frequencies 30 - 40 Hz when the power increases (Fig. 7). We use the same method for 22.06.2015 geomagnetic storm (Figs. 8 - 12). The noise is very high and the correlation is obviously only if we take more days.

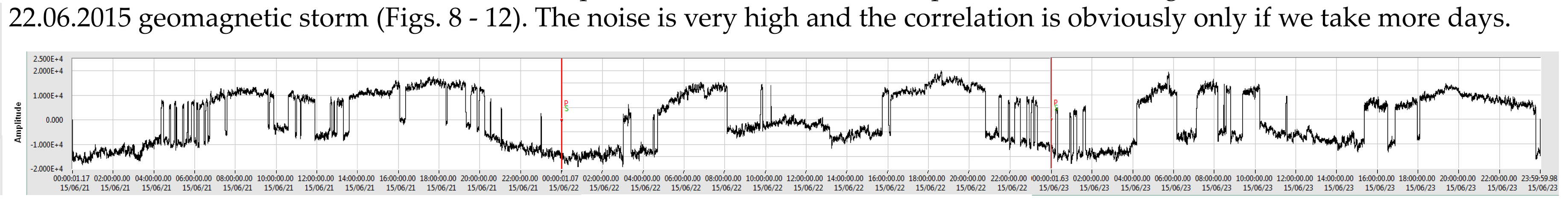

Fig. 9 ULF BISR, Median filter, 21 - 23.06.2015 period

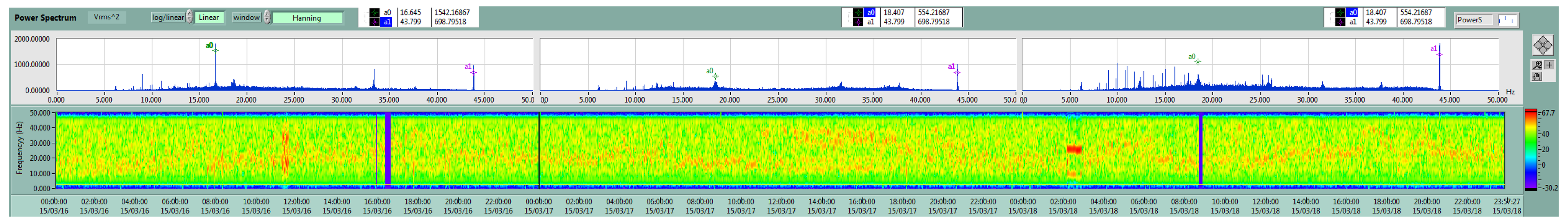

Fig. 7. ULF BISR, high pass 10Hz, Butterworth, 16 - 18.03.2015 period

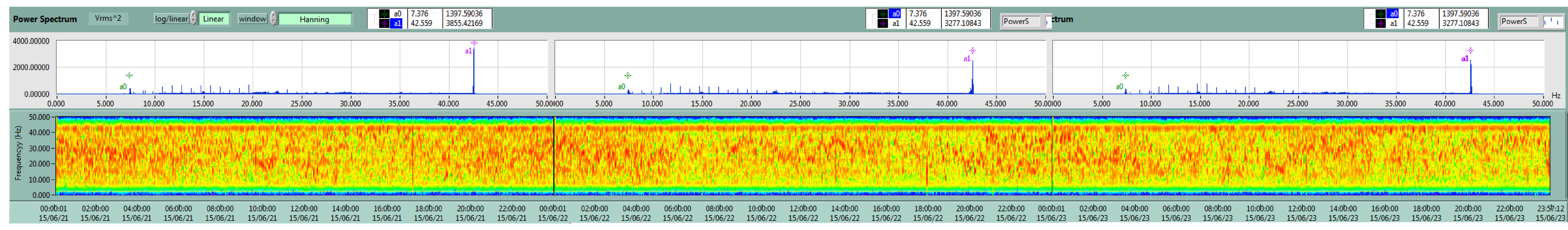

Fig. 10. ULF BISR, high pass 10Hz, Butterworth, 21 - 23.06.2015 period

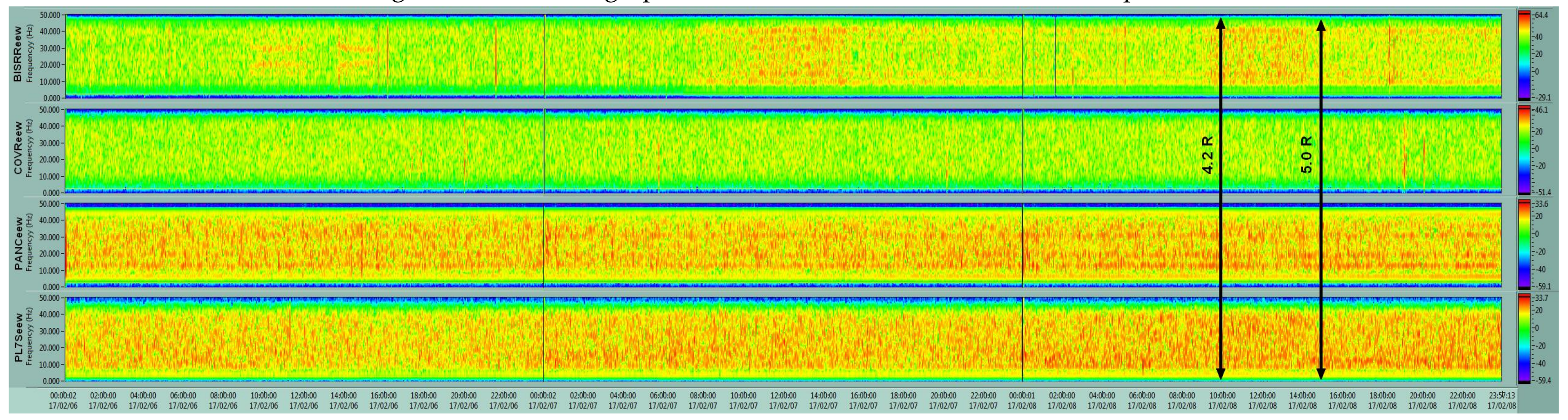

Fig. 13. ULF in 4 station, 4.2R and 5R on 08.02.2017

Another case when we could have ULF disturbances is caused by tectonic stress. In Fig. 13 we use a high pass 10Hz Butterworth filter for a sequence of 2 earthquakes with magnitude 4.2R and 5 R with epicenter in Vrancea area, 08.02.217. We have a correlation in stations BISR and PL7S . It is hard to say the same thing for COVR and PANC (the noise is higher). The LAIC concept includes the ULF generated by tectonic stress [1].

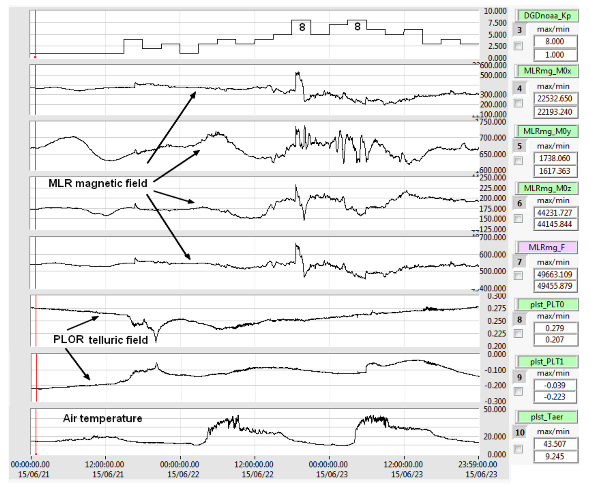

Fig. 12. Magnetic field Kp, 21 - 23.06.2015

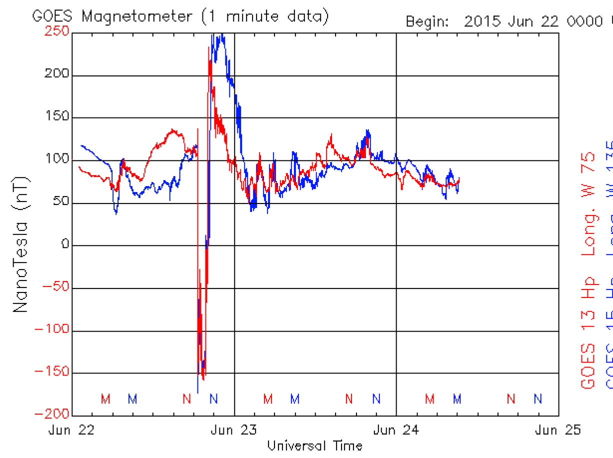

Fig. 11. NOAA, GOES, 22 - 24.06.2015

5. Conclusions

An ULF monitoring network integrated in a multidisciplinary activity has the chance to provide useful information on the effects of solar explosions and tectonic stress. We analyzed two cases of effects over ULF waves: geomagnetic storms and tectonic stress. In both cases we have disturbances but we can see these after the events (we cannot anticipate in this moment). One cause is the quality of receiver (we started with a cheap solution). The seismicity of Vrancea area is not so high to generate important ULF waves, too. The relation with seismicity is useful to make a forecast next to other AeroSolSys' parameters like electromagnetic field, radon, CO_2, infrasound, seismoacoustic, air ionization and solar radiation monitoring (Earth's energy budget). The analysis has to correlate these factors with global and local environmental factors. A new approach is to monitor the satellite communication latency compared to WiMAX land solution in the same place. We have this case in Bisoca station. The latency could indicate high perturbation in communication (geomagnetic storms, high tectonic stress) but it depends on traffic. To eliminate this factor we use another station that uses the same satellite but located in a far away place. Fig. 14 shows this application, the same traffic and the differences. Another future analysis will use the Probability Density Function (PDF) applied on PSD for noise evaluation [5].

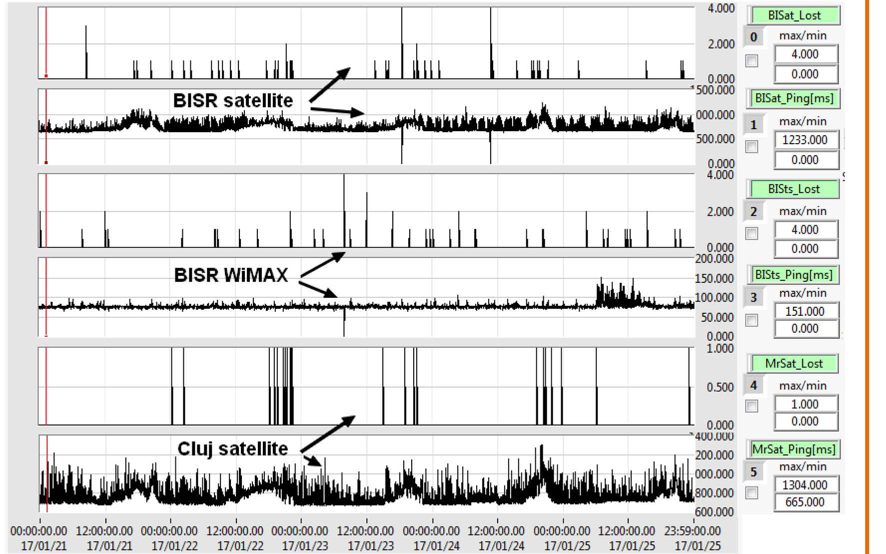

Fig. 14 Satellite EUTELSAT and WiMAX land communication latency

6. References

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7. Acknowledgements

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