Project abstract

The idea behind the project is the concept of a complex and multidisciplinary research, which seeks a fresh perspective on geophysical phenomena associated with earthquakes preparation periods obtained by simultaneous processing of complementary records obtained from the networks offered by partner institutions in Romania and Cyprus. This initiative is the first attempt to investigate ionospheric perturbations over Europe related to the European earthquakes, using combined and complementary ways of monitoring and analysis.

There have been pursued both the propagation characteristics in the ionosphere of very low and low frequencies (VLF / LF) radio waves (available to project partners from Romania via the INFREP) and also at very high frequencies (HF) (data belonging to the partner of Cyprus). The ionospheric properties taken from the total electron content (TEC) habe been obtained by advanced analysis of GPS / GNSS data recorded in both partner countries, but never processed for this purpose in Romania.

The project investigated interactions in the Earth-Space coupled system in correlation with earthquakes in Europe, using ionosphere monitoring systems existing in both countries: GNSS / GPS from Romania and Europe, INFREP VLF / LF receivers installed in Eforie North, Romania and Helen SAT Site, in southern Cyprus, AWESOME VLF/LF data managed by the partner from Cyprus and the European ionosondes data accessible to the partner in Cyprus.

The primary objective was to study seismo ionospheric phenomena and identify peculiarities of their manifestation in correlation with earthquakes. Using experimental observations and advanced mathematical processing, the project attempts to identify the associated ionospheric signatures of earthquakes.

Objectives of the execution phase were:

Objective 1.1 Seismic and magnetic data management and database in which the seismic zoning was conducted in Europe and hence the catalogs of earthquakes for the period 1998 to 2015 European have been created. Seismic sources were revealed (Figure 1 a and b) from the study area, located within the fifth Fresnel zone of radio wave propagation paths monitored by the receivers from Romania and Cyprus. The receivers belong to INFREP. Also in this objective geomagnetic conditions were assessed and the global database 2015 Kp was achieved.

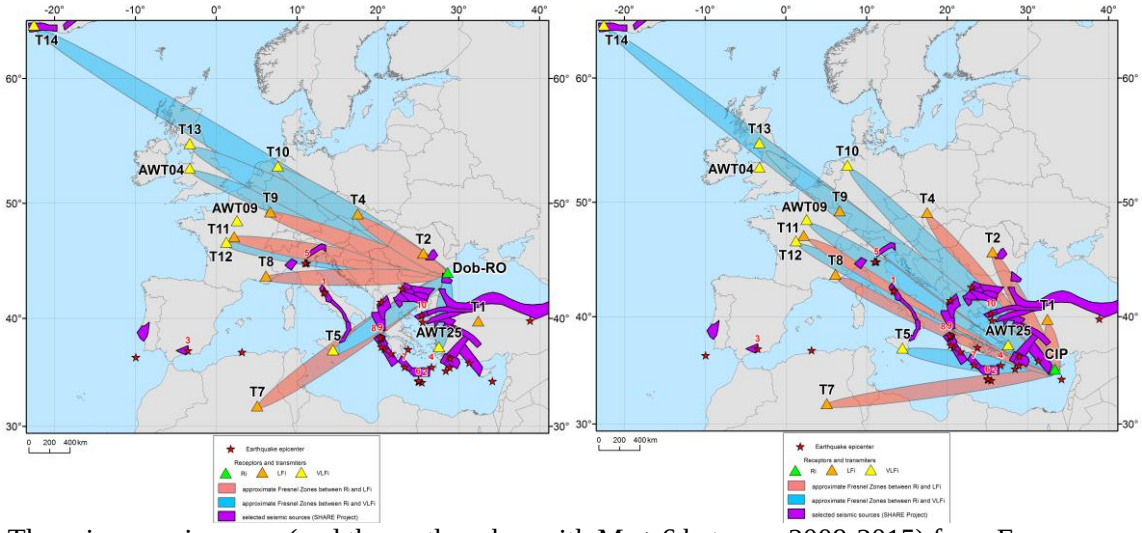

Figure 1. The seismogenic zones (and the earthquakes with Mw>6 between 2009-2015) from Europe crossed by the 5th Fresnel Zone of the radio path monitored by a. DOB-Ro receiver and b. CIP receiver

Objective 2.1. Analysis and investigation of the electromagnetic data (EM) offered by INFREP (VLF / LF). Within this objective we have managed the major disturbances (amplitude and phase) registered with the network INFREP LF / VLF and try to correlate them with their possible causes (Figure 2).

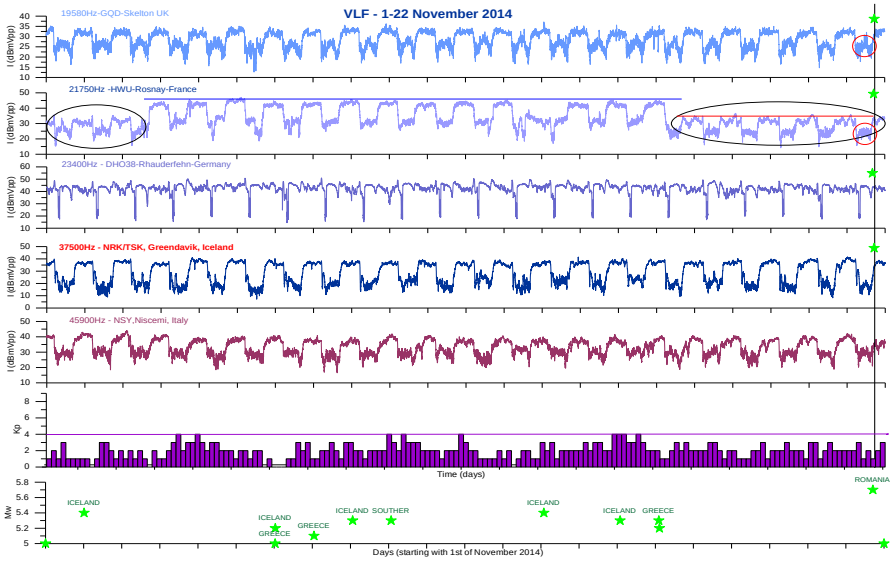

Figure 2. The diagrams with the VLF data recorded by Dob-Ro receiver, the Kp index and the European earthquakes occurred between 1-22 November 2014, before the largest Vrancea crustal earthquake recorded by the Romanian Seismic network.

The data have also been analysed with Terminator Time (TT) and Night Time fluctuation (NT) for detecting the seismo-ionospheric perturbations.

Objective 2.2. TEC investigations using GPS/GNSS data offered by the Romanian and Cyprus partners (INCDFP and FRC).

In this objective the RINEX data from the GPS /GNSS data of INCDFP, Romania and from the free European networks have been processed for obtaining information about TEC (total electron content) before, during and after a large earthquake. We have created differential TEC maps before, during and after the largest earthquakes that occurred in Romania (Figure 3) and Europe between 2009 and 2015, using statistical methods and correlation techniques for the identification of seismic signatures in TEC distribution.

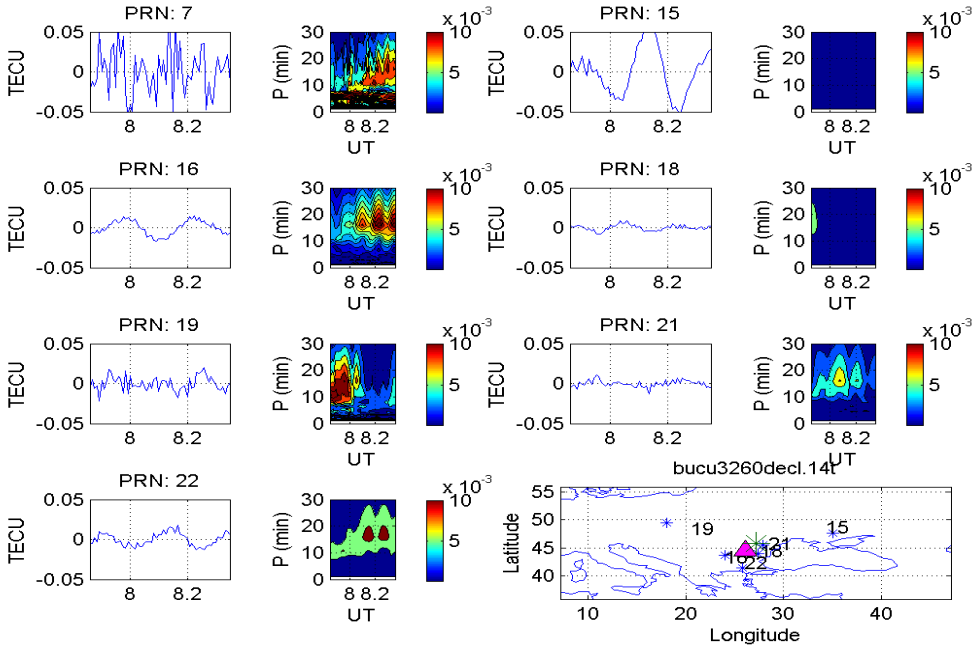

Figure 3. Fluctuations of differential TEC (middle panels) obtained from measurements of 7 satellites passing over the preparation zone during periods when large drop of cross-correlation coefficient was found on 22 November 2014. The power spectrum of the normalized amplitude is also shown (right panels). Map shows the number and position of satellites (blue asterisks), the position of the GPS receiver at (pink triangle) the same date BUCU station , and the epicenter (green asterisk) of the earthquake at 22nd November 2014.

Objective 2.3. The investigation of high ionoshpheric layers using data provided by the European Ionosondes
The main purpose of this objective is to identify earthquake signatures on various ionosonde-derived ionospheric characteristics and features expressed in terms of ionograms and time-series of ionospheric characteristics using an array of techniques. The same approach as with TEC data was applied for ionosondes for foF2 (critical frequency of the F2-layer) data. In this case data processing required manual scaling of ionograms to elliminate errors from autoscaling algorithms before cross-correlation analysis was applied. The daily cross-correlation coefficient between ionospheric foF2 variations observed at the site located inside and the site located outside the preparation zone was assessed. For each ionosonde station, the auto-correlation coefficient was also performed, by estimating the daily auto-correlation coefficient (Figure 4) between one day and the next day.

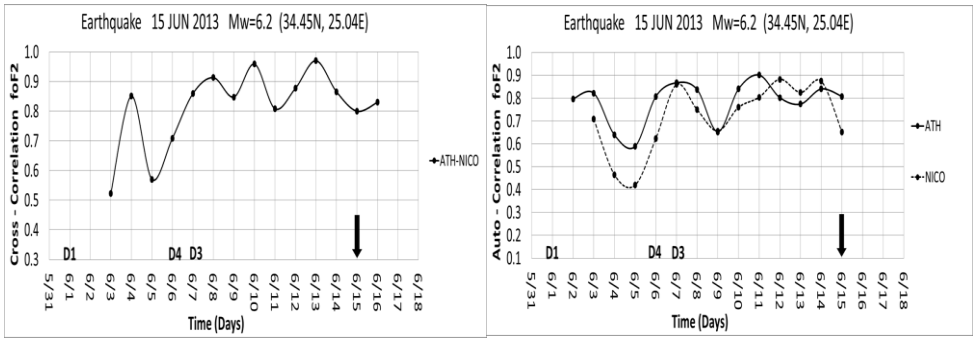

Figure 4. Left panel: cross-correlation coefficient for vTEC signals for the selected stations for the earthquake of 15 June 2013. Right panel: auto-correlation coefficient for same stations. Black arrow indicates the day of earthquake. Geomagnetically disturbed days are denoted with Di following the NCDC ranking criteria.

The quantifiable results of the project are: Database with VLF / LF records; Radio propagation anomalies; TEC database; Statistical analysis and correlations of TEC; Differential maps of TEC; Ionograms; foF2 correlations;
Dissemination of results was achieved in ISI journals (6 articles) and in national (8 presentations) and international (10 presentations) conferences, at FRC and NIEP, and also on the project website (http://ines.infp.ro/ informatii.html). The paper presented by one of the young PhD involved in this project, which it was achieved after the working visit from June 2015, received a special prize at 13th International Balkan Conference Workshop on Applied Physics, Constanta, Romania, 2-7 July 2015. This activity has resulted in a publishing of a joint article in a ISI journal.
The main conclusion that emerged from all the studies is that during the preparation of an earthquake occurring anomalous events in all the layers of the ionosphere, with manifestations in wave propagation at low and very low frequencies (LF and VLF), and also in the total electron content (TEC) from the highest layers of the ionosphere. These studies have encouraged us to continue along this way and we want that in the near future to try to develop this idea in other projects funded nationally and internationally. Another future goal is the automation of the identification process and the detection of seismic precursor signatures for a valid seismic forecasts, that would have a major impact both in the scientific but also in the economic and social environment.

The most important result of this project remains after all the friendship between the members of the research teams from the partners countries and the wish to continue the cooperation for developing and testing new methods for seismic forecast.