The paper presents the infrasound monitoring network installed at Plostina site, its characteristics and observations regarding its detection capability. Plostina is located at 45.8512 N latitude and 26.6499 E longitude in the Vrancea (Romania) epicentral zone, is characterized by a low infrasound noise background (due to the fact that it is located far from cultural sources of acoustic perturbations) and is one of the most modern monitoring sites under the administration of the National Institute for Earth Physics (NIEP). Starting with July 2006, NIEP, AZEL – Designing Group S.R.L. and Bucharest University (BU) joined in a research consortium who’s project – Complex Multidisciplinary Research System On Precursory Phenomena Associated With Strong Intermediate Vrancea Earthquakes, In Conformity With The Latest International Approaches – MEMFIS – was financed by the Romanian Ministry of Research and Education, through the Program Excellence Research and had as a final purpose a new and modern geophysical monitoring network, that uses specific instruments providing information on acoustic (both earth's seismic and atmosphere's infrasonic activities), electric, magnetic and electromagnetic fields to find the correlations between monitored fields and the preparatory stage of strong intermediate earthquakes in Vrancea zone. Different connections between the activity of the acoustic field and other geophysical fields are presented, as well.

Key words: Earthquakes forecast, infrasonic monitoring, acoustic and electromagnetic fields coupling, seismic precursors.

1. INTRODUCTION

Infrasounds are radiated by a variety of geophysical processes including earthquakes, severe weather, volcanic activity, geomagnetic activity, ocean waves, avalanches, turbulence aloft, and meteors. The general properties of these signals are described in the context of the measurement challenges presented in detecting them. A brief history provides background concerning the evolution of infrasonic detection technology. Recent improvements in both hardware and processing software have made passive detection and identification of infrasonic sources on a continuous basis practical and should lead to valuable operational applications.
These hardware and software advances will be described. The detection of meteors, meteorites, and space debris is an area reviewed to indicate the capabilities and uses of infrasonic observing systems. Infrasonic systems together with seismic, hydroacoustic, and radionuclide systems are involved in the International Monitoring System and offer wide opportunities for future synergistic research focused on the monitoring of nuclear test explosions in atmosphere as they are interdicted by international treaties [1].

Another kind of infrasound fluctuations in the Earth atmosphere results from the action of numerous geospheric processes and processes in near space. Action of the energy of a space origin on the Earth processes is usually connected to electromagnetic radiations and solar corpuscular flows. The interaction of electromagnetic radiation with heterogeneities of the atmosphere transparency can result in generation of acoustic fluctuations in a wide range of frequencies. The transparency heterogeneities of the atmosphere are significantly determined by solar activity. One can expect that the solar activity should rhythmically influence the spectrum of the infrasound fluctuations of the atmosphere. The widely known connection of solar activity with biospheric processes can occur through the acoustic channel [2–5].

The monitoring network installed at Plostina site (Vrancea seismic zone) will be presented from the perspective of its capability to detect different types of infrasonic events and the possibility to correlate them with the seismic, geomagnetic and atmospheric electric fields anomalies.

2. THE ACTUAL STATE

The National Institute for Earth Physics and AZEL – Designing Group S.R.L. have started to monitor the infrasonic activity of the atmosphere since 2008. The monitoring site is located at Plostina Geophysical Observatory (Vrancea seismic zone). Six infrasound monitoring devices (microbarometers) are deployed in this site. Three of them (PLO2, PLO3 and PLO4), constructed by AZEL – Designing Group S.R.L., constitute a small aperture network, named IOANE (Infrasound Operational Network) which is a subcomponent of the multidisciplinary monitoring network, MEMFIS. This network uses MBAZEL2007 microbarometers with simple wind-noise reduction systems which are disposed in the corners of a triangle having its sides of approximately 500m (Table 1).

<table>
<thead>
<tr>
<th>Infrasonic Station Code</th>
<th>Country</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude (MSL)</th>
</tr>
</thead>
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<tr>
<td>PLO2</td>
<td>Romania</td>
<td>45.8502N</td>
<td>26.6438E</td>
<td>694</td>
</tr>
<tr>
<td>PLO3</td>
<td>Romania</td>
<td>45.8539N</td>
<td>26.6455E</td>
<td>708</td>
</tr>
<tr>
<td>PLO4/IPH4</td>
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<td>45.8512N</td>
<td>26.6499E</td>
<td>656</td>
</tr>
<tr>
<td>IPH5</td>
<td>Romania</td>
<td>45.8420N</td>
<td>26.6415</td>
<td>690</td>
</tr>
<tr>
<td>IPH6</td>
<td>Romania</td>
<td>45.8455</td>
<td>26.6635</td>
<td>634</td>
</tr>
</tbody>
</table>
Plostina Geophysical Observatory is also equipped with three more infrasound stations: IPH4, IPH5 and IPH6. These constitute the IPLOR network (Infrasound Plostina Array) and are equipped with Chaparral Physics Model 25 microbarometers with 4 inlet ports. IPLOR is also distributed in the corners of a triangle which has its sides of approximately 2.5km (Fig. 1).

Fig. 2. The IPLOR infrasound monitoring network, consisting in the three stations IPH4, IPH5 and IPH6. The daisy-shaped wind noise reduction system in the right of the figure is used at IPH4, while IPH5 and IPH6 use simple, porous hose filters.

There have been made some interesting observations, related to the detection capability of this network, to the data completeness and to the correlation of the acoustic activity of the atmosphere with different geophysical processes.

Because IOANE is a component of MEMFIS, which is intended to be used as a complex monitoring network of the geophysical fields, besides microbarometers there are also an electric field monitor, that measures the vertical component of the atmospheric electric field and two triaxial flux-gate magnetometers.

3. INFRASONIC FLUCTUATIONS OF THE ATMOSPHERE RELATED TO THUNDERSTORMS

The first data provided by IOANE network revealed that is possible to detect the approaching thunderstorms from distances as long as few hundreds kilometers. The time difference between the recording moment of electric field disturbances and the recording moment of the induced infrasonic fluctuations of the atmosphere gives the possibility to compute the approximate distance to the thunderstorm.

The network is capable to record infrasonic atmospheric disturbances caused by approaching thunderstorms. It have been noticed that far electric discharges in atmosphere produce infrasonic fluctuations, recorded by the network. The electric discharges (lightnings) produce a relative large spectrum of acoustic disturbances,
from which the low frequency components travel for long distances. The electric activity of the atmosphere were recorded with an electric field monitor (EFM100-Boltek), capable to measure the vertical atmospheric electric field within the range -20kV/m to +20kV/m.

Assuming a propagation speed of the acoustic waves of about 340m/s, it was determined that distances to the event were of over 300 km. The instantaneous arrivals of magnetic disturbances (recorded by triaxial magnetometers) with the acoustic ones indicates that the thunderstorm is local.

Typical evolution of the atmospheric electric field, as the storm is approaching, is characterized by an increasing of the electric field value, from approximately 100V/m (in fair-weather conditions), to higher values which depends on the static charge of the cloud mass and the distance to it (Fig. 3).

[6] has shown that molecular attenuation is not significant to infrasonic propagation (5×10^-8 dB/km), whereas sound at 2 kHz will attenuate at 5 dB/km. Since infrasound below 1 Hz is virtually not attenuated by atmospheric absorption, it is detectable at distances of thousands of kilometers from the source. Thus, an infrasonic wave at a frequency lower than 1 Hz will travel for thousands of kilometers with less attenuation than a sound wave at 2 kHz which travels for a distance of about 300 m. Temperature and wind speed changes in the atmosphere contribute to sound refraction, guiding sound waves as they travel for long distances. Some waves escape and travel to great heights in the ionosphere where they dissipate, while other sound rays are trapped and bounce back and forth many times between the Earth’s surface and the upper atmosphere. The atmosphere acts as a waveguide that traps most of the acoustic energy [7].

Data recorded by the electric field monitor on 15th of July 2008 show a very stormy day, with 7 different rounds of storms, starting at approximately 02:00 UTC and ending at 18:00 UTC. Infrasonic data recorded in this day are correlated with the presence of different rounds of thunderstorms and with the electric discharges in atmosphere. As it can be seen, the most violent storm occurs at 13:00 UTC and lasts until 14:00. The infrasonic fluctuations during this period are the largest within that day, reaching values of ± 4 Pa (Fig. 4).

Infrasonic fluctuations occur after periods ranging to tens of minutes from the electric field disturbances caused by lightnings. This suggests that the distance to
the lightning ranges to hundreds of kilometers. The infrasonic fluctuations of atmosphere are correlated between the two stations. Time difference between the arrival of electric disturbances caused by lightnings and the arrival of the infrasonic fluctuations is of approximately 18 minutes, which, at a propagation speed of acoustic waves through atmosphere of about 340m/s, represents a distance of over 300 km. Electric field data were high-pass filtered from 0.01 Hz to reject the low frequency component having very large amplitude (± 20 kV/m).

After filtering, distant discharges which produce only 0.5 kV/m perturbations (or smaller) became visible (Fig. 5).

Fig. 4. The day of 15. 07. 2008. Recordings of infrasound activity (upper panel) and atmospheric vertical electric field (lower panel).

Fig. 5. PLO4 station. The day of 15. 07. 2008, between 00:17 and 02:17 UTC. Recordings of infrasound activity (upper panel) and atmospheric vertical electric field (lower panel).

The cluster of lightnings detected at 00:55 UTC produces infrasonic fluctuations at 01:13 UTC, which is 18 minutes later.
4. CRUSTAL SEISMIC EVENT AND INFRASONIC FLUCTUATIONS OF THE ATMOSPHERE

Infrasonic fluctuations of the atmosphere are also caused by the seismic activity. The influence of seismic activity on these fluctuations is a very complex process and does not consist only in piston radiation of oscillating lithosphere plates. The infrasonic fluctuations can be caused by gas release from lithosphere cracks during increase of seismic activity, oscillations of lithospheric plates, aerosol heterogeneities in the atmosphere. Also, the infrasonic fluctuation of atmosphere can create alternate stresses on the Earth surface and penetrate at significant depths in lithosphere. Penetrating into lithosphere the infrasonic fluctuation influence the speed of the movement of fluids, telluric electrical fields and also on local seismic fluctuations. Such processes occur on the large territories and can render the essential influence on seismic activity. Thus, the infrasound in the atmosphere can be both the result of seismic fluctuations and also actively influence them. The character of the interchange oscillatory energy between lithosphere and atmosphere can indicate the processes of preparation of large earthquakes.

On the 6th of September 2008 a crustal earthquake occurred in Vrancea seismic area. The earthquake had a depth of 13 km, a magnitude M = 4.4 and its epicenter was at only 15 km from the recording network. Some very interesting data were obtained from the recordings of the infrasonic activity of the atmosphere which is correlated with the activity of the geomagnetic field, recorded by the triaxial magnetometers. Data recorded before, during and after this crustal seismic event suggest the coupling between the two geophysical fields and revealed obvious anomalies of the geomagnetic and acoustic fields in the extremely low frequency range (ELF). Moreover, there are clear indications of the correlation between the geomagnetic activity and the infrasonic one. The seismic movement was recorded by the microbarometers installed at PLO2 and PLO3 (Fig. 6).

![Fig. 6. PLO2 station. Infrasonic data in the frequency range 0.1–4 Hz (upper panel) reveals the moment of the seismic motion arrival. The geomagnetic anomalies are shown in the lower panel.](image-url)
The plot represents the filtered data between 18:00:00.000 and 22:00:00.000 UTC. A 2nd order band-pass Butterworth filter was applied on the acoustic channel. The cut-off frequencies are equal to 0.1Hz and 4 Hz, respectively. Also, a 2nd order band-pass Butterworth filter was applied on the geomagnetic channel, having the cut-off frequencies of 0.01 Hz and 0.1 Hz, respectively. In this plot, the moment in which the seismic movement was recorded by the microbarometers, at 19:48:04.800 UTC, is marked and clearly visible.

Gabor spectrograms of the acoustic and geomagnetic channels of PLO2 and PLO3 station were represented, to analyze the behavior of the recorded signals in the time-frequency domain. The spectrograms are of the 4th order, and a Gaussian window of 256 samples was used. Data were band-pass filtered with a 2nd order Butterworth filter having cut-off frequencies of 0.01 Hz and 4 Hz. It can be observed that the geomagnetic activity has a good correspondence with the infrasonic activity of the atmosphere. Infrasonic data are represented in the upper panel. Geomagnetic data are shown in the lower panel (Fig. 7).

![Fig. 7. PLO3 station. Gabor spectrogram of the acoustic and geomagnetic channels, between 10:00:00 and 11:00:00 UTC, 06. 09. 2008, 9 hours before the M = 4.4 crustal earthquake.](image)

The seismic movement has induced a large spectrum perturbation signal in the microbarometers (Fig. 8). At PLO2 station the seismic movement induced the movement of microbarometer, visible as a red dot in the spectrogram, at about 4 Hz (Fig. 9). In this plots, the earthquake appears at second 2900. The spectrogram of the infrasonic signals in the hour in which the earthquake took place reveals the moment of the seismic movement occurrence. The signal has a large spectrum, between 0.01Hz and 5Hz. This moment is visible on the spectrogram, at second 2900. It should be noted that the spectrum of the infrasonic signals shows an increased activity with approximately 40 minutes before the occurrence of the earthquake (around second 600) (Figs. 8 and 9).
There have been made investigations regarding the power density spectrum of the site’s ambiental noise. MBAZEL2007 microbarometers, equipped with simple wind-noise reduction systems, made of buried porous hoses, presents a good detection capability. This is illustrated by the PSD plots that have been made. These plots are showing not only a low background noise (even lower than the noise of the Chaparral sensors) but also reveal the presence of a peak at 0.2 Hz, which is generated by the global background infrasonic signal generated by the ocean swell (microbaroms). Noise PSD plots were performed on the three sites, in order to determine their noise characteristics and detection capability. These plots show that...
MBAZEL2007 microbarometers installed in the three locations have a noise better than -70 dB/1 Hz, relative to 1 Pa$^2$/Hz. The peaks around 0.2Hz represents the recording of the microbaroms, which constitute a background signal, produced by the ocean swell (Fig. 10).

Fig. 10. Noise PSD of the three infrasound monitoring stations PLO2, PLO3 and PLO4.
6. CONCLUSIONS

IOANE network is the first infrasound monitoring system installed in Romania by National Institute for Earth's Physics and AZEL – Designing Group S.R.L. After one year of monitoring we have made some interesting observations regarding its capability to detect events that produce infrasonic fluctuations of the atmosphere. As a first step toward an accurate measuring system, this network proved its utility in monitoring local and regional acoustic events as thunderstorms and preseismic phenomena.

As IOANE is a part of the multidisciplinary geophysical monitoring network MEMFIS, it can help to understand the mechanism by which infrasonic fluctuations of the atmosphere are related to other geophysical events as fluctuations of the geomagnetic field or atmospheric electrical field are.

Until now, the network provided reliable data which helped to understand the propagation of infrasounds through the atmosphere, but future developments of the data processing techniques are still necessary.

REFERENCES

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