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IDENTIFICATION OF NEAR QUARRY BLASTS USING PLOŞTINA INFRASOUND ARRAY – CASE STUDY FOR DOBROGEA (SOUTH-EAST ROMANIA)

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Abstract. The Infrasound Ploştina Array (IPLOR) is an acoustic array of 2.5 km aperture designed and installed in 2009 in the epicentral Vrancea seismogenic area, at the Carpathian Arc bend in Romania. The Network belongs to the National Institute for Earth Physics (NIEP) and includes 4 infrasound stations and 7 seismic stations. The goal of the present study is to analyze the capacity of the infrasound array of Ploştina (Romania) to detect and discriminate quarry blasts from local earthquakes. More than 50% of the shallow seismicity annually recorded in Romania is coming from industrial blasts. Ploştina network description and signal processing procedures are discussed in Section 2, Data and Methods. The results of this study are presented in Section 3, and the final discussions conclusions in the end.

Key words: infrasound, microbarometer.

1. INTRODUCTION

Infrasound waves are acoustic waves with frequency range below 20 Hz. They travel at sound speed, 343 m/s at 20 °C in air. Infrasound propagation depends primarily on the composition of the atmosphere, wind direction and thermal structure of the atmosphere [1]. The presence of infrasound signals is dependent on diurnal and seasonal fluctuations of the wind [1]. Fluctuations in the pressure of the sound waves are generally small in relation to the ambient pressure.

Regular infrasound detections started basically in the 1950s and 1960s during the nuclear test era. However, the infrasound observations have been gaining importance over the past 15 years since a global network microbarometer arrays was developed as a part of the verification measures for a Comprehensive Nuclear Test-Ban Treaty (CTBT) and infrasound was chosen as one of the monitoring techniques for the CTBT (*e.g.*, [2, 3]). Nowadays, the observation of infrasound is performed with various instruments by scientists around the world (see [4] for a comprehensive overview).

In addition, attention for low-frequency (< 20 Hz) acoustic wave propagation through the atmosphere has become greater since besides nuclear explosion monitoring, infrasound proved to be able to detect other natural and artificial sources, of eruptive or explosive origin. These are for example man-made signatures: like mining blasts, rocket starts, supersonic flights, etc. [5, 6, 7, 8, 9], geo-hazards: meteoroids, volcanic activity, earthquakes, etc. [10, 11, 12, 13], and meteorological sources: severe weather, thunderstorms and microbaroms [14, 15, 16]. Infrasound observations furthermore allow modeling advances which enable accurate prediction on infrasonic propagation paths (*e.g.*, [17, 18, 19]) and on dynamics and state of the atmosphere itself [9, 20]. They contribute also to investigations on specific events, such as polar aurora [21, 22, 23], solar eclipses [24] or glaciers.

Most infrasound signals recorded by IMS networks (International Monitoring System) come from sources near the Earth's surface. Examples of sources are explosive nuclear tests (*e.g.*, [25]), quarries and mine explosions and trucks explosive (bomb trap) [26].

The goal of the present study is to analyze the capacity of the infrasound array of Ploştina (Romania) to detect and discriminate quarry blasts from local earthquakes. More than 50% of the shallow seismicity annually recorded in Romania is coming from industrial blasts. Therefore, the discrimination of man-made events from tectonic events is of great interest to assess regional and national catalogues. Our investigation is focused on a particular region (Dobrogea, in the south-east Romania) where a few tens of quarry blast sites are presently active.

Ploştina network description and signal processing procedures are discussed in Section 2, Data and Methods. The results of this study are presented in Section 3, and the final discussions conclusions in the end.

2. DATA AND METHODS

The Infrasound Ploştina Array (IPLOR) is an acoustic array of 2.5 km aperture designed and installed in 2009 in the epicentral Vrancea seismogenic area, at the Carpathian Arc bend in Romania (Fig. 1). The Vrancea region is of highest interest from seismological point of view taking into account the great concentration of seismic activity generated constantly in a well-define seismogenic volume (*e.g.*, [27]).

The Network belongs to the National Institute for Earth Physics (NIEP) and includes 4 infrasound stations (IPH4, IPH5, IPH6, IPH7) and 7 seismic stations (PLOR1, PLOR2, PLOR3, PLOR4, PLOR5, PLOR6, PLOR7) [28]. In sites 4, 5, 6 and 7, infrasound sensors are collocated with the seismic ones (Fig. 2). Stations 2, 3 and 4 are also equipped with 3 C magnetometers. An electric field sensor is operating at the central station (4) to measure the static electric field generated by storms (lightning). The same station is equipped also with a weather station.

Fig. 1 – Location of the infrasound station Ploştina array, National Data Center (Măgurele) and Dobrogea (dashed area) (http://google earth.com).

Data are continuously recorded at Plostina Seismic Observatory and transmitted in real time by dedicated lines to NIEP, where specialized programs are processing them. Communication is done *via* an optical fiber using TCP/IP to Purchase Local Centre located at Vrincioaia Observatory (located at about 7 km SE of Ploştina) and from there to the National Data Center at Măgurele.

Data recorded with IPLOR network are automatically converted using a program based on the PMCC algorithm (progressive multi-channel correlation method). So far, the experience in Romania in detecting and discriminating quarry blast events from seismic events on the basis of infrasound observation and processing is limited. Integration of these data into current monitoring and research is growing nowadays taking into account their integration into a broader system for warning natural and man-made hazards.

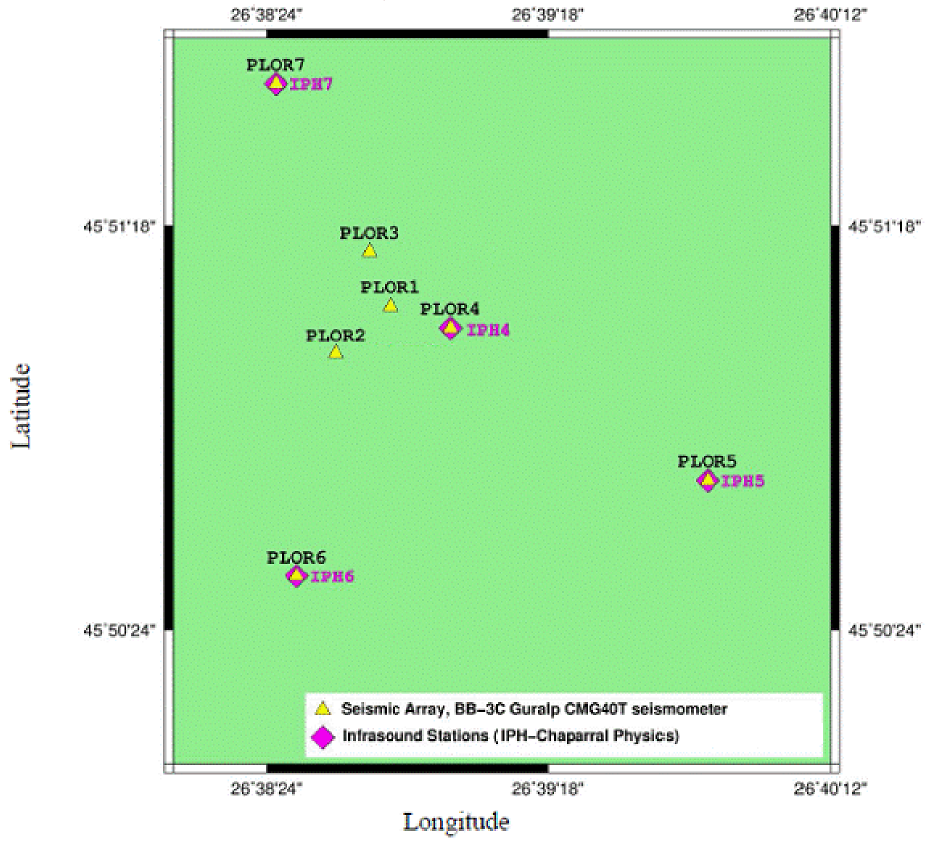


Fig. 2 – Seismo-acoustic array configuration at Ploştina [29].

The study region selected for the present work (Dobrogea) is characterized by a low to moderate seismic activity and a high rate of events coming from quarry blasts. There are more than 40 quarries in the region (Fig. 3), located at about 200 km distance from Ploştina.

For this study we selected and analyzed the events recorded during 2011 in the Romplus catalogue [30] that took place in Dobrogea region – 188 events in total with magnitude between 1.9 and 3.2 (Fig. 3). Taking into account the characteristics (frequency range between 0.002 and 20 Hz,) of the infrasound sensors, the IPLOR array was proven to be effective in detecting signals produced by quarry and mine blasts. To discriminate natural from artificial events we used both infrasound and seismic networks.

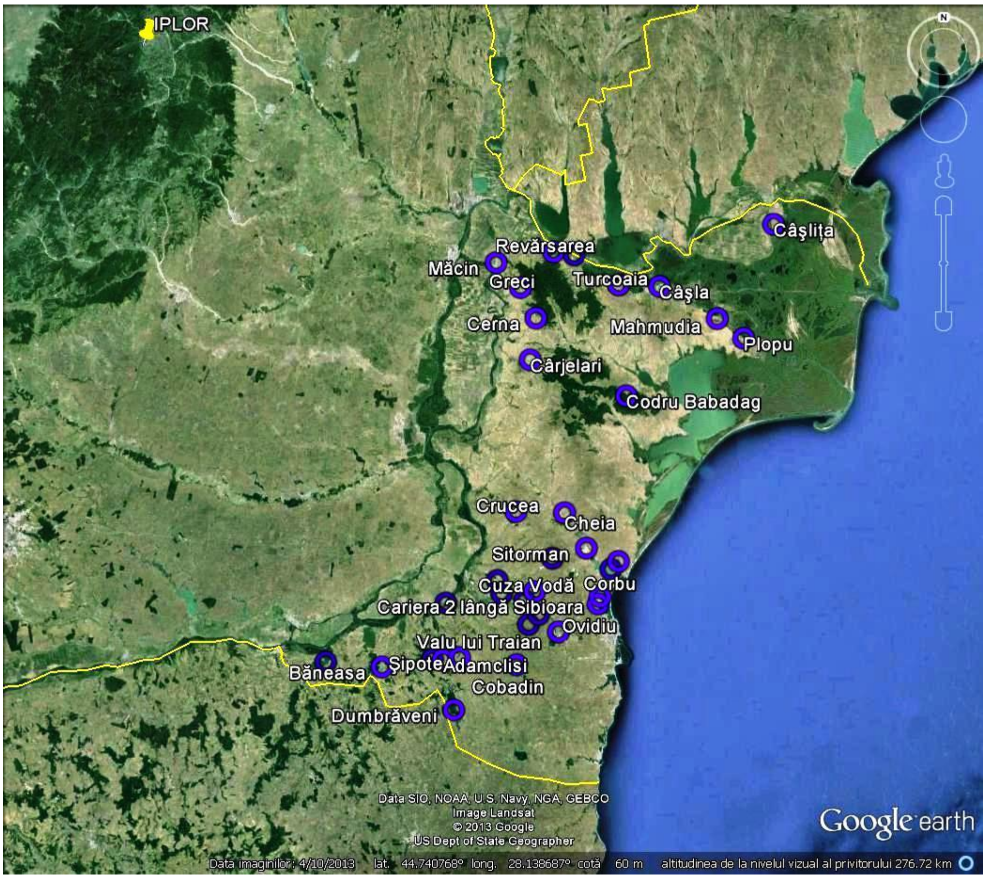


Fig. 3 – Location of mines and quarries in the Dobrogea region and epicenters of the events recorded in 2011 (http://google earth.com).

Distribution of the catalogue events as a function of hour and working day suggests a strong contribution from artificial events (Fig. 4).

The seismo-acoustic analysis was carried out as follows:

(1) first of all, we detected the infrasound signals and estimated automatically their characteristics (back-azimuth, speed, frequency content) using a DFX-PMCC detector to this purpose [31];

(2) starting from the catalogue data (time origin, azimuth and epicentral distance to Ploştina) we selected working windows considered acceptable relatively to the errors and we looked for the events that were detected within these windows. The parameters taken into consideration are the distance source – PLOR, the back-azimuth and the travel time (or propagation velocity).

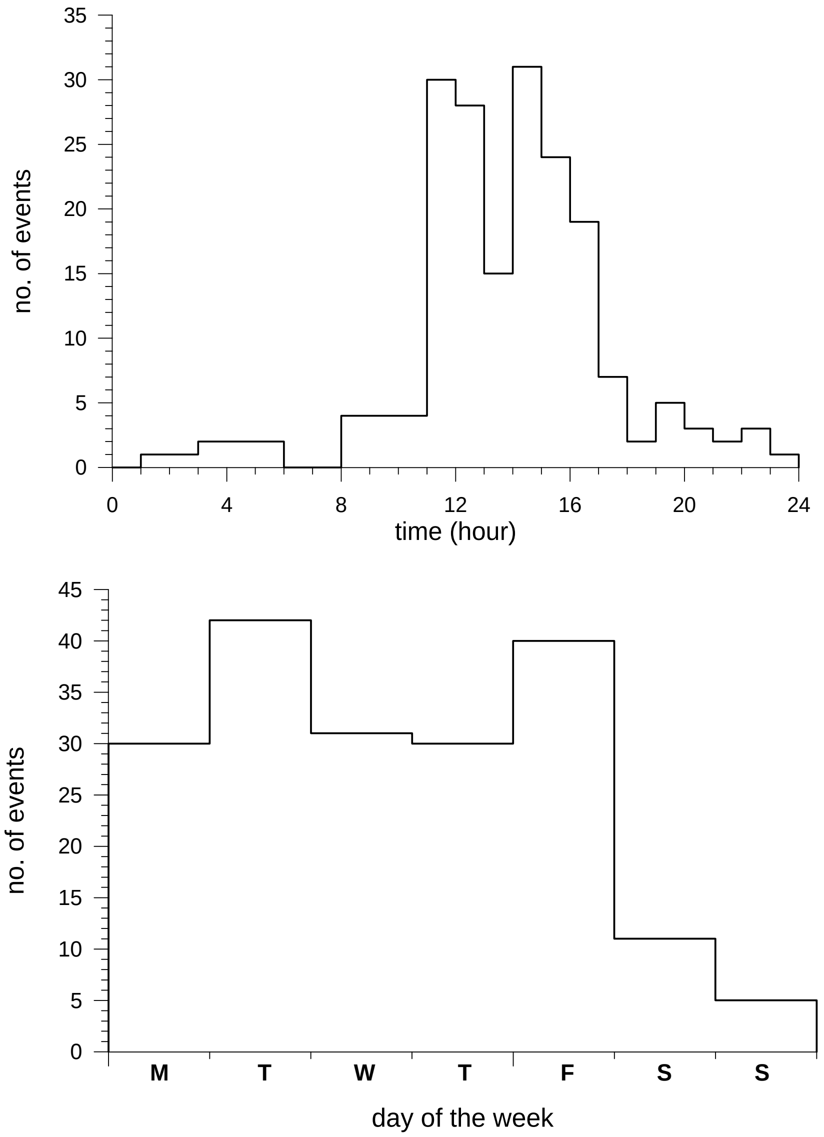


Fig. 4 – Distribution of events occurred in 2011 in Dobrogea (Romplus catalogue data) as a function of hour (top) and day of the week (bottom).

An event is considered to be an explosion if its parameters are included in the above mentioned windows, respectively the back-azimuth and the propagation velocity correspond to those of the sound waves. Once identified as explosion, the signal is processed with the "beamfit" technique [32, 33] in order to evaluate the velocity and the back azimuth of the wave within the window previously identified by the array.

3. RESULTS AND DISCUSSION

After processing and correlating all the data recorded by the four array stations, comparing them with the Romplus catalogue data, from a total of 1996 automatic detections in 2011 by IPLOR array as infrasound signals in the back-azimuth domain between 110^{o} and 150^{o}, 20 were associated with explosions in Dobrogea. They are given in Table 1 and represented in Fig. 5 by stars. Note, that none of the possible earthquakes recorded in Dobrogea in 2011 was identified by the infrasound network. Therefore, we conclude, in agreement with other similar investigations, that for low or moderate seismic events, infrasound signals are too weak to be detected by Ploştina network, while, in the case of comparable size explosions, sound waves are more intense and enable the detection of such events. In this way, we have at hand an efficient tool to discriminate quarry blasts from earthquakes.

Table 1

Data recorded by the IPLOR network in 2011 (Romplus catalog) that correlate with events in Dobrogea close to mines and quarries

Date	Origin time (hh:mm:ss)	Arrival time (hh:mm:ss)	Lat. (^{o}N)	Lon. (^{o}E)	Back-azimuth		Velocity (km/s)	Frequency (Hz)
					Expected	Observed		
Jan 20	9:10:11	9:17:28	45.14	28.26	123.95	121.555	0.342	1.48
Jan 20	11:39:10	11:50:24	44.19	28.37	145.69	143.096	0.349	2.66
Apr 13	11:12:42	11:23:42	44.35	28.56	134.41	137.297	0.356	2.37
May 12	14:15:52	14:25:39	44.49	28.31	138.33	138.625	0.340	2.48
May 12	14:37:44	14:47:27	44.58	28.42	137.27	134.825	0.341	1.31
May 30	9:26:04	9:36:23	44.37	28.32	142.63	140.801	0.355	1.77
May 31	11:27:43	11:37:50	45.08	29.05	114.85	113.686	0.358	2.18
Jun 16	8:26:37	8:33:52	45.12	28.23	125.11	122.774	0.353	1.36
Jul 01	14:48:16	14:55:40	45.08	28.24	122.34	124.008	0.340	1.61
Aug 02	13:50:40	14:00:00	44.61	28.32	139.16	135.850	0.364	1.59
Aug 02	14:46:39	14:55:57	44.65	28.37	135.41	134.059	0.352	0.94
Aug 04	16:44:47	16:52:49	44.97	28.33	127.07	126.072	0.352	1.45
Aug 09	8:32:03	8:39:23	45.11	28.25	123.16	122.791	0.352	1.21
Aug 09	9:27:07	9:37:05	45.07	29	114.59	114.445	0.348	1.46
Aug 10	10:17:10	10:24:21	45.11	28.2	124.49	123.650	0.330	1.29
Aug 17	9:58:38	10:08:55	45.11	29.12	115.64	112.219	0.341	1.63
Aug 25	12:48:05	12:55:24	45.21	28.33	117.85	117.901	0.358	1.33
Aug 31	13:09:26	13:19:24	44.53	28.43	152.15	135.753	0.344	1.53
Sep 05	13:57:13	14:05:34	45.18	28.61	116.00	115.269	0.350	1.23
Sep 08	8:34:22	8:41:20	45.1	28.12	122.20	125.465	0.340	2.19

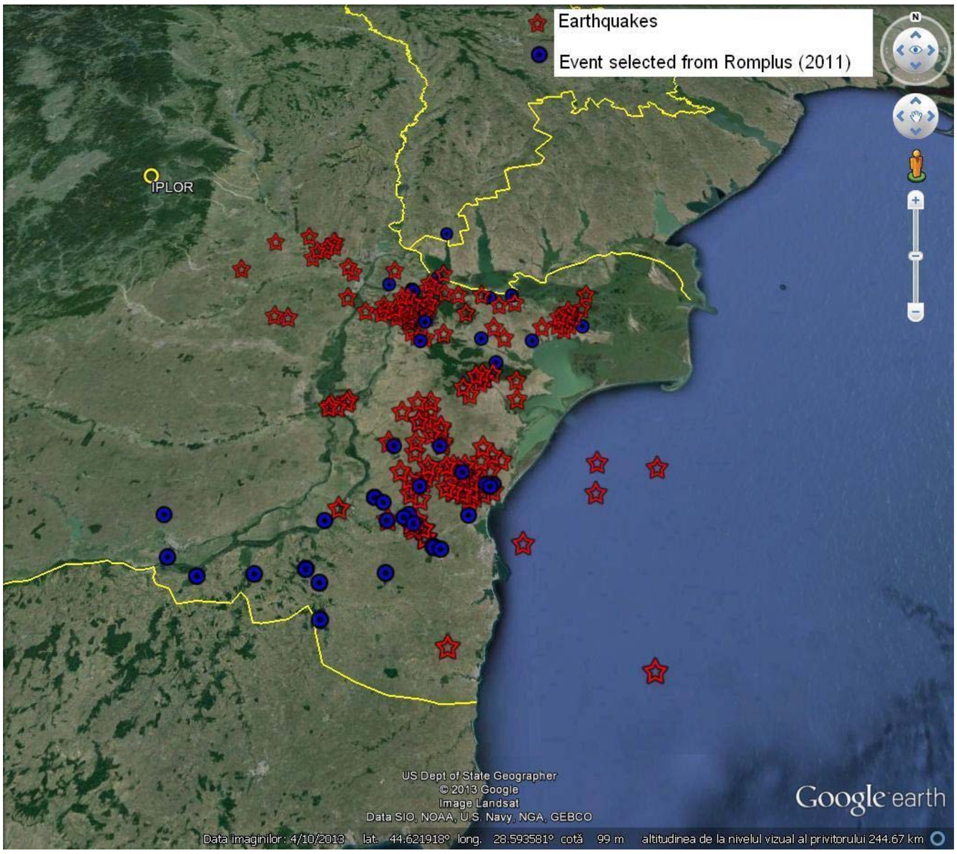


Fig. 5 – Events occurred in 2011 in Dobrogea and identified at IPLOR as explosions (http://google earth.com).

The back-azimuth values (expected and observed) for IPLOR are shown in Fig. 6.

The distribution of events detected as explosions as a function of back azimuth (Fig. 7) emphasizes three groups of events: around 113° back azimuth (quarries in Greci–Mahmudia region), 124° (quarries in Turcoaia–Mircea Voda region) and 134° (associated with a large group of quarries, as can be seen in Fig. 3).

To illustrate graphically the results, we selected one of 21 events the printed version and three events for the on-line version. Four diagrams are presented for each event (Fig. 8): (a) window with the automatic detection and recorded infrasound signal on the selected four channels at Ploştina, (b) infrasonic signal spectrogram recorded at IPH4 channel, (c) seismogram (velocity) recorded by the closest station to epicenter, (d) signal spectrogram at the same station.

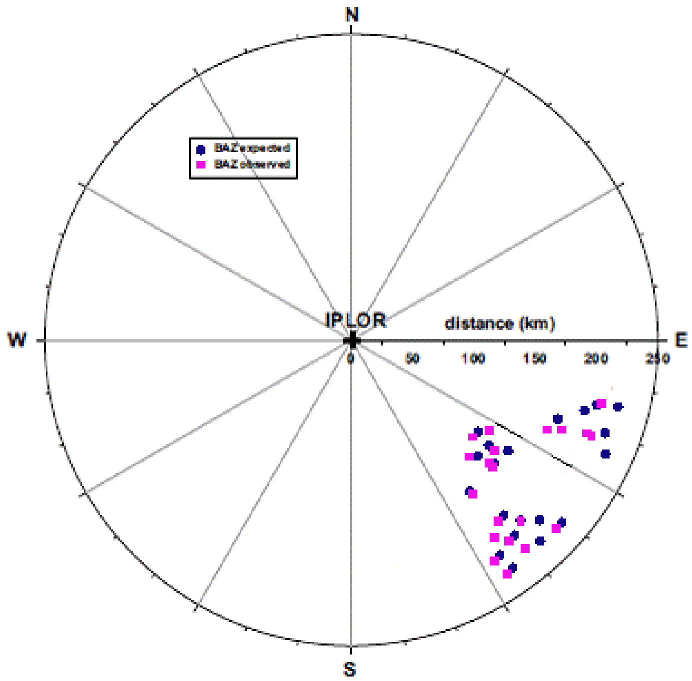


Fig. 6 – Back azimuth distribution for computed (blue) and observed (red) values [29].

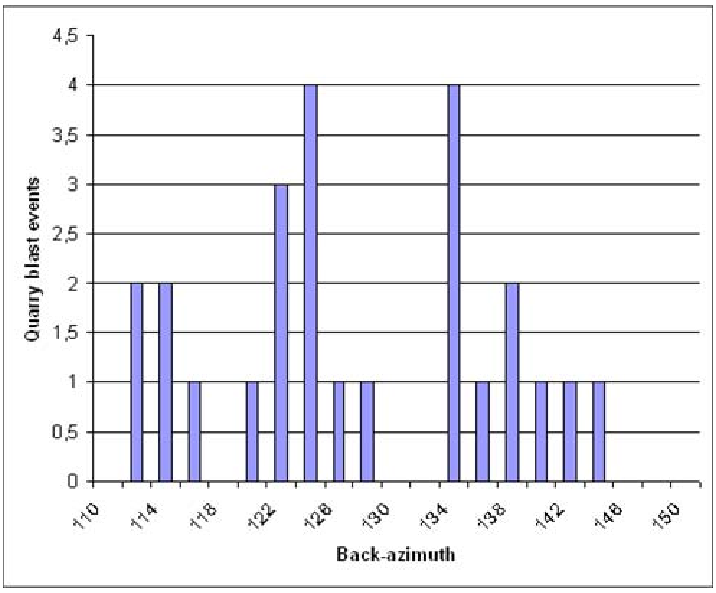
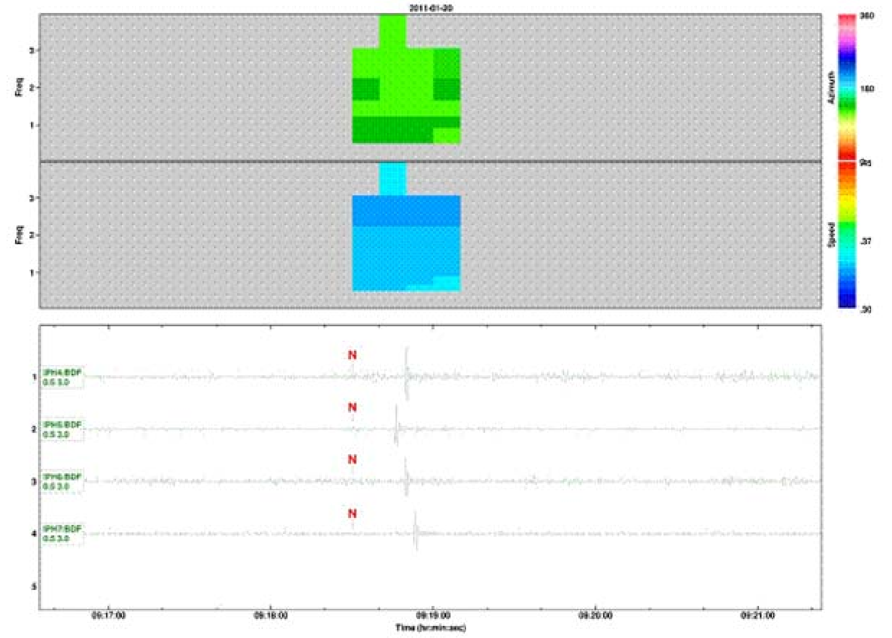
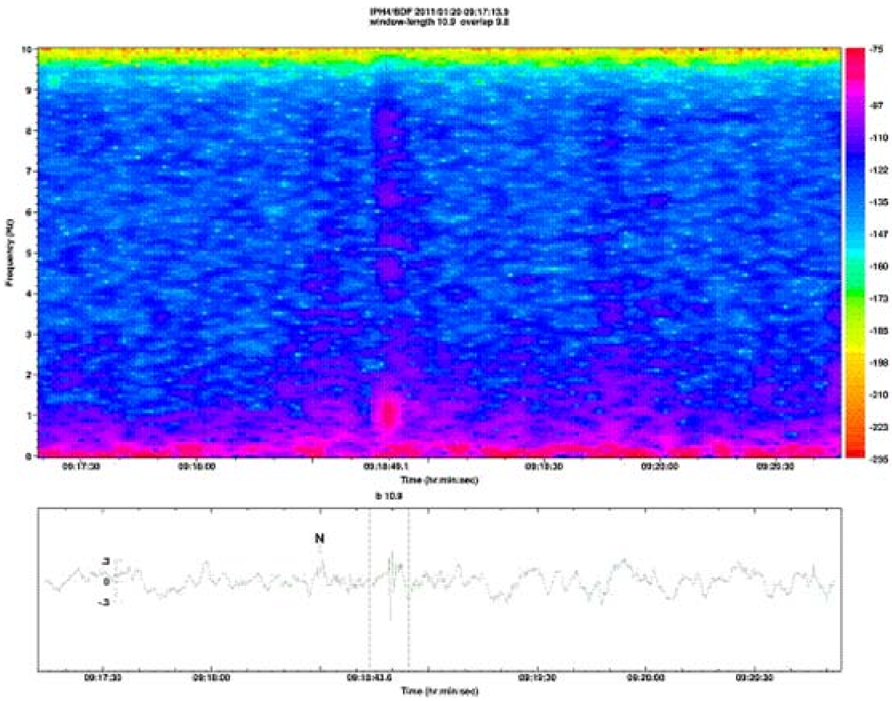


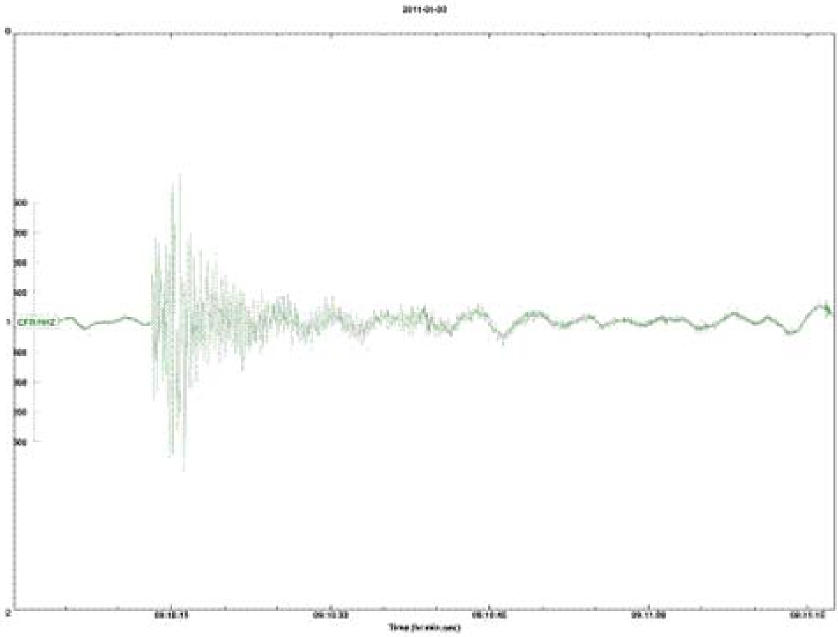
Fig. 7 – Distribution of events occurred in 2011 in Dobrogea and detected by PMCC algorithm as quarry blasts.



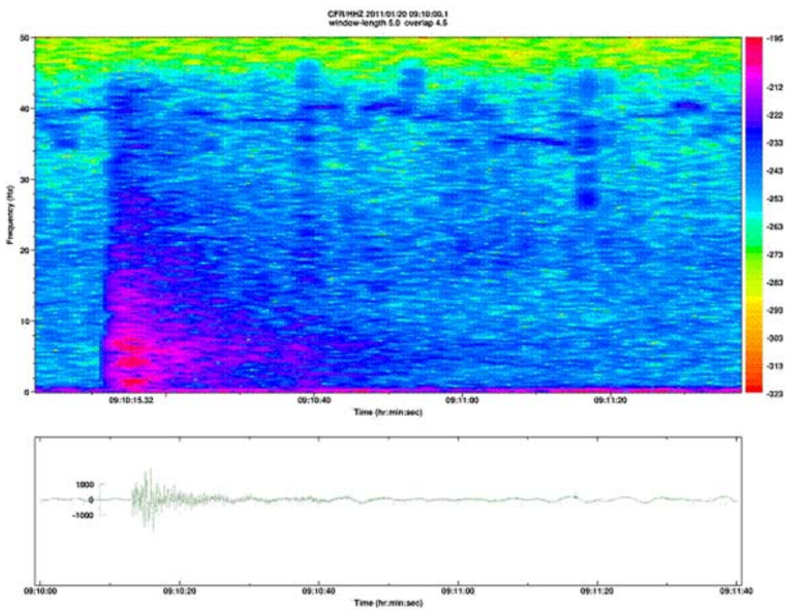
(a)



(b)



(c)



(d)

Fig. 8 – The event of January 20, 2011, 9:10:11, identified as quarry blast at Greci 2 site.
The seismogram (c) is velocity vertical component at CFR seismological station.
The amplitude scale in the spectrograms (b) and (d) is in nm.

A few specific features are coming out after analyzing our results:

(1) The travel time for the sound to propagate from epicenter to array site (difference between columns 3 and 2 in Table 1) correlates very well with the distance between them: < 7.4 min > for the group of quarries located close to CFR station and < 10 min > for the group of quarries located close to TLCR station and the group of quarries located close to TIRR station (< *a* > means average value of *a*).

(2) Speed value and frequency seems to be roughly independent on quarry site location.

(3) Infrasound signal amplitude correlates with distance.

(4) In many cases, the infrasound signal consists in two phases, shifted in time by 10 to 20 s. The first coming signal is in all cases of lower amplitude.

4. CONCLUSIONS

The Dobrogea region, located in South-East Romania, is one of the most active areas in the country as concerns the industrial explosions activity. Some seismic activity is also generated there, overlapping roughly the same area (Peceneaga-Camena fault or Sfântu Gheorghe fault as examples). For this reason, the discrimination between earthquakes and explosions is of highest interest in this region.

Processing infrasound data recoded by Ploştina array in Vrancea, at about 200 km distance from Dobrogea sites, we tested the capacity of these data to detect acoustic signals generated by mining blasts in Dobrogea. Since these signals are of short period (0.4–1.0 s) and given the characteristics of infrasound sensors (frequency range, sensitivity) installed in Ploştina array, identification and characterization of infrasound signals produced by quarries and mines proved to be applicable and useful for future investigations, despite the generally small amplitude of the signals.

For this stage of the work, the key issue in discriminating artificial from seismic events is the lack of detectable infrasound signals for tectonic events of small-to-moderate size generated in Dobrogea. On the contrary, the explosions of similar size are partly detected by using multi-channel correlation algorithm and array processing techniques. In a future step, we shall combine acoustic and seismic data as recorded by Ploştina array in order to calibrate the detected signals and enhance the discrimination capability of the array. As a consequence, we shall apply this procedure to clean the Romplus earthquake catalogue [4] by separating artificial events from tectonic ones. The procedure may be also particularly important in identifying and monitoring the danger created by anthropogenic sources of pollution (chemical plants, nuclear power plants and power plants, refineries, mines).

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