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DETECTING ACCIDENTAL CHEMICAL EXPLOSIONS USING THE SEISMO-ACOUSTIC NETWORK OF PLOŞTINA, ROMANIA

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Abstract. The Infrasound Ploștina Array (IPLOR) is part of a seismo-acoustic array with 2.5 km aperture, designed and installed in 2009 in the epicentral Vrancea seismogenic area, at the Carpathian Arc bend in Romania. The array belongs to the National Institute for Earth Physics and includes four infrasound stations and seven seismic stations. The purpose of this study is to analyze the ability of Ploștina infrasound array to detect and discriminate accidental chemical explosions located at regional distances. Two recent chemical explosions produced in Cyprus (2011) and in South-eastern Bulgaria (2012) are investigated. The multi-channel correlation algorithm is applied for the identification and characterization of the infrasound signals generated by the two explosive events, as concerns back azimuth, propagation velocity and frequency content. By applying this approach, we prove the efficiency of Ploștina array in identifying and characterizing infrasound signals caused by accidental chemical explosions.

Key words: infrasound, Plostina array, chemical explosion.

1. INTRODUCTION

Infrasound monitoring has been selected as a standard technology for detecting possible nuclear explosions in accordance with the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty. Recently, infrasound observations have been also applied in scientific research for monitoring volcanic activities and accidental chemical explosions [1].

Infrasonic waves are generated by a large variety of natural and man-made sources [2]. Natural sources include meteors, auroras, convective storms and lightning, tornadoes, interacting large amplitude ocean waves, earthquakes, icequakes, landslides, avalanches, the calving of icebergs and glaciers, continuously erupting and explosive volcanoes, tsunamis, waterfalls and coastal surf. Man-made sources of infrasound include nuclear explosions, mining and other chemical explosions, the launch and re-entry of satellites, spacecraft and rockets, aircraft, industrial sources such as exhaust fumes from industrial plants, oil and gas refinery flares, hydroelectric dams, wind generators and other cultural sources [3].

Table 1 provides a list of the most important types of observed infrasonic waves, including their typical range of frequencies and maximum amplitudes.

Table 1

Characteristics of infrasound signals [4]

Infrasound source	**Frequency (Hz)**	**Amplitude observed (Pa)**	**Estimated distance sensing (km)**
Nuclear explosions in the atmosphere	0,002–20	>20	>20000
Mining explosions	0,05–20	~5	>5000
Chemical explosions	0,05–20	~10	>5000
Gas exhausts from industrial activities	1–20	~0,5	~1000
Volcanic erruptions	0,002–20	>20	>20000
Earthquakes	0,005–10	~4	>10000

Chemical explosions generate characteristic sharp-onset infrasonic waves. The signature of these events is generally similar to the signature observed from mining explosions. Many of these events are detected only at regional distances, but some larger accidental explosions have been detected at distances of more than 5,000 km [5, 6, 7].

The purpose of this study is to analyze the ability of Ploştina infrasound array to detect and discriminate accidental chemical explosions. To this aim, the recent chemical explosions produced in Cyprus (in 2011) and in southeastern Bulgaria (in 2012) are investigated.

2. OBSERVATION DATA

A seismo-acoustic network of 2.5 km aperture was installed in 2009 in Romania, in the Vrancea epicentral area by the National Institute for Earth Physics – NIEP (Fig. 1). The configuration of the Ploştina Infrasound Array (IPLOR) comprises seven seismic stations: PLOR1, PLOR2, PLOR3, PLOR4, PLOR5, PLOR6, PLOR7 and four infrasound stations: IPH4, IPH5, IPH6, IPH7 [8].

Fig. 1 – Seismo-acoustic network of Ploştina, Vrancea.

Data are continuously recorded and transmitted in real time by dedicated lines to the NIEP, where specialized programs of archiving and processing are operating. Communication is done via an optical fiber using TCP / IP from Vrincioaia Observatory (located at about 7 km SE of Ploştina) to the National Data Center belonging to NIEP.

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 events caused by accidental chemical explosions 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.

Since IPLOR has been operating, two accidental chemical explosions were recorded, one produced in the south-eastern Bulgaria, the other in Cyprus (Fig. 2). The first explosion occurred at an ammunition depot near Sliven on June 5, 2012, around 11:50 UTC and was recorded by IPLOR infrasound array. According to Nikolay Miloshev, Director of the Institute of Geophysics, Bulgarian Academy of Sciences, the most important of explosions had a magnitude of 1.5 on the Richter scale (Sofia News Agency [9]).

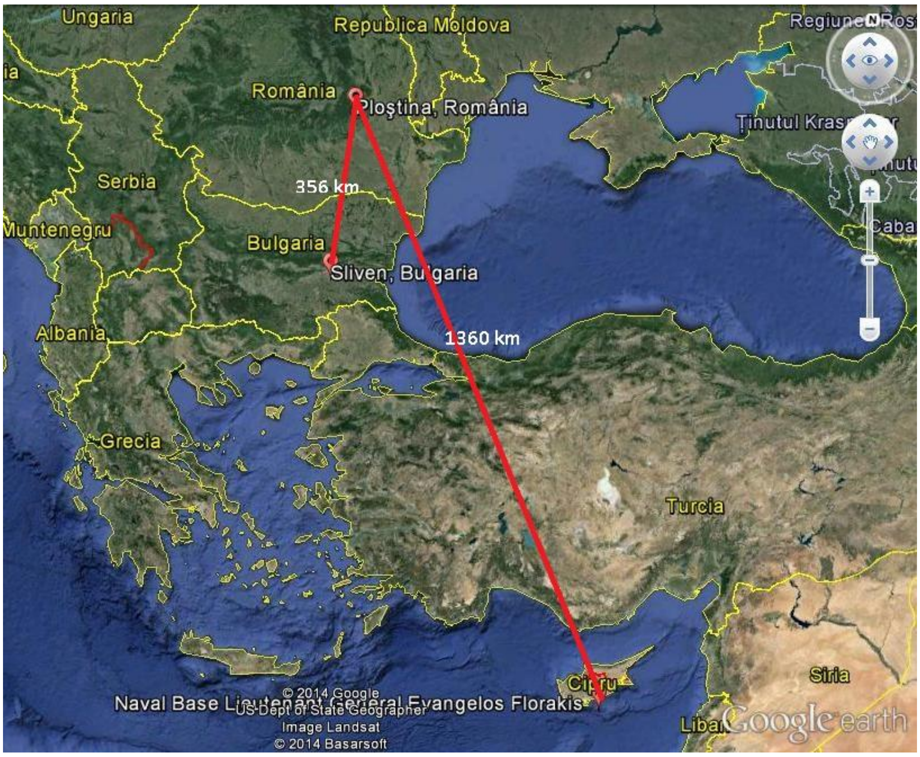


Fig. 2 – Location of the two explosions recorded by IPLOR array: Bulgaria (June 5, 2012, 11:50 UTC) and Cyprus (July 11, 2011, 03:40 UTC).

Fig. 3 – The explosion produced on June 5, 2012 at 11:50 UTC in southeastern Bulgaria.

All residents of the village Gorno Alexandrovo had to leave their homes. The access in the whole area within a radius of three kilometers was closed (Fig. 3).

Another industrial chemical explosion that occurred at an ammunition depot from Evangelos Florakis Naval Base (Cyprus) on 11 July 2011, at around 03:40 UTC was recorded by IPLOR infrasound array (Fig. 2).

3. DATA ANALYSIS

The infrasound signals are detected using a DFX-PMCC detector [10]. The detector is able to estimate automatically the back-azimuth, horizontal velocity and frequency content associated with the explosion signals.

The parameters taken into consideration are the distance source – IPLOR, the back-azimuth and the travel time (or propagation velocity).

The events corresponding to the back-azimuth of the blast location in southeastern Bulgaria (back-azimuth between 180^o and 210^o) are represented with blue symbols. Time and coordinates of the chemical explosion are given in Table 2 together with the computed parameters.

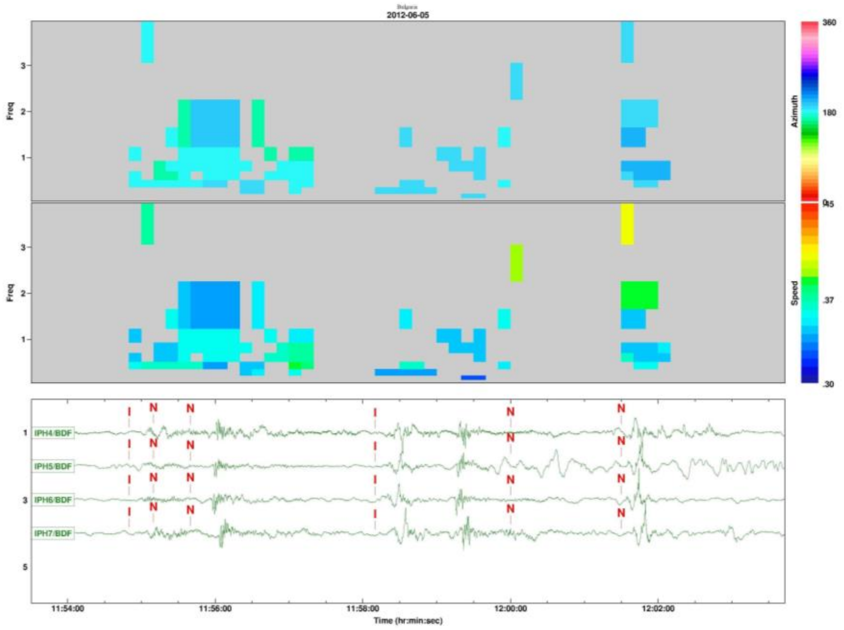
Table 2

Data recorded at infrasounds stations on 05th June 2012

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		
05 June 2012	11:40:00	11:56:02	42.64	26.66	179.75	181.93	0.362	0.73
		11:55:50				166.02	0.351	1.18
		11:55:55				194.75	0.340	1.65
		11:56:10				185.85	0.348	0.63

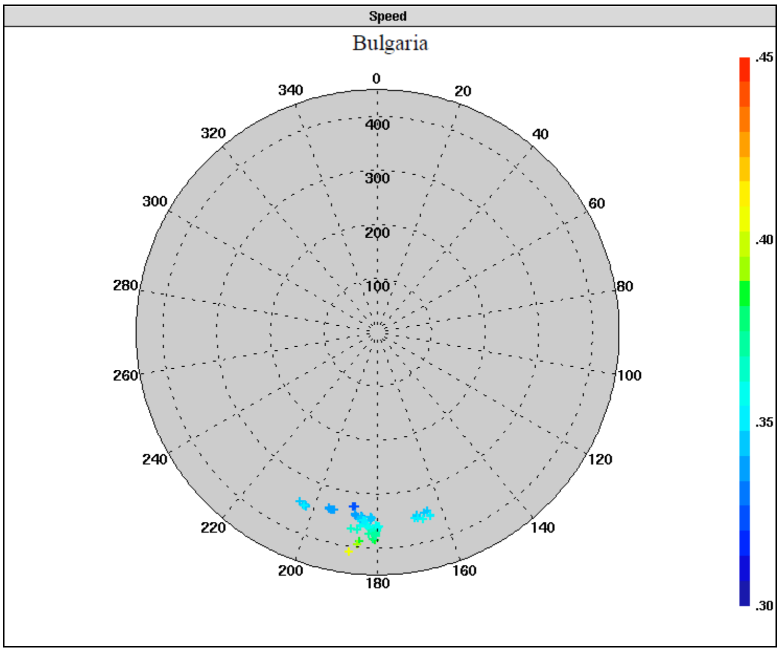
The results of automatically data processing for the event recorded on June 05, 2012 are shown in Fig. 4: a – waveform channels and infrasound detected signals; b – polar representation of the detection back-azimuth; c – spectrogram of the infrasonic waveforms computed for IPH4 channel.

The data recorded for the explosion of Cyprus are presented in Table 3 and shown in Fig. 5. A set of events was detected with back azimuth between 150^o and 170^o which locates the region where the explosion occurred.



2012-06-05
Freq
Azimuth
Speed
IPH4/BDF
IPH5/BDF
IPH6/BDF
IPH7/BDF
11:54:00
11:56:00
11:58:00
12:00:00
12:02:00
Time (hr:min:sec)

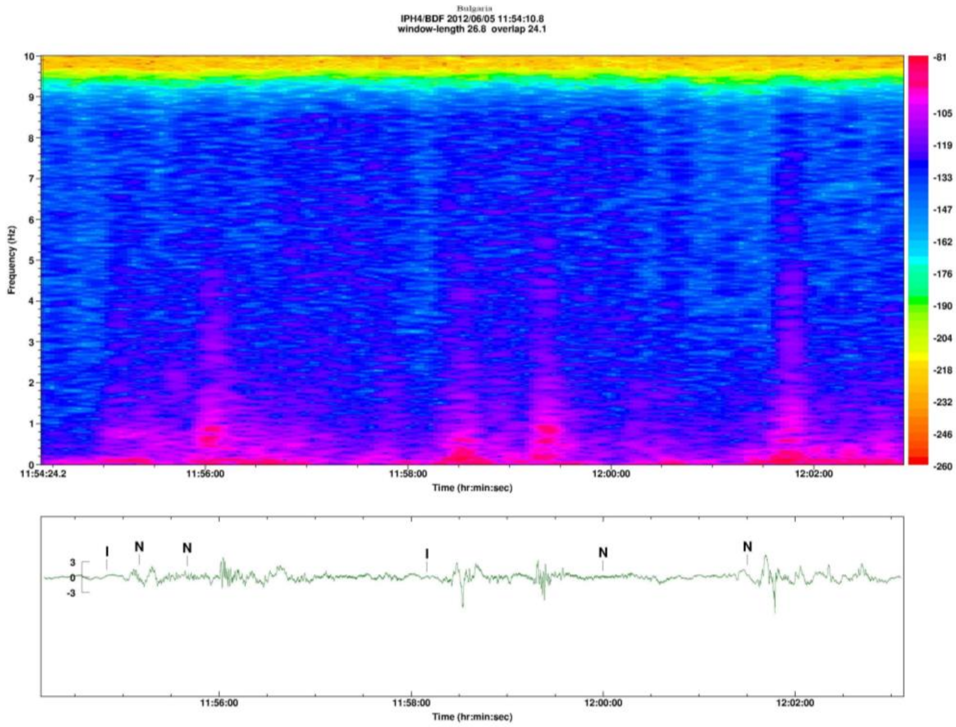
a)



Speed
Bulgaria
.45
.40
.35
.30

b)

Fig. 4



c)

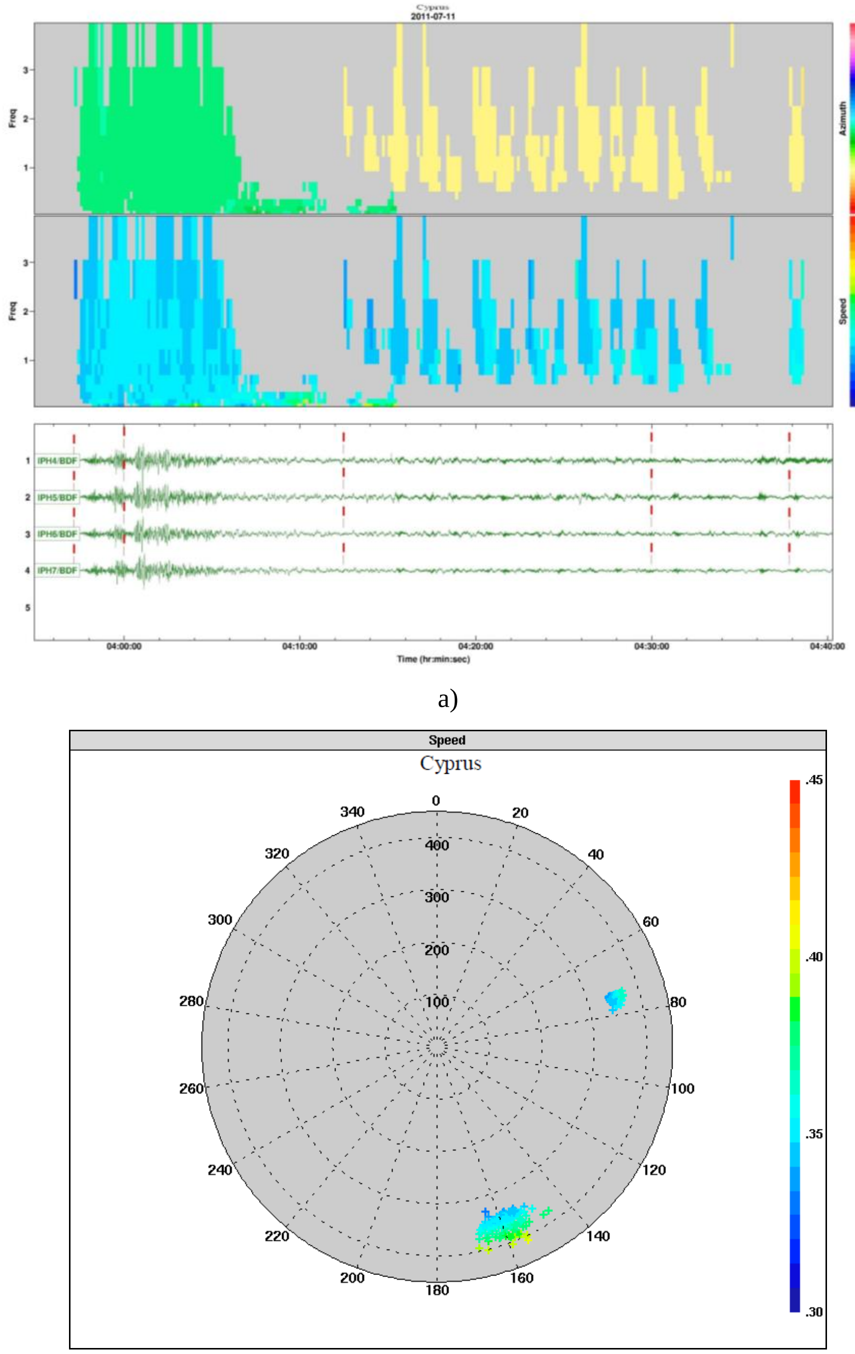
Fig. 4 (continued) – The event on 05 June 2012 11:40 UTC identified as chemical explosion at a munitions depot in southeastern Bulgaria: a) waveform channels and infrasound detected signals; b) polar representation of the detection back-azimuth; c) spectrogram of the infrasonic waveforms computed for IPH4 channel.

Table 3

Data recorded at IPLOR array on 11th July 2011

Date	Origin time (hh:mm:ss)	Arrival time (hh:mm:ss)	Lat. (°N)	Lon. (°E)	Back-azimuth		Velocity (km/s)	Frequency (Hz)
					Expected	Observed		
11 Jul 2011	03:35:00	03:51:40	35.13	33.43	165.75	168.97	0.354	1.61
		03:57:10				159.99	0.351	1.07
		04:00:00				157.93	0.356	0.82
		04:02:00				160.85	0.350	1.31

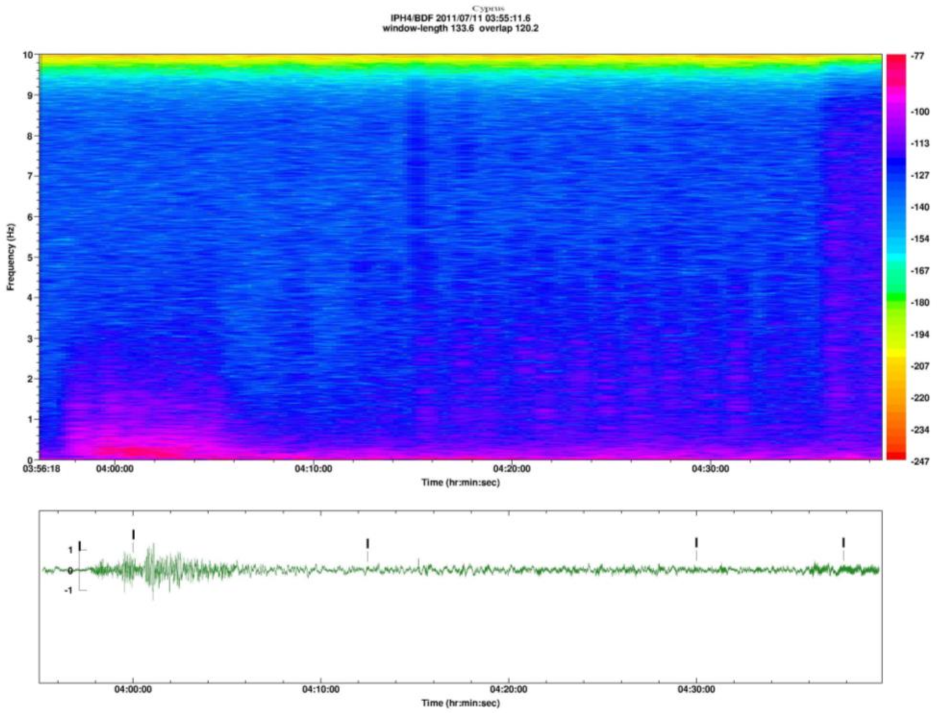
The results of automatically data processing for the event recorded on July 11, 2011 are shown in Fig. 5: a – waveform channels and infrasound detected signals; b – polar representation of the detection back-azimuth; c – spectrogram of the infrasonic waveforms computed for IPH4 channel.


Cyprus
2011-07-11
Freq
Azimuth
Speed
IPH4/BDF
IPH5/BDF
IPH6/BDF
IPH7/BDF
04:00:00
04:10:00
04:20:00
04:30:00
04:40:00
Time (hr:min:sec)
Speed
Cyprus
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
400
300
200
100
.45
.40
.35
.30

a)

b)

Fig. 5



c)

Fig. 5 (continued) – The event on 11July 2011 03:50 GMT identified as chemical explosion at a munitions depot in Cyprus: a) waveform channels and infrasound detected signals; b) polar representation of the detection back-azimuth; c) spectrogram of the infrasonic waveforms computed for IPH4 channel.

Results show that for the distance between Ploştina array and the explosions' locations in south-eastern Bulgaria (~356 km) and Cyprus (~1360 km), the generated sound waves were sufficiently intense to be well recorded. In both cases, several signals were identified during the considered time interval, representing multi-path phases and secondary successive blasts as well. As resulted from spectrograms, the characteristic frequency content of for the detected infrasound signals rangers between 0.5 and 3.0 Hz.

4. CONCLUSIONS

The main purpose of the paper is to test the capacity of the Ploştina infrasound array to detect acoustic signals generated by accidental chemical explosions occurred at regional distances (hundreds of kilometers). The recent chemical explosions produced in Cyprus (2011) and in South-eastern Bulgaria

(2012) are investigated. The infrasound signals are strong enough to be well recorded by the array and to be detected and categorized in terms of specific parameters.

The multi-channel correlation algorithm is applied for the identification and characterization of the infrasound signals generated by the two explosive events in Cyprus and Bulgaria. Taken into account the characteristics of the infrasound sensors (frequency range, sensitivity) and of the infrasound signals (back azimuth, propagation velocity, frequency content), Ploştina array proved to be efficient in identifying and characterizing infrasound signals caused by accidental chemical explosions.

By applying the procedures described in this paper, infrasound analysis turns out to be particularly important for monitoring dangerous events artificially coming from anthropogenic sources of pollution, such as chemical plants, nuclear power plants and power plants, refineries and mines.

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