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Detection of an explosion at the Kakhovka HPP dam by the Ukrainian geophysical network

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INTRODUCTION AND MAIN RESULTS

Verification of regional events is a key task for national monitoring systems. Ukraine's NDC demonstrated this capability by detecting the May 5, 2023 explosion at the Kakhovka HPP dam.

Joint seismic and infrasound analysis confirmed the explosive nature, localized the event, and provided objective data for investigation

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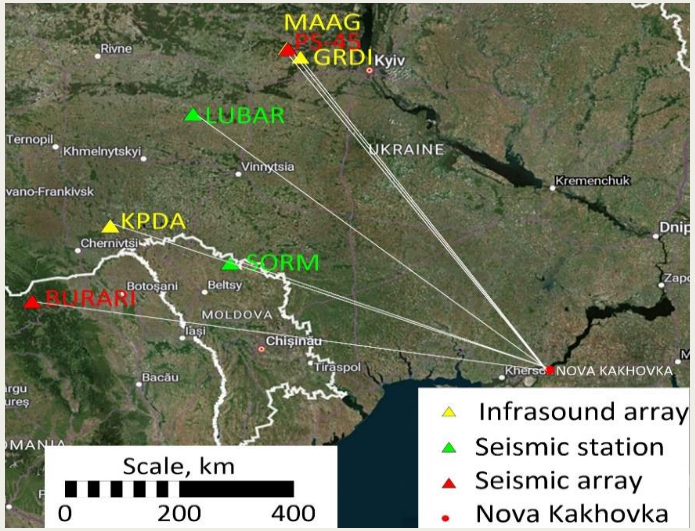
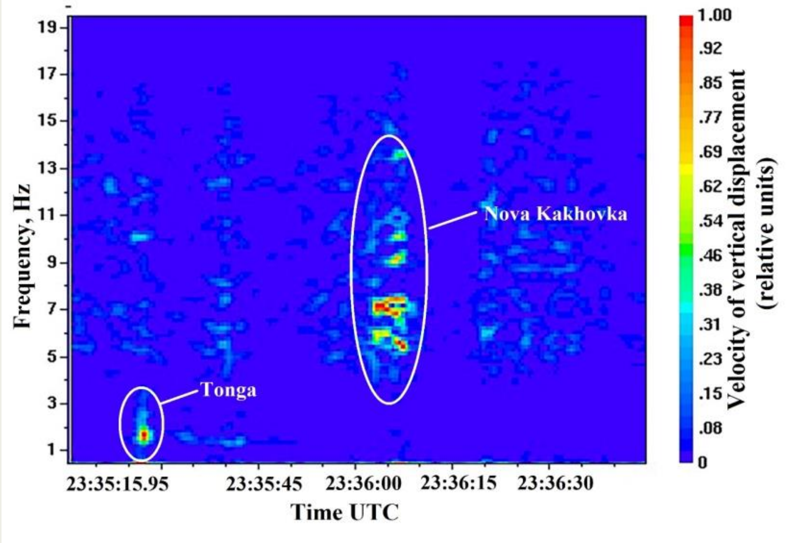
Introduction

On June 5, 2023, at 23:34:50 UTC, a seismic event was recorded by the Main Center of Special Monitoring (MCSM). The signal was registered by seismic arrays PS45 (Ukraine) and BURARI (Romania) and seismic stations SORM (Moldova) and LUBAR (Ukraine).

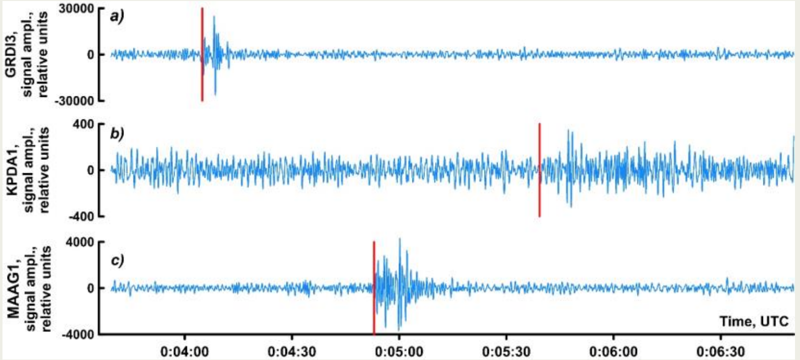


Determining the exact time of the recorded event posed challenges due to low energy, the limited number of seismic stations that detected it, and the overlapping of signals from different seismic events. At the PS45 seismic array, the signal for the seismic event registration overlapped with another seismic event (Tonga, 23:16:02, -19.4 -175.52, M=4.3). However, by employing spectral analysis and subsequent filtering in different frequency bands, we separate the local high-frequency signal and the low-frequency teleseismic signal..

Event Detection



Spectrogram of vertical channel AK01 of PS45 seismic array

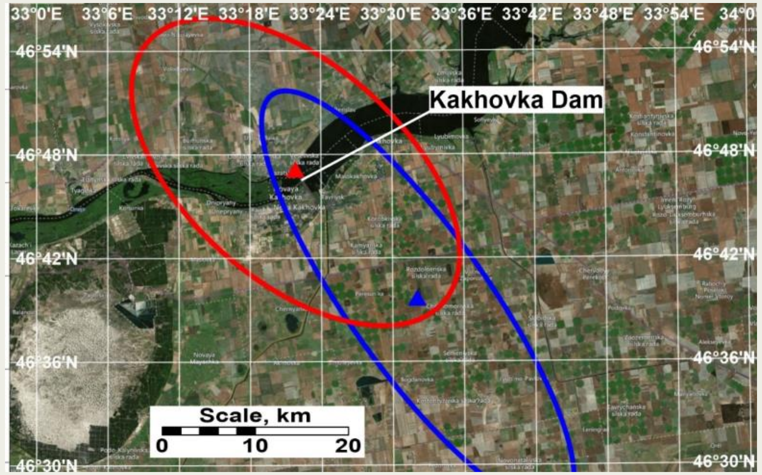


Signal waveforms on infrasound arrays. a) KPDA (Kamianets-Podilskyi); b) MAAG (Malyn); c) GRDI (Gorodok).

Event Location

Infrasound signals were registered using the infrasound arrays(3-4 microbarographs). The infrasound arrays KPDA (Kamyanets-Podilskyi), MAAG (Malyn), and GRDI (Gorodok) were used to calculate the coordinates..Signals from different sensors are compared using cross-correlation, which helps to determine the time delay in the signal registration between pairs of sensors.

The event`s epicenter was determined using the azimuths of the infrasound arrays. The calculated coordinates for the epicenter. In the Figure he position of the epicenter and its error ellipse are shown. The seismic (red) and infrasound (blue) methods placed the event's location within 19 km of each other. The difference is attributed to lower accuracy in infrasound measurements and the unfavorable geometry of the infrasound array locations.



Energy parameters were estimated from infrasound data using an empirical formula proposed by AFTAC (Air Force Technical Applications Center)[47]:

*Y(TNT)=2*T5.923.34* (5)

where *Y* – yield estimate in kilotons TNT; *T* – the period of the infrasound signal measured at the site of maximum amplitude.

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Seismic Yield Estimation

The energy of the registered event was determined according to the method tested in Ukraine. Energy estimation in TNT equivalent for seismic data is based on the earthquake energy class K equal to lg(E), where E is the energy of the earthquake (event) in joules. When determining the energy class of the event, the maximum amplitude of P- and S-waves was used:

$$K = 1.8 \lg(A_p + A_s) + \sigma(\Delta). \quad (1)$$

where: Ap and As – maximum amplitude P and S - waves in microns; σ(Δ) – calibration function for Ap + As in the range of distances from 10 to 3,000 km.

For this event, according to seismic records, it was established that Ap=0.61nm and As=0 nm. σ(Δ)=6.124 (the value obtained by the Rautian nomogram). Based on these values according to expression (1), the energy class of the event was K=5.74 (magnitude M=1). .

Statistical data on explosions in the northern and central regions of Ukraine were used to determine the relationship between energy class K and estimates of the power of explosions (estimated explosive yield) Y in TNT equivalent (kg of TNT). Such a relationship between energy class K and the power of explosions (yield estimate of explosions) Y has the form:

$$K = 1.5511 \lg(Y) + 1.2653 \quad (2)$$

which is equivalent to the following:

$$Y = 10^{((K-1.2653)/1.5511)} \quad (3)$$

For this event, the yield according to (4) Y = 767 kg TNT.

Infrasound Yield Estimation

Energy parameters were estimated from infrasound data using an empirical formula proposed by AFTAC (Air Force Technical Applications Center)

$$Y_{(TNT)} = 2 * \left(\frac{T}{5.92}\right)^{3.34} \quad (4)$$

where *Y* – yield estimate in kilotons TNT; *T* – the period of the infrasound signal measured at the site of maximum amplitude.

The prevailing periods for infrasound arrays were as follows: MAAG T=0.59s, KPDA T=0.55s, and GRDI T=0.63s. Based on Formula 5, the event energies were determined to be 903 kg of TNT for MAAG, 714 kg of TNT for KPDA, and 1,125 kg of TNT for GRDI. On average, this amounts to 914±170 kg of TNT. Seismic measurements indicated a similar value, which largely confirms the reliability of the results obtained from both methods.

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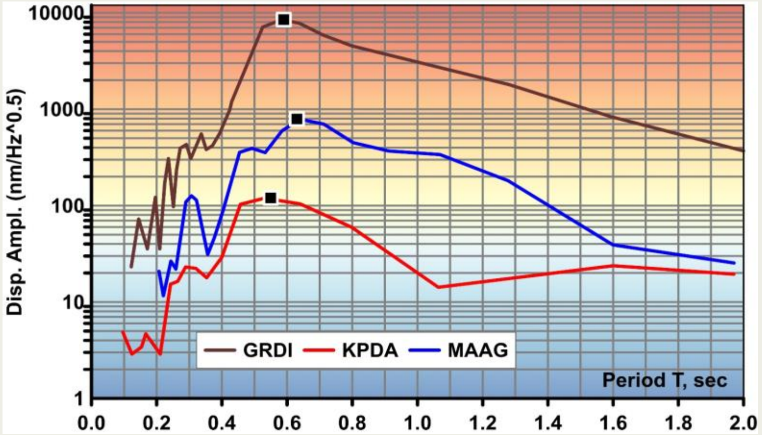

Conclusions

Therefore, the seismic and infrasound data are in good agreement with each other and allow us to speculate about an explosion.

It is important to note that natural weak earthquakes produce inherently weak infrasound signals. It is known that natural earthquakes with magnitudes (M) less than 3 are usually not detectable by infrasound. Given that the magnitude of the seismic event in question was M=1 (leading to an energy class K=1.8M+4=5.74), we can conclude that this event was not a natural weak earthquake.

Also, we can reject the idea that the seismic and infrasound signals were caused by a sudden release of water from the reservoir due to the dam being destroyed. When water is released from a dam, it creates low signal/noise ratio infrasound signals that last from several hours to several days. In the case of explosions, however, we observe a high signal-to-noise ratio and short-duration infrasonic signals. Similar observations are seen in the recorded seismograms, where clear P-wave introductions and rapid decays are followed by oscillations in a high-frequency range, characteristic of explosions.

The most important result of our work is the objective identification and localization of the event, confirmed through multi-technology analysis. This not only validates the effectiveness of Ukraine's NDC, but also showcases a methodology that can be adapted for nuclear event verification..