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Infrasound detection of meteors

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ABSTRACT

Meteorites that penetrate the atmosphere generate infrasound waves of very low frequency content. These waves can be detected even at large distances. In this study, we analyzed the infrasound waves produced by three meteors.

The October 7, 2008 TC3 meteor fell over the north Sudan Nubian Desert, the February 15, 2013 Russian fireball, and the February 6, 2016 Atlantic meteor near to the Brazil coast.

The signals of these three meteors were detected by the infrasound sensors of the International Monitoring System (IMS) of the Comprehensive Test Ban Treaty Organization (CTBTO). The progressive Multi Channel Technique is applied to the signals in order to locate these infrasound sources. Correlation of the recorded signals in the collocated elements of each array enables to calculate the delays at the different array element relative to a reference one as a way to estimate the azimuth and velocity of the coming infrasound signals. The meteorite infrasound signals show a sudden change in pressure with azimuth due to its track variation at different heights in the atmosphere. Due to movement of the source, a change in azimuth with time occurs. Our deduced locations correlate well with those obtained from the catalogues of the IDC of the CTBTO.

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1. Introduction

Sound waves in the atmosphere become audible to humans if the frequency is in the range of 20–20,000 Hz, and become inaudible for frequencies higher than 20,000 Hz or lower than 20 Hz. Sound waves are then called infrasound which is usually considered at 0.002 Hz (Evers, 2008). It is analogous to the low frequency light waves which are called infrared and invisible (Gossard and Hooke, 1975). Infrasound signals travel with the speed of sound; 343 m/s at 20 °C in air near to the Earth's surface. This velocity increases at higher temperatures, in a downwind situation, and vice versa. Furthermore, this velocity depends on the fundamental property of the material, which also holds for solids and fluids.

Meteors are considered as an important source of infrasound waves. Most meteors have a low luminosity and occur at high altitudes in the atmosphere. Only a fraction of meteoroids give rise to high luminosity meteors and called fireballs. Large cometary meteors are usually destroyed at very high altitudes over 80 km. Only meteoroids with high strength can give rise to deep penetrating fireballs that can produce explosions when the dynamic pressure is higher than the meteoroid strength. The infrasound signals resulting from these meteors have been recorded by the IMS of the CTBTO. Monitoring meteors is a common use of the huge facilities of this organization other than the verifications of the nuclear explosions. The October 7, 2008 TC3 meteor fell over the north Sudan Nubian Desert, the February 15, 2013 Russian fireball, and the February 6, 2016 Atlantic meteor near to the Brazil coast represent the three studied examples that have been recorded by the infrasound network of the IMS of the CTBTO.

The TC3 meteor which had fallen over the north Sudan in the Nubian Desert had been recorded in a far station; I32 Ke in Kenya. The Russian fireball is considered as the biggest infrasound event which had been recorded by the IMS. The blast was detected at 20 infrasound stations in the CTBTO's network. The Atlantic meteor which had fallen near to the Brazil coast has been recorded in the I27 De station located in the Antarctica at about 5000 km from the source.

In this study, we analyze the infrasound signals of these three meteors using the data recorded by the infrasound stations of

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the IMS in order to find their sources locations. This could be an important input for the evaluation of the atmospheric conditions. Locating infrasound sources represents a key target of the CTBTO. Our deduced locations will be correlated with those obtained from the catalogues of the IDC of the CTBTO.

2. Data source

All the waveforms data are obtained from the infrasound network of the IMS of CTBTO. This network consists of 60 infrasound stations distributed all over the world (Fig. 1). The stations list which are used in this study are listed in Table 1.

3. Data processing

Progressive multi-channel cross correlation (Cansi, 1995; Cansi and Klinger, 1997) is used to analyze the infrasound waves. It considers these waves as a set of plane waves, as the infrasound station consists of array of sensors. Therefore, the correlation function between the sensors can be computed and also can be used to differentiate between signals and noise.

The correlation function is used to calculate the propagation time of the wave between sensors i and j. For each sub-network (i, j, k), the sum of time delays $\Delta t_{ij} + \Delta t_{jk} + \Delta t_{ki}$ is computed. In case of a planar wave across the array, the closure relation $\Delta t_{ij} + \Delta t_{jk} + \Delta t_{ki} = 0$ should be obtained (Cansi and Klinger, 1997). In the presence of a background noise, the measured delays are the result of random phase combinations and the closure relation given earlier is no longer valid. The consistency of the set of delays obtained using all sensors is then defined as a mean quadratic residual of the closure relation, and detection is declared if the consistency value is below a given threshold (Le Pichon et al., 2010).

Table 1
Infrasound stations used in this study.

Station	Latitude	Longitude	Location
I31 Kz	50.406970°	58.034820°	Kazakhstan
I43 Ru	56.721360°	37.217590°	Russia
I32 Ke	−1.242160°	36.827210°	Kenya
I27 De	−70.701100°	−8.302910°	Antarctica

Some parameters can be computed from correlation; like apparent velocity and azimuth which are very useful to describe the infrasound waves. Apparent velocity can be easily computed using the locations of two sensors and the difference in arrival times between them. Using the delay time between all sensors, the azimuth and the apparent velocity across the array can be computed. The slowness vector which represents the wave propagation direction is obtained by combining the apparent velocity of the waveform signal across the elements of the array and the azimuth.

Assuming a homogeneous elastic medium, the wave front takes the same time to cover the distance between S_1 and S_2 as between the projection of the two sensors on the ray: S_1' and S_2'. So the time difference between the arrivals can be calculated by:

$$\Delta T_{12} = T_2 - T_1 = \frac{\overline{S_1' S_2'}}{v_a}, \quad (1)$$

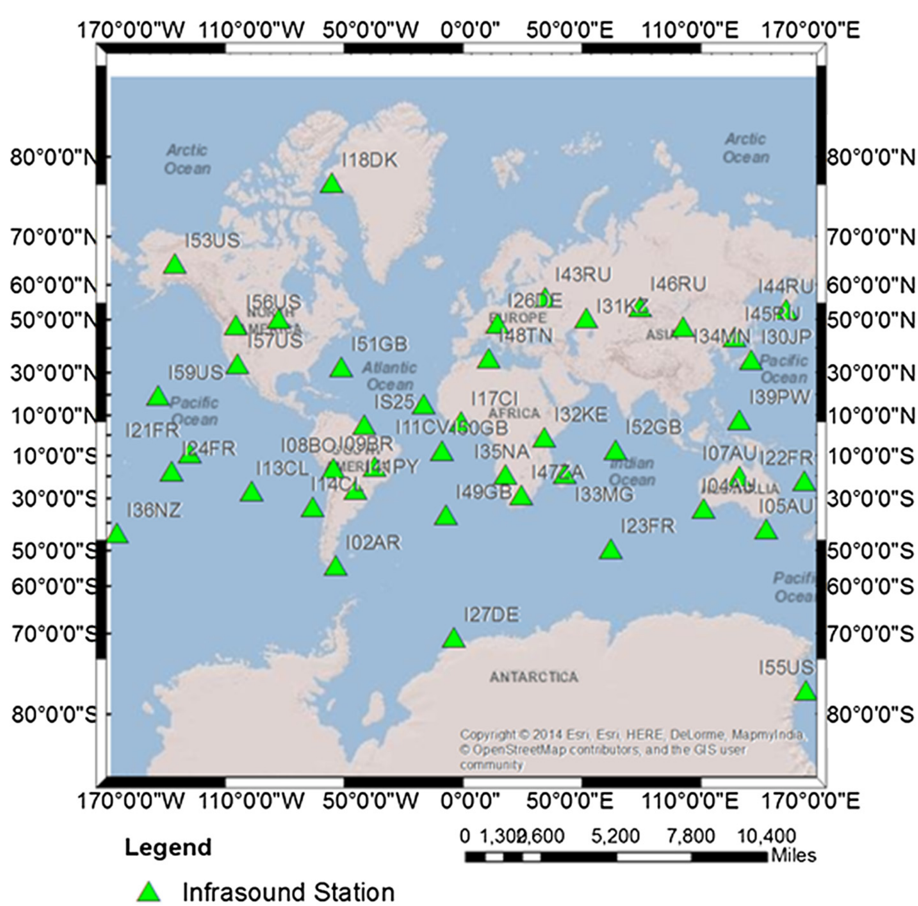

Fig. 1. The infrasound stations of International Monitoring System.

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