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Atmospheric infrasound observed during intense convective storms on 9–10 July 2011

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ABSTRACT

Atmospheric infrasound of frequencies 0.1–4 Hz observed in Central Europe during convective storms on 9–10 July 2011 from 21:00 to 02:57 UT was analysed. Azimuth of signal arrival followed positions of the convective storms passing over the region of measurements from south-west to north-east. Significant variations in azimuths of signal arrival (up to 105°) occurred periodically between 21:30 and 23:00 UT, at the time of maximum development of convective storms. Sprites (discharges in the mesosphere) seem to be potential sources of these infrasound signals. Stable infrasound arrivals were observed between 02:00 and 02:57 UT from direction where abating convective storms were located.

1. Introduction

Convective storms are known as an efficient source of infrasound over a wide frequency range. The general term "convective storm" includes convective processes and phenomena that occur during development of cumulonimbus clouds (Rezacova et al., 2007).

Potential infrasound sources in convective storms have been studied extensively. Goerke and Woodward (1966) found that the infrasound source is located at the leading edge of the convective storm and they associated the source with the region of maximum convective forces for the severe weather system on 25 July 1965. Further studies related infrasound generating mechanisms with vortex motions, turbulence, and electrical discharges in the atmosphere.

Infrasound frequencies of 0.02–0.1 Hz generated by convective storms was observed at the distances more than 1500 km from the source storm; infrasound signals of frequencies 0.5–20 Hz emitted by tornadoes were reported up to the distance of 300 km (Campus and Christie, 2010).

1.1. Infrasound generated by vortex motions

Bedard (2005) analysed observation of infrasound in the frequency range 0.5–5 Hz and discussed potential mechanisms of infrasound generation. He concludes that the signal is most likely generated by radial vibrations of vortex modelled by Abdullah (1966). The frequency of emitted infrasound depends mainly on the radius of the vortex core.

The model of Abdullah has been independently obtained by Schmitter (2010) and questioned by Schecter (2012). Also, Schecter et al. (2008) review a Rossby wave model of vortex sound radiation. The vortex infrasound radiation process is an area of active research.

The tornado-boundary-layer-surface interaction model of Tatom et al. (1995) can explain generation of infrasound and audible sound of frequencies of the order of several Hz and tens of Hz.

The co-rotating vortex model (Powell, 1964; Georges, 1976; Mitchell et al., 1992) predicts frequencies lower than 0.5 Hz. The frequency of infrasound emitted by co-rotating vortices is twice the frequency of rotation. If more than two vortices co-rotate, higher frequencies will be generated. Bedard (2005) refers to Thompson (1968) and Morikawa and Swenson (1971) and states that system of up to six co-rotating vortices can be stable.

Bedard (2005) reports two significant hailstorms that did not generate acoustic signals in the frequency band 0.5–2.5 Hz. No tornadoes, mesocyclones, or funnels were observed in these storms. Bedard (2005) concludes that the presence of vortex motions may be essential for generation of severe weather infrasound of frequencies near 1 Hz.

1.2. Infrasound generated by turbulence

Akhalkatsi and Gogoberidze (2009, 2011) studied turbulence in saturated moist air as a potential source of infrasound of broad and smooth spectra. They suggested that infrasound generating

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mechanism in strong convective storms is a monopole source related to heat production during condensation of moisture. High acoustic power of the source is connected with low LCL (lifting condensation level) heights and high values of CAPE (convective available potential energy). The characteristic frequencies of acoustic waves emitted by this monopole source are of the order of tenths of Hz.

1.3. Infrasound generated by sprites

Farges and Blanc (2010) reported infrasound events characterised by large variations in azimuth of signal arrival extending from 90° to 150°. The azimuth variations were accompanied by changes of signal inclination in the range of 10–60°. The events were of duration of about 1 min. The authors used infrasound inversion method and associated the signals with sprites. The infrasound sources were located at altitudes of 40–100 km and their horizontal extents were from 75 to 150 km. Sprites are triggered by lightning discharges with positive polarity. According to Soula et al. (2009), sprites occur when the ratio between positive cloud-to-ground discharges (CG+) and negative cloud-to-ground discharges (CG-) increases. Liszka (2004) found that chirp spectra (frequency of the signal changes in time) are characteristic for signals from sprites. Farges et al. (2005) explains the chirp spectra in terms of the combined effect of the source size and the thermospheric filtering of infrasound. Infrasonic chirps occur in a broad frequency range of 0.5–8 Hz (Liszka and Hobara, 2006).

1.4. Infrasound generated by lightning discharges

Arechiga et al. (2011) analysed infrasound pulses in thunderstorms and found good agreement between the position of acoustic sources localised from infrasound measurements and the position of lightning channels obtained from Lightning Mapping Array (LMA). Johnson et al. (2011) found that infrasound of higher frequencies (4–40 Hz) captures the source region measured by LMA more precisely than low frequency infrasound (1–10 Hz). The authors suggest that LMA and infrasound detections may complement each other when studying processes in the discharge. Assink et al. (2008) studied infrasound signals from lightning. They found association between shock waves and cloud-to-ground discharges that occurred up to the distance of 50 km from the infrasound measurement site. Spectra of observed shock waves were mostly in the range 1–5 Hz. Similar results for infrasound signals from cloud-to-ground discharges were obtained by Farges and Blanc (2010). Liszka (2008) also describes signals of short duration and of limited extent of arrival azimuth that were generated by distant cloud-to-ground discharges and adds that cloud-to-cloud discharges can produce signals of duration up to 30 s arriving from extended gradually changing azimuths. Chum et al. (2013) observed narrow infrasound pulses of duration of 1–2 s that occurred 11–50 s after rapid changes of electrostatic field at the site of microbarograph measurements. The pulses always had a form of compression followed by a decompression phase. The authors related them to cloud-to-cloud discharges and discussed possible generation mechanisms.

In this paper, we present observations of infrasound in the Czech Republic on 9–10 July 2011 at 21:00–02:57 UT. We focus on signals in the frequency band 0.1–4 Hz and study their possible relation with convective storms that occurred at the distance less than 250 km from the microbarograph array in the above mentioned time interval.

2. Data and methods

2.1. Equipment for infrasound measurements

Experimental microbarograph array is located at observatory Panska Ves (50°31' N 14°34' E). Three microbarographs are distributed on the grass ground of the observatory and are arranged in a nearly equilateral triangle; the distance between sensors is ~200 m (Fig. 1). Differential microbarographs are of the type ISGM03. The sensors are placed underground in insulated capsules; thus are protected from temperature fluctuations. As a wind noise protection, porous hoses of length of 4 m were used; four hoses are attached with each sensor. Operational range of the microbarographs stated by the manufacturer is 0.02–4 Hz. Pressure fluctuations can also be detected outside of this frequency range. However, one has to bear in mind that the response sensitivity gradually decreases at frequencies below 0.02 Hz and above 4 Hz. The sensor response is highly sensitive down to frequencies around 0.01 Hz. Data are stored with sampling frequency of 25 Hz.

The ground of the observatory is located on a gentle slope; height differences between the individual sensors are lower than 10 m. In the close surroundings, isolated hills are located to the south east and east in the distance around 1.5 km. Their relative height above the observatory is approximately 110–160 m. Generally, there are mostly hilly areas and highlands in the studied region (where the observatory and convective storms were located); it means relative heights are up to 300 m. Bohemia is surrounded by mountains with maximum height above sea level 1602 m. The mountain ring is in the distance approximately 40 km to the north, 150 km to the west, and 200 km to the south from the observatory.

2.2. Measurements and data processing

Parameters of infrasound arrival – azimuth, apparent velocity, signal to noise ratio – were determined using Fisher detector in the time domain (Melton and Bailey, 1957).

Fisher detector distinguishes coherent infrasound signal travelling over the array from a non-coherent noise based on a statistical hypothesis test.

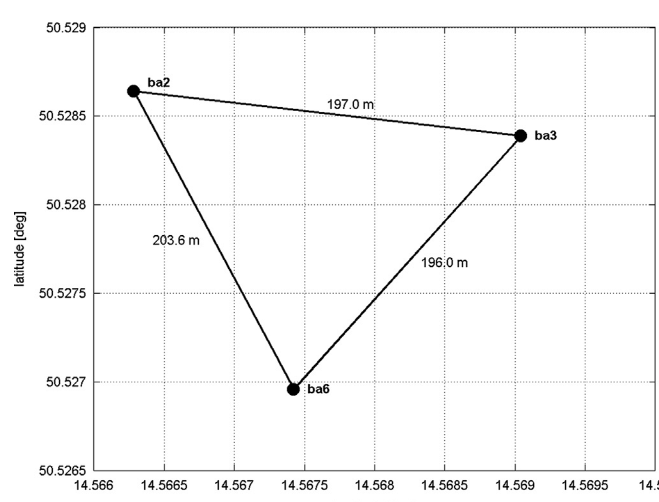

Fig. 1. Infrasound array at observatory Panska Ves. Position of sensors ba2, ba3, and ba6 is represented with circles. Distance between the sensors is shown.