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Powerful Seismovibrators as a Possible Source of Acoustic and Electromagnetic Disturbances

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Abstract. The observations of the disturbances of the acoustic, electric and magnetic fields at various distances from a vibroseismic source (5-12 Hz frequency range) are presented. Two centrifugal vibrosources (VS) with sinusoidal vibrational force onto the ground of 100 and 40 tons are used. Infrasonic signals are reliably recorded at distances up to 50 km. When the acoustic signal is large, a seismic signal with the same arrival time is also detected. Magnetic and atmospheric electric fields are detected at distances of several kilometers. These signals have practically zero lag time and precede the acoustic and seismic signals. The disturbances caused by the VS were also registered by telluric field measurements at distances up to 2 km from the source.

1 Introduction

Various electromagnetic phenomena accompanying seismic processes have been described (Gohberg et al., 1988; Fraser-Smith et al., 1990; Parrot, 1990). Similar investigations have been conducted using chemical and nuclear explosives (e.g. Jacobson et al., 1986; Blanc and Rickel, 1989; Simons, 1995; Sweeney, 1996). More possibilities for studying these phenomena are provided by powerful vibroseismic sources (VS) (Alekseev and Nikolaev, 1997; Kuznetsov et al., 1999a). The VS can be used to investigate potential earthquake precursor mechanisms. In this paper we present observations of acoustic and electromagnetic disturbances that occur during active vibroseismic sounding.

2 Vibrosources and Measurement System

The VS installed at the Bystrovka vibroseismic test area (Novosibirsk, Russia) are centrifugal vibrosources CVS-100 and CVS-40 and hydroresonant vibrosource HRV-50, with sinusoidal vibrational force onto the ground of 100, 40, and 50 tons, respectively. All vibroseismic sources utilize vertically oscillating masses (metallic for CVS and water for HRV) with oscillation amplitude of about 0.5 cm. The equivalent output seismic power is a few kilowatts. The VS were operated both in monochromatic mode and in sweep-mode. The working frequency range is from 5 to 12 Hz; the accuracy of frequency is 10^{-7} Hz. In sweep-mode the frequency changes linearly and continuously during the session, which lasts for 20 to 50 minutes.

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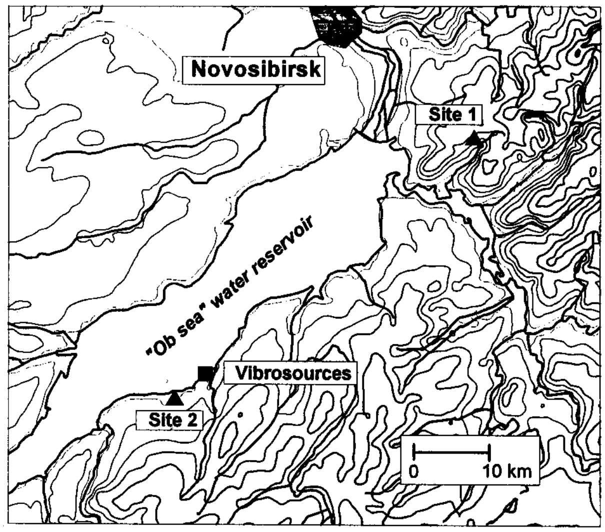

Fig. 1. Map shows a location of the seismovibrators at the vibroseismic test area "Bystrovka" near Novosibirsk (black square) and the recording system sites (black triangles): Site 1 is the magnetic-ionospheric station "Klyuchi" (Geophysical observatory), Site 2 is the Bystrovka settlement.

Field measurement system (Kuznetsov et al., 1999b) includes two sensors for measuring the atmospheric electric field (a string type with a sensitivity of about 1 V/m and a receiver with a vertical antenna with a sensitivity of about 1 mV/m), an induction coil magnetometer with a sensitivity on the order of 0.001 nT, two infrasonic sensors (a strain gauge with a sensitivity on the order of 0.1 Pa and a piezoceramic gauge with a sensitivity of ~0.001 Pa), a vertical seismograph with electromechanical response of 16 V/(m/s) in the frequency range of 1-30 Hz, and a system for telluric measurements. Calibration of the measuring system has not yet been performed; hence the stated instrument sensitivities are only accurate to within about an order of magnitude and exact amplitude measurements cannot be presented in physical units.

In Fig. 1 the area near to Novosibirsk is shown, where the experiments were realized. Only sites of the location of the recording system on significant distances from CV are marked.

3 Results

3.1 Acoustic disturbances during vibroseismic sounding

Measurements performed in 1997-1999 demonstrate that the VS are effective generators of infrasound in the 5-12 Hz frequency range; the infrasound is confidently registered at distances of some tens of kilometers. Acoustic signal parameters vary over a wide range: at 50 km distance the amplitude varies by a factor of ten while the arrival time varies from 135-160 s. As an example, Fig. 2 shows the cross-correlation functions (CCF) between a reference sweep signal and simultaneously recorded seismic (left panel) and acoustic (right panel) signals at a distance of 50 km (Site 1). The reference sweep signal is a signal of the form $\sin(2pft)$, where $f = f_0 + 0.5bt$ is the linearly varying frequency of the VS, f_0 is an initial value of sweep frequency (usually it is 6.25 Hz for CVS-100 and 8.49 Hz for CVS-40), $b = 1.1641531 \times 10^{-3}$ Hz/s, and t is the duration of a session (about 45-50 minutes).

The seismic signal clearly shows first phases with arrival times from 7 to 35 s. The second seismic phases have arrival times equal to the acoustic arrival times; they represent local ground oscillations due to acoustic waves generated by the VS. A remarkable feature of the left upper curve in Fig. 2 is the considerably large amplitude of the second seismic arrival compared with the amplitude of the direct seismic signal propagating in the lithosphere; in this case the infrasonic signal was also very strong. The arrival time of the infrasonic signal (right panel of Fig. 2) varies from 135 to 160 s, indicating various paths of propagation. Observations using spatially separated infrasonic sensors have shown that acoustic wave reflections can sometimes originate from atmospheric altitudes of 8-10 km. Analysis of ground meteorological data has shown that the infrasonic amplitudes and arrival times are not obviously correlated

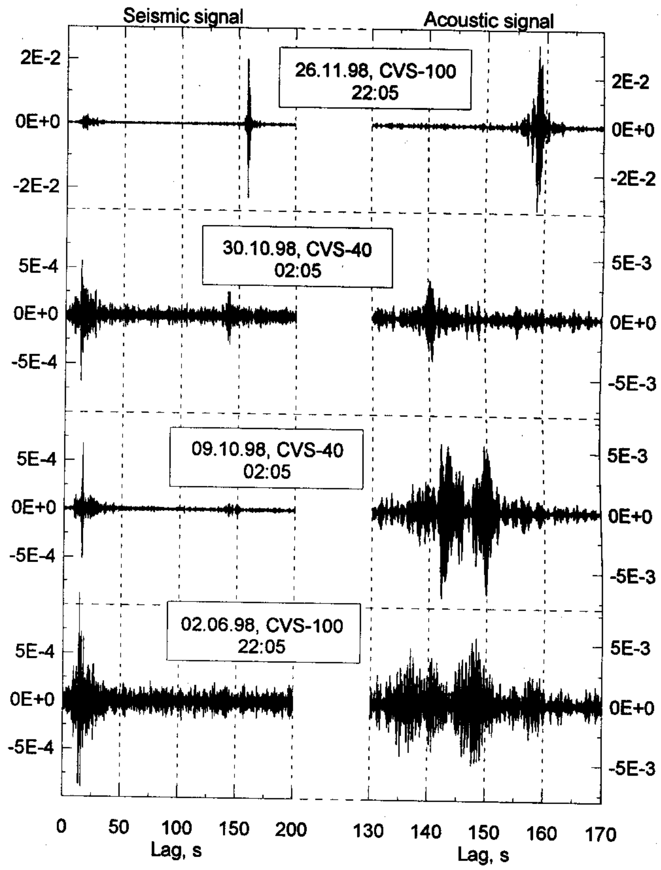

Fig. 2. Examples of cross-correlation functions between the vibrosource reference sweep-signal and simultaneously recorded seismic (left panel) and infrasonic (right panel) data at Site 1, which show a wide range of signal parameters. The same scale is used for ordinate axes (in relative units).

with wind velocity or direction, temperature or atmospheric pressure. Infrasonic propagation is likely controlled by the distribution of parameters (temperature, wind) at higher altitudes within the atmosphere and will be the subject of future research.

3.2 Electromagnetic disturbances

The electric signals were registered only at short distances from the VS both in monochromatic and sweep-mode. The CCF between a reference sweep-signal of the CVS-100 and records of two electric sensors located 700 m from VS are shown in Fig. 3. The CCF for seismic, acoustic, and magnetic signals, which were recorded simultaneously with electric signals, are also presented. Electric disturbances with practically zero lag are detected. We assume that these disturbances are caused by oscillations of the atmospheric volume charges under the action of the acoustic wave or by oscillations of charges on the VS. We note that disturbances of the electric field with the frequency of the VS are found for the CVS-100 and the CVS-40, and for the hydroresonant

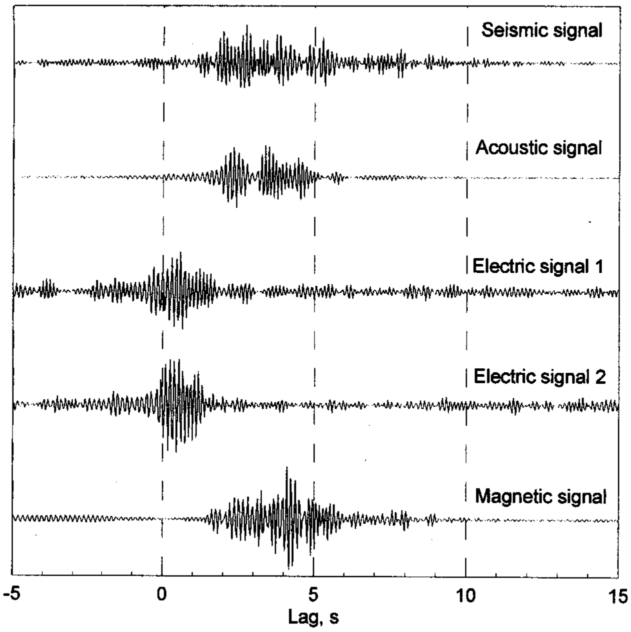

Fig. 3. The CCF (in relative units) between a reference sweep-signal of the CVS-100 and records of seismic, infrasonic, two electric and magnetic sensors located 700 m from VS.

vibrosource, HRV-50, which has a pneumatic drive without electric circuits that could generate the observed signals. This suggests that the disturbances are caused by atmospheric oscillations excited by the acoustic waves.

The CCF between the reference sweep-signal and the magnetic and seismic signals at a distance of 4.5 km from the VS (Site 2), are shown in Fig. 4. The maximum of the magnetic sensor directivity was oriented towards the VS. There are several wave modes in the magnetic channel. The first mode can be seen to have a very small arrival time with respect to the start of the VS operation. Probably, it is caused by electromagnetic radiation originating in the vicinity of the VS. We note that the first magnetic modes were not observed at sites located at other directions from VS (see, for example, Fig. 3) indicating directivity of the EM-radiation.

The second and third modes of the magnetic signal in Fig. 4 practically coincide with the first and the second modes of the seismic signal, suggesting that these magnetic modes arise as the result of the mechanical oscillations of the magnetic sensor caused by the seismic waves. This phenomenon is well known for high-sensitivity magnetic induction sensors. In order to decrease this effect the observations were made during a sweep-mode, which allowed us to separate the different waves in time (see Fig. 4). In addition, we utilized an elastic suspension of the magnetic sensor and placed it inside Helmholtz coils to compensate the greatest (vertical) component of the geomagnetic field. The value of the coil current was selected using a sensitive flux-gate magnetometer, which controlled the amplitude of the field inside the coils. The data shown in Fig. 4 are recorded using the compensation system. The amplitudes of the second and the third magnetic modes are not equal to zero due to the effect of the uncompensated (horizontal) geomagnetic components.

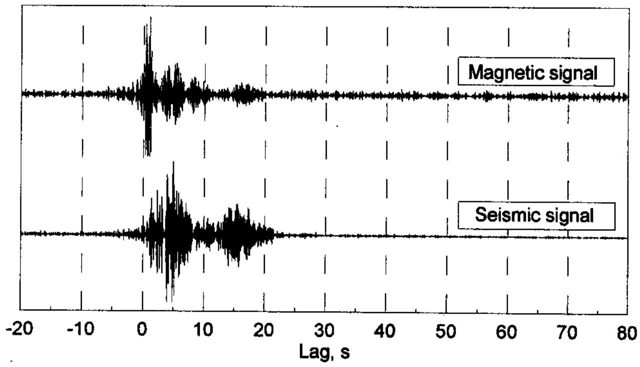

Fig. 4. The CCF (in relative units) between a reference sweep-signal of the CVS-100 and records of seismic and magnetic sensors at 4.5 km distance of from VS (Site 2). Helmholtz coils have been utilized to compensate the vertical component of the Earth's magnetic field.

Disturbances of a telluric electric field at a distance of 1.5 km were also found. The measurements were performed in monochromatic mode of the CVS-100 with an operating frequency of 7 Hz. This frequency is clearly visible in the telluric signal spectrum. Fig. 5 shows a contour plot of time dependence of the telluric amplitude spectrum. During vibroseismic sounding frequency peaks of 1, 6, and 8 Hz are also detected. This may be caused by amplitude modulation with a frequency of 1 Hz of a main signal with a frequency of 7 Hz and by a demodulation of the signal by some non-linear elements of an electric signal excited by the arriving seismic waves.

4 Conclusions

Preliminary analysis of combined measurements made during operation of the powerful centrifugal vibrosources CVS-100, CVS-40 and the hydroresonant vibrosource HRV-50, with output force of 100, 40 and 50 tons, respectively, has revealed the presence of seismic, acoustic, and electromagnetic signals over distances of hundreds of meters up to several tens of kilometers. There is wide scatter of amplitudes and arrival times of the recorded acoustic signals at distances up to 50 km. These observations demonstrate that 1) vibrosources are effective infrasound sources, and 2) vibrosources can be used to study variations in infrasound propagation and their relations to meteorological parameters. The existence of acoustic and seismic signals with approximately equal arrival times at distances up to 50 km from the vibrosources, and with apparent velocities of about 300-400 m/s is experimentally confirmed. Hence, the VS can be utilized to study wave interaction processes on interface boundaries (for example, air-coupled Rayleigh waves on the solid-air interface).

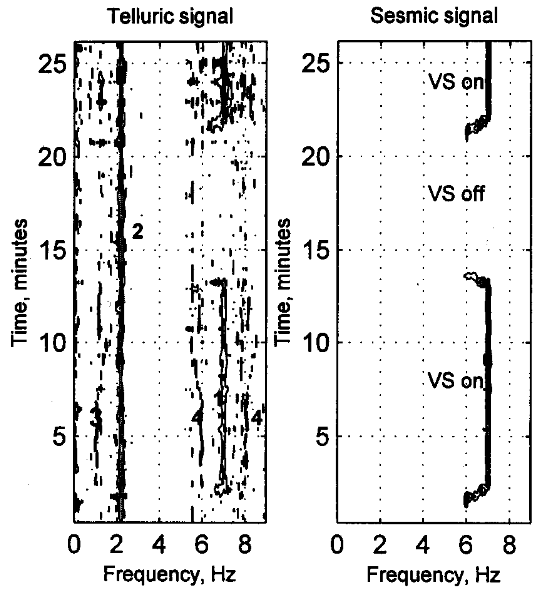

Fig. 5. Contour plots of the time dependence of the telluric (left panel) and seismic (right panel) amplitude spectra. The numbers "1" and "2" indicate the frequency of the VS and the "alias" frequency of noise at 50 Hz, respectively. The numbers "3" and "4" indicate the unstable telluric harmonics. Signals are recorded at a distance of 1.5 km from VS.

The existence of an electromagnetic wave radiated during vibroseismic sounding has been experimentally established using a magnetic induction sensor and electrometers. The propagation velocity of this wave is close to the velocity of light while the frequency is equal to the working frequency of the SV. These signals may be related to the generation of currents in the atmosphere and in the lithosphere near the VS.

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