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Detection of Infrasound from the Vitim Bolide on September 24, 2002

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An infrasonic signal from an atmospheric bolide explosion was detected on September 24, 2002 near the Vitim river, Irkutsk region (57.9 N, 112.9 E). The signal was detected by three spatially separated microbarographs of the Polar Geophysical Institute (PGI), Kola Science Center, Russian Academy of Sciences, Apatity (67.6 N, 33 E) at a distance of 4000 km from the source. The acoustic-gravity signal from a falling meteorite at high latitudes was detected at such a distance for the first time in Russia. © *2003 MAIK "Nauka/Interperiodica".*

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The generation and propagation of acoustic-gravity waves induced by meteoric bodies invading the atmosphere were studied in [1–5]. According to satellite data, large bodies 1–10 m in size, which are responsible for the bolide phenomenon, appear no more frequently than once a year [6]. Meteorites such as the Tunguska meteorite collide with the Earth no more frequently than once per one thousand years [6]. The character of wave radiation depends on the energy release to the atmosphere and on the parameters of the atmosphere. Therefore, the mass of a meteoric body can be estimated from variations in atmospheric pressure recorded by microbarographs [1, 2], and a conclusion about the existence of a waveguide in the atmosphere can be drawn. The formation of atmospheric waveguides at various altitudes determined by the temperature and wind-velocity gradients [7], as well as the superreflection effect [8], allow the infrasonic signal to cover hundreds and thousands of kilometers from a source.

We report here the results of our preliminary analysis of the infrasonic signal from the Vitim bolide, which was detected on September 24, 2002 by microbarographs of the PGI at a distance of 4000 km from the source. According to the information from the Institute of Solar–Terrestrial Physics, Siberian Division, Russian Academy of Sciences, a large space object (presumably a meteorite) fell near the Vitim river at a distance of several tens of kilometers from Bodaibo, Irkutsk region. The fall of the space body was preceded by an explosion at an altitude of 30 km, which was detected by U.S. satellites at 16:49 UT on September 24, 2002. According to eyewitnesses, a large shooting star drew a line through the night sky and collapsed on the hills. A blinding flash illuminated the taiga for several instants with a bright light resembling electric light, and then such a strong explosion thundered that ground shaking similar to that from an earthquake was felt over several kilometers from the fall point.

The table presents some U.S. satellite data on bolides (coordinates and radiation energies) since 1991 [6]. For most bolides, an infrasonic signal was detected by a global network of infrasound-monitoring stations [5, 6]. As is seen, the Vitim bolide is among the largest recently detected bolides.

Energy and coordinates of points where some bolides entered the atmosphere according to U.S. satellites [6]

Date	UT	Coordinates	*E*, J
7.05.1991	23:04	50 N, 15 W	5×10^{10}
15.06.1994	00:03	46 N, 73 W	1.3×10^{10}
9.10.1997	18:47	32 N, 106 W	1.9×10^{11}
16.8.1999	05:18	35 N, 107 W	3.8×10^{10}
18.01.2000	16:43	60 N, 135 W	1.1×10^{12}
18.02.2000	09:26	1 S, 109 E	3.6×10^{12}
6.05.2000	11:54	50 N, 18 E	2.5×10^{10}
25.08.2000	01:12	15 N, 106 W	1.4×10^{12}
23.04.2001	06:12	28 N, 134 W	4.6×10^{12}
9.03.2002	01:20	7 N, 147 W	2.2×10^{11}
6.06.2002	04:28	34 N, 21 E	3.8×10^{12}
25.07.2002	15:58	29 S, 47 E	2.5×10^{11}
24.09.2002	16:49	57.91 N, 112.9 E	8.6×10^{11}

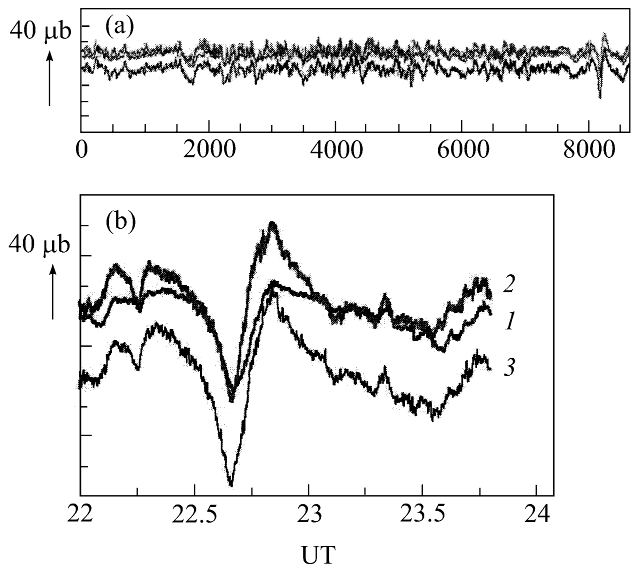

Fig. 1. Records of microbarographs at the Apatity observatory for (a) the entire day of September 24, 2002 and (b) the 22:00–24:00 UT interval.

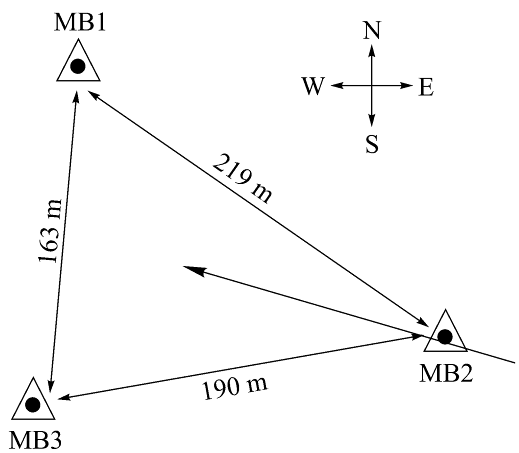

Fig. 2. Scheme of the arrangement of microbarographs (MB1–MB3).

The infrasonic signal was detected by three spatially separated microbarographs of the PGI high-altitude measuring complex [9]. In addition to these microbarographs for measuring variations in atmospheric pressure in the frequency range from 0.0001 to 1 Hz, the complex includes the electric-field sensors and an instrument for measuring the air conductivity. The computer data-acquisition system can gain information with a polling frequency of five times per second.

Figure 1 shows the records of three microbarographs on September 24, 2002. It is clearly seen that all three detectors fixed the arrival of an infrasonic signal with the maximum amplitude $\Delta P \cong 45$ dyn/cm^2 at ~22:20 UT. This signal is clearly seen even against the background of continuously observed downstream waves associated with the neighboring Khibiny mountains [9].

Figure 2 shows the arrangement of three microbarographs. By the method of separated receivers, a horizontal-trace velocity of 247 m/s and a wave-arrival angle of 117° (measured from north) were determined from the measured differences between the signal arrival times. Using the time of signal arrival (~22:20 UT) and the distance from the source (~4000 km), one can estimate the average horizontal projection of signal-propagation velocity at $V = R/T = 209$ m/s. This value, together with the source azimuth, as calculated from geographical coordinates (113°), agree with the value of horizontal trace and the signal arrival direction, which were calculated from the data of three microbarographs. Such velocities are characteristic for the signal propagation in the thermosphere (at altitudes > 85 km) [7], which can be due to the west circulation of air masses at stratospheric heights at the given latitude in this season.

The bolide mass was estimated using the relationships between the energy E_0 of a pulsed source and the disturbed pressure ΔP detected at the distance R from the radiation source [1, 10]. According to [1],

$$\Delta P \approx \frac{(\gamma-1)E_0(R-ct)\exp\left(\dfrac{-z/2H-(ct-R)^2}{R_0^2\sin^2\theta + L^2\cos^2\theta}\right)}{2\pi^{3/2}R(R_0^2\sin^2\theta + L^2\cos^2\theta)^{1/2}}. \quad (1)$$

Here, c is the speed of sound, H scales the altitude of uniform atmosphere, L is the length of the meteoric trace, $\gamma = 1.4$ is the specific heat ratio, θ is the angle between the direction of infrasonic signal and the axis of meteoric trace,

$$R_0 = M_0^{1/3}V_0^2/2(2gHQ_0)1/2\rho_0^{1/3} \quad (2)$$

is the average radius of the meteoric trace, where M_0 and V_0 (11.2 km/s < V_0 < 73.2 km/s) are the meteoric mass and velocity, respectively, and $Q_0 = 8 \times 10^{10}$ erg/g is the latent evaporation heat [1].

Assuming that the detected infrasonic signal propagates in the plane perpendicular to the axis of meteoric trace ($\theta = \pi/2$), we find from Eq. (1) that [1]

$$\Delta P \approx (\gamma-1)E_0/2\pi^{3/2}RR_0^2. \quad (3)$$

Substituting $\Delta P = 45$ dyn/cm^2 and the average velocity $V_0 = 30$ km/s into Eq. (3), we obtain $M_0 = 6$ ton. This value is a lower limit, because Eq. (3) was derived for a signal propagating without reflections [1]. In the case under consideration, the propagating infrasonic signal undergoes multiple reflections from the waveguide walls [7].

Reed [10] proposed the following empirical relation between the explosion energy E_0 (kilotons of TNT;

1 kiloton of TNT = 4.185×10^{12} J) and the disturbed pressure ΔP (kPa) at distance R (km):

$$\Delta P = 11.8 E_0^{0.4} R^{-1.2}. \tag{4}$$

This gives M_0 = 38 and 1 ton, respectively, for limiting velocities V_0 = 11.2 and 73.2 km/s.

The table presents the radiation energies of the bolide, which were obtained from the satellite optical data. The optical radiation energy comprises from 5 to 10% of the total energy of bolide [6]. In our case, the optical energy is $E = 8.6 \times 10^{11}$ J. Assuming that this value is equal to 10% of the total energy E_0, we obtain the bolide mass M_0 = 142 and 3.5 ton for two limiting velocities, respectively. These values are in satisfactory agreement with the above estimates obtained from the amplitude of the infrasonic signal.

The analysis of this event corroborates the previous conclusion that bright heavy bolides can be responsible for high-power pulsed radiation of acoustic-gravity waves in the Earth's atmosphere, which can be detected by microbarographs at a distance of several thousands of kilometers.

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