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Chelyabinsk meteoroid: seismological observations

Anna Dobrynina (1), Vladimir Chechelnitsky (2), Evgeny Chernykh (1), and Vladimir Sankov (1)
(1) Institute of the Earth's Crust, Siberian Branch of Russian Academy Sciences, Irkutsk, Russian Federation (dobrynina@crust.irk.ru, +73952426900), (2) Baikal Regional Seismological Center of Geophysical Survey of Siberian branch of Russian academy of sciences, Irkutsk, Russian Federation

The aim of present work was analysis of seismological phenomena emerged due to Chelyabinsk airburst (15 February 2013). According to different astronomical and seismological agencies reports airburst coordinates and time vary over a wide range and its energy ranges from 70 kt to 1.4 Mkt of TNT equivalent (1 kt = $4.185 \cdot 10^{12}$ J) [reports by NASA; USGS; CTBTO; Perm Regional Seismological Center; Kazakhstan Seismological Center; Department of Physics and Astronomy of University of Western Ontario; Le Pichon et al., 2013; Borovicka et al., 2013; Brown et al., 2013; Tauzin et al., 2013; Gokhberg et al., 2013; Seleznev et al., 2013]. We used records obtained by broadband seismic station global networks (Iris/Ida, Iris/USGS) and by regional networks (Iris/China, Kazakhstan, Kyrgyzstan and Baikal Regional Seismological Center). Data provided by IRIS Data Management System (Seattle, Washington, USA, www.iris.edu/).

Seismogram visual analysis showed the presence at several stations of the seismic wave, which at the time of occurrence and form may be associated with the explosion of a meteoroid. It was recorded at 32 stations and is a short period motion (period T = 3-16 sec) for up to 1 minute. This wave was defined by us as the Rayleigh surface wave. Maximum epicentral distance at which confidently fixed surface wave is about 3650 km (station LSA, Tibet). At stations located farther away from the airburst site, the signal is noisy by surface waves from the earthquake Tonga (February 15, 2013, origin time 03:02:23.3, M=5.8, coordinates -19.72N, -174.48W, report by USGS). Spectral analysis showed that the recorded signal at short epicentral distances (up to 1300 km) is most manifest in the low frequency range - 0.25 (0.5) up to 1 Hz, while the remote stations for surface wave is lost in microseismic noise.

A visual analysis of the arrival times of Rayleigh waves at seismic stations located at different epicentral distances are marked with their nonlinear: at close distances much lower rate than in the remote, and the average 2.4 and 3.2 km/s, respectively. This nonlinearity can be explained from the viewpoint of surface Rayleigh wave as a result of exposure to acoustic (infrasound) wave from the explosion of a meteoroid in atmosphere on the earth's surface [Tauzin et al., 2013; Ewing et al., 1957; Edwards et al., 2007]. The difference in the velocities of seismic and acoustic waves (velocity of propagation of sound waves in air is $\sim$0.3 km/s) explains the relatively low rate of arrival of the surface wave at seismic stations close. The average surface wave velocity is 3.2 km/s. Dominant period method was used for estimation of surface wave attenuation - values obtained seismic Q and its dependence on frequency. Dependence of Q on the frequency is exponential: $Q_R(f)=1700 \cdot \exp^{1.2}$.

Seismic energy was evaluated by surface wave magnitude (magnitude Ms and MS). To calculate the magnitude of the maximum amplitude used Ms surface wave measured at periods ranging from 18 to 22 sec, for calculating the magnitude MS - ranging from 3 to 60 sec. The resulting average values are equal magnitudes 4.1 and 4.2.

Analysis of the azimuthal distribution of values for surface wave magnitude (Ms), the maximum amplitudes and frequencies of surface waves showed that these parameters have a distinct azimuthal orientation, oriented according to the flight path of the meteoroid. Fixed azimuthal orientation can be explained by the Doppler effect - the dependence of the oscillation frequency of the direction of motion of the source. The minimum and maximum periods of vibration amplitudes and frequencies are marked in the direction of source motion and vice versa.

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