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IONOSPHERIC EFFECTS OF METEOR EXPLOSION OVER NORTH FINLAND ON NOVEMBER 2017

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Abstract. On November 16, 2017 at 16:40:22 UT over Northern Finland a powerful explosion, caused by meteor destruction, had occurred. The entry of the meteor to the atmosphere and its destruction were recorded by the all sky camera at the radio physical observatory Verkhnetulomsky (68.59°N, 31.75°E), and the response of the high-latitude lower ionosphere to this explosion was recorded by the radar of the partial reflections at the radio physical observatory Tumanny (69.0°N, 35.7°E). After the explosion the considerable disturbances in the ordinary wave amplitude at the heights of 80-95 km have appeared. Using the temporal variations of the ordinary wave amplitude the periods corresponding to resonant atmospheric modes were identified: the acoustic cut-off period and the Brunt-Väisälä period, and also temperature and sonic speed at the mesopause heights were calculated. It was suggested that the disturbances could be caused by the waves which had magnetohydrodynamic nature.

1. Introduction

The wave processes from artificial and natural sources of high energy developing in the atmosphere of the Earth play an important role in formation of structure and dynamics of the ionosphere [*Gossard and Hooke*, 1975; *Impact of the missile …*, 2016]. Nowadays the big interest is to study a possible influence of powerful meteoroid explosions on the Earth, like Chelyabinsk's meteoroid and more powerful ones. It has not only scientific interest but the interest from the point of view of possible influence on the human life. Flights and destructions of large meteors in the atmosphere are followed by emergence of wave disturbances of various natures: shock, acoustic-gravity, magnetohydrodynamic (MHD), electromagnetic, and seismic waves [*Catastrophic influences …*, 2005]. The main source of disturbances in the atmosphere during the explosions of meteoroids is shock waves. Disturbances from the flight and the explosion of a meteor extend to distances in hundreds and thousands of kilometers in the atmospheric wave guides which were created at various heights by gradients of temperature, speed and direction of winds and other reasons. In a number of works problems of generation and propagation of the acoustic-gravity waves [*Golitsyn et al.*, 1977] and magnetohydrodynamic waves [*Sorokin et al.*, 1982] were considered for the similar events.

A large number of works are devoted to the effects in the ionosphere caused by various sources of disturbances of natural and technogenic origins (solar flares, meteoroid flights, processes in magnetosphere, as well as chemical and nuclear bursts, launches and flights rockets, modification of the ionosphere by powerful radio waves etc.). Because of difficulty of measurement of the environment parameters at ionospheric heights and simultaneous action of various sources of disturbances up to the end there are uncertain mechanisms of generation and transfer of disturbances in the middle atmosphere [*Akhmedov and Kunitsyn*, 2004]. Studies of reaction of the polar lower ionosphere to the flights of meteoroids are carried out incidentally [*Cherniakov et al.*, 2017; *Tereshchenko et al.*, 2014] therefore it is necessary to increase the number of observations, especially in high latitudes.

In the work researches of changes of characteristics of partially reflected radio signals (amplitudes of ordinary and extraordinary partially reflected waves) during the explosion of the meteor over the Northern Finland are provided. Results were received on the basis of the partial reflection radar data of the Polar Geophysical Institute located at the radio physical observatory Tumanny (69.0°N, 35.7°E) [*Tereshchenko et al.*, 2003]. The meteor path projection to the Earth and the main visible features of the meteor explosion were received according to the all sky camera data from radio physical observatory Verkhnetulomsky (68.59°N, 31.75°E).

2. Results of observations and data processing

A powerful meteor explosion has happened on November 16, 2017 at 16:40:22 UT over the Northern Finland (68.7°N, 23.8°E). In Fig. 1 the consecutive frames of the meteor flight which were recorded by the all sky camera at the radio physical observatory Verkhnetulomsky (Fig. 2) with the exposure about 1 s are shown. The meteor had entered into the dense layers of the atmosphere approximately at 16:40:15 UT, its visible flight continued about six seconds. During the flight the significant increase in brightness of a glow owing to fast heat-up of meteor substance was recorded. On the fourth and fifth seconds of the registration the bright flash which lit all the sky was watched. The increase in brightness of diffused light in the field of the zenith was more than by 40 times relatively the background glow of the night sky at the place of observation.

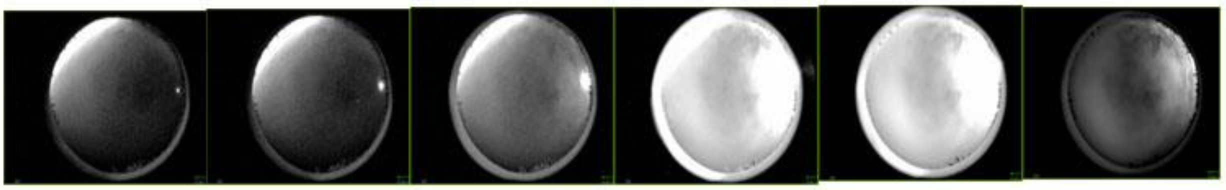

Figure 1. The meteor explosion has recorded by the all sky camera.

Reaction of the ionosphere to this explosion was observed by the partial reflection radar at the radio physical observatory Tumanny (Fig. 2). The white shaped line going from the south to the place of the meteor explosion specifies the direction of the meteor movement to the place of the explosion. Distance from the explosion place to the radio physical observatory Tumanny is about 480 km.

Figure 2. Meteor explosion place and positions of the radio physical observatories Tumanny and Verkhnetulomsky.

The two-dimensional distribution of amplitude of the ordinary wave received according to the partial reflection radar data from 16:20 UT till 18:40 UT including the moment of the meteor explosion (the solid vertical line) is given in Fig. 3. Ellipses show the two regions of strong amplitude disturbances which appeared after the meteor explosion. Digits designate order numbers of the disturbances.

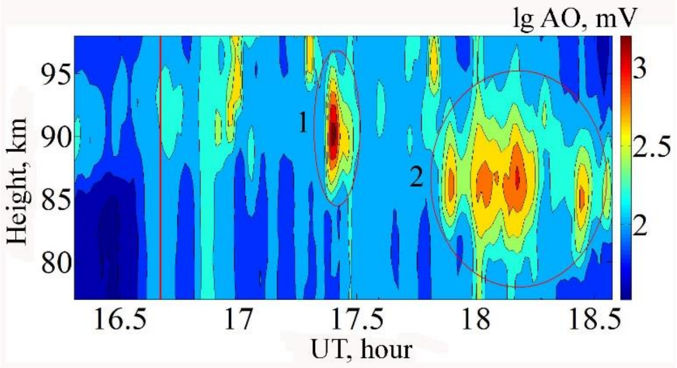

Figure 3. Two-dimensional distribution of the ordinary wave amplitude on November 16, 2017.

The 1st disturbance had very sharp increasing of amplitude at the heights of 85-95 km; the 2nd one was like a wave packet at the heights of 80-93 km. The destruction of a meteor as the result of an explosion is followed by appearance of a shock wave. In the place of formation of shock waves their amplitudes are considerable, first of all, because of a pressure jump. Propagation speed of such waves depends on the power of the explosion and can significantly exceed sonic speed at the ionospheric heights. It is necessary to mark that initial shock waves, in turn, are the source of weak shock waves and internal gravity waves which also appear at the region of observation. The internal gravity waves can be also generated during the flight and the explosion of a meteor. The first disturbance in ordinary wave amplitude was at the heights of 85-95 km at 17:21:39 UT in the form of a pulse with duration on the level 0.5 about 5 min (Fig. 3, 1) and had come from the explosion place with the velocity about 220 m/s. The second one (2) was at 17:50:42 UT at the heights of 80-93 km and its velocity of arrival was about 115 m/s. The duration of the wave packet was about 40 min. The sharp appearance of the first disturbances could be explained by arrival of some kind of a shock wave from the meteor explosion to the region of observation. The second disturbance has the appearance of the packet of waves caused by passing of the internal gravity waves through the directional pattern of the radar antenna. Slow velocities of wave arrival to the point of observation could be explained if the disturbances would be considered as having magnetohydrodynamic nature [*Sorokin and Fedorovich*, 1982; *Tereshchenko et al.*, 2014].

On the basis of the two-dimensional distribution (Fig. 3) in the range of periods from 2 min up to 11 min the time spectra of power density of the ordinary wave amplitudes, which were partially reflected from the heights of 75-90 km, were calculated. The sample of the calculation is shown in Fig. 4a. All the calculations were done with the MATLAB language and its applications. For obtaining of necessary wave periods the digital elliptical bandpass filter (Kauer filter) was used. In the range of heights of 85-95 km the maximum values of intensity spectral component of partially reflected radio signals were observed at the heights about 90 km. The power density spectrum for the 90 km in the Fig. 4a contains well expressed components.

Basic acoustic-gravity wave theory in the atmosphere gives an opportunity to describe many of wave-like oscillations in the atmosphere [*Yeh and Liu*, 1974; *Knižová and Mošna*, 2011]. In case of the plane-stratified, isothermal atmosphere and constant gravity with height there are two frequency domains for atmospheric waves where they can propagate as acoustic and gravity waves. The domain can be described by two resonant frequencies of the atmosphere: the acoustic cut-off frequency ω_a and the Brunt-Väisälä frequency ω_B. The atmosphere is compressible gas which after being compressed then released and began to oscillate near its equilibrium state. The oscillation frequency is defined as the acoustic cut-off frequency $\omega_a = c/2H$, where c is speed of sound

$$c = \sqrt{\gamma g H}\ ,$$

γ is the ratio of specific heats at constant pressure and constant volume, g is the gravitational acceleration and H is the scale height. The second characteristic frequency of the atmosphere is the Brunt-Väisälä frequency which is defined as the buoyancy frequency at which a vertically displaced parcel will oscillate within a statically stable environment. In our case we can consider the atmosphere for chosen heights as isothermal one and write down the frequency as

$$\omega_B^2 = (\gamma - 1) g^2 / c^2\ .$$

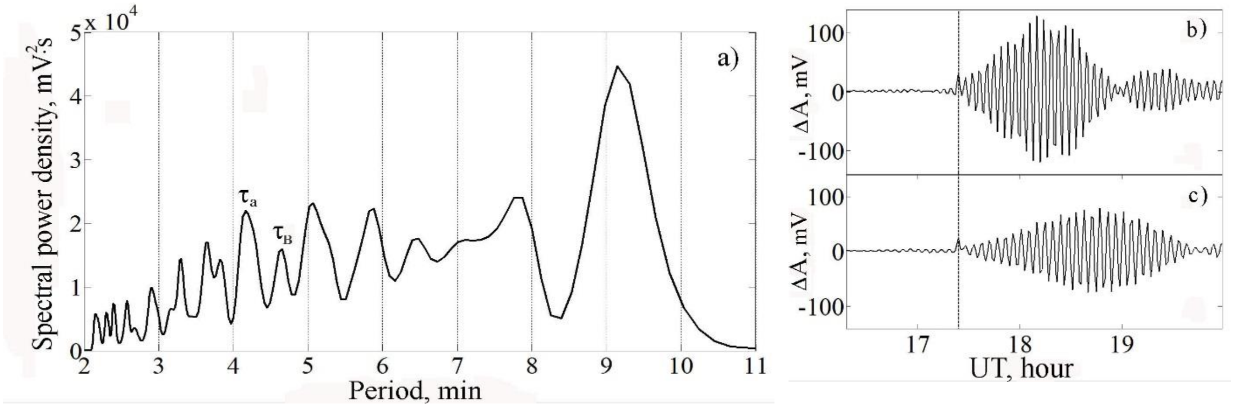

Figure 4. ***a***) spectral power density of the partially reflected ordinary wave at the height 90 km; ***b***), ***c***) spectral components τ_a (*b*) and τ_B (*c*), filtered by the digital elliptical passband filter from the radio signal.

As the result of the analyses of our experimental spectral lines on the basis of the theory of acoustic-gravity waves and the empirical model of composition and temperature of the atmosphere (NRLMSISE-00[3]) the periods of oscillations with the acoustic cut-off period $\tau_a = 4.19$ min and the Brunt-Väisälä period $\tau_B = 4.64$ min, corresponding to resonance atmosphere periods, were identified. Spectral maxima for which $\tau < \tau_a$ belong to acoustic modes (infrasound) and maxima for $\tau > \tau_B$ belong to gravity modes [*Gossard and Hooke*, 1974]. The most intensive spectral maximum with the period of 9.22 min is related to the internal gravity mode (the second disturbances in Fig. 3) which is generated in the atmosphere in the neighborhood of the meteor explosion place. It is remarkable that the value of the period of this mode is multiple to the Brunt-Väisälä period for the height of the atmosphere considered in this case.

We will be noted also that excitation of resonance oscillations τ_a and τ_B matched the moment of passing of the first disturbance through the zenith of radio physical observatory Tumanny (the vertical lines in Fig. 4b, c). The maximum values of amplitude of the gravity mode delay relative to the maximum of amplitude of the acoustic mode is approximately 30 min. Values of the periods of atmospheric resonances correspond to temperature and sonic speed at the height of 90 km are equal ~ 189 K and 275 m/s, respectively. If we suppose that the infrasonic pulse has moved with the calculated speed and has caused appearance of the first disturbance, and also it propagated in the atmospheric duct at the thermosphere base in the layer with inverse of temperature. In this case length of the way passed by the

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[3] NRLMSISE-00 Atmosphere Model, *https://ccmc.gsfc.nasa.gov/modelweb/models/nrlmsise00.php (*18.06.2018)

wave pulse from the moment of the meteor explosion to the point of observation is equal to about 660 km. This distance includes length of a wave guide and an oblique section of a way to wave guide height.

3. Conclusions

Thus, the meteor explosion caused propagation of a shock acoustic wave obliquely up over the place of the meteor falling. The wave at the height of an atmospheric duct was transformed to the infrasonic pulse and the gravity modes of internal gravity waves which caused in the case of the waveguide propagation modulation of ionospheric parameters over the partial reflection radar at the radio physical observatory Tumanny. In some cases intensification of periods of temporal variations of the ordinary wave amplitude corresponds to resonant atmospheric modes: the acoustic cut-off period and the Brunt-Väisälä period were observed and it gave an opportunity to calculate temperature and sonic speed at some mesosphere heights.

References

Akhmedov, R.R. and Kunitsyn, V.E. (2004). Simulation of the ionospheric disturbances caused by earthquakes and explosions. *Geomagnetism and Aeronomy* 44 (1), 95-101.

Catastrophic influences of space bodies. (2005). Eds V.V. Adushkin, I.V. Nemchinov. Institute of Dynamics of Geospheres of RAS, M.: Akademkniga, 310 pp. (in Russian)

Cherniakov, S.M., Nikolashkin, S.V., Tereshchenko, V.A. (2017). Vilyuysk meteor explosion: ionospheric and geomagnetic effects in the high-latitude lower ionosphere // *Proceedings SPIE 10466*, 104664U-1–104664U-8, doi:10.1117/12.2282360.

Golitsyn, G.S., Grigoriev, G.I. and Dokuchaev, V.P. (1977). Emission of acoustic-gravity waves during movement of meteors in the atmosphere. *Izvestiya. Atmospheric and Oceanic Physics* 13, 926-935 (in Russian).

Gossard, E., and Hooke, W. H. (1975). Waves in the Atmosphere. Amsterdam & Oxford & New York, Elsevier Scientific Publishing Company, 442 pp.

Impact of the missile and space equipment on the environment. (2016). Eds. V.V. Adushkin, S.I. Kozlov, M.V. Silnikov, M.: Geos, 795 pp. (in Russian)

Knížová, P.K. and Mošna, Z. (2011). Acoustic-Gravity Waves in the ionosphere During Solar Eclipse Events. In Acoustic Waves – From Microdevices to Helioseismology, InTech, 303-320.

Sorokin, V.M., and Fedorovich, G.V. (1982). Physics of slow MHD-waves in ionospheric plasma. M.: Energoizdat, 135 pp. (in Russian).

Sorokin, V.M., Fedorovich, G.V., Ferberg, V.A., Shashunkina, V.M. and Yudovich, L.A. (1982). Ionospheric effects of “Slylab” falling, in Ionospheric forecasting, M.: Nauka, 138-143 (in Russian).

Tereshchenko, V.D., Vasiliev, E.B., Ovchinnikov, N.A. and Popov, A.A. (2003). Middle wave radio radar of the Polar Geophysical Institute for researches of the lower ionosphere. In Equipment and technique of a geophysical experiment, Apatity: KSC RAS, 37-46 (in Russian).

Tereshchenko, V.D., Vasiliev, E.B., Tereshchenko, V.A., Ogloblina, O.F. and Cherniakov, S.M. (2014). Wave disturbances in the polar lower ionosphere during Chelyabinsk meteorite falling // *Physics of Auroral Phenomena, Proceedings XXXVII Annual Seminar*, Apatity, Russia, 25–28 February 2014. Apatity: KSC RAS, PGI, 104-107 (in Russian).

Yeh, K.C. and Liu, C.H. (1974). Acoustic-gravity waves in the upper atmosphere. *Reviews of Geophysics and Space Physics* 12 (2), 193-216.