"Physics of Auroral Phenomena", Proc. XL Annual Seminar, Apatity, pp. 104-107, 2017

Polar Geophysical Institute

SIBERIAN METEORS: IONOSPHERIC AND GEOMAGNETIC EFFECTS IN THE LOWER IONOSPHERE OF HIGH LATITUDES

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Abstract. Reaction of the high-latitude lower ionosphere and the geomagnetic field to explosions of two Siberian meteoroids according to amplitudes of partially reflected ordinary and extraordinary waves, received by the partial reflection facility of the Tumanny radiophysical observatory (69.0°N, 35.7°E), and geomagnetic field variations of the Lovozero geomagnetic observatory (68.0°N, 35.0°E) of the Polar Geophysical Institute had been considered. The first meteor has blown up at 21:29 UT, 4 March 2014, over the Vilyuysk district (Yakutia, Russia) (64.3°N, 123.1°E). The second meteor has blown up at 11:37 UT, 6 December 2016, in the region located near Sayanogorsk (Khakassia, Russia) (52.9°N, 91.4°E). It was shown that explosions have caused changes in the ionosphere and the geomagnetic field, and also appearance of waves of different types: internal gravity waves and slow magneto-hydrodynamic waves.

Introduction. The greatest attention of researchers is drawn by invasion into the Earth atmosphere of large meteoroids as their flights and the subsequent destructions are followed by various light, acoustic, seismic disturbances which are fixed by ground and satellite means of observations. First of all an explosion of a meteoroid is followed by a shock wave which is the most powerful manifestation of explosion in the atmosphere. Sound disturbances from the explosion extend to many tens and hundreds of km depending on the height of destruction of a meteoroid. Infrasonic disturbances extend to distances in hundreds and thousands of km, depending on conditions of atmospheric wave guides. Also during the disintegration of meteoroids, processes of generation and propagation of acoustic gravity waves which cause moving ionospheric disturbances in the ionosphere are of interest. As a rule, at the same time in the atmosphere and the geomagnetic field wave disturbances of various nature are generated which, eventually, cause changes of structure and dynamics of the ionosphere. Simultaneous actions of various sources of disturbances, and also difficulties of measurements of the environment parameters at these heights complicate identification of mechanisms of generation and transfer of disturbances. Many works have devoted to the effects in the ionosphere caused by flights of meteoroids but as a rule they have considered the effects observed at the heights over 100 km. Studies of the polar lower ionosphere reaction to flights of meteoroids were much less conducted [*Tereshchenko et al.*, 2014, 2015]. Therefore it is necessary to increase the number of observations, especially in the high-latitude ionosphere.

1. Technical parameters of the partial reflection facility. The partial reflection facility is in the Tumanny radiophysical observatory, the Murmansk region, Russia (69.0°N, 35.7°E). Power of the transmitter at the working frequency 2.6 MHz is about 60 kW; duration of the pulse is 15 μs; the frequency of sounding by ordinary and extraordinary waves is 1 s; the delay between pulses of the waves is 275 ms. Receiver sensitivity is 0.5 μV; sounding range is from 30 km; sounding steps on height are 0.5·n km, where n = 1, 2, 3, …. Transceiving antenna has 38 cross-dipoles; antenna area about 10^5 m^2; directional pattern width on the level of half power is about 19°×22° [*Tereshchenko et al.*, 2003].

2. Parameters of places of observations and explosions of meteors. The first meteor has blown up at 21:29 UT, 4 March 2014, over the Vilyuysk district (Yakutia, Russia) (64.3°N, 123.1°E). The second meteor has blown up at 21:29 UT, 6 December 2016, in the region located near Sayanogorsk (Khakassia, Russia) (52.9°N, 91.4°E). For the analysis, amplitudes of ordinary and extraordinary waves, received by the partial reflection radar, and variations of the geomagnetic field of the Lovozero geomagnetic observatory (68.0°N, 35.0°E) have been considered. Distance from the explosion place of the Vilyuysk meteor to the Tumanny observatory about 3560 km and from the explosion place of the Sayanogorsk meteor is about 3360 km (Fig. 1).

3. Vilyuysk meteor. During the expedition of researchers of the Institute of Cosmophysical Research and Aeronomy SB RAS, Yakutsk, it became clear that on 4 March 2014 in the atmosphere had flown a meteoroid which had turned into a meteor and had probably broken up with the falling to the Earth as meteorites. Data processing of video registrations gave opportunity to specify the explosion epicenter with the accuracy of 4 km on width and 9 km on length. The epicenter is located at 85-90 km to the northeast of Vilyuysk at the point with approximate coordinates of 64.2°N, 121.9°E. Explosion of the meteor was in the range of heights from 16 km to 24 km as a result of strong heating caused of braking of the body in the atmosphere. According to preliminary estimates the initial size of the body was about one meter, and the power, calculated on the flash duration, was about 0.5-1 kilotons in a trotyl equivalent. It was established that the body has entered to the atmosphere from the northwest (the azimuth of 130-140 degrees) with the inclination of 40-50 degrees and the speed about 32 km/s.

Figure 1. Map of meteor explosion positions and the Tumanny observatory.

3.1. Geomagnetic conditions and ionospheric effects. A meteor flight in the atmosphere of the Earth is followed by various effects. First of all it makes impact on the environment including the geomagnetic field. Influence of explosions of meteoroids on the geomagnetic field was considered by different researchers [*Chernogor*, 2014]. In our case for consideration of geomagnetic conditions and behavior of reaction of the geomagnetic field during the explosion and after that it was used data of the IMAGE magnetic stations and the Lovozero observatory. The observatory is situated near the Tumanny observatory and at the distance of 3610 km at the place of the Vilyuysk meteor explosion. Geomagnetic conditions during the meteor explosion were disturbed, there was a substorm. On the Fig. 2 it is shown behavior of IMAGE electrojet indicators which characterize well enough the geomagnetic situation in the auroral zone of our region (*http://space.fmi.fi/image/il_index/*). Red colour shows IE indicator, green one – IU, blue one – IL. The figure shows two days on 4 and 5 March 2014 for to know geomagnetic situation during the explosion and after that. As we can see during the explosion there was a substorm. It continued about till 1 UT on 5 March. After the time there was the quite period when we can consider the reaction of the geomagnetic field on the explosion.

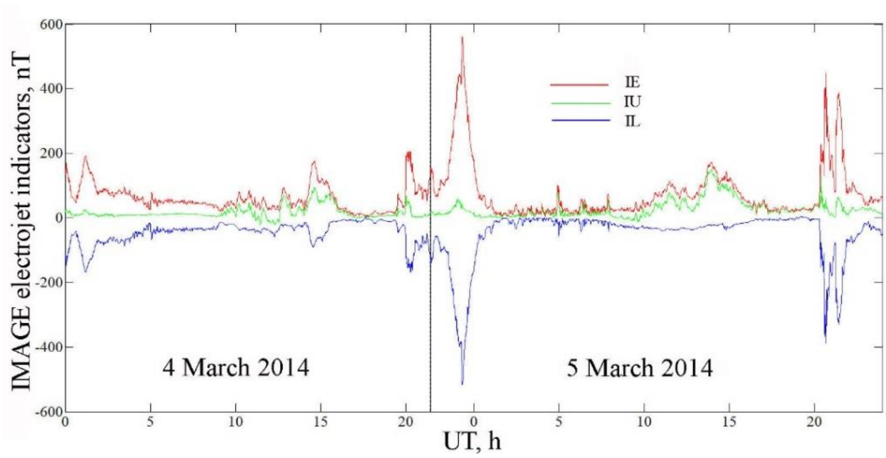

Figure 2. IMAGE electrojet indicators on 4 and 5 March 2014.

On the Fig. 3 (left) the behavior the IMAGE electrojet indicators during the quite period of the geomagnetic field of 5 March is shown. At that period we definitely can see several sections with specific behavior. Beginnings of the sections are designated by red dotted vertical lines and digits before them. The 1st section shows wavelike behavior which can be connected with wavelike disturbances which come to the region of observations. The next sections (2-4) have sharp increasing of the IE electrojet indicator.

Typical periods of natural oscillations of the atmosphere (Brant-Väisälä periods) at the heights of the lower ionosphere are about 5-10 min, depending on the state of the atmosphere. Therefore, in the variations of the amplitudes of ordinary and extraordinary waves, the presence of wave processes with periods longer than the Brant-Väisälä period (from 10 to 80 min, internal gravity waves) was analyzed.

Fig. 3 (right) shows the amplitude of the ordinary wave (upper) and its wavelet spectrum. On the figure (right, lower) the D component of the geomagnetic field at the Lovozero observatory is shown. Behavior of the D component is very similar to behavior of electrojet indicator IE. Periods of waves in ordinary wave amplitude as well as in the D component at the 1st section have similar behavior and differ from other sections (2-4). It can be said that the waves at sections (2-4) have different nature than waves of the 1st section. At the sections (2-4) amplitude has soliton-like appearance. If we suggest that it is a manifestation of the coming disturbances from the meteor explosion so the velocity of the disturbances are: $v_1 \approx 230$ m/s, $v_2 \approx 140$ m/s, $v_3 \approx 120$ m/s, $v_4 \approx 100$ m/s. The 1st section shows two waves with the periods of 25 and 54 minutes which continues about 3 hours. In the 1st section waves can be considered as typical internal gravity waves which usually come from the place of a meteor explosion. Such velocities (v_1) are typical for the thermospheric waves propagation (at the altitude > 85 km). The coming waves of the 2nd – 4th sections can be describe as slow magneto-hydrodynamic waves (MHD-waves). The velocities of the waves are in the range of the types of waves which spreading after explosion in the lower ionosphere [*Sorokin, Fedorovich, 1982; Chernogor*, 2011; *Tereshchenko et al*., 2014].

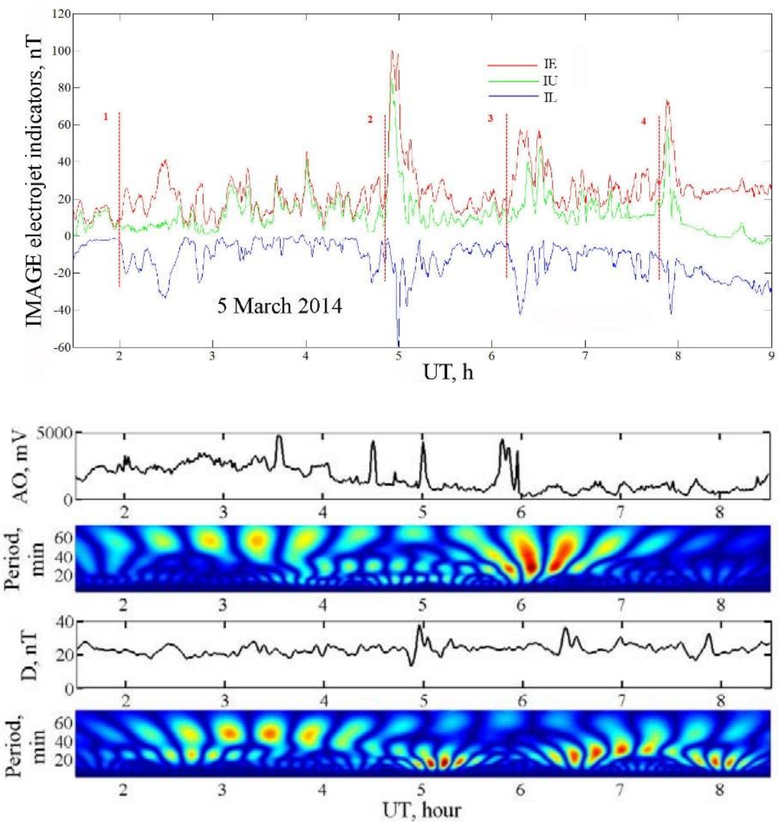

Figure 3. IMAGE electrojet indicators during the quite period of the geomagnetic field (*top*). Ordinary wave amplitude at the height of 100 km and its wavelet spectrum (*bottom*). D component of the geomagnetic field (the Lovozero observatory) and its wavelet spectrum (*lower*).

4. Sayanogorsk meteor. According to the operational headquarters of the Civil Defense and Emergency Situations in Sayanogorsk, the meteor has exploded at 11:37 UT, 6 December 2016, in the region (52.9°N, 91.4°E). The flare from the fall of the meteor was such a force that it was seen by the residents of the capital of Khakassia (Abakan), which is 80 kilometers from Sayanogorsk.

4.1. Geomagnetic conditions and ionospheric effects. Geomagnetic conditions before the meteor explosion were not disturbed, but just after the explosion there was a substorm. On the Fig. 4 it is shown behavior of IMAGE electrojet indicators. The first quite geomagnetic period is shown by the letter I, the second – II. Variations of the geomagnetic field at the Lovozero observatory are very similar to IMAGE electrojet indicators.

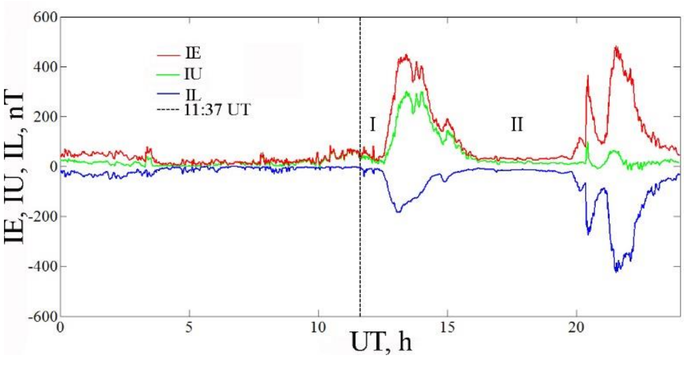

Figure 4. IMAGE electrojet indicators on 6 December 2016.

On the Fig. 5 the periods are shown more detailed. On the Fig. 5 (left) it can be chosen two coming waves. The arrival velocity of the first wave (1) to the Lovozero observatory is approximately 6.8 km/s, the second one (2) is 1.9 km/s. According to [*Chernogor*, 2011, 2014], such kind of perturbations in the geomagnetic field can be caused by slow MHD waves propagating at this speed. On the Fig. 5 (right) behavior the IMAGE electrojet indicators during the second quite period (II) of the geomagnetic field. There can be seen two different areas in behavior of the IMAGE electrojet indicators. The first picture (section 3) has an N-like one, the second picture (section 4) has wave-like one.

On the Fig. 6 (left) extraordinary waves amplitude (upper) and D component (the Lovozero observatory) (lower) for the Ist site and (right) for the IInd site are shown. If we suggest that changes in the D component of the geomagnetic field is the manifestation of the coming disturbances from the meteor explosion so the velocities of the disturbances are: $v_3 \approx 183$ m/s, $v_4 \approx 160$ m/s. The 3rd wave can be caused by the internal gravity wave, and the 4th wave – by the slow magneto-hydrodynamic one [*Chernogor*, 2011, 2014; *Tereshchenko*, 2014]. Extraordinary wave amplitude has good agreement with the changing of the D component.

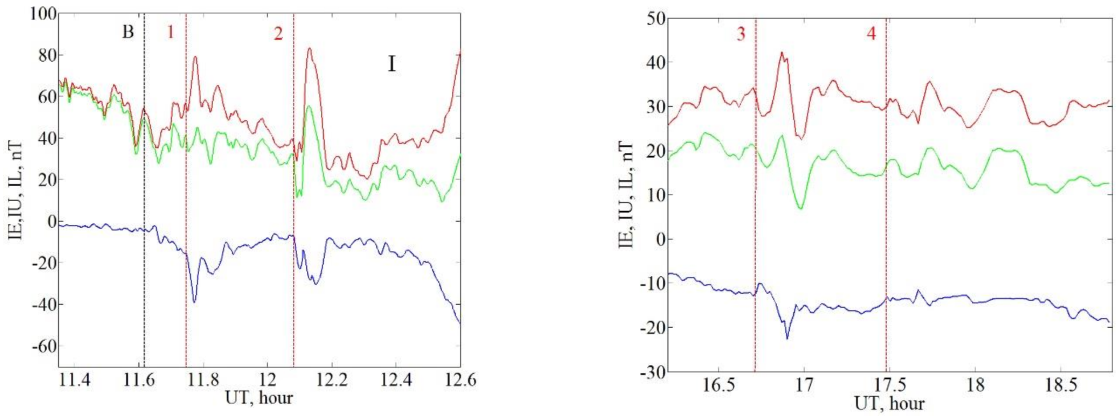

Figure 5. IMAGE electrojet indicators during the first quite period (I) of the geomagnetic field (*left*); during the second quite period (II) of the geomagnetic field (*right*).

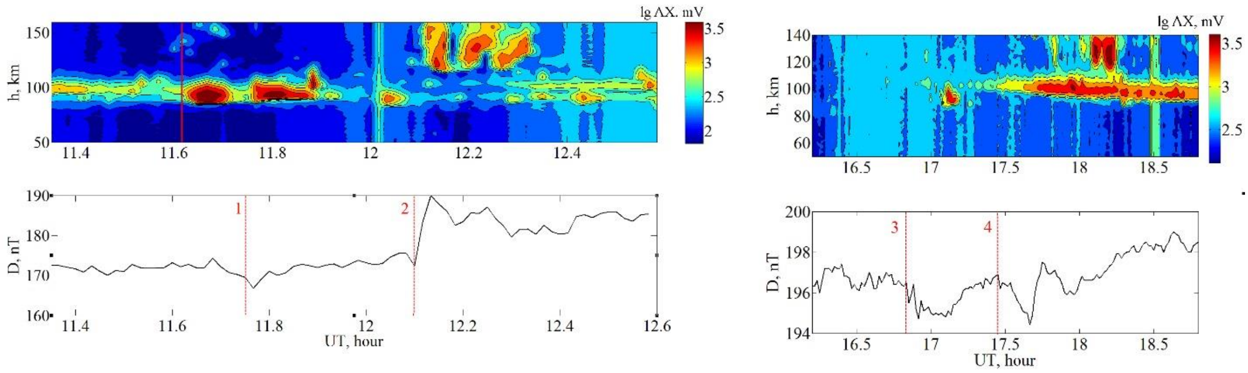

Figure 6. Extraordinary wave amplitude (*upper*) and D component (the Lovozero observatory) (*lower*) for the I[st] site (*left*); the II[nd] site (*right*).

Summary. Influence of the Siberian meteors explosions on the lower ionosphere and the geomagnetic field were considered. The events were during substorms at the place of observation. Nevertheless it was shown that the explosions of the meteors caused changes in the ionosphere and the geomagnetic field, as well as the appearance of waves of various types: internal gravity waves and slow magneto-hydrodynamic waves.

Acknowledgements. We thank the institutes who maintain the IMAGE Magnetometer Array.

References

Chernogor L.F. Oscillations of the geomagnetic field caused by the flight of Vitim bolide on September 24, 2002 // Geomagnetism and Aeronomy. V. 51 (1). P. 116-130. 2011.

Chernogor L.F. Geomagnetic field effects of the Chelyabinsk meteoroid // Geomagnetism and Aeronomy. V. 54 (5). P. 613-624. 2014.

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

Tereshchenko V.D., Tereshchenko V.A., Ogloblina O.F., Cherniakov S.M. The wave disturbances caused by the flight and the explosion of the Kola meteorite on 19.4.2014 in the lower ionosphere of the Earth // Proc. XXIX All-Russian symposium "Radar research of environment", 25-26 March 2015, Saint-Petersburg, Russia / Ed. M.M. Penkov, SPb: VKA. Is. 11. P. 648-654. 2015. (in Russian)

Tereshchenko V.D., Vasiljev E.B., Ovchinnikov N.A., Popov A.A. Medium wave radar of Polar Geophysical Institute for research of the lower ionosphere. Technical equipment and techniques of geophysical experiment. Apatity: KSC RAS, PGI. P. 37-46. 2003. (in Russian)

Tereshchenko V.D., Vasiljev E.B., Tereshchenko V.A., Ogloblina O.F., Cherniakov S.M. Wave disturbances in the lower polar ionosphere during the fall of the Chelyabinsk meteorite // Physics of Auroral Phenomena, Proc. XXXVII Annual Seminar, Apatity, Russia, 25–28 February 2014. Apatity: KSC RAS, PGI. P. 104-107. 2014.