"Physics of Auroral Phenomena", Proc. XLI Annual Seminar, Apatity, pp. 98-101, 2018

Polar Geophysical Institute

DOI: 10.25702/KSC.2588-0039.2018.41.98-101

REACTION OF THE GEOMAGNETIC FIELD TO THE FLIGHTS OF THE VILYUISK AND SAYANOGORSK METEORS

S.M. Cherniakov[1], R.A. Rakhmatulin[2], S.V. Nikolashkin[3]

[1]*Polar Geophysical Institute, Murmansk, Russia*
[2]*Institute Solar-Terrestrial Physics SB RAS, Irkutsk, Russia*
[3]*Institute of Cosmophysical Research and Aeronomy SB RAS, Yakutsk, Russia*
e-mails: sergeich@pgi.ru, rav@iszf.ru, nikolashkin@ikfia.ysn.ru

Abstract. Reaction of the geomagnetic field to the destruction of meteors in Yakutia (Vilyuysk) (on March 4, 2014 21:29 UT; 64.3°N, 123.1°E) and Khakassia (Sayanogorsk) (on December 6, 2016 11:37 UT; 52.9°N, 91.4°E) and the behavior of the geomagnetic field in the control days on March 7-8, 2014 and on December 4, 2016 according to the data of the magnetic observatory "Irkutsk" of the Institute of Solar-Terrestrial Physics of the Siberian Branch of the Russian Academy of Science (52.23°N, 104.25°E) were considered. The analysis of variations of the geomagnetic field components has shown that flights and explosions of the meteors were followed by emergence of geomagnetic disturbances near the magnetic observatory. Speeds of their propagation from places of the meteor explosions to the magnetic observatory were estimated. Possible mechanisms of influence of the explosions on the geomagnetic field are considered.

1. Introduction

The geomagnetic field is the indicator of many processes happening on the Earth, in the surrounding space and in the Sun. Variations of the geomagnetic field represent imposing of various disturbances of the geomagnetic field. Their identification is sometimes rather difficult task. The task is facilitated if parameters of the phenomenon which has caused a disturbance are known (the place, time, characteristics, etc.). All this also belongs to the meteoroids coming into the terrestrial atmosphere, and which passes are followed by various processes: heating, evaporation of particles of a space body, combustion and destruction of a meteoroid, sometimes in the form of explosion, ionization of the atmosphere, generation of various types of waves, including electromagnetic, shock (SW), acoustic-gravity (AGW), slow magnetohydrodynamic (MHD), and also disturbances of the geomagnetic field. The effect of influence on the geomagnetic field of passes and destruction of meteoroids was studied insufficiently. Still there are various mechanisms of generation of geomagnetic disturbances [*Bronshten*, 2002; *Ivanov*, 1964; *Kovalev et al*., 2006; *Rakhmatulin et al*., 2013; *Chernogor*, 2014; *Savchenko*, 1975; *Shaidurov*, 2015].

The magnetic observatory "Irkutsk"[1] (Fig. 1) is located at the distance of 21 km from Irkutsk. Coordinates of the magnetic pavilion where the digital variometer is located are 52.23°N; 104.25°E.

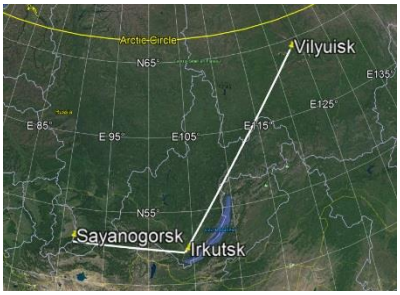

Figure. 1. Places of explosions of the Vilyuisk and Sayanogorsk meteors

2. Vilyuisk meteor

The Vilyuysk meteor has blown up at 21:29 UT on March 4, 2014. The description of the explosion and the characteristic of the meteor are given in the work [*Cherniakov et al*., 2017]. In Fig. 1 places of the meteor explosion and the magnetic observatory "Irkutsk" are shown. Distance from the place of the explosion to the magnetic observatory "Irkutsk" is about 1720 km. According to the World Data Center in Kyoto[2], at the time of the explosion the geomagnetic situation was quiet. During observations of the meteor other possible sources of disturbances in the geomagnetic field (starts of rockets, earthquakes, etc.) have not been found.

For comparison of the behavior of the geomagnetic field in the day of the meteor pass with undisturbed conditions of the geomagnetic field quiet days on March 7-8, 2014 have been chosen. Fig. 2*a-c* show variations of D, H and Z components before and after the Vilyuysk meteor explosion on March 4-5, 2014 (the continuous line) and variations of D, H and Z components in the same time during the quiet days on March 7-8, 2014 (the shaped line). In Fig. 2*a-c* it is visible that after explosion there were changes in the geomagnetic variations on March 4-5, 2014 which differ from the course of the geomagnetic variations in the quiet period. These changes can be referred to the changes caused

[1] Institute of Solar-Terrestrial Physics SB RAS *http://en.iszf.irk.ru* (15.06.2018)
[2] *http://wdc.kugi.kyoto-u.ac.jp/kp/* (15.06.2018)

by emergence of disturbances in the geomagnetic field from the meteor explosion. For the wavelet analysis of geomagnetic field variations the time periods in the range from 2 to 35 min were chosen. 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. Variations with the periods were usually observed during similar events.

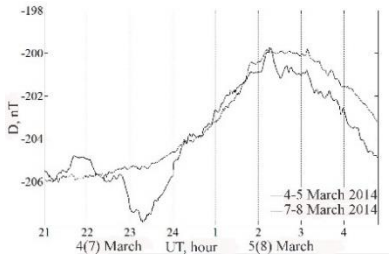

Figure 2*a*. D component

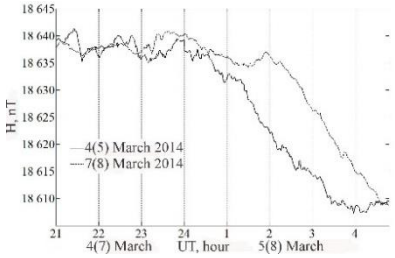

Figure 2*b*. H component

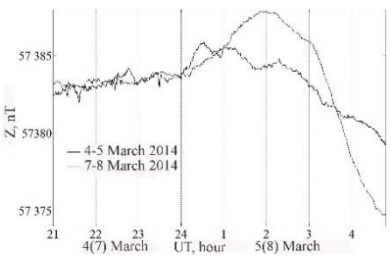

Figure 2*c*. Z component

In Fig. 3*a* it is provided the D component of the geomagnetic field (the middle figure), in the top figure the filtered D component is, in the lower figure its wavelet spectrum is (the same will be in figures of the components H and Z). The time of the meteor explosion is shown in the top figure by the vertical line. In figures it is possible to allocate three groups of the wave disturbances which have appeared after the Vilyuysk meteor explosion. The first group of disturbances was shown near the magnetic observatory practically just after the meteor explosion. Its duration was about an hour, till 22:30 UT. The second group of disturbances has come at 23:00 UT and continued a little more than two hours. The third group of disturbances has appeared at 02:10 UT. Duration of this disturbance was about two and a half hour. Changes of the D component in size during the first disturbance were about ±0.2 nT, in the second and third groups were about ±0.4 nT.

The second group of waves in the D component has come in 91 min after the explosion. Speed of arrival of this disturbance was about 315 m/s. Judging by the nature of change of magnetic field it can be qualified as the arrival of a shock wave, and then infrasonic waves. The third group of disturbances has come at 2:06 UT on March 5, 2014. Speed of its arrival was about 100 m/s.

In Fig. 3*b* and 3*c* the behavior of H and Z components is shown. Arrival of the first group of disturbances is most accurately noticeable.

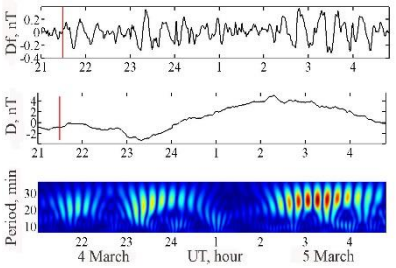

Figure 3*a*. D component

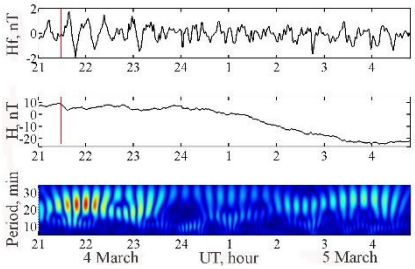

Figure 3*b*. H component

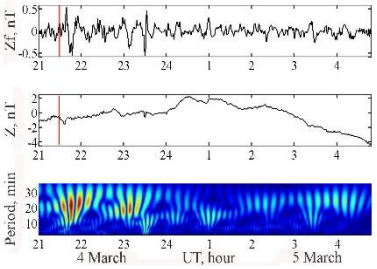

Figure 3*c*. Z component

3. Sayanogorsk meteor

The Sayanogorsk meteor has blown up on December 6, 2016 at 11:37 UT in the region between the settlements of Bogoslovka, Sizoy and Cheryomushki (52.9°N, 91.4°E). The flash from the meteor explosion was such power that it was seen by residents of Abakan (the capital of Khakassia) located in 80 km from Sayanogorsk. The distance between the place of the meteor explosion and the magnetic observatory "Irkutsk" is about 870 km (Fig. 1). The geomagnetic situation during the flight and the explosion of the meteor was weakly disturbed one.

In Fig. 4*a-c* it is shown behavior of components of the geomagnetic field in the control day on December 4, 2016 (quiet geomagnetic day, the dot line) and in the day of the meteor explosion on December 6, 2016 (the continuous line). Time of the explosion is marked by the vertical line. It is visible that after the meteor explosion in the geomagnetic field there were noticeable changes.

Unlike the Vilyuysk meteor explosion after the meteor explosion in Khakassia the arrival of groups of waves, which did not manage to be accurately divided, was observed. At 12:10 UT in the D component (Fig. 5*a*) the first weak wave manifestations became visible. Propagation speed of this disturbance from the meteor explosion to the magnetic station "Irkutsk" was about 440 m/s. At 13:00 UT essential strengthening of wave activity had occurred due to emergence of the signal which had an impulse form. Its speed of arrival could be estimated as 180 m/s. Duration of the phenomenon was about an hour and a half.

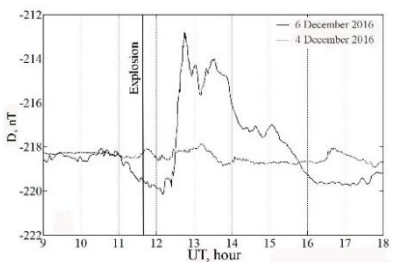

Figure 4*a*. D component

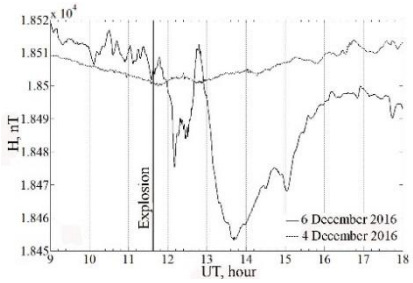

Figure 4*b*. H component

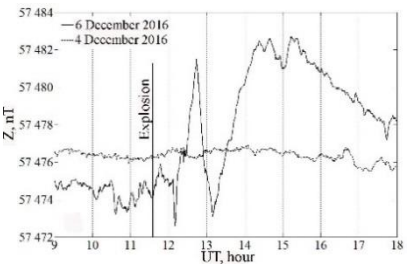

Figure 4*c*. Z component

In the H component it is possible to note also its sharp change at 12:10 UT (Fig. 5*b*). Speed of propagation of the disturbance from the meteor explosion to the magnetic station "Irkutsk" was about 440 m/s. The following group of disturbance has come at 12:20 UT. Speed of propagation of this group was about 340 m/s. These speeds of 440 and 340 m/s also correspond to speeds of arrival of the acoustic shock wave (ASW) and AGW, respectively, which are generated in the place of the meteor explosion.

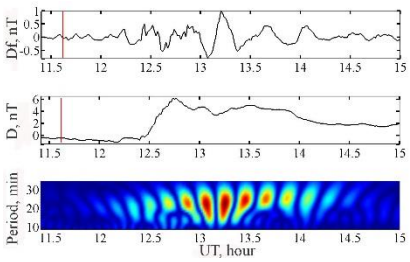

Figure 5*a*. D component

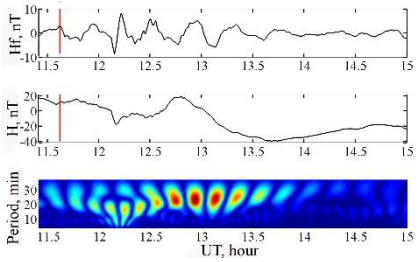

Figure 5*b*. H component

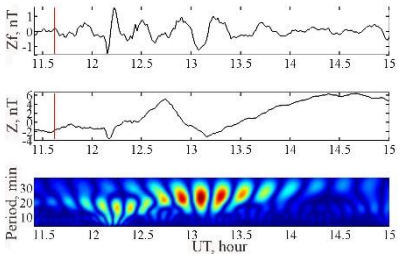

Figure 5*c*. Z component

In the Z component its sharp change also was at 12:10 UT (Fig. 5*c*). Time of propagation of these disturbances from the meteor explosion to the magnetic station "Irkutsk" was about 440 m/s. The following group of disturbances has come at 12:20 UT. Speed of propagation of this group was about 340 m/s. These speeds of 440 and 340 m/s also correspond to speeds of arrival of ASW and AGW, respectively, which are generated in the place of the meteor explosion. The behavior of the Z component is in many respects similar to the behavior of the H component.

4. Discussion

Vilyuisk meteor. The first wave manifestations in the geomagnetic field, mainly in H and Z components, before meteor explosions can be connected with reaction of geomagnetic field to emergence of a ballistic SW during the entrance of the meteoroid to more dense layers of the atmosphere [*Savchenko*, 1975]. As a rule speed of meteor movements are significantly more sound speed, therefore for meteors, big by the sizes, the supersonic movement in rather dense atmosphere is followed by emergence of the head SW passing on a stream into the departed ASW. In the place of formation of SW their amplitude is considerable, first of all, because of pressure jump. Speed of propagation of such waves can exceed considerably sound speed at the ionospheric heights. We will note that SW, in turn, is a source of AGW and slow MHD waves which then also appear near the place of observation. For the heights of the F region, by estimates of *Chernogor* [2009], speed of propagation of slow MHD waves can reach tens of kilometers per second. Propagation of such slow MHD wave at the heights of the F region of the ionosphere before the meteor explosion can cause emergence of a response of the geomagnetic field to the coming wave as a result of her impact on magnetoactive plasma and modulation of ionospheric parameters, first of all ionospheric currents in the E-region of the ionosphere, the movement of neutral components in the field of coming shock and slow MHD waves.

The second group of waves in the D component has come in 91 min after the explosion. Speed of arrival of this disturbance was about 315 m/s. It corresponds to speeds of propagation of AGW. Judging by the nature of change of the geomagnetic field during the initial stage of the second group from 23:00 UT till 23:30 UT it can be considered as arrival at first of SW, and then gravity waves. The third group of disturbances has come at 2:06 UT on March 5. Speed of its arrival was about 100 m/s. Calculated values of horizontal phase speeds of the slow MHD wave for the parameters of the environment found by means of the MSIS-E-90 model at the heights of 110-130 km for the case of the explosion of the Chelyabinsk meteor on February 15, 2013 at 03:20 UT were equal 100-160 m/s [*Tereshchenko et al.*, 2014]. The value of 100 m/s corresponds to the value of speed at the thermospheric height of 110 km. In case of explosion of the Vilyuysk meteor model conditions during propagation of disturbances are close to the considered conditions during explosion of the Chelyabinsk meteor. Therefore it is possible to assume that satisfactory compliance

between rated speed slow MHD wave and the speed received from variations of the geomagnetic field testifies in favor of thermosphere propagation of the disturbance from the explosion of the Vilyuysk meteor. Different speeds of propagation slow MHD waves (the first and third group of indignations) can be explained with various propagation channels (in the first case it is F region, in the third one it is E region).

Sayanogorsk meteor. The pass of the Sayanogorsk meteor and its destruction have made stronger impact on the geomagnetic field. It can be connected with the fact that the explosion has happened in more short distance from the magnetic observatory in Irkutsk (870 km), than in the case of the Vilyuysk meteor (1720 km). The first and second groups of disturbances in H and Z component have come around 12:10 and 12:20 UT with a speed of 440 and 340 m/s, respectively. Effects in the geomagnetic field can be connected with passing through the ionosphere of SW which was formed during the meteor explosion [*Ivanov*, 1964]. Judging by sharp change of the components of the geomagnetic field during arrival of the first group, they can be caused by SW. During its movement in the atmosphere SW turns into weak SW, acoustic waves and AGW and can propagate to long distances. They can be the cause of appearance of the second group of wave disturbance at 12:20 UT in H and Z components. All the components have a wavy appearance. Reaction of the magnetic component is different. The maximum changes were in H component (about 20 nT), the minimum one was in D component about 2 nT. It can be connected with geometry of geomagnetic field near Irkutsk as magnetic declination at the place is close to zero and, therefore, direction of propagation of disturbances from the meteor explosion were along the D component (Fig. 1).

5. Conclusion

The analysis of variations of the geomagnetic field during passes and destructions of the Vilyuysk and Sayanogorsk meteors is made. Passes and explosions of these meteors have caused changes in the geomagnetic field.

After the pass and the explosion of the Vilyuysk meteor three groups of disturbances in the geomagnetic field which had the speed of tens km/s, 315 m/s and 100 m/s have been marked. The first group of disturbances can be caused by propagation of slow MHD waves in F region of the ionosphere, the second one - by the internal gravity waves formed during propagation of ASW, the third one - by propagation of slow MHD waves at the E region heights. The pass and the explosion of the Sayanogorsk meteor have caused appearance of two groups of disturbances in the geomagnetic field which had the speed of 440 m/s and 340 m/s. The first group of disturbances can be caused by propagation of ASW, the second one – by AGW formed at generation of ASW during the explosion and its propagation.

Wave manifestations in the geomagnetic field can be caused by direct influence slow MHD waves on magnetoactive plasma and also modulation of ionospheric parameters, first of all the ionospheric currents in the E region of the ionosphere or on the movement of neutral components and the charged environment in the field of the coming ASW and AGW.

References

Bronshten, V.A. (2002). Magnetic effect of the Tungus meteorite. *Geomagnetism and Aeronomy* 42 (6), 816-818.

Cherniakov, S.M., Nikolashkin, S.V., and Tereshchenko, V.A. (2017). Vilyuysk meteor explosion: ionospheric and geomagnetic effects in the high-latitude lower ionosphere. *Proc. SPIE 10466*, 23rd International Symposium Atmospheric and Ocean Optics: Atmospheric Physics, 3-7 July 2017, Irkutsk. - P. 104664U-1–104664U-8; http://spie.org/Publications/Proceedings/Paper/10.1117/12.2282360; doi:10.1117/12.2282360.

Chernogor, L.F. (2009). Radio physical and geomagnetic effects of launches of rockets. Kharkov: KHSU, 386 p. (in Russian)

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

Ivanov, K.G. (1964). Geomagnetic effect of Tungus falling. *Meteoritika* 24,141-151 (in Russian).

Kovalev, A.T., Nemchinov, I.V., Shuvalov, V.V. (2006). Ionospheric and magnetospheric disturbances as a result of fallings of small comets and asteroids. *Astronomichesky vestnik* 40 (1), 65-76 (in Russian).

Rakhmatulin, R.A., Pashinin, A.Yu., Lipko, Yu.V., Khomutov, S.Yu., and Babakhov, I.Yu. (2013). About possible geoeffectiveness the pass of the Chelyabinsk meteoroid in the magnetic field of the Earth. *Solar-Terrestrial Physics* 24, 64-69 (in Russian).

Savchenko, Yu.N. (1975). Geomagnetic disturbances caused by shock waves of large meteorite bodies. *Geomagnetism and Aeronomy* 15 (6), 1047-1053.

Tereshchenko, V.D., Tereshchenko, V.A., Ogloblina, O.F., and Cherniakov, S.M. (2014). Behaviour of the polar ionosphere after the burst of the Chelyabinsk meteorite. *Proc. XXIV All-Russian conference "Propagation of radio waves"*, Irkutsk, 29 June – 5 July 2014, V. 2, 5-8 (in Russian).

Shaidurov, V.V. (2015). Magnetic effects of the 1908 Tungus events. *Herald of SibSAU* 16 (3), 624-631 (in Russian).