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Ionosphere response to geomagnetic storms on 7–8 September 2017 over Kharkiv (Ukraine)

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Abstract

Response of middle latitude ionospheric F-region to two sequential geomagnetic storms on 7–8 September 2017 has been studied using the incoherent scatter radar of Institute of Ionosphere (49.60ºN, 36.30ºE). The G3-class geomagnetic storm on 7 September and the G4-class geomagnetic storm on 8 September had close intensities. The first geomagnetic storm was accompanied by the positive disturbance during the main phase and the negative disturbance during the recovery phase. Effects of the second geomagnetic storm caused the negative disturbance. The ionosphere was characterized by a large-scale variation in critical frequency *fo*F2 (from 6 to 8 MHz and from 6 to 4 MHz), F2-layer peak height *hm*F2 (by 70–80 km) and the vertical plasma drift velocity oscillations (up to 50–80 m/s).

1 Introduction

Studying the influence of extreme events on processes in the Sun – interplanetary medium – magnetosphere – ionosphere – atmosphere – the Earth system is one of the most important and topical tasks of the solar-terrestrial physics [1–4]. Geospace storms can significantly modify the chemical and dynamics processes in the ionosphere-thermosphere system. The complexity and variability of the physical processes that form the ionospheric storm, the dependence of the contribution of various physical mechanisms on the geographical region lead to a large variety of observed phenomena in different regions of the Earth. Despite the fact that to date, a large number of experiments and theoretical results have been accumulated, there are still questions in predicting the reaction of the ionosphere depending on the level of solar activity. Investigation of the manifestations of the effects of geospace storms in the ionospheric plasma today remains an important problem for geophysicists. Ionospheric processes directly depend not only on the level of the heliophysical situation, but also on the location of the observation point. The purpose of the work is to analyze the altitude-temporal variations of ionospheric parameters over Ukraine during strong geomagnetic storms on September 7–8, 2017.

2 Geophysical conditions

The geomagnetic storm on September 8, 2017 was preceded by a series of intense flares on the Sun: M-class eruptions with coronal mass ejections (CME) toward Earth on September 4, a major X9.3-class flare with CME on September 6, M2.4, M1.4, M7.3-class and X1.3-class on September 7 (https://spaceweather.com/). The CME on September 6 was the most geoeffective. It arrived earlier than expected and hit Earth's magnetic field at ~23:00 UT (hereinafter UT is used) as a result it was produced a strong G3-class geomagnetic storm on 7 September. Fig. 1 illustrates the solar wind velocity *Vsw*, interplanetary magnetic field (IMF) *Bz* component measured from ACE satellite, and geomagnetic activity indices *AE*, *Dst* and *Kp* during 5–10 September 2017 [https://omniweb.gsfc.nasa.gov, https://swdcdb.kugi.kyoto-u.ac.jp]. Solar wind speed was between 200–400 km/s during 5–7 September. On 7 September after 20:00, the IMF *Bz* component sharply turned southward and attained its maximum value of –34.2 nT at 23:45. *AE* reached 1157 nT, *Kp* increased from 3– to 8–, and *Dst* decreased to about –69 nT during this period. The CME clouds produced the first geomagnetic storm with storm commencement at about 20:00. After 23:33, *Vsw* began to increase. *Kp* reached a maximum value of 8 during 00:00–03:00 and *Dst* decreased to –124 nT at 02:00. It was the end of storm main phase. At about 03:00, the IMF *Bz* component crossed its zero level.

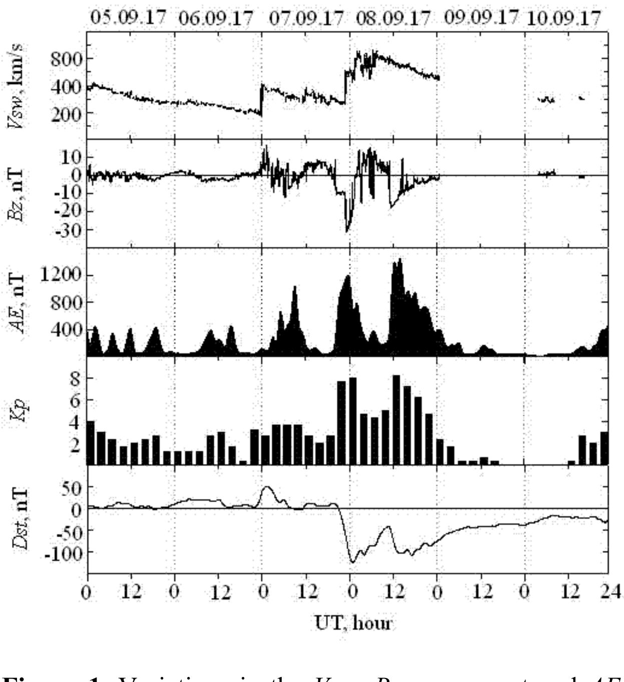

Figure 1. Variations in the *Vsw*, *Bz* component and *AE*, *Kp* and *Dst* indices.

Under the influence of a strong high-speed storm cloud, the earth's geomagnetic field was still active on 8 September and a severe G4-class geomagnetic storm commenced mid-day. On 8 September, the solar wind continued to blow faster than 700 km/s. While the storm was recovering, at 11:35, *Bz* sharply turned southward again and had negative values during about 3 hours. It attained its maximum value of about –17.5 nT at 11:55. The *AE* index increased to 1442 nT at 14:00, *Kp* reached 8+ and *Dst* decreased to –103 nT at 15:00. The storm main phase ended with minimum of *Dst* index at 18:00 when its value was –109 nT. After 18:00 on 8 September the recovery phase of geomagnetic storm had become.

3 Instruments

Incoherent scatter radar. The VHF incoherent scatter (IS) radar of Institute of Ionosphere [5, 6] is located in Ionospheric Observatory near Kharkiv city (49.60ºN, 36.30ºE, the geomagnetic coordinates are Φ=45.7°, Λ=117.8°). Radar includes a receiving and transmitting two-mirror zenith-directed parabolic antenna of 100 m in diameter. The effective aperture of the antenna is about 3700 m^2, and the width of the main beam is 1.3°. The peak pulse power of the radio-transmitter is up to 2 MW. The pulse repetition frequency is 24.4 Hz. The effective noise temperature of the system is 470–980 K. The composite dual-frequency sounding signal consists of two radio pulse elements. The first pulse has a duration of 660 µs, carrier frequency f_0=158 MHz, and the second one has a duration of 130 µs, and frequency f_1=f_0+0.1 MHz. The received, amplified and converted echo signal from the first element is used to determine the ionospheric parameters (with 100 km height resolution) from the measured quadrature components of the IS signal correlation function, and the echo signal from the second element is used to estimate the power of the IS signal with 20 km height resolution and refine the altitude profile of the electron density. Features of the measurement technique and the IS signal processing are presented in [6–8]. IS radar allows measuring the following ionospheric parameters: electron density N, ion T_i and electron T_e temperatures, a vertical component of the plasma motion velocity V_z, and ion composition with high accuracy (usually error is 1–10% in N, T_i, T_e, the fractions of H^+ and He^+ ions, and 1–30 m/s in V_z depending on the altitude, time of day, solar and geomagnetic activity). The investigated altitude range is usually 100–700 km, but can reach 100–1500 km in high solar activity period.

Ionosonde. The digital ionosonde is located not far from the IS radar in Radiophysical Observatory of V.N. Karazin Kharkiv National University (49.63ºN, 36.33ºE). It was used in collaboration with the IS radar for monitoring the general condition of the ionosphere, measuring the *fo*F2 (and, accordingly, the *Nm*F2) and for calibration of the determined by IS method normalized electron density profile at its maximum. The main parameters of the ionosonde are the following: the transmitter pulse power is up to 1.5 kW, the pulse length is 100 µs, the frequency range is 1–16 MHz, and the repetition frequency is 125 Hz. Error in *fo*F2 determining is no more than 0.05 MHz.

4 Experimental data

4.1 Fluctuations in *fo*F2 and *hm*F2

Fig. 2 shows plots of *fo*F2 observed by ionosonde station in Kharkiv during the period of 5–10 September 2017. Red line is median *fo*F2 values on 3 September over Moscow taken as data during quite geomagnetic conditions (https://ulcar.uml.edu/DIDBase/) presented for comparison. As can be seen from Fig. 2, the daytime *fo*F2 observations on 6 September at Kharkiv and Moscow stations have a good correlation. On 7 September, the *fo*F2 increased from 6 to 8 MHz during 09:00–10:00, the δ*fo*F2 reached about +45%. In turn the *hm*F2 (that was obtained from the IS radar observations) increased from 190–200 to 270–275 km. During 00:00–03:00 on 7 September *Vsw* speed increased sharply from 200 to 400 km and *Dst* index increased to +50 nT. During the main phase of G3-class geomagnetic storm, *fo*F2 increased on 7 September, δ*fo*F2 reached +43%. Before 24:00, *fo*F2 became to decrease. During this time, the *hm*F2 values were upper than during quite conditions. The ionosphere at middle-latitudes was characterized by a negative storm effect during the recovery phase of the storm. On 8 September during 03:00–12:00, the negative ionospheric disturbance was observed, *fo*F2 decreased from about 6 to 4 MHz during 10:30–12:30. Accordingly, δ*fo*F2 had negative values and its maximum value was about –35%.

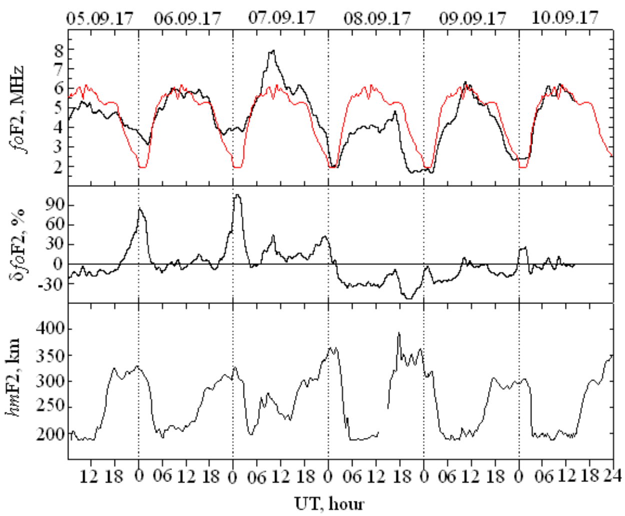

Figure 2. Variations in *fo*F2, δ*fo*F2 and *hm*F2 during the period of 5–10 September 2017 observed over Kharkiv.

As a result of the second G4-class geomagnetic storm, the next negative ionospheric disturbance had begun after 17:00. The δ*fo*F2 lowered to –53%. The severe storm on 8 September contributed to an increase in the F2-layer peak height from 290–320 km to 340–385 km.

4.2 Variations in T_e and T_i

Fig. 3 illustrates the behavior of the T_e and T_i at altitudes of 200–550 km during 05–10 September. The *fo*F2 increase by 2 MHz and the *hm*F2 increase by 75–80 km were accompanied with ionospheric plasma temperatures decrease during 09:00–12:00 on 7 September. Variations in T_i were changed at altitudes of 300–550 km. The geomagnetic storm start on 7 September was accompanied by heating of the plasma at night on 8 September during 00:00–03:00, the diurnal variations of the T_e and T_i temperatures were changed significantly. At altitudes of 200–250 km, T_e decreased during the recovery phase of the storm. As for T_i, its diurnal variations were changed to sizeable extent at all observed altitudes. As a result of the influence of the second storm, the temporal temperature variations in the evening of 8 September and during 00:00–03:00 on 9 September also differed from the variations under quite conditions of 6 September. On September 9, temperatures have not yet regained their characteristic diurnal variations.

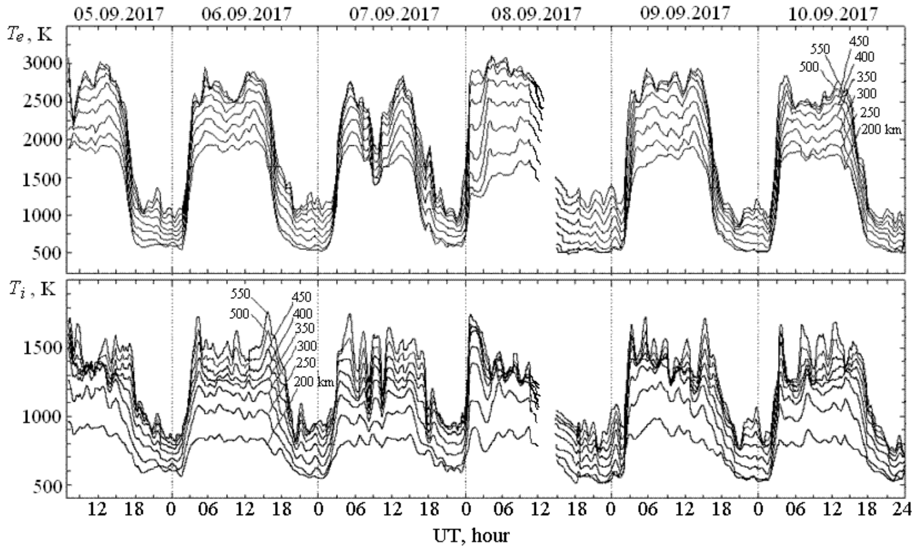

Figure 3. Variations in T_e and T_i during the period of 5–10 September 2017 observed over Kharkiv.

4.3 Variations in V_z

Geomagnetic storm has affected the vertical component of the ionospheric plasma motion velocity V_z (Fig. 4). On 7 September, from 12:00 to 24:00, oscillations in V_z variations at altitudes of 200–310 km were recorded with a period of about 3 hours and amplitude of about 9 m/s.

On 8 September, at 00:00 (approximately 2 hours after the start of the main phase of the geomagnetic storm), single V_z oscillations (up to 50–80 m/s) arose at altitudes of 420–530 km. The absolute value of the downward ($V_z < 0$) plasma drift velocity first decreased. At altitudes of 470–530 km, the plasma changed the direction of motion from downward to upward ($V_z > 0$) one, and then again to downward with a further increase in the V_z absolute value. The maximum V_z deviation occurred about 01:00. The beginning of this whole process coincided with the beginning of the decrease in *fo*F2. The next oscillation (in the direction of increasing the magnitude of the downward plasma motion velocity) took place at all altitudes with an extremum about 02:00. A similar deviation in the V_z variations was observed from 04:15 to 06:30 with an extremum (~40 m/s) at 05:45. As a result of the second geomagnetic disturbance, two deviations in V_z variations occurred with a maximum decrease in its modulus at 15:00 and an increase at 17:00.

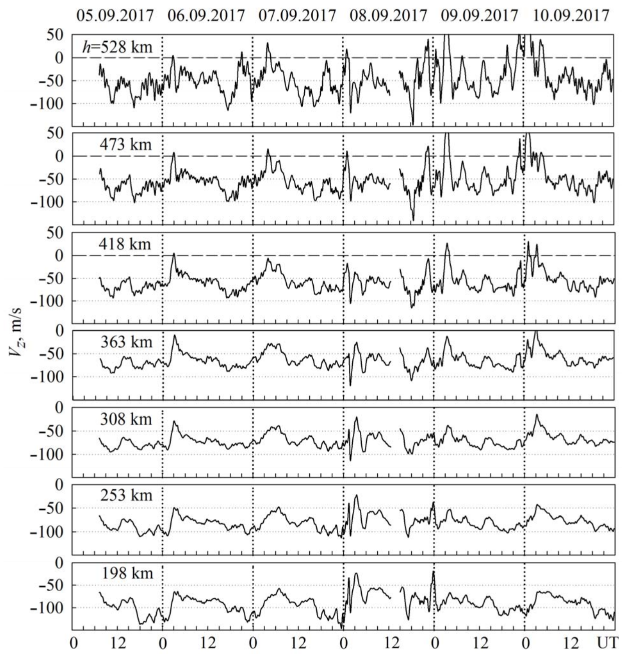

Figure 4. Temporal variations in the vertical plasma drift velocity V_z at fixed altitudes.

5 Discussion

The data presented in this paper have shown the response of middle latitude ionosphere to two sequential geomagnetic storms with close intensities. The multi-instrument observations at mid- and high-latitudes of Northern Hemisphere [9] showed that the impact on the ionosphere of the first and second storms was rather similar. However, ionospheric response on two sequent storms was complex, especially during the second storm. The ionosphere disturbance in period 7–8 September 2017 is characterized by a short positive ionospheric storm during the main phase of the first geomagnetic storm, a long-duration negative storm during the recovery phase of the same geomagnetic storm, and a much stronger negative storm during the recovery phase of the second geomagnetic storm. Observed positive phase in *fo*F2 and the large increase in *hm*F2 during the main phase of the storm (at night-time) were most probably caused by the equatorward wind and an eastward penetration electric field. During the first negative disturbance on 8 September, significant changes in *hm*F2 were not observed, whereas the diurnal variations in T_e and T_i were changed significantly. The increase in plasma temperature observed during two negative disturbances and the decrease in [O]/[N2] ratio from 0.55 (on 7 September) to 0.35 (on 8 September) (http://guvitimed.jhuapl.edu/) led to decrease in *fo*F2 [10].

6 Conclusions

In this paper, we have analyzed the ionospheric storm effects accompanied two successive strong geomagnetic storms. The main results of this study are as follows:

1. Strong geomagnetic storms were accompanied by a positive and two negative disturbances of the ionosphere over Kharkiv, the extreme points of the critical frequency deviation were about +45%, –35% and –53% respectively.

2. Strong storms in the geospace contributed to an increase in the F2-layer peak from 190–200 to 270–275 km during the positive storm and from 290–320 km to 340–385 km during the second negative storm.

3. Plasma heating was observed at night September 7–8. During a prolonged negative ionospheric perturbation, the diurnal variations in the temperatures of electrons and ions were changed significantly.

4. During the main phase of the first geomagnetic storm, the quasiperiodic oscillations in the vertical drift velocity V_z were observed at altitudes of 200–310 km with a period of about 3 hours and amplitude of about 9 m/s. Single V_z oscillations (up to 50–80 m/s) were detected during the recovery phases of both geomagnetic storms.

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7 References

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