Ionosphere response to space weather events on 21–23 March 2017 in the central region of Europe

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Abstract

The paper presents the results of experimental studies of the manifestations of ionospheric storms in the Central European region during the geomagnetic storm on March 21–23, 2017. The time dependences of the critical frequency of the ionospheric F2 layer *fo*F2 and the F2 peak height *hm*F2, the altitude-time dependences of the electron temperature T_e, ion temperature T_i, electron density N_e and vertical ionospheric plasma drift velocity V_z in the altitude range 190–500 km for disturbed and reference days were obtained. The minor storm was featured by the presence of three negative phases of ionospheric disturbance.

1 Introduction

High-speed solar wind streams as coronal mass ejections can cause not only disturbances of the magnetosphere but also severe geomagnetic storms under certain conditions. The ability of high-speed solar wind streams in causing geomagnetic storms is referred to as geoeffectiveness. Coronal holes are solar sources of geoeffective structures. In this paper we presented ionospheric effects during such one of geomagnetic storms. Ionospheric storms remain topical task and challenging topic of upper atmosphere physics today. A number of studies have been published to summarize the understanding of ionospheric storms from both observations and theoretical models of ionosphere [1–4]. Due to complexity and variability of the physical processes that form the ionospheric storms, there are still open questions and contradictions in understanding of some aspects of ionospheric processes. Scientists have the goal to explore the characteristics, causes and consequences of ionosphere structures and dynamics processes during not only strong disturbed conditions but also during minor storms.

The purpose of this paper is to present and compare the results of studies of ionosphere effects during a minor geomagnetic storm on 21–23 March 2017.

2 Instruments and data

The solar wind and interplanetary magnetic field (IMF) conditions were assessed using the data from ACE (Advanced Composition Explorer) satellite. The ground-based measurement data were obtained from the VHF incoherent scatter (IS) radar (49.60ºN, 36.30ºE, the geomagnetic coordinates are Φ=45.7°, Λ=117.8°) and the digital ionosonde (49.63ºN, 36.33ºE).

The IS radar is located in Ionospheric Observatory of Institute of Ionosphere [5] near Kharkiv city. Radar includes a receiving and transmitting two-mirror zenith-directed parabolic antenna of 100 m in diameter. The antenna effective aperture is about 3700 m^2, the width of the main beam is 1.3°. The peak pulse power of the radio-transmitter is 2 MW. The pulse repetition frequency is 24.4 Hz. Features of the measurement technique and the IS signal processing are presented in [6, 7].

The digital ionosonde is located in Radiophysical Observatory of V.N. Karazin Kharkiv National University not far from the IS radar. It was for monitoring the general condition of the ionosphere, measuring the critical frequency *fo*F2 and for calibration of the determined by IS method normalized electron density profile at its maximum. The transmitter pulse power of the ionosonde 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.

3 Geophysical conditions

On March 18, 2017, a wide stream of solar wind began to flow from the coronal hole, which turned toward Earth (https://spaceweather.com/). Solar wind from the coronal hole began to reach Earth on 20 March (see Fig. 1). Fig. 1 illustrates the solar wind parameters, components of interplanetary magnetic field, and indices of geomagnetic activity during 20–24 March 2017 [https://omniweb.gsfc.nasa.gov, https://swdcdb.kugi.kyoto-u.ac.jp].

On 20 March after 20:00 UT (hereinafter UT is used), the density n_{sw} had increased by 2 times. The n_{sw} still increased to 07:00 on 21 March. During this time, the dynamic pressure p_{sw} increased too. As a result, index AE reached 436 nT and index K_p was 4. Index D_{st} had positive values and at 08:00 sharply reached –2 nT. Solar wind velocity V_{sw} and its temperature T_{sw} continued to increase. T_{sw} was 4.7·10^5 K at 11:00, V_{sw} was 615 km/s at 14:00. At 15:00, T_{sw} had its maximum value 4.84·10^5 K. After 08:00, B_y and B_z components had southward direction, and after 11:00 D_{st} values began to decrease. At 17:00, p_{sw} reached 4.7 nPa, and maximum of AE index was 971 nT. Index K_p was 5– during 15:00–18:00 and minimum of index D_{st} was –24 nT. During next increasing of p_{sw} to 5 nPa from 19:00–22:00, *AE* maximum was 956 nT, K_p maximum was 5+, minimum of D_{st} index was –27 nT at 19:00. It was a minor G1-class geomagnetic storm (NOAA space weather scale for geomagnetic storms).

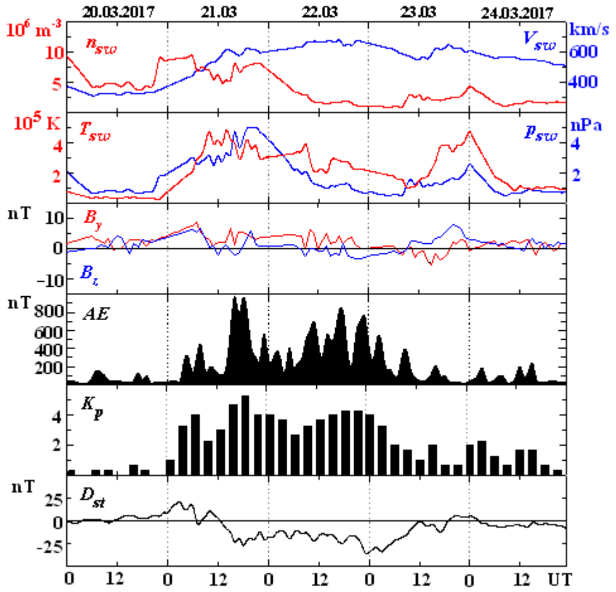

Figure 1. Variations of solar wind parameters: density n_{sw}, velocity V_{sw}, temperature T_{sw} and dynamic pressure p_{sw}; IMF B_y and B_z components, *AE*, K_p and D_{st} indices.

On March 22, magnetosphere was disturbed: solar wind velocity was more 600 km/s and its temperature had sharp increases. Variations of B_z-component were sharp too. The *AE* index had three clear highs: 692, 825 and 754 nT. K_p maximum was 4+ during 18:00–24:00. D_{st} minimum was –35 at 24:00 and at 01:00 on 23 March.

On March 23, velocity V_{sw} was more 500 km/s and temperature T_{sw} had big values more $4 \cdot 10^5$ K. Values of geomagnetic activity indices began to decrease and the recovery phase had become. On 24 March Earth's magnetosphere was quiet.

4 Experimental data

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

Fig. 2 shows plots of critical frequency *fo*F2 observed by Kharkiv ionosonde station and its deviations δ*fo*F2. Green line is median values of *fo*F2 during quiet geomagnetic conditions on March 20, 2017; red line is following experiment data during the period of 21–23 March 2017. From about 20:00 on 21 March to 07:00 on 23 March there was three-phase negative ionospheric disturbance with extreme δ*fo*F2 deviations up to –40, –20 and –32% respectively. The values of the F-region electron peak density (*Nm*F2), corresponding to the *fo*F2 frequency, decreased by 2, 1.4, and 1.7 times, respectively.

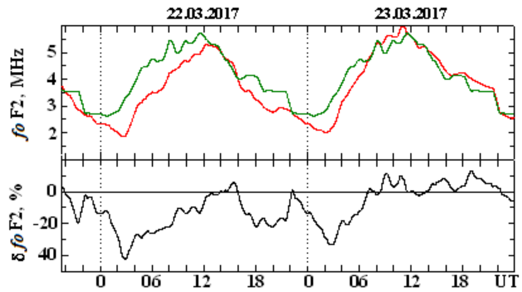

Figure 2. Temporal variations in *fo*F2 and δ*fo*F2.

Fig. 3 presents the behaviors of F2-layer peak height (*hm*F2) during minor storm (red line), during reference days of March 23–25, 2010 (green line), and the deviations of height (δ*hm*F2). Reference days of 23–25 March, 2010 had similar heliophysical conditions characterized by the solar activity index F10.7 to the period of IS studies in March 2017. According to the IS radar data, fluctuations in *hm*F2 did not exceed 10–15%. So, geomagnetic conditions had little effect on its variations.

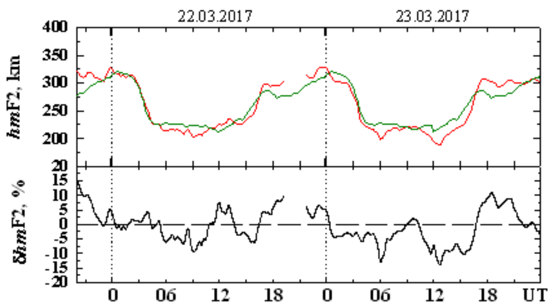

Figure 3. Temporal variations in *hm*F2 and δ*hm*F2.

4.2 Variations in N_e

During negative phase of the ionospheric disturbance, the electron density N_e decreased by 1.5–3.5 times at altitudes of 200–500 km. The altitude-temporal dependences of electron density N_e during the experiment period of 21–23 March, 2017 and reference days of 23–25 March, 2010 are presented in Fig. 4. We see, the greatest N_e changes were observed at heights of about 300 km.

4.3 Variations in T_e and T_i

The behavior of temperatures T_e and T_i at altitudes of 200–450 km during IS experiment days of 21–23 March 2017 and reference days of 23–25 March 2010 is presented in Fig. 5. The beginning of the first negative ionosphere phase was accompanied by the heating: on 21 March 2017, we see quick increase of T_e about 03:00. The T_e increasing during the first and the third negative phases of ionosphere disturbance reached 250 K or 10%. During the second negative phase, at heights of 400–450 km, T_e had decreased on about 100 K. The T_i changes during disturbance were insignificant.

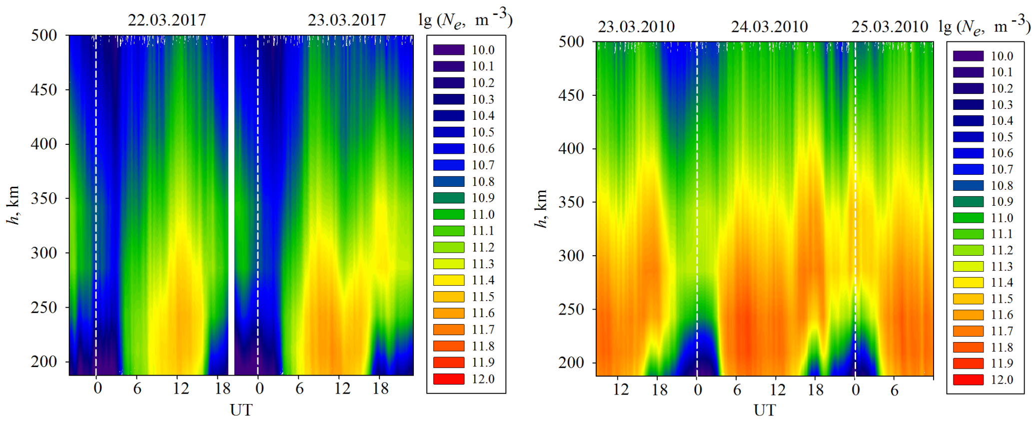

Figure 4. Variations in N_e during the experiment period of 21–23 March, 2017 and reference days of 23–25 March, 2010.

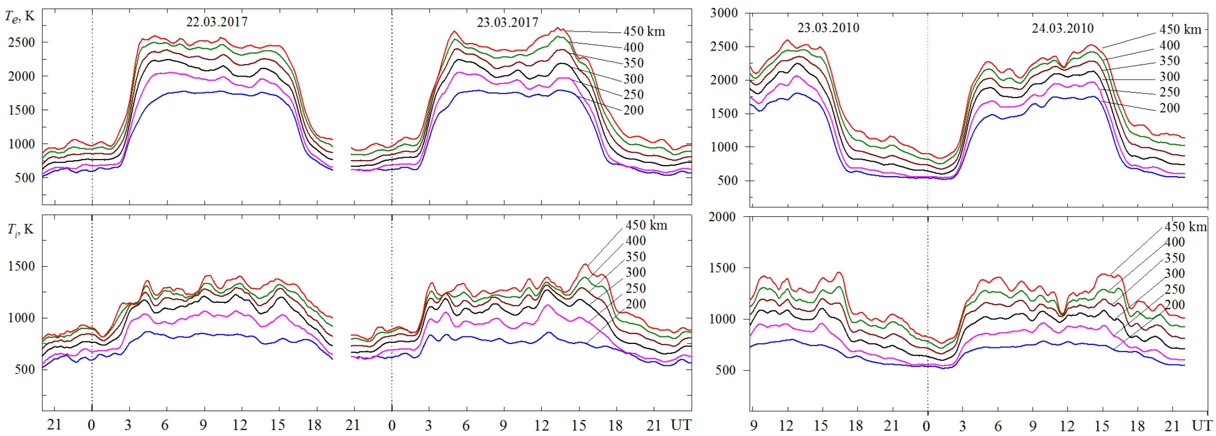

Figure 5. Variations in T_e, T_i during the experiment period of 21–23 March, 2017 and reference days of 23–25 March, 2010.

4.3 Variations in V_z

Fig. 6 illustrates the temporal variations in the vertical plasma drift velocity V_z at fixed altitudes during 21–23 March 2017 (red lines) and during reference days 23–25 March 2010 (green lines).

On March 22, from 01:33 to 05:30, a decrease in the absolute value of the velocity of the downward (V_z<0) plasma drift was observed with a change in the direction of plasma movement to an upward one (V_z>0), followed by the restoration of V_z. The largest deviations in velocity variations at all heights (with respect to the data obtained on the reference day on March 24, 2010) were recorded at 03:45. They were 40, 37, 35, 29, and 13 m/s at heights of 198, 253, 308, 363, and 418 km, respectively. The second fluctuation of V_z was observed in the opposite direction from 05:30 to 06:45 with an extreme at 06:00. From 22:55 on March 21 to 04:36 on March 22, 2017, quasi-periodic oscillations of V_z with a period of about 50 minutes were observed. Differences were revealed between the results of V_z measurements on March 23, 2017 and on the reference day on March 25, 2010 in the period during 00:00–03:45. The largest deviations of V_z took place at 02:00 and were 22, 2, –16, –27, and –29 m/s at heights of 198, 253, 308, 363, and 418 km, respectively.

5 Discussion

The data presented above have shown the response of middle latitude ionosphere to the interplanetary events on 21–22 March 2017. Changes in *fo*F2 variations during 22–23 March 2017 resulted from the input of solar wind energy captured by the Earth's magnetosphere and then released and dissipated into the auroral ionosphere on March 21–22, 2017. The geomagnetic storm had weak influence on variations of F2-layer peak height *hm*F2 over Ukraine and temperatures of electrons and ions. Similar effects were observed during the recovery phase of geomagnetic storm on March 14–17, 2016 [8]. However, we see appreciable difference in electron density in the altitude range 200–500 km. In turn, it was accompanied by composition changes of O and N_2 throughout the period of disturbed magnetosphere: the decrease in [O]/[N_2] ratio from 0.45–0.5 on 20 March, to 0.4–0.45 on 21 March, to 0.1–0.2 on 22–23 March (http://guvitimed.jhuapl.edu) and it led to decrease in *fo*F2. Apparently, the motion of heated gas from auroral region to middle latitudes did not have time to cool down. As a result, [O]/[N_2] ratio decreased and the increase in T_e during the first and the third negative phases, we managed to observe disturbances of mid-latitude ionosphere during 22–23 March 2017 in the central region of Europe.

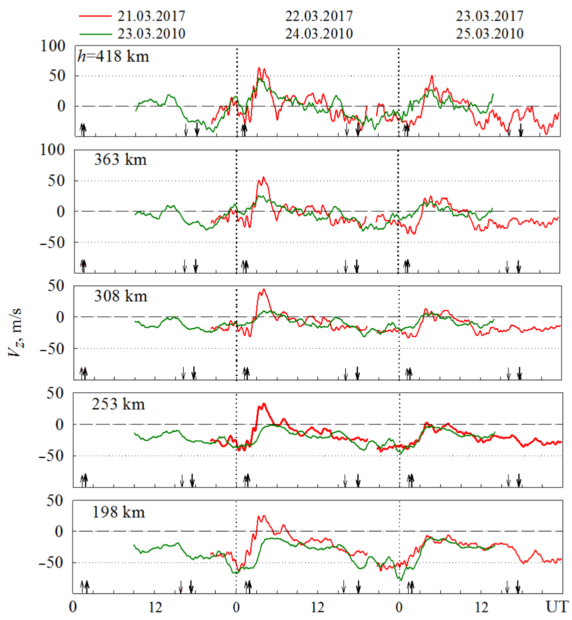

Figure 5. Temporal variations in V_z at fixed altitudes. The instants of sunrise and sunset at the corresponding altitudes are indicated by bold arrows for the Kharkiv incoherent scatter radar (49.6° N, 36.3° E) and thin arrows for the magnetically conjugated region (36.5° S, 52.2° E).

6 Conclusions

We have analyzed the ionospheric storm effects at middle latitude as a response to the minor G1-class geomagnetic storm during 21–22 March 2017. The main results of this study are as follows.

1. The minor geomagnetic storm caused a three-phase negative ionospheric disturbance over Ukraine with the critical frequency *fo*F2 decreasing to 40, 20 and 32% respectively. It reduced to electron density *Nm*F2 decrease in 2, 1.4 and 1.7 tames, respectively.

2. The ionospheric disturbance was accompanied by an insignificant heating of the ionosphere plasma: the electron temperature increased by an average of 250 K and the ion temperature changed slightly.

3. During the storm, significant deviations in the ionosphere plasma drift velocity variations were observed. The greatest velocity changes recorded on 22 March at 03:45 varied with altitude from 40 up to 13 m/s in the altitude range of 200–420 km. From 22:55 on 21 March to 04:36 on 22 March, quasiperiodic velocity oscillations with a period of about 50 minutes were observed.

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7 References

1. I. F. Domnin, L. Ya. Emelyanov, S. V. Katsko, L. F. Chernogor, “Ionospheric effects of geospace storm of November 13–14, 2012”, *Radio Phys. Radio Astron.*, **19**, 2, February 2014, pp. 170–180. http://doi.org/10.15407/rpra19.02.170 (in Russian).

2. L. Ya. Emel’yanov, M. V. Lyashenko, L. F. Chernogor, I. F. Domnin, “Motion of Ionospheric Plasma: Results of Observations above Kharkiv in Solar Cycle 24”, *Geomagn. Aeron.*, **58**, 4, July 2018, pp. 533–547, http://doi.org/10.1134/S001679321802007X.

3. S. V. Katsko, L. Ya. Emelyanov, I. F. Domnin, L. F. Chernogor, ”Ionosphere response to geomagnetic storms on 7–8 September 2017 over Kharkiv (Ukraine)”, *URSI GASS 2020, Rome, Italy, 29 August – 5 September 2020. Conference Proceedings,* 2020. http://doi.org/10.23919/URSIGASS49373.2020.9232440.

4. D. R. Themens et al., “Topside electron density representations for mid and high latitudes: A new NeQuick and E-CHAIM topside parameterization”, *J. Geoph. Res.: Space Phys.*, **123**, 2018, pp. 1–15. http://doi.org/10.1002/2017JA024817.

5. L. Ya. Emelyanov, T. G. Zhivolup, “History of the development of IS radars and founding of the Institute of Ionosphere in Ukraine”, *Hist. Geo Space Sci.*, **4**, 1, February 2013, pp. 7–17. http://doi.org/10.5194/hgss-4-7-2013.

6. I. F. Domnin et al., “Kharkiv Incoherent Scatter Facility”, *Bulletin of NTU “KhPI”. Series: Radiophysics and ionosphere,* no. 47 (1089), 2014, pp. 28–42. http://repository.kpi.kharkov.ua/bitstream/KhPI-Press/11199/1/vestnik_HPI_2014_47_Domnin_Kharkiv.pdf.

7. O. Bogomaz, D. Kotov, S. Panasenko, L. Emelyanov, “Advances in software for analysis of Kharkiv incoherent scatter radar data”, *2017 International Conference on Information and Telecommunication Technologies and Radio Electronics (UkrMiCo) 11–15 Sept. 2017, Odesa, Ukraine, IEEE Conference Publications*, 2017, pp. 531–535. http://doi.org/10.1109/UkrMiCo.2017.8095425.

8. S. V. Katsko, L. Ya. Emelyanov, L. F. Chernogor. The ionosphere effects observing over Kharkiv during the relaxation phase of geomagnetic storm on March 14–17, 2016. *Bulletin of NTU “KhPI”. Series: Radiophysics and ionosphere*, 34, 2016, pp. 8–12. http://nbuv.gov.ua/UJRN/vcpiri_2016_34_4 (in Russian).