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 foF2 and the F2 peak height hmF2, the altitude-time dependences of the electron temperature Te, ion temperature Ti, electron density Ne and vertical ionospheric plasma drift velocity Vz 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 ionospheric 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 (49.60°N, 36.30°E, the geomagnetic coordinates are Φ=45.7°, Λ=117.8°) and the digital ionosonde (49.63°N, 36.33°E).

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 m², 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 foF2 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 foF2 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://swecdb.kugi.kyoto-u.ac.jp].

On 20 March after 20:00 UT (hereinafter UT is used), the density nsw increased by 2 times. The nsw still increased to 07:00 on 21 March. During this time, the dynamic pressure psw increased too. As a result, index AE reached 436 nT and index Kp was 4. Index Dst had positive values and at 08:00 sharply reached −2 nT. Solar wind velocity Vsw and its temperature Tsw continued to increase. Tsw was 4.7·10⁵ K at 11:00, Vsw was 615 km/s at 14:00. At 15:00, Tsw had its maximum value 4.84·10⁵ K. After 08:00, By and Bz components had southward direction, and after 11:00 Bx values began to decrease. At 17:00, psw reached 4.7 nPa, and maximum of AE index was 971 nT. Index Kp was 5– during 15:00–18:00 and
minimum of index $D_{st}$ was $-24$ nT. During next increasing of $p_w$ 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).

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 $foF2$ and $hmF2$

Fig. 2 shows plots of critical frequency $foF2$ observed by Kharkiv ionosonde station and its deviations $\delta foF2$. Green line is median values of $foF2$ 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 $\delta foF2$ deviations up to $-40$, $-20$ and $-32$% respectively. The values of the F-region electron peak density ($NmF2$), corresponding to the $foF2$ frequency, decreased by 2, 1.4, and 1.7 times, respectively.

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.
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 $f_o F_2$ 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 $h m F_2$ 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 $f_o F_2$. 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.
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 $f_{o}F_2$ decreasing to 40, 20 and 32% respectively. It reduced to electron density $N_{m}F_2$ 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.

6 Acknowledgements

The authors thank A.F. Kononenko and O.V. Bogomaz for their help in conducting experiments at Kharkiv IS radar. The work is partially supported by projects 0119U100032 “Investigations of long-term changes of the plasmasphere: new results for security into the space and on Earth” funded by MES of Ukraine, 0117U004133 “Investigations of plasma drift velocity and wave processes in the midlatitude ionosphere of the Central European region under conditions of low solar activity” funded by NAS of Ukraine, and 2020.02/0015, “Theoretical and experimental studies of global disturbances from natural and technogenic sources in the Earth-atmosphere-ionosphere system”.

7 References


