Variations in the ionospheric parameters over midlatitude Europe region during September 6 – 10, 2017 geomagnetic storm caused by coronal mass ejections

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Geomagnetic storms (GS) significantly affect ionospheric variability and state of ionization. The irregular processes occurring in the ionosphere exert influence on modern HF technologies both in outer space, for example, on satellites, and on Earth-based infrastructures such as radars, navigation systems and radio communications. Therefore, understanding and modeling the effect of GS on variations of various ionospheric parameters is extremely important for applied purposes.

This study presents the response of the European midlatitude ionosphere on the intense GS of September 6 – 10, 2017. The key point is that this GS was caused by coronal mass ejections (CMEs) with a full-halo on September 6. Another important aspect is that the aurora oval extended to lower latitudes during the analyzed period.
Space weather conditions

Figure 1. Time series of (a) $D_{st}$ and $K_p$ geomagnetic activity indices, (b) the IMF $B_z$ and $B_y$ components, (c) magnitude of $B$ component of the IMF and IEF $E_y$, (d) solar wind speed $V$ and AE index, (e) pressure $P$ and temperature $T$ during the period of 6 - 10 September 2017.

(https://omniweb.gsfc.nasa.gov/form/dx1.html)
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**Kharkiv incoherent scatter (IS) radar**

**Geographic coordinates:** 49.6°N, 36.3°E  
**Antenna:** 100-m fixed, zenith-directed  
**Operating frequency:** 158 MHz  
**Measured parameters:** The height profiles of electron ($T_e$) and ion ($T_i$) temperature, variations in the F2 peak electron density ($NmF2$), height ($hmF2$) and critical frequency ($foF2$), a vertical component of the plasma motion velocity, ion composition, IS power data.  
**Height resolution:** for IS power - 20 km, for $T_e, T_i$ and ion composition - 100 km

The calibration of electron density profiles is performed using ionosonde located in the vicinity of the IS radar. 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 $foF2$ determining is no more than 0.05 MHz.
Results

Figure - Variations in $T_e$, $NmF2$ and $hmF2$ during the period of 6–10 September 2017 observed over Kharkiv.
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Figure - Variations in \( Te \), \( NmF2 \) and \( hmF2 \) during the period of 6–10 September 2017 observed over Kharkiv,\( _{12} \)}
For determining the TID vertical propagation parameters (vertical phase velocity $V_z$ and wavelength $\lambda_z$), we used cross-correlation analysis. In this case, the value of $V_z$ is estimated using approximation of time lag or advances for oscillations at a number of altitudes relative to fluctuations at a specific altitude (200 km). Then $V_z = \frac{dz}{d\tau} \approx \frac{\Delta z}{\Delta \tau}$, where $\Delta z$ is a difference between two adjacent altitudes; $\Delta \tau$ is difference between time advances or lags for these altitudes; $\lambda_z = V_z T$. 

**Fig. – Stages of data analysis:**

a) IS power $P$ values (red) with trend (black dotted line);

b) absolute variations $\Delta P$;

c) relative variations $\delta P$;

d) 60 – 120 min band-pass filtered of $\delta P$;

e) energy periodogram $\delta S_P$;

f) altitude-time dependence of 5 – 125 min and 60 – 120 min band-pass filtered variations of $\delta P$;

g) altitude profiles of relative amplitudes
Results

Figure - Amplitude spectra of relative variations in IS signal power $\delta P$ at the altitude of 200 km (top panel) and altitude-time dependence of $\delta P$ band-pass filtered in the range of 120 – 240 min (bottom panel).
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**TIDs parameters:**

- Dominant periods: $150 - 180$ min
- Maximum values of $\delta P$ vary from 14 to 30%
- $h_{\text{max}} = 200 - 225$ km
- $V_z = 35 - 50$ m/s and $\Lambda_z = 250 - 400$ km.
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In this study we analyzed the ionospheric behavior over midlatitude European region during the period of intense geomagnetic storm 6 – 10 September 2017, caused by CMEs. A strong increase of $NmF2$ accompanied by a sharp $Te$ decrease and significant $hmF2$ uplift were found. It was revealed that a sharp spike in $Te$ associated with the minimum of $Dst$ – index. Whereas, along with a sharp decrease in $Te$, there was an increase in $NmF2$ to about 5000 K and $hmF2$ by 65 km.

In addition, LSTIDs with the periods of 120 – 240 min as well as their vertical parameters were estimated. Intense fluctuations were observed in the morning and evening hours, which indicated the solar terminator as the most likely additional source of their generation.
Thank you for your attention!