INCOHERENT SCATTER RADAR STUDY OF THE APRIL 28-29, 2001 STORM AT KHARKIV

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ABSTRACT

The most notable features are (1) the burst of the electric field in the ~00:06–10:00 UT interval during which the O+ ion fluxes exhibit a wave-like fluctuation at 300 km altitude with the peak-to-peak amplitude of 6×10^7 cm^{-2} s^{-1} and even a reverse in direction from upward to downward at 600 km and 900 km altitudes with the peak-to-peak amplitudes of 2×10^7 cm^{-2} s^{-1} and 0.8×10^7 cm^{-2} s^{-1}, respectively; (2) hmF2 uplifting during ~07:00–08:30 UT time interval; (3) traveling ionospheric disturbance around hmF2 during entire April 28, 2001.

INTRODUCTION

The Kharkiv Observatory at 49.6 degrees north latitude, 36.3 degrees east longitude is well situated to observe effects related to magnetosphere-ionosphere coupling deep in the plasmasphere, L ≈ 2.0. The Kharkiv VHF incoherent scatter radar has been in operation through several solar cycles and used to monitor ionospheric features and response over the altitude range of 100 km to approximately 1500 km with a typical altitude resolution of 40 km to 120 km.

As Kharkiv ISR measurements show, storms are generally associated with significant changes in the behavior of the ionosphere, which can be explained in terms of thermospheric disturbances, variations in ion composition, Joule heating enhancements in the high-latitude thermosphere, and other processes.

SOLAR-GEOPHYSICAL CONDITIONS [1]

The four days April 24 – 27, 2001 preceding the storm interval were geomagnetically quiet, with daily Ap varying between 7 and 8. The geomagnetic storm of April 28 – 29 began with a gradual storm commencement observed on April 28. Kp reached a maximum of 5+ for three 3-h intervals and Ap was 28 on that day. The geomagnetic field was disturbed on 28 – 29 April due to the coronal mass ejection passage. The disturbance began with a sudden impulse at 05:03 UT on April 28, 2001 (76 nT, as measured by the Boulder USGS magnetometer) followed by unsettled to major storm levels. The disturbance ended around midday on April 29, 2001. Quiet to unsettled conditions occurred during the remainder of the period.

INCOHERENT SCATTER RADAR EXPERIMENT ANALYSIS

The Kharkiv incoherent scatter radar experiment ran from 12:03 UT on April 26, 2001 to 03:58 UT on April 29, 2001, and encompassed approximately the 250 km to 1500 km height range. The radar operates at 158 MHz (1.9-m wavelength) with a ~2.4 MW peak power. The measurements were acquired with a one-minute resolution and then binned in fifteen-minute intervals. The VHF radar vertically pointed parabolic 100-m antenna emitted uncoded single pulses of 800-micros in length providing a relatively poor ~120 km height resolution for improving the signal to noise ratio at great heights where the light ions dominate. The auto-correlation function measurements were taken at a number of time delays, typically 18, with a ~30-micros lag [2]. The temperatures and ion number densities were estimated by comparing experimental and theoretical auto-correlation functions [2]. The sine and cosine samples of the IF output were fed into the computer routine that provided simultaneous data on the vertical component of the ionospheric plasma drift versus height.

F2 REGION PEAK

On the whole, a positive ionospheric storm was observed, and the foF2 values exceeded quiet time reference values acquired on April 27, 2001 by up to ~1.5 MHz over the ~02:00–11:00 UT interval. During this time interval, the most notable feature is a brief uplifting near the F2 region peak during ~07:00–08:30 UT time interval (Fig. 1). The time dependences of the F-layer peak altitude, hmF2, the F-region peak density, NmF2, (Fig. 2) and the vertical component of the ionospheric plasma drift near the F2 peak show maxima of ~1 hour in duration after a sudden impulse at 05:03 UT on April 28, 2001. The increase in the vertical component of the upward drift velocity occurred first, with a maximum effect at ~07:20 UT (Fig. 3), then, the maximum effect in hmF2 followed at ~08:00 UT (Fig. 1), and finally in NmF2 at ~08:40 UT (Fig. 2).

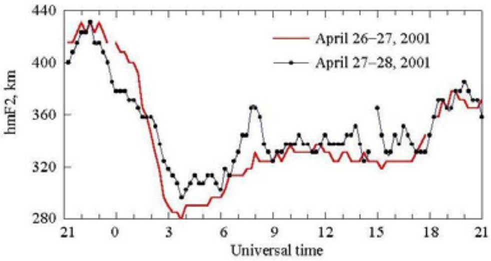

Fig.1. F2-region peak height on a reference quiet day April 27, 2001 and the disturbed day April 28, 2001

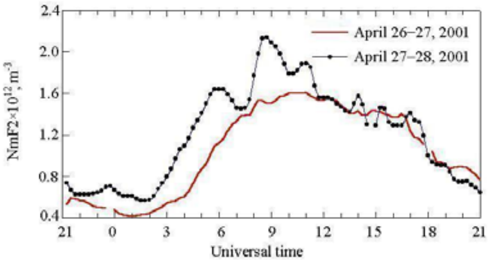

Fig. 2. F2-region peak density on a reference quiet day April 27, 2001 and the disturbed day April 28, 2001

PLASMA DRIFT VELOCITIES

Observations with the vertical incoherent scatter radar over the altitude range from 250 to 800 km over Kharkiv on the disturbed day have revealed that the vertical component of the plasma drift velocity changes sign and an upward flux appears in the topside ionosphere. The occurrence of the maxima in the vertical drift versus altitude displays a pronounced time delay from 06:45 UT at 800 km, through 07:00 UT at 600 km, to 07:15 UT at 400 km, and 07:30 UT at 250 km, which yields an apparent downward maximum progression speed of ~200 m/s.

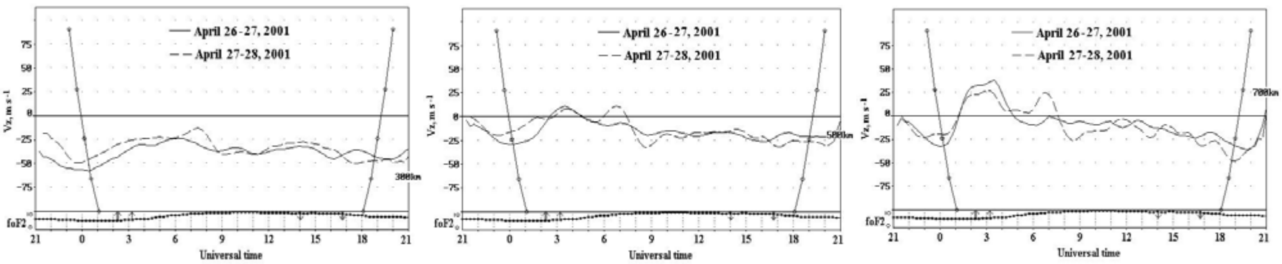

Fig. 3. Vertical component of the plasma drift velocity on a reference quiet day April 27, 2001 and the disturbed day April 28, 2001

O^+ ION FLUXES

The O+ ion fluxes exhibit a wave-like fluctuation at 300 km altitude with the peak-to-peak amplitude of 6×10^7 cm^{-2} s^{-1} and even a reverse in direction from upward to downward at 600 km and 900 km altitudes with the peak-to-peak amplitudes of 2×10^7 cm^{-2} s^{-1} and 0.8×10^7 cm^{-2} s^{-1}, respectively (Fig. 4).

The one-dimensional ISR observations do not differentiate directly between the effects of an eastward (westward) electric field or an equatorward (poleward) surge in the neutral wind, which could be offered for an interpretation that accounts for the measured effects. In the paper [3] treating severe geomagnetic storm effects, Foster and Rich invoked the following solution to a similar problem of choosing between the two opportunities. The response to winds

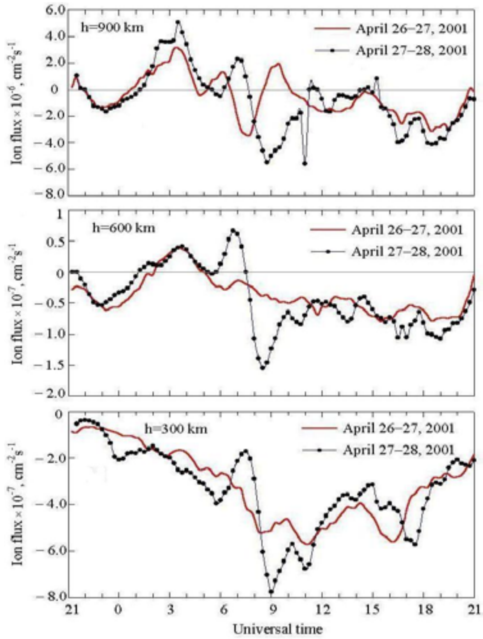

Fig. 4. O+ ion fluxes on a reference quiet day April 27, 2001 and the disturbed day April 28, 2001

propagating equatorward from a high-latitude disturbance is characterized by increases in hmF2 that travel from north to south with no change in foF2 or total electron content. The effect of a penetrating eastward magnetospheric electric field is to uplift the F2 layer, producing an increase in hmF2 and an increase in foF2 at slightly later times at midlatitudes, which is the case, as mentioned above, during the April 28-29, 2001 storm interval. The absence of the relevant data on the spatial and temporal global development of the disturbance does not enable us to unambiguously determine the cause of the rise in the ionospheric parameters by using this approach. However, the estimates of the ion drag by the neutrals indicate that the wind cannot account for the effects observed at 600 km and especially 900 km altitude.

Hence, we may suggest that this brief uplifting of the ionospheric F2 layer over the April 28-29, 2001 storm period is the effect of the destabilization of the mid-latitude ionosphere by a storm-induced eastward electric field penetrating the inner plasmasphere.

ELECTRON DENSITY

Comparison of the electron iso-density contours observed on April 28, 2001, with a calculated ionospheric response to propagating acoustic-gravity waves [4] indicates the existence of a traveling ionospheric disturbance in the ionosphere, while on the previous geomagnetically quiet day, April 27, 2001, such a disturbance was not observed (Fig. 5).

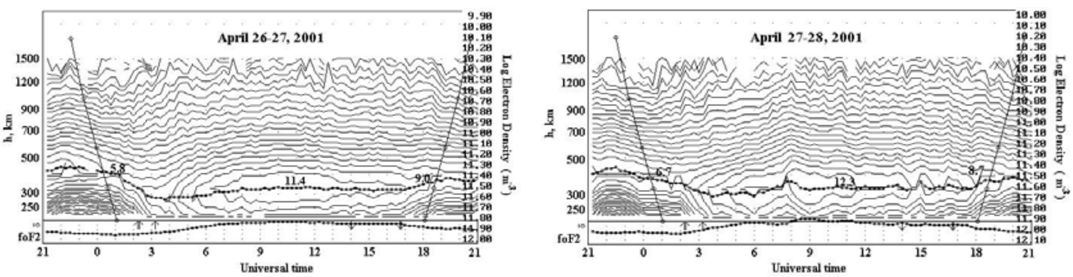

Fig. 5. Counters of electron density on a reference quiet day April 27, 2001 and the disturbed day April 28, 2001

ELECTRON TEMPERATURES

The most notable variations in the electron temperature were measured over the ~300-700 km altitude range from ~03:30 UT to ~04:30 UT on April 28, 2001 when the contours plots exhibit a decrease of ~500 K compared with the those observed on the reference day (Fig. 6).

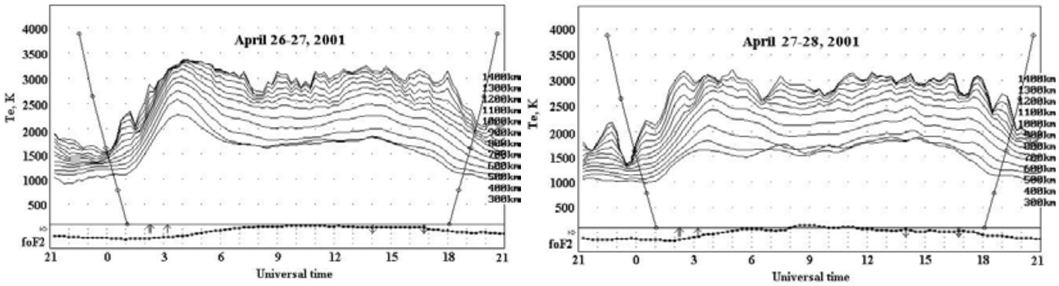

Fig. 6. Electron temperature on a reference quiet day April 27, 2001 and the disturbed day April 28, 2001

ION TEMPERATURES

The ion temperatures measured during the storm of April 28-29, 2001 interval did not display easily detected changes (Fig. 7).

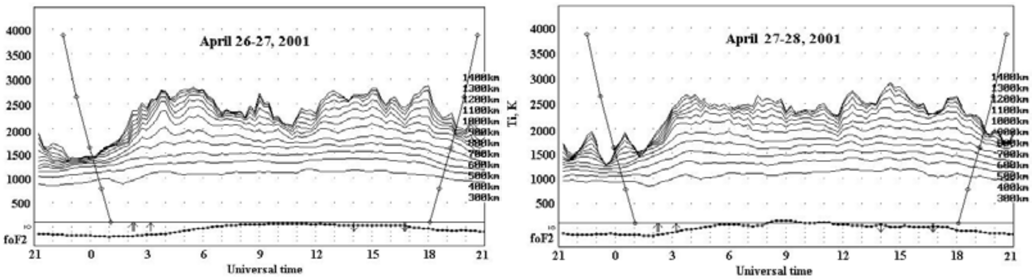

Fig. 7. Ion temperature on a reference quiet day April 27, 2001 and the disturbed day April 28, 2001

HYDROGEN IONS

On a reference quiet day April 27, 2001 and the disturbed day April 28, 2001, the level where the H^+ ion and O^+ ion number densities are equal remained beyond the 1200–1500 km altitude region at night and during the day at higher levels where the measurement errors become unacceptably high. The largest changes in hydrogen ion densities were observed at ~03:00 UT on April 28, 2001when the concentrations developed deep minima that spanned the altitude range from 1100 to 1500 km, while on the previous geomagnetically quiet day they were higher in altitude.

CONCLUSION

Observations of the topside ionosphere and protonosphere over Kharkiv during the April 28-29, 2001 storm have been presented. On the whole, a positive ionospheric storm was observed. In particular, the burst of the electric field during which the O+ ion fluxes exhibit a wave-like fluctuation or even a reverse in direction from upward to downward, and traveling ionospheric disturbance around hmF2 during entire April 28, 2001. The vertical component of the ionospheric plasma drift near the F2 peak show maxima of ~1 hour in duration after a sudden impulse at 05:03 UT on April 28, 2001 [1]. The increase in the vertical component of the upward drift velocity occurred first, with a maximum effect at ~07:20 UT. Then, the maximum effect in hmF2 followed at ~08:00 UT, and finally in NmF2 at ~08:40 UT. The most notable feature of the F2 region peak is its brief uplifting during ~07:00–08:30 UT time interval on April 28, 2001.

REFERENCES

[1] http://solar.sec.noaa.gov
[2] V. I. Taran, D. A. Dzyubanov, Ye. I. Grigorenko, and V. N. Lysenko, "Calculation of upper atmosphere dynamic characteristics from ionospheric data", *VIII-th International Conference on Mathematical Methods in Electromagnetic Theory, Kharkov, Ukraine*, vol. 2, pp. 633-634,2000 (in Russian).
[3] J. C. Foster, and F. J. Rich, "Prompt midlatitude electric field effects during severe geomagnetic storms", *J. Geophys. Res.*, 103, 26367, 1998.
[4] G. Kirchengast, "Characteristics of high-latitude TIDs from different causative mechanisms deduced by theoretical modeling", *J. Geophys. Res.*, vol. 102, 4597, 1997.