BEHAVIOR FEATURES OF THE MID-LATITUDE IONOSPHERE DURING VERY STRONG GEOMAGNETIC DISTURBANCES

G.A.Zherebtsov(1), **A.P.Potekhin**(2), **E.B.Romanova**(3), **A.V.Tashchilin**(4), **and B.G.Shpynev**(5)

(1)*Institute of Solar-Terrestrial Physics, 664033,Irkutsk, P.O.Box 4026, Russia, E-mail: - uzel@iszf.irk.ru*

(2)*As (1) above, but E-mail: - potekhin@iszf.irk.ru*

(3)*As (1) above, but E-mail: - ebr@iszf.irk.ru*

(4)*As (1) above, but E-mail: - avt@iszf.irk.ru*

(5)*As (1) above, but E-mail: - shpynev@iszf.irk.ru*

ABSTRACT

This paper presents the results of observations (acquired with the Irkutsk incoherent scatter radar) of space-time variations of such ionospheric parameters as the electron density, electron and ion temperatures during two very strong magnetic storms of September 25, 1998 and July 15, 2000. Numerical simulation results on the mid-latitude ionosphere response to these events are also presented. It has been found that the ionospheric response to the magnetic storms under consideration was controlled mainly by a disturbance in the composition of the neutral atmosphere.

INTRODUCTION

Extensive research on ionospheric storms has been underway for over four decades now, and the main processes governing the mechanism responsible for the formation and evolution of an ionospheric disturbance have been essentially understood to date [1,2]. At subauroral and mid-latitudes, these processes include primarily the interaction of ionospheric plasma with equatorward propagating disturbances of the thermospheric wind and the composition of the neutral atmosphere, as well as the effects of expansion (toward low latitudes) of the areas of energetic electron precipitation and magnetospheric convection [2]. As a result of the numerous experimental and theoretical investigations, it has been ascertained that the character of the ionospheric response to a particular geomagnetic storm depends quite crucially on the sequence and intensity of the effects of these factors under given geophysical conditions. This paper presents the results of observations made with the Irkutsk incoherent scatter radar (52.9 N, 103.3 E) of space-time variations of ionospheric parameters during two very strong magnetic storms of September 25, 1998 and July 15, 2000. Numerical simulation results on the mid-latitude ionosphere response to these events are also presented.

EXPERIMENTAL EVIDENCE

The September 25, 1998 geomagnetic storm was triggered by a solar wind disturbance propagating with the velocity of ~850 km/s when B_z ~ -18 nT. The first contact of the disturbance with the Earth's magnetosphere (sudden storm commencement) occurred at ~23:45 UT on September 24. During the storm, the planetary index of geomagnetic activity was as high as Kp ~ 8.5, and the Dst index ~ -207 nT. During the main phase lasting from 02:00 to 17:00 UT of September 25, there were strong variations of both the horizontal and vertical components of the geomagnetic field vector. The storm was accompanied by a powerful M-class X-ray flare. According to observational data from the DMSP satellite, in the Asian sector of the northern hemisphere the equatorial boundaries of the auroral oval and of the magnetospheric convection zone shifted during the main storm phase to geographic latitudes ~ 60° and ~ 55°, respectively. An analysis of radar measurements showed the following, most typical features of the mid-latitude F-region ionospheric response to this storm. In the first place, there was no positive phase of the ionospheric storm. Second, during the main phase, a strong negative disturbance of the electron density N_e was observed to reach a two/three-fold decrease near the F2-layer peak. And, third, the electron temperature at that period exceeded greatly (by 500 - 600 K) the undisturbed values for the preceding day. The ion temperature also increased appreciably relative to September 24, by ~300 K. In the morning of the next day of September 26, the F2-region parameters were already close to undisturbed values, which is indicative of a rapid recovery of the ionosphere.

The July 15, 2000 magnetic storm was one of the strongest geomagnetic disturbances for the last 20 years. The geomagnetic activity index Kp reached the value 9.0, and the Dst-index decreased to the value -300 nT. The storm began on July 15 at 14:30 UT and persisted till 6:00 UT of July 16. Auroral emission pictures taken by NOAA satellites showed that the auroral oval was expanding during the maximum storm phase to geographic latitudes ~ 50°. Throughout the entire disturbed day of July 15 and over the course of the next day there was a significant increase in electron density in the ionospheric F-region in excess of a factor of 2 when compared with the preceding undisturbed period. Furthermore, the E-region total electron content increased dramatically. Throughout the day of July 16 there were very high values of the electron and ion temperatures, which exceeded 5000 K for Te and 2400 K for Ti.

During the concerned geomagnetic disturbances of September 25, 1998 and July 15, 2000, backscattered signals were recorded, the power of which was 2-3 orders of magnitude higher than that of usual IS signals. Such signals arrive from ranges of 450-1100 km, and their power changed drastically with the distance and time (see Fig. 1). An analysis showed that the observed powerful echoes were caused by the scattering from two-stream current instabilities of the ionospheric E-layer which are produced in the presence of a strong electric field (> 25 mV/m). Such signals which are collectively known as the "radio aurora" arrive from the northward direction with respect to the Irkutsk radar and are received by the lower lobes of the antenna beam. To record the scattering of this type requires that the aspect angle condition is satisfied, i.e. the angle between geomagnetic field lines and the scattering direction must approach the right angle. An analysis of the power of these coherent echoes revealed quasi-periodic oscillations with a period of ~10-15 min. These oscillations correlate with magnetic field variations according to the data from the magnetometer at Irkutsk, and with total electron content variations according to the data from GPS receivers, and are most likely to be caused by magnetic field Ps6 pulsations [3].

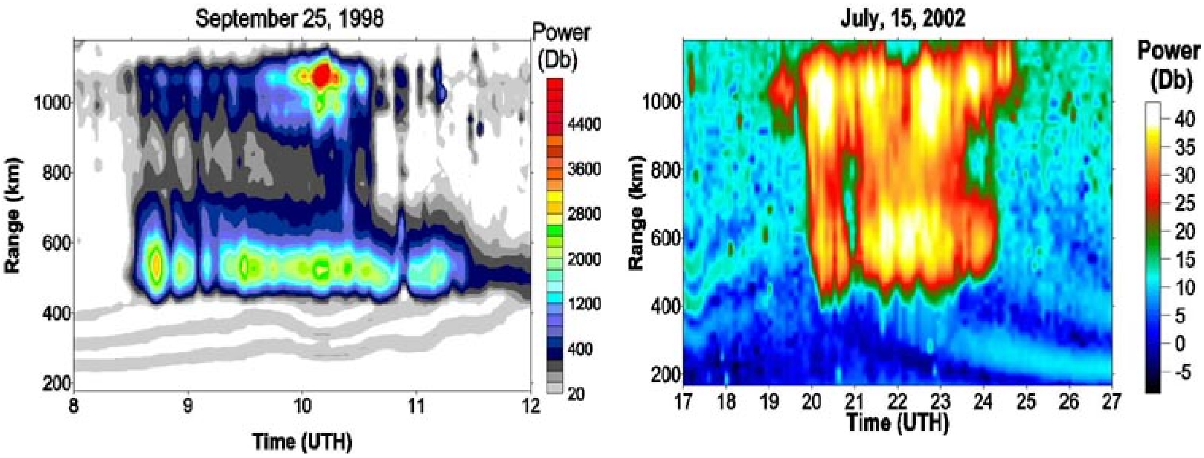

Fig. 1. Coherent echoes during magnetic storms September 25, 1998 and July 15, 2000.

MODELING OF THE IONOSPHERIC STORMS

The numerical model for ionosphere-plasmasphere coupling that was developed at the ISTP SB RAS, was used to interpret the observational data on the ionospheric response to the magnetospheric disturbances of September 25, 1998 and July 15, 2000. The model is based on numerically solving a system of nonstationary balance equations of particles and thermal plasma energy within closed geomagnetic flux tubes whose bases are anchored at 100 km altitude. It is assumed that plasma consists of atomic O^+, H^+, N^+ and He^+ and molecular N_2^+, O_2^+ and NO^+ ions [4]. The description of the space-time temperature and density variations of the components O, O_2, H and N used a global empirical model of the thermosphere, MSIS-86 [5], and the velocities of the horizontal thermospheric wind were determined in terms of the HWM-90 model [6]. The reference spectrum EUVAC [7] of solar radiation was used to calculate the photoionization rates and the energy spectra of primary photoelectrons.

The response of the mid-latitude ionosphere to the magnetic storms under consideration was simulated by calculating the variations of plasma parameters throughout the entire geomagnetic tube whose foot lies at the point with geographical coordinates 52°N and 105°E. The calculations were performed for two periods: from September 14 to 27, 1998, ($F_{10.7} \approx$ 120-145) and from July 3 to 17, 2000 ($F_{10.7} \approx$ 160-255) starting from some arbitrary initial conditions corresponding to a low plasma content within the tube.

The currently generally accepted picture of the ionospheric storm evolution consists of two stages, one of which is associated with an enhancement of the equatorward-directed meridional wind, and the other reflects variations in

neutral composition [8,9,10]. Depending on the intensity of the magnetospheric disturbance and on the local time of its onset, the behavior of the ionosphere at these stages can be essentially different [1,2,8,9].
To verify the correspondence of the above concept of the formation of the ionospheric response to the magnetic storm and the above measurements from the IS radar, three versions of a calculation of the ionospheric behavior were realized for the periods spanning both undisturbed and disturbed days. In the first version, the variations of ionospheric parameters, the neutral wind and of the solar UV spectrum were specified according to selected empirical models. It was obtained that the calculated values of the electron density are systematically too high compared with measurements. For achieving the best correspondence between results of calculations and observed electron density variations near the F2-layer maximum on undisturbed days, the UV fluxes for all spectral intervals in EUVAC were reduced by a factor of 0.75 and values of atomic oxygen density were reduced by the same manner. Results of this correction (second version) are shown in Fig. 2 and correspond to a portion of the curves for September 23 and 24 and July 14-15. It is clearly seen that this correction removed the systematic error between calculations and measurements.

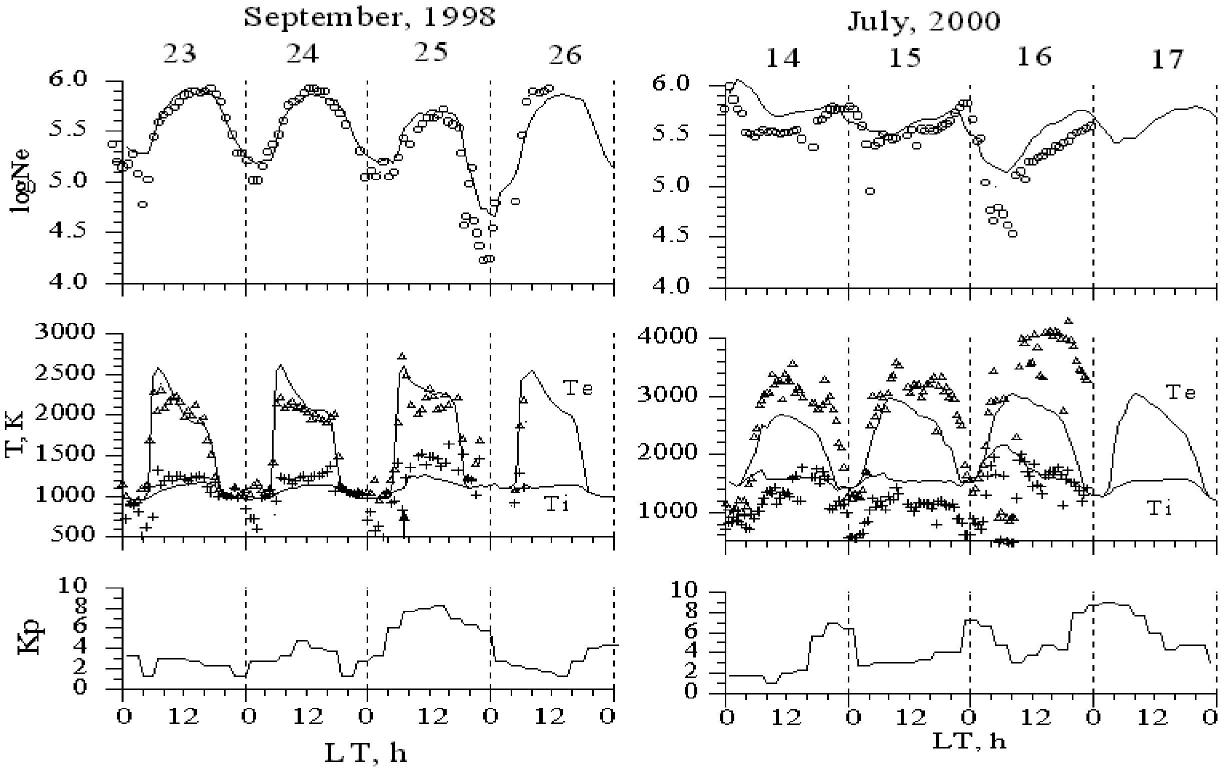

Fig 2. Variations of the calculated and measured ionospheric parameters at 300 km (September, 1998) and 400 km (July, 2000) altitudes. Circles, triangle and crosses correspond to the measured values of Ne, Te and Ti, respectively.

In the third version, we made a correction of the thermospheric parameters calculated in terms of the MSIS-86 and HWM-90 models but only for September 25 and July 16 in order to reproduce the behavior of the ionosphere on the disturbed days. To do this, in the first place, it was assumed that in 15 minutes after the magnetic storms onset the velocity of the equatorward-directed meridional wind increased abruptly by 200 m/s and so persisted during three hour. Secondly, at the same points of time, the neutral composition was altered in such a way that the value of R = [O/N2] decreased by a factor of 2.5 compared with the MSIS-86 model. As comparisons with observational data showed, the selected value of the decrease in number-density composition R in relation to the MSIS-86 model is a typical one [2,8,10,12]. This correction factor of the composition remained unchanged in calculations in the course of September 25 as well as July 26. It is evident from calculated results that, although the wind enhancement produces an upward-directed ion flow throughout the entire F-region and in the topside ionosphere, this is unable to form a positive disturbance in the ionosphere. The reason for that is that the storm onset occurred in the morning (September 25) or pre-midnight (July 15) hours when the wind-induced F2-layer going up proceeded in the presence of weak sources of ion production, while - according to the F2-layer formation theory [1,13] - this does not involve an electron density increase in the layer maximum. Thus the ionospheric storms under consideration were the negative disturbances whose characteristics were controlled mainly by the disturbance dynamics of the neutral atmospheric composition. Note that the assumption about the constancy of the correction factor of R during September 25 and 26 does not wholly represent the facts as it leads to too low calculated values of the electron density for September 26. Conceivably the number-density composition on that day was already close to undisturbed conditions.

As is apparent from Fig. 3, the measured and calculated electron temperature variations are in good agreement on the disturbed day as well, whereas the calculated ion temperatures are found to be somewhat too low compared with those measured on September 25. This is the result of the incorrect description of the heating of the disturbed thermosphere in terms of the MSIS-86 model. The measurements from the Millstone Hill radar [14] and from satellites [12] showed that actual values of neutral temperature can exceed model values by 200-300 K. The most discrepancy of calculations and measurements takes place for electron temperature in disturbed day on July 16, 2000. The probable reason of that is the fact, that the model does not take into account some important source of heating, arising in midlatitude ionosphere during the very strong magnetic storm.

CONCLUSION

The Irkutsk Incoherent Scatter observational data on the ionospheric conditions during a strong geomagnetic storms of September 25, 1998 and July 15, 2000 have been compared with results of calculations performed on the basis of a numerical model of the ionosphere and plasmasphere. It has been shown that the measured variations of electron density, electron and ion temperatures are reproduced reasonably accurately in model calculations. Furthermore, the ionospheric responses to the concerned magnetic storms were controlled mainly by a disturbances in the composition of the neutral atmosphere.

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