"Physics of Auroral Phenomena", Proc. XXV Annual Seminar, Apatity, pp.107-110, 2002

Polar Geophysical Institute

SIMULATION OF THE SPATIAL STRUCTURE OF THE HIGH-LATITUDE F-REGION FOR DIFFERENT CONDITIONS OF SOLAR ILLUMINATION OF THE IONOSPHERE

G.I. Mingaleva and V.S. Mingalev *(Polar Geophysical Institute, Apatity, Russia, e-mail:mingalev@pgi.kolasc.net.ru)*

Abstract. The results of numerical simulation of the spatial structure of the high-latitude F-region ionosphere are presented and analyzed. Particular attention is given to the heat regime of the F layer. The results were obtained by applying a mathematical model of the convecting high-latitude ionosphere, developed earlier in the Polar Geophysical Institute. The model produces three-dimensional distributions of the electron density, positive ion velocity, electron and ion temperatures at the F-layer altitudes. The mathematical model is applied to investigate how do the different conditions of solar illumination affect the spatial structure of the high-latitude F-region ionosphere. The results indicate that different solar illuminations, conditioned by the daily rotation of the geomagnetic and geographic poles around each other, ought to influence appreciably the spatial structure of the high-latitude ionosphere, in particular, the heat regime of the F layer.

Introduction

The main ionospheric trough is a well-known morphological feature of the night side F layer at sub-auroral latitudes. The trough appears as a band of decreased electron concentration relative to the ionosphere both poleward and equatorward of it. The trough is rather a steady ionospheric formation existing mainly on the night side of the Earth in winter [*Moffett and Quegan*, 1983]. One of the outstanding phenomena is the existence of electron temperature peaks at F-region altitudes in a number of situations in the main ionospheric trough. Satellite measurements often demonstrate extremely high electron temperatures in trough region [*Schunk and Nagy*, 1978; *Best and Wagner*, 1983; *Rodger et al*., 1992, and references therein]. It is known that the very high electron temperatures in the F region at high latitudes may be conditioned by the enhanced altitudinal electron temperature gradient [*Kozyra et al*., 1986]. Therefore, the explanation of the origin of the electron temperature peaks in the main ionospheric trough was based on the employment of external causes. In particular, the capacity of the magnetospheric heat flux into the ionosphere to create electron temperature hot spots in the high-latitude ionosphere had been substantiated by applying the mathematical model of the convecting high-latitude ionosphere by *Schunk et al*. [1986].

However, the origin of the electron temperature peaks in the main ionospheric trough may be interpreted without employment of external causes. Indeed, in the study by *Mingaleva and Mingalev* [1996] it was found that electron temperature hot spots in the main ionospheric trough can arise owing to the formation mechanism conditioned by internal ionospheric processes only. Three conditions, to be satisfied simultaneously, are necessary for the formation of the considered electron temperature hot spots: first, low values of electron density; second, illumination of the upper F region and darkness of the lower F region; third, low values of neutral component densities. These conditions are valid in the main ionospheric trough near the solar terminator on the nightside when the density of the neutral atmosphere is not high. Besides, it was found that solar activity variations influence appreciably the origins of the electron temperature hot spots in the main ionospheric trough due to the identified formation mechanism, and that the lower 10.7-cm solar flux is, the higher values of the electron temperature inside hot spots ought to be. Moreover, there was studied the influence of seasonal variations on the efficiency of the identified formation mechanism. It was found that the manifestation of the considered electron temperature peaks in the main ionospheric trough owing to internal ionospheric processes ought to be low in summer, while higher in equinox, and still much higher in winter.

The purpose of this paper is to examine how do the different solar illuminations, conditioned by the daily rotation of the geomagnetic and geographic poles around each other, influence the spatial structure of the high-latitude ionosphere and the identified mechanism responsible for the formation of the electron temperature peaks in the main ionospheric trough.

Numerical model

In the study by *Mingaleva and Mingalev* [1996], cited above, the mathematical model of the convecting high-latitude ionosphere, described in that study, has been applied. In the present study, the improved version of this mathematical model [*Mingaleva and Mingalev,* 1998] is applied. The main improvement of the model consists in that the model has acquired the capability of producing spatial distributions of ionospheric quantities at the F-layer altitudes including not only polar latitudes, but also subauroral ones. Besides, the geomagnetic and geographic axes are not assumed to be collinear. The latter circumstance allows us to investigate the influence of different conditions of solar illumination, connected with the daily rotation of the geomagnetic and geographic poles around each other, on the spatial structure of the high-latitude ionosphere.

The applied numerical model takes into consideration the strong magnetization of the plasma at F-layer altitudes and the attachment of the charged particles of the F-region ionosphere to the magnetic field lines. As a consequence, the F-layer ionosphere plasma drift in the direction perpendicular to the magnetic field **B** is strongly affected by the electric field **E** and follows **E**´ **B** convection paths (or the flow trajectories). In the model calculations a part of the magnetic field tube of the ionospheric plasma is considered at distances between 100-700 km from the earth along the magnetic field line. The temporal history is traced of the ionospheric plasma included in this part of the magnetic field tube moving along the flow trajectory through a neutral atmosphere.

The motion of the F-layer ionosphere plasma may be separated into two flows: the first one; a plasma flow parallel to the magnetic field; the second, a plasma drift in the direction perpendicular to the magnetic field. The parallel plasma flow in the part of the magnetic field tube is described by the system of transport equations, which consists of the continuity equation, equation of motion for ion gas, and heat conduction equations for ion and electron gases. The equations provide for the direct and resonantly scattered EUV solar radiation, energy-dependent chemical reactions, production due to auroral electron and proton precipitations, frictional force between ions and neutrals, accelerational and viscous forces of ion gas, thermal conductions of electron and ion gases, heating due to ion-neutral friction, Joule heating, heating due to solar EUV photons and precipitating electrons and protons, and electron energy losses due to elastic and inelastic collisions. The plasma drift in the direction perpendicular to the magnetic field coincides with the motion of the magnetic field tube along the flow trajectory which may be obtained using the plasma convection pattern. The use of plasma convection pattern allows us not only to obtain the configurations of the flow trajectories but also to calculate the plasma drift velocity along them at an F-layer altitude.

We consider only the steady plasma convection patterns for which the flow trajectories are known to be closed. For each flow trajectory, we obtain variations of ionospheric quantities with time (along the flow trajectory), that is, the profiles against distance from the earth along the geomagnetic field line of the electron density, positive ion velocity, and electron and ion temperatures are obtained by solving a system of transport equations of ionospheric plasma. These profiles result in two-dimensional steady distributions of ionospheric quantities along each flow trajectory. By tracing many field tubes of plasma along a set of flow trajectories, we can construct three-dimensional steady distributions of ionospheric quantities.

The neutral atmosphere composition, system of transport equations of ionospheric plasma, input parameters of the model, numerical method, and boundary conditions were described in detail in the study by *Mingaleva and Mingalev* [1998].

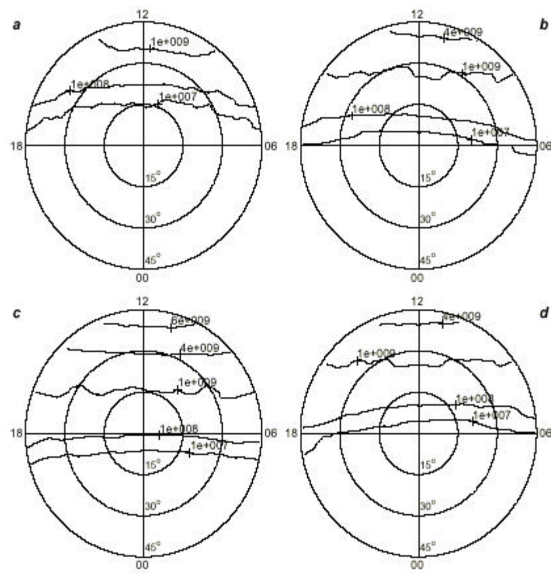

Fig.1. The horizontal distributions of the maximum values of the photoionisation rate (in $m^{-3}s^{-1}$) for four different moments: **a** UT=04.30; **b** UT=10.30; **c** UT= 16.30; **d** UT=22.30. The solar terminator at the earth's surface is located approximately along the isoline of $1\cdot10^{8}$ $m^{-3}s^{-1}$. Magnetic local time (MLT) and magnetic colatitude are indicated on the plot.

Ionospheric simulation

One of the input parameters of the model is the plasma convection pattern. In the present study we utilize the plasma convection model which is the combination of the pattern B of the empirical convection models at polar latitudes of *Heppner* [1997] and the empirical model of ionospheric electric fields at middle latitudes, developed by *Richmond et al.* [1980]. An applied numerical model can describe different combinations of the solar cycle, geomagnetic activity level, and season. For the present study, the calculations are performed for autumn (5 November) and not high solar activity ($F_{10.7}$ =101) conditions under low geomagnetic activity (K_p = 1) in the absence of the electron and ion heat fluxes through the upper boundary. The spatial configuration of the electron and proton precipitation zones as well as intensities and average energies of the precipitating electrons and protons were chosen as the ones, consistent with the statistical model of *Hardy et al.* [1989].

To evaluate the role of different solar illuminations, conditioned by the daily rotation of the geomagnetic and geographic poles around each other, on the formation of the spatial structure of the high-latitude F-region ionosphere, we have made calculations for four distinct moments of UT: 04.30, 10.30, 16.30, and 22.30. It is generally understood that the conditions of solar illumination of the polar cap and auroral oval have to be different for distinct moments of UT. In the model calculations, the altitudinal profiles of the photoionisation rate are computed for various points of the earth's surface. All these profiles have pronounced maximums, that is, the maximum values of the photoionisation rate, which can lie at different altitudes for distinct points. The horizontal distributions of the maximum values of the photoionisation rate for the four considered moments of UT are shown in Fig.1. It can be seen that the solar illumination of the high-latitude region depends significantly on the UT. The illumination degree of the high-latitude region is minimal at 04.30 UT, maximal at 16.30 UT, and intermediate at other moments.

The computed distributions of the electron concentration at level of 300 km, obtained for the four considered moments of UT, are shown in Fig.2. It is easy to see that the computed distributions of the electron concentration illustrate both common characteristic features of the high-latitude ionosphere and distinctions caused by the different conditions of solar illumination. The electron concentration distributions contain the well-known tongue of ionization, extended from the local noon side of the earth across the polar cap to the night side, as well as the main ionospheric trough on the night side of the earth. However, the extension of the main ionospheric trough turns out to be different at various UT. The shortest ionospheric trough takes place at 16.30 UT when the illumination degree of the high-latitude region is maximal. The most extended ionospheric trough takes place at 04.30 UT when the illumination degree of the high-latitude region is minimal, with the trough stretching far on the dayside of the earth. Comparing Figs.1 and 2, we can see that the extension of the trough zones, stretched on the dayside of the earth, is governed by the location of the solar terminator during the day.

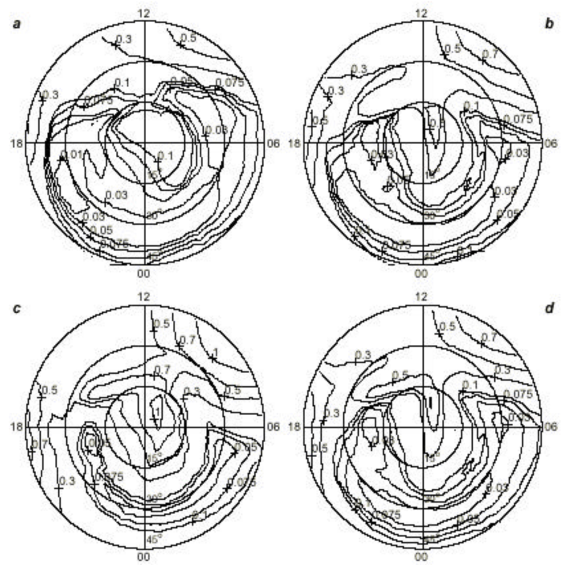

Fig.2. The simulated distributions of the electron concentration (in units of 10^{12} m^{-3}) at level of 300 km obtained for four different moments: **a** UT=04.30; **b** UT=10.30; **c** UT= 16.30; **d** UT=22.30.

The computed distributions of the electron temperature at the level of 300 km, obtained for the four considered moments of UT, are shown in Fig.3. It can be seen that the electron temperature hot spots may be formed in the main ionospheric trough in the dawn and dusk sectors. It may be recalled that the model calculations have been performed under condition that the electron and ion heat fluxes from the magnetosphere into the ionosphere are absent. Therefore, the electron temperature hot spots, situated in the morning and evening sectors of the main ionospheric trough, have arisen owing to internal ionospheric processes by means of the formation mechanism identified by *Mingaleva and Mingalev* [1996]. The simulation results indicate that the amount and location of the hot spots may be different at various UT. Usually, there exist two hot spots both in the morning and in the evening sectors. However, only one hot spot exists at 04.30 UT when the illumination degree of the high-latitude region is minimal, with the hot spot lying in the morning sector. The locations of the electron temperature hot spots are connected with the diurnal displacement of the solar terminator with reference to the geomagnetic pole. Inside hot spots, maximum values of the electron temperature may be different at various UT, too.

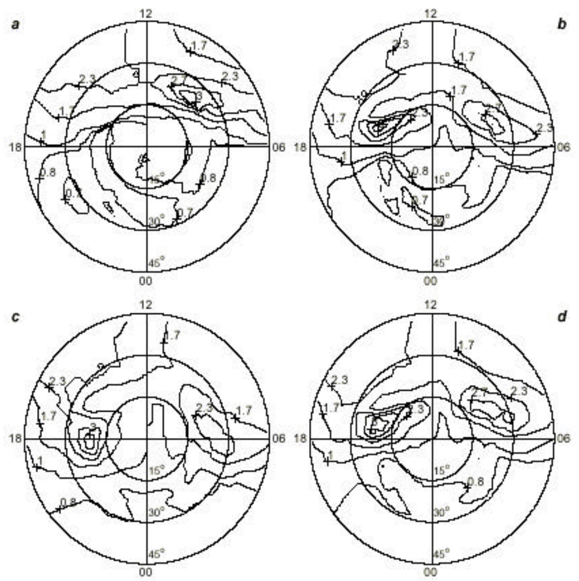

Fig.3. The simulated distributions of the electron temperature (in units of 10^3 °K) at level of 300 km obtained for four different moments: **a** UT=04.30; **b** UT=10.30; **c** UT= 16.30; **d** UT=22.30

Conclusions

The mathematical model of the convecting high-latitude ionosphere, which enables one to calculate three-dimensional distributions of the electron density, positive ion velocity, electron and ion temperatures at the F-layer altitudes, was applied to investigate how do the different solar illuminations, conditioned by the daily rotation of the geomagnetic and geographic poles around each other, affect the spatial structure of the high-latitude F-region ionosphere. The calculations were made for four distinct moments of UT during one autumn day. The simulation results have reproduced the remarkable features of the high-latitude ionosphere such as the main ionospheric trough and electron temperature hot spots in the morning and evening sectors of this trough. It was found that the latter hot spots arise owing to internal ionospheric processes by means of the formation mechanism identified by *Mingaleva and Mingalev* [1996]. The simulation results indicated that the UT-dependence of the solar terminator location with reference to the geomagnetic pole influence appreciably both the configuration of the main ionospheric trough and the manifestation of the mechanism responsible for the formation of the electron temperature peaks in the morning and evening sectors of the main ionospheric trough and the locations of these peaks.

References

Best, A., and C.-U. Wagner, Variations of electron density and electron temperature in the main trough of the ionosphere, pp.19-41, in *Physical processes in main ionospheric trough region*, eds. N.P. Benkova, C.-U. Wagner, and L. Triskova, GFU CSAV, Praha, 1983.

Hardy, D.A., M.S. Gussenhoven, and D. Brautigam, A statistical model of auroral ion precipitation, *J. Geophys. Res.*, 94, 370-392, 1989.

Heppner, J.P., Empirical models of high-latitude electric fields, *J.Geophys.Res.*, 82, 1115-1125, 1977.

Kozyra, J.U., L.H. Brace, T.E. Cravens, and A.F. Nagy, A statistical study of the subauroral electron temperature enhancement using Dynamics Explorer 2 Langmuir probe observations, *J. Geophys. Res.*, 91, 11270-11280, 1986.

Mingaleva, G.I., and V.S. Mingalev, The formation of electron temperature hot spots in the main ionospheric trough by the internal processes, *Ann. Geophys.*, 14, 816-825, 1996.

Mingaleva, G.I., and V.S. Mingalev, Three-dimensional mathematical model of the polar and subauroral ionosphere (in Russian), pp.251-265, in *Modeling of the upper polar atmosphere processes*, eds. V.E. Ivanov, Ya.A. Sakharov, and N.V.Golubtsova, PGI, Murmansk, 1998.

Moffett, R.J., and S. Quegan, The mid-latitude trough in the electron concentration of the ionospheric F layer: a review of observation and modeling, *J. Atmos.Terr. Phys.*, 45, 315-343, 1983.

Richmond, A.D., M. Blanc, B.A. Emery, R.H. Wand, B.G. Fejer, R.F. Woodman, S. Ganguly, P. Amayenc, R.A. Behnke, C. Calderon, and J.V. Evans, An empirical model of quiet-day ionospheric electric fields at middle and low latitudes, *J.Geophys. Res.*, 85, 4658-4664, 1980.

Rodger, A.S., R.J. Moffett, and S. Quegan, The role of ion drift in the formation of ionisation troughs in the mid- and high-latitude ionosphere - a review, *J. Atmos. Terr. Phys.*, 54, 1-30, 1992.

Schunk, R.W., and A.F. Nagy, Electron temperatures in the F region of the ionosphere: Theory and observations, *Rev. Geophys. Space Phys.*, 16, 355-399, 1978.

Schunk, R.W., J.J. Sojka, and M.D. Bowline, Theoretical study of the electron temperature in the high-latitude ionosphere for solar maximum and winter conditions, *J. Geophys. Res.*, 91, 12041-12054, 1986.