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# EFFECT OF THE AZIMUTH IMF ON THE SPATIAL STRUCTURE OF THE POLAR F-REGION IONOSPHERE

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**Abstract.** The mathematical model of the convecting high-latitude ionosphere is applied in order to investigate how the direction of the horizontal projection of the interplanetary magnetic field (IMF) affects the spatial structure of the high-latitude F region. The applied model produces three-dimensional distributions of the electron density, positive ion velocity, and electron and ion temperatures at the F-layer altitudes. The input parameter of the model, governed by the IMF, is the plasma convection pattern. Simulations are performed for two distinct plasma convection patterns corresponding to two different orientations of the IMF for which the horizontal projection of the IMF has the opposite directions. The vertical projection of the IMF is assumed to be southward for both orientations of the IMF. The results indicate that the direction of the azimuth IMF ought to influence conspicuously on the spatial structure of the high-latitude ionosphere, in particular, on the heat regime of the F region.

## Introduction.

It is generally understood now that solar wind parameters influence appreciably the large-scale convection of the magnetosphere-ionosphere plasma. One of the parameter of the solar wind, which governs the behaviour of the earth's magnetosphere, is the interplanetary magnetic field (IMF), the magnitude and direction of which can vary considerably with time. The variations of the IMF, conditioned by changes of the solar wind parameters, can influence the spatial structure of the high-latitude ionosphere. The effect of azimuth components of the IMF on the spatial distribution of ionospheric quantities at the F-layer altitudes has been already investigated using the mathematical models, in particular, by *Galperin et al.* [1980] and *Sirnikova et al*. [1984]. However, the used mathematical models had some essential restrictions. In fact, the mathematical model, used by *Galperin et al*. [1980], permitted to calculate the electron concentration only. The mathematical model, utilised by *Sirnikova et al*. [1984], even though allowed one to calculate not only the electron concentration but also the electron and ion temperatures, nevertheless, used the simplified distributions of thermospheric parameters. The latter mathematical model has been recently improved by *Mingaleva and Mingalev* [1998] so that the more realistic empirical model has been used for the calculation of distributions of thermospheric densities and temperatures, moreover, the boundary of the region, embraced by the mathematical model, has been enlarged from polar to subauroral latitudes. The purpose of this paper is to investigate the effect of the direction of the horizontal projection of the IMF on the formation of the spatial structure of the high-latitude ionosphere, in particular, on the electron and ion temperature distributions.

## Ionospheric model

The improved version of the mathematical model of the convecting high-latitude ionosphere, developed by *Mingaleva and Mingalev* [1998], is used in the present study. The model takes into account the strong magnetization of the plasma at F-layer altitudes. As a consequence, the charged particles of the F-region ionosphere may be considered to be attached to the magnetic field lines. The ionosphere plasma drift in the direction perpendicular to the magnetic field **B** is strongly affected by the electric field **E**. The F-layer ionosphere plasma transport perpendicular to magnetic field lines follows **E** x **B** convection paths (or the flow trajectories). 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 part of the magnetic field tube of plasma is carried over a high-latitude region by the convection electric field. In the model calculations the temporal history of the ionospheric plasma is traced in the part of the magnetic field tube moving along the flow trajectory through a neutral atmosphere. As a consequence of the strong magnetization of plasma at F-layer altitudes, its motion may be separated into two flows: the first, plasma flow parallel to the magnetic field; the second, 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

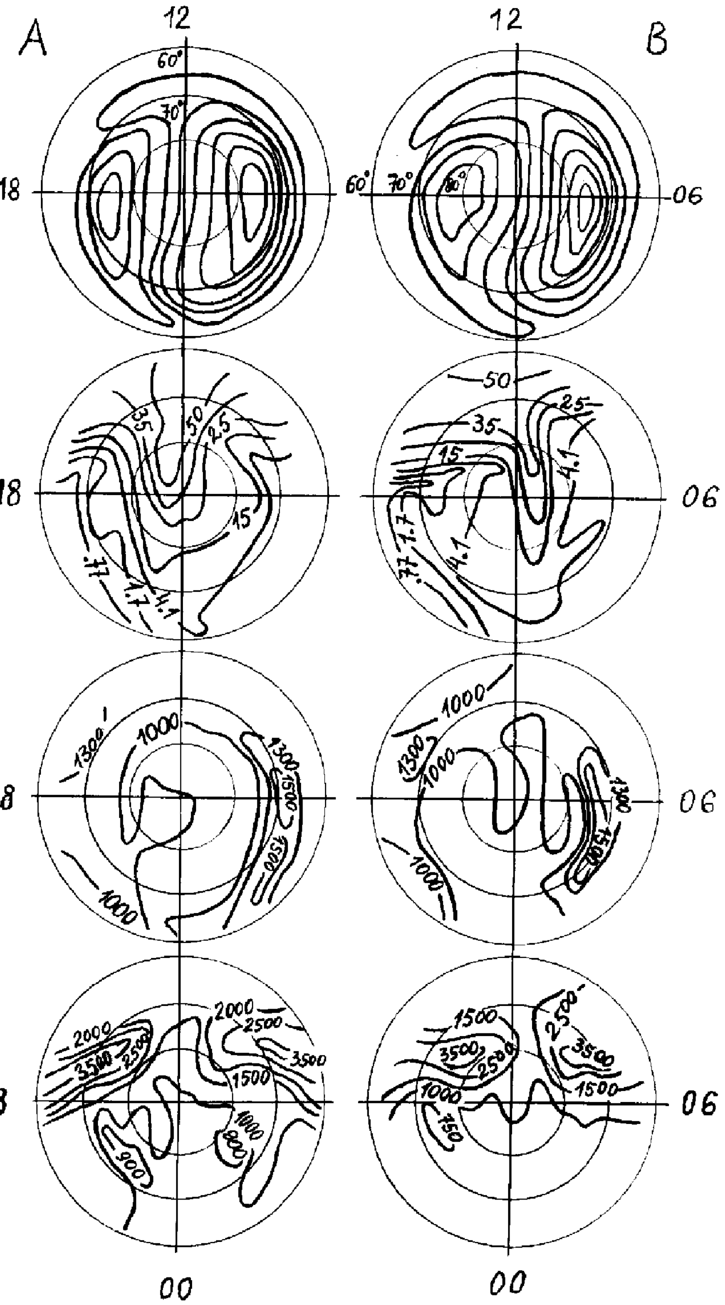


Fig.1. The patterns A (left) and B (right) of the empirical convection models at polar latitudes of *Heppner* [1977] used in the model calculations (the top panel). The calculated distributions of ionospheric quantities obtained using the convection patterns A (left) and B (right) at level h = 300 km: the electron concentration (the second panel); ion temperature (the third panel); electron temperature (the fourth panel). Magnetic local time (MLT) and magnetic latitude are indicated in the plot. The electron concentration are given in units of $10^4$ $cm^{-3}$ and temperatures in $^oK$.

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. Just the plasma convection pattern is the input parameter of the model dependent on the IMF. Utilizing the plasma convection pattern we obtain the configurations of the flow trajectories and 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 the 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 the system of transport equations of ionospheric plasma. These profiles result in a two-dimensional steady distributions of ionospheric quantities along the trajectory of each flow. By tracing many field tubes of plasma along a set of flow trajectories, we can construct three-dimensional steady distributions of ionospheric quantities.

To calculate spatial distributions of ionospheric quantities by using our mathematical model, in addition to the plasma convection pattern, several input parameters must be given, including neutral atmosphere densities and temperatures, soft electron and proton precipitation characteristics, distributions of zonal and meridional components of the neutral wind and so forth. Setting of the input parameters of the model was in detail described in the study by *Mingaleva and Mingalev* [1998]. In particular, the distributions of thermospheric parameters are calculated from the empirical model of *Jacchia* [1977].

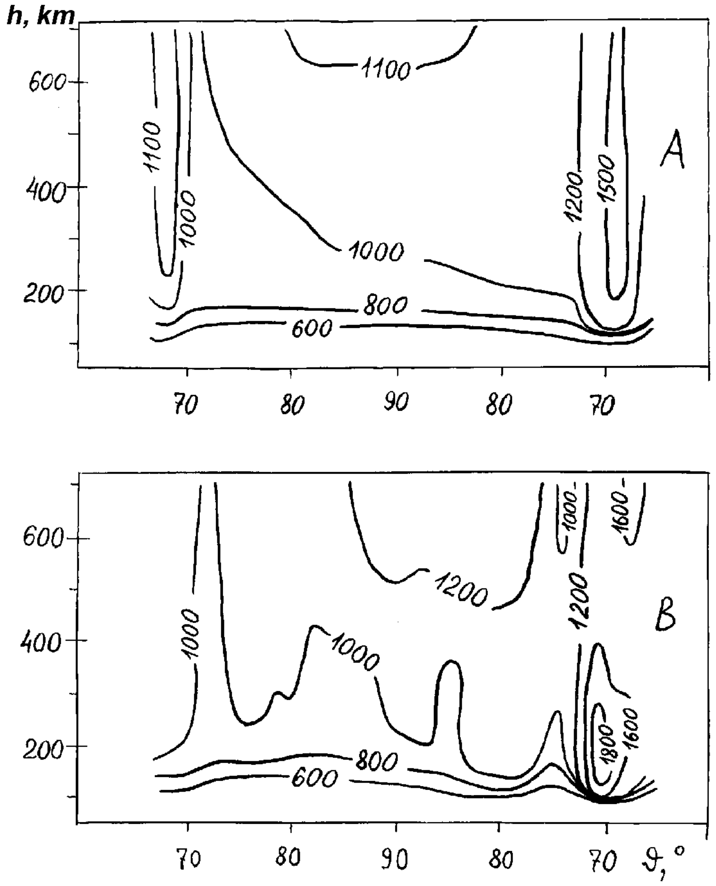


Fig. 2. The calculated isolines of the ion temperature (in °K) over the magnetic meridian 18-06 MLT obtained by using the convection patterns A (top) and B (bottom). The magnetic latitude ϑ (in deg) is shown on the horizontal axis.

## Ionospheric simulation

Our mathematical model can describe different combinations of the solar cycle, geomagnetic activity level, and season. For the present study, the calculations were performed for winter and middle solar activity ($F_{10.7}$ = 150) conditions under low geomagnetic activity (Kp = 2).

To evaluate the role of the direction of the horizontal projection of the IMF on the formation of the spatial structure of the high-latitude F-region ionosphere, we have made calculations for two distinct cases in which the plasma convection pattern was different. The utilised plasma convection patterns corresponded to two different orientations of the IMF, with the horizontal projection of the IMF having the opposite directions. The horizontal projection of the IMF was assumed to have the azimuth angle in the 270-360° range for the first orientation and in the 90-180° range for the second orientation. For both orientations, the vertical projection of the IMF was assumed to be southward. The plasma convection patterns, corresponding to the first and second orientations of the IMF, were the patterns A and B of the empirical convection models at polar latitudes by *Heppner* [1977], respectively. Indeed, the pattern A of empirical convection models by *Heppner* [1977] corresponds to the vector of the IMF the azimuth components of which satisfy the relations $B_x > 0$ and $B_y < 0$. For the pattern B of empirical convection models by *Heppner* [1977], the relations $B_x < 0$ and $B_y > 0$ take place for the azimuth components of the vector of the IMF.

It should be emphasized that the plasma convection pattern varies markedly with the IMF. However, for the southward IMF, the patterns possess some common characteristic features, in particular, they have two vortex cells with antisunward flow over the polar cap and return flow equatorward of the auroral oval. The convection patterns, utilized in the present study, are shown in the top panel of Fig.1. Also, Figure 1 presents the results of simulation of the spatial structure of the high-latitude F region, obtained for two distinct convection patterns. The computed isolines of the ion temperature (in °K) over the magnetic meridian 18-06 MLT and electron temperature (in °K) over the magnetic meridian 15-03 MLT, obtained for two convection patterns, are shown in Figs. 2 and 3, respectively.

The computed distributions of ionospheric quantities illustrate both common characteristic features of the high-latitude ionosphere and distinctions caused by the direction of the horizontal projection of the IMF. The electron concentration distributions (the second panel of Fig.1) contain the well-known tongue of ionization, extended from the local noonside of the earth across the polar cap to the nightside, as well as the polar wall of the main ionospheric trough. It can be seen that the tongue of ionization is displaced to the dusk for the first orientation of the IMF and to the dawn for the second orientation of the IMF. This is a well-known manifestation of the effect of Svalgard-Mansurov in the ionosphere [*Galperin et al.*,1980; *Sirnikova et al.*, 1984].

One of the essential peculiarities of the high-latitude ionosphere is the existence of regions of increased ion temperature in the dawn and dusk sectors. These ion temperature hot spots are originated by frictional heating of ionospheric plasma produced by enhanced convection electric fields in the morning and evening sectors. From Figs. 1 (the third panel) and 2 we can see that, in the morning sector, the values of the ion temperature, calculated for the

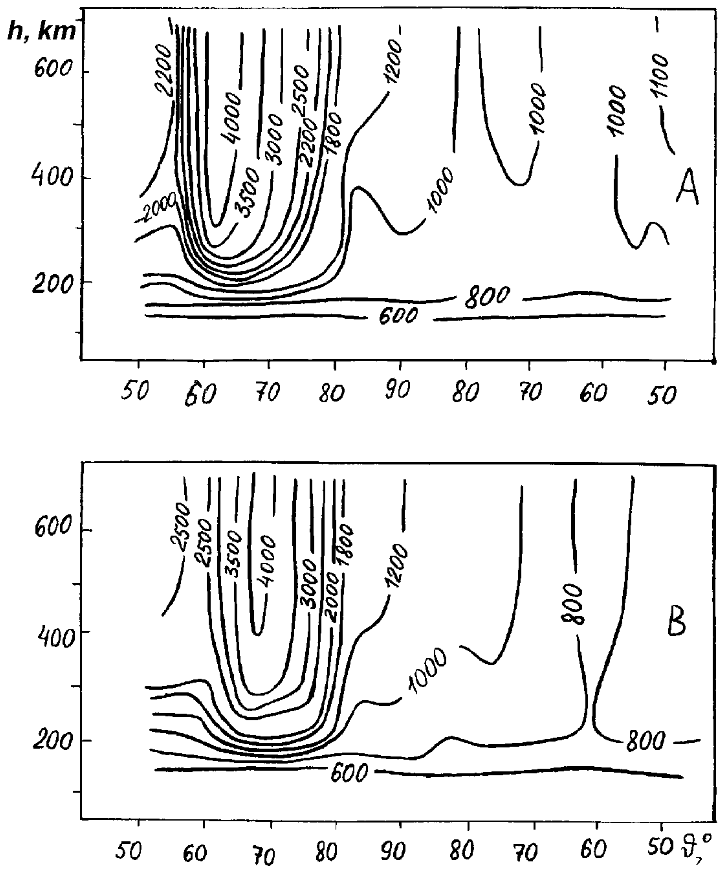


Fig. 3. The calculated isolines of the electron temperature (in °K) over the magnetic meridian 15-03 MLT obtained using the convection patterns A (top) and B (bottom). The magnetic latitude ϑ (in deg) is shown on the horizontal axis.

second orientation of the IMF, must be greater than the values of $T_i$, computed for the first orientation of the IMF, for more than 300°K at F-layer altitudes.

The conspicuous feature of the high-latitude ionosphere is the existence of electron temperature hot spots in the main ionospheric trough. From Fig.1 (the fourth panel) we see two regions where the electron temperature is enhanced. It can be seen that these regions are situated in the morning and evening sectors. The physical mechanism responsible for the formation of these regions was identified by *Mingaleva and Mingalev* [1996]. The simulation results indicate that the direction of the horizontal projection of the IMF influences the location of the electron temperature hot spots. From. Fig.3 we see that the difference between the magnetic latitudes of the electron temperature hot spots, obtained for the first and second orientations of the IMF, can achieve the value of about 8°. The electron temperature hot spots, calculated for the first orientation of the IMF, must be located more equatorial than those, computed for the second orientation of the IMF.

## Conclusions

The mathematical model of the convecting high-latitude ionosphere, which can produce three-dimensional distributions of the electron density, positive ion velocity, and electron and ion temperatures at the F-layer altitudes, was applied to investigate how the direction of the horizontal projection of the IMF affects the formation of the spatial structure of the high-latitude ionosphere. The calculations were made for two cases in which the plasma convection pattern (the input to the model) was different. The utilized plasma convection patterns correspond to two different orientations of the IMF, with the horizontal projection of the IMF having the opposite directions. For the first case, the azimuth components of the vector of the IMF satisfy the relations $B_x > 0$ and $B_y < 0$. For the second case, the relations $B_x < 0$ and $B_y > 0$ take place for the azimuth components of the vector of the IMF. For both cases, the vertical projection of the IMF is assumed to be southward. The simulation results indicated that the direction of the horizontal projection of the IMF ought to influence conspicuously the formation of the spatial structure of the high-latitude ionosphere, in particular, the electron and ion temperature distributions.

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