DIFFERENT RESPONSE OF THE AURORAL IONOSPHERE AT ALTITUDES 800 KM AND 300 KM TO THE SOLAR WIND PERTURBATIONS

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ABSTRACT

We explore behavior of the ionospheric plasma components at altitude 800 km and at heights of F-region under impact of the electric field caused by the solar wind dynamics. Enhancement of electric field E value causes violation of thermodynamic equilibrium which leads to "escape" of the electrons while for the ions such enhancement of E means increased intensity of the ion flux (h ~800km). Plasma at h<300 km is basically collisional due to high density of the neutral atmosphere. The Joule heating of plasma causes increasing of Ti and Vi values with correspondent enhancement of the rate of recombination and decrease of Ne_{max} value.

INTRODUCTION

Detailed satellite measurements of the plasma characteristics in the dayside magnetosphere revealed complex structure of this part of the near-Earth space. Further studies of these magnetospheric regions dynamics, plasma populations intensities, their dependence on the external factors led to more full understanding of the fundamental problem of energy transfer process from the solar wind to the Earth's magnetosphere – ionosphere – atmosphere system. Some people postulated decisive role of the reconnection of the interplanetary magnetic field with terrestrial magnetic field [1]. Very important experimental results were reported by [2] where they demonstrated significant spatial and temporal expansion of all magnetospheric dayside regions under enhanced solar wind dynamic pressure. Important part in this process belongs to connection of solar wind with magnetospheric dayside region which could be a source of the electromotive force produced by massive solar wind plasma injection into it [3]. It is well known that the high-latitude ionosphere is a footprint of the correspondent parts of the Earth's magnetosphere. So, all processes of interaction between the solar wind and magnetosphere could be effectively traced by the ionospheric measurements [4] showed that the electron density in the dayside high-latitude ionospheric F2 region strongly depends on the subsolar distance between the magnetopause and the Earth, i.e. on the solar wind dynamic pressure [5]. Enhanced solar wind dynamic pressure caused significant depletion of the electron density in the high- latitude F2 region. It was the first experimental indication of the direct influence of the solar wind dynamic pressure on the ionospheric plasma density dynamics. Naturally that the next step of investigations could be simultaneous analysis of the processes in different altitudes of ionosphere. The ideal instrument for such study could be the incoherent scatter radar data, which include such ionospheric parameters as electron density Ne, ion Ti and electron Te temperatures as well as ionospheric plasma drift velocity Vp, measured in altitude range 90-500 km with high time and height resolution.

OBSERVATIONS

The situations in the dayside parts of the upper boundary of ionosphere were analysed by means of the measurements made by the DMSP F6 and F7 satellites in August –September 1986. Also we used in this study the data obtained by means of incoherent scatter radar EISCAT located in Tromso, Norway (invariant latitude λ= 66.42°N). EISCAT measures such ionospheric parameters as electron density Ne, electron and ion temperatures Te and Ti in the height interval 90- 500 km. Triple- station receiving system of EISCAT allows to measure parameters of the full vector of ionospheric electric field at altitude 270 km. In this study EISCAT data for September 20-26 of 1998 taken for every 5 minutes were analysed. Unfortunately it was impossible for a number of reasons to analyze simultaneous ionospheric and satellite observations but we tried to select for analysis periods of the same seasonal conditions as well as levels of solar and geomagnetic activities. As the first step of the study the situation at the height of 800 km is considered. Figure 1 shows the dependence of the intensity of precipitating fluxes of ions(a) and electrons (b) in upper boundary of ionosphere as measured by DMSP satellites on the magnetopause position relative to the Earth. One can see that enhanced activity of the solar wind sharply increases ion population at upper boundary of ionosphere while it does not actually influence the correspondent electron population. The situation in the auroral ionosphere as a function of the magnetopause position is shown below. Figure 2 demonstrates temporal variations of the magnetopause position in the Earth radius Re units (a) and the ion temperature (b) at ionospheric heights 180 –200 km for period of 22.09.1998. The hourly averaged data are shown. A sudden sharp increase of Ti values corresponding to close approach of the magnetospause to the Earth on 26.09 is seen clearly. If we present this situation as the ion temperature in ionosphere dependence on the magnetopause position (Figure 3) we will find that correlation between these two parameters is rather high (r= 0.76). The increase of the solar wind energy transferring into magnetosphere – ionosphere system leads to enhancement of the ion temperature and presumably to the ion drift velocity in the ionosphere. Unique qualities of the EISCAT data give the opportunity to check this suggestion.

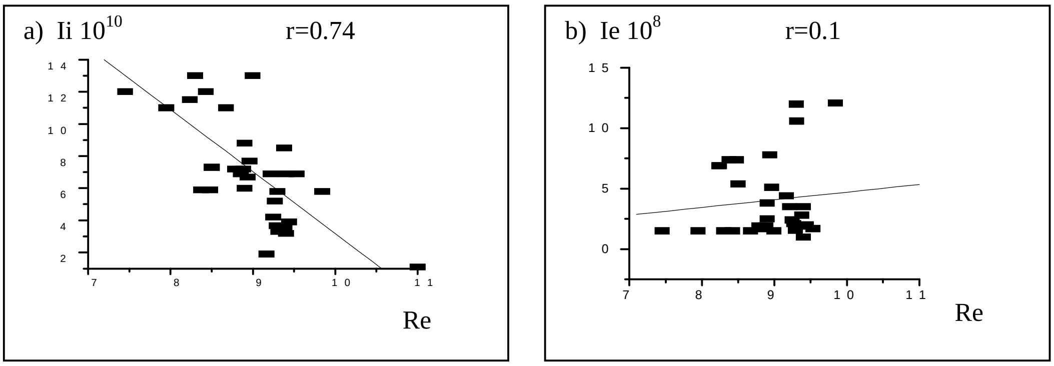

Fig. 1. 800 km: Dependence of intensity of precipitation of ions (Ii) and electrons (Ie) as measured by DMSP satellites on magnetopause position expressed in the Earth radius Re units.

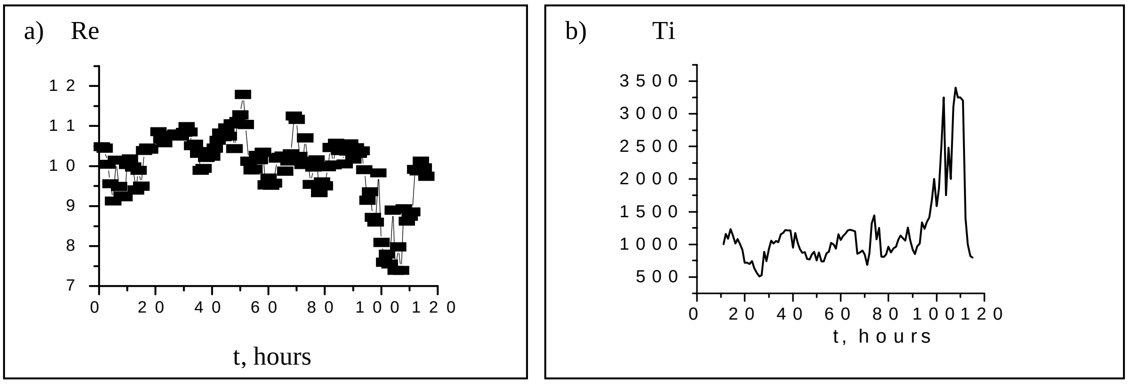

Fig. 2. Temporal variations of position magnetopause (a) and ion temperature at altitudes 180 - 200km as measured by EISCAT (b) for period from 22.09 to 26.09. 1998. The hourly averaged data are shown.

In excellent correspondence to the data of Figure 3 the correlation between Vi and Re is very high (r=0.75) and Vi increases notably with magnetopause approach to the Earth, i.e. with increase of the solar wind energy transferring into the Earth's magnetosphere – ionosphere system. Finally, the EISCAT data show remarkably that the F- region electron density values drop significantly with the magnetopause approaching the Earth (Figure 3, panel c). This phenomena was described previously by [4] in their study of the high-latitude vertical ionosonde data.

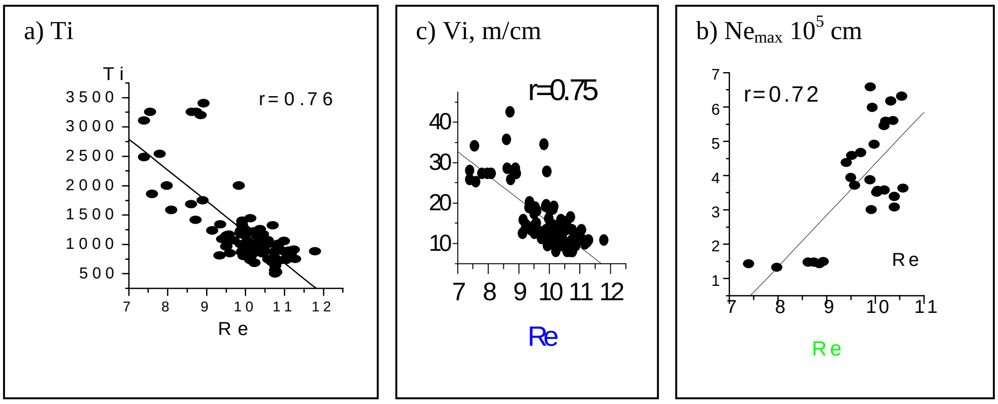

Fig. 3. Relation between magnetopause position and Ti at altitudes 180-200 km (a), values of ion velocity (b) an Ne_{max} (c) as measured by EISCAT for the same period

DISCUSSION

The obtained data can be explained by different influence of field-aligned electric field produced by the solar wind interaction with magnetopause [6] on charged particles at ionospheric altitudes 800 and 300 km. As a starting point an idea suggested by Lundin [6] that the enhanced solar wind dynamic pressure caused increase of the solar wind plasma penetration into boundary regions of the magnetosphere was used. It was suggested here that the electro-motive force (EMF) generator driven by the solar wind energy operates in boundary layers of magnetosphere. One can expect enhancement of the dayside magnetopause currents due to the magnetosphere compression under influence of the solar wind dynamic pressure variations. These currents produce excessive electric fields of polarization E in the magnetosphere , which cause the separation of the charged particles drift in the system magnetosphere -ionosphere. The experimental measurements of magnetospheric E made by [7] at ISEE satellite for similar conditions showed that real values of E exceed 1 mV/m and could be as great as 10 mV/m. A question arises: could such electric fields change the charged particles behavior or not? Alfven and Falthammar in [6] showed that even weak electric field can influence movement of low-energy charged particles. They estimated extreme value of electric field whose influence can exceed influence of magnetic field as following

$$E \gg 5\ 10^{-4}\ \varepsilon \qquad (1)$$

where E – value of electric field in mV/m, ε - energy of the particle in keV. For experimental data of [2] who measured particles with energy of several keV we received limit value of electric field .E= 0.5 mV/m for particles with ε=1keV. Its value is close to experimental data of [7]. So, we can make a conclusion that this polarization electric field could effectively influence dynamics of the charged particle penetration into the magnetosphere. Moreover this effect could be comparable with influence of terrestrial magnetic field. Influence of electric field on particles will be different at different altitudes of ionosphere. At h=800 km where plasma consists of two main components (ions and electrons) electric field influence will be determined by frictional processes between ions and electrons. Thermodynamic equilibrium means that the force of electric field determining charge particles movement F_e must be equal to friction force F_{fr} and therefore we have

$$F_e=F_{fr} \qquad (2)$$

We did a rough estimation of extreme values of electric field when thermodynamic equilibrium is violated in the ionosphere at altitude 800 km. For it we used the following extreme value of electric field as comparing with force of frictional processes given by [6]

$$E_{extr}= 4\pi |e|^3 n_i \ln\lambda / m_e v_t^2 \qquad (3)$$

where e – charge of electron, n_i – density of ions, $\ln\lambda$ - Coulomb's logarithm by [6], m_e – mass of electron, v_t - thermal velocity of electron. For typical parameters of ionosphere such values of electric field could be expressed as following

for electrons: $$E^e_{extr} \approx 1\ 10^{-2}\ \text{mV/m} \qquad (4)$$

for ions $$E^i_{extr} \approx 10\ \text{mV/m} \qquad (5)$$

So, it is clear that even small variations of E (several mV/m) are very effective for electrons and could cause so called "escape" of electrons due to violation of thermodynamic equilibrium. On the other hand this equilibrium continues to be justified for ion fluxes under such electric field variations and intensity of fluxes of ions is proportional to values of electric field i.e. position of magnetopause (Fig. 1).

Situation in ionospheric F region is different because in this case it is necessary to take into account presence of the neutral components which determine many processes on these altitudes. Briefly this situation could be described as following:

1.Ionospheric plasma in F region (altitude 300 km) is basically collisional one due to high neutral atmosphere density. Values of the collision frequencies "ion-neutral" and "electron –neutral" differ from that at altitude 800 km

$$[\nu_{in}(300) / \nu_{in}(800)] \approx 10^3 \quad (6)$$

$$[\nu_{en}(300) / \nu_{en}\ 800)] \approx 5\text{-}7 \quad (7)$$

where ν_{in}, ν_{en} - frequencies of collision electrons and ions with neutral components.

2. At altitudes below 200 km there is a strong anisotropy in conductivity

$$\sigma_h > \sigma_p > \sigma_{||} \quad (8)$$

where σ_h – Hall conductivity, σ_p – Pedersen conductivity, $\sigma_{||}$ - conductivity of along of magnetic field. So, the Hall conductivity exceeds others types of conductivity and many processes at these altitudes will be determined by Hall currents –their values and distribution. The currents under influence of enhancement of electric fields cause Joule heating of ionosphere during disturbed conditions.

Therefore Joule heating takes place in E-region

$$dQ=\sigma_h E^2 dt \quad (9)$$

where Q – value of heating, σ_h – Hall conductivity, E – value of electric field, t – time. Joule heating with corresponding increase of T_i and V_i causes changes of scale height H together with composition of neutral atmosphere and enhancement of rate of recombination in the F-region (decreasing of Ne_{max}) that we can see on Figure 3.

CONCLUSIONS

Supposing that the solar wind produces polarization electrical field in the magnetosphere we suggested that magnitude of this electric field depended on magnetopause position which is a function of solar wind dynamic pressure and Bz orientation. This electric field is big enough to influence motions of the charged particles in inside of magnetosphere. This influence is different for electrons and ions due to difference in their charge and mass. Enhancement of E causes violation of thermodynamic equilibrium which leads to "escape" of electrons while for ions such enhancement will mean increased intensity of the ions (h>800 km). At ionospheric heights (h<300 km) the situation is different comparing with that at h=800 km because collision frequencies "ion-neutral" and "electron –neutral" increase greatly and anisotropy of plasma conductance appears. In this case Joule heating of plasma plays a significant role. We present experimental evidences of these phenomena. So, it is reasonable to suggest that the processes at different altitudes of auroral ionosphere are induced by the solar wind dynamics.

REFERENCES

[1] Cowley, S.W.H., and M. Lookwood, Excitation and decay of solar wind flows in the magnetosphere –ionosphere system, *Ann. Geophys*., 10, 103-115, 1992.

[2] Newell, P.T., and C.-I. Meng,, Ionospheric projections of magnetospheric regions under low and high solar wind pressure conditions, *J. Geophys. Res*., 99, (A1), 273- 286, 1994.

[3] Lundin, R., Processes in the magnetospheric boundary layer, *Phys. Scripta*, T18, 85- 102, 1987.

[4] Makarova, L.N., and A.V. Shirochkov, The magnetopause position as an indicator of the ionization level in the dayside high latitude ionosphere,*Radio Sci*., 33, 1877- 1884, 1998.

[5] Roelof, E.C., and D.G. Sibeck, Magnetopause shape as a bivariate function of interplanetary magnetic field Bz and solar wind dynamic pressure, *J. Geophys. Res*., 98, (A12), 21421- 21450, 1993.

[6] Alfven, H., C.G. Falthammar, Cosmical electrodinamics, Clarendon Press, Oxford, 1963.

[7] Mozer, F.S., Electric field evidence on the viscous interaction at the magnetopause, *Geophys. Res. Lett*., 11, 135-140, 1984.