"Physics of Auroral Phenomena", Proc. XXVII Annual Seminar, Apatity, pp. 21-24 , 2004

Polar Geophysical Institute

A STUDY OF THE COUPLING BETWEEN IONOSPHERIC CONVECTION AND THERMOSPHERIC CIRCULATION DISTURBED BY MAGNETIC STORM

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Abstract. At high latitudes, the large-scale ionospheric convection pattern is contributed mainly by the action of magnetospheric dynamo. Under disturbed conditions, the intensity of both magnetospheric and ionospheric convection increases. It is so because of strengthening of the electric field and current sources in the magnetosphere. The atmospheric circulation changes with some time-delay compared to the convection and precipitation patterns. Thermospheric winds may be much more intense when magnetospheric disturbance, such as magnetospheric substorm, already deceases. Therefore ionospheric disturbance dynamo may contribute significantly to the overall convection pattern in the periods of magnetic storms, especially at middle and low latitudes. To simulate the coupling between ionospheric convection and thermospheric circulation, the numerical model is proposed and calculations are performed.

1. Model equations

The numerical model of ionosphere-thermosphere coupling is presented with the following transport equations written for neutral and charged particles and the continuity equation of electric currents (Zakharov *et al.*, 1998):

$$\begin{cases} \dfrac{\partial \rho_n}{\partial t} + div(\rho_n \vec{V}_n) = 0 \\ \rho_n (\dfrac{\partial \vec{V}_n}{\partial t} + (\vec{V}_n \nabla)\vec{V}_n) + \nabla p_n = \vec{F}_n \\ \dfrac{i_n p_n}{2T_n} (\dfrac{\partial T_n}{\partial t} + div(T_n \vec{V}_n)) + p_n div(\vec{V}_n) = Q_n, \end{cases} \tag{1}$$

where ρ_n, p_n, and T_n are the mass density, pressure and temperature of neutral gas, respectively, i_n is the number of degrees of freedom per a neutral particle, $\vec{V}_n$ is the mean mass velocity of a neutral particle, $\vec{F}_n$ and Q_n are the density of total external force and total power density of thermal sources and losses per unit of volume of neutral gas, respectively,

$$\begin{cases} \dfrac{\partial n_i}{\partial t} + div(n_i \vec{V}_i) = q_i \\ \rho_i (\dfrac{\partial \vec{V}_i}{\partial t} + (\vec{V}_i \nabla)\vec{V}_i) + \nabla(p_i) = \vec{F}_i \\ \dfrac{i_i p_i}{2T_i} (\dfrac{\partial T_i}{\partial t} + div(T_i \vec{V}_i)) + p_i div(\vec{V}_i) = Q_i \\ \dfrac{3 p_e}{2T_e} (\dfrac{\partial T_e}{\partial t} + div(T_e \vec{V}_e)) + p_e div(\vec{V}_e) = Q_e, \end{cases} \tag{2}$$

where n_i, ρ_i, p_i, and T_i are the density, mass density, pressure, and temperature of ions, respectively, i_i is the number of degrees of freedom per an ion, $\vec{V}_i$ and $\vec{V}_e$ are the mean mass velocity of ion and of electron, respectively, p_e and T_e are the pressure and temperature of electrons, respectively, Q_i and Q_e are the total power density of thermal sources and losses per unit of volume of the ion and electron gas, respectively, $\vec{F}_i$ is the density of total external force per unit of volume of the ion gas,

$$div\,\vec{j} = 0, \tag{3}$$

where $\vec{j}$ is the density of electric current, $\vec{j} = \hat{\sigma}(\vec{E} + \vec{V}_n \times \vec{B})$ in accordance with the Ohm law employed for ionospheric plasma, $\hat{\sigma}$ is the tensor of electric conductivity of plasma, $\vec{E}$ is the strength of electric field, and $\vec{B}$ is the induction of geomagnetic field.

To study the large-scale processes, the effects of the inertial forces acting on charged particles in the ionosphere as well as of the electric fields parallel to $\vec{B}$ in the current-layer of ionosphere and magnetosphere are neglected. Let U designate the potential of electric field ($\vec{E} = -grad\,U$). In the ionosphere, the dipole model of geomagnetic field is used. The integration of Eq. (3) is performed along each of geomagnetic field-lines from the lower boundary of the ionospheric current layer in the southern hemisphere to the lower boundary of the same layer in the northern hemisphere. This results in the equation designated to calculate the electric potential U. The description of integration is cumbersome (Zakharov and Pudovkin, 1996) so that is omitted here. At the lower boundary of ionosphere, the penetration of electric currents from the ionosphere into the neutral atmosphere is neglected.

The system of the model equations obtained above is integrated with use of the spherical coordinates (r, θ, λ), where r is the geocentric distance, θ and λ are the geographical colatitude and longitude, respectively. To integrate this system, the method of finite differences is used. To this purpose, two difference grids are employed. They are non-uniform and embedded each other. In particular, the equation obtained for electric potential is integrated using the matrix sweep method. In numerical calculations, the numbers of the grid nodes taken on height, colatitude, and longitude are given to be equal to 45, 50, and 24, respectively.

2. Discussion of the results and conclusions

The numerical model described above is developed to estimate how much the magnetospheric sources of momentum and of energy influence the behavior of the ionosphere-thermosphere system under magnetic storm-type conditions. To verify the results of numerical calculations, the EISCAT data on amplitudes and phases of the wind harmonics presented by Nozava and Brekke (1994) are used. It is found that the difference between calculated values of amplitudes and corresponding experimental ones may be as large as 50%. In the case of phase, the same difference may be as large as 1 - 2 hours. This difference takes larger values with number of the wind harmonic. The values of the electron density calculated for the altitude of 132 km are verified in the same manner. The electron density is verified similarly using the model results presented by Kaschenko and Nikitin (1987), and the similar results of comparison were obtained for the low-latitude ionosphere. The geomagnetic conditions given to perform the calculations correspond to those observed in March, 6 1976.

To perform the calculations, the empirical models of field-aligned electric currents (FAC) flowing between the ionosphere and magnetosphere (Rich and Kamide, 1983) and of fluxes of the auroral electrons precipitating from the magnetosphere into the ionosphere (Spiro *et al.*, 1982) are used. To provide the self-consistent calculations of electric fields in the northern and southern hemispheres, the FAC model presented by Rich and Kamide (1983) is used to give the symmetric part of FAC. Calculations are carried out in two stages. At the first stage, the calculations were carried out for quiet conditions in order to describe the steady-state behavior of the ionosphere-thermosphere system. At the second stage, the behavior of this system is studied under disturbed conditions. Then, the harmonic analysis is performed in order compare each other the behavior of the wind system under quiet and disturbed conditions. Our calculations show that the thermospheric circulation changes with some time-delay with respect to the ionospheric convection. This time-delay is about of 0.5 – 1 hours for the polar ionosphere and becomes larger with colatitude. The effects of the ionospheric disturbance dynamo become more essential while the magnetic storm subsides.

The potential patterns calculated by us (see Table 1 and Fig. 1) for the northern ionosphere are consistent with those obtained earlier by Zakharov and Pudovkin (1996).

Table 1. Calculated parameters of the convection patterns

The time t counted from the substorm maximum	30′	90′	190′	360′
U_{min}, kV	-21,5	-15,0	-12,6	-10,0
U_{max}, kV	40,7	27,4	22,6	18,5

In Fig. 2, the amplitude (left) and phase (right) of the first harmonic of longitudinal component of the neutral wind velocity are calculated for the northern hemisphere in dependence on the time t, solid and dashed lines relate to the quiet and substorm conditions, respectively.

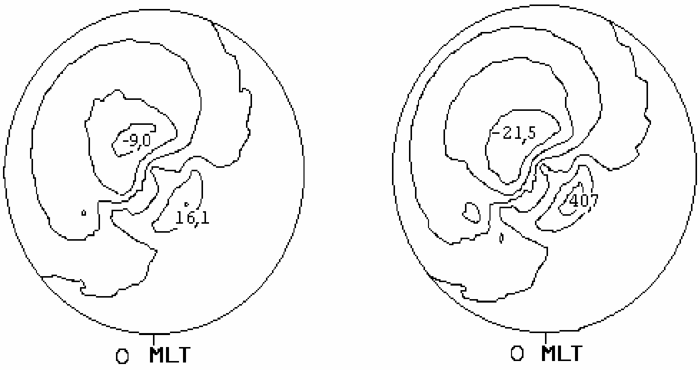

Fig..1. Electric equipotentials (kV) calculated for the quiet (left) and substorm (right, t = 30') conditions

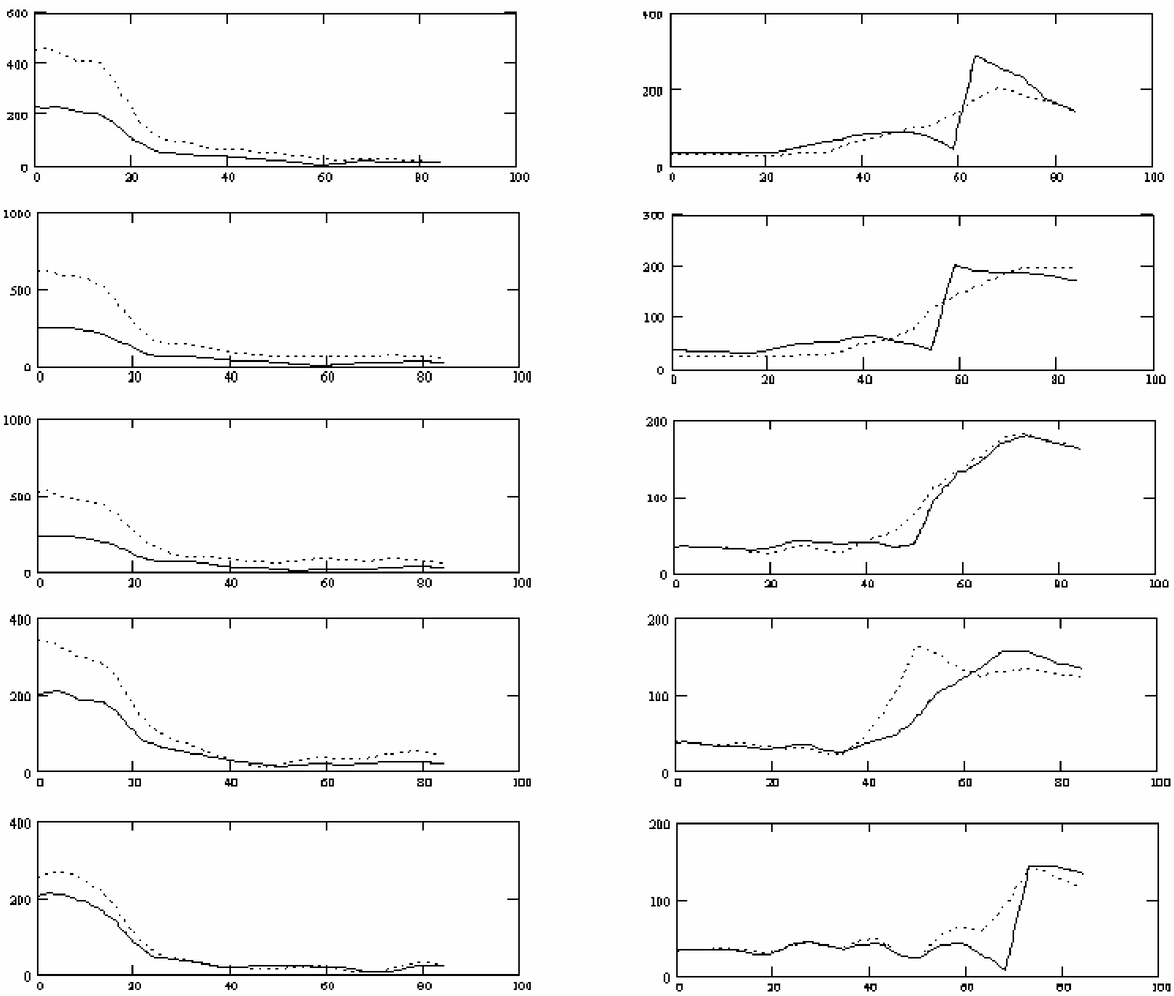

Fig.. 2. The amplitude (left) and phase (right) calculated for the first harmonic of longitudinal component of the neutral wind velocity (m/s) in dependence on colatitude: solid and dashed lines are obtained for the quiet and substorm conditions, respectively, and for $t = -30', 30', 90', 190'$ и $360'$

The analysis of the results of calculations shows that magnetospheric substorm influences strongly the parameters of thermospheric circulation. For instance, the amplitude of the first harmonic mentioned above is about two times larger for the substorm conditions in comparison with quiet conditions. This increase propagates from high to lower latitudes ($\sim 50^0$) with time while the magnetic storm proceeds. The increase is appreciable in the period of 10 hours after the substorm is gradually falling down. In the polar region, the amplitude is about 1.5 times lager after 4.5 hours in comparison with quiet conditions. The phase of the first harmonic changes most strongly at middle latitudes.

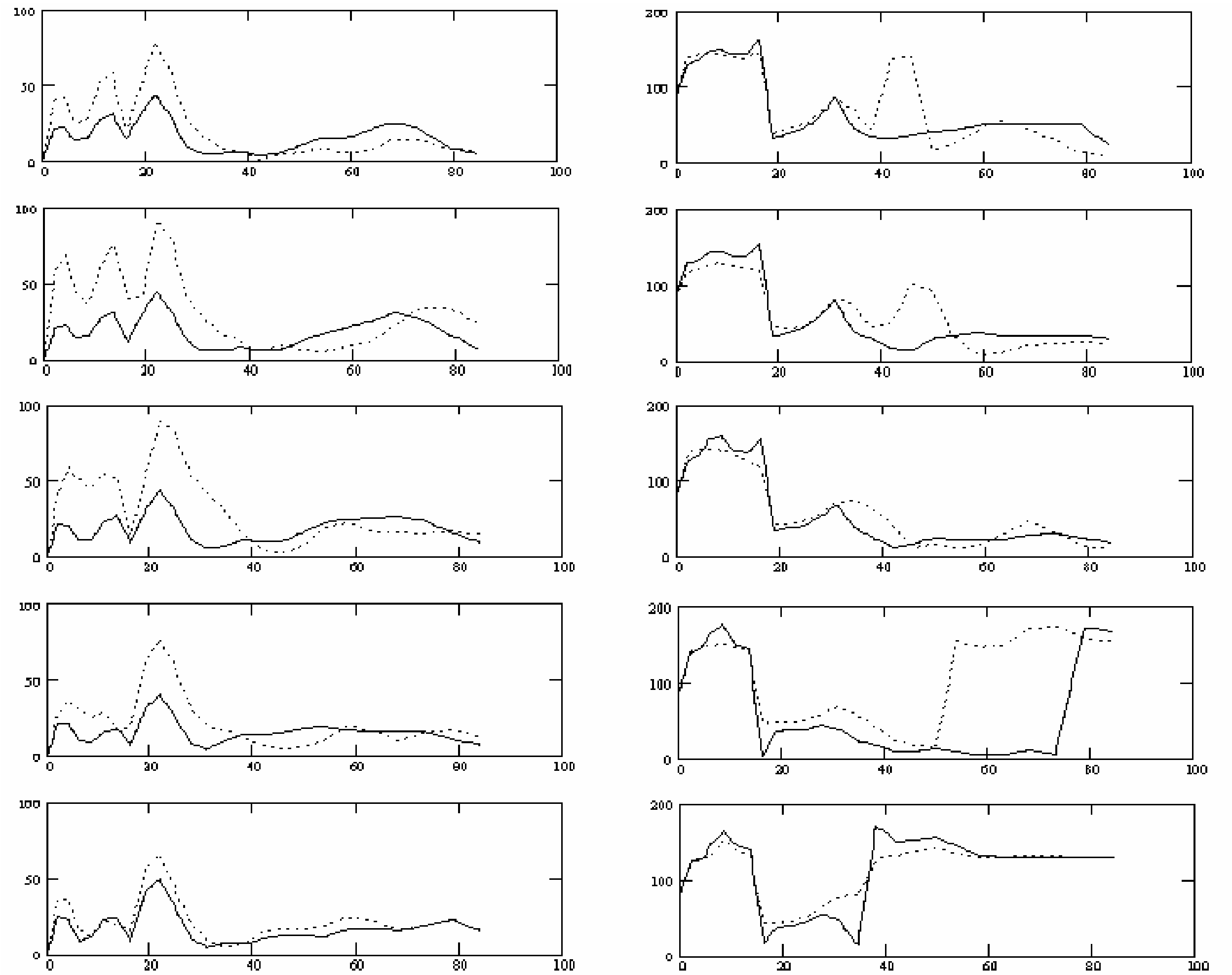

Fig.. 3. The amplitude (left) and phase (right) calculated for the second harmonic of longitudinal component of the neutral wind velocity(m/s) in dependence on colatitude: solid and dashed lines are obtained for the quiet and substorm conditions, respectively, and for $t = -30', 30', 90', 190'$ и $360'$

The behavior of the amplitude and of phase of the second harmonic is more complicated (see Fig. 3). Comparing Fig. 2 and Fig. 3 each other, one may conclude that the substorm influences the amplitude larger than phase.

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