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THE CURRENTS DURING DIPOLARIZATION OF THE EARTH MAGNETIC FIELDS

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Introduction

One of the most important features of the expansive phase of the substorm is the sudden intensification of the western electrojet and the dipolarisation of the Earth magnetic field lines. The Earth magnetic field lines, stretched in the magnetosphere tail, are shortened during the expansive phase of the substorm and take form close to the dipolar on distances equal to 6 radiuses of the Earth (R_E) and more. Because of the shortening of the Earth magnetic field lines the plasma pressure varies and it causes appearance of the currents along the magnetic field lines. In this paper we investigate whether these currents can cause the intensification of the western electrojet during the substorm expansive phase.

The model of the magnetic field

The magnetic field on distances 6-10 R_E is considered potential and equal to the sum of a dipole magnetic field and a disturbed field, connected with the currents along the magnetopause and currents in the magnetosphere tail. The contribution of the disturbed magnetic field is limited by two first harmonics of the magnetic potential, the second one is azimuthal–asymmetrical harmonic. In the geocentric coordinates system, where the axis *x* is directed to the Sun and the axis *z* corresponds to the direction of the axis of the Earth magnetic dipole, the formula for the magnetic potential with two harmonics of the disturbed field is:

$$\psi = -\frac{B_0 R_E^3}{r^3} z - \gamma_1 z - \gamma_2 xz \, , \qquad (1)$$

where γ_1=115 nT, γ_2- the coefficient of the azimuthal-asymmetrical harmonic. At the end of the substorm growth phase $\gamma_2=10.85/R_E$ nT, for the expansive phase substorm $\gamma_2=5.425/R_E$ nT. These values have been selected so that in the best way to correspond to the observations [1].

The formula for calculation of the field-aligned currents

Processes in the magnetosphere on distances 6-10 R_E we shall consider in the magnetohydrodynamic approach. The pressure of plasma *p* we consider constant along the Earth magnetic field lines. The equation for the adiabatic process is:

$$\frac{d}{dt}(pV^{\gamma}) = 0 \, , \qquad (2)$$

where $V = B_I \int \frac{ds}{B}$ - the volume of the magnetic flux tube with unit magnetic flux in the ionosphere, B_I - the induction of the magnetic field in the ionosphere, γ=5/3 – the ratio of the adiabatic process.
The field-aligned currents can be calculated by the formula [2-3]:

$$j_{//} = \frac{1}{B_I}(\vec{e}_z[\nabla p \times \nabla V]) \quad , \qquad (3)$$

where $\vec{e}_z$ – the unit vector directed along the magnetic field. The current flowing from the ionosphere of the northern hemisphere defined to be positive, the gradients are calculated at the ionospheric level.
Formula (3) can be rewritten in the other form:

$$j_{//} = \frac{1}{B_I V^{\gamma}}(\vec{e}_z[\nabla pV^{\gamma} \times \nabla V]) \qquad (4)$$

We calculate the field-aligned currents neglecting the magnetic flux tubes drift. It is justified if the magnetic flux tubes drift along the longitudinal direction. In this case solution of the equation (2) is $p_1 V_1^{\gamma} = p_2 V_2^{\gamma}$, where the volume of the magnetic flux tube and the plasma pressure at the end of the growth phase and the expansive phase of the substorm are marked by indexes 1,2. We shall assume for convenience that the field-aligned currents at the end of the growth phase are zero, then the vectors ∇p_1 and ∇V_1 are collinear. In this case the model pressure profile in the plasma is:

$$p_1 = \frac{p_0 V_0^{\alpha}}{V_1^{\alpha}} \qquad (5)$$

The outer boundary of the plasma layer is stable with respect to the interchange instability if $\nabla p V^{\gamma} > 0$, in our case this condition is fulfilled at $\alpha < \gamma$.

According to observations in the plasma layer of the magnetosphere tail there are plasma flows before the expansive phase substorm as towards the Earth and in the opposite direction as well, which are accompanied by magnetic impuls. It can mean development of the interchange instability of the plasma layer in this area. We shall consider that in this area $\nabla p V^{\gamma} < 0$, and $\alpha > \gamma$. The formula for the field-aligned current at the end of expansive phase substorm is:

$$j_{//} = \frac{p_0 V_1^{\gamma-\alpha-1}(\gamma - \alpha)}{B_I V_2^{\gamma}} (\vec{e}_z [\nabla V_1 \times \nabla V_2]) \qquad (6)$$

Spatial distribution and values of field-aligned currents

Volume of the magnetic flux tubes V_1 and V_2 for the magnetic potential (1) are calculated numerically in each mesh point with step 1^0 on latitude and 5^0 on longitude, since 16^0 colatitude. Figures 1 and 2 show the values of the volumes V_1 and V_2 accordingly for the substorm growth phase and expansive phase substorm. The values of volumes are given in terms $m^2 R_E$. It is clearly seen that the isolines of the equal volume during the growth phase and expansive phases substorm do not coincide, there are the currents along magnetic field lines. Figure 3 shows the distribution and values of the currents. The plasma pressure p_0 in the plasma layer on distances $8R_E$ at the end of the growth phase was 10 nPa. The power of the plasma pressure decrease assumes equal α=1 down 22^0 and α=2.5 in the interval 16^0-22^0. According to calculations the value of currents reaches 0.7 A/km^2, the maximum of the current flowing from the ionosphere locates close to 20 MLT, the maximum of the current flowing in the ionosphere locates close to 04 MLT. The obtained system of field-aligned currents should be closed in the ionosphere by the western direction current. This current should have the Hall nature, as the current flowing in the plasma layer. Observations of the electric fields in the midnight sector of ionosphere during the expansive phase substorm also show the Hall nature of the western electrojet. According to observations the electric field in this region has the predominately southern direction [4]. Fig.4 shows radial distribution of the plasma pressure in the equatorial cross section of the magnetosphere along the noon-midnight line on the night side of the magnetosphere at the end of growth and expansive phase substorm. The pressure on distances more then 6 R_E during the expansive phase substorm decreases to some extent, the decreasing pressure in the magnetosphere tail during the expansive phase substorm is obtained by results of the observations [5].

Summary

According to the obtained results the intensification of the western electrojet and dipolarisation of the Earth magnetic field lines during an expansive phase substorm are interdependent phenomena. At dipolarisation of the Earth magnetic field lines the system of field-aligned currents are formed, the currents flowing from the ionosphere in premidnight hours and flowing in the ionosphere after midnight. The intensity of field-aligned currents of this system is sufficient to increase the transverse ionospheric current of the western direction. This current will have the Hall nature, as well as currents flowing in the plasma layer. The appearance of the current wedge of the substorm can be caused by the decrease pressure near midnight in the plasma sheet as a result of the dipolarization magnetic field lines with the assumption $\nabla p V^{\gamma}$ <0.

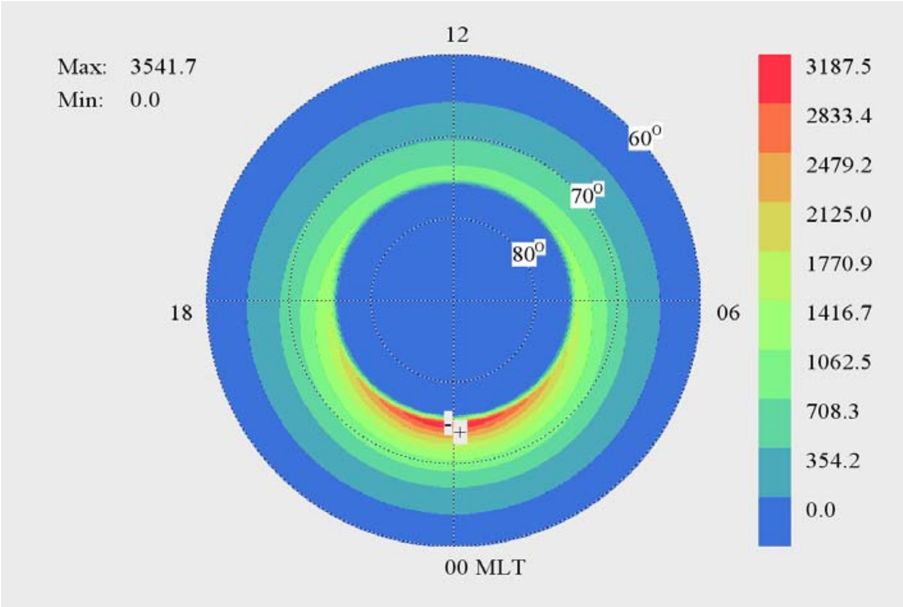


Fig.1 The distributions magnetic flux tubes for the substorm growth phase.

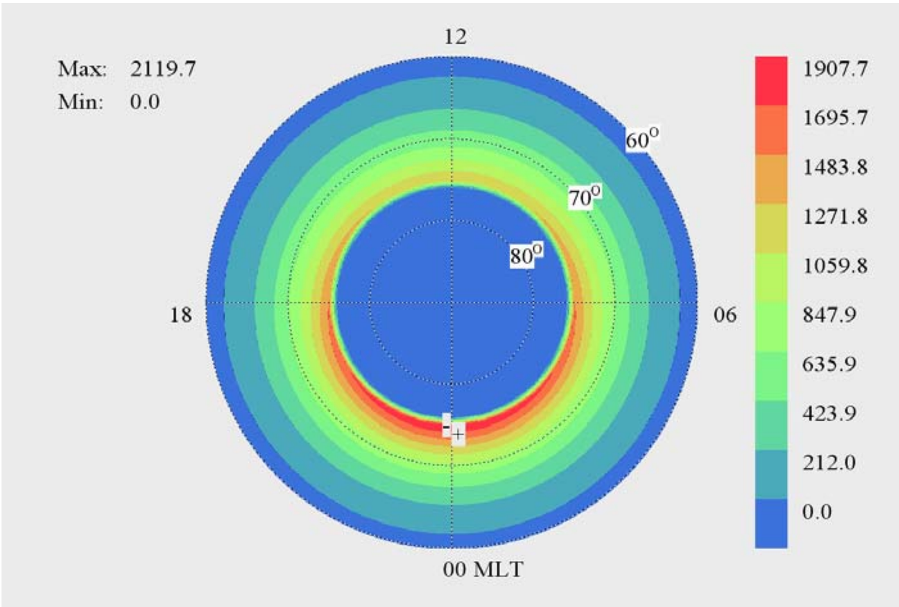


Fig.2 The distributions magnetic flux tubes for the substorm expansive phase.

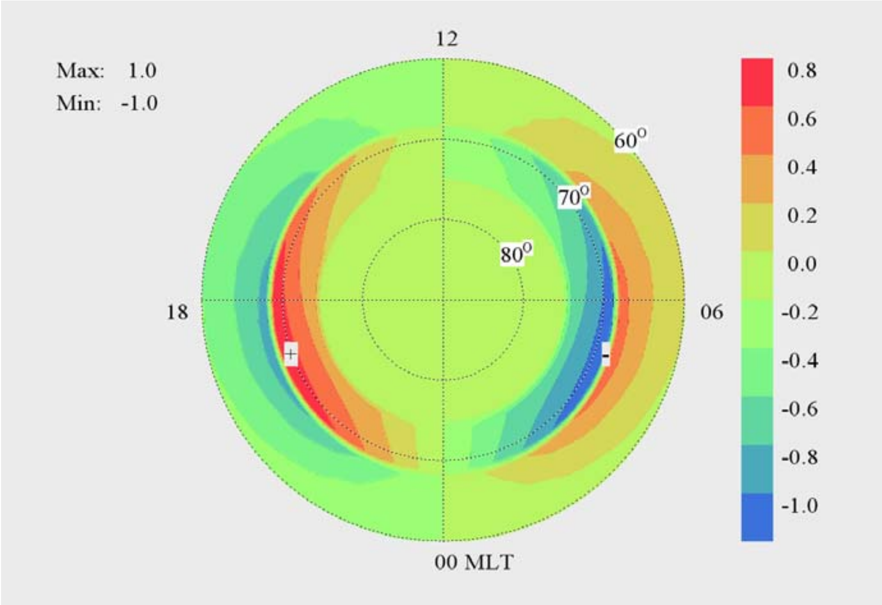
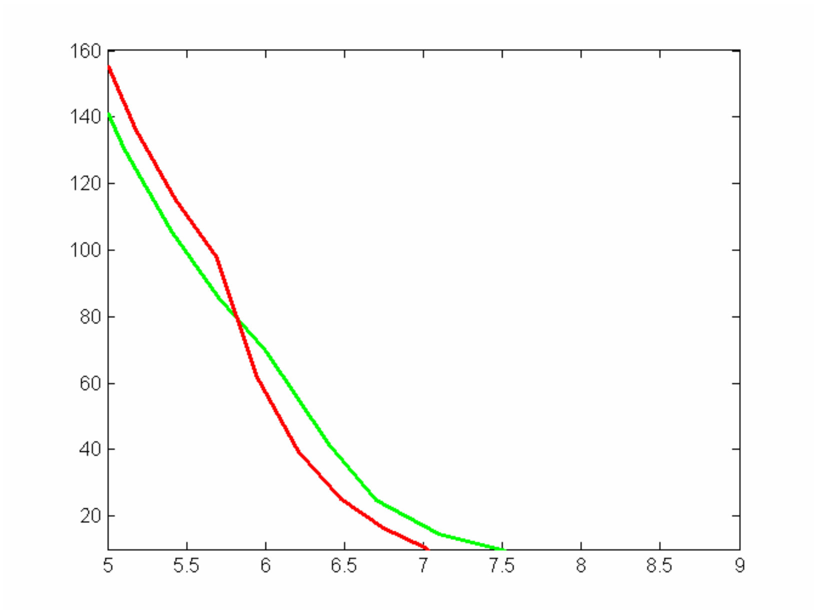


Fig.3 The distributions field-aligned currents (A/km^2) for the substorm expansive phase.



r/R_E

Fig.4 The radial profile of the plasma pressure (nPa) in the equatorial cross section of the magnetosphere along the noon-midnight line on the night side of the magnetosphere at the end of growth (green line) and expansive phase (red line) of the substorm.

References

1.Hamilton D.C.,Gloeckler G.,Ipavich F.M., Studemann W.,Wilken B., Kremser G., Ring current development during great geomagnetic storm of February 1986. //J.Geophys.Res.-1988.-V.93, №A12.-P.14343-14355

2. Vasyliunas, V. M.: Mathematical models of magnetospheric convection and its coupling to the ionosphere, in Particles and Fields in the Magnetosphere, edited by B. M. McCormac, 60–71, D.Reidel, Norwell, Mass., 1970.

3. Tverskoy B.A. Field-aligned currents in magnetosphere. // Geomagnetism and aeronomy (in Russian)-1982.-V.22, №6, p.991-995.

4. Gjerloev, J. W., and R. A. Hoffman, The convection electric field in auroral substorms, *J.Geophys.Res.,106*, 12,919, 2001.

5. L. R. Lyons, C.-P. Wang, T. Nagai,2 T. Mukai, Y. Saito, and J. C. Samson , Substorm inner plasma sheet particle reduction, *J.Geophys.Res.*, 108, A12, 1426, 2003