Global modeling of the magnetosphere in terms of paraboloid model of magnetospheric magnetic field

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The solar wind influence on the magnetospheric state is sufficiently non-linear especially during strong disturbances. The magnetospheric current systems response on external driving non-synchronously and demonstrate the different response and decay times. They depend not only on current but also on previous solar wind conditions ("prehistory"). The detailed analyses of the magnetic storms of different intensities show that magnetospheric current systems demonstrate dependence on parameters originating from solar wind as well as from the magnetosphere (e.g., *Dst* and *AL* indices) [*Alexeev et al., 2001; Kalegaev et al., 2005*]. Geomagnetic indices reflect the non-linear character of solar wind – magnetosphere coupling. Taking into account solar wind parameters jointly with the geomagnetic indices as input for magnetospheric models allows representing non-linear response of the magnetospheric magnetic field on solar wind driving, taking into account also "prehistory effect".

The magnetospheric current systems response on solar wind driving can be analyzed on the base of paraboloid model of the Earth's magnetospheric magnetic field A2000. Paraboloid model of the Earth's magnetosphere [*Alexeev et al., 1996; Alexeev et al., 2001; Alexeev et al., 2003*] determines the magnetospheric magnetic field from each large scale current system as an analytical solution of the Laplace equation inside the fixed shape magnetosphere (paraboloid of revolution). The condition B_n =0 is assumed at the magnetopause. Paraboloid model represents the magnetic fields of the ring current B_r, of the tail current including the closure currents on the magnetopause B_t, of the Region 1 field-aligned currents B_{fac}, of the magnetopause currents screening the dipole field B_{sd} and of the magnetopause currents screening the ring current B_{sr}:

$$B_m = B_{sd}(\psi, R_1) + B_t(\psi, R_1, R_2, \Phi_\infty) + B_r(\psi, b_r) + B_{sr}(\psi, R_1, b) + B_{fac}(I_{||}). \qquad (1)$$

The model is not connected with some database which imposes the limitations on the model's region of validity, so it can describe the magnetic field during quiet as well as disturbed and extremely disturbed periods. The storm-time dynamics of the magnetosphere is represented as temporal variations of the large-scale current systems.

The model input are key parameters of the magnetospheric current systems, which represent their location and intensity:

- the geomagnetic dipole tilt angle ψ;
- the magnetopause stand-off distance R_1;
- the distance to the inner edge of the tail current sheet R_2;
- the magnetic flux through the tail lobes Φ_{pc};
- the ring current magnetic field at the Earth's center b_r;
- the maximum intensity of the field-aligned current $I_\|$.

Model parameters are calculated through the empirical data. These calculations can be performed on the different manner using so-called *submodels (*see [*Alexeev et al., 1996; Alexeev et al., 2003*]), realizing the dependences of the parameters on different sets of empirical data. Unlike the Tsyganenko models, the A2000 parameters calculation is not "embedded" into the model. Submodels can be changed or replased by user to change the methods of magnetic field calculations depending on data availability. Such approach allows flexible take into account the different physical features of solar wind - magnetosphere coupling and variety of geomagnetic conditions.

In previously published case-studies [*Alexeev et al., 1996; Alexeev et al., 2001; Kalegaev et al., 2005*], the subsolar distance was calculated by [*Shue et al, 1998*] model:

$$R_1 = \{10.22 + 1.29 \tanh[0.184(B_z + 8.14)]\}(nv^2)^{-\frac{1}{6.6}}. \qquad (2)$$

The distance to the magnetospheric tail was calculated as dipole projection of the auroral oval equator ward boundary at midnight φ_n: $R_2 = 1/\cos^2\varphi_n$, where φ_n is determined by [*Starkov, 1993*] :

$$\varphi_n = 74{,}9^o - 8{,}6^o \cdot \log_{10}(-Dst). \qquad (3)$$

The magnetic flux through the tail lobe Φ_{pc}, was represented as a sum of the magnetic flux $\Phi_0 = 370 MWb$, associated with the slow, adiabatic evolution of the geomagnetic tail and magnetic flux Φ_s, associated with substorm activity [*Alexeev et al., 1996; Alexeev et al., 2001*]. Φ_s was determined by equation

$$\Phi_s = -\frac{AL}{7}\frac{\pi R_1^2}{2}\sqrt{\frac{2R_2}{R_1}+1} \qquad (4)$$

The ring current magnetic field at the Earth's centre $\boldsymbol{b_r}$ (including symmetrical and asymmetrical parts of RC, see [*Kalegaev and Ganushkina, 2005*]) was represented as solution of the Burton equation [*Burton et al., 1975*]:

$$\frac{db_r}{dt} = F(E) - \frac{b_r}{\tau}. \qquad (5)$$

It is resulted from joint action of injection and decay processes. The injection function is represented as

$$F(E) : \begin{cases} d(E_y - 0{,}5), & E_y > 0.5 \text{ мВ/м} \\ 0, & E_y < 0.5 \text{ мВ/м} \end{cases} \qquad (6)$$

where E_y is dawn-dusk electric field in solar wind, and d is injection amplitude. The ring current decay time is determined as $\tau(E_y) = 2.37 e^{9.74/(4.78+E_y)}$ [*O'Brien and McPherron, 2001*]. The single free parameter for each injection d is determined as a best fit between *Dst* and *Dst* calculated by the model. Along with [*Kalegaev et al., 2005*] ring current is dominant *Dst* source during this strong magnetic storms.

The magnetic field magnetospheric magnetic field variations on the Earth's surface were analyzed during magnetic storm on October 28-31, 2003. The extreme CMEs influenced this intense magnetic storm in the Earth's magnetosphere, accompanied by strong magnetopause compression and auroral oval expansion. Interplanetary shocks influenced two-hump's magnetic storm with Dst up to -400nT. Figure 1 (left panel) presents the data of the magnetic storms on October 28-31 (ACE measured data and WDC C2, Kyoto data): (a) IMF B_z component, the solar wind (b) density and (c) velocity, (d) *Dst*, (e) *AL*.

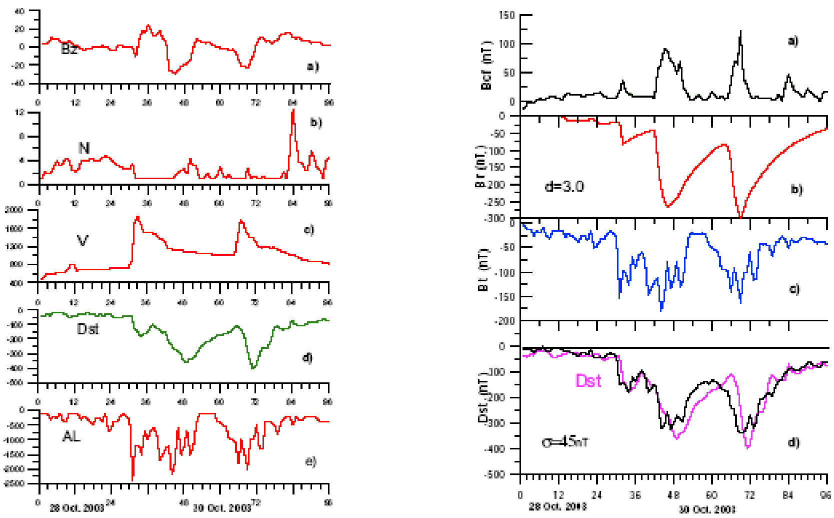

Fig. 2. Overview of magnetic storm event on October 28-31, 2003 (left panel) and Dst and its sources calculated by paraboloid model (right panel)

The solar wind plasma data (velocity and density, IMF B_z, AL and Dst indices determine the paraboloid model input parameters. Figure 1 (right panel) represents the contributions to Dst of the magnetospheric current systems calculated by paraboloid model (currents on the magnetopause, a; ring current, b; tail current, c) as well as comparisons between Dst and calculated Dst (d) during October 28-31, 2003 magnetic storm. The RMS deviation between calculations and measurements was 45 nT that is about of 10% of Dst maximum. During the first, slow, injection the tail current contribution dominates and magnetospheric dynamics was controlled directly by solar wind. The next two strong injections are related with intense ring current formation and decay.

The solar wind changes reveal themselves not only in ground magnetic field variation. They change the whole magnetospheric magnetic field structure. Fig. 2 represents the noon-midnight magnetospheric cross-section section on Jan 9, 1997, UT=12:00 (quiet conditions) and Jan 10, 1997, UT=10:00

(moderate magnetic storm maximum) calculated by paraboloid model. One can see the evidences of tail current increase during magnetic storm main phase.

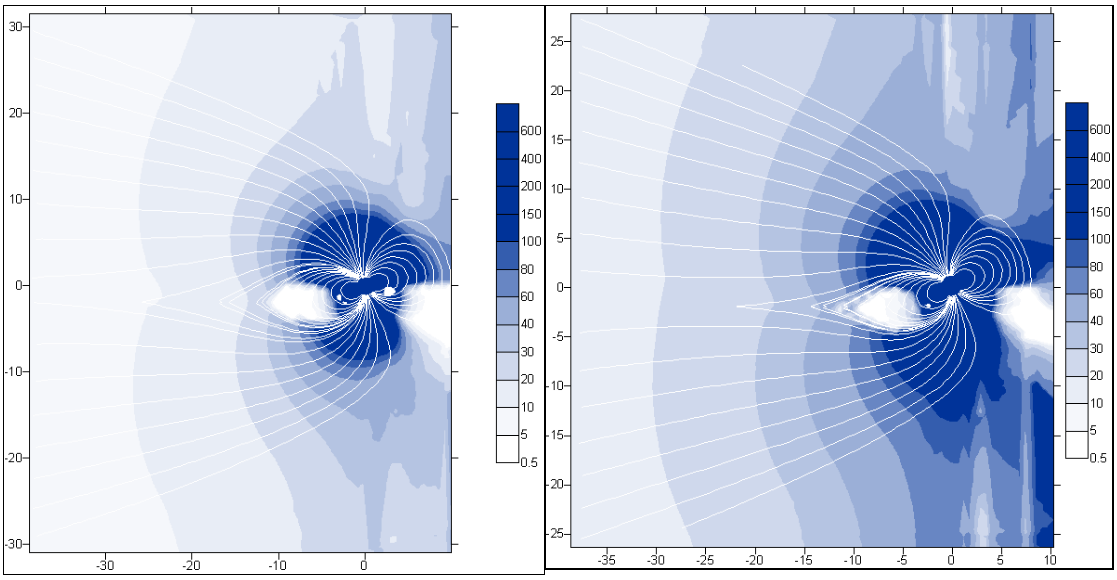

Fig. 2. The magnetic field structure in the noon-midnight magnetosphere cross-section on Jan 9, 1997, UT=12:00 and Jan 10, 1997, UT=10:00.

A2000 model allows to perform the near real-time calculations based on empirical data for any level of disturbance. The solar wind driving of the magnetospheric magnetic field is realized through the dependence of the model parameters on empirical data (solar wind plasma parameters, IMF, AL and Dst). The auxiliary models, *submodels*, can be changed while the magnetic filed calculated by the model remains to be satisfying the boundary conditions. Such three-level structure of the model (data – parameters – magnetic field) allows flexible taking into account the data availability changing the “data-parameters” calculation scheme (changing the *submodels*). One can provide the model tuning, changing the time delay of the different current systems in response to solar wind driving as well as their saturation during the storm-time.

Bibliography

1. Alexeev I.I., E.S.Belenkaya, S.Y.Bobrovnikov, V.V.Kalegaev, Modelling of the electromagnetic field in the interplanetary space and in the Earth's magnetosphere, Space Science Rev., **107**, 7 (2003).
2. Alexeev I. I., Belenkaya E. S., Kalegaev V. V., Feldstein Y. I., Grafe A., Magnetic storms and magnetotail currents, J. Geophys. Res., **101**, 7737 (1996).
3. Alexeev I.I.. Kalegaev V.V., Belenkaya E.S., Bobrovnikov S.Yu., Feldstein Ya.I., Gromova L.I., The Model Description of Magnetospheric Magnetic Field in the Course of Magnetic Storm on January 9-12, 1997, J. Geophys. Res., **106**, 25683 (2001).
4. Belenkaya E.S., I.I.Alexeev, and C.R.Clauer, Field-aligned current distribution in the transition current system, Journal of Geophys. Res., 109, A11207, doi:10.1029/2004JA010484, 2004.

5. Burton R. K., McPherron R. L., Russell C. T., An empirical relationship between interplanetary conditions and Dst, J. Geophys. Res., **80**, 4204 (1975).
6. Kalegaev V.V., Ganushkina N. Yu., Global magnetospheric dynamics during magnetic storms of different intensities. AGU Monograph "Physics and Modeling of the Inner Magnetosphere", 293, (2005).
7. Kalegaev V. V., Ganushkina N. Yu., Pulkkinen T. I., Kubyshkina M. V., Singer H. J., Russell C. T., Relation between the ring current and the tail current during magnetic storms, Ann. Geoph. **26**, 523 (2005).
8. O'Brien T. P., McPherron R. L., An empirical phase space analysis of ring current dynamics: Solar wind control of injectionand decay, J. Geophys. Res., **105**, 7707 (2000).
9. Shue J.-H., Song P., Russel C. T., Steinberg J .T., Chao J. K., Zastenker G., Vaisberg O. L., Kokubun S., Singer H. S., Detman T. R., Kawano H., Magnetopause location under extreme solar wind conditions, J. Geophys. Res., 103,17691-17700, 1998.
10. Starkov, G.V., Planetary morphology of the aurora, In *Magnetosphere-Ionosphere Physics*, S.-Petersburg: Nauka, 85-90, 1993.