INTERNATIONAL STANDARD **ISO WD 22009**

WORKING DRAFT

Space System - Space Environment
(Natural and Artificial)

Model of Earth's Magnetospheric Magnetic Field

I.I. Alexeev, V.V. Kalegaev, Yu.G. Lyutov, M.I. Panasyuk,
Skobeltsyn Institute of Nuclear Physics,
Moscow State University , Russia,

and J. M. Quinn
Geomagnetics Group, U. S. Geological Servey MS 966
Federal Center, Denver, CO 80225-0046, U. S. A.

$$\vec{B} = \vec{B}_{int} + \vec{B}_{ext}, \quad nT \tag{1}$$

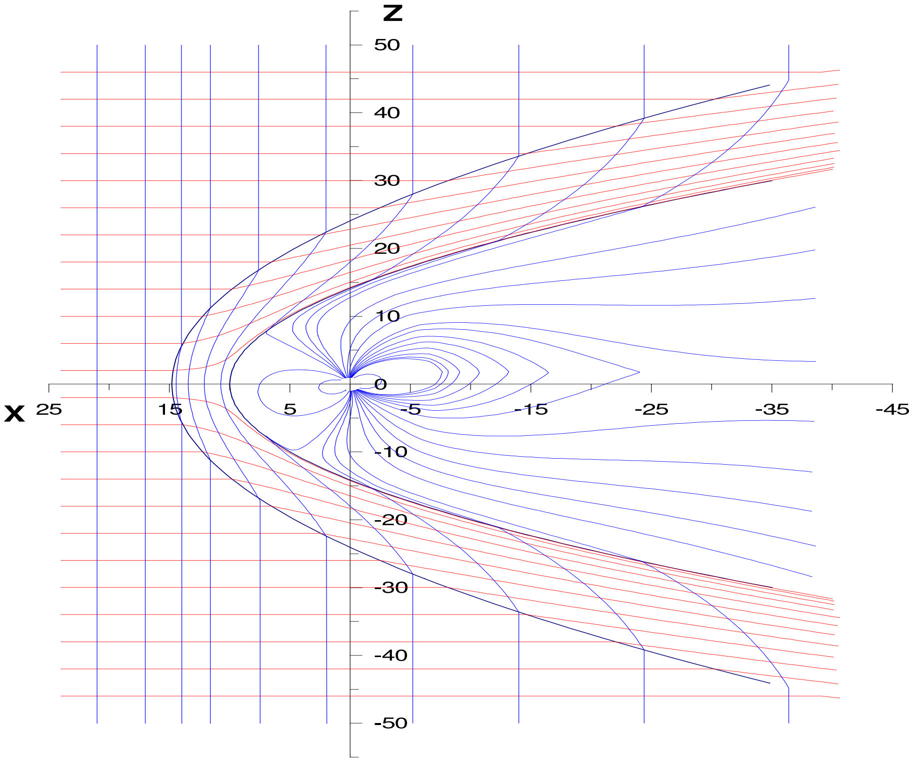


Figure 1: Magnetic field lines in the magnetospheric meridional plane

- Modeling
- Parametrization

- Empirical Models:
  - Mead-Faierfield, 1975;
  - Tsyganenko, T87, T89, T96;
  - Ostapenko-Maltsev, OM97.
- Analytical Models:
  - Hilmer and Voigt, HV95;
  - Olson and Pfitzer, OP95;
  - Alexeev, A99.

Magnetic Field in the Magnetosphere

$$B = B_{int} + B_m \tag{2}$$

B_{int} - **IGRF95, International Geomagnetic Reference Field**

B_m - **Magnetic Field of Magnetospheric Currents**

Objectives

- **standardazation of methods for calculations of magnetospheric currents magnetic field formed by the large-scale magnetospheric current systems, depending on the conditions in the Earth's environment;**
- **standardization of the methods of description of the magnetospheric magnetic field by temporal variations of the parameters of the magnetospheric current systems;**
- **standardization of the parameters of the magnetospheric current systems;**
- **standardization of a technique for calculation of the main parameters of the magnetospheric model by using the overall set of data of measurements in the Earth's environment.**

The Model Requirements

- day-side/night-side asymmetry (i.e., compression of the magneosphere on the day-side and extension on the night-side due to the interaction of the Solar Wind)
- daily and season variations
- accounts for the geomagnetic dipole inclination (tilt angle) relative to the plane orthogonal to the Earth-Sun line within a range of $-35°$ to $+35°$
- a dependence on interplanetary medium parameters (model parametrization)
- the close relation with the International Geomagnetic Reference Field (IGRF)
- the model allows to calculate separately the magnetic field of the Chapman-Ferraro currents, of the geotail current system, of the ring current, of the Region 1 field-aligned currents, of the magnetopause currents screening the ring current.
- model consists of a small set of physical input parameters
- the input parameters depend on real-time, or near-real-time Empirical Data:
  1. Solar Wind data
  2. Auroral Oval size and location
  3. AL and Dst magnetic indices
- the model characterizes the magnetospheric magnetic field under both Solar Quiet and Disturbed conditions, without restrictions/limits imposed on the values of interplanetary medium parameters
- although in the framework of the proposed standard, the model is intended to be used inside the geostationary orbit it must be selfconsistently enable to provide calculations in the whole magnetosphere

Paraboloid model of the magnetosphere (A99)

$$B_m = B_{CFD}(R_1) + B_T(R_1, R_2, \Phi_\infty) + B_{FAC}(I) + B_R(b_R) + B_{CFR}(R_1, b_R)$$

B_D - the geomagnetic dipole magnetic field;
B_{CFD} - the magnetic field of Chapman-Ferraro currents on the magnetopause screening the dipole field;
B_T - the geotail current system magnetic field;
B_R - the ring current magnetic field;
B_{FAC} - the field of Region 1 field-aligned currents;
B_{CFR} - magnetic field of the magnetopause currents screening the RC.
Alexeev I.I. // Geomagnetizm i aeronomia, 1978, v.18. p.656
Alexeev, Belenkaya, Kalegaev, Feldstein// JGR, V.101, P.7737, 1996.

Paraboloid Model is **available at**
http://alpha.npi.msu.su/english/lvm/dynamod.html

Input Parameters:

- ψ - geomagnetic dipole tilt angle;
- R_1 - distance to the subsolar point of the magnetosphere;
- R_2 - distance to the inner edge of the geotail current sheet;
- Φ_∞ - the magnetic flux through the tail lobes;
- I (the total Region 1 field-aligned current);
- b_R - the ring current magnetic field at the Earth's centre.

Input Parameters depend on Empirical Data: solar wind data; auroral oval data; AL and Dst indices.

The main advantages of the paraboloid model A99

- **Paraboloid Model is three-level model:**

$\boxed{\textbf{Empirical data - Input Parameters – Model}}$

- **Dynamical paraboloid model allows to calculate the magnetospheric magnetic field during quite periods as well as in the course of strong disturbances in the whole magnetosphere without any limitation on the model parameters.**

  Unlike the empirical models any level of disturbance can be considered (see for example T96 model valid only for $D_{st} > -100nT$, $|B_z| < 5nT$)).

- **The paraboloid model enable correctly to take into account the IMF penetration into magnetosphere using the paraboloid model of magnetosheath magnetic field (see Alexeev, Kalegaev, JGR, 100, 19267, 1995).**

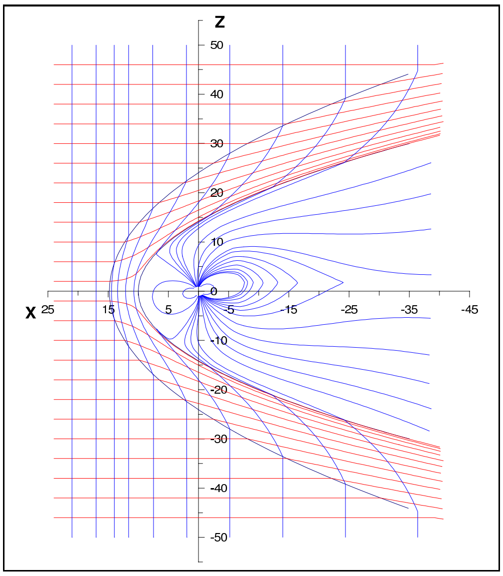


Figure 2: Magnetic field lines in the magnetospheric meridional plane

Accuracy of the Model and Comparison With Experimental Data

1. Stationary Case. The comparison with the Large Magnetosphere Magnetic Field Data Base

(Faierfield et al., J. Geophys. Res., 99, 11319, 1994)

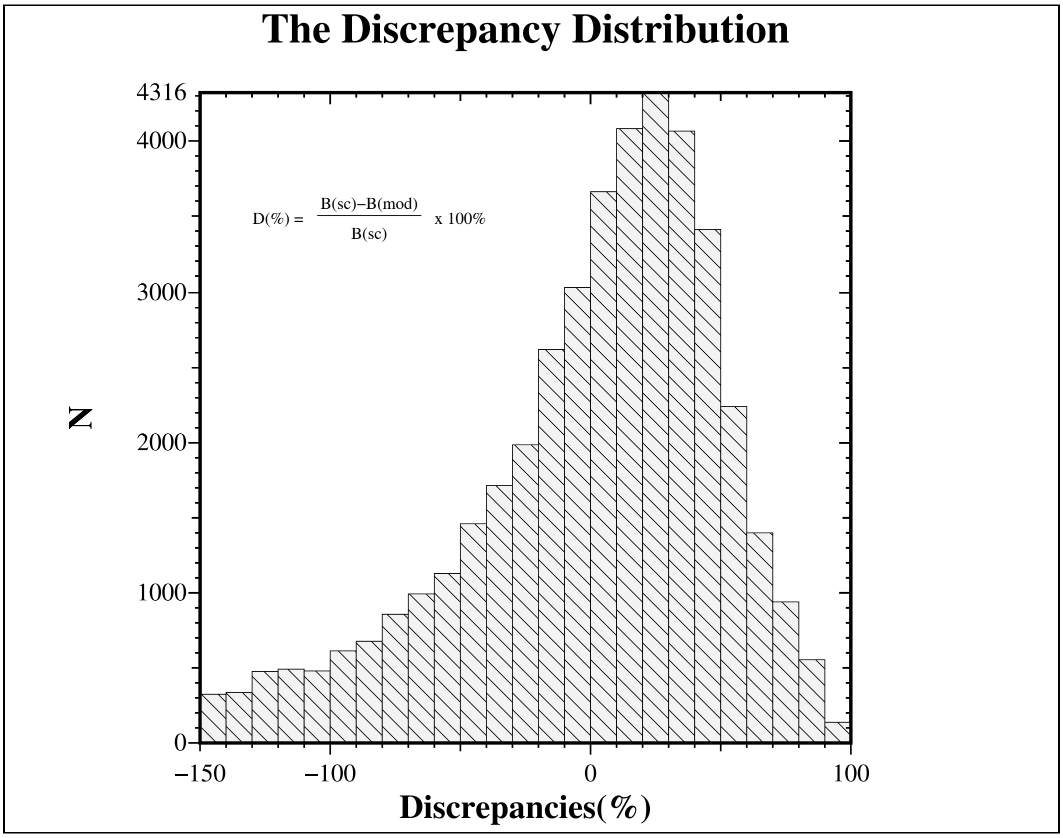


Figure 3: The distribution of discrepancies of magnetospheric field magnetic induction calculated in term of the parabolic model, compared with experimental data. B_{sc}[nT] is the field measured onboard spacecrafts, B_M[nT] is the field calculated in terms of the parabolic model, N is for statistics.

The distribution of relative discrepancies integral over the overall experimental material (45181 measurements). The discrepancy mean value is about +3% (the distrubution is, by definition, asymmetric with a long negative "tail"), σ of the distribution being of $\sim$ 80%.

2. Stationary Case. The comparison with the Large Magnetosphere Magnetic Field Data Base

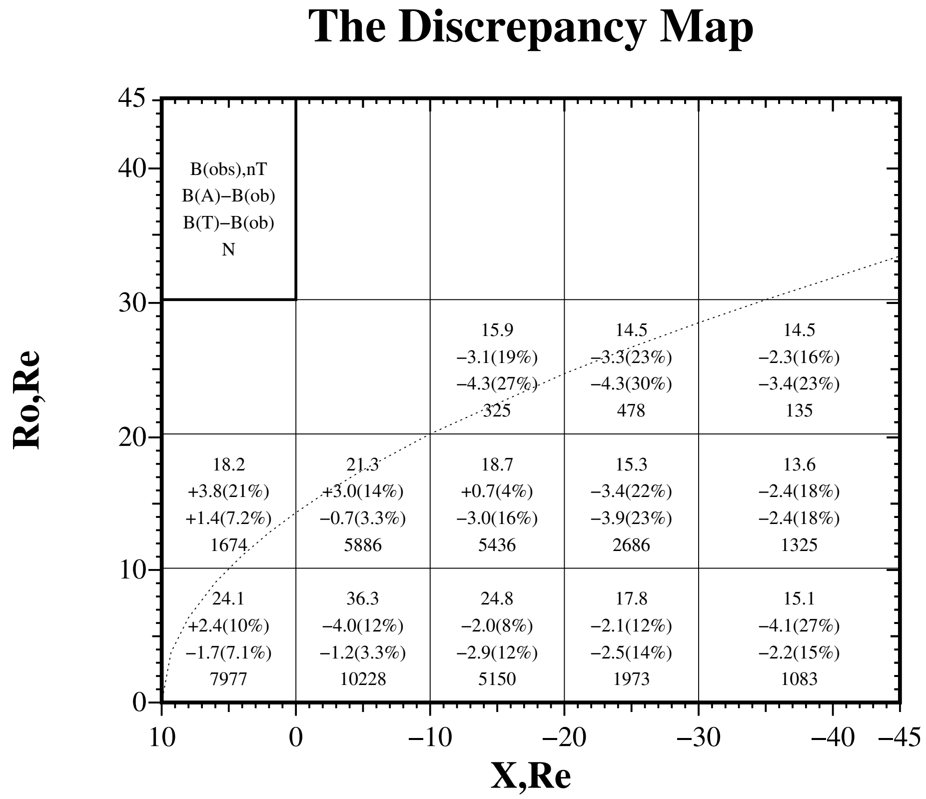
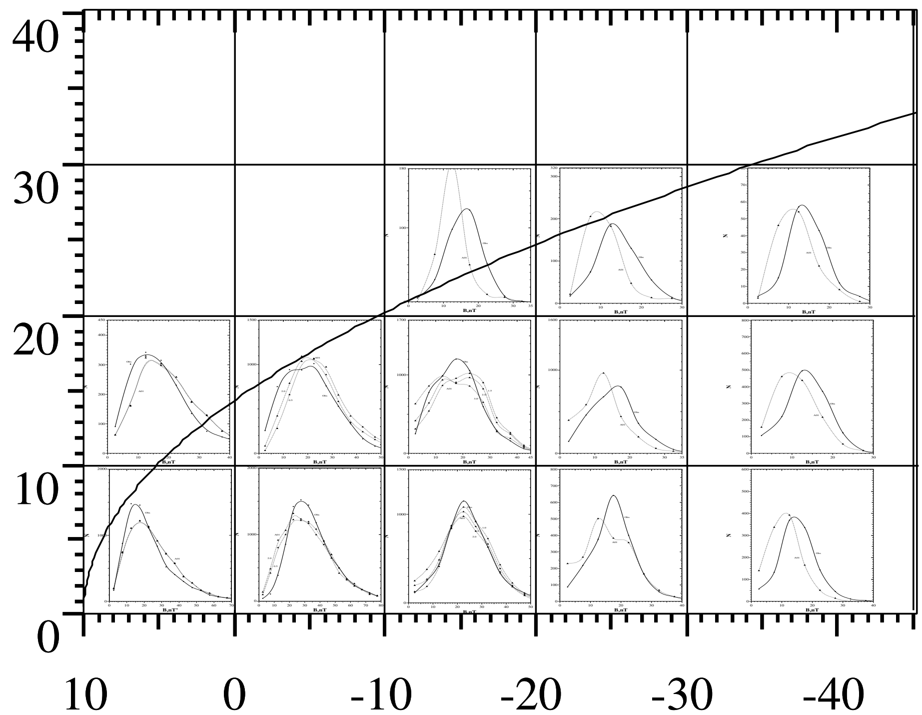


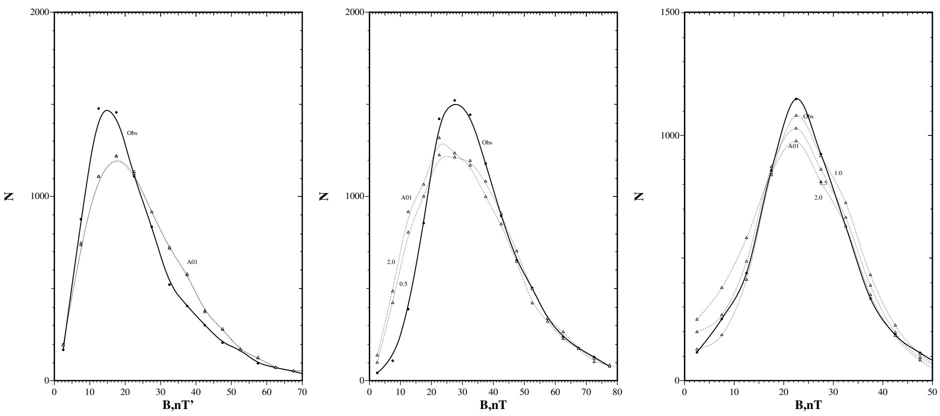
Figure 4: The distribution of the discrepancies of magnetospheric magnetic field calculated in term of the paraboloid model, compared with experimental data. In the singled out cell the format of data is shown: $B(obs)$,nT, is the measured onboard spacecrafts magnetic field averaged in cells, $B(A)$,nT, is the average field calculated in terms of the paraboloid model, $B(T)$,nT, is the average field calculated in terms of the T96 model, N is for statistics.

Figure presents the distribution of absolute and relative discrepancies differential in x and ρ. The weight of each discrepancy value (statistics) is shown in the corresponding cell in x and ρ. Near the geostationary orbit in the magnetosphere nightside the discrepancy is, on average, 12.3 nT for $-10 < x \leq 0$ and $0 \leq \rho < 10$, and in the magnetosphere dayside it is, on average, 3.4 nT for $0 < x \leq 10$ and the same values of ρ.

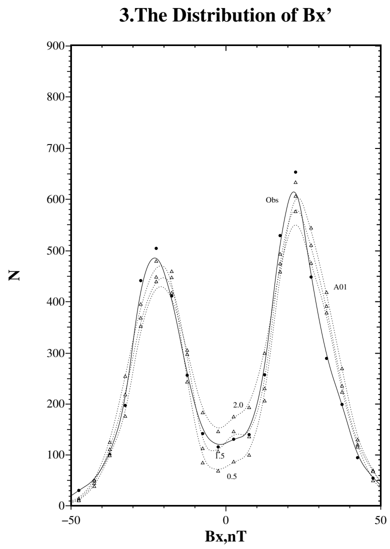
3. Stationary Case. The comparison with the Large Magnetosphere Magnetic Field Data Base



The magnetic field module distributions over the whole statistics in the different cells in the Earth's magnetosphere, measured and calculated by paraboloid model.

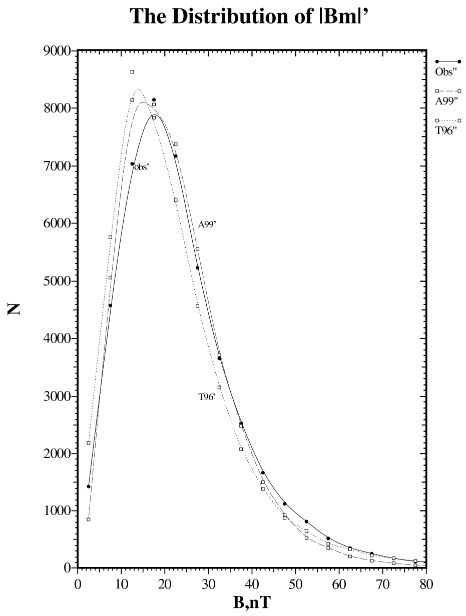


The magnetic field module distributions (measured and calculated by A99) in the near-Earth (x, ρ) cells (10:0; 0:10), (0:-10; 0:10), (-10:-20; 0:10) of the magnetosphere.



The magnetic field B_x component distribution (measured and calculated by A99) in the near-Earth (x, ρ) cell (-10:-20; 0:10) of the magnetosphere.

4. Stationary Case. The comparison with T96 model.



The magnetic field module distribution in tthe whole magnetosphere, measured (solid line), calculated by T96 (dotted line) and calculated by A99 (dashed line).

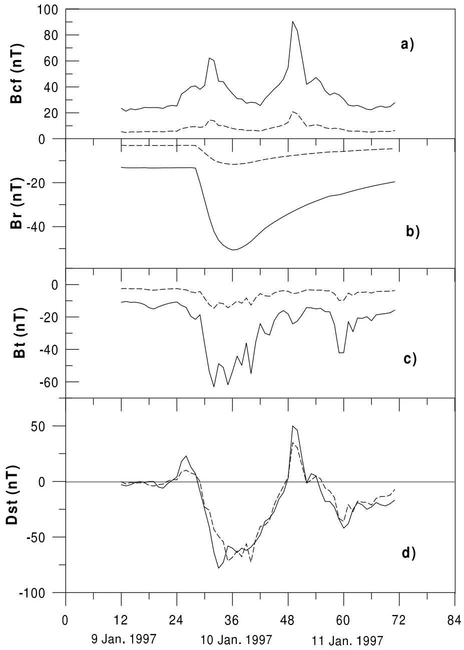
Kp	A99	T96	Measurements
$0, 0^+$	13.8	14.9	15.5
$1^-, 1$	16.9	16.3	17.6
$1^+, 2^-$	18.3	18.6	20.3
$2, 2^+$	21.6	20.6	22.6
$3^-, 3, 3^+$	25.3	24.1	26.3
$4^-, 4, 4^+$	30.0	28.1	31.3
$5^-, 5$	34.8	33.4	35.4

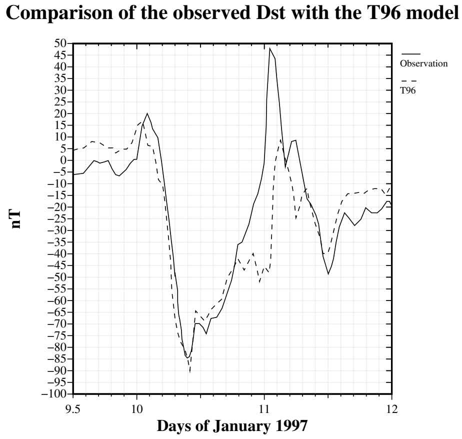
Table 1:

the comparison of magnetic field calculated by paraboloid model (A99) Tsyganenko model (T96) and measured magnetic field from Large Magnetosphere Magnetic Field Data Base averaged by the levels of disturbances.

For very quite conditions T96 model gives the better results than A99. For Kp between 1^- and 2^- the results are comparable. For disturbed conditions ($Kp > 2$) A99 gives the better results than T96.

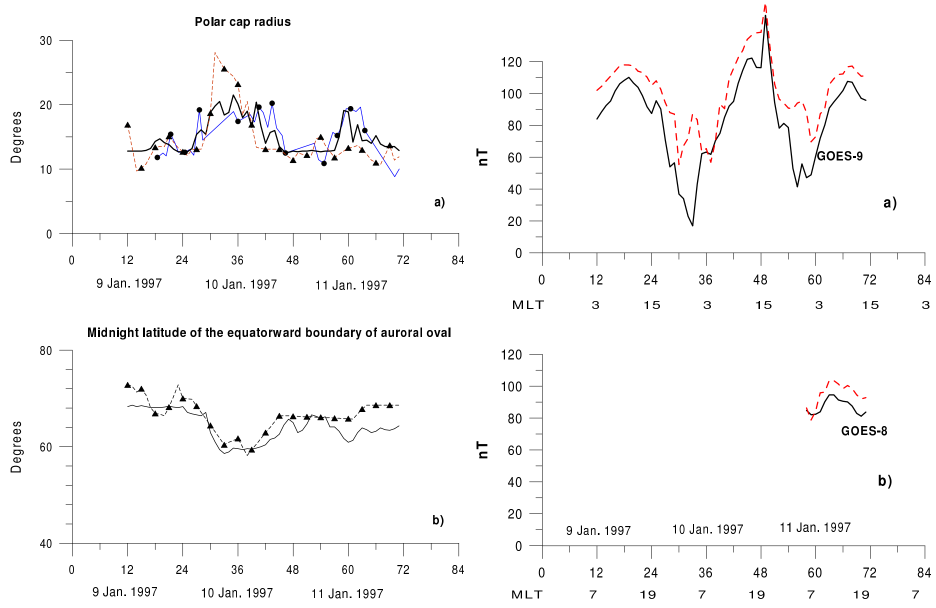
5. Nonstationary Case. The comparison of modelled magnetic field with *Dst* (January 1997 Case). A99 and T96 Models.





- Fig.1. (a) Magnetic field of currents on the magnetopause, (b, c) the ring current magnetic field and tail current magnetic field, respectively, at the Earth's surface (solid curves) and the corresponding magnetic field due to currents induced inside the Earth (dashed curves), and (d) Dst (heavy solid curve) and total magnetic field, B_M (dashed curve), calculated at the Earth's surface by A99 in the course of the magnetic storm on January 9–12, 1997.
- Fig.2. Dst (heavy solid curve) and total magnetic field, B_M (dashed curve), calculated at the Earth's surface by T96 in the course of the magnetic storm on January 9–12, 1997 (See [Turner et al., 2000]).

6. Nonstationary Case. The comparison of modelled magnetic field with DMSP, Polar and GOES-6 Measurements (January 1997 Case).



- Fig.1. (a) Comparison of the polar cap radius calculated from the magnetic flux value Φ_∞ (solid curve) with radii obtained from the measurements on board DMSP F10-F13 (marked with triangles) and from the Polar Ultraviolet Imager (UVI) images (marked with circles). (b) Comparison of the midnight latitude of the equatorward boundary of the polar oval calculated in terms of paraboloid model (solid curve) and that calculated by the data measurements on board DMSP F10-F13 (marked with triangles).

- Fig.2. Comparison of the magnetic fields calculated in terms of the paraboloid model and measured during the magnetic storm on January 9–12 , 1997, along the (a) GOES 9 orbit and (b) GOES 8 orbit.

The Recent Project Activities

- The comparisons of the model calculations with the Large Magnetosphere Magnetic Field Data Base (Faierfield, Tsyganenko, et al., Journal of Geophysical Research, V.11, p.11319-11326, 1994) was made.
- The detailed comparisons of the model calculations with observations in the course of several magnetic storms was made.
- The Authors' Version and Working Draft of Project have been sent to the scientists and specialists interested in the subject from 11 countries. The Authors' Version and Working Draft of Project have been refereed and corrected by the scientists and specialists from the
  - **France** (Daniel M. Boscher, ONERA-CERT/DESP)
  - **Japan** (Hiroshi Suzuki, Yukihito Kitazawa (Ishikawajima-Harima Heavy Industries Co., Ltd.), Prof. T. Iemori (Kyoto University))
  - **Russia** (Dr. Alexandr Schevurev (STC "Kosmos") and Dr. V.P. Nikitskiy (RS Corp. "Energiya"))
- In accordance with Resolution 151, taken at the recent plenary meeting of TC20/SC14 in Brazil, and with request made by James E. French (Secretary of ISO TC20/SC14), the Approved Work Item (AWI) "Space systems - Space environment - Model of the Earth's magnetospheric magnetic field" has been registered with the ISO Central Secretariat and given the number 22009.
- During IAGA-IASPEI Joint Assembly in Hanoi (25 August 2001) it was approved that the evaluation of the the ISO magnetospheric model is in the field of interest of the WG 3 of Division V of IAGA. It was decided to create the scientific subcommittee of the Division V Working Group 3 of International Association Geomagnetism and Aeronomy for the examination of the ISO magnetospheric model. This activity must be jointed with Division III and take into account an Internal Field Model (IGRF) and influence of the solar wind (Division IV) on the magnetospheric model.

- The results of investigations were published in
  - Alexeev I.I., E.S.Belenkaya, V.V.Kalegaev, Y.I. Feldstein, A. Grafe, *Journ. of Geoph. Res.,* V.101, P. 7737, 1996.
  - V.V. Kalegaev, I.I. Alexeev, Y.I. Feldstein, L.I. Gromova, A. Grafe, M. Greenspan, *Geomagn. Aeronom.,* V. 38, N 3, p.10-16, 1998.
  - Dremukhina, L. A., Ya. I. Feldstein, I. I. Alexeev, V. V. Kalegaev and M. Greenspan, *J. Geophys. Res.*, 104, NoA12, p.28351-28360, 1999.
  - V.V.Kalegaev, and A. Dmitriev, *Advances in Space Research.* 26, N1, p.117-120, 2000.
  - Kalegaev, V. V., I.I.Alexeev, Ya.I.Feldstein, Journal of Atm and Sol-Terr Phys, V. 63/5, p.473-479, 2001.
  - Alexeev, I. I., and Y. I. Feldstein, *J. Atmos. Sol. Terr. Phys.*, 63, 331, 2001.
  - Alexeev I.I., E.S.Belenkaya, R. Clauer, *Journ. of Geoph. Res.*, V.105, P.21119, 2000.
  - R. Clauer, Alexeev I.I., E.S.Belenkaya,*Journ. of Geoph. Res.*, 2001, accepted.
  - Alexeev, I. I., V. V. Kalegaev, E. S. Belenkaya, S. Y. Bobrovnikov, Ya. I. Feldstein and L. I. Gromova, *Journ. of Geoph. Res.*, 2001, accepted.

CONCLUSIONS

Scientific groups from Skobeltsyn Institute of Nuclear Physics, Moscow State University and from Geological Survey, USA propose:

- **Approve the activity connected with the development of ISO Standard "Space System - Space Environment (Natural and Artificial). Model of Earth's Magnetospheric Magnetic Field."**
- **Approve the paraboloid model as a candidate model for Standard development.**