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Abstract: Web-portal http://www.magnetosphere.ru allows to calculate the magnetic field in the magnetospheres of magnetized planets (Mercury, Earth, Jupiter and Saturn). The magnetic field in the Earth's magnetosphere can be obtained in the real-time mode using concurrent measurements of the solar wind monitoring satellites. The parameters of the magnetic field models for Mercury, Jupiter and Saturn magnetospheres can be obtained from in citu satellite measurements. The main aim of this work is to create the prototype of data service that allows to represent the magnetic field inside the magnetospheres of Mercury, Earth, Jupiter, and Saturn.

1 Introduction and goals

The magnetic field in the magnetospheres of magnetized planets (Mercury, Earth, Jupiter and Saturn) can be represented as a sum

$$B = B_{in} + B_m$$

where B_{in} is the internal magnetic field originated from the currents flowing in the planetary core while B_m is the magnetic field produced by large-scale magnetospheric currents. The internal magnetic field changes slowly but it rotates with the planet, so one can observe the total magnetic field variations in the inner magnetosphere due to planetary rotation. Internal magnetic field can be represented as an expansion in spherical functions. The expansion coefficients are usually determined from magnetic field measurement data and updated after several years.

The external magnetic field B_m is produced by currents that form magnetospheric shape. The main current systems are: Chapman-Ferraro current, cross-tail current and ring current. One can consider also field-aligned currents, partial ring current, ionospheric currents. All these currents are under strong influence of the solar wind flowing past the magnetosphere. Magnetospheric magnetic field structure and dynamics are controlled by solar wind and interplanetary magnetic field. Theoretical models based on the first principles describe the magnetospheric dynamics as the variations of the large-scale magnetospheric current systems due to solar wind changes.

Generalized paraboloid model of the magnetosphere is intended for describing the magnetospheric dynamics taking into account the intrinsic planetary magnetic field, the magnetopause current magnetic field, the tail current system magnetic field, the magnetodisc magnetic field, the ring current magnetic field, and the interplanetary magnetic field penetrated from solar wind. Such modular structure allows to represent the magnetic field inside the magnetospheres of magnetized planets.
Web-portal http://www.magnetosphere.ru (see Fig. 1) allows to calculate the magnetic field induction vector in the Earth's magnetosphere in the real-time mode using concurrent measurements of the solar wind monitoring satellites. The main aim of this project is to create the prototype of data service that allows to represent the magnetic field inside the magnetospheres of Mercury, Earth, Jupiter, and Saturn.

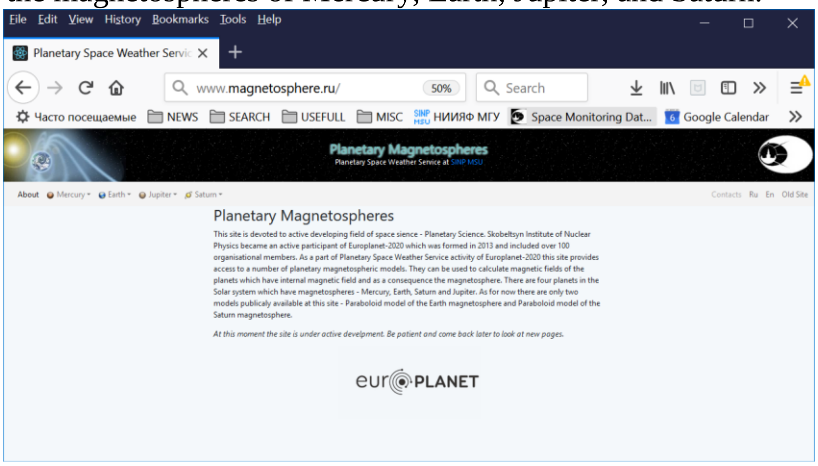

Figure 1 - Web-portal Magnetosphere.ru

2 Implementation

2.1 Paraboloid Magnetospheric Model of the Earth

The magnetic field can be calculated in the solar magnetospheric coordinate system only inside the Earth's magnetosphere, in the region -40 < x < 20 R_e; -30 < y,z < 30 R_e, which is bounded by magnetopause, represented by paraboloid of revolution. Inside the magnetopause paraboloid model (PM) of the Earth's magnetosphere (*Alexeev et al*., 2003), the magnetospheric magnetic field of each large scale current system is determined by an analytical solution of the Laplace equation for magnetic field scalar potential. The magnetic field component normal to the magnetopause is assumed to be zero. The model represents magnetic field inside the magnetosphere as a sum of internal planetary magnetic field, given by the IGRF2015 model and the external one (B_m) represented by a superposition of the magnetic fields of the ring current, B_r, the tail current system including the currents across a tail and their closure currents on the magnetopause, B_t, the Region 1 field-aligned currents, B_{fac}, the magnetopause currents screening the dipole field, B_{sd}, and the magnetopause currents screening the ring current magnetic field, B_{sr}:

$$B_m = B_{sd}(\psi, R_1) + B_t(\psi, R_1, R_2, \Phi_\infty) + B_r(\psi, b_r) + B_{sr}(\psi, R_1, b_r) + B_{IMF}.$$

Here B_{IMF} is the partially penetrated into the magnetosphere interplanetary magnetic field. The model input values are the 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_∞;
- the ring current magnetic field at the Earth's center b_r.

The time dependent model parameters are calculated by the empirical data (solar wind density (*n*), velocity (*v*), Dst and AL indices, interplanetary magnetic field B-components (IMF_B)) and by the current date/time using special submodels (*Alexeev et al., 2003, Kalegaev, 2011*) optimizing parameter dependences on the specific sets of empirical data. Input model parameters could be specified by user or can be taken fully or partially from database for a given time moment.

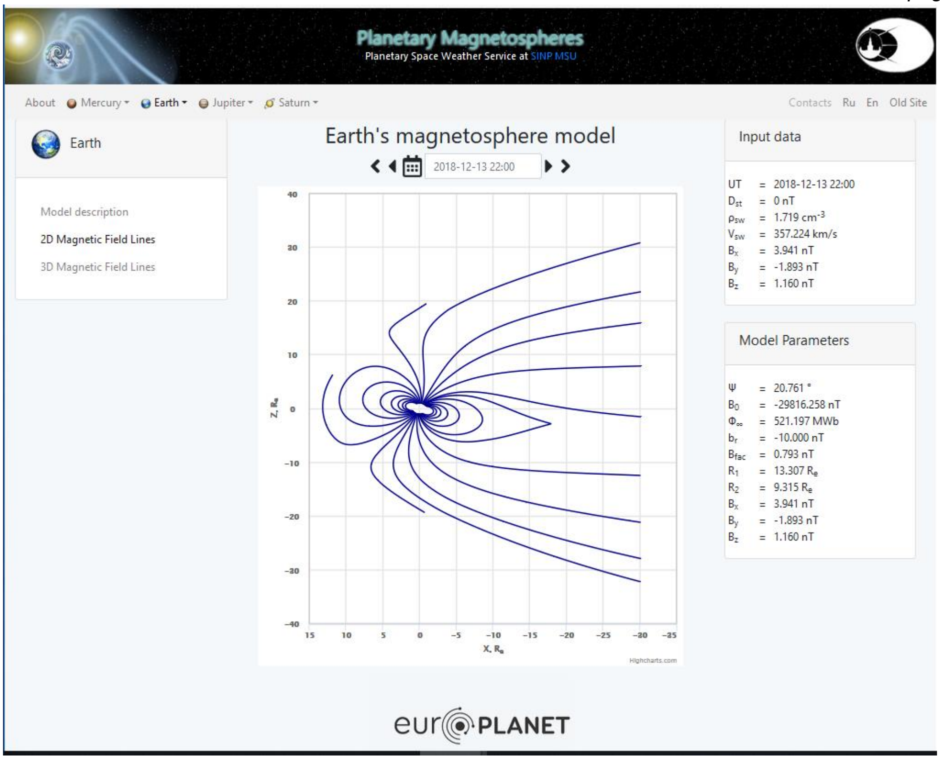

Figure 2- Earth's magnetosphere calculated for solar wind conditions at 22:00 on 13 December 2018

Figure 1 represents the magnetic field lines in the noon-midnight plane calculated for solar wind conditions at 22:00 on 13 December 2018. Solar wind conditions (input data) and model parameters are presented in the tables to the right of the figure.

2.2 Paraboloid Magnetospheric Model of Mercury

The magnetic field can be calculated only inside the Hermean magnetosphere that is implied to be bounded by magnetopause, represented by paraboloid of revolution in the region -5.5 < x < 2.6 R_m; -4.1 < y,z < 4.1 R_m in the Hermean solar magnetospheric coordinates system. The paraboloid model (*Alexeev at al.*, 2010) represents magnetic field as a sum of the Hermean internal magnetic field B_{INT} and magnetic fields of the tail current, B_t, the magnetopause currents, B_{sd}, and the interplanetary magnetic field partially penetrated into the magnetosphere of Mercury, B_{IMF}:

$$B = B_{INT}(BD) + B_{sd}(RSS) + B_t(RSS, R2, BT, DZ) + B_{IMF}(IMF\_B).$$

Model input parameters (all are optional):

- BD - Dipole field strength on the equator of the Mercury;
- Flux - Magnetic flux at the polar cap open field line region;
- RSS - Subsolar magnetopause distance in the Mercury radii (2439km);
- R2 – The distance to the inner edge of the tail current sheet;
- DZ - Northern displacement of the dipole relative to the center of the Mercury;
- IMF_B - Components of the Interplanetary Magnetic Field penetrated into the Mercury’s magnetosphere (in the HSM coordinate system).

2.3 Paraboloid Magnetospheric Model of Saturn

The magnetic field can be calculated only inside the Kronian magnetosphere, which is bounded by magnetopause, represented by paraboloid of revolution (in the region -1200 < x < 40 Rs ; -500 < y, z < 500 Rs in the Kronian Solar-Magnetospheric coordinate system). The paraboloid model (*Alexeev at al.*, 2006) represents magnetic field as a sum of the Kronian internal magnetic field B_{INT} (*Burton et al.,2010*) and magnetic field of the external sources B_m, which is a superposition of the magnetic fields of the magnetodisc, B_r, the tail current system including currents across the tail and their closure currents on the magnetopause, B_t, the magnetopause currents, B_{sd}, and the interplanetary magnetic field partially penetrated into the Kronian magnetosphere, B_{IMF}:

$$B_m = B_{sd}(RSS) + B_t(RSS, R2, BT) + B_r(RD1, RB2, BDC) + B_{IMF}(IMF\_B).$$

Model input parameters (all are optional):

- BDC - Magnetic field at the magnetodisc (MD) outer edge
- BT - Minus Z-component of the magnetic field at the tail current sheet inner edge
- RD2 - Distance to the inner edge of the MD
- RD1 - Distance to the outer edge of the MD
- R2 - Distance to the inner edge of the tail current sheet
- Rss - Magnetopause stand-off distance
- IMF_B - Components of the Interplanetary Magnetic Field penetrated into the magnetosphere in the KSM coordinate system

For each input model parameter a user can set a value manually or take a value by default.

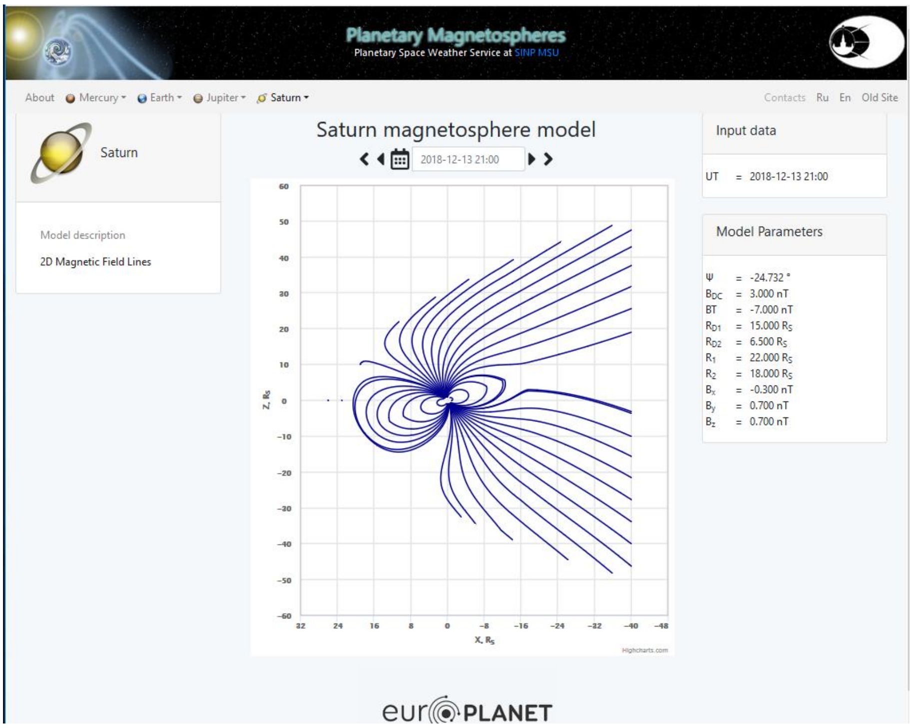

Figure 3 - Kronian magnetosphere structure calculated for the average model parameters.

Figure 2 represent the magnetic field lines in the noon-midnight plane calculated for average model parameters characterising the magnetospheric current systems. Model parameters are presented in the table to the right of the Figure 2.

2.4 Paraboloid Magnetospheric Model of Jupiter

The magnetic field can be calculated only inside the Jovian magnetosphere, which is bounded by magnetopause, represented by paraboloid of revolution (in the region -450 < x < 150 Rj; -300 < y, z < 300 Rj in the Jovian Solar-Magnetospheric coordinates system). The paraboloid model (*Alexeev and Belenkaya*, 2005) represents magnetic field as a sum of the Jovian dipole magnetic field B_{INT} (System III model) and the magnetic field of the external sources B_m, which is a superposition of the magnetic fields of the magnetodisc, B_r, the tail current system including tail currents and their the closure currents on the magnetopause, B_t, the magnetopause currents, B_{sd}, and the interplanetary magnetic field partially penetrated into the Jovian magnetosphere, B_{IMF} :

$$B_m = B_{sd}(R_{SS}) + B_t(R_{SS}, R2, BT) + B_r(RD1, RD2, BDC) + B_{IMF}(IMF\_B).$$

Model input parameters:

- BDC - Magnetic field at the magnetodisc (MD) outer edge
- BT - Minus Z-component of the magnetic field at the tail current sheet inner edge
- RD2 - Distance to the inner edge of the MD
- RD1 - Distance to the outer edge of the MD
- R2 - Distance to the inner edge of the tail current sheet
- Rss - Magnetopause stand-off distance
- IMF_B - Components of the Interplanetary Magnetic Field partially penetrated into the Jovian magnetosphere in the JSM coordinate system.

For each input model parameter a user can set a value manually or take a value by default.

2.5 Access to models

Models can be accessed through http://www.magnetosphere.ru Web-site.
On November 18, 2018 only calculations in the framework of Earth's magnetosphere model is available.

3 Future development

The next stage is to develop prototype of data service that allows to represent the magnetic field inside the magnetospheres of Mercury, Earth, Jupiter, and Saturn. Model parameters can be specified by user or can be accessed through EPN-TAP services to provide "on-the-fly" calculations of the planetary magnetic field model in the framework of Europlanet Research infrastructure.

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