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Space environment (natural and artificial) — Model of the Earth's magnetospheric magnetic field

Environnement spatial (naturel et artificiel) — Modèle du champ magnétique de la magnétosphère de la terre

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles,* Subcommittee SC 14, *Space systems and operations.*

This second edition cancels and replaces the first edition (ISO 22009:2009), which has been technically revised.

The main changes are as follows:

— upgraded list of the relevant models;

— added connection with the IGRF geomagnetic model;

— added field-aligned currents;

— added data availability information;

— added information about magnetospheric current systems modelling.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document describes the main requirements to the Earth's magnetospheric magnetic field model. A model satisfying the set of requirements is described in Annexes A and B as a working example. The model can be used in scientific and engineering applications and is intended to calculate the magnetic induction field generated from a variety of current systems located on the boundaries and within the boundaries of the Earth's magnetosphere under a wide range of environmental conditions, quiet and disturbed, affected by solar-terrestrial interactions simulated by solar activity such as solar flares and related phenomena which induce terrestrial magnetic disturbances such as magnetic storms.

The main goals of standardisation of the Earth's magnetospheric magnetic field are:

— providing the unambiguous presentation of the magnetic field in the Earth's magnetosphere;

— providing compatibility of results of interpretation and analysis of space experiments;

— providing less labour-consuming character of calculations of the magnetic field of magnetospheric currents in the space at geocentric distances of 1,0 to 6,6 Earth's radii (R_E);

— providing the most reliable calculations of all elements of the geomagnetic field in the space environment.

The magnetic field model presented in the Annex A (general description) and Annex B (submodels) can be used to forecast radiation situation in the space, including the periods of intense magnetic disturbances (magnetic storms) when developing systems of spacecraft magnetic orientation, when forecasting the influence of magnetic disturbances on transcontinental piping and power transmission lines.

Space environment (natural and artificial) — Model of the Earth's magnetospheric magnetic field

1 Scope

This document describes the main magnetospheric large-scale current systems and the magnetic field in the Earth's magnetosphere and provides the main requirements to the model of the magnetospheric magnetic field. Ionospheric currents are not considered in this document. The document also provides a working example of the model and establishes the parameters of magnetospheric large-scale current systems which are changing in accordance with conditions in the space environment. The document can be used to develop the new models of magnetospheric magnetic field. Such models are useful in investigating physical processes in the Earth's magnetosphere as well as in calculations, developing, testing and estimating the results of exploitation of spacecrafts and other equipment operating in the space environment.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
magnetospheric magnetic field
external magnetic field
external magnetospheric magnetic field
magnetic field produced by *magnetospheric magnetic field sources* (3.4)

3.2
geomagnetic dipole tilt angle
angle of inclination of the geomagnetic dipole to the plane orthogonal to the Earth-Sun line

3.3
internal magnetic field
magnetic field produced by the sources inside the Earth's core

Note 1 to entry: It can be presented in the form of a series of spherical harmonic functions.

Note 2 to entry: The expansion coefficients (IGRF model) undergo very slight changes in time.

Note 3 to entry: The International Association of Geomagnetism and Aeronomy (IAGA) is responsible for IGRF model development and modifications and approves its coefficients every 5 years.

Note 4 to entry: The internal magnetic field is described in ISO 16695.

3.4
magnetospheric magnetic field sources
sources of magnetic fields including the following:

— currents flowing over the magnetopause and screening the geomagnetic dipole magnetic field;

— currents flowing inside the Earth's magnetosphere:

  — tail current, produced by currents across the geomagnetic tail and closure currents on the magnetopause;

  — ring current, including symmetrical ring current, circling around the Earth and carried by trapped particles and partial ring current, produced by currents flowing outside the region of symmetrical ring current, mostly in the pre-midnight sector of equatorial plane, closured by field-aligned and ionospheric currents;

  — field-aligned currents, produced by currents flowing along the auroral magnetic field lines, closured by currents on the magnetopause and in the ionosphere;

— currents flowing over the magnetopause and screening the ring current and partial ring current magnetic fields

Note 1 to entry: In different magnetospheric models, either predefined current systems or current systems dependent on parameters calculated from satellite data are used.

Note 2 to entry: Electric currents flowing entirely in the ionosphere (ionospheric currents) contribute to the magnetic field variation at altitudes below 1 000 km. In the region above 1,5 Re effect of ionospheric current is insignificant. Magnetic field of ionospheric currents is not the subject of this document.

3.5
magnetopause stand-off distance
geocentric distance to the subsolar point on the magnetopause

3.6
solar-magnetospheric coordinates
Cartesian geocentric coordinates, where X-axis is directed to the Sun, Z-axis lies in the one plane with OX axis and geomagnetic dipole axis and Y-axis supplements the X and Z axes to the right-hand system

4 General concepts and assumptions

4.1 Magnetic field induction in the Earth's magnetosphere

Vector of magnetic field induction $\vec{B}_{\mathrm{M}}$ in the Earth's magnetosphere is calculated by Formula (1).

$$\vec{B}_{\mathrm{M}} = \vec{B}_1 + \vec{B}_2 \tag{1}$$

where

$\vec{B}_1$ is the vector of induction of the internal magnetic field, in nT;

$\vec{B}_2$ is the vector of induction of the magnetospheric magnetic field, in nT.

The magnetic field of the magnetospheric currents (magnetospheric magnetic field), $\vec{B}_2$, is calculated in terms of the quantitative model of the magnetosphere.

4.2 Magnetospheric magnetic field standardization: process-based approach

The magnetospheric magnetic field standard does not specify a single magnetospheric model, theoretical or empirical. In order to encourage continual improvements in magnetospheric modelling, this document is process-based for determining the magnetospheric magnetic field. Magnetospheric magnetic field model, after its development, may satisfy the requirements in Clause 4 and the list of criteria presented in Clause 5. The working example of the model is presented in the Annex A and

shall be reconsidered every 5 years on the basis of competitions of the candidate models. The current working example is presented in Annex A.

5 Model requirements

5.1 General

— The model of the magnetic field of magnetospheric currents (referred to below as "model") presents the vector of induction of magnetospheric currents in solar-magnetospheric coordinates.

— The model describes a regular part of the magnetic field in the region from 1,0 R_E to 6,6 R_E.

— The model reflects compression of the Earth's magnetosphere in the dayside due to interaction with the solar wind, day-night asymmetry (the field on the nightside is weakened), day and season variations.

— The model takes into account the geomagnetic dipole tilt angle, varying in the range from $-35°$ to $+35°$.

5.2 The magnetospheric magnetic field sources

The standardised magnetospheric magnetic field is produced by currents described in 3.3. Ionospheric currents' effect is not considered in this document.

5.3 Parameterization

Each magnetospheric source of magnetic field depends on parameters which are calculated from empirical data.

5.4 Magnetospheric dynamics

The magnetospheric dynamics is determined to be a sequence of its instant states.

5.5 Model testing and comparison with measurements

The model testing is carrying out with the help of databases which include the spacecraft-based and on-ground measurements. The dataset used for the model testing is presented in the Annex C.

6 List of criteria

The conformity criteria for this document consist of the activities common for any candidate magnetospheric magnetic field model. These criteria specify the conformity process which includes the model documenting, publishing and testing.

— The candidate model shall include the statement of the modelling approach used (empirical or theoretical model). The empirical models are required to include a clear specification of the input data used to derive the model and where these data were measured. Theoretical models are required to include a description of the physical principles and approaches that are used as the basis of the model.

— The statement about the candidate model area of application and domain applicability should be included.

— The statement about the rms errors during the model calculations comparison with observational data obtained from measurements should be included. For empirical models, the comparisons should also be made with data, different from those from which the model was built.

— The description and implementation of the magnetospheric magnetic field model should be published in internationally-accessible refereed journals.

Annex A
(normative)

Paraboloid model of the magnetospheric magnetic field: calculation of induction of the magnetic field of the magnetospheric currents

A.1 General

The magnetospheric magnetic field calculated by paraboloid model is the solution of the magnetostatic problem inside the paraboloid of revolution.

A.2 Paraboloid model of the magnetic field of magnetospheric currents

A.2.1 General

Vector of induction of the magnetic field of magnetospheric currents is calculated by Formula (A.1).

$$\vec{B}_2 = \vec{B}_{sd}(\psi, R_1) + \vec{B}_t(\psi, R_1, R_2, \Phi_\infty) + \vec{B}_r(\psi, b_t) + \vec{B}_{sr}(\psi, R_1, b_r) + \vec{B}_{fac}(I_0) \quad \text{(A.1)}$$

where

$\vec{B}_{sd}$ is the magnetic field of currents on the magnetopause screening the dipole field;

$\vec{B}_t$ is the magnetic field of the magnetospheric tail;

$\vec{B}_r$ is the magnetic field of the ring current;

$\vec{B}_{sr}$ is the magnetic field of currents on the magnetopause, screening the ring current field;

$\vec{B}_{fac}$ is the magnetic field of region 1 field-aligned currents.

The components of the magnetic field of magnetospheric currents, $\vec{B}_{sd}$, $\vec{B}_t$, $\vec{B}_r$, $\vec{B}_{sr}$, $\vec{B}_{fac}$ are calculated separately in terms of the paraboloid model of the magnetosphere in the form of series in the Bessel functions or Legendre polynomials.

A.2.2 Parameters

The components of the magnetic field of magnetospheric currents, $\vec{B}_{sd}$, $\vec{B}_t$, $\vec{B}_r$, $\vec{B}_{sr}$, $\vec{B}_{fac}$ are determined by the values of parameters of the magnetospheric current systems:

— ψ is the geomagnetic dipole tilt angle, in degrees;

— $\vec{R}_1$ is the distance to the subsolar point at the magnetopause, in R_E;

— $\vec{R}_2$ is the distance to the earthward edge of the magnetospheric tail current sheet, in R_E;

— Φ_∞ is the magnetic flux in the tail lobes, defining the current intensity in the magnetotail, in Wb;

— b_r is the intensity of the ring current magnetic field at the Earth's centre, in nT;