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Dipole sources of the main geomagnetic field

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Abstract

The parameters of 15 arbitrary dipoles that, in aggregate, represent the main geomagnetic field (MGF) are estimated to obtain information on the distribution of MGF sources within the Earth in the form of dipoles with an arbitrary position and value of the magnetic moment vector. For an adequate estimation of the results, the method of obtaining the data is described, including: the eccentric dipole model and the derivation of the basic formulas for the magnetic field components of an arbitrary dipole; the method of estimating the parameters of these dipoles, including the computational scheme and optimization method; necessary constraints on the dipoles parameters and a justification of the choice of the initial values in the optimization fitting of the parameters. The results are presented as a map of the location of the centers of the dipoles and their northern axial poles for the epochs 1955 and 2005 and plots of changes in all six parameters of 15 dipoles for 50 years. Most of the dipole centers are located in the lower mantle. The results suggest the existence of current systems in the lower mantle that produce dipole magnetic fields. These currents are provided by the high conductivity of wüstite, an important component of the mantle, which, at a depth of 1000–2200 km, transforms to the low-spin state of iron with increased density and electrical conductivity.
Keywords: main geomagnetic field; eccentric dipoles; instability of dipole representation; initial values; constraints; wüstite; systems of currents in the lower mantle

Introduction

In the history of geomagnetism, numerous attempts have been made to represent the main geomagnetic field (MGF) as the sum of the fields of a system of eccentric fields. The theoretical possibility of such a representation is known. Although a dipole is a mathematical abstraction as applied to the main magnetic field, model, the physical sources of dipole fields are eddy currents in the Earth's interior. The main geomagnetic dipole is a system of eddy currents in the outer core. They are distributed around the inner core in the form of coils oriented almost along the rotation axis of the Earth with the oppositely directed current lines in the northern and southern hemispheres (Jacobs, 1987).

The dipole representation of the geomagnetic field had two objectives.

The first is an analytical description of the field measured by various systems of discrete observations (observatories, secular variation, ground, aeromagnetic, marine surveying, and satellite measurements) using smooth functions. For this, the dipole representation was used along with spherical harmonic analysis for some time as long as the accuracy of the Gauss series was low and the description of the field by a system of dipoles gave the same accuracy (Kolesova, 1985; Kropachev and Kolesova, 1967). In this case, the orientation of each dipole was of little significance, so that the system of simple radial (vertical) dipole was used fairly widely (Kolesova, 1985; Pudovkin et al., 1968; Yanovskii, 1978). At present, the more complex description of the MGF cannot compete in accuracy with spherical harmonic analysis and interest in the latter waned.

The second objective was to describe the MGF sources, their distribution within the Earth in the form of dipoles with an arbitrary position, value, and orientation of the magnetic moment vector. The present work was performed with this objective.

The leading line of research on the problem of the MGF sources is the modeling of these sources in the outer core of the Earth by integrating the magnetohydrodynamic (MHD) equations with the boundary conditions:

– the structure of the dipole field, which is considered axial and is therefore specified by the first three coefficients of the Gauss series;

– variations in the dipole field—changes in the modulus and direction (inversion) of the magnetic moment;

– variations in the nondipole part of the field—westward drift (Starchenko, 2013).

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