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IS THE EARTH'S DIPOLE ACTUALLY INCLINED WITH RESPECT TO THE ROTATION AXIS?

S.-I. AKASOFU
Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK 99775-0800, U.S.A.

and

T. SAITO

Geophysical Institute, Tohoku University, Sendai, Japan

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Abstract—Planetary exploration by deep space probes in recent years has shown that the dipole moment of some magnetized planets has a surprisingly large inclination angle with respect to the rotation axis. Applying the method we have developed for the source surface magnetic field of the Sun (a spherical surface of 2.5 solar radii), it is suggested that the main dipole of the Earth and the magnetized planets may actually be axial (the magnetic moment being parallel or antiparallel to the rotation axis), and that two or three smaller dipoles near the core surface could be responsible for the apparent inclination of the main dipole. In formulating a dynamo theory of the planetary magnetic field, such a possibility should be considered, as well as the inclined dipole case.

1. INTRODUCTION

The spherical harmonic analysis of the Earth's magnetic field indicates that the main field can be represented, as a first approximation, by a centered dipole, and that the dipole axis is inclined with respect to the rotation axis by about 11.5° (Chapman and Bartels, 1940; Cain and Cain, 1968).

In recent years, planetary exploration has considerably increased our knowledge of planetary magnetic fields. The inclination angle of the dipole axis of the magnetized planets, with respect to the rotation axis, is given in Table 1.

In Table 1, we added the source surface field of the Sun. We did this because on the basis of the spherical harmonic analysis, Hoeksema (1984) showed that the source surface field (a spherical surface of 2.5 solar radii) of the Sun can be represented, as a first approximation, by a dipole field and further, that the dipole moment thus obtained rotates from ~0° to ~180° (or from ~180° to ~0°) during a sunspot cycle; see also Saito *et al.* (1989a). One can see that Saturn is the only planet that has the main dipole with a very small inclination angle. This situation, apparently, should be considered an exception.

In this paper, the method we developed to study the solar field on the source surface (a spherical surface of 2.5 solar radii) and its relation to the photospheric fields is applied to the Earth's magnetic field. Our analysis suggests that the main dipole may actually be axial and that a few smaller dipoles near the surface of the core are responsible for the apparent inclination of the main dipole, when the Earth's field is observed on the Earth's surface or above it.

2. ANALYSIS AND RESULTS

The mathematical analysis of our method is described in detail in Section 2 of Saito *et al.* (1989b).

TABLE 1. INCLINATION ANGLE OF THE MAGNETIZED PLANETS

Planet	Inclination angle	References
Earth	11 30′	Chapman and Bartels, 1940
Jupiter	~10	Hide and Stannard, 1976
Saturn	~1	Connerney *et al.*, 1988
Uranus	~60	Ness *et al.*, 1986
Neptune	~47	Ness *et al.*, 1989
Solar source surface	0 ±90	Hoeksema, 1984

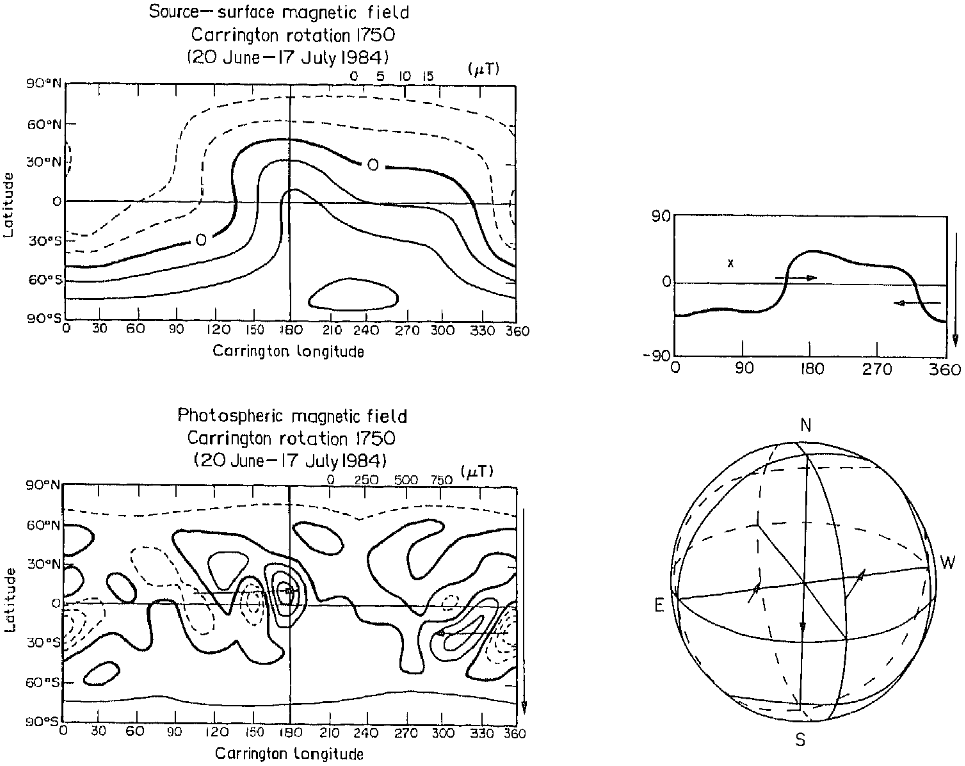

Fig. 1. The upper left: the magnetic field distribution on the source surface for Carrington rotation 1750.

The line with (O) is the neutral line. Solid lines (+2.5, +5.0) indicate the positive (away from the Sun) field and dotted lines (−2.5, −5.0) the negative (toward the Sun) field (courtesy of the Wilcox Solar Observatory). The lower left: the smoothed photospheric magnetic field (courtesy of the Wilcox Solar Observatory). The arrows are the fictitious dipoles which are transferred from the upper right diagram. The upper right: the neutral line reproduced by the combined effect of the central dipole (its orientation and magnitude are indicated by an arrow just to the right-hand side) and two fictitious dipoles. The lower right: a spherical presentation of the upper right diagram. The view longitude of the sphere is indicated by a cross in the upper right diagram.

We use here a format similar to the one used in their paper. That is to say, we treat the magnetic equator like the neutral line on the source surface (a sphere of 2.5 solar radii).

Figure 1 shows, in the lower left, the photospheric magnetic field data during Carrington Rotation 1750 (20 June–17 July, 1984). The upper left diagram shows the corresponding magnetic field on the source surface (which corresponds to the surface of the Earth), together with the neutral line (which corresponds to the magnetic equator of the Earth). The upper right diagram shows the neutral line which is reproduced by our method. In order to reproduce the observed neutral line on the source surface, we assume the axial dipole to be at the center of the Sun and two dipoles near the equatorial plane of the photosphere; for details of the method, see Saito *et al.* (1989b). The relative magnitude of the axial dipole is indicated on the right-hand side. The two dipoles are located in low latitudes on the photosphere in this particular case. One can see that the axial dipole and the two photospheric dipoles reproduce fairly well the observed neutral line in the upper left diagram. In the lower right, we show the three dipoles and the neutral line using the spherical representation. The cross in the upper right diagram shows the longitude view of the spherical presentation.

The two photospheric dipoles thus obtained are transferred to the lower left diagram to show that each of the two dipoles is fairly well co-located with a large-scale dipolar field on the photosphere. Note that since the observed dipole represents those above the photo-

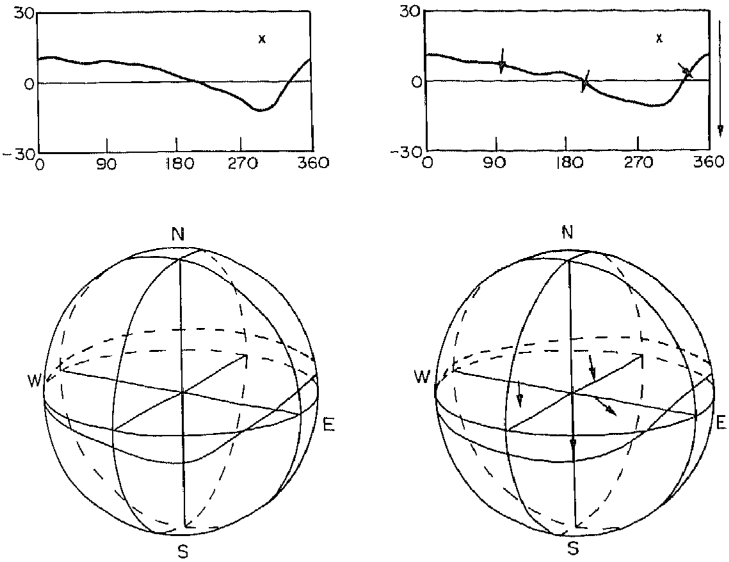

FIG. 2. THE UPPER- AND LOWER-LEFT PRESENTATIONS SHOW THE OBSERVED MAGNETIC EQUATOR OF THE EARTH IN THE STANDARD AND SPHERICAL PROJECTIONS, RESPECTIVELY.
The upper- and lower-right presentations show the magnetic equator reproduced by the axial and three dipoles on the core surface, which are indicated in both presentations.

sphere, the source dipole points from a negative (the line of sight component pointing toward the solar surface) to a positive (the line of sight component pointing away from the solar surface) field.

Now we apply the method demonstrated above the the Earth's field. It is our finding that three dipoles near the core surface can reproduce fairly well the magnetic equator (Fig. 2). The three dipoles are found to be located at longitudes ~105, ~210 and ~330, respectively; thus, they are located southeast of Hawaii, at the Atlantic ocean between Africa and South America, and at the southern part of Thailand, respectively. The combined effect of the three dipoles tends to incline the main dipole and shifts it from the center of the Earth, when the combined field of the axial dipole and the three dipoles is observed from the Earth's surface or above it.

3. DISCUSSION

The actual location and the magnitude of the three dipoles could be a little different from what we have determined (in terms of the location, at most ±10 in longitude and latitude). Thus, unlike the spherical harmonic analysis of the Earth's field, our analysis cannot provide a unique result in a strict sense. However, one should keep in mind that the spherical harmonic function provides only a mathematical representation of the Earth's magnetic field, but not uniquely physical processes involved. Thus, it is suggested that in formulating a dynamo theory, the presence of the axial main dipole, with a few small dipoles near the core surface, should be considered as a possible case, as well as the included dipole case.

If the three dipole fields exist near the core boundary, they may represent large-scale leakage fluxes from the core. Indeed, Bloxham and Gubbins (1985, 1987) have already mapped such fluxes. However, such an identification is not easy, because only a small net flux of large-scale fields contributes to the fields on the source surface. This situation was pointed out by Levine (1980).

Thus, although it is of great interest to find some similarity between photospheric magnetic field and the magnetic flux distribution on the core surface (Bloxham and Gubbins, 1985, 1987), we do not expect that the three fictitious dipoles can be easily identified in their magnetic flux distribution on the core surface. Only large-scale net fluxes are expected to contribute to the magnetic field on the Earth's surface. Nevertheless, it is interesting to note that large leakage fluxes from the core surface exist. So far, we have not found any obvious relationship between our dipoles and the mantle convection pattern (e.g. Bercovici *et al.*, 1989), the anomaly of seismic wave speed (e.g. Dziewonski and Woodhouse, 1987), the core-mantle boundary topography (Forte and Peltier, 1989), and the hot spots (Weinstein and Olson, 1989).

It is interesting to speculate that the observed large inclination angle of the main dipole (determined by the spherical harmonic analysis) for Uranus and Neptune are also only apparent, that the main dipole is axially aligned and that dipoles near the core surface are responsible for the apparent inclination and also for the observed eccentricity.

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REFERENCES

Bercovici, D., Schubert, G. and Glatzmaier, G. A. (1989) Influence of heating mode on three-dimensional mantle convect. *Geophys. Res. Lett.* **16**, 617.

Bloxham, J. and Gubbins, D. (1985) The secular variation of Earth's magnetic field. *Nature* **317**, 777.

Bloxham, J. and Gubbins, D. (1987) Morphology of the geomagnetic field and implications for the geodynamo. *Nature* **325**, 509.

Cain, J. C. and Cain, S. J. (1968) Derivation of the international geomagnetic reference field [IG RF (10/68)]. Goddard Space Flight Center Report X-612-68-501.

Connerney, J. E. P., Davis, L., Jr. and Chenette, D. L. (1988) Magnetic field models, in *Saturn* (Edited by Gehrels, T. and Matthews, M. S.), p. 354. University of Arizona Press, Tucson, Arizona.

Dziewonski, A. M. and Woodhouse, J. H. (1987) Global images of the Earth's interior. *Science* **236**, 37.

Forte, A. M. and Peltier, W. R. (1989) Core-mantle boundary topography and whole-mantle convection. *Geophys. Res. Lett.* **16**, 621.

Hide, R. and Stannard, D. (1976) Jupiter's magnetism, in *Jupiter* (Edited by Gehrels, T.), p. 767. University of Arizona Press, Tucson, Arizona.

Hoeksema, J. T. (1984) Structure and evolution of the large scale solar and heliospheric magnetic fields. Doctoral thesis, Stanford University, Stanford, CA.

Levine, R. H. (1980) Evolution of coronal and interplanetary magnetic fields, in *Solar and Interplanetary Dynamics* (Edited by Dryer, M. and Tandberg-Hanssen, E.), p. 1. IAU Symposium No. 91. D. Reidel, Holland.

Ness, N. F., Acuña, M. H., Behannon, K. W., Burlaga, L. F., Connerney, J. E. P., Leppine, R. P. and Neubauer, F. M. (1986) Magnetic fields at Uranus. *Science* **233**, 85.

Ness, N. F., Acuña, M. H., Burlaga, L. F., Connerney, J. E. P., Leppine, R. P. and Neubauer, F. M. (1989) Magnetic fields at Neptune. *Science* **246**, 1473.

Saito, T. and Akasofu, S.-I. (1990) On the nature of the photospheric dipoles of the triple dipole model of the solar source surface field, *J. geophys. Res.* (submitted).

Saito, T., Ōki, T., Akasofu, S.-I. and Olmsted, C. (1989a) The sunspot cycle variations of the neutral line on the surface. *J. geophys. Res.* **94**, 5453.

Saito, T., Ōki, T., Olmsted, C. and Akasofu, S.-I. (1989b) A representation of the magnetic neutral line on the solar source surface in terms of the Sun's axial dipole at the center and two equatorial dipoles in the photosphere. *J. geophys. Res.* **94**, 14,493.

Weinstein, S. A. and Olson, P. L. (1989) The proximity of hot spots to convergent and divergent plate boundaries. *Geophys. Res. Lett.* **16**, 433.