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# LOCATION OF THE SOURCE OF THE GEOMAGNETIC FIELD GENERATION

**V.V. Kuznetsov**

Institute of Cosmophysical Researches and Radio Wave Propagation Far-Eastern Branch, Russian Academy of Sciences, 684034, Kamchatskiy Kray, Paratunka, Mirnaya st., 7, Russia

E-mail: vvkuz38@mail.ru

Using well-known data on the structure of the geomagnetic field it is shown that its generation source is located at the boundary between the Earth inner and outer cores, most likely, in the F-layer.

*Key words: geomagnetic field, generation source location*

## Introduction

As generally accepted in geodynamo model the geomagnetic field dipole source is located in the outer core, closer to the boundary with mantle or at the boundary itself. As a rule, the question on the location of the generation source is not usually discussed in Geomagnetism, nevertheless, some attempts to determine the source size (depth of is location in Earth radius fractions R) are known. It is possible to estimate it on the basis of available data on geomagnetic field structure. Several methods to estimate the size of geomagnetic field generation source are considered and compared with the results of similar estimates obtained by different authors.

## Computer model

Computer modeling of the geomagnetic field by a set of current loops was carried out in a number of papers by L.R. Alldridge [1]-[4], as well as in the paper [5]. The optimal number of loops and the radius of their arrangement were obtained. In all these investigations the unequivocal result that the source of the geomagnetic field is located at the radius $a = 0.2\ R$, where $R$ is the Earth radius was obtained.

*Kuznetsov Vladimir Valeryevich* – Dr. Sci. (Tech.), Leading Researcher comprehensive geophysical observatory «Paratunka», Institute of Cosmophysical Researches and Radio Wave Propagation FEB RAS.

## Estimation based on the dipole size

The size of the Earth magnetic field generation region was estimated by Zhizhimov O.L. [6] on the basis of spherical coefficient analysis. Here the author supposed that the expansion of the field by the spherical functions on the Earth surface and the expansion of this field on the small-parameter such as the ratio of the source size to the distance to it are equivalent. Knowing the value of the small parameter, it is possible to estimate the source characteristic size if one assumes that the source generates only the lowest multipoles in the form of magnetic charges, dipoles, and quadrupoles.In modeling on even and uneven harmonics of the geomagnetic field expansion, the unequivocal result that the depth of magnetic field generation turned out to be equal to $x = a/R = 0.2R$ ($R$ is the Earth radius) was obtained. This approach is considered in detail below.

The simplest model for a source with a dipole moment is a system of two opposite charges arranged symmetrically relatively the Earth center. The potential of the dipole with the finite size (distance between the charges is 2) is: Рассмотрим этот подход немного подробнее.

$$V(\vec{R}) = \sum_{lm} A_{lm} l_{em}(\vec{R}), \tag{1}$$

where coefficients $A_{lm}$ are linearly related to the standard harmonic coefficients by:

$$(-1)^m \frac{R}{2}\sqrt{\frac{2\pi}{2l+1}}\,(g_l^m + ih_l^m),\;\; A_{l0} = R\sqrt{\frac{2\pi}{2l+1}} g_l^0,\;\; A_{l-m} = (-1)^m A_{lm}. \tag{2}$$

Model dipole parameters lead to the following expression:

$$x = \left\{ \frac{A_3^+ C_3 + C_3^+ A_3}{2 C_3^+ C_3} \right\}^{1/2}, \tag{3}$$

that is the estimation of dipole eigen size. Here, composed of $A_3$ and $C_3$ coefficients the column matrixes are implied under $A_{3m}, C_{3m}$. Значок “+” sign means Hermitean conjugation. Numerical values of $x$ are shown in Fig. 1.

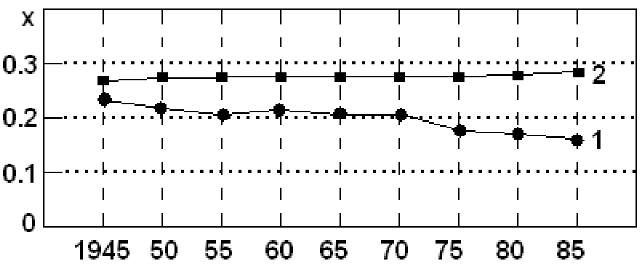


Fig. 1. Model source size for dipole (1) and quadrupole (2)

## Estimation by the distance between virtual magnetic poles (VMP)

Estimating the non-dipolarity degree of geomagnetic field source Kuznetsov V.V. [7]investigated the relation of the distance between two different VMP and this between the points of their observation. If all VMP are at the same point, then the geomagnetic field is dipole. If the distance between two VMP is equal to this between the points where the poles were determined, it would show the absence of dipole character of the field and the inclination of a line in Fig. 2-a would be equal to 45°.

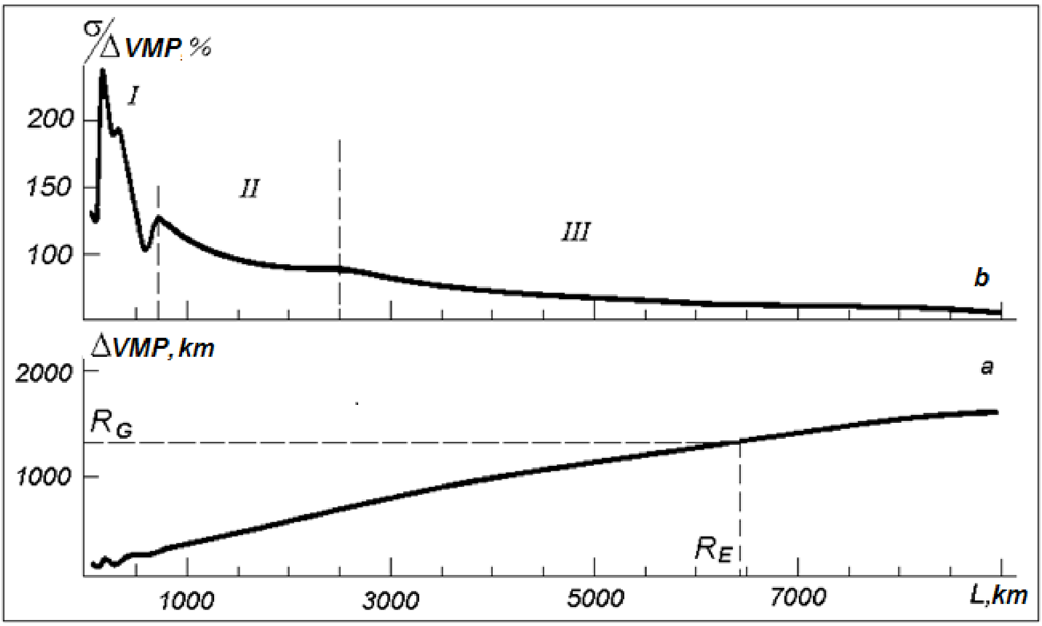


Fig. 2. The distance between virtual magnetic poles, determined at the observatories and the distance between these observatories $L - a$; $b$ - the relative root-mean-square deviation s from the VMF average coordinates related to $L$.

In fact, this angle is significantly less, which indicates the dipole character of geomagnetic field. Taking the distance $L$ between two observatories, i.e. points of VMP determination, to be equal to the Earth radius $R_E$, then the distance between VMP is 0.2 $R_E$, that is equal to the inner core radius $R_G$ (Fig. 2-a). It confirms once more the validity of former estimations.

Fig. 2-b illustrates the variation of relative root-mean-square deviation $\sigma$ from VMP average value ($\sigma/\Delta$VMP) with the distance $L$. The curve in Fig. 2-b consists of three parts, marked by *I, II, III*. In part *I* the sharp changes of $\sigma/\Delta$VMP are observed. Most likely, it is explained by the fact that when the distance between the observatories is short ($L < 700$ km), magnetic anomalies, natural for the Earth crust, have their impact. In part *II*, the decrease of $\sigma/\Delta$VMP is due to the increase of depth factors effects over the crust ones. In part *III* ($L > 2500$ км) a smooth decrease of $\sigma/\Delta$VMP associated with the decrease of depth source effect during the increase of an averaging interval (the last point on the curve $L \approx 9000$ was obtained by averaging of 16110 values) is observed.

## Estimation by spatial dimension of anomaly

In our model global magnetic anomalies (GMA) are presented by magnetic dipoles. It is known that if it is a central dipole (its center is on the Earth rotation axis), then its components are:

$$Z = (2m/4\pi) \times \cos\left(\theta/r^3\right), H = (m/4\pi) \times \sin\left(\theta/r^3\right) \quad , \qquad (4)$$

where $m$ is the dipole moment, and $\theta$ is the angle between a vector, directed to the point on the Earth surface where the dipole is pointing at and $Z = \max$ , and a vector, directed to the point where one intends to determine the dipole field values (Fig. 3).

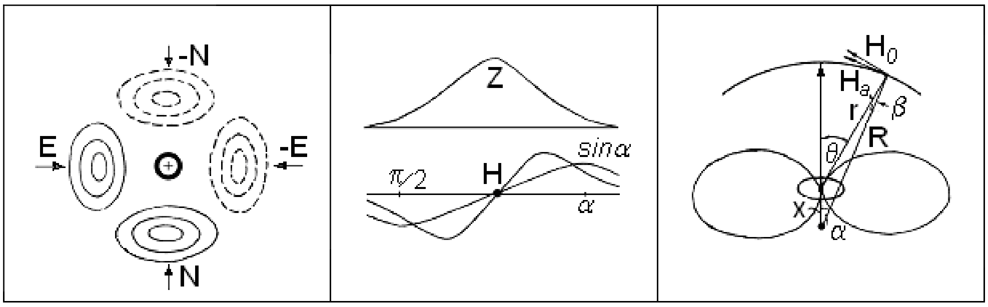


Fig. 3. Estimation of the Earth radius part appropriate to the region of the source of the magnetic anomaly field generation

It follows from the figure that on the maps of geomagnetic field $E$- and $N$-components, we observe their maxima and minima distant from the dipole center (we should note, that there are such maxima and minima on maps indeed). If we succeeded to estimate the distances (in geographic degrees) from the dipole center to these component maxima, we would be able to estimate the depth where GMA generation takes place. We are interested in angle, but to estimate $x$ value (Fig. 3) we use the values of $\theta$ and $\alpha$ angles (in geographic degrees). Note that GMA dipole field coordinates do not coincide with the central dipole form. Equating the Earth radius to a unit ($R = 1$), supposing that:

$$H_\theta = \sin\left(\theta / r^3\right) = \max.$$

and taking the obvious relation: $\sin(\theta) = \sin(\alpha/r)$, we obtain:

$$H_\theta = \sin\left(\theta / r^4\right).$$

If $\beta\,(\beta = \theta - \alpha)$ is the angle between $H_\alpha$ and $H_\theta$ vectors , then $H_\theta$ value should be multiplied by: $\cos(\beta) = (1 - x\cos(\alpha)) / r$.

It results in:

$$H_\alpha = \sin(\alpha)\,(1 - x\cos(\alpha)) \Big/ r^5, r = \left(1 + x^2 - 2x\cos(\alpha)\right)^{1/2}. \quad (5)$$

Having determined $\alpha$ values for GMA and for secular variation current focuses from the maps of the Earth magnetic field $E$- and $N$-components, $x$ average value equal to $x = 0.2\,(\pm 0.1)\,R$. is obtained.

## Estimation of the source location by geomagnetic spectrum

Geomagnetic field spectrum was studied in the papers [8]-[10]. Geomagnetic field spectrum is the variation of geomagnetic field root-mean-square intensity $R_n$, estimated on the Earth surface ($R_n$ dimension is given in $(\mathrm{nTl})^2$) as a sum of $n$-th power harmonics from the harmonic number:

$$R_n = (n+1) \sum_{m=0}^{n} \left[(g_n^m)^2 + (h_n^m)^2\right]. \quad (6)$$

In the paper [9], a set of Rn values is presented in a table from which it is clear that the main part of the field intensity (95%) is concentrated in the region of geomagnetic field generation (dipole field) with $n = 1$ harmonic. The spectrum pattern is a declining curve for the harmonics with the power from 1 to $n = 13$. For the harmonics of the higher order, the curve is horizontal.

$$R_n = 1.349 \times 10^9 (0.270)^n (nT)^2. \tag{7}$$

Estimating the shape of geomagnetic field spectrum relative to the core-mantle boundary, it was shown [8]-[9] that $R_n$ coefficients decrease smoothly to a certain n value corresponding to that boundary and then they begin to increase. The nature of Rn increase is not quite clear. This increase (dots on Fig. 4-b) does not fit the formula (7).

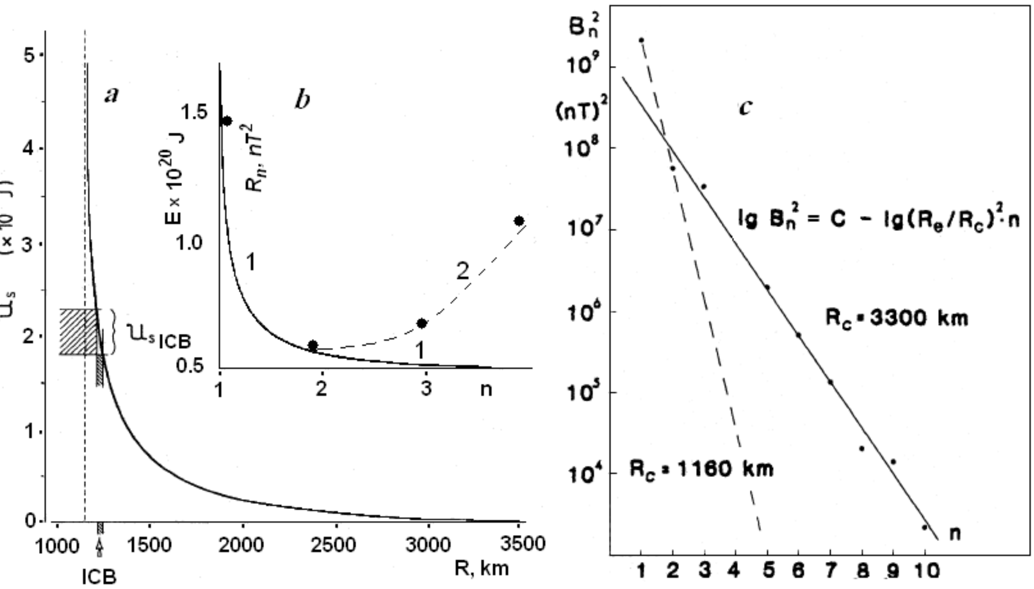


Fig. 4. Estimation of geomagnetic field energy value depending on the Earth radius ($a$) [9], on the number of spherical harmonic ($b$) for the inner core surface, geomagnetic field spectrum () for two spheres with $R_c$ radius [10]

The authors [9]) try to explain this phenomenon by a possible effect of the crust and mantle magnetic fields. Most likely, the spectrum steepening determined in some papers is associated with a computational algorithm which does not take into account the fact that determined for the Earth surface Gauss coefficients $g_n^m$ and $h_n^m$ were applied to estimate the spectrum on inner spheres. It is equivalent to the situation when, for example, some function limited by a defined interval would be expanded in a series of polynoms and then the expansion final level would be transferred into the interval defined for this function. Here similarly the coefficients for the harmonics series which does not fit a new interval will increase as the harmonic number grows, whereas they decreased within the limited interval discussed earlier.

$R_n$ is the total root-mean-square contribution into the vector range of all harmonics with $n$ power. $R_n$ calculated according to IGRF 1980 data applying equation 6 ([10]) is shown in Fig. 4-c. The regression line decline (solid line) yields the core boundary radius of 3300 km. The dashed line passing through the first two harmonic coefficients is a spatial spectrum of magnetic field source located in the inner core.

## Modeling by magnetic dipoles and current loops

In modeling an iterative damped Newton-Gauss method was applied to minimize an efficiency function. Square of an averaged over the Earth surface residual field, that is the difference between the model and the observed ones, was used as the efficiency function [11].

It was shown that the most optimal generator is a differential current system with a short distance between circular loops. By the search of current loop dimensions and arrangement, and values of magnetic dipoles on the Earth inner spheres, it was determined that the main (prevailing) part of the Earth magnetic moment is generated in the volume adjacently surrounding the inner core ($R_G = 0.2\ R_E$). The most optimal number of current loops additional to the central axial dipole is four, as well as four global magnetic anomalies are observed. The geomagnetic field configuration of the central dipole and four dipoles (current loops) as most corresponding to the observable one (Fig. 5) is obtained if the calculated geographic coordinates of dipoles do not coincide with the coordinates of GMA dipoles which vectors are at some angle to the inner core surface.

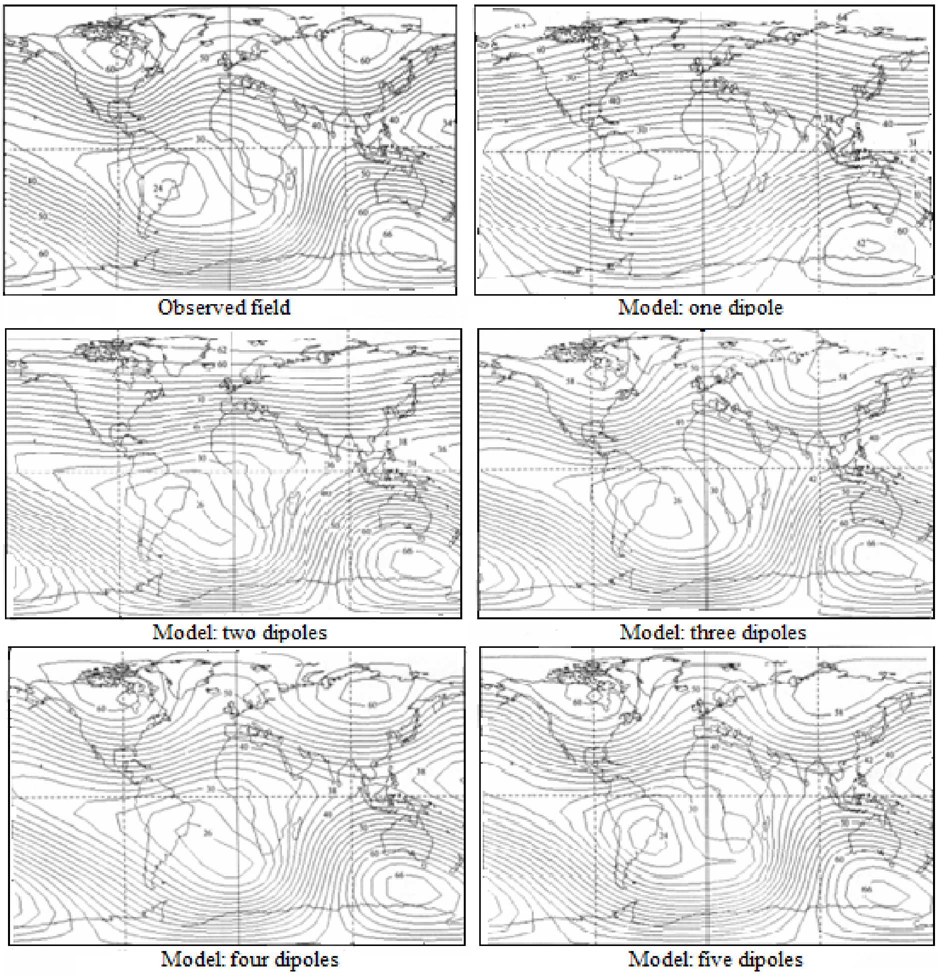


**Fig. 5.** Geomagnetic field structure for different number of dipoles located on the sphere of the radius $= 0.2\ R$

In the table the dipole directions are indicated by errors, and the dipole field moduli (Md) are given in Tesla per volume ($^3 \times 10^{15}$).

*Table*

| Dipole | Central | Canadian | Siberian | Brazilian | Southern |
|---|---|---|---|---|---|
| Coordinates | 78.3 °S106 °E | 60 °N 90 °W | 60 °N 120 °E | 15 °S 90 °W | 70 °S 150 °E |
| Calc. coord. | 63.3 S25.3 °E | 24 N 62.8 W | 45 N 66.8 °E | 69.1 S9.9 °W | 72.5 S133 °E |
| M.d.$\times 10^{15}$Тм$^3$ | 7.8 | 1.8 | 2.4 | 4.3 | 2,5 |
| Dip. direct. | ↓ | ↓ | ↓ | ↑ | ↓ |

As clear from the table the moduli of the central dipole and GMA are comparable-sized, and the moduli of three anomalies enhance the main field, whereas the modulus of the Brazil anomaly decreases it.

## Conclusion

All well-known methods for estimation of the source location result in: the geomagnetic field is generated at the boundary of the inner core. This fundamental result contradicts the geodynamo classical model. The boundary between the inner (G) and the outer (E) cores is easily detected by seismological methods. With real thickness of about 100 km the boundary is called the F-layer.

The distribution of P-waves velocities in the F-layer allows to suppose that the first-order phase transition takes place here. It means that electric charges may be generated in the layer with their separation during mass transfer and double electric layer appears. Taking into account these conditions, it is real that the geomagnetic field is generated just in this layer.

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