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1. Introduction

Nowadays the specialists in geophysics, biology, medicine, mechanics, psychology, and many other fields often pay an attention to the geomagnetic variations (GMV) influence on existence and evolution of different systems and objects. These scientific and practical interests are based on the fact, that some elements of GMV or their combinations can directly or indirectly affect biological, technical and other objects and systems. As a result distorted normal conditions of the system existence force it either to adapt to the changes of geomagnetic field (because of deformation, mutation, etc.) or keep existing in stressed (or instable) state [Kusche, 1978]. So, it's obvious that the problem of GMV research, identification and estimation is topical theme both on scientific and technical levels.

2. A brief review of geomagnetic field and its variations

Contemporary scientific researches suppose that Earth's outer core is liquid and mainly metal, and ferromagnetic elements, such as iron and nickel, are among its main components (at depths greater than 670 km) and make the mass fraction of the Earth's core ~85.5 % и ~5.2 % respectively, that in sum is more than 90 %. Continuous rotation of the Earth and its core causes constant flows and electric currents in it, which provide the presence of geomagnetic field (according to the laws of magnetic hydrodynamics). Thus because of the Earth's magnetosphere complex and heterogeneous structure (Fig. 1) its force characteristics are extremely unevenly distributed over the surface of the planet and in the near-Earth space.

So, the research results proof, that geomagnetic field induction on the edge of magnetosphere (magnetopause, Fig. 1) is ~10.03 mTl, near the Earth's surface on the equator is ~20–40 μTl, and near the poles is ~60–70 μTl. Besides a number of periodical (sometimes irrational) events of various power and origin contribute to the deviation of field force characteristics from the steady-state values. Because of that reason the mentioned parameters are mainly averaged, and also are probabilistic due to the GMV. GMV are traditionally described as detected deviations of the Earth's magnetosphere amplitude-frequency characteristics from some nominal values. These values are supposed to be used as characteristics of normal (unperturbed) state of Earth's magnetosphere B0.

Table 1 represents a variant of GMV classification scheme. It includes mostly researched GMV causes, and also quantitative estimation of their amplitude-frequency and probability characteristics. (In the case of Table 1 data verification classification scheme-table can be corrected).

Table 1. A classification of natural geomagnetic variations

Genetic	Probabilistic		Morphological	
Genesis	Probability of happening, *P* [%]	Activity Period, *T*, hours	Amplitudes Range, ±Δ*B*, [nTl]	Frequencies Range, *f*, [Hz] (period)
The Earth's rotation around its own axis	100	–	100–200	~11.6·10–6 (23 hours, 56 minutes, 4 seconds)
The Moon's rotation around the Earth	100	–	2–5	~11.2·10–6 (24 hours, 50 minutes)

The Sun's rotation around its own axis	100	–	40–60	~4.6·10–7 (25 days, 9 hours, 7 minutes)
The Earth's rotation around the Sun	100	–	10–200	~31.7·10–9 (365 days, 6 hours, 9 minutes)
The Sun's rotation around its own axis	100	–	10–30	~1.4·10–9 (20–22 years)
Earth magnetic anomalies	Depends on geographic coordinates	–	Up to 20·103	~0
The motion of matter and wave processes in the Earth's core	100	–	10–120	~2.5·10–10 (10–50 years)
The Sun wind	~5–7	40–50	(0.05–1.5)103	2–10–5 (10–72 hours)
Schumann resonance	~25–70	4–7	(0.1–1.8)10–3	7–8

Due to the data in Table 1, it's fair to conclude that in the most cases GMV are stacked in the amplitude-frequency response of weak low-frequency magnetic fields, which are limited as:

$$\Delta B = [3\cdot 10^{-9}–20\cdot 10^{-6}] \text{ Tl}; f = [0–8] \text{ Hz}.$$

So, for example, magnetic field induction near the Earth's surface on equator and poles is estimated as ~30 μTl ± ΔB and ~65 μTl ± ΔB respectively.

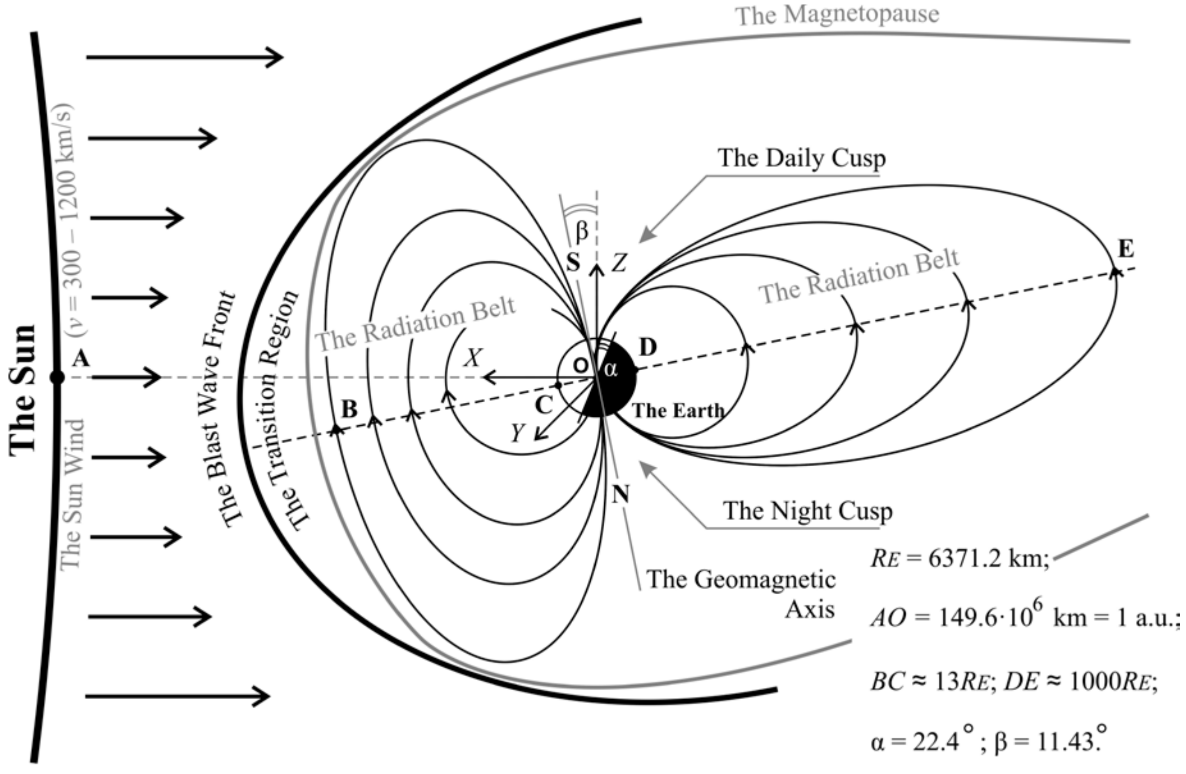

Figure 1. A structure of geomagnetic field

3. Research problem

Nowadays a problem of GMV parameters registration is partly solved by a number of magnetic observatories. The magnetic observatories are the institutes, where parametric and astronomical observations of Earth's magnetosphere are performed. Published results of the appropriate researches mainly describe a character and dynamics of GMV parameters variation on stationary point of the Earth's surface. This point is strongly defined by geographical coordinates and altitude.

But it is still not clear, what is the influence of the particular geomagnetic field to the object (of biological or technical origin). The object transition in heterogeneous unperturbed geomagnetic field causes GMV only at the concrete object and its surrounding environment. To formalize the geomagnetic field influence we enter and use a new term – geomagnetic pseudostorm [Vorobev, 2012].

The geomagnetic pseudostorm is an effect of GMV equivalent, which is observed within the object existence in unperturbed anisotropic geomagnetic field on condition of nonzero linear or angular speed of the object [Vorobev, 2012], [Vorobev, 2013].

4. Conceptual view of geomagnetic pseudostorm

To demonstrate geomagnetic pseudostorm effect it's proposed to draw an analogy between the magnetic and force actions. The magnetic action is performed on static test object from the disturbed geomagnetic field. And the force action is observed in the other object in the flow of anisotropic fluids, which changes its direction and speed. This analogy demonstrates dynamics of magnet and force actions from real magnetic storms on research static object or system.

Let's keep anisotropic properties of the liquid to qualitatively estimate force actions performed on the object on condition of environment static character. It's assumed that the object has nonzero linear or angular speed. It is obvious that action dynamic in the changed environment can be compared to the dynamic from the previous example. And this dynamic depends on both speed of the object and the gradient of environment heterogeneity.

It is considered to project this analogy to the test object in the anisotropic magnetic field. In this case the suggested term of geomagnetic pseudostorm (GMPS) reflects the typical effects, which are observed while the real magnetic storms acting on the object on conditions of anisotropy of the unperturbed geomagnetic field and nonzero linear or angular speed of the object.

5. Modeling and estimation of undisturbed geomagnetic field parameters

Consider the full vector of geomagnetic field induction in the geographical point with defined space-time coordinates as follows:

$$B_{\mathrm{ge}} = B_1 + B_2 + B_3,$$

where B_1 is vector of geomagnetic field induction of "on-Earth" sources; B_2 is regular component of geomagnetic field induction of magnetosphere currents, which is calculated in solar-magnetospheric coordinate system; B_3 is irrational component of geomagnetic field induction of magnetosphere currents, including technogenic nature.

As a fundamental mathematical model it's supposed to use an expression of quantitative estimation of scalar geomagnetic field induction of "on-Earth" sources U, [nTl·km] at the geographical space point with spherical coordinates r, θ, λ, which is defined as:

$$U = R_E \sum_{n=1}^{N} \sum_{m=0}^{n} (g_n^m \cos(m\lambda) + h_n^m \sin(m\lambda))(\frac{R_{\mathrm{E}}}{r}) P_n^m \cos\theta, \qquad (1)$$

where r is a distance from Earth center to the observation point (geocentric distance), km; λ is longitude from the Greenwich meridian, degrees; θ is a polar angle (addition to the latitude, $\theta = (\pi/2) - \varphi'$, degrees, where φ' is a latitude in spherical coordinates, degrees); RE is an average radius of the Earth, R_E = 6371,03, [km]; $g_{nm}(t)$ and $h_{nm}(t)$ are spherical harmonic coefficients, nTl, which depend on time value; P_{nm} is an orthogonal polynomial normalized by Schmidt associated Legendre functions with power n, order m, which is defined as (2):

$$P_n^m \cos\theta = 1\cdot 3\cdot 5\cdot ...(2n-1)\cdot\left(\frac{\varepsilon_m}{(n+m)!(n-m)!}\right)^{1/2}\times$$
$$\times\sin^m\theta[\cos^{n-m}\theta - \frac{(n-m)(n-m-1)}{2(2n-1)}\cos^{n-m-2}\theta +$$
$$+\frac{(n-m)(n-m-1)(n-m-2)(n-m-3)}{2\cdot 4(2n-1)(2n-3)}\cos^{n-m-4}\theta - ...], \quad (2)$$

where ε_m is normalization factor (ε_m = 2 for $m \geq 1$ and ε_m = 1 for m = 0); n is a power of spherical harmonics; m is an order of spherical harmonics.

From the scientific publications an expression (1) is widely known as the Gaussian and is commonly used for calculating geomagnetic field induction of "on-Earth" sources. Also this expression is acknowledged by the international standard for quantitative estimation of the undisturbed Earth's magnetosphere.

It is assumed that $B_0 \approx B_1$, where B_0 is an induction of undisturbed geomagnetic field in local spatio-temporal point of the earth's surface; B_1 is geomagnetic field induction of "on-Earth" sources.

It is well-known that on condition of sufficiently homogeneous and precise input data (for example, obtained by satellite) the spherical harmonic coefficients can be represented by 12 or 13 rows.

The coefficients of the higher harmonics are comparable to or less than the accuracy of these coefficients determination. In this research it's suggested to use 12 harmonics, and the accuracy of calculating geomagnetic field near the Earth surface is less than 2 %. In other words geomagnetic field component $B_1 \approx B_0$ reflects the force characteristics of the undisturbed geomagnetic field with an accuracy of less than 98 %. This value is assumed as sufficient parameter for observations and analyses of geomagnetic field state.

The technique of calculating the main parameters of the geomagnetic field and geographical coordinates of geomagnetic dipole is shown on Fig. 2. This technique represents a base for experimental programming complex "GEOmagnetic_v1.0" realization. The complex "GEOmagnetic_v1.0" performs automated calculation of main parameters of undisturbed geomagnetic field by the defined space-time coordinates [Vorobev, 13].

It is necessary to mention that further realization of experimental programming complex "GEOmagnetic_v1.0" on mobile platform will increase functional possibilities and provide operativeness of research and calculations. This realization is useful to the wide variety of specialists from geophysical sphere.

It is suggested to use planetary matrix of altitudes (Table 2) to develop an information base for creating (with necessary resolution) "a map" of quantitative estimation of distribution of geomagnetic induction vector for "on-Earth" sources B0 (a map of geomagnetic field magnetic induction isolines). This map also considers topographic features of the researched area (Table 3). The estimated relative error of calculations is no more than ~ 3%.

In more common case a program "GEOmagnetic_v1.0" can be used to form arrays similar to the data from Table 3. These arrays can be automatically generated both for estimation of global planetary near-Earth geomagnetic state, and for research of regional distribution of on-Earth sources geomagnetic induction vector in static time scale or in dynamic mode.

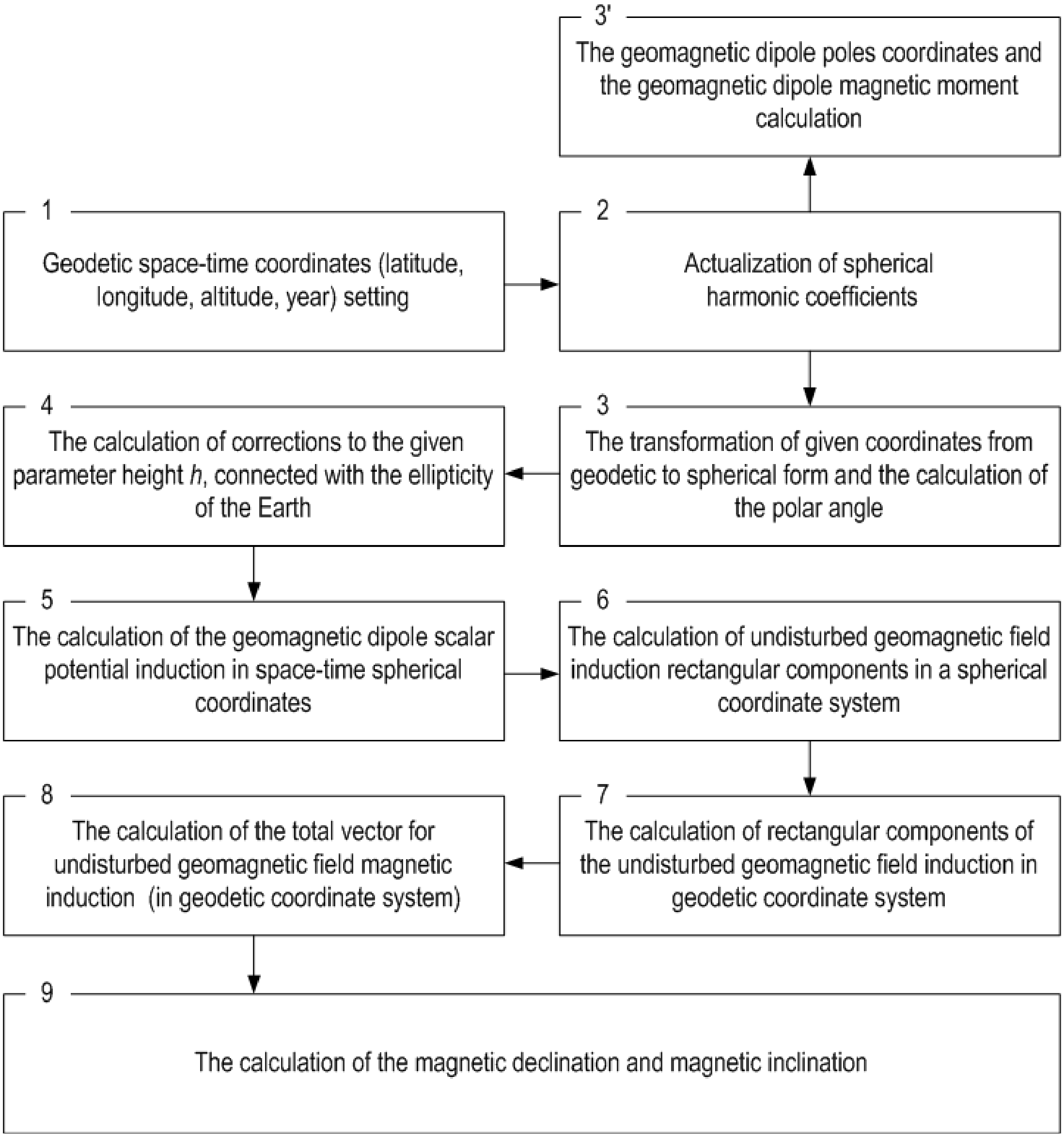

Figure 2. The methodic of undisturbed geomagnetic field parameters calculation

So, this approach allows scientists and specialists operatively generate and analyse the tendencies of geomagnetic induction vector distribution in near-Earth space with any necessary resolution.

Table 2. A planetary matrix of parameter h, km

longitude / latitude	150^o wl.	120^o wl.	90^o wl.	60^o wl.	30^o wl.	0^o
80^o nl.	0	0	0	1.5	0.2	0
60^o nl.	0.75	0.75	0	0	0	0
40^o nl.	0	1.5	0.25	0	0	0
20^o nl.	0	0	0.1	0	0	0.75
0^o (equator)	0	0	0	0.1	0	0
20^o sl.	0	0	0	0.1	0	0
40^o sl.	0	0	0	0	0	0
60^o sl.	0	0	0	0	0	0
80^o sl	0	0	0	0	0	0

longitude / latitude	30° el.	60° el.	90° el.	120° el.	150° el.	180° el.
80° nl.	0	0	0	0	0	0
60° nl.	0.1	0.35	0.75	0.35	1.0	0
40° nl.	1.0	0.1	1.5	0.1	0	0
20° nl.	0.35	0	0	0	0	0
0° (equator)	1.0	0	0	0.1	0	0
20° sl.	1.5	0	0	0	0	0
40° sl.	0	0	0	0	0	0
60° sl.	0	0	0	0	0	0
80° sl	0	0	0	0	0	0

Table 3. A planetary matrix of parameter B_0, μTl

longitude / latitude	150° wl.	120° wl.	90° wl.	60° wl.	30° wl.	0°
80° nl.	57.6	57.4	56.8	55.9	54.9	54.5
60° nl.	55.1	59.0	59.8	54.5	51.4	49.7
40° nl.	44.1	51.5	55.3	49.7	43.3	43.0
20° nl.	35.0	39.9	43.1	38.6	34.1	35.5
0° (equator)	32.3	31.2	30.5	28.1	28.5	32.8
20° sl.	37.0	30.6	24.1	20.2	24.4	28.8
40° sl.	47.1	38.6	26.9	19.2	22.4	23.4
60° sl.	57.6	49.3	38.1	29.3	27.1	27.2
80° sl	59.1	55.6	50.1	45.8	42.9	43.4

longitude / latitude	30° el.	60° el.	90° el.	120° el.	150° el.	180° el.
80° nl.	55.3	56.9	58.3	58.7	58.3	57.8
60° nl.	50.2	56.5	59.6	61.2	55.5	52.7
40° nl.	46.1	50.9	55.8	54.2	44.6	40.3
20° nl.	39.0	42.5	44.7	42.7	35.3	32.9
0° (equator)	36.7	38.2	43.1	41.6	38.1	34.7
20° sl.	29.6	39.8	51.9	52.9	60.3	55.4
40° sl.	26.7	42.2	57.9	64.5	62.8	64.0
60° sl.	33.0	45.9	59.5	67.8	68.5	60.8
80° sl	47.1	52.4	56.8	59.6	60.8	44.0

6. Geomagnetic pseudostorm effect explanation

Let's consider the main characteristics of geomagnetic pseudostorm (GMPS) and define its mathematical expressions for quantitative estimation:

– GMPS amplitude is a maximum increase of magnetic induction value of the studied object because of its near-Earth transition from point A_i to point B_{j-1}:

$$B_{atr} = B_{0\_Bi-j} - B_{0\_Ai} ,$$

where B_{0_Ai} and B_{0_Bi-j} are the inductions of geomagnetic field of "on-Earth" sources in start and final point of object transition, [nTl].

– GMPS intensity is a physical quantity, which is numerically equal to the rate of growth (or reduction) of undisturbed geomagnetic field induction relatively to the reference frame associated with the object moving in near-Earth space:

$$I_B = \frac{\partial B}{\partial t} \approx \frac{B_{0\_Bi-j} - B_{0\_Ai}}{t_2 - t_1} \cdot 10^3,$$

where I_B is GMPS intensity, [pTl], t_1 and t_2 are start and final time moments of the object moving.

– GMPS frequency is a physical quantity, which reflects frequency properties of GMPS influencing on the studied object:

$$f_B = \frac{1}{2\Delta t}, \tag{3}$$

where Δt is time for moving the object from point Ai to point B_{i-j}. In more common case Δt is a time interval between two calculations of geomagnetic field induction for the appropriate geographical point (it is equal to sampling step) (Fig. 3).

If necessary the frequency analysis of the data signal can be detected on the basis of discrete Fourier transformations. But high-frequency GMPS while moving object in near-Earth space is quite rare. That's why it seems to be more rational and sufficient to use expression (3) for estimating GMPS frequency parameter.

– GMPS potentiality (geomagnetic induction gradient) is a vector in 3-dimensional area, which direction points to the direction of the quickest increase of absolute value of undisturbed geomagnetic field induction. This vector module is equal to the increase speed of B_0 in the same geographical direction [nTl/rad; nTl/rad; nTl/km].

$$G_B = \nabla B_0(\theta, \lambda, r) = \text{grad } B_0(\theta, \lambda, r) = \left(\frac{\partial B_0}{\partial \theta}, \frac{\partial B_0}{\partial \lambda}, \frac{\partial B_0}{\partial r} \right),$$

where B_0 is defined as follows (according to the technique represented on Fig. 1 and expression (1)):

$$\begin{aligned} B_0^2(r, \lambda, \theta)[\text{нТл}] = &\left[\frac{1}{r} \frac{\partial U}{\partial \theta} \cos(\varphi - \varphi') + \frac{\partial U}{\partial r} \sin(\varphi - \varphi') \right]^2 + \\ + &\left[\frac{1}{r \cdot \sin\theta} \frac{\partial U}{\partial \theta} \right]^2 + \left[\frac{\partial U}{\partial \theta} \cos(\varphi - \varphi') - \frac{1}{r} \frac{\partial U}{\partial r} \sin(\varphi - \varphi') \right]^2, \end{aligned} \tag{4}$$

where φ is a latitude (positive to the north direction); φ' is a latitude in spherical coordinates; λ is longitude (positive to the east direction); θ is an addition to the latitude; r is geocentric distance taking into account the flattening of the Earth.

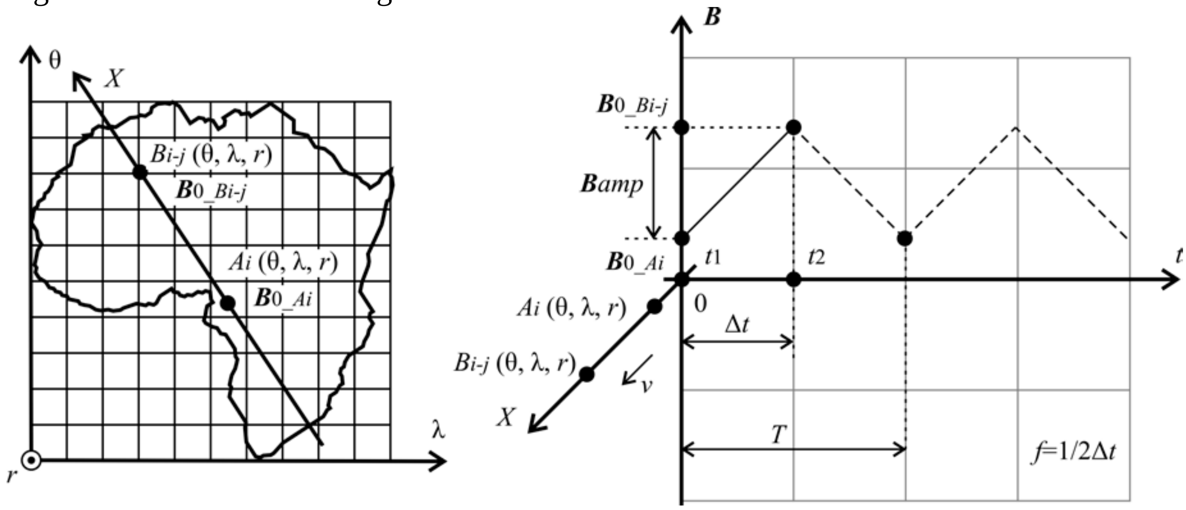

Figure 3. To the explanation of the term "GMPS frequency"

Analysis of the quantitative evaluation of geomagnetic induction gradient provides a base for the judgments about the maximum intensity of GMPS in this geographic area. So, G_B parameter firstly must be considered during development of marine, aviation and airspace navigation maps. More detailed research has shown that GMPS potentiality by latitude and longitude has a wide arrange (0.5–50 μTl/rad). Also GMPS potentiality can be both positive and negative, that is a reflection of undisturbed geomagnetic field anisotropy.

Geomagnetic field induction gradient by the altitude (geocentric distance) is in the range -10…-30 nTl/km and is always negative. This fact proves that the intensity of GMPS in the area of biosphere vital activity (Earth's surface and the lower layers of the troposphere) is always greater than the same parameter out of its limits (the upper troposphere, stratosphere, mesosphere, etc.).

The distribution of typical areas of geomagnetic field can be represented as a quadrangle ABCD (Fig. 4). Taking into account this quadrangle and effect of GMPS the further research of geomagnetic isolines synthesized map (Table 3, Fig. 4) led to the conclusion that the maximum value of GMPS potentiality by latitude (and as result the intensity of GMPS on moving from north to south) is in the center of the line AD. This point coincides with geometric center of Bermuda triangle, which is defined on Fig. 4 as EFG. This situation can be explained by the fact that the line AD, which connects centers of geomagnetic field typical areas, is the shortest line relatively to the lines AB, BC and CD. It means that geomagnetic isolines density (by the latitude) at the center of this line is much greater than at the other lines (AB, BC, CD).

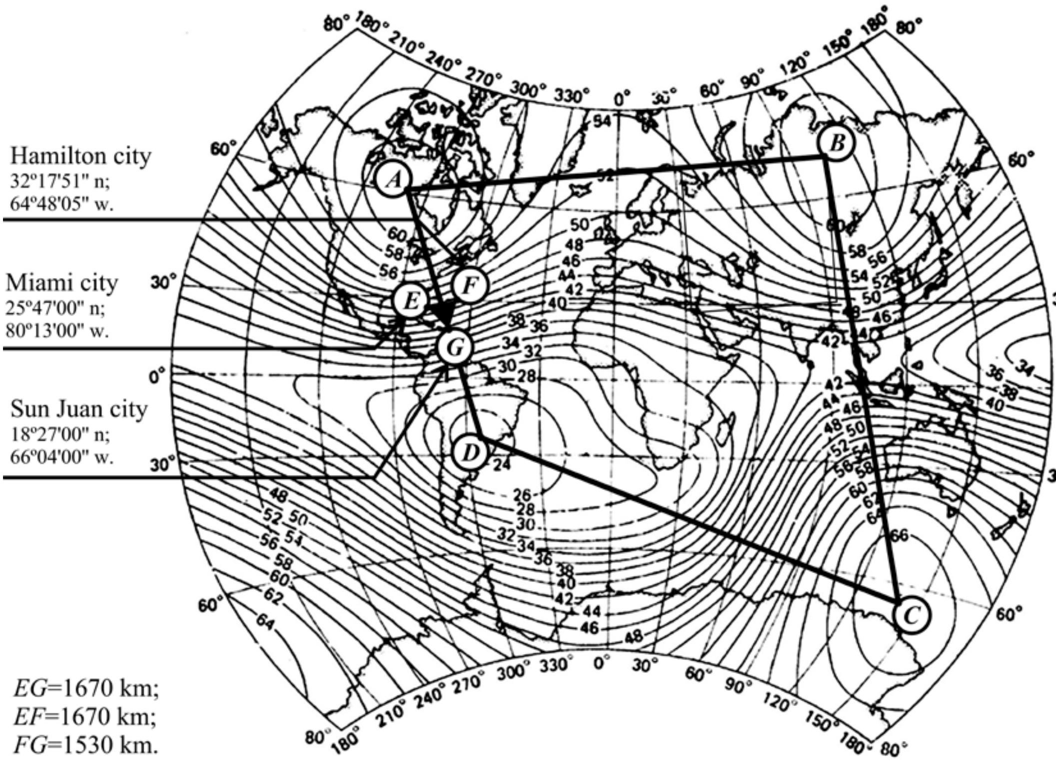

Figure 4. An example of magnetic isolines map

Comparison of this conclusion with the possible effects of GMV actions on technical and biological moving objects is suggested as indirect explanation of Bermuda triangle phenomena.

7. Conclusion

The main results described in the paper are:

– the geomagnetic pseudostorm effect is suggested, described and modeled, its main parameters are outlined;

– complex of mathematical, programming and methodological tools for automated calculation and estimation of geomagnetic pseudostorm effect is developed;

– the new approach to the explanation of Bermuda Triangle phenomena on the basis of geomagnetic pseudostorm effect is suggested;

– it is scientifically proofed, that it is useful to take into account the geomagnetic pseudostorm effect by studying law-frequent magnetic fields and their influence on technical and biological objects which are moving in near-Earth space.

– it is demonstrated, that of the fact that complex estimation of geomagnetic pseudostorm effect increases reliability and accuracy of the GMV identification process on the basis of their genetic feature and origin.

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