Web-Based Geoinformation System for Exploring Geomagnetic Field, Its Variations and Anomalies

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Abstract. In the modern World, specialists in many scientific and applied spheres consider parameters of geomagnetic field, its variations and anomalies as one of the key factors, which can influence on systems and objects of various origins. The estimation of the influence requires an effective approach to analyze the principles of distribution of geomagnetic field parameters on the Earth's surface, its subsoil and in circumterrestrial space. The approach causes a complicated problem to be solved, which is concerned with modeling and visualization of parameters of geomagnetic field, its variations and anomalies. The most effective and obvious solution to this problem is supposed to be a geoinformation system, because of the geodata-centric character of the problem itself. In this paper the authors suggest the solution, which is based on modern geoinformation and web technologies and provides the mechanisms to calculate, analyze and visualize parameters of geomagnetic field and its variations.

Keywords: Geoinformation systems · Geomagnetic field · Geomagnetic variations · Geomagnetic anomalies · 2D/3D-visualization

1 Introduction

Geomagnetic field is well-known as the magnetic force field that surrounds the Earth. To simplify the description of the geomagnetic field it can be defined as a large bar magnet placed at the center of the Earth, with its south end oriented toward the north magnetic pole. The main goal of the Earth's magnetic field is to deflect most of the solar wind. Otherwise the charged particles of the solar wind would strip away the ozone layer of the Earth and all the systems and objects at the planet would be subjected to the influence of harmful ultraviolet radiation [1].

Geomagnetic field is shaped somewhat like a comet, which tail stretches for hundreds of thousands of kilometers in the direction opposite to the Sun and accumulates magnetic energy [2]. This area is called the magnetosphere and its shape is formed in response to the dynamic pressure of the solar wind (Fig. 1).

At any point on the Earth's surface the geomagnetic field is a combination of several magnetic fields generated by various sources. These fields are superimposed on and interact with each other [3].

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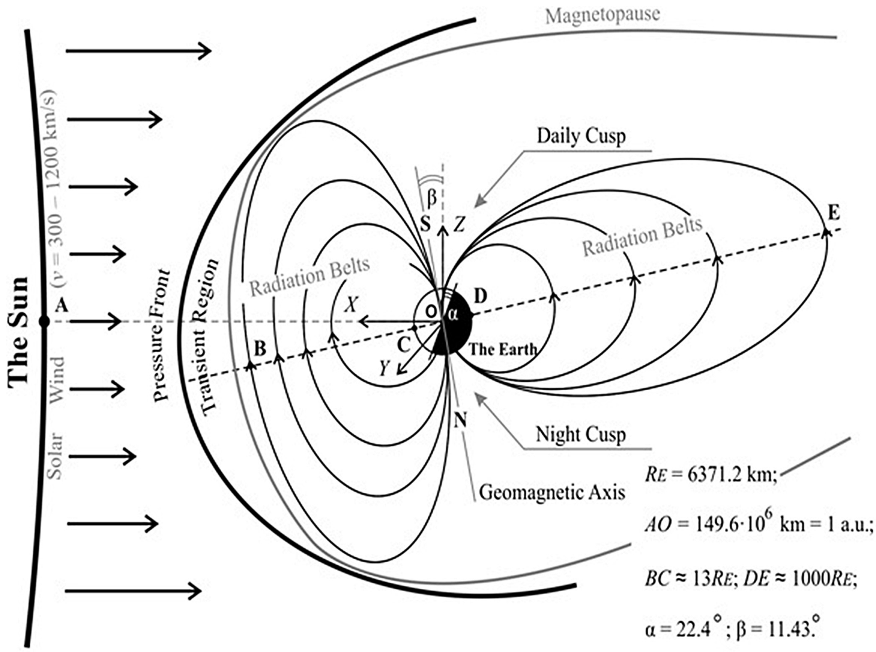

Fig. 1. A structure of geomagnetic field.

However, more than 90 % of the geomagnetic field measured is generated in the Earth's outer core (e.g. internal sources of the planet). This part of the geomagnetic field is known as the main field. It varies slowly in time and can be described by mathematical models [3].

Geomagnetic field is not stable and changes with periodicities from about 0.3 s to hundreds of years. These changes are often referred to as geomagnetic variations, which can arise from both sources external to the Earth or internal to the Earth. For example, sometimes the energy in magnetosphere tail is released in explosions. They heat up plasma, and cause powerful electric currents. At this moment the magnetosphere is filled to capacity with hot plasma, while its electric currents embrace the entire near-Earth space. These phenomena are referred to as magnetic storms [3].

One more important type of geomagnetic field change is caused by the object movement in anisotropic magnetic field. The parameters of geomagnetic field (which influence at the object) can vary significantly.

It is well known that some components of geomagnetic variations or their combinations can influence on biological, technical, geological and other objects and systems in common and on human in particular [4, 5]. There are a lot of known cases, when geomagnetic variations and anomalies affect the performance of equipment, upset radio communications, blackout radars, disrupt radio navigation systems, and endanger living organisms. Also there are some studies that describe correlations between human behavior and geomagnetic activity that might support some causal relations. Many animals use the magnetic field like we use GPS to navigate. So any changes of geomagnetic field can cause some troubles for them.

Today the problem of monitoring of geomagnetic field and its variations parameters is partially solved by various ways. First, there are traditional magnetic measurements, which have routinely been carried out on the ground and over the oceans since 16th century. Next, a global view of geomagnetic field and how it changes is provided several by several magnetometry satellites in near-Earth orbit. And finally, geomagnetic field can be studied by a number of magnetic observatories (The magnetic observatory is a scientific organization, which is specialized on parametric and astronomical observations of the Earth's magnetosphere). The registered information about magnetic field and ionosphere state is regularly sent to the International centers in Russia, USA, Denmark and Japan. In these centers the information is registered, analyzed and partially available to the broader audience with some delay. Today there are about 100 geomagnetic observatories, and one third of them are in Europe [2].

Today monitoring, registration, visualization, analysis, forecast and identification of geomagnetic variations is a relevant sophisticated fundamental scientific problem with strong applied character.

All the data measured and collected about geomagnetic field is distributed in various sources and archives. There is still no integrated information space to get any data about geomagnetic field at any point of the Earth's surface at any moment of time. The obvious way to solve the problem is to implement innovative information technologies there. In particular the most expectations are about using geoinformation systems to solve the problem. In this paper the authors suggest an approach to study, monitoring, analyze and visualize geomagnetic field, its variations and anomalies, which is based on modern Web and geoinformation technologies.

2 Information Technologies to Explore Geomagnetic Field

In spite of the wide variety of specialized geoinformation systems there are no advanced hard- and software, which provide a calculation, geospatial connection, visualization and analysis of geomagnetic field, its variations and anomalies.

All the known information resources can be divided into two main groups. First one is represented by a complex of online databases from a number of magnetic observatories. These databases can be used by the following way. A user chooses an observatory and the period and gets a file with result to upload or to online plot it on screen. To use this data it is necessary to do something special to make a layer between these uploaded files located somewhere and user applications. However this approach is quite enough just to look through data.

Another solution is represented by geomagnetic calculators. To obtain necessary data a user enters coordinates of the place and gets parameters of normal magnetic field in the point. The great disadvantage here is that a user has to know the exact coordinates (no place name or something else). Sometimes it is a problem.

An example of modern geomagnetic calculator is the service, which is provided by NOAA (National Oceanic and Atmospheric Administration) and available at http://www.ngdc.noaa.gov/geomag-web. However the calculation results are out of limits of permissible errors. It is takes no much time to ensure about incorrect work of some tools, absence of visualization tools and multilingual support, bad geolocation and non-informative interface.

It is important to mention, that due to low-efficiency, limited functionality and incorrect work of the known solutions the topicality, scientific and applied interest to such a solution development continuously increases. The necessary thing here is a set of mathematical models, which can describe the main field as a number of equations, based on the spatiotemporal parameters of the point of the Earth's surface.

3 Mathematical Modeling of Geomagnetic Field and Its Variations

The full vector of the Earth's magnetic field intensity in any geographical point with spatiotemporal coordinates is defined as follows [6]:

$$\boldsymbol{B}_{ge} = \boldsymbol{B}_1 + \boldsymbol{B}_2 + \boldsymbol{B}_3,$$

where $\boldsymbol{B}_1$ is an intensity vector of geomagnetic field of intraterrestrial sources; $\boldsymbol{B}_2$ is a regular component of intensity vector of geomagnetic field of magnetosphere currents, which is calculated in solar-magnetosphere coordinate system; $\boldsymbol{B}_3$ is a geomagnetic field intensity vector component with technogenic origin.

Normal (undisturbed) geomagnetic field is supposed as a value of $\boldsymbol{B}_1$ vector with excluding a component, which is caused by rocks magnetic properties (including magnetic anomalies). So this component is excluded as a geomagnetic variation:

$$\boldsymbol{B}_0 = \boldsymbol{B}_1 - \Delta\boldsymbol{B}'_1,$$

where $\boldsymbol{B}_0$ is undisturbed geomagnetic field intensity in the point with spatiotemporal coordinates; $\Delta\boldsymbol{B}'_1$ is component of intraterrestrial sources geomagnetic field, which represents magnetic properties of the rocks.

Solving the problem of $\boldsymbol{B}_0$ parameters analytical estimation, it is helpful to represent the main field model by spherical harmonic series, depending on geographical coordinates.

The scalar potential of intraterrestrial sources geomagnetic field induction U [nT·km] in the point with spherical coordinates r, θ, λ is defined by the expression (1).

$$U = R_E \times \\ \times \sum_{n=1}^{N} \sum_{m=0}^{n} \left(g_n^m \cos(m\lambda) + h_n^m \sin(m\lambda) \right) \left(\frac{R_E}{r} \right)^{n+1} P_n^m \cos(\theta), \tag{1}$$

where r is a distance from the Earth's center to observation point (geocentric distance), [km]; λ is a longitude from Greenwich meridian, [degrees]; θ is a polar angle (colatitude, θ = (π/2)−φ′, [degrees], where φ′ is a latitude in spherical coordinates, [degrees]); R_E is an average radius of the Earth, R_E = 6371.03, [km]; $g_m^n(t)$, $h_m^n(t)$ are spherical harmonic coefficients, [nT], which depend on time; p_m^n are Schmidt normalized associated Legendre functions of degree n and order m.

In specialized literature the expression (1) is widely known as a Gaussian and generally recognized as an international standard for undisturbed state of geomagnetic field.

The amount of performed spherical harmonic analysis is significant. However a problem of spherical harmonic optimal length of still acute.

Thus, the analyses with great amount of elements prove Gauss's hypothesis about convergence of spherical harmonic, which represents a geomagnetic potential. As usual in spherical harmonic analyses the harmonics are limited by 8–10 elements. But for sufficiently homogeneous and highly accurate data (for example, as like as in satellite imaging) the harmonics series can be extended up to 12 and 13 harmonics. Coefficients of harmonics with higher orders by their values are compared with or less than error of coefficients definition.

Due to the main field temporal variations the coefficients of harmonic series (spherical harmonic coefficients) are periodically (once in 5 years) recalculated with the new experimental data.

The main field changes for one year (or secular variation) are also represented by spherical harmonics series, which are available at http://www.ngdc.noaa.gov/IAGA/vmod/igrf11coeffs.txt.

Schmidt normalized associated Legendre functions p_m^n from expression (1) in general can be defined as an orthogonal polynomial, which is represented as follows (2).

$$\begin{aligned} P_n^m(\cos(\theta)) &= 1\cdot 3\cdot 5\ldots\sqrt{\frac{\varepsilon_m}{(n+m)!(n-m)!}}\times \\ &\times \sin^m\theta[\cos^{n-m}\theta - \frac{(n-m)(n-m-1)}{2(2n-1)}\cos^{n-m-2} + \\ &+ \frac{(n-m)(n-m-1)(n-m-2)(n-m-3)}{2\cdot 4(2n-1)(2n-3)}\cos^{n-m-4}\theta - \ldots], \end{aligned} \tag{2}$$

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

4 Geomagnetic Pseudostorm Effect

Here it is supposed to enter the term geomagnetic pseudostorm, which is intended to represent real geomagnetic field influence on the object in conditions of its non-zero speed and undisturbed geomagnetic field anisotropy [6]. Let us describe some main parameters of geomagnetic pseudostorm effect [6].

Range of geomagnetic pseudostorm is a difference between maximal and minimal values of geomagnetic field induction in area of the object, which is moving in anisotropic magnetic field during the time period or at the distance:

$$\boldsymbol{B}_{\mathrm{GMPS}} = \boldsymbol{B}_{0\ \max} - \boldsymbol{B}_{0\ \min},$$

where $\boldsymbol{B}_{0\ \max}$ and $\boldsymbol{B}_{0\ \min}$ are maximal and minimal values of geomagnetic field induction, [nT] in area of the object, which is moving in anisotropic magnetic field.

Frequency spectrum of geomagnetic pseudostorm is a function of distribution of geomagnetic pseudostorm amplitude spectrum in frequency area for continuous and discrete variants, which is defined by the following expressions:

$$B^*(f) = \int_{-\infty}^{+\infty} B_0(t) e i^{-2\pi f t} dt \text{ or } B^*(f) = \frac{1}{M} \sum_{t=0}^{M-1} B_0(t) e^{\frac{-2\pi f t}{M}},$$

where B^* is a frequency spectrum of geomagnetic pseudostorm; $\boldsymbol{B_0}$ is a value of geomagnetic field induction in the point with spatiotemporal coordinates; M is a quantity of registered values with constant discretization step by time.

Constant component of geomagnetic pseudostorm is a vector of harmonics superposition vertical shift, which represent frequency spectrum of geomagnetic pseudostorm:

$$B_{//} = \frac{1}{M} \sum_{t=0}^{M-1} B_0(t),$$

where M is a quantity of registered values with the discretization step.

Intensity of geomagnetic pseudostorm is a physical quantity, which is numerically equal to the speed of undisturbed geomagnetic field characteristic change in time relatively to the frame of reference, which is connected to the moving object and depends on the object speed:

$$I_{\mathrm{GMPS}} = \frac{\partial B_0}{\partial t},$$

where $\boldsymbol{I}_{\mathrm{GMPS}}$ is GMPS intensity, [nT/s];

Potentiality of geomagnetic pseudostorm (geomagnetic induction gradient) is a vector, which is oriented in three-dimensional space and points to the direction of the fastest increase of undisturbed geomagnetic field induction absolute value. The vector by its absolute value is equal to the increase speed of $\boldsymbol{B_0}$ in the geographical direction, [nT/rad; nT/rad; nT/km] and depends on the object position.

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

where $\boldsymbol{B_0}$ is an induction (intensity) of geomagnetic field in the point with spatiotemporal coordinates:

$$B_0^2(\theta, \lambda, r)[\mathrm{nT}] = \left[\frac{1}{r}\frac{\partial U}{\partial \theta}\cos(\varphi - \phi') - \frac{\partial U}{\partial r}\sin(\varphi - \phi')\right]^2 + \\ + \left[-\frac{1}{r \cdot \sin\theta}\frac{\partial U}{\partial \theta}\right]^2 + \left[-\frac{\partial U}{\partial r}\cos(\varphi - \phi') - \frac{1}{r}\frac{\partial U}{\partial \theta}\sin(\varphi - \phi')\right]^2.$$

So the analysis of geomagnetic field induction gradient distribution allows defining an area of possible maximal intensity of geomagnetic pseudostorm of in the geographical region. So, the parameter G_B must be taken into account in developing aerospace navigation maps and flight paths [6].

Next to study the geomagnetic pseudostorm effect there is an example of the flight route AA-973 of «American Airlines» from New York (JFK) to Rio de Janeiro (RIO). The flight path is represented as an array of spatial coordinates, which describe the airplane position, taken during flight in equal time intervals. The array allows calculating geomagnetic field parameters for each set of spatial coordinates.

The results of amplitude and frequency analysis of flight data and parameters of geomagnetic field are represented on Fig. 2. Here are some special points (Fig. 2(a)):

- t_1–t_2 – takeoff time;
- t_2–t_4 – flight on cruise speed at the altitude of 11033 m;
- t_4–t_5 – landing time;
- t_3 – passing the equator.

5 G-Service to Explore Geomagnetic Field

To take all advantages and recover all disadvantages of existing projects for exploring geomagnetic field the authors have suggested and developed special web-service, which is based on a set of mathematical models, defined at previous sections.

The service is called GIMS Calculator (or G-Service) and provides a set of instrumental tools to calculate parameters of normal geomagnetic field in the user-defined point [6]. The service is available at URL: http://www.geomagnet.ru.

On the logical and programming levels the web application is a set of complex procedures, which provide the realization of geospatial data visualization and analysis of geomagnetic field parameters in the point with spatiotemporal coordinates.

With the lower abstraction the web application is a special class of web page, which is developed according to three-tier client-server architecture. The visible and adapted to the user (after rendering) markup of the page is realized via W3C-standardized markup language HTML (specifically, its XML-type modification XHTML) [6].

The page design is performed in traditional table style: each region of the page is the table cell of various levels. However, the table-like layout of the page is not the only design solution here: there is also block-type layout via HTML-elements div, which logically structure the page by its semantics. For example, one block HTML-element stands for the region with map [7], another – for the region with spatiotemporal coordinates of the point, and the last – for the region with geomagnetic field parameters calculation results.

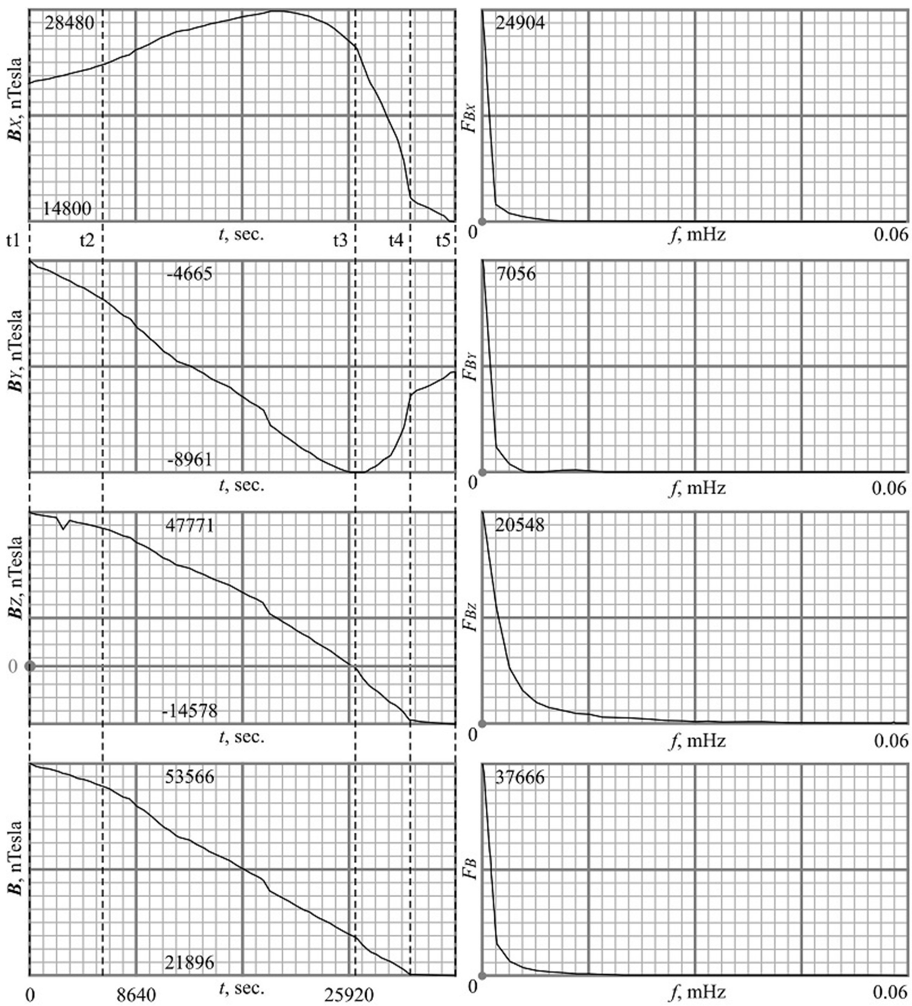

Fig. 2. Experimental data analysis results.

The great feature of the service is its integration with a map: parameters of the point and the map are placed on the one screen. User can enter coordinates into input fields or pick up a point directly on map.

User window of service “GIMS-calculator” is logically divided into two functional areas (panels). Left panel (Fig. 3) is supposed for loading and rendering the Earth’s surface maps fragments in either scheme or photo. Right panel is supposed for representing the input parameters/initial conditions, calculation results and “GIMS-calculator” functionality control. (The initial conditions are defined as spatiotemporal default coordinates: 54.7249° N, 55.9425° E, 0.172 km amsl) [6].

Calculation of parameters of geomagnetic field is based on spatiotemporal coordinates of the point on the Earth's surface. To define a point a user can apply one of the following approaches:

- Geolocation. It is the simplest way to define the current geographical position of the user. Geospatial coordinates of user location are defined by IP address of device, which is used for accessing the Internet. This possibility allows the user to get the point without its searching on the map or filling the appropriate input fields. This feature increases its efficiency and speed of the research.
- Pick up a point on the map. By the map rendered in service window a user can choose any point he is interested in. A user can move through the map (using keyboard or mouse) and click at the point. All necessary spatiotemporal parameters of the point are calculated automatically and immediately displayed on screen.
- Enter coordinates. It is a good way to calculate parameters of geomagnetic field and see the point on map with high accuracy (up to a few meters). A user enters the coordinates into the input fields, provided by the service. After that the service displays the point on the map and the parameters of normal geomagnetic field there.
- Enter address. It is a function often referred to as geocoding. To find the point a user enters address of the place he is interested in. The address can be represented at any level (city name, address with city and street names, full address including building number, etc.). Also the address is represented in special information window, which is connected with the point on the map. The solution of this task is based on special Google API geocoding service (exactly by its realization – reverse geocoding). Geocoding is a transformation from address full form "postal code, country, city, street, building number" or short form into the coordinates set "north latitude, east longitude". Reverse geocoding provides address description by the coordinates.

A geocoding service is also an asynchronous function: it supposes status check, callback function and array of results. Geocoding realization in API is based on the object google.maps.Geocoder. The resulting array contains multiple representation of address (because of reversal geocoding) with various detailing levels. First element of the array (with index equal to 0) is the most detailed address, which is used to be represented in information window.

User-defined spatiotemporal coordinates put the center of the map visible fragment relatively to the geographical point, which is defined by them. The point is outlined by the marker with geolocation results.

An important feature of "GIMS-calculator" is data representation in one of the two formats: DD (decimal degrees) and DMS (degrees – minutes – seconds). Depending on the chosen format a user gets the appropriate input mask. Also the application supposes the automatic transformation of coordinate systems via checking the appropriate radio button.

The altitude of the point is also calculated automatically (but it can be corrected by a user) on the basis of latitude and longitude input values. An altitude value is represented in International System of Units or Imperial and US customary measurement systems.

As in previous case, the direct and indirect transformations are available. To calculate an altitude (or elevation) of the point the system uses special Google API service

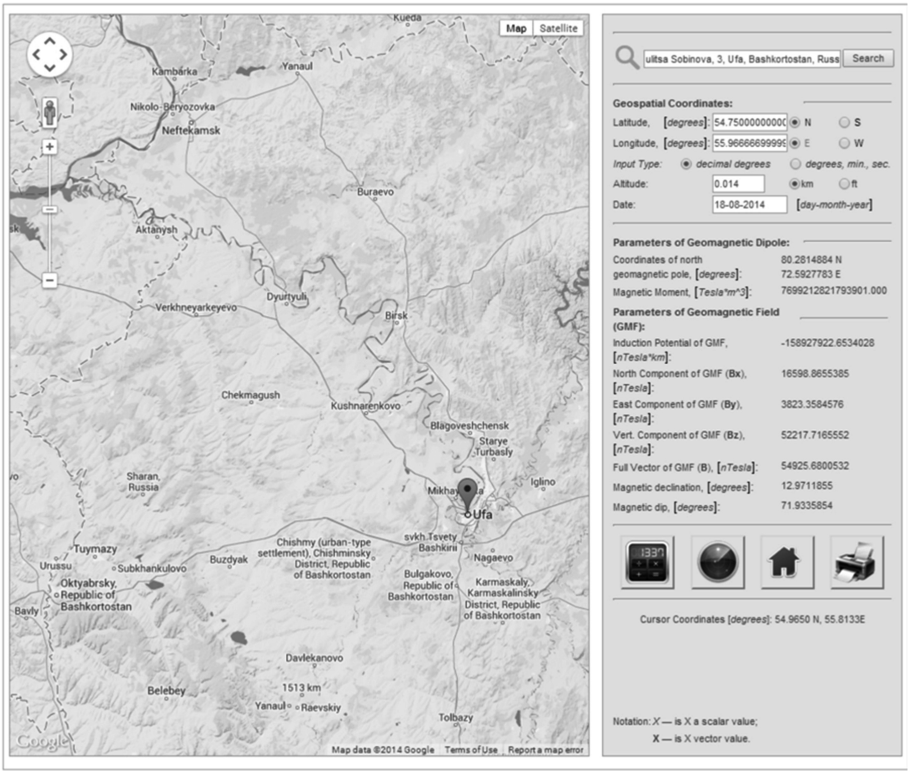

Fig. 3. "GIMS-calculator" user interface.

"ElevationService". It is an object with an asynchronous interaction: after sending a request to the server a user (or a web page) does not wait for its response and keeps performing all existing operations (or start new ones) in background mode. The system also takes into account the metric system and represents the results in the appropriate form.

After picking the point a user can calculate parameters of geomagnetic field there. By default the "GIMS-calculator" represents parameters of geomagnetic field in international system of units. So this data can be analyzed without any preliminary calculations.

The main parameters of geomagnetic field to be calculated are the following:

- north component of geomagnetic field induction vector;
- vertical component of geomagnetic field induction vector;
- magnetic declination and dip;
- scalar potential of geomagnetic field induction vector.

It is important to mention, that the "GIMS-calculator" calculates the parameters of geomagnetic field and its variations depending on the date, which user enters as an input parameter. By default this parameter is set to current date, but a user can change it to any other.

To calculate the parameters of geomagnetic field and its variations the system actualizes matrices of spherical harmonic coefficients. It calculates the current epoch and the difference between the result value and the moment for geomagnetic field analysis. And the resulting difference is a normalization multiplier for the harmonic coefficients matrices.

To visualize the results of calculation the system provides a set of contours, where each contour is a curve along which the parameter of geomagnetic field has a constant value. A user chooses a parameter to be visualized and the system renders on the map a set of contours, which represent a distribution of magnetic field on the Earth's surface (Fig. 4).

It is important to mention that "GIMS Calculator" is based on the authors-suggested algorithm of calculation of parameters of geomagnetic field. The algorithm supposes special scheme to minimize the possible error because of the rounding. The error of the calculation is less than 2 %.

Also to extend the functionality of the developed Web GIS "GIMS-calculator" there were programmed an option of generating electronic report about the research results with file or printer form and a possibility of three-dimensional modeling.

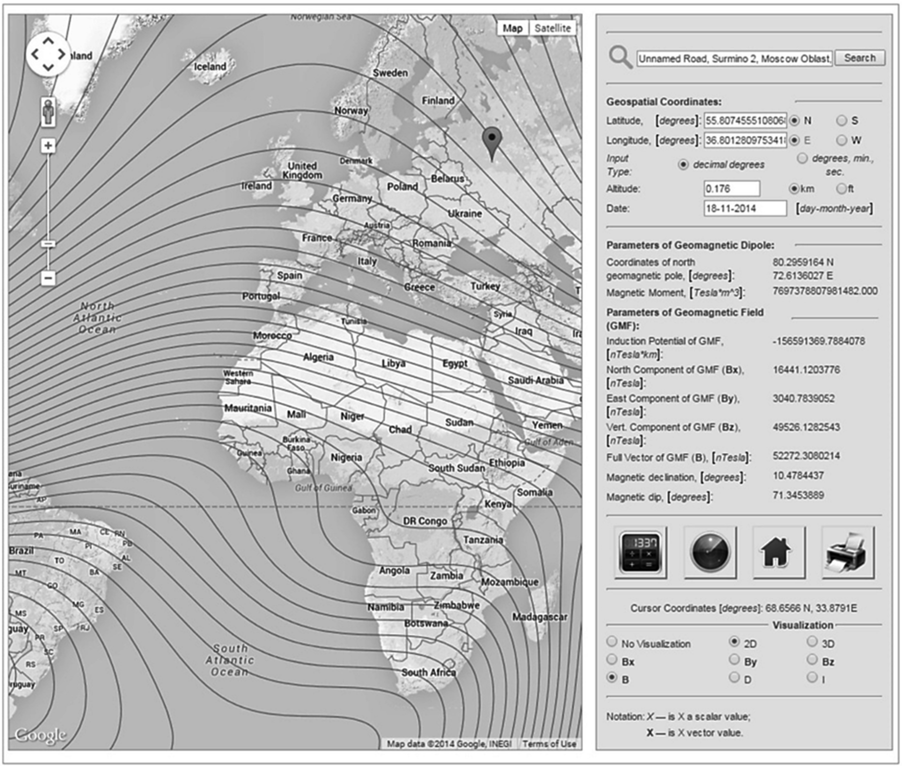

Fig. 4. Contours in "GIMS-calculator".

6 Three-Dimensional Visualization of Geomagnetic Field

An effective solution for complicated problem of modeling and visualization of geomagnetic field and its variations parameters is a key to understand the principles of geomagnetic field parameters distribution on the Earth's surface, its subsoil and in circumterrestrial space.

Three-dimensional representation of calculation of parameters of GMF and its variations is one of the main aspects in solution of visualization problems of both geospatial data and parameters of geomagnetic field, its variations and anomalies. It is obvious, that in this case geoinformation system provides much more information than any other system or technology. And it is even more important due to the dynamic properties and multilevel scale ability.

Today a problem of geographical and attributive spatial data three-dimensional visualization is usually solved via web applications of special type, which are known as virtual globes. It is important to mention, that virtual globes technology is based on the Earth's surface representation as a sphere with applied graphical layers.

Virtual globes integration with applications is provided by special API, which is a set of programming functions for creation, visualization and manipulation of three-dimensional spatial data.

Programming interface is used by an application as a set of local or remote functions. These functions can be used with the special possibilities of interpreter, which is already used or additionally loaded on user computer.

Usually three-dimensional geomodeling represents information on two levels: geographical and attributive. A geographical description of geospatial data supposes three-dimensional visualization of the Earth's surface with variable zoom and detail parameters. And the attributive component of the data is represented as a set of numerical values, which correspond to values of GMF parameters for spatial coordinates with an appropriate step.

To perform three-dimensional geomodeling the "GIMS-calculator" applies a technology of virtual globes or geobrowsers (Google Earth API). It is important to mention, that geobrowsers technology is based on the Earth's surface representation as a sphere with applied graphical layers (Fig. 5).

Three-dimensional geomodeling is provided by "GIMS-calculator" just similar to two-dimensional representation. A user chooses a parameter to be visualized, and the system renders data on the globe.

The "GIMS-calculator" defines layers to be represented on the globe in KML format. Keyhole Markup Language is one of the most popular formats of geodata representation, which is supposed as XML-oriented description of three-dimensional model of the Earth surface and the objects on it. The description on KML is a set of geographical and attributive data.

Each KML layer in necessity can be overlaid on any other layer (for example, data about seismic, volcanic activities, medical statistics, geological maps, etc.). It provides an effective tool for complex analysis of various parameters, correlation and principles definition. Numerical value of the parameter (physical value), which is distributed along the one contour, is available via picking the appropriate line with mouse cursor.

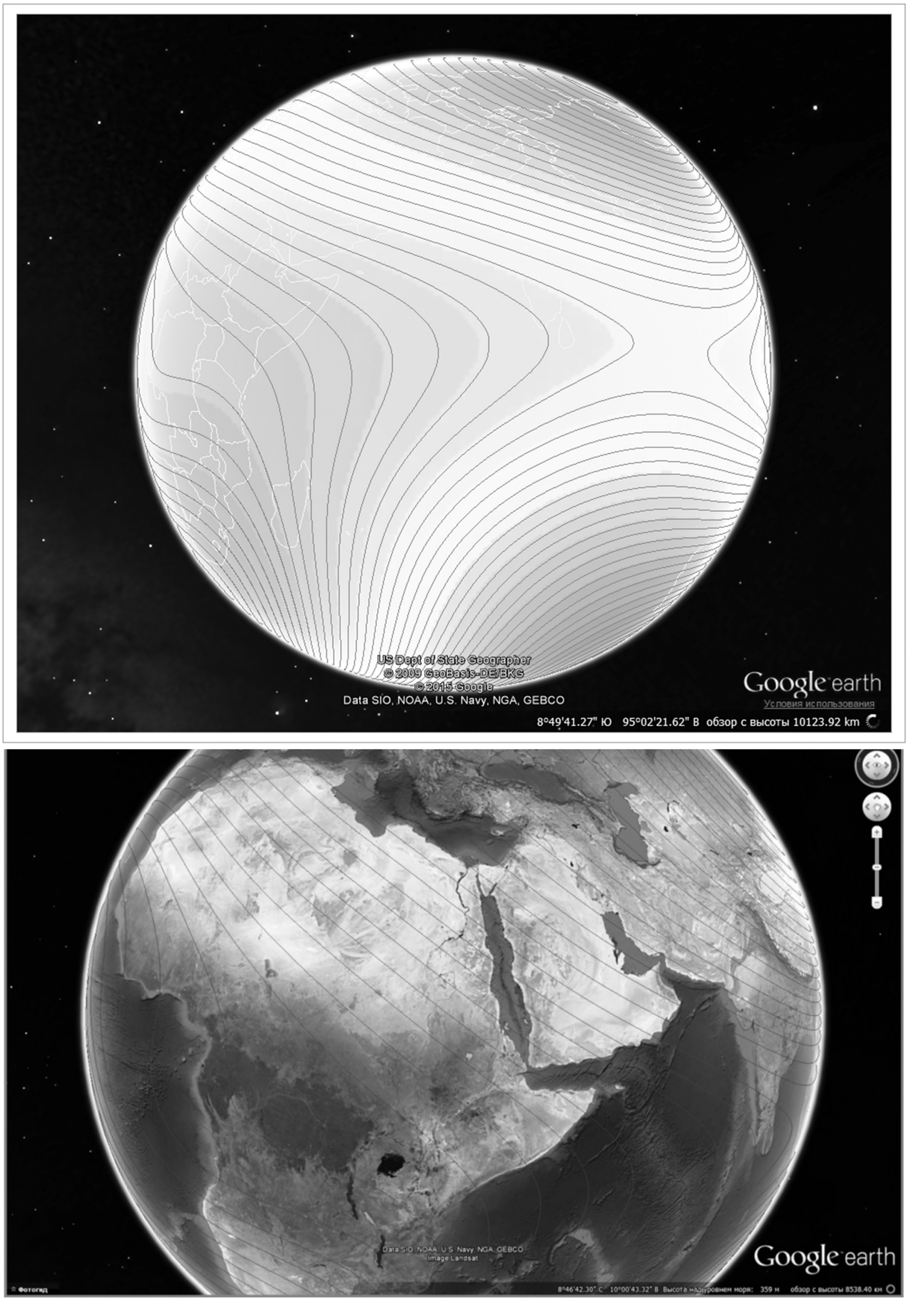

Fig. 5. Three-dimensional geomodeling in "GIMS-calculator".

Various methods of visual data representation (color outlining, gradient, etc.) significantly increase the model informativeness. Active layers (country borders, cities, rivers, etc.) managing keeps the key points of the model with decreasing the probability of possible error.

7 Conclusion

- Geomagnetic field is a complex structured natural matter with ambiguous field characteristics, which is distributed in the Earth (and near-Earth) space and interacts with both astronomical objects and objects/processes on the Earth's surface, subsoil and in near-Earth space. Geomagnetic field and its variation can influence on systems and objects of various origins. The estimation of the influence requires an effective approach to analyze the principles of distribution of geomagnetic field parameters on the Earth's surface, its subsoil and in circumterrestrial space. The approach causes a complicated problem to be solved, which is concerned with modeling and visualization of geomagnetic field and its variations parameters. The most effective and obvious solution to this problem is supposed to be a geoinformation system.
- Web-based geoinformation system "GIMS-Calculator" provides the complex calculation, analysis and 2D/3D-visualization of geomagnetic field and its variations parameters. Geomagnetic field and its variations models, which are represented and described by "GIMS-Calculator", meet the requirements of specialists in various areas. They effectively provide formatting and structuring the data about the Earth magnetosphere parameters and their further analysis.

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References

1. Campbell, W.H.: Introduction to Geomagnetic Fields, 2nd edn. Cambridge University Press, Cambridge (2003)
2. Mandea, M., Korte, M.: Geomagnetic observations and models. IAGA Special Sopron Series, vol. 5. Springer, Heidelberg (2011)
3. Merrill, R.T., McElhinny, M.W., McFadden, P.L.: The Magnetic Field of the Earth. Academic Press, Cambridge (1996)
4. Chizhevskii, A.L.: Earth Echo of Sun Storms. Mysl, Moscow (1976). (in Russian)
5. Vernadsky, V.I.: The Biosphere and the Noosphere. Iris Press, Moscow (2004). (in Russian)
6. Vorobev, A.V., Shakirova, G.R.: Pseudostorm effect: computer modelling, calculation and experiment analyzes. In: Proceedings of the 14th SGEM GeoConference on Informatics, Geoinformatics and Remote Sensing, vol. 1, pp. 745–751 (2014)
7. Haklay, M., Singleton, A., Parker, C.: Web mapping 2.0: the neogeography of the geo web. Geogr. Compass **2**, 2011–2039 (2008)

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