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THE METHODS FOR CALCULATION OF DECLINATION (D) FOR SPACED OF MAGNETIC OBSERVATORIES

Abstract. Calculations of the base values of the geomagnetic declination from the experimental data and from the data computed from various modern geomagnetic field models for spaced of geomagnetic observatories are presented: «Almatinskaya» (AAA) [43.25° N; 76.92° E] Institute of the Ionosphere, Almaty, Kazakhstan; «Kluchi» (NVS) of the Russian Academy of Sciences, Novosibirsk, Russia [54.85° N; 83.23° E]; «Irkutsk» (IRT) of the Institute of Solar-Terrestrial Physics of, Irkutsk, Russia [52.17° N, 104.45° E]. The characteristics of the results of the study of the time course and the spatial distribution of the values of the geomagnetic declination are given. The estimation of accuracy of calculation of geomagnetic declination by modern models of a geomagnetic field is presented. It is shown that the values of geomagnetic declination for spaced of geomagnetic observatories AAA, NVS, IRT from observed observational data change their values by years, so for AAA and NVS there is an increase, and for IRT the decrease in the values of geomagnetic declination. For NVS and AAA, geomagnetic declination moves eastward, and for IRT in the west. It is shown that the performed calculations of geomagnetic declination for two models International Geomagnetic Reference Field and World Magnetic Model for the coordinates AAA, NVS and IRT agree well with each other over the years, with small differences in seconds; the geomagnetic declination values for AAA increase in years with a gradient of about 0.6 min/year, for NVS decrease with a gradient of about 1.6 min/year, for IRT decrease with a gradient of about -4.5 min/year; model-calculated geomagnetic declination for AAA and NVS have an eastern direction, and for IRT, the western direction.

Key words: declination, the experimental data, magnetic observatory, world magnetic models.

1. Introduction. The geomagnetic declination is of fundamental economic technical and practical importance which defines great interest to this element of the geomagnetic field in many sectors of the national economy and in science. The geomagnetic declination D is designed to orientate the movement of objects in space and used to solve various scientific and production problems, e.g. during construction of nuclear and hydraulic power plants, power lines, undergrounds, for preparation of air navigation charts. The magnetic declination changes with time and in space, of which account must be taken during accurate determination of magnetic azimuths of headings. To obtain reliable information about the declination D for any area it is necessary to have the data on declination at several ground points (stations) [1,2]. The best option is to resume an observation program at the secular variation points (SVP) within the Republic of Kazakhstan. But because the resumption of the SVP involves some difficulties, calculations of D using the geomagnetic field models can be used, e.g., IGRF (International Geomagnetic Reference Field), and/or other more detailed models. To solve the problems of high-precision navigation of a moving object it is necessary to know two types of initial data at each trajectory point: 1) position of an object (current coordinates); 2) direction of movement. The first type of data, current coordinates of an object, is provided using the satellite navigation system. The second type of data, direction of movement, is usually determined based on measurement of azimuth with respect to position of the north geomagnetic pole. The coordinates of geomagnetic pole do not remain constant – they drift over time, hence, an error is introduced into the azimuth value. Position of the north magnetic pole (NMP) according to Olsen model CHAOS (A Model of Earth's Magnetic Field derived from CHAMP), confirmed by ground surveys is shown in figure 1 [3]. Forecast of the NMP position for the next few years is made based on the assumption that the average speed and direction of the NMP movement did *not change after 2007.* Direction of geomagnetic pole relative to geographic one at each point of the Earth is determined by the value of the geomagnetic field declination, and this value is measured in geomagnetic observatories with high precision by state-of-the-art magnetometers. Multi-year measurements of declination D, which are conducted by magnetic observatories, show that the magnetic declination varies over time. For example, in the observatory of Pleschenitsy (Belarus) the declination increased from D = 5° 02.7' to D = 7° 07.7' (1960÷2006); in the observatory of Belsk (Poland) the declination increased from D = 2° 04.2' to D = 4° 37.7' (1996÷2005); in Irkutsk (Russia) the declination from the east in 1887 D = +2° 24' crossed a zero value in 1934 moved westward in 2001 D = -2° 24' [1].

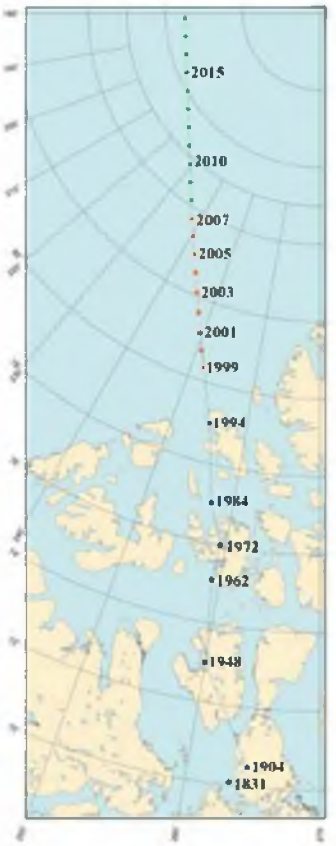

Figure 1 – The NMP position according to direct measurements (blue circles), data computed from the geomagnetic field model CHAOS (red cubes), forecasted position (green cubes) for the next few years [3]

Accordingly, account is taken of the changes in the magnetic declinations during precision navigation to reduce errors during determination of azimuth. All modern navigation charts contain information on the amount of declination of the geomagnetic field. Due to the geomagnetic pole drift these charts should be updated. In addition, for precision navigation of aircrafts, the leading international airports regularly take measurements of the geomagnetic field declination. When it is impossible to obtain reliable information on declination D for any area under field conditions, computation of the geomagnetic declination from geomagnetic field models can be used. The geomagnetic field models make it possible to calculate magnetic field of the Earth and its components in certain coordinates in view of various sources of the field [4-14]. There are several such models, let us provide the most well-known ones of these: International Geomagnetic Reference Field (IGRF) http://www.ngdc.noaa.gov/IAGA/. IGRF model represents the main field without external sources. Coefficients used in IGRF models are based on various data, such as: geomagnetic measurements taken by observatories; aerial photography data [9-12]; World Magnetic Model (WMM) http://www.geomag.bgs.ac.uk. The WMM is the standard model used by the U.S. Department of Defense, the U.K. Ministry of Defence, the North Atlantic Treaty Organization

(NATO) and the International Hydrographic Organization (IHO) when solving scientific-production problems [13,14]. The goal of this work is to describe the methods for calculation of geomagnetic declination (D) for spaced of magnetic observatories.

2. Calculations of declination D base values based on experimental data obtained at spaced geomagnetic observatories

Magnetic observatories provide information about the geomagnetic field using the data of variation stations, the sensors of which are relative instruments with rather narrow measuring range. Absolute values of variations are occasionally determined by carrying out the fundamental observations through which reveal the base values in nT of zero stresses in the measuring channels of digital stations [15-21]. For example, the adopted values in the observatory of Irkutsk are the intervals of constant base values with jerks between these intervals. In the observatory of Novosibirsk, the observable data are approximated by smoothing spline (between jerks). In the geomagnetic observatory "Almatinskaya", obtaining of "adopted" base values is the approximation of initial data by some function that most optimally reflects the behavior of the base lines. The parametric approximation is used, the function type is determined in advance, the objective is to select the optimum coefficients. Base values are computed using the following equations: X=FcosIcosD, Y=FcosIsinD, Z=FsinI,

where X – northern component, Y – eastern component, Z – vertical component, F – total field intensit (vector field amplitude), I – inclination (the angle between the field vector and the horizontal plane measured downwards from horizontal axis). Calculations based on the results of observations in observatories also consist of calculation of the average angles and determination of the declination in angular minutes using the equation:

$$D_i = \text{atan}\left(\frac{Yi}{Xi}\right),$$

where D – declination of the geomagnetic field (the angle of the horizontal component the field from true north, measured clockwise).

To obtain actual values of declination D three spaced geomagnetic observatories, IMOs members – "Almatinskaya" geomagnetic observatory [43.25°N; 76.92°E] of the Institute of Ionosphere, Almaty, RK; "Kluchi" geophysical observatory of the Russian Academy of Sciences (RAS), Novosibirsk, RF [54.85°N; 83.23°E]; "Irkutsk" geomagnetic observatory of the Institute of Solar-Terrestrial Physics of the RAS, Irkutsk, RF [52.17°N, 104.45°E].

In "Almatinskaya" geomagnetic observatory (IAGA code AAA), observations of declination D are made by Lemi-203 ferrobprobe declinometer based on 3T2KP theodolite. To obtain absolute values of the geomagnetic field from variation data it is required to add the values of basic levels of variometers to variations. At Novosibirsk complex magnetic ionospheric station ("Kluchi" geophysical observatory) (IAGA code NVS), declination D observations are conducted by ferroprobe (declinometers-inclinometers) magnetometers based on non-magnetic Theo020B and 3T2KP theodolites. The observational technique for declination D is standard. Elements used in computation of the average annual values of declination D for geophysical observatory NVS are components X, Y, Z of the geomagnetic field. In "Irkutsk" geomagnetic observatory (IAGA code IRT), observations of declination D are made by THEO-010A and Lemi-203 ferroprobe declinometers/inclinometers. Elements used in computation of the average annual values of declination D for IRT are H, D, Z (H-horizontal component; D-declination; Z-vertical component of the geomagnetic field). Actual values of D obtained using the data of geomagnetic observatories AAA, NVS, IRT for the period of 2005-2017 are shown in table 1.

Thus, the actual values of geomagnetic declination D for spaced geomagnetic observatories "Almatinskaya", "Kluchi", "Irkutsk" for the period 2005-2017 were found as a result of calculations. Let us note that the obtained values of declination D for NVS and AA are positive, and values of declination D for IRT are negative. This suggests that declinations D for Novosibirsk and Almaty move eastward and declinations D for Irkutsk move westward. The declination calculation results based on observatories' observed data show changes in values D by years, thus, there was an increase in values D for AAA and NVS and decrease for IRT.

Table 1 – Average annual values of geomagnetic declination D obtained from experimental data at geomagnetic observatories AAA, NVS, IRT

Year	AAA The Republic of Kazakhstan (43.25°N;76.92°E)		NVS Russia (54.85°N;83.23°E)		IRT Russia (52.17°N;104.45°E)	
	D deg min	Elements	D deg min	Elements	D deg min	Elements
2005	4 46.6	XYZ	8 26.5	XYZ	-2 48.7	DHZ
2006	4 47.5	XYZ	8 23.9	XYZ	-2 53.4	DHZ
2007	4 47.8	XYZ	8 22.2	XYZ	-2 57.5	DHZ
2008	4 49.2	XYZ	8 20.6	XYZ	-3 02.0	DHZ
2009	4 51.2	XYZ	8 18.9	XYZ	-3 06.6	DHZ
2010	4 52.6	XYZ	8 17.7	XYZ	-3 11.4	DHZ
2011	4 52.9	XYZ	8 16.2	XYZ	-3 15.6	DHZ
2012	4 57.0	XYZ	8 16.2	XYZ	-3 16.8	DHZ
2013	5 0.0	XYZ	8 16.2	XYZ	-3 25.2	DHZ
2014	5 3.6	XYZ	8 16.2	XYZ	-3 28.8	DHZ
2015	5 5.4	XYZ	8 16.2	XYZ	-3 32.4	DHZ
2016	5 7.2	XYZ	8 15.0	XYZ	-3 39.0	DHZ
2017	5 9.0	XYZ	8 13.8	XYZ	-3 47.4	DHZ

3. Calculations of declination D from the modern models of the geomagnetic field for spaced geomagnetic observatories

It is known that the general geomagnetic field is composed of several magnetic fields generated by various sources. These are the main field which is formed by the sources in the Earth's liquid outer core, it changes very slowly; the field of magnetic anomalies of the Earth's crust, the changes are very slow; the external fields caused by currents in the ionosphere and magnetic sphere of the Earth, the changes are very rapid; the field of electric currents in the Earth's crust and Earth's external mantle, currents are formed during changes in the external fields, the changes are rapid; ocean currents also have their effect. The modern models of the magnetic field make it possible to calculate slow (secular) variations without regard for very rapid changes caused by solar activity. The modern models also do not take into account the magnetic anomalies. But because the magnetic anomalies are few, and the majority of the main components of the geomagnetic field are subject to slow (secular) variations, the accuracy of geomagnetic parameters computed from models is quite high. Thus, accuracy in computations of the geomagnetic declination obtained by IGRF and WMM models is about 0.5° (30') [17, 19]. In view of the foregoing, two models of the geomagnetic field were picked to calculate the declination D for spaced geomagnetic observatories. The average annual values of declination D for geomagnetic observatory AAA [43.25°N; 76.92°E], geophysical observatory NVS [54.85°N; 83.23°E] and geomagnetic observatory IRT [52.17°N; 104.45°E] were computed with IGRF and WMM models for the period of 2005-2017.

Table 2 shows the values of declination D for geomagnetic observatories AAA, NVS, IRT received from computations using two models IGRF and WMM for the period of 2005-2017. Both models showed that D for AAA increase with a gradient of about 0.6 min/year, positive values of D point to eastward declination for calculation site coordinates. The values of magnetic declinations for NVS observatory decrease with a gradient of about 1.6 min/year, positive values of declination D point to eastward declinations for calculation site coordinates. The values of geomagnetic declinations for IRT reduce with a gradient of about -4.5 min/year, the negative values of D point to westward declination for calculation site coordinates.

Thus, the average annual values of geomagnetic declinations D (2005-2017) for coordinates of AAA, NVS and IRT observatories computed with two models (IGRF and WMM) correlate well with each other by years, with minor variances in seconds. Model calculations also showed that the average annual values of geomagnetic declinations D for geomagnetic observatory AAA increase by years with a gradient of about 0.6 min/year, for geomagnetic observatory NVS decrease with a gradient of about 1.6 min/year, for geomagnetic observatory IRT decrease with a gradient of about -4.5 min/year. The geomagnetic declinations for AAA and geomagnetic observatory NVS are eastern (positive) and geomagnetic declinations for IRT are western (negative).

Table 2 – Model calculated average annual values of D for geomagnetic observatories AAA, NVS, IRT for the period of 2005-2017

Year	AAA The Republic of Kazakhstan (43.25°N;76.92°E)		NVS Russia (54.85°N;83.23°E)		IRT Russia (52.17°N;104.45°E)	
	IGRF D deg min	WMM D deg min	IGRF D deg min	WMM D deg min	IGRF D deg min	WMM D deg min
2005	4 45.7	4 46.2	8 40.0	8 40.0	-2 54.3	-2 52.7
2006	4 46.3	4 46.9	8 38.3	8 38.3	-2 58.7	-2 57.0
2007	4 46.9	4 47.6	8 36.5	8 36.5	-3 03.2	-3 01.7
2008	4 47.6	4 48.2	8 34.7	8 34.8	-3 07.6	-3 06.2
2009	4 48.2	4 48.9	8 32.9	8 33.0	-3 12.1	-3 10.7
2010	4 48.9	4 49.7	8 31.2	8 31.3	-3 16.6	-3 15.2
2011	4 49.7	4 50.3	8 29.9	8 29.6	-3 20.6	-3 19.6
2012	4 53.5	4 54.9	8 30.9	8 30.5	-3 24.5	-3 23.6
2013	4 55.7	4 57.1	8 30.7	8 30.4	-3 28.3	-3 27.5
2014	4 57.8	5 0.2	8 30.5	8 30.2	-3 32.2	-3 35.9
2015	4 59.9	5 0.9	8 30.2	8 30.3	-3 36.1	-3 39.5
2016	5 2.4	5 3.5	8 30.7	8 30.6	-3 38.9	-3 42.9
2017	5 4.9	5 6.2	8 31.2	8 31.0	-3 41.6	-3 46.5

4. Comparative analysis of the results of D declination calculation based on experimental geomagnetic data and various modern models of the geomagnetic field

Experimentally calculated values of declination D show that the geomagnetic declination varies in space most strongly. Thus, values of declination D for various coordinates may differ relative to each other by 1.5-2 times. For example, for coordinates of "Almatinskaya" observatory D= 4°46.6', and for coordinates of "Kluchi" observatory D =8°26.5' (table 1). The values of geomagnetic declinations D found as a result of calculations using IGRF and WMM models (table 2) also show that D may vary significantly at spaced ground points.

The geomagnetic declination D also varies over time. Analysis of data received from observatories' observations showed that for the period of 2005-2017 the values of geomagnetic declinations D for geomagnetic observatory AAA increased from 4°46.6' in 2005 to 5°09.0' in 2017; for the same period the values D for NVS reduced from 8°26.5' to 8°13.8'; D for geomagnetic observatory IRT went down from -2°48.7' in 2005 to -3°47.4' in 2017 (table 1). According to the data obtained based on model calculations, the values of geomagnetic declinations D for geomagnetic observatory AAA increased by 4.0 min (IGRF) and 4.1 min (WMM) (table 2); for the same period D for geomagnetic observatory NVS reduced by 10.1 min (IGRF) and by 10.4 min (WMM) (table 2); D for IRT reduced by 26.3 min (IGRF) and by 26.9 min (WMM) (table 2). Let us note that the values of geomagnetic declinations D obtained as a result of computation from IGRF and WMM models correlate well with the data obtained by observatory's observations (table 1).

It is known that per each 1 km of the line length (topographic map) deviation of 1° gives 17.5m. Consequently, deviation of 0.2÷4.0 min gives 0.06÷1.16 m; 4.0÷6.0 min − 1.16÷1.75 m; 13.0÷15.0 min − 3.8÷4.4 m [1,2]. Thus, calculations of declinations D for spaced points using IGRF and WMM models result in insignificant variances of about 0.06÷4.4 m from actual observatory data. The geomagnetic declinations D obtained based on WMM model more accurately reflect the real picture of changes D, since model calculated declinations D are more close to the values calculated based on observatory's observations. The above given calculations of D confirm high accuracy of D calculation based on IGRF and WMM models. For example, accuracy of magnetic declinations received based on this model for coordinates of observatory AAA is up to 4 min (0.07°), for observatory NVS is up to 15 minutes (0.25°), for observatory IRT is up to 6 min (0.1°).

5. Conclusion. Thus, the average annual values of the geomagnetic declinations D were obtained for spaced geomagnetic observatories "Almatinskaya", "Kluchi", "Irkutsk" for the period of 2005-2017. The results of declination calculations based on observatories' observed data show changes in values D by years, and so, there was an increase for AAA and NVS and decrease of the values of the geomagnetic declination D for IRT. The geomagnetic declinations move eastward for NVS and AAA and westward for IRT. Performed calculations of the geomagnetic declinations D using two models IGRF and WMM for the period of 2005-2017 for coordinates AAA, NVS and IRT showed that the values D correlate well with each other by years, with minor variances in seconds; the values of the geomagnetic declinations for AAA increase by years with a gradient of about 0.6 min/year, for NVS decrease with a gradient of about 1.6 min/year, for IRT decrease with a gradient of about -4.5 min /year; model calculated geomagnetic declinations for AAA and NVS are directed eastward and for IRT are directed westward. Comparison analysis of experimental and model calculated values D showed that the values D for spaced objects obtained based on IGRF and WMM models correlate well with the values D calculated based on observatory's observations. Spatial and temporal heterogeneity of the geomagnetic declinations was confirmed. The values of the geomagnetic declinations D obtained based on experimental observatory data and computations from IGRF and WMM models show that D may vary considerably at spaced ground points by 1.5–2 times relative to each other. For example, for coordinates of "Almatinskaya" observatory D=4°46.6', and for coordinates of "Kluchi" observatory D = 8°26.5'. The geomagnetic declination D also varies with time. The values of magnetic declinations obtained from observatory observations show that for the period of 2005-2017 the values of the geomagnetic declinations D for AAA increased; for the same period for NVS and IRT reduced. According to the data received based on model calculations, the values of the geomagnetic declinations D for AAA increased by 4.0 min (IGRF) and by 4.1 (WMM); for the same period for NVS D went down by 10.1 (IGRF) and by 10.4 (WMM); for IRT D went down by 26.3 min (IGRF) and by 26.9 min (WMM). The WMM model of the magnetic field more accurately reflects the real picture of the changes in the geomagnetic declinations, since the values of the geomagnetic declinations D obtained from computations based on it are more close to actual observatory data. The values D obtained from computations based on IGRF also have minor discrepancies with the actual observatory values D. Data analysis showed that the accuracy of calculation based on IGRF and WMM models is very high, thus, the accuracy of the magnetic declination in these models for coordinates of observatory AAA is up to 4 min (0.07°), for observatory NVS is up to 15 min (0.25°), for observatory IRT is up to 6 min (0.1°). Hence, it might be advisable to use both models IGRF and WMM for calculations of D in any areas (except for abnormal ones), when it is impossible to measure declinations D with a site visit. However, it is worth noting that the models of the magnetic field reduce the accuracy of calculated geomagnetic parameters over the years (by the end of a time interval given in the models).

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КЕҢІСТІКТІК ТАРАТЫЛҒАН МАГНИТТІК ОБСЕРВАТОРИЯЛАР ҮШІН ГЕОМАГНИТТІ КЕМУДІ (D) ЕСЕПТЕУ ӘДІСТЕРІ

Аннотация. Геомагнитті ауытқудың экономикалық-техникалық және практикалық маңызы зор, бұл халық шаруашылығының көптеген салаларында және ғылымда геомагнитті өрістің осы элементіне үлкен қызығушылықты анықтайды. D геомагниттік төмендеу кеңістікте объектілердің қозғалысын бағдарлау үшін қызмет етеді және әртүрлі ғылыми және өндірістік міндеттерді шешу кезінде, мысалы, атом және гидроэлектростанцияларын, электр беру желілерін, метрополитендерді салу кезінде, аэронавигациялық карталарды жасау үшін пайдаланылады. Магниттік төмендеу уақыт ағымымен және кеңістікте өзгереді, бұл бағыттардың магниттік азимуттарын нақты анықтау кезінде ескеру қажет. D төмендеу туралы сенімді ақпарат алу үшін кез келген аумақ үшін бірнеше жер пункттерінде (нүктелерінде) төмен түсу жөніндегі деректер болуы қажет. Ең жақсы нұсқа-Қазақстан Республикасының аумағында ғасырлық жүріс пункттеріндегі бақылау бағдарламасын жаңарту. Бірақ ғасыр жүрісі пункттерін жаңарту белгілі бір қиындықтармен байланысты болғандықтан, геомагнитті өріс үлгілері бойынша D есептерін, мысалы Igrf (International Geomagnetic Reference Field) геомагнитті өріс халықаралық анықтамалық моделі және/немесе басқа да егжей-тегжейлі модельдер бойынша пайдалануға болады.

Қозғалыстағы объектінің жоғары дәлдіктегі навигация міндеттерін шешу үшін қозғалыс траекториясының әрбір нүктесінде бастапқы деректердің екі түрін білу қажет: 1) объектінің орналасқан жері

(ағымдағы координаттар); 2) қозғалыс бағыты. Деректердің бірінші Түрі, объектінің ағымдағы координаттары спутниктік навигациялық жүйелердің көмегімен қамтамасыз етіледі. Екінші деректер типі, қозғалыс бағыты, әдетте, солтүстік геомагниттік полюстің жағдайына қатысты азимутты өлшеу негізінде анықталады. Геомагнитті полюстің координаттары тұрақты болып қала бермейді-уақыт өте келе дрейфуют, тиісінше азимут көлеміне қате енгізіледі. Олсен CHAOS (CHAOS (A Model of Earth's Magnetic Field derived from CHAMP) моделіне сәйкес солтүстік магниттік полюстің орны.

Геомагнитті полюс бағыты жердің әрбір нүктесіндегі географиялық жағынан геомагнитті өрістің төмендеу шамасымен анықталады және бұл шама жоғары дәлдікпен геомагнитті обсерваторияларда қазіргі магнитометрлермен өлшенеді.

Осы жұмыстың мақсаты кеңістіктік-таратылған магниттік обсерваториялар үшін геомагнитті кемуді (D) есептеу әдісін сипаттау болып табылады.

Эксперименталды деректер бойынша және кеңістіктік-таратылған геомагнитті обсерваториялар үшін әртүрлі қазіргі заманғы модельдер бойынша есептелген геомагнитті өріс деректері бойынша геомагнитті ауытқудың базалық мәндерінің есептері ұсынылған: «Алматинская» (AAA) [43.25°N; 76.92°E] Ионосфера институты, Алматы қ., ҚР; Ресей Ғылым академиясының (РҒА) «Ключи» (NVS) геофизикалық обсерваториясы, Новосибирск қ., РФ [54.85°N; 83.23°E]; Күн-Жер физикасы институтының «Иркутск» (IRT), Иркутск қ., РФ [52.17°N, 104.45°E].

"Алматинская" геомагнитті обсерваториясында (IAGA коды AAA) 3Т2КП теодолит базасында Lemi-203 феррозонды деклинометрмен D қисаюын бақылауды жүргізеді. Новосибирск кешенді магнитті-ионосфералық станциясында ("Ключи" геофизикалық обсерваториясы) (IAGA коды NVS) D қисаюын бақылауды феррозонды (деклинометрлер-инклинометрлер) магнитті Theo020B және 3Т2КП теодолиттер базасында магнитометрлермен жүргізеді. Геомагнитті обсерваториясы "Иркутск" (IAGA коды IRT) жүргізеді және бақылау өзін D феррозондовыми деклинометрами/инклинометрами THEO-010A және Lemi-203. 2005-2017 жылдар аралығында AAA, NVS, IRT геомагнитті обсерваторияларының деректері бойынша алынған D нақты мәндері.

Геомагниттік ауытқу мәндерінің уақытша жүрісін және кеңістіктік таралуын зерттеу нәтижелеріне сипаттама берілді. Геомагнитті өрістің қазіргі заманғы модельдерімен геомагнитті ауытқуын есептеу дәлдігін бағалау ұсынылған. Бақыланған обсерваторлық деректер бойынша AAA, NVS, IRT кеңістіктік - таратылған геомагниттік обсерваториялар үшін геомагнитті ауытқулардың мәндері жылдар бойынша өз мәнін өзгертетіні көрсетілген, сондықтан AAA және NVS үшін ұлғаю, ал IRT үшін геомагнитті ауытқу мәндерінің азаюы орын алады. NFS және AAA үшін геомагниттік ауытқулар шығыс бағытта, ал IRT үшін батыс бағытта жылжиды. AAA, NVS және IRT координаттары үшін igrf және WMM екі үлгісі бойынша геомагнитті ауытқулардың орындалған есептері секундта аз айырмашылықтары бар жылдар бойынша өзара жақсы келіседі; AAA үшін геомагнитті ауытқулардың мәндері шамамен 0.6 мин/жыл градиентімен жылдар бойынша ұлғаяды, NVS үшін шамамен 1.6 мин/жыл градиентімен азаяды, IRT үшін ретті градиентпен азаяды-4.5 мин/жыл; AAA және IRT үшін модельді есептелген геомагнитті NVS шығыс бағыты бар, ал IRT батыс үшін.

Түйін сөздер: геомагнитті төмендеу, эксперименттік деректер, әлемдік магниттік модельдер.

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МЕТОДЫ РАСЧЕТА ГЕОМАГНИТНОГО СКЛОНЕНИЯ (D) ДЛЯ ПРОСТРАНСТВЕННО- РАЗНЕСЕННЫХ МАГНИТНЫХ ОБСЕРВАТОРИЙ

Аннотация. Геомагнитное склонение имеет важное экономико-техническое и практическое значение, что определяет большой интерес к этому элементу геомагнитного поля во многих отраслях народного хозяйства и в науке. Геомагнитное склонение D служит для ориентировки движения объектов в пространстве и используется при решении различных научных и производственных задач, например, при строительстве атомных и гидроэлектростанций, линий электропередач, метрополитенов, для составления аэронавигационных карт. Магнитное склонение изменяется с течением времени и в пространстве, что необходимо учитывать при точном определении магнитных азимутов направлений. Для получения достоверной информации о склонении D для любой территории необходимо иметь данные по склонению в нескольких пунктах (точках) местности. Лучший вариант – это возобновление на территории Республики Казахстан программы наблюдений на пунктах векового хода. Но так как возобновление пунктов векового хода связано с определенными трудностями, то можно использовать расчеты D по моделям геомагнитного

поля, например, Международная Справочная Модель Геомагнитного Поля IGRF (International Geomagnetic Reference Field) и/или другие более детальным моделям.

Для решения задач высокоточной навигации движущегося объекта необходимо знать в каждой точке траектории движения два типа исходных данных: 1) местоположение объекта (текущие координаты); 2) направление движения. Первый тип данных, текущие координаты объекта, обеспечивается с помощью спутниковых навигационных систем. Второй тип данных, направление движения, как правило, определяется на основе измерения азимута относительно положения северного геомагнитного полюса. Координаты геомагнитного полюса не остаются постоянными – дрейфуют со временем, соответственно вносится ошибка в величину азимута. Положение северного магнитного полюса, согласно модели Олсена CHAOS (A Model of Earth's Magnetic Field derived from CHAMP, подтвержденной наземными исследованиями.

Направление на геомагнитный полюс относительно географического в каждой точке Земли определяется величиной склонения геомагнитного поля, и эта величина с высокой точностью измеряется в геомагнитных обсерваториях современными магнитометрами.

Целью настоящей работы является описание метода расчета геомагнитного склонения (D) для пространственно-разнесенных магнитных обсерваторий.

Представлены расчеты базовых значений геомагнитного склонения по экспериментальным данным и по данным рассчитанным по различным современным моделям геомагнитного поля для пространственно-разнесенных геомагнитных обсерваторий: «Алматинская» (AAA) [43.25°N; 76.92°E] Институт ионосферы, г. Алматы, Республика Казахстан; геофизическая обсерватория «Ключи» (NVS) Российской академии наук, г. Новосибирск, Россия [54.85°N; 83.23°E]; геомагнитная обсерватория «Иркутск» (IRT) Института Солнечно-земной физики Российской академии наук, г. Иркутск, Россия [52.17°N, 104.45°E].

В геомагнитной обсерватории «Алматинская» (IAGA код AAA) проводят наблюдения склонения D феррозондовым деклинометром Lemi-203 на базе теодолита 3Т2КП. В Новосибирской комплексной магнитно-ионосферной станции (геофизическая обсерватория «Ключи») (IAGA код NVS) наблюдения склонения D проводят феррозондовыми (деклинометрами-инклинометрами) магнитометрами на базе немагнитных теодолитов Theo020B и 3Т2КП. В геомагнитной обсерватории «Иркутск» (IAGA код IRT) проводят наблюдения склонения D феррозондовыми деклинометрами/инклинометрами THEO-010A и Lemi-203. Реальные значения D, полученные по данным геомагнитных обсерваторий AAA, NVS, IRT за период 2005-2017 гг.

Дана характеристика результатам исследования временного хода и пространственного распределения значений геомагнитного склонения. Представлена оценка точности расчета геомагнитного склонения современными моделями геомагнитного поля. Показано, что значения геомагнитных склонений для пространственно- разнесенных геомагнитных обсерваторий AAA, NVS, IRT по наблюдаемым обсерваторским данным меняют свои значения по годам, так для AAA и NVS происходит увеличение, а для IRT уменьшение значений геомагнитного склонения. Для NVS и AAA геомагнитные склонения смещаются в восточном направлении, а для IRT в западном. Показано, что выполненные расчеты геомагнитных склонений по двум моделям (Международная Справочная Модель Геомагнитного Поля (IGRF) и Всемирная Модель Магнитного Поля (WMM)) для координат AAA, NVS и IRT, хорошо согласуются между собой по годам, имея небольшие различия в секундах; значения геомагнитных склонений для AAA увеличиваются по годам с градиентом порядка 0.6 мин/год, для NVS уменьшаются с градиентом порядка 1.6 мин/год, для IRT уменьшаются с градиентом порядка -4.5 мин/год; модельно рассчитанные геомагнитные склонения для AAA и NVS имеют восточное направление, а для IRT западное.

Ключевые слова: геомагнитное склонение, экспериментальные данные, мировые магнитные модели.

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