GEOMAGNETIC FIELD OF UKRAINE: ESTIMATION OF INTERNAL AND EXTERNAL SOURCES CONTRIBUTION

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ABSTRACT. This article is considering some aspects of differentiation between internal and external sources of the Earth's magnetic field; it estimates also the contribution of different sources into total field as well as its variations. The surveys results of ukrainian magnetic observatories were used to fulfil the task.

1. Introduction

Geomagnetic field of the Ukraine is the unique one compairing with the fields of Central and Western Europe countries. It is concerned the presence of high-intensive regional and local anomalies and important temporal variations of the field too.

As it is known the Earth's magnetic field is a fields total of numerous internal and external sources. It is important to estimate the contribution of one or another sources into total Earth's magnetic field to single out its component per se as a means of studying its nature, origination mechanism and so on. Specifically, to study the processes that are having place into the Earth's liquid core it is necessary to separate only the part of the field that is connected exactly with this object; to study lithspheric magnetization it is required to exclude the effects of the core field, of ionospheric and magnetospheric sources that is to subtract it from the measured field values. But the problem is that different sources anomalies are frequently overlapping by waves and intensity wide-ranging. Thus the magnetic field anomalies having thousands kilometres wavelengths may be connected with the Earth's core as well as with its lithosphere (even partially). Naturally it is more difficult to make out the nature of sources of the Earth's magnetic field variations: long-period as well as short-period ones. The variations of internal and external nature are often interdependent and mutually causal. Those are for instance geomagnetic variations induced into Earth's crust. It occurs due to the core field variation as well as due to ionospheric and magnetospheric field sources (Verbanac et al., 2007; Thebault et al., 2009; Orliuk et al., 2011). That is why in this article some aspects of differentiation between internal and external sources of the Earth's magnetic field are analysed; estimation of the contribution of different sources into total field as well as its variations are presented. The surveys results of ukrainian magnetic observatories were used uppermost to fulfill the task.

2. Magnetic field of the Earth

Space-temporal structure of the Earth's magnetic field B is defined by total of different sources fields:

$$B = Bn + Ba + Bв$$

where Bn is normal (main) Earth's; Ba is anomal magnetic field (lithospheric field); $Bв$ is external field. In whole for the planet magnetic field B is considerably changing above ground and in its near space (Orliuk & Romenets, 2011).

Data about magnetic field on the territory of the Ukraine are obtained as a result of different-scale mapping of magnetic field induction module or its vertical component. In conformity with created map, magnetic field induction module B on the territory of the Ukraine is varying from 48000 nTs to 57000 nTs (Fig. 1).

Measurements of magnetic induction B full vector, its northern component Bx, eastern one By and vertical one Bz are carrying out by geomagnetic observatories (GO). On the territory of the Ukraine there are three Gos: "Kyiv", "Lviv" and "Odesa" that are equipped by up-to-date instrumentation for precise measurement (see Fig. 1).

Total values of magnetic field components of internal and external sources are registered during observations surveys. According to surveys and calculations results the increment of full vector of magnetic field induction over the period of 1958-2008 is 1223 nT for GO "Kyiv", 1144 nT for GO "Odesa", 1323 nT for GO "Lviv". Average annual increment makes correspondingly 24.5 nT, 23.3 nT и 26.5 nT (Orliuk et al., 2011). On this background the anomalies of geomagnetic field increment are observed. They are represented in the figure 2.

Internal Earth's magnetic field is composed of main and anomal magnetic fields. Main geomagnetic field (core field) consists from dipole and non-dipole parts and is taking as a normal geomagnetic field of the Earth pertinence B_{IGRF}. As a rule it is seen as spheric harmonic series having certain quantity harmonics, usually 10-13 (Purucker, 2011). At this field an anomaly magnetic field is imposed that is conditioned by magnetic sources into Earth's crust as well as induced magnetic field that is due to the conductivity and permanent of lithospheres rocks. Normal field value B_{IGRF} was calculated by the model *IGRF 1945-2015 Model Coefficients 2015* (http://omniweb.gsfc.nasa).

After the observations results and its interpretation is defined that the most important changes take place into main (normal) magnetic field, the increment of it for the territory of the Ukraine makes about 1200 nT during last 50 years.

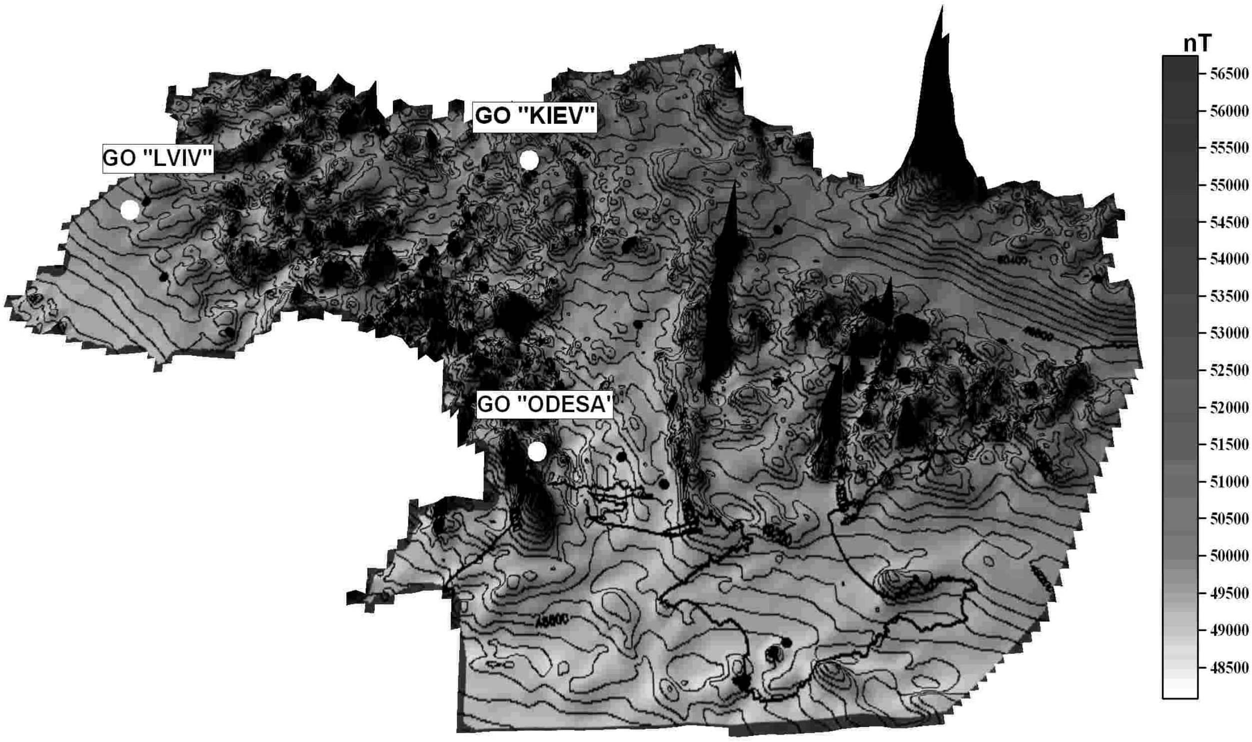

Figure 1: 3D surface of the geomagnetic field *B* on the territory of Ukraine (Orliuk, Romenets, 2002) and location of magnetic observatories

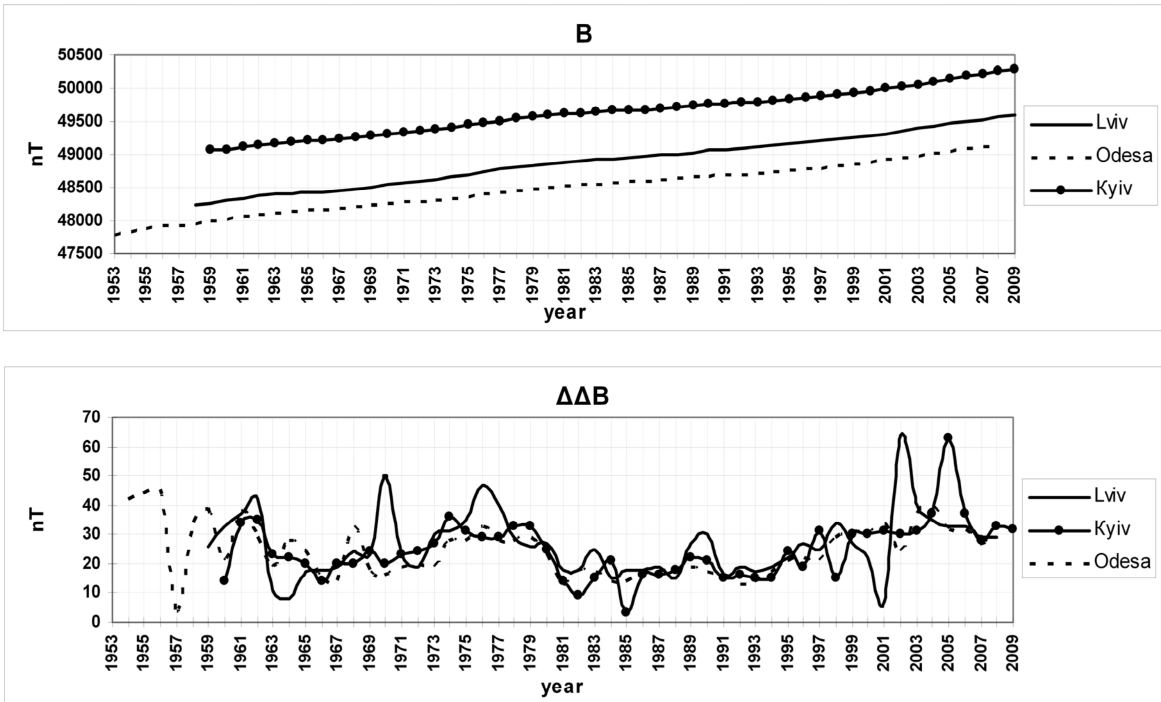

Figure 2: Variation of full vector of magnetic field *B* intensity and its average annual increment by the data of Ukrainian geomagnetic observatories

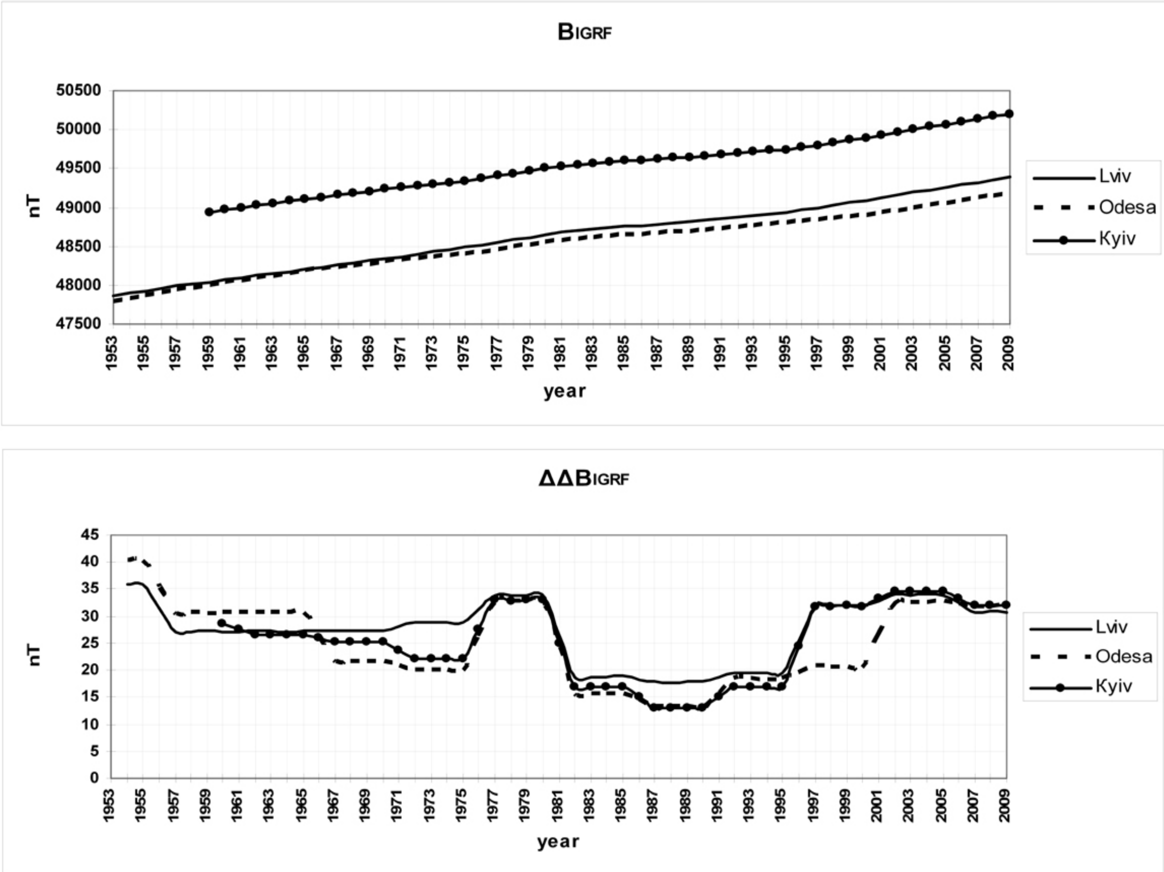

Figure 3: Variation of normal component B_{IGRF} and its average annual increment by the data of Ukrainian geomagnetic observatories

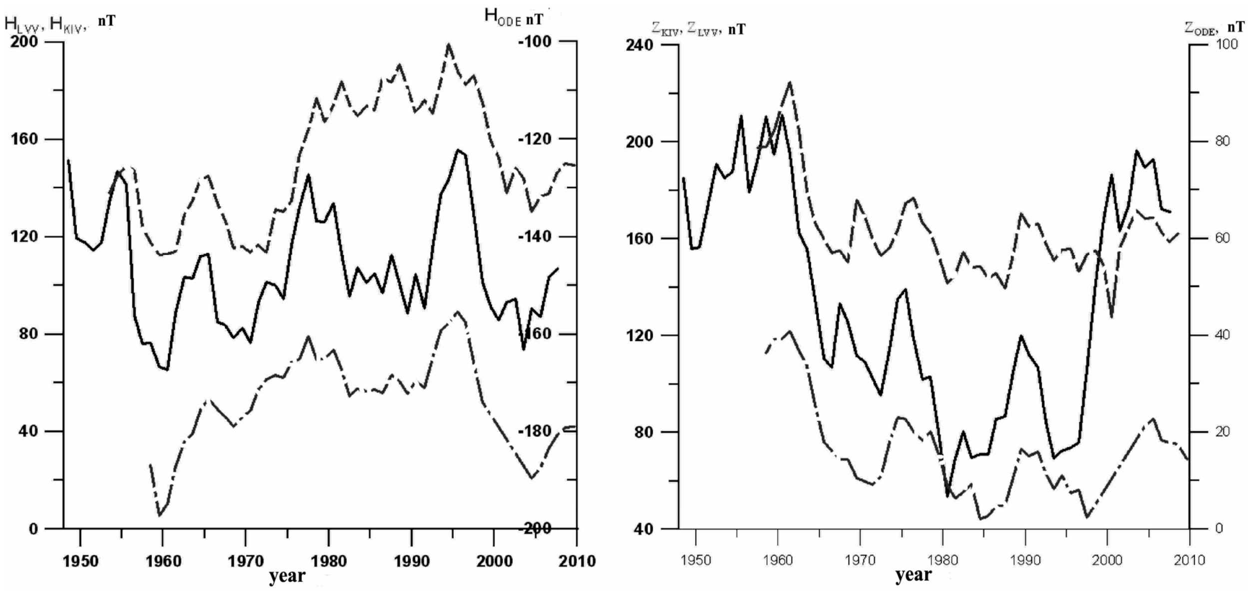

Figure 4: Average annual values B-B_{IGRF} of horizontal (a) and vertical (b) components of alternating field vector for geomagnetic observatories "Kyiv" (point – dotted curve), "Lviv" (dotted curve) and "Odesa" (black curve)

Specifically comparing the module *Bn* value for different parts of the Ukraine we can see that at 1950 south-western and southern parts are characterized by 47000 nT module *Bn* value, north-eastern and northern parts – by 49800 nT module *Bn* value, whereas at 2000, correspondingly, by 48200 nT and 50500 nT module *Bn* values (Orliuk, Romenets, 2002). According to the data of GO "Kyiv" the increment of normal *Bn* component during 1958-2008 is 1256 nT, for GO "Odesa" it makes 1186 nT, for GO "Lviv" – 1343 nT. So average annual increment *Bn* is characterized correspondingly by the following values: GO "Kyiv" – 25.1 nT/year, GO "Odesa" – 23.8 nT/year, GO "Lviv" – 26.8 nT/year (Fig. 3).

Let us examine long-term changing's of secular variations (*SV*) field. *SV*-value is defined as difference between consecutive average annual values of three orthogonal components and absolute intensity of geomagnetic field that are fixed continuously by magnetic observatories. Calculations admit to exclude automatically those field variations that have less than one year periods, that are generated by external sources and that are alternating-sign ones. However the variations of geomagnetic field generated by ring magnetospheric current that are reflecting at horizontal *Bn* field component and vertical *Bz* one are always of the same sign. Therefore in magnetically active years *Bn* component is always smaller and *Bz*-component is always greater, than in quiet years. Solar-diurnal *Bs*-variation (*Sq*) has the same effect. Under the influence of external sources the secular variations *SV* obtained by average annual values will include the components related to solar and, correspondingly, magnetic activity (Verbanac et al., 2007). It is extremely actual task to define each source components of the field. To distinguish the variations depending on external and internal sources we have to subtract main part of a field that is formed by the currents at core-mantle discontinuity from average annual field value measured in the observatory. External sources contribution for all observatories have been evaluated by difference of average annual value for all days and by quiet days ($B – B_{Sq}$).

3. External geomagnetic field

At present vast data array (ground as well as aerocosmic ones) about space and temporal alterations of geomagnetic field are accumulated however the identification procedure of geomagnetic variations at midlatitudes from different sources is not worked out. In connection with large-scale researches of terrestrial space it become evident that main external sources of geomagnetic variations are located in high-latitude ionosphere and distant magnetosphere. Irregular variations are caused by magnetospheric currents and currents of high-latitude ionospheric currents that are appearing in the Earth's field in the form of magnetic storms (Akasofi, Chapman, 1975). Regular variations are originating by solar and cosmic radiation and are revealing as a quiet solar-diurnal variation (Yanovsky, 1978).

External sources contribution for all the observatories is evaluated by means of difference between average annual induction value *B* during all the days and in quiet ones ($B – B_{Sq}$). Fig. 4 (a, b) shows average annual $B\text{-}B_{IGRF}$ value of horizontal (B_H) and vertical (B_Z) component of geomagnetic field full vector. As it is seen by Fig 4 (a) average annual value of *Bn* component at GO "Lviv", "Kyiv" and "Odesa" is changing in in-phase way. Ranges of variations at GO "Lviv" are from 112.6 nTs to 199.3 nTs, at "Kyiv" – from 5.7 nTs to 89.3 nTs, at "Odesa" from -122.2 to 167.4 nTs. Average annual values of B_Z – component (Fig. 4 (b) at GO "Lviv" (dotted curve), "Kyiv" (point-dotted curve), "Odesa" (black curve) are changing in in-phase way. Ranges of variations at GO "Lviv" are from 140.6 nTs to 224.6 nTs, at "Kyiv" – from 44.9 nTs to 121.6 nTs, at "Odesa" from 6.8 nTs to 85.5 nTs.

Numerous researches were devoted to the problem of external sources of geomagmetic disturbances. Specifically geomagnetic field variation induced by magnetospheric and ionospheric sources in the midlatitudes may be represented as

$$\Delta=DR+DT+DCF+DP+ Sq \qquad (1)$$

where *DR* is the variation of ring magnetospheric current (includes and partial ring current);

DT is the variation of currents at magnetosphere tail;

DCF is the variation of currents at magnetopause;

DP is the variation of ionospheric currents in auroral zone and reverse currents spreading in midlatitudes;

Sq is quiet solar-diurnal variation.

To identify the variation sources during magnetic storms it is necessary to choose a reference (zero) level of geomagnetic variations values and its alterations depending on season and solar activity. As usually solar-diurnal variation (*Sq*) serves a reference level for irregular variations. However it is known well (Sumaruk & Sumaruk, 2004), that this variation amplitude is changing under season change and alteration of solar activity cycle phase as well as of latitude one.

Ionospheric current systems are the source of *Sq*-variations (Space Geophysics, 1976). Its intensity is depending generally on electromagnetic radiation of the sun in visible light, ultraviolet and X-ray ranges. Ionosphere lighting is changing after seasons and is negligible depending on alteration of solar activity cycle phase. Intensity of ultraviolet and X-ray radiation of the sun is depending on alteration of solar activity and is not depending on season. *Sq*-variation is intimately connected with equatorial electrojet (Yaremenko, 1970).

As it is shown in the work (Sumaruk, Sumaruk, 2005), solar-diurnal variation in midlaltitudes has two components: constant one for given month, that is not depending on solar activity and variable one, its value is depending on solar activity. Constant for given month component Sq^{i} is not changing during solar activity cycle but its amplitude is varying for each month. The most probable is that Sq^{i} is generated by ionospheric dynamo currents whose intensity is proportional to ionospheric conductivity linked up with electromagnet sun radiation.

Value of alternating component Sq^{m} is depending in straight lines on the sun activity expressed by Wolf numbers (*W*). Sq^{m} is generated by magnetospheric currents whose intensity is changing with changing of solar wind parameters and "trapped" in it interplanet magnetic field.

Amplitudes of *Sq*-variations of ukrainian observatories are given in the Table 1.

Table 1: Changes of *Sq*-variations diurnal amplitudes.

Solar activity	Winter		
	Sq(H), nT	*Sq*(D), min	*Sq*(Z), nT
Low	7-13	1,7-3,1	4-15
High	27-50	6,5-13,6	5-18
	Summer		
Low	20-32	6,4-11,5	5-14
High	37-62	12,7-18,5	12-36

Magnetospheric sources *DR, DT, DCF* variations reflect well *Dst*-index of magnetic activity. It is obtained from the data of four low-latitude geomagnetic observatories. Index is regularly calculated and published in *IAGA* bulletins as well as is exposed at the sites of international data centers specifically in Kioto (Japan, *http://swdccdb.kugi.kyoto-u.ac.jp*).

In midlatitudes the value of Δ_m magnetospheric sources can be in a first approximation calculated by formula

$$\Delta_m = D_{st} \cdot \cos\Phi$$

where Φ is geomagnetic latitude of the observatory. As the geomagnetic latitudes difference of ukrainian observatories is changing in the range of 4^0 so Δ_m will change in the range of 0.003 that not exceed the calculation error.

Value of *DCF* variation from currents during magnetopause is determined by model calculations. Paraboloid A2000 magnetospheric model (Alexeev et al., 1996), T02 magnetospheric model of Tsyganenko (Tsyganenko, 2002; Maksimenko et al., 2006), magnetospheric model of Mead (Mead & Beard, 1964) are used frequently with it. *DCF*-variation value calculated by different models is balanced/ proportional in size. For instance, variation corrections caused by magnetopause currents that were calculated by Mead model (Sumaruk & Sumaruk, 2006), in quiet days (*DCF*) have +14 nTs value of horizontal component and -13 nTs of vertical component for midlatitude observatory. Error for *DCF*-variation of magnetic declination in quiet periods is reaching $\pm 0.05^0$ and is changing after phase with *Sq*-variation change. As it is shown (Feldstein, 1973), during magnetically quiet days *DCF*- variations are compensated by *DT*-variations.

Variation from ionospheric currents in auroral zone and its reverse currents in midlatitudes are described by means of auroral activity indexes *AE, AU, AL*. As it is known (Space Geophysics, 1976), when large-scale magnetic storms ($Dst > -150$ nTs) take place the focuses of auroral ionospheric currents are shifting towards midlatitudes. During initial phase of magnetic storm midlatitude observatories are influenced directly by reverse ionospheric currents. *Dst* increase is conditioning direct influence of eastern (*AU*) or western (*AL*) electrojets on the observatories (Sumaruk & Sumaruk, 1994) depending on local time. *AE*-indexes are calcilated by the data of magnetic observatories train of auroral belt. When magnetic activity is high *AE*-indexes are underestimated and to calculate it we need to use suauroral observatories data (Sumaruk & Sumaruk, 2006).

Value of irregular variations of geomagnetic field can be defined as

$$H - Sq$$

where *H* is the value of geomagnetic field horizontal component (Sumaruk & Sumaruk, 2006). *Sq*-variation is calculated by five internationaly quiet days. Horizontal component is reflecting best the variations caused by external sources. Proposed difference minimizes the influence of internal sources of geomagnetic field.

Based on above-stated the identification of geomagnetic variations external sources after ukrainian observatories data is proposed. As it is shown in the research (Sumaruk & Sumaruk, 2006), about eighty percents of irregular variations of magnetic field on the territory of the Ukraine during magnetic storms are generated by magnetospheric sources and only one fifth of them has ionospheric nature. Results obtained for 11 maximal storms of 21-22 solar activity cycles agree well with the results of other researchers (Maksimenko et al., 2006; Yaremenko, Melnyk, 2005) and are represented in the Table 2.

Table 2: Ratio of variation value from magnetospheric and ionospheric currents.

№	*Dst*, nT	*DR+DT*,%	*DCF*,%	*DP*,%
1	249	62	17	21
2	220	71	17	12
3	291	74	14	12
4	219	72	11	17
5	338	65	19	16
6	303	66	20	14
7	169	55	18	27
8	559	66	18	16
9	298	62	20	18
10	198	55	23	22
11	297	62	22	16
average		65	18	17

Results discussion and summary

Fulfilled investigations of space-temporal structure of geomagnetic field of the Ukrainian territory are significant to work out some problems of magnetology and ecology. Magnetic field of the Ukraine is in a manner unique as compared with the fields of another countries of the Europe in terms of regional and local anomalies occurrence of high intensity as well as of its important changes with time.

The dynamics of magnetic field are calculated as well as internal and external sources contribution in field variations is evaluated with use of data obtained by ukrainian observatories during last fifty years.

First of all let us to underline important changes of magnetic field for the Ukraine in whole. Specifically the increment of full vector value of magnetic field induction during 1958 – 2008 years is 1223 nTs for GO “Kyiv”, 1144 nTs for GO "Odesa", 1323 nTs for GO "Lviv". Dominant part of this increment (B_n=1200 nTs during 50 years) is caused by increasing of main Earth's magnetic field.

High-frequency geomagnetic variations of external field with periods of day or less caused by magnetospheric or ionospheric currents are not changing so signaficantly compairing with long-period variations of internal nature. External field variations are changing in the range of nTs first tens and only under very important magnetic storms its intensity can reach some hundreds nTs.

The variations from magnetospheric and ionospheric sources have been calculated by models. They were compared with observed field changes on the Earth surface subject to variable reference level. It shown that during magnetic distorbances about 80% of field variations in midlatitudes are generated by magnetospheric sources and 20% – by ionospheric ones.

On the whole summarizing the above it is possible to state a fact that the Earth's magnetic field on the territory of the Ukraine is changing considerably in space as well as in time. The contribution of internal sources is important for long-period variations and of external ones – for short-period variations.

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