ELEMENTS AND STRUCTURE OF THE NORMAL GEOMAGNETIC FIELD IN THE REPUBLIC OF MACEDONIA

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ABSTRACT. This paper presents the research of the normal geomagnetic field of the Republic of Macedonia. The complex geological structure of the explored area ofregional and local character, has an important impact on the geomagnetic field. The geomagnetic field is composed of two components: normal and anomalous field. The geomagnetic field represents an important segment in the regulation of the natural processes on the Earth, which makes its permanent observation and study of special importance. Conducted investigations of the geomagnetic field maintain the continuity of monitoring and studying of the field changes in the area of the Republic of Macedonia which started in 2000.

Keywords: geomagnetic field, total field, declination, inclination, normal field, geomagnetic models and maps

ЕЛЕМЕНТИ И СТРУКТУРА НА НОРМАЛНОТО ГЕОМАГНИТНО ПОЛЕ В РЕПУБЛИКА МАКЕДОНИЯ

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РЕЗЮМЕ. Тази статия представя изследването на нормалното геомагнитно поле на Република Македония. Комплексната геоложка структура на изследваната област от регионален и местен характер има важно влияние върху геомагнитното поле. Геомагнитното поле се състои от два компонента: нормално и аномално поле. Геомагнитното поле представлява важен сегмент в регулирането на естествените процеси на Земята, което прави неговото постоянно наблюдение и изследване особено важно. Проведените изследвания на геомагнитното поле поддържат непрекъснатостта на мониторинга и изучаването на промените в полето в областта на Република Македония, започнали през 2000 г.

Ключови думи: геомагнитно поле, общо поле, деклинация, наклон, нормално поле, геомагнитни модели и карти

Introduction

The geomagnetic field reflects the Earth's structure, the processes within it, as well as the external influences. The field is presented as a sum of three components: (Delipetrov, 2003).

- Normal geomagnetic field which reflects the causes of magnetism in the core and the mantle. This component includes agents that are in the depths of the earth's crust, but they are spread throughout the territory of the Republic of Macedonia;
- Regional geomagnetic anomalous field affected by characteristic generators of the magnetic field in the separated neotectonic zones in the Republic of Macedonia;
- Local geomagnetic field which is in direct correlation with the geological structures in the upper part of the Earth's crust with expressed magnetic features (increased concentration of ferrous magnetic minerals).

The territory of the Republic of Macedonia, as part of the Alpine orogen in the Balkan Peninsula, is characterized by a very complex geological structure, where structural segments are separated - zones which are widespread in the Balkan Peninsula. In recent geological history, neotectonic phase, different geological processes have divided these areas in separated units. The different geological structure and processes in these regions have significant impact on the structure of the geomagnetic field. There is no other such small area as the Republic of Macedonia with so complex geological structure and hence, with such structure of the local geomagnetic field in whole Europe.

Models and maps of the elements of the normal geomagnetic field in the Republic of Macedonia

Two methods of modeling of the geomagnetic field prevail today, one is the method of spherical harmonic analysis and the other is the method of polynomial analysis.

The normal field for a territory can be expressed by:

$$E(\Delta\varphi,\Delta\Delta\lambda) = a_1 + a_2 \cdot \Delta\varphi + a_3 \cdot \Delta\lambda + a_4 \cdot \Delta\varphi^2 + a_5 \cdot \Delta\lambda^2 + a_6 \Delta\varphi \cdot \Delta\lambda$$

where:

$E(\Delta\varphi, \Delta\lambda)$ – is the value for the normal field of the point with coordinates φ_1 and λ_1;

φ_1 and λ_1 – is the geographic latitude and longitude of the place;

φ_0 and λ_0 – is the geographic latitude and longitude of the point depending on which measurements are being reduced; for the Republic of Macedonia the central point is φ_0 = 41,50° and λ_0 = 22°;

$\Delta\varphi = \varphi_1 - \varphi_0$ – is the difference of geographic latitudes in minutes;

$\Delta\lambda = \lambda_1 - \lambda_0$ – is the difference of geographic longitudes in minutes;

a_i – are the coefficients for corresponding differences in nT/min (γ/min.), i.e. minutes / minutes or gammas and minutes. Usually, the differences of latitude and longitude are calculated in terms of coordinates of the geomagnetic observatory located on that territory.

Observations of the geomagnetic field of a given territory (usually state) are carried out in two parallel procedures. One is permanent monitoring of the geomagnetic field in an observatory. Another procedure that is performed periodically every 3 to 5 years are terrestrial observations of the basic network of repeat stations, and observations of the secondary net within a period of 10 years.

Based on this data collection about the geomagnetic field every five years, maps and models of the elements of the normal geomagnetic field for a given epoch are made.

Model of the elements of the normal geomagnetic field in the Republic of Macedonia

Field measurements were conducted on the fifteen repeat stations in Macedonia. (Delipetrev, 2011)]

During the field measurements, the following instruments were used:

- DI Fluxgate magnetometer – an instrument that measures values of the geomagnetic declination D and inclination I. The instrument consists of a non - magnetic theodolite and fluxgate sensor mounted on the telescope, so the optical and magnetic axes are parallel (fig. 1).
- Proton - magnetometer - GEOMETRICS G-856.

A model of the elements of the normal geomagnetic field in the Republic of Macedonia (Table 3) is made on the basis of the measured data (Table 1).

Fig. 1. DIFlux magnetometer - theodolite with Fluxgate sensor on the top

Table 1.
Measured data on the repeat stations

Station	H (nT)	X (nT)	Y (nT)	Z (nT)
Tetovo	24233.26	?	?	39941.46
Egri	24751.17	24716.87	1302.71	39237.34
Mavrovo	24264.10	24231.20	1263.12	39704.21
Plackovica	24288.75	24251.75	1340.17	39822.61
Slivnica	24379.72	24337.21	1439.08	39790.33
Vodno	24207.50	24169.74	1351.72	39950.88
Bajlovce	23883.98	23853.08	1214.61	40156.53
Island Gradot	24530.80	24484.68	1503.55	39402.71
Nikolic	24540.18	24504.80	1317.27	39576.18
Ponikva	24110.89	24073.10	1349.27	40111.39
St. Maria Precesna	24350.92	24315.68	1309.65	39651.61
Crna Skala	24227.53	24189.96	1348.62	40140.25
Luke	23937.17	23898.48	1360.40	40464.26
Galicica	24727.66	24696.04	1250.18	39098.67
Prilep lake	24520.03	24485.53	1300.37	39665.69

Table 2.
Coefficients of the model of the normal geomagnetic field

	Coefficients					
Ele-ment	a_0	a_1	a_2	a_3	a_4	a_5
D	3.6278	0.118	-0.0386	0.078	0.0154	-0.3455
I	58.088	-0.037	-0.1578	0.119	0.0928	-0.4256
T	46550	-24.449	-172.278	-20.585	197.784	-449.635
H	24607	11.072	17.149	-95.376	38.900	57.755
X	24558	7.939	18.218	-97.322	37.095	66.862
Y	15560	46.635	-15.966	23.628	13.308	-145.088
Z	39514	-36.462	-217.088	33.564	210.554	-567.011

Table 3.
Values of the normal geomagnetic field calculated with the coefficient from Table 2

Stations	D	I	T	H	X	Y	Z
Galicica	3.378	57.276	46271	25014	24970	1474	38927
Egri	3.465	57.367	46330	24984	24938	1510	39016
St. Maria Precesna	3.533	58.039	46453	24590	24543	1515	39411
Mavrovo	3.466	58.122	46451	24531	24486	1483	39445
Prilep lake	3.509	57.854	46567	24777	24731	1517	39428
Vodno	3.597	58.298	46671	24526	24477	1539	39707
Bajlovce	3.507	58.850	46675	24144	24099	1477	39945
Ponikva	3.721	58.603	46750	24355	24304	1581	39905
Plackovica	3.698	58.217	46575	24531	24480	1582	39591
Luke	3.737	59.005	46235	23809	23759	1552	39633
Tetovo	3.617	58.346	46683	24499	24450	1546	39738
Island Gradot	3.946	57.667	46327	24777	24719	1685	39144
Nikolic	3.499	57.823	46493	24759	24713	1511	39352
Slivnica	3.983	58.166	46607	24583	24524	1708	39596
Crna Skala	3.769	58.244	46903	24685	24632	1623	39881

Maps of the elements of the normal geomagnetic field of the Republic of Macedonia

The declination of the observed territory varies form 3,378° on the measuring point Galicica to 3,983° on the station Slivnica. Declination varies in the interval ΔD = 0,605° (Fig. 2).

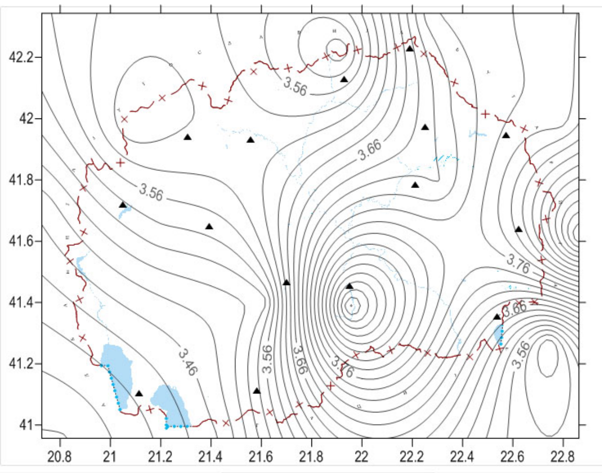

Fig. 2. Map of declination, D

Analysis of the declination field shows that on the observed territory the extreme stands in the central southern part, near the measuring station Island Gradot. The field is quiet in the west and northwest, which should be expected according to the geological structure.

From the observations, the inclination varies from Galicica 57.276° ≤ I ≤ 59,005° Luke. The mean value of inclination is Isr = 58,125°. The field of inclination I related to that of the declination is more homogenous and relatively quiet. There is a slight twisting of isolines in the central southern part (Fig. 3).

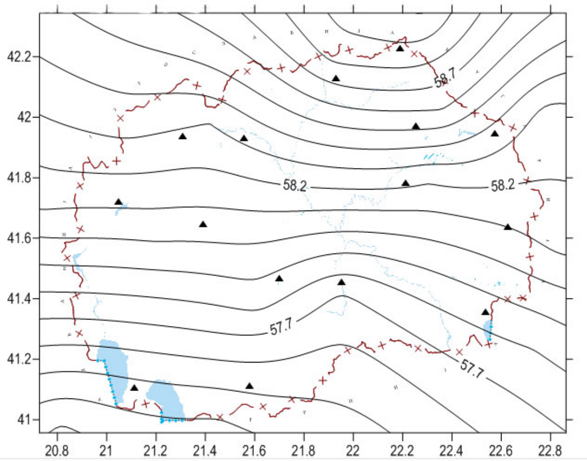

Fig. 3. Map of the inclination, I

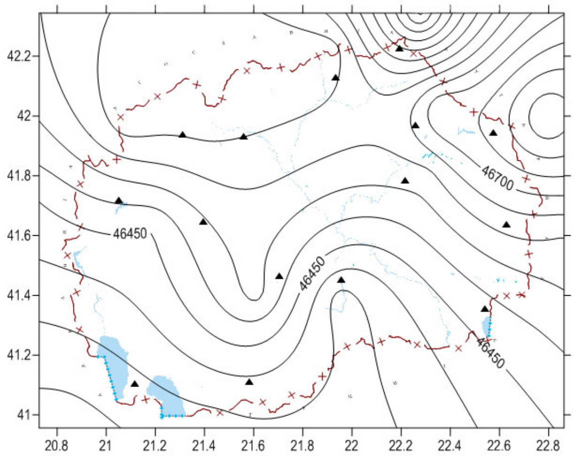

Fig. 4. Map of total intensity, T

Values of the measured points for the total field vector T varies in the interval from 46 235 nT on the repeat station Luke to 46 903 nT on the point Crna Skala. The interval of variation is ∆T = 371,0 nT. The field is relatively quiet with a twisting of the isolines in the central southern part and in the northeastern part (Fig. 4).

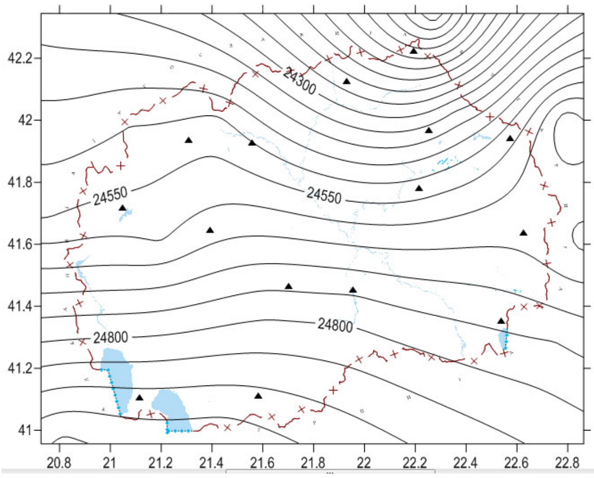

Fig. 5. Map of horizontal component, H

Analyzing the map of the horizontal component H (Fig. 5) from north in the area of Bajlovce with a minimum value of 24150 nT toward south shows an increase to H_{max} = 25000 nT in the area of Ohrid and Prespa Lake, i.e. in the region of the repeat station Galicica. The average value of the field is H_{sr} = 24575 nT. The interval, in which the horizontal component on the observed territory varies, is ∆H = 850 nT. The field is homogenous and relatively quite.

The field of the northern component X (Fig. 6) is relatively quiet and with a maximum value X_{max} = 24900 nT from southwest, decreasing toward north and in the northeastern part it has a minimum value X_{min} = 24100 nT. The average value of the northern component is X_{sr} = 24500 nT. The interval of variation is ∆X = 800 nT.

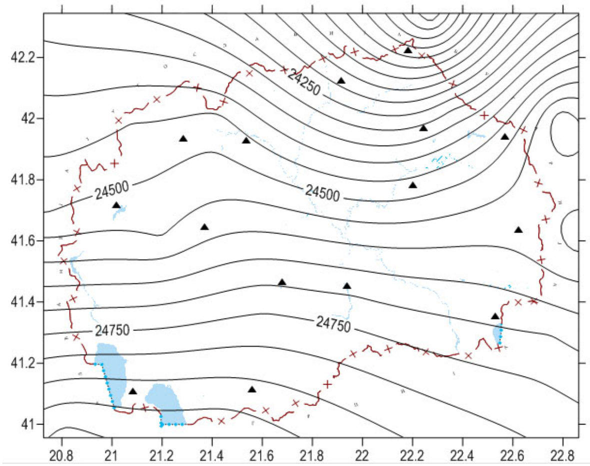

Fig. 6. Map of the northern component, X

The field of the eastern component Y (Fig. 7) varies from Ymin = 1470 nT in the area of the repat stations Galicica and Bajlovce to Ymax = 1700 nT at the repeat stations Slivnica and

Island Gradot. The western part of the Republic of Macedonia has a quieter field related to the central and the eastern part. The expressed extreme is present in the southern part. The value of the component varies in the interval of ΔY = 250 nT. The average value is Ysr = 1595 nT.

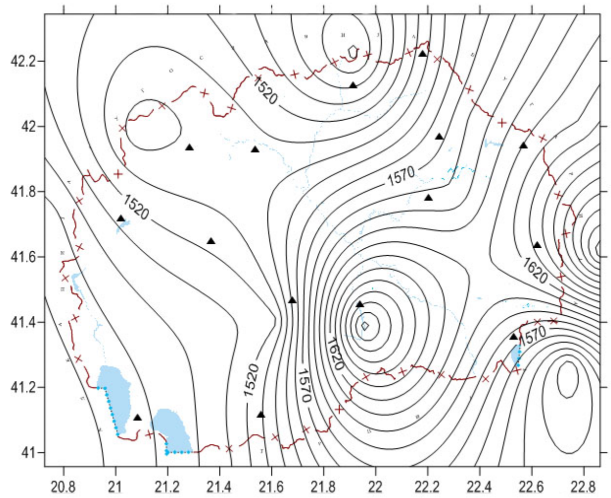

Fig. 7. Map of the eastern component Y

The field of the vertical component Z (Fig. 8) is relatively quiet with expressed twisting of the isolines in the northeastern and central southern part. The maximum value is in the area of the repeat station Bajlovce Zmax = 39945 nT, and minimum value is in the region of the repeat station Galicica Zmin = 38927 nT. The average value of the component is Zsr = 39435 nT. The interval of variation is ΔZ = 1018 nT.

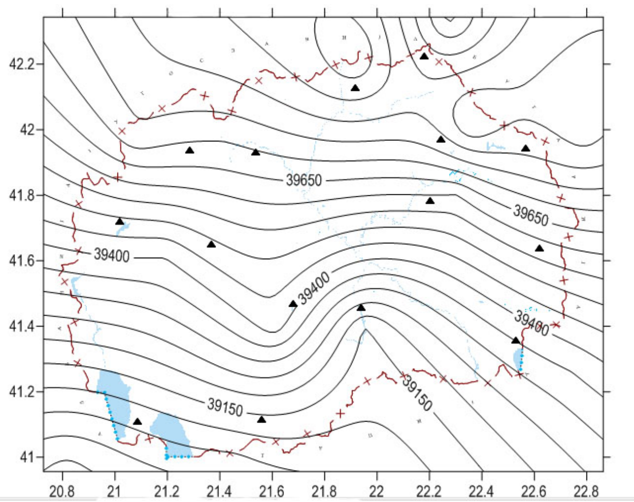

Fig. 8. Map of the vertical component, Z

The fields of declination - D and eastern Y component are more complex in terms of other components of the field. In all maps, the western part of the territory of the Republic of Macedonia has a quieter field compared to the central and eastern part.

The comparison of maps of the relevant elements of the normal field from previous measurements in 1990 showed lower degree of similarity with these maps because of the use of a different network of repeat stations, the greater distance and difference in applied technology.

Structure of the geomagnetic field

The geomagnetic field on the Earth's surface is a sum of vectors of many different magnetic fields:

$$T = T_0 + T_M + T_a + T_e + \delta T.$$

The implemented geomagnetic field observation and the applied methodology of data processing have eliminated the influence of the local anomaly field T_{al}, the electromagnetic field T_e, and the impact of short time variations of the field δT.

In order to eliminate the influence of geomagnetic causes that are deep underground, and because their dimensions and area of influence are far beyond the territory of the investigated area, anIGRF (International Geomagnetic Reference Field) model is used as a filter that reflects the impact of normal geomagnetic field, in this case shown by two components: the field- T_0 and the axial dipole field- T_K on the continent.

Maps of the differences of the normal geomagnetic field's elements between the IGRF model and our model were created (Figs. 9 - 12). (Panovska et al., 2006)

The analysis of the components of the regional anomaly of the geomagnetic field Tar reflects the neotectonic regionalization of the Republic of Macedonia in three mega blocks:

- Eastern Macedonian zone;
- Vardar zone;
- Western Macedonian zone including Pelagonian block.

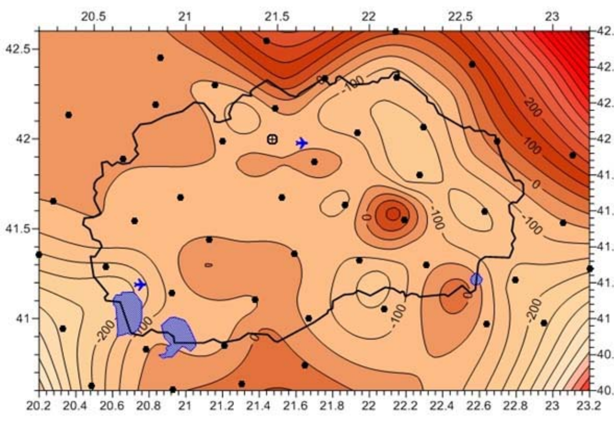

Fig. 9. Map of ΔT between our measurements and IGRF model

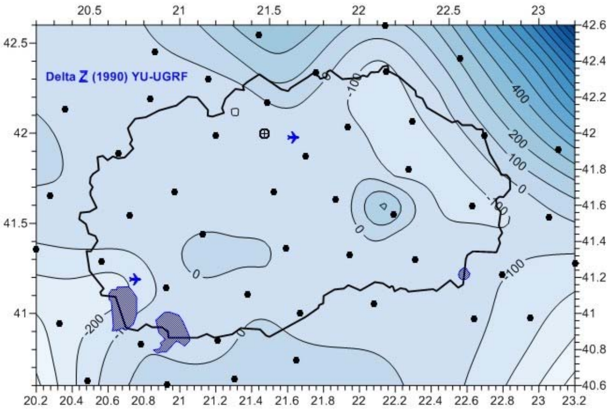

Fig. 10. Map of ∆Z between our measurements and IGRF model

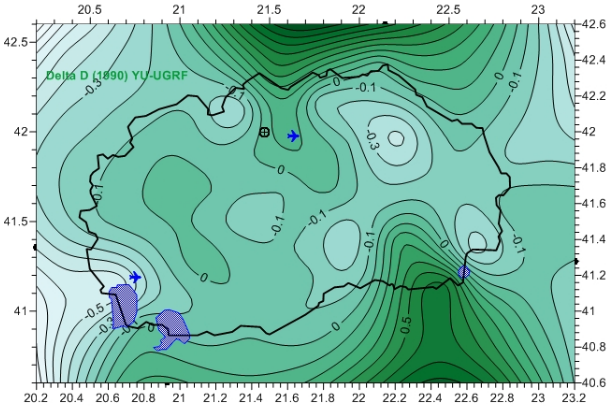

Fig. 11. Map of ∆D between our measurements and IGRF model

Conclusion

From the data presented on the elements and structure of the normal geomagnetic field in the Republic of Macedonia, it can be concluded the following:

- The maps and the elements' models of the normal geomagnetic field express the specificity of the area of the Republic of Macedonia;
- The presented data for the declination can have wide application in all activities where compass is used;
- Maps of the differences of the normal geomagnetic field elements between the IGRF model and our model were created.

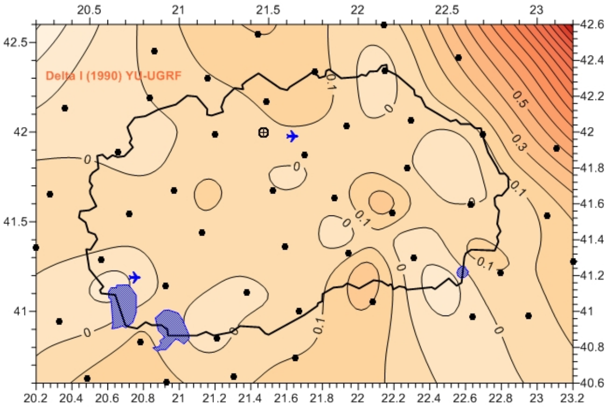

Fig. 12. Map of ∆I between our measurements and IGRF model

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