New geomagnetic measurements in the Republic of Macedonia

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Article history
Received July 13, 2011; accepted March 22, 2013.
Subject classification:
Geomagnetic survey, Geomagnetic field, Repeat station, Measurements.

ABSTRACT

This study presents measurements of the geomagnetic field of the Republic of Macedonia, performed through a network of newly defined repeat stations. The measurements of these elements were in the intervals of 3.378° ≤ ΔD ≤ 3.983°, 57.276° ≤ I ≤ 59.005°, and 46 235 nT ≤ F ≤ 46903 nT. The geomagnetic data were processed and the results of the observed elements of the geomagnetic field on the repeat stations are presented. Additional data processing was performed to calculate the reduced values of the intensive elements of the field at the level of H_{500} a.s.l.. Based on these data, new maps of the geomagnetic field of the Republic of Macedonia are developed, together with the polynomial model of the elements of the geomagnetic field for the 2010.0 epoch.

1. Introduction

The territory of the Republic of Macedonia occupies the central part of the Balkans Peninsula, with an area of 25,713 km^2. The terrain is mountainous due to highly active neotectonic processes. These processes have formed uplift blocks, with crests to 2,600 m a.s.l. and blocks of sinking depressions that mainly spread east to west [Arsovski 1997].

The geomagnetic investigations can be divided into three periods. The first period began in the 19th century and finished in 1945. Scientists from mainly European countries were engaged in infrequent special expeditions to investigate the geomagnetic field in the Balkans, which included investigations in the territory of the present-day Republic of Macedonia. The second period was from 1945 to 1991, when Macedonia was a constitutional part of Yugoslavia, and the third period began after the declaration of independence in 1991.

The geomagnetic observations for the territory of the Republic of Macedonia up to 1990 were carried out by teams of scientists from the Geomagnetic Observatory Grocka (Republic of Serbia). To continue monitoring and to obtain new data for the geomagnetic field of Macedonia, Panovska and Delipetrov [2006] developed the appropriate maps and models for the given epochs. In 2002, the first measurements of the geomagnetic field for the locations of Plackovica, Ponikva and Galicica were initiated, with the help of the Royal Meteorological Institute Geomagnetic Observatory in Dourbes (Belgium). This report presents the results from the terrestrial measurements and data processing, and the newly developed maps and the polynomial model of the geomagnetic field of Macedonia.

2. The repeat station network

The geomagnetic field in a given area is measured for a network of repeat stations, often at five-year intervals. Based on these measurements, the raw geomagnetic data are collected and processed, which produces models and maps of the geomagnetic field elements.

A team from the Faculty of Natural Sciences, 'Goce Delcev' University (Stip, Republic of Macedonia) conducted investigations to define the repeat station network in the Republic of Macedonia. The repeat station networks of 16 countries were investigated, with the mean distance between stations of 230 km, which varied from 53 km to 415 km.

In the process of defining the repeat station network, geomagnetic measurements were performed for every point in four directions (north, south, east, west) at intervals of 1 m at a distance of 10 m. The International Association of Geomagnetism and Aeronomy guidance states that the maximum gradient of the magnetic field for repeat stations should not exceed 50 nT in a radius of 10 m. The selected repeat stations in Macedonia have a gradient below 1 nT [Rasson and Delipetrov 2006].

Based on these investigations and the characteristics of Macedonia, a network of 15 repeat stations was defined (Figure 1, Table 1). The minimum distance be-

Figure 1. Map of the repeat stations in the Republic of Macedonia.

tween the repeat stations is 26.1 km, with a maximum distance of 201.3 km, and a mean distance of 98.6 km. The lowest repeat station is Nikolic, at an altitude of 300 m a.s.l., while the highest is Galicica, at 1,684 m a.s.l.

3. Normal geomagnetic field maps

The first field measurements for the definition of the repeat station network were carried out in 2002-2003 with the instruments from the geomagnetic observatory in Dourbes (Belgium), with the help of Jean Rasson. The second series of geomagnetic field measurements was carried out in 2007-2009 for the newly established repeat station network (Table 1).

The repeat station measurements in 2007-2009 were performed with the instruments of the 'Goce Delcev' University. The instruments used were a LEMI 203 DIM sensor, a Geometrics G 856 proton magnetometer, and a Trimble global positioning system (GPS).

During the field observations, the declination D, inclination I, and total field vector F were measured. As there is no geomagnetic observatory available in the Republic of Macedonia, a time-series from the Panagjuriste Observatory (Bulgaria) was used. This observatory was selected due to its proximity, as it is 225 km away, with coordinates: latitude, 42.52°N; longitude, 24.18°E; altitude: 556 m a.s.l. The time-series data was used to reduce the results of the 2010.0 epoch, and to calculate the mean yearly changes in the geomagnetic field. The measurements for the 2010.0 epoch are given in Table 2 and illustrated in Figures 2-4.Using the data from Tables 1 and 2, a reduction of the intensive measurements was made to the level h = 500 m a.s.l. (Table 3).

For any intensive field element with a value E [e.g., De Santis et al. 2003] at a height h, the correction ΔE for computing its value for h = 500 m is expressed as:

$$|\Delta E| = \frac{3Eh}{R+h} = \frac{3Rh}{R} \qquad (1)$$

where R = 6,371.2 km is the Earth mean radius. Table 3 shows the corrections and reduced values for F_{500}, H_{500} and Z_{500}. Using the software SURFER 9 and the data from Tables 2 and 3, the maps of the elements for the normal geomagnetic field were created (Figures 2-4).

The declination (D) in the observed area varies from 3.378° for the repeat station Galicica, to 3.983° for station Slivnica. The mean declination from the ob-

Repeat station	Geographic latitude (°:min:sec)	Geographic longitude (°:min:sec)	Altitude (m)
Bajlovce	42:13:16	21:55:17	592
Crna skala	41:59:41	22:47:28	833
Egri	41:23:15	21:57:06	626
Galicica	40:57:56	21:26:54	1684
Island Gradot	40:57:23	20:48:51	317
Luke	42:20:39	22:16:29	1180
Mavrovo	41:42:58	20:43:38	1418
Nikolic	41:15:54	22:44:36	300
Plackovica	41:47:41	22:18:13	677
Ponikca	42:01:35	22:21:29	1618
Prilep Lake	41:24:11	21:36:32	870
Slivnica	41:37:38	21:11:36	1252
St. Marija Precesna	41:36:54	22:51:46	837
Tetovo	41:59:09	21:04:46	522
Vodno	41:58:40	21:24:57	569

Table 1. GPS coordinates of the repeat stations.

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

Table 2. Reduced measurements for the epoch 2010.5. D, declination; I, Inclination; T, Total intensity; H, Horizontal component; X, East component; Y, North component; Z, vertical component.

Station	ΔF_{500} (nT)	ΔH_{500} (nT)	ΔZ_{50} (nT)	F_{500} (nT)	H_{500} (nT)	Z_{500} (nT)
Bajlovce	2.0219	1.0459	1.7201	46677.02	24145.05	39708.72
Crna skala	7.3540	3.8704	6.2530	46910.35	24688.87	39887.25
Egri	2.7487	1.4823	2.3148	46332.75	24985.48	39018.31
Galicica	25.7917	13.9429	21.6981	46296.79	25027.94	38948.70
Island Gradot	-3.9921	-2.1351	-3.3731	46323.01	24774.86	39140.63
Luke	14.8024	7.6226	12.6888	46249.80	23816.62	39645.69
Mavrovo	20.0759	10.6022	17.0479	46471.08	24541.60	39462.05
Nikolic	-4.3786	-2.3317	-3.7060	46488.62	24756.67	39348.29
Plackovica	3.8816	2.0444	3.2996	46578.88	24533.04	39594.30
Ponikca	24.6064	12.8190	21.0036	46774.61	24367.82	39926.01
Prilep Lake	8.1125	4.3164	6.8688	46575.11	24781.32	39434.87
Slivnica	16.5013	8.7037	14.0190	46623.50	24591.70	39610.02
St. Marija Precesna	7.3709	3.9018	6.2535	46460.27	24593.90	39417.25
Tetovo	0.4836	0.2538	0.4116	46683.48	24499.25	39738.41
Vodno	1.5163	0.7968	1.2901	46672.52	24536.80	39708.29

Table 3. Corrections and reduced values for the intensive field elements at h = 500 m a.s.l.

served data is $D_{sr} = 3.628°$. The means of the geomagnetic fields are calculated using an arithmetic mean. Analysis of the declination field shows that for the observed territory, the most extreme value is in the central southern part, near the measuring station of Island Gradot. The field is quiet in the west and northwest parts of the country.

The observations show that the inclination varies from 57.276° for Galicica to 59.005° for Luke station. The mean inclination (I) is $I_{sr} = 58.125°$. The inclination field compared to the declination is more homogenous and relatively quiet. There is a slight twisting of the isolines in the central-southern part. The measured points for the total field vector (F) vary from 46,235 nT for Luke to 46,903 nT for the repeat station Crna Skala. The mean total field vector is F_{sr} = 46,532 nT. The western part of the field, as the western-Macedonia part, has a quiet field. Again, there is a twisting of the iso-

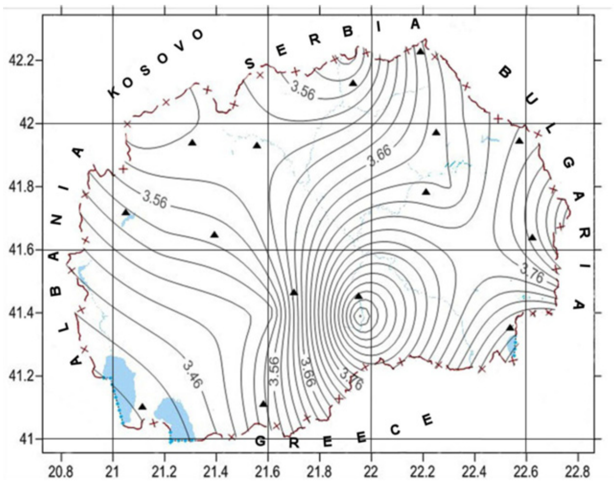

Figure 2. Map of the declination D for the 2010.0 epoch.

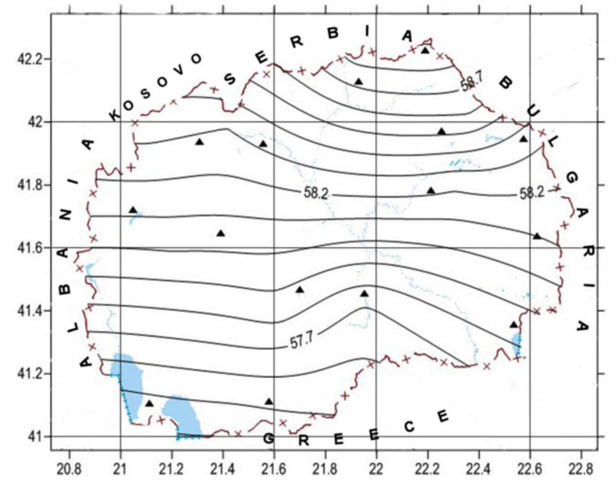

Figure 3. Map of the inclination I for the 2010.0 epoch.

lines in the central-southern part.

The maps presented here (Figures 2-4) show that the largest deformations in the field occur in the central part and the eastern Macedonia zone.

The geomagnetic field on the Earth surface can be present as the vector sum of many different components:

$$\vec{T} = \vec{T}_0 + \vec{T}_m + \vec{T}_a + \vec{T}_e + \delta\vec{T} \qquad (2)$$

where, $\vec{T}_0$ is the field of the homogenous magnetized Earth, or the field of a dipole magnet, $\vec{T}_m$ is the field from the magnetic objects in the deeper parts of the Earth, known as the nondipole or field of continents, $\vec{T}_a$ is the field created by the magnetization of the upper parts of the Earth crust, known as the anomalous field, $\vec{T}_e$ is the field related to external phenomena with respect to the Earth surface, and $\delta\vec{T}$ is the field of variations.

With the measurement procedure performed and the processing of the collected data, components $\vec{T}_e$ and $\delta\vec{T}$ can be eliminated. The anomalous field $\vec{T}_a$ can be represented as a sum of two components:

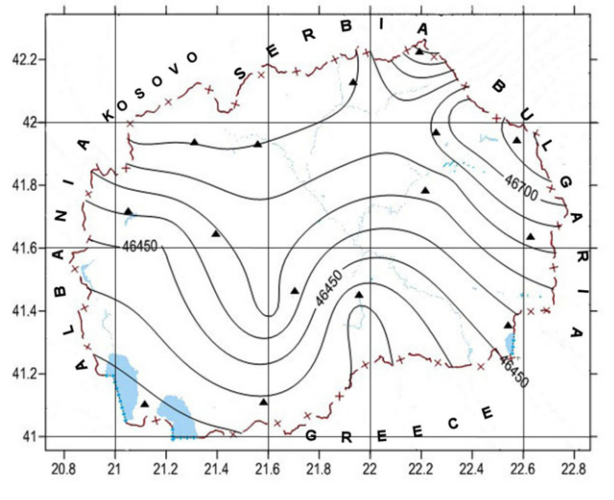

Figure 4. Map of total field vector F for the 2010.0 epoch.

$$\vec{T}_a = \vec{T}_a^r + \vec{T}_a^I \qquad (3)$$

where, $\vec{T}_a^r$ is the regional anomalous field for the observed territory, which is caused by the influence of the magnetic layers and the deeper parts of the Earth crust, and which is manifest over larger areas, $\vec{T}_a^r$ is the local anomalous field for the observed territory. This field results from the magnetic media (rock, ore deposits) near the Earth surface, which influences a relatively small area. Separation of the local and anomalous fields depends on the size of the area investigated. The methodology and the observations of the geomagnetic field allow the elimination of the anomalous component of local character, $\vec{T}_a^I$.

The Italian Geomagnetic Reference Field models represent the geomagnetic field generated in the core, or the component (T_0) and the nondipole field (T_m), or the sum of these two.

The referent model for an investigated territory (state) is given by:

$$\vec{T}_{NM} = \vec{T}_0 + \vec{T}_m + \vec{T}_a^r \qquad (4)$$

The influence of the regional component presents specific geomagnetic features for the explored area that create differences from the global geomagnetic models of the Earth. For a more precise definition of the regional geomagnetic field, observations on a denser network of repeat stations should be made.

4. Model of the normal geomagnetic field of the Republic of Macedonia

Today, two methods of modeling geomagnetic fields have been defined: one that uses spherical harmonic analysis, and the other, polynomial analysis. Studies show that for areas with <15° spatial angle, polynomial analysis is an effective method [De Santis et al. 1999]. Given the size of the territory of the Repub-

Element	Coefficient					
	a_0	a_1	a_2	a_3	a_4	a_5
D (°)	3.6278	0.1176	-0.0386	0.0778	0.0154	-0.3455
I (°)	58.0876	-0.0367	-0.1578	0.1196	0.0928	-0.4256
T (nT)	46550	-24.4499	-172.2784	-20.5894	197.7838	-449.6354
H (nT)	24607	11.0723	17.1495	-95.3759	38.9003	57.7547
X (nT)	24558	7.9397	18.2187	-97.3217	37.0952	66.8624
Y (nT)	15560	46.6355	-15.9659	23.6280	13.3079	-145.0884
Z (nT)	39514	-36.4622	-217.0881	33.5642	210.5535	-567.0112

Table 4. Model for the 2010.0 epoch.

lic of Macedonia, the polynomial model is appropriate.

To calculate the coefficients of the polynomial model, the method of least squares is used. The geomagnetic field for a given territory can be expressed as:

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

where, $E(\Delta\varphi,\Delta\lambda)$ is a normal field of the point with coordinates φ_1 and λ_1, φ_1 and λ_1 are the geographic latitude and longitude of the point, respectively, φ_0 and λ_0 are the geographic latitude and longitude of the point, respectively, in respect of which the measurements are reduced. For the Republic of Macedonia, the central point is for $\varphi_0 = 41.50°$ and $\lambda_0 = 22°$. Then, $\Delta\varphi = \varphi_1 - \varphi_0$ is the difference in the geographic latitudes, in minutes, $\Delta\lambda = \lambda_1 - \lambda_0$ is the difference in the geographic longitudes, in minutes, and a_i is the coefficient for the corresponding differences in nT/min; i.e., min/min. Usually, the differences in the latitude and longitude are calculated in terms of the coordinates of the geomagnetic observatory located in that territory.

The normal field of the territory of Macedonia is calculated according to the measurements of absolute values for the total intensity (F), declination (D) and inclination (I) for the period from 2007-2009 for the 15 network stations. The values for the other components of the geomagnetic field are derived from these (Table 1). Calculate coefficients or polynomial model from the absolute measurements for 2010.0 epoch is given in (Table 4).

5. Conclusions

This report presents the measurements of the geomagnetic field of the Republic of Macedonia. The geomagnetic field observations were carried out for the newly developed repeat station network in 2007-2009. The data gathered was processed and the maps of the geomagnetic field elements are produced here. With the reduction in H_{500} a.s.l., the influence of the relief was minimized in relation to the regional magnetic component presented. The data are used to create the polynomial model of the elements of the geomagnetic field for the 2010.0 epoch. The model is a second-degree polynomial in longitude and latitude and consists of observations of six coefficients for each magnetic element.

The measurements given in this report are a continuation of the observations on the geomagnetic field in the Republic of Macedonia that was started after 2000. The geomagnetic model can be used for further studies and analysis of the geomagnetic field of this area.

Acknowledgements. The authors would like to thank Dr Jean Rasson, Royal Meteorological Institute Geomagnetic Observatory, Dourbes, Belgium, for help with the recording in 2002-2003, the University of Goce Delcev, for support from the Tempus Project *Geomagnetic measurements and quality standards*, and the Panagjuriste Observatory, Bulgaria, for the geomagnetic observatory time-series.

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