REPORT ON THE EVOLUTION OF THE GEOMAGNETIC FIELD ON THE ROMANIAN TERRITORY. HORIZONTAL COMPONENT BETWEEN 2010 AND 2020

VENERA DOBRICĂ, CRIȘAN DEMETRESCU

„Sabba S. Ştefănescu" Institute of Geodynamics, Romanian Academy

The evolution of the Earth's magnetic field on the Romanian territory is reported based on geomagnetic measurements of the horizontal component taken at the 26 repeat stations of the Romanian secular variation network during the time interval 2010–2020. The determined values were corrected for diurnal variation and then reduced to the mid-year, using continuous recordings from the geomagnetic Surlari observatory. By means of these values at a certain geomagnetic epoch, the geographical distribution of geomagnetic element, on the Romanian territory, is achieved. The slow change of the geomagnetic field, so-called secular variation, in the study interval seems to be marked by lateral variations in the magnetic properties of the crust. The methodology and the information acquired in this study would contribute to a better knowledge of the Earth's magnetic field metrology and its applicability in scientific purposes.

Keywords: geomagnetic measurements, repeat station, secular variation, Romanian territory.

1. INTRODUCTION

The magnetic field of the Earth is monitored both at ground, by means of magnetic observatories and repeat stations, and from space, by means of satellites, leading to complex studies and modeling of the geomagnetic field. The data from repeat station surveys are an important source for secular variation studies, for modelling of the geomagnetic field at both local and global scales, enabling to improve and update the geomagnetic maps of certain areas at national and/or regional scales, and in practice for navigation purposes. The long-term change of the geomagnetic field – the secular variation – the change underwent by the main geomagnetic field produced through a dynamo process in the outer core is of great importance to geodynamo modeling. The secular variation studies deal with satellites data (presently SWARM constellation), observatory annual means and/or with repeat station data. The information from geomagnetic observatories is supplemented at regional level by repeated measurements in a station network called secular variation network. Generally, a country of Romania's size has only one observatory the Romanian one is known as Surlari geomagnetic observatory (IAGA code, SUA). Concerning the space-time evolution of the geomagnetic field over the Romanian territory, we have to mention the constant effort in the last 6 decades, since 1964, for monitoring by systematic survey of the geomagnetic field at the National Secular Variation Network, consisting of 26 repeat stations.

Reports on measurement results and their interpretation in terms of secular variation and normal field distribution, for the period between 1964 and 1980, were published (Atanasiu *et al.*, 1965; 1967; 1970; 1974; 1976; Demetrescu *et al.*, 1985), highlighting the need for continuous monitoring of this phenomena. Demetrescu *et al.* (2011) have reported measurements of the horizontal component at the repeat stations, between 1980 and 2004, these being interpreted according to insights from the analysis of long time series provided by geomagnetic observatories (Demetrescu and Dobrică, 2005).

The space-time evolution of the main geomagnetic field and of its secular variation has been published (Demetrescu *et al.*, 2011; Dobrică *et al.*, 2012, Greculeasa *et al.*, 2014–

2015), resulting in a complex and detailed model pointing out a certain space distribution that reflect the peculiarities of magnetic underground in the investigated area covered by the repeat stations network.

Based on measurements taken in the repeat stations from the national secular variation network, the geographical distribution of isogones (lines of equal magnetic declination), from 0.5 to 0.5 degrees, at various geomagnetic epochs, on the Romanian territory, was investigated as well, representing an important achievement useful not only for scientific but also for applied purposes, namely for national aeronautical safety and security (Isac *et al*., 2016).

At the European level, as a result of a better understanding of the role of data from repeat stations in deciphering the space-time evolution of the geomagnetic field, the magnetic declination map, based on magnetic declination measurements, for 2006 geomagnetic epoch, scale 1:20.000.000, was developed (Duma *et al*., 2012).

Becoming aware of the importance of repeat station survey, studies published by Brkic *et al*. (2013), Valach *et al*. (2016), Dominici *et al*. (2017), Csontos and Sugar (2024) reported on the data from certain repeat station networks.

In the last years there were some studies discussing the ground based data, repeat stations data included, and satellite data in the context of deriving, on various time intervals, regional geomagnetic field and secular variation models, over certain areas (Kotze and Korte, 2016; Nahayo and Korte, 2022; Puente-Borque *et al*., 2023).

In this study we focus on the annual values of geomagnetic horizontal component, taken between 2010 and 2020 in the stations of the secular variation network, in order to infer information on the space-time evolution of the geomagnetic field on the Romanian territory. We display data in Section 2 and briefly describe the steps taken to get the annual value at a repeat station and then in Section 3, results and discussion are presented, while Section 4 is dedicated to concluding remarks.

2. DATA

Since 2010, in Romania, geomagnetic measurements of the horizontal component (H), total intensity (F), magnetic declination (D) and magnetic inclination (I), have been performed at the repeat stations. The absolute values of declination and inclination have been taken by means of a DI-Flux theodolite (Bartington Mag 01H), and of total intensity by a proton magnetometer (Geometrics G-856). The horizontal component, although might be determined from D, I and F, was also controlled by two QHMs (Quartz Horizontal Magnetometer), in order to continue the measurement series started in 1964. As it was mentioned, systematic surveys, in the time interval 2010–2020, were conducted during yearly field campaigns at the Romanian repeat stations network (Fig. 1) consisting of 26 repeat stations, unevenly distributed on the country scale, and at the geomagnetic observatory at the beginning and end of each field campaign. After taking the measurements in a repeat station they are processed according to a well-established protocol to get geomagnetic element measured values. Then the achieved values are corrected for diurnal variation and translated to the time of the first measurement of the series taken according to the observations agreement, by means of continuous recordings from the Surlari geomagnetic observatory. Going further the obtained values are reduced to the middle of the year (geomagnetic epoch year.5) in which measurements were taken using annual means provided by the observatory.

Figure 1. Geographical distribution of repeat stations and the location of the geomagnetic observatory (SUA).

As an example, the measured geomagnetic elements in the year 2017 and reduced to the middle of the year, for the 26 repeat stations and the Surlari observatory, are presented in Table 1.

As regards the horizontal component of the geomagnetic field, the determined values according to the above mentioned methodology, available in the database of the Natural Fields Laboratory of the Institute of Geodynamics, in the time interval 2010–2020, are reported in Table 2.

Table 1

The elements of the geomagnetic field from the Romanian repeat stations of the secular variation network at the geomagnetic epoch 2017.5

No.	Station	λ (deg.)	ϕ (deg.)	H (nT)	D (deg.)	Z (nT)	F (nT)
1	Alexandria	25,367	43,967	23053	5,1361	42365	48233
2	Babadag	28,764	44,872	22597	6,2527	43285	48778
3	Bistriţa	24,486	47,195	21287	5,4053	44076	48948
4	Breţcu	26,357	46,058	21879	6,0688	43606	48787
5	Chişineu-Criş	21,540	46,544	21687	4,9122	43574	48673
6	Cluj	23,547	46,698	21524	5,4112	43776	48781
7	Costeşti	24,893	44,659	22698	5,2930	42769	48419
8	Deva	22,917	45,857	22103	4,9661	43138	48472
9	Dumbrăviţa	21,290	45,833	22078	5,2018	43093	48420
10	Gropeni	27,869	45,086	22460	6,0668	43237	48723
11	Herculane	22,449	44,922	22594	4,9564	42534	48164
12	Huşi	28,003	46,679	21560	6,6150	44181	49161
13	Lipova	21,724	46,052	21957	4,9901	43132	48400
14	Livada	23,134	47,849	20997	5,4275	44376	49093
15	Mizil	26,375	44,992	22493	5,6921	43120	48635
16	Negru-Vodă	28,243	43,820	23124	5,7092	42573	48635
17	Rădăuţi	25,948	47,821	20911	5,9274	44601	49260
18	Sadova	23,940	43,895	23224	5,0604	42208	48178
19	Săveni	26,883	47,966	20823	6,5310	45161	49730
20	Stamora	21,244	45,284	22402	4,9861	42647	48174
21	Strehaia	23,169	44,618	22770	5,4472	42425	48158
22	Şelimbăr	24,187	45,752	22163	5,1861	43235	48586
23	Şomcuta	23,439	47,500	21199	5,2861	44175	49000
24	Tonea	27,415	44,202	22972	5,9022	42657	48450
25	Vaida	21,985	47,252	21326	4,9290	43929	48832
26	Văratec	26,292	47,152	21321	5,9942	44306	49169
27	Surlari	26,253	44,680	22695	5,5733	42797	48443

Table 2

The horizontal component of the geomagnetic field (nT) from the Romanian repeat stations of the secular variation network between 2010–2020

Station/Year	2010.5	2011.5	2012.5	2013.5	2014.5	2015.5	2016.5	2017.5	2018.5	2019.5	2020.5
Saveni	20860	20831	20821	20840	20807	20829	20824	20823	20823	20823	20820
Livada	20962	20940	20969	20861	20985	20998	20994	20997	21008	21010	21028
Radauti	20885	20942	20770	20840	20903	20908	20915	20911	20916	20905	20941
Somcuta	21153	21139	21168	21069	21220	21194	21179	21199	21192	21186	21209
Vaida	21260	21229	21304	21268	21361	21321	21316	21326	21337	21339	21350
Bistrita	21259	21304	21273	21219	21246	21293	21291	21287	21304	21305	21319
Varatec	21236	21484	21271	21331	21304	21380	21327	21321	21334	21334	21353
Cluj	21450	21497	21456	21450	21508	21510	21520	21524	21528	21540	21535
Husi	21547	21502	21544	21576	21502	21595	21566	21560	21566	21566	21602
Chisineu-Cris	21592	21676	21612	21615	21697	21677	21672	21687	21690	21696	21730
Bretcu	21857	21859	21822	21835	21864	21873	21878	21879	21893	21899	0
Lipova	21935	21924	21942	21900	21990	21949	21941	21957	21974	21976	21993
Deva	22027	22068	22043	22049	22124	22097	22102	22103	22119	22094	22121
Dumbravita	21959	22056	22028	21885	22004	22058	22047	22078	22094	22077	22121
Şelimbar	22154	22188	22150	22111	22204	22153	22164	22163	22185	22184	22156
Stamora	22355	22378	22372	22317	22408	22385	22392	22402	22405	22388	0
Gropeni	22447	22405	22401	22467	22417	22478	22456	22460	22470	22483	22472
Mizil	22502	22570	22540	22489	22570	22554	22547	22493	22564	22559	22583
Herculane	22529	22568	22559	22572	22590	22579	22584	22594	22624	22603	22626
Babadag	22587	22557	22511	22555	22515	22604	22596	22597	22611	22613	0
Surlari	22683	22679	22678	22687	22695	22688	22696	22695	22704	22709	22710
Costesti	22624	22618	0	22711	22674	22686	22685	22698	22698	22705	22715
Strehaia	22749	22739	22678	22717	22774	22819	22753	22770	22780	22782	22818
Tonea	22931	22911	22955	22813	22985	22985	22969	22972	22977	22994	0
Alexandria	23026	22988	0	23007	23049	23044	23050	23053	23059	23055	0
Sadova	23235	23215	23233	23195	23229	23217	23222	23224	23244	23252	0
Negru-Voda	23113	23058	23055	23059	23060	23114	23115	23124	23134	23146	0

3. RESULTS AND DISCUSSION

The temporal evolution of horizontal component

The temporal evolution of the horizontal component measured at the 26 repeat stations of the Romanian secular variation network, in the time interval 2010–2020, is presented in Fig. 2.

In order to discuss the obtained temporal evolution of the geomagnetic field on the national territory we plotted, in Fig. 2, the annual values from the Surlari geomagnetic observatory, in the same period of time, as well. It can be seen as for the first part of the analyzed time interval, the data from the repeat stations show a higher variability compared to the data from observatory, while for the second part the variability is very small and of the same kind as that from the observatory.

When comparing the two types of geomagnetic data, from observatory and from repeat stations, the different quality of them must be taken into account. While the annual average value provided by a geomagnetic observatory is based on continuous measurements for the entire year, the value obtained for a repeat station is based on several measurements, usually taken in a single day of the year, to which a series of corrections are applied to get the representative value at the geomagnetic epoch corresponding to the middle of the year.

The variation of the horizontal component presents first, in the interval 2010–2014, a decrease by a few nT/year, in the case of the Surlari observatory, and a few tens of nT/year, in the case of repeated stations, followed by an almost constant variation, in the time interval 2014–2020, around the value of 0–10 nT/year.

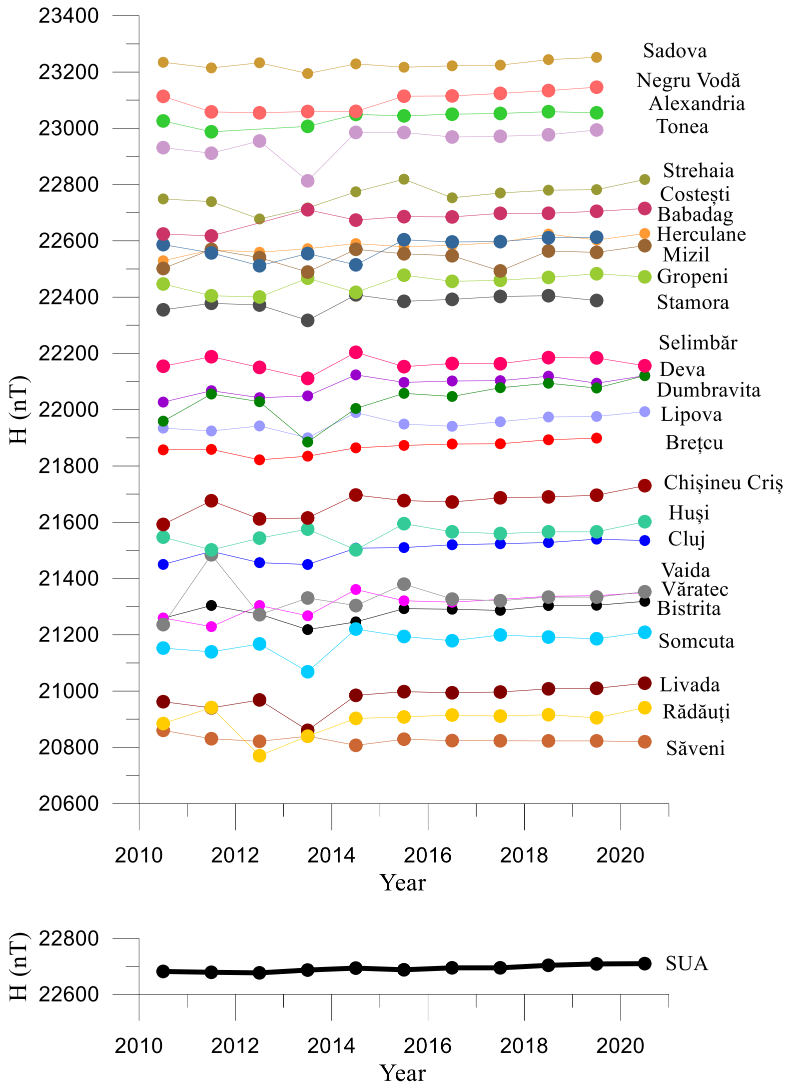

Figure 2. The temporal evolution of the horizontal component at repeat stations (upper panel) and Surlari geomagnetic observatory (lower panel) between 2010–2020.

Therefore, as a conclusion, the analysis of the temporal evolution of H component reveals, on the one hand, the coherence of the long term variation on the studied area, and, on the other hand, the presence of amplitude differences that might be assigned to the local magnetic structure of the underground, characteristic of each individual repeat station.

The spatial evolution of horizontal component

As it seems, there are small differences from year to year in comparison to the order of magnitude of H values, which implies a similar spatial evolution of this geomagnetic component over Romanian territory. Consequently, we display, as an example, in Fig. 3, only the geographical distribution of horizontal component at the geomagnetic epoch 2017.5. The horizontal component of the geomagnetic field on the Romanian territory varied approximately uniform from a value of about 20770 nT in the northern part of the country to a value of about 23250 nT in the southern part.

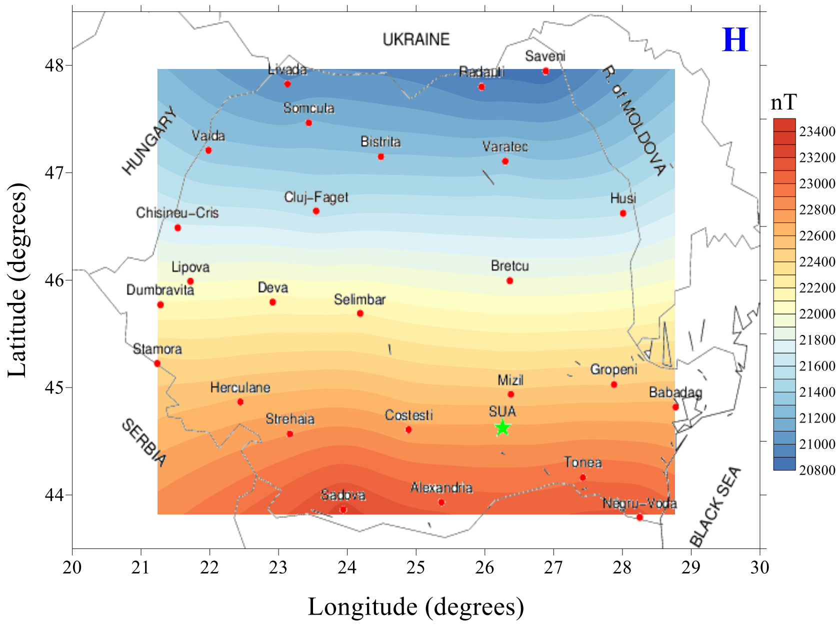

Figure 3. The geographical distribution of the horizontal component over Romanian territory at geomagnetic epoch 2017.5.

The secular variation of the geomagnetic field

Concerning the determination of the long-term change of the main geomagnetic field, it means the secular variation, the temporal evolution of the horizontal component of geomagnetic field is investigated. It can be noted that, in the time period 2010–2020, at each of the repeat stations, the H component variation might be considered, in a first instance, as linear. To prove this claim, we show in Fig. 4, as an example, the horizontal component variation, in terms of annual values, at the Surlari observatory and at two repeat stations (Herculane and Cluj). The shape of that evolution indicates the possibility of describing the secular variation in the analyzed period as being given by the slope of the straight line through the points.

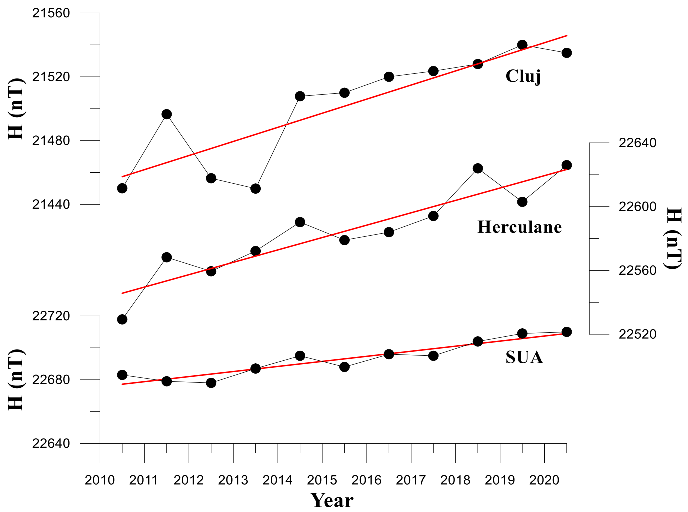

Figure 4. The annual values (points) of H at SUA and two repeat stations together with the best linear fit (red lines) describing the average secular variation between 2010–2020.

The secular variation has computed for each of the repeat stations and the cooresponding values have been mapped at the country scale. In Fig. 5, the geographical distribution of the secular variation of geomagnetic field is displayed. The order of magnitude of the secular variation, in the time period 2010–2020, is of about 2–13 nT/year, as evidenced by analysing the temporal evolution of H geomagnetic component.

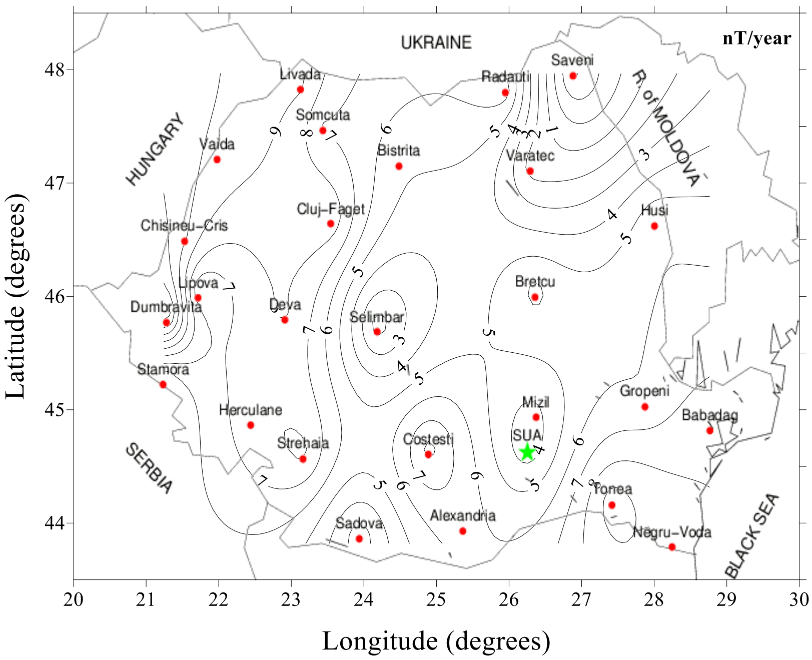

Figure 5. The geographical distribution of the average secular variation in the interval 2010–2020 of the horizontal component.

The distribution of Fig. 5 shows particular regional patterns, with smaller values in NE and central part of the study area and higher values on the most western part, which probably are due to lateral variations of the magnetic properties of crustal rocks. It is evident at this time that the analysed time segment, 2010–2020, is too short to allow approaching the more complex studies such as the external sunspot cycle variation present in data, having in view that we are looking at about one solar cycle (~11 year), or the induced fields in the crust and mantle.

More detailed studies, taking into account the representation of the field by means of isolines described by second degree polynomials in geographical coordinates would ensure a very good approximation of the evolution of the geomagnetic field, will be tackled later.

4. CONCLUDING REMARKS

The evolution of the geomagnetic field over Romanian territory, both in space and time, has been reported by analysing the geomagnetic horizontal component measurements performed at the repeat stations of the secular variation network between 2010 and 2020.

The analysis reveals both the coherence of the long term variation on the studied area and the presence of amplitude differences that might be assigned to the local magnetic structure of the underground, characteristic of each individual repeat station. In the study time interval, the horizontal component of the geomagnetic field on the Romanian territory is increasing approximately uniform from north to south from the values of about 20770 nT to 23250 nT, and its secular variation, with values ranging from few nT/year to few tens nT/year, is presenting regional patterns that might be related to the lateral variations of magnetic properties of crustal rocks

The data presented in this paper should be regarded in the context of long-term variations of the geomagnetic field and would be the subject of the future studies.

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