ABSOLUTE GEOMAGNETIC MEASUREMENTS – A NATIONAL AIR TRAFFIC SAFETY PRIORITY

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Abstract. The geomagnetism team at the Surlari National Geomagnetic Observatory aims to provide to the Romanian Air Traffic Services Administration with services and products as follows: runway azimuth determination, magnetic declination information and isogonal maps and magnetic declination data for the area around the airport. The Earth's magnetic field is composed of the contribution of several sources. Even if we explore various measurements and models, mainly the variation of the normal field for aeronautical applications, the local and regional characteristics of the declination are useful for some types of aeronautical maps such as approach instruments, SID, STAR, approach visuals, etc. Periodic geomagnetic measurements are required for this purpose. Together with ROMATSA aeronautical experts, the observatory contributes through a standard procedure to the characterization, almost in real time, of the spatial distribution and the temporal evolution of the internal geomagnetic field for the improvement of aeronautical and airport safety on the Romanian territory. Here we demonstrate the local peculiarity of the geomagnetic field and the need to periodically update the declination over an airport. This activity is an interesting application of geomagnetic data collected by magnetic observatories.

Keywords: declination, geomagnetic observatories, security, air traffic.

Rezumat. Măsurători geomagnetice absolute – o prioritate pentru siguranța traficului aerian național. Echipa de geomagnetism de la Observatorul Național Geomagnetic Surlari își propune să ofere Administrației Serviciilor de Trafic Aerian din România servicii și produse astfel: determinarea azimutului pistei, informații despre declinația magnetică și hărți izogonale și date despre declinația magnetică pentru zona din jurul aeroportului. Câmpul magnetic al Pământului este compus din contribuția mai multor surse. Chiar dacă explorăm prin măsurători și modele, în special variația câmpului normal pentru aplicații aeronautice, caracteristicile locale și regionale ale declinației sunt utile pentru unele tipuri de hărți aeronautice precum instrumente de apropiere, SID, STAR, vizuale de apropiere etc. În acest scop, sunt necesare măsurători geomagnetice periodice. Împreună cu experții aeronautici ROMATSA, observatorul contribuie printr-o procedură standard la caracterizarea, aproape în timp real, a distribuției spațiale și a evoluției temporale a câmpului geomagnetic intern pentru îmbunătățirea siguranței aeronautice și aeroportuare pe teritoriul României. Aici demonstrăm particularitatea locală a câmpului geomagnetic și necesitatea actualizării periodice a declinației în apropierea aeroporturilor. Această activitate este o aplicație interesantă a datelor geomagnetice colectate de observatoarele magnetice.

Cuvinte cheie: declinație, observatoare geomagnetice, securitate, trafic aerian.

INTRODUCTION

The Earth's magnetic field, also called the geomagnetic field, is defined as the magnetic field produced by all sources inside and outside the solid Earth until the magnetopause, the limit at which the magnetic field manifests. Beyond this limit there is the interplanetary magnetic field (IMF), generated by solar activity, being carried by the solar wind. Today it is a certainty that the magnetic declination has an important spatial-temporal dynamics and the precise knowledge of its value at a given moment is of particular importance for air and naval navigation (IANCU, 2019).

From one point to another the geomagnetic field shows variations, sometimes these being quite significant, both in terms of intensity and direction. This has been observed through continuous monitoring (currently the geomagnetic field is monitored by measurements from geomagnetic observatories, repeated stations on national networks and from space via satellites).

If the geographic north is placed on the axis of the earth's rotation, the magnetic north, the one indicated by the compasses, is not fixed, and therefore is not located in the same place as the geographic north. In 1492, while crossing the Atlantic, Columbus noticed that when using the compass, the north indicated by it was different from the calculations that took into account the position of the stars. He also noted that the compass clearly changed direction as its ships moved away from the European continent, approaching the American continent, expressing the local character of the magnetic declination.

The magnetic declination is the angle between the geographic north direction and the magnetic north direction at a given point and is measured in degrees. The declination is measured clockwise and has values in the range 0 - 360º. The lines joining the points with the same value of the magnetic declination are called isogons. On the Romanian territory the declination varies between 5° - 7° for the year 2020 (Fig. 1).

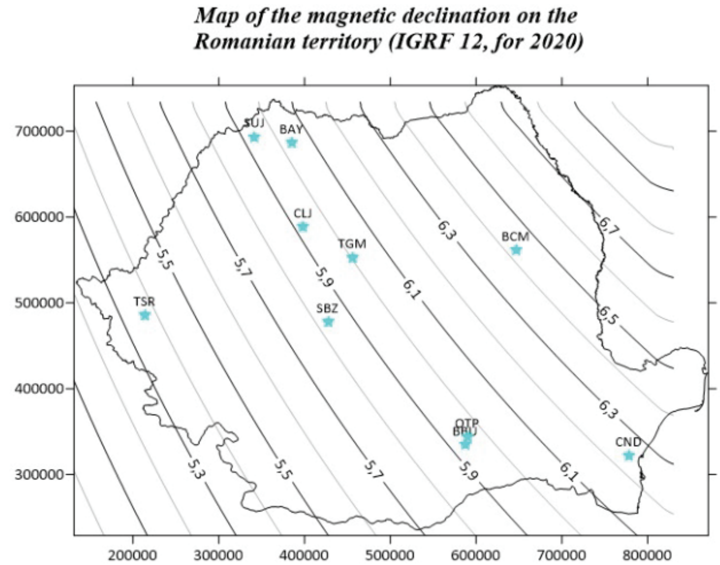


Figure 1. Map of the magnetic declination on the Romanian territory using IGRF 12 model, epoch 2020.5 (THÉBAULT et al., 2015) (original).

METHODS

The periodic monitoring of secular variation at national level is an essential component in minimizing risks in air traffic. The calculation of the declination of the geomagnetic field in the areas with airport facility, as opposed to the calculation of the declination in the repetition network for determining the secular variation, must also take into account the local component produced by the crustal geomagnetic field. This is useful because in navigation one should know the value of the declination generated by all permanent sources of the geomagnetic field. In the case of secular variation, this effect is removed by selecting stations in areas without anomalous sources in the subsoil (ferrous ore deposits, ultra-basic and basic rocks, sedimentary rocks with a high magnetite content).

Starting with 1991, the Romanian Administration of Air Traffic Services (ROMATSA R.A) provides air traffic services for aircraft performing GAT (General Air Traffic) flights under IFR (instrument flight rules) both in the Romanian airspace and in any other airspace delegated to Romania by international agreements. ROMATSA ensures the unitary management and development of the aircraft management activities (***. www.romatsa.ro).

Measurements carried out in 2010, 2018 and 2020 near airports were taken into account. These were carried out by specialists from the Surlari National Geomagnetic Observatory, which is also a reference station for drawing up national geomagnetic maps.

The Surlari Observatory plays a prominent role as national reference station and provides long time series since 1943 (CONSTANTINESCU, 1943). Starting with 1996, as INTERMAGNET member (***. www.intermagnet.org), Surlari (SUA – International Association of Geomagnetism and Aeronomy (IAGA) assigned code) has to ensure the highest quality for produced data, in accordance with the standards set up by IAGA Working Group V-OBS (***. www.bgs.ac.uk/iaga/vobs) (ISAC et al., 2018).

The measurement technique for determining the absolute values of the elements of the vector defining the magnetic field at a given point at a given time is as follows (NEWITT et al., 1996):

- determinations with a proton magnetometer, with the probe placed above the station terminal, at the same height as the other devices used and then at a point 10-15 m from the terminal - measurements (every 5 seconds) throughout the performance of the others measurements at the station;
- two - three determinations of the declination D, alternating with two or three determinations of the inclination, executed with the magnetometer DI Flux;
- theodolite visa to the star to determine the azimuth (geographical north or true north) - at least 10 readings;
- visas to azimuthal landmarks;
- 10 final measurements with a proton magnetometer on the site at the beginning of operations;
- continuous measurements of the magnetic field components (X, Y, Z) with a vector magnetometer, at approximately 15 m from the station, for 5-6 hours.

Both at the beginning and at the end of the field campaign, comparative measurements were performed on the reference non-magnetic measurement pillar within the Surlari geomagnetic observatory. In this way, the measurements performed in the field were validated and possible errors were evaluated.

Equipment used. Observer practice is guided by the IAGA Handbook (JERZY & SUCKSDORFF, 1996), and in order to maintain standards at the INTERMAGNET level (***. www.intermagnet.org), the system of continuous acquisition of magnetic field variations is in accordance with the observer routine observed by all planetary geomagnetic observatories. It consists of:

- FGE triaxial fluxgate magnetometer;
- Overhauser GEM Systems GSM90 proton scalar magnetometer;
- Data logger MAGDALOG.

The FGE vector magnetometer is built by the Danish Meteorological Institute using three commercial fluxgate sensors, mounted in a 12x12x12 cm3 marble cube by means of quartz tubes containing compensation coils that ensure maximum stability or drift up to 3 nT / year. The temperature variation coefficient of the sensor is below 0.2 nT / °C and of the electronic part, below 0.1 nT/ °C.

For a good baseline stability (Fig. 2), the suspended version of the marble cube, by means of a cardan-type suspension, is adopted by most geomagnetic observatories. In this way, the drift of the baseline is below 2-3 nT/year, a result obtained even where a classic fluxgate would have a drift of over 100 nT/year. The error of alignment of the three vector components is of maximum 2 mrad (7 min. of arc), and that of the cardan suspension is of +/- 0.5°. The sensitivity of the instrument is 400 nT/V.

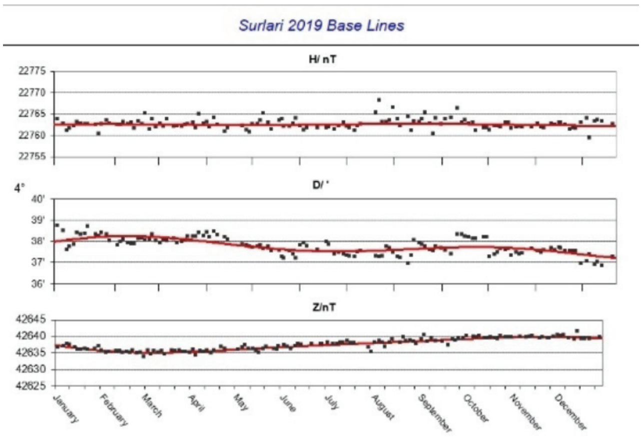


Figure 2. 2019 Baseline from Surlari National Geomagnetic Observatory (original).

The Overhauser GSM90 proton magnetometer is a scalar magnetometer designed for magnetic observatories or other applications (volcanology), where stability and accuracy are strictly necessary. With a resolution of 0.01 nT, an absolute accuracy of 0.2 nT and a drift of 0.05 nT / year, it can be used successfully in calculating basic values for a magnetic observer.

The MAGDALOG data logger was created at the Adolf Schmidt Observatory, Niemegk, especially for the acquisition of geomagnetic data, by the observer, since 1994, being a precursor of the G-DAS 2002 developed by the British Geological Survey, also for the same purpose, but MAGDALOG being further improved in 2001. System sampling rate: 2 Hz vector FGE, 0.2 Hz scalar GSM. The time base of the logger date is given by a built-in GPS.

Vector recording (FGE) and scalar (GSM) recording systems are considered classics and are used in many traditional geomagnetic observatories in countries such as Japan, Germany, Denmark, Norway, Finland, Spain, the United Kingdom, South Africa, Hungary, Bulgaria, Indonesia, New Zealand, Namibia, international stations in Antarctica, etc.

The declination was determined using a unidirectional Bartington fluxgate magnetometer mounted on a non-magnetic theodolite (IANCU et al., 2012). To determine the declination, a set of four determinations of the direction of the magnetic field vector and one of ten measurements of the position of the sun at the meridian were performed for each point.

Following these determinations, the position of the geographical and magnetic meridians for the station located (solar azimuth G (i)) can be determined on the basis of a calculation formula:

$$G(i) = H(i) - arctg\frac{\sin TT(i)\cos D(i)}{\sin F\cos TT(i) - \cos F\sin D(i)}$$

where:

G(i) is the angle corresponding to the meridian of the place geographically;

H(i) is the angle read on the horizontal circle of theodolite on the time T(i) when the all solar disk was framed in the collimator of theodolite; φ is the latitude in degrees of arc;

D is the average declination of the sun for the time interval of measurements;

T(i) is the time to achieve measurement;

TT(i) = T(i)×15+ λ + (ΔEt / 24)×T(i)+ Eti +180 (2)

λ is longitude;

ΔEt = Eti − Et f (3)

ΔEt represents the difference between time at beginning (moment in which was made the first measurement and the moment the final measurement was made). Et values are taken from the site https://gml.noaa.gov/grad/solcalc/azel.html.

Eti is the initial equation of time;

Et f is the final equation of time.

Declination was calculated by the formula:

D (i) = Md-G (i) (4) where

Md is the average reading on the horizontal circle of theodolite when the sensor was positioned in the direction of the horizontal component of geomagnetic field. After determining the declination, each direction of the horizontal component magnetic field vector was measured four times (SU: South with magnetometer up, ND: North with magnetometer down, SD: South with magnetometer down, NU: North with magnetometer up) and the total field vector inclination was calculated according to the following formula:

$$I=180 - ((180 - SU) + (360 - ND) + (SD - 180) + NU)/4$$

Having determined the absolute values of declination, inclination and total field, other components of the geomagnetic field were calculated (Hx –North, Hy – East, Hz – vertical down).

The accuracy of determining the instantaneous value of the magnetic declination was ± 2 seconds of sexagesimal degree, and that of the total geomagnetic field T is ± 1 nT (nano Tesla - unit of measurement in SI for the magnetic field = 10-9 T) (ASIMOPOLOS et al., 2011).

Both Trimble GeoXH GPS equipment with an accuracy of decimeters (220 channel GNSS receiver with real-time H-Star technology) with the possibility of field processing and with the possibility of subsequent repositioning by guiding the user through a graphical representation as well as a Garmin GPS for verification.

The reduction technique to a certain epoch consists of reducing the field instantaneous data to the Surlari Observatory annual mean data for the year/epoch needed. The reduction for declination was performed for each airport and for epochs 2010.5, 2015.5 and 2018.5. This is done by adding to the measured value the difference between the value of the declination recorded at Surlari on the day of measurement, corrected with the diurnal variation and the average annual value determined for the Surlari Observatory at the epoch of reporting.

DCorrdiurn_Surlari = D (tiSurlari) + ΔDdiurn_Surlari where

D (tiSurlari)= is the value measured at Surlari at the initial moment of the onfield measurement (ti)

ΔDdiurn_Surlari=the diurnal variation correction at Surlari observatory for the moment of field measurement

DCorrdiurn_Surlari = the value of the declination recorded at Surlari on the day of measurement, corrected with the daily variation

DRed_2021.5 = D (ti) + (DCorrdiurn_Surlari- Danual mean_2021.5) where

D (ti) = declination value measured in the airport area at time ti

Danual mean_2021.5) = the annual mean value of the declination at the Surlari Observatory, calculated for the epoch at which the reduction is desired (SAINT-LOUIS, 2008).

Bringing to the same epoch can be done both for epochs before the measurement and for epochs after this date. For example, the data measured in 2022 can only be reduced to epochs lower than 2021.5. but the data measured in 2010, 2015, 2018 can be brought to the epoch 2021, 5 or to epochs closer to the moment of the measurement.

The goal was to obtain the magnetic element D for all the airports, using the method explained above. The results are given in Tables 1, 2 and 3.

RESULTS AND DISCUSSIONS

Two methods were used to calculate the diurnal variation correction, depending on the degree of disturbance of the day. For the quiet days the average value was used for the interval 23:00 – 01:00 LT, while in the case of the disturbed days the average value for the same time interval was used, but the 5 quiet days of the respective month were taken into account.

Following the processing of the measured data (Tables 1-3) in the field, the 3 maps (Fig. 3) resulted, which show how the magnetic declination varied for each area. We can see that the declination varies, for the analysed period, with values between 0.10° - 0.18° / year depending on the area where the airport is located, the variation is to the west.

In the 3 images (Fig. 3) it can be highlighted very well that the local anomalies keep their position even if the declination varies in absolute value. And from here it results that the measurements are performed correctly and the anomalies are real and not generated by measurement errors. The local anomalies can be highlighted both in figure 3, where we find the measurements performed in the area of the airports, as well as in figure 4 where we have the difference between the measurements and the IGRF 12 model. The latter highlights more clearly the position and shape of the anomalies which are located over Cluj (CLJ) and Targu Mures (TGM) airports at the 2010.5 epoch, over Targu Mures (TGM) and Brasov (BRV) at the 2018.5 epoch and over Targu Mures (TGM) only at the 2018.5 epoch.

Table 1. Decline values in airport areas for 2010.

No. crt.	Airport name / location	Airport code	Long. (°)	Lat. (°)	D (°)
1	International Airport Arad - Arad	ARW	21,27316667	46,16952778	4,1764
2	International Airport ″George Enescu″ - Bacău	BCM	26,91386111	46,53263889	5,5017
3	International Airport Maramureș – Baia Mare	BAY	23,46994444	47,66158333	4,9258
4	International Airport ″Aurel Vlaicu″ - Băneasa	BBU	26,10336111	44,50072222	4,671972
5	International Airport Craiova – Craiova	CRA	23,91202778	44,31763889	4,464389
6	International Airport ″Avram Iancu″ - Cluj Napoca	CLJ	23,67102778	46,78455556	4,8253
7	International Airport Iași – Iași	IAS	27,61813889	47,175	4,9156
8	International Airport ″Mihail Kogălniceanu″- Constanța	CND	28,49063889	44,34063889	4,956
9	International Airport Oradea – Oradea	OMR	21,89713889	47,03158333	4,3417
10	International Airport ″Henri Coandă″ - Otopeni	OTP	26,13436111	44,58208333	4,4433
11	International Airport Satu Mare – Satu Mare	SUJ	22,89286111	47,71994444	4,3417
12	International Airport ″Ștefan ce Mare″ - Suceava	SCV	26,35188889	47,68361111	5,4533
13	International Airport Transilvania – Târgu Mureș	TGM	24,4325	46,47208333	4,1722
14	International Airport ″Traian Vuia″ - Timișoara	TSR	21,31897222	45,80727778	4,1764
15	Aeroportul ″Delat Dunării″ - Tulcea	TCE	28,71975	45,06213889	4,86
16	Surlari National Geomagnetic Observatory - reference station	SUA	26,25361111	44,67777778	4,837

Table 2. Decline values in airport areas for 2018.

No. crt.	Airport name / location	Airport code	Long. (°)	Lat. (°)	D (°)
1	International Airport Arad - Arad	ARW	21,27316667	46,16952778	5,015754
2	International Airport ″George Enescu″ - Bacău	BCM	26,91386111	46,53263889	6,390969
3	International Airport Maramureș – Baia Mare	BAY	23,46994444	47,66158333	5,807644
4	International Airport Brașov – Ghimbav	BRV	25,52719444	45,687	5,497967
5	International Airport Craiova – Craiova	CRA	23,91202778	44,31763889	5,355208
6	Aeroportul International ″Avram Iancu″ - Cluj Napoca	CLJ	23,67102778	46,78455556	5,637397
7	International Airport Iași – Iași	IAS	27,61813889	47,175	6,176505
8	International Airport ″Mihail Kogălniceanu″- Constanța	CND	28,49063889	44,34063889	5,928607
9	International Airport Oradea – Oradea	OMR	21,89713889	47,03158333	5,174299
10	International Airport Satu Mare – Satu Mare	SUJ	22,89286111	47,71994444	5,520422
11	International Airport Sibiu - Sibiu	SBZ	24,06377778	45,79122222	5,600815
12	International Airport ″Ștefan ce Mare″ - Suceava	SCV	26,35188889	47,68361111	6,268845
13	International Airport Transilvania – Târgu Mureș	TGM	24,4325	46,47208333	5,489561
14	International Airport ″Traian Vuia″ - Timișoara	TSR	21,31897222	45,80727778	5,077474
15	Aeroportul ″Delat Dunării″ - Tulcea	TCE	28,71975	45,06213889	6,300127
16	Surlari National Geomagnetic Observatory - reference station	SUA	26,25361111	44,67777778	5,747

Table 3. Decline values in airport areas for 2020.

No. crt.	Airport name / location	Airport code	Long. (°)	Lat. (°)	D (°)
1	International Airport ″George Enescu″ - Bacău	BCM	26,91386111	46,53263889	6,645144
2	International Airport Maramureș – Baia Mare	BAY	23,46994444	47,66158333	6,362418
3	International Airport ″Aurel Vlaicu″ - Băneasa	BBU	26,10336111	44,50072222	6,107476
4	Aeroportul International ″Avram Iancu″ - Cluj Napoca	CLJ	23,67102778	46,78455556	6,250899
5	International Airport ″Mihail Kogălniceanu″- Constanța	CND	28,49063889	44,34063889	6,482692
6	International Airport ″Henri Coandă″ - Otopeni	OTP	26,13436111	44,58208333	6,007037
7	International Airport Satu Mare – Satu Mare	SUJ	22,89286111	47,71994444	5,944973
8	International Airport Sibiu - Sibiu	SBZ	24,06377778	45,79122222	6,180319
9	International Airport Transilvania – Târgu Mureș	TGM	24,4325	46,47208333	5,745417
10	International Airport ″Traian Vuia″ - Timișoara	TSR	21,31897222	45,80727778	5,729917
11	Surlari National Geomagnetic Observatory - reference station	SUA	26,25361111	44,67777778	5,916

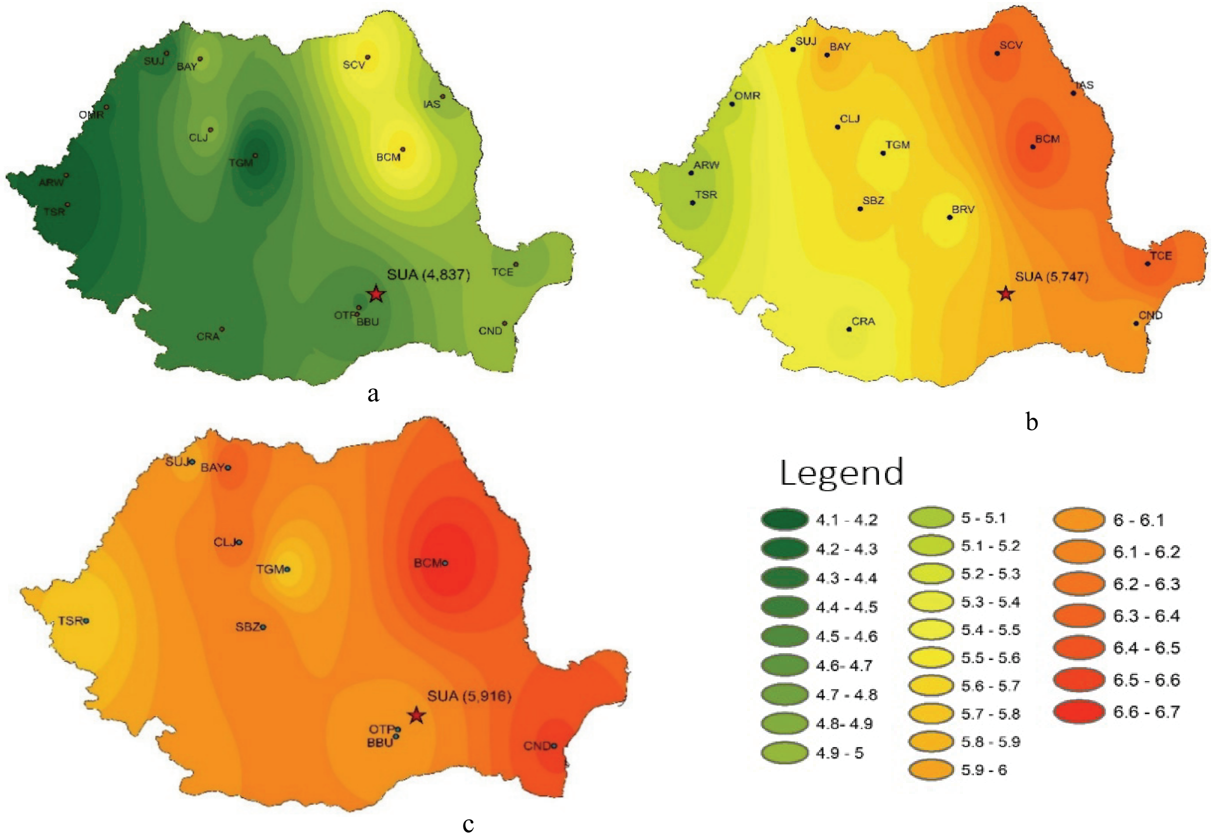
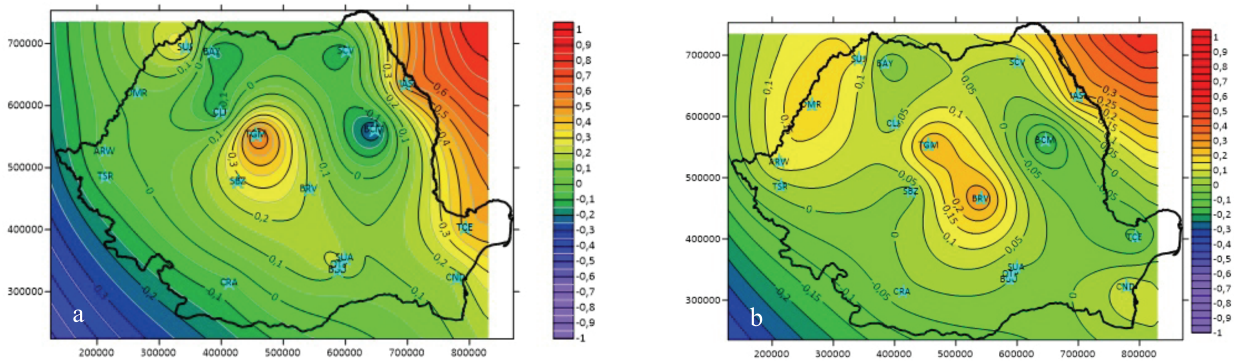


Figure 3. Magnetic declination in the area of airports for the epoch: a) 2010.5; b) 2018.5; c) 2020.5 (original).



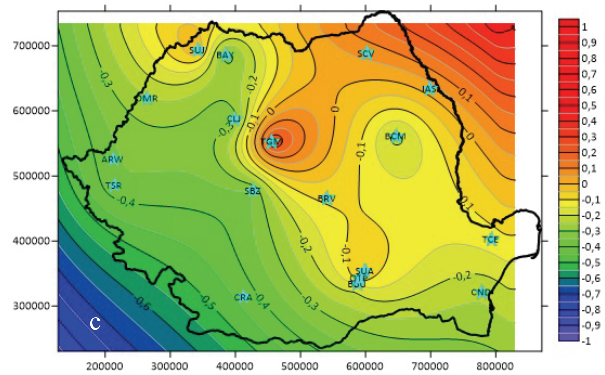


Figure 4. The differences between the measurements in the airport area and the IGRF model for the epochs: a) 2010.5, b) 2018.5, c) 2020.5 (original).

CONCLUSIONS

It is emphasized that the declination value for any location is affected by local natural anomalous sources and the secular variation of the geomagnetic field. In the case of airport facilities and other air navigation facilities (radio beacons, radio beacons) these variations can be sources of risks for air navigation and for this reason it is recommended to resume measurements in airport areas, facilities and, in particular, the compensation platforms of the companies that ensure the production and maintenance of the aircraft, for a period of about 3 years. Even today, the magnetic compass is still the basic navigation instrument on aircrafts and it would be used in exceptional cases when radio navigation systems do not operate reliably. Surveyors must have a correct understanding of geomagnetism and due to that, the personnel from the Surlari National Geomagnetic Observatory is trained to perform such airport geomagnetic survey.

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Received: April 15, 2022
Accepted: August 10, 2022