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# Report on the magnetic survey in Slovakia for the 2014.5 epoch

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**Abstract:** The models of the distribution of the elements of the geomagnetic field must be updated regularly. For this purpose geomagnetic measurements have to be carried out repeatedly at geomagnetic observatories as well as at temporary observation points. In this paper the results of the geomagnetic survey that was carried out in Slovakia in the year 2014 are presented. The measurements were performed at 12 observation points and they were reduced to the 2014.5 epoch. The secular variation between 2007.5 and 2014.5 was also calculated. The obtained values of the geomagnetic elements were used for calculating a 1st-degree polynomial model for the distribution of magnetic declination, inclination and total field. The comparison with the IGRF model showed that the polynomial model provided more accurate results for magnetic inclination and total field. For magnetic declination, on the contrary, the IGRF model produced slightly better results than the polynomial model.

**Key words:** geomagnetic field, secular variations, polynomial model

## 1. Introduction

There is a well known fact that the vector of the geomagnetic field on the Earth's surface changes its strength and its direction from one place to another. Moreover, this field undergoes temporal changes. These facts need to be considered when employing information about the geomagnetic field, for instance when utilizing classical magnetic compass. A model of spatial distribution of the geomagnetic field is thus required, which describes the field distribution for the desired time instant.

The model must obviously be updated regularly, which requires performance of new measurements of the geomagnetic field. The places where

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the measurements have to be performed, should be reasonably distributed all over the globe or at least over a local area: The former case is typical for global models, such as the International Geomagnetic Reference Field (IGRF)[1] and the World Magnetic Model (WMM)[2]. In the latter case, local models can be created or updated. The 1st-degree polynomial models of the distribution of the geomagnetic field in Slovakia, which were published in *Váczyová (1999), Valach et al. (2004), Valach et al. (2006), Dolinský et al. (2009)*, are examples of such a local model.

In 2004 the necessity for repeating geomagnetic measurements led to the establishment of a national magnetic repeat stations network. At the beginning, the network consisted of six stations (*Valach et al., 2004; Valach et al., 2006*) and the network has been reoccupied every two years. However, the number of stabilized repeat stations gradually decreased because some of them were lost due to growing artificial noise. It was eventually decided to compensate for lost stations by a slightly denser network of provisional observation points.

This paper reports the results of the last magnetic survey that was carried out in Slovakia in 2014. Here only two stabilized stations were used: One of them was the Hurbanovo Magnetic Observatory, which is situated in the southwest part of Slovakia. The other station was Úbrež, which is situated at the opposite end of the country. In addition to these two stations, the geomagnetic field was measured at ten provisional points (see Table 1).

Further in the paper, the 1st-degree polynomial model for three geomagnetic elements is presented. The measured data are then compared with this polynomial model as well as with the IGRF model. Lastly, the values of the geomagnetic field in the 2014.5 epoch are compared with the data of the detailed magnetic survey that was carried out in the epoch 2007.5 by *Dolinský et al. (2009)*.

## 2. Measuring instruments and data processing method

The standard method, which is described in *Newitt et al. (1996)*, was used for the measurements of the geomagnetic field at the observation points.

[1] http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html
[2] https://www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml

This method combines two measuring instruments: (1) a proton precession magnetometer for gauging the total strength of the magnetic field ($F$) and (2) a DI-flux theodolite, which is an instrument for determination of the direction of the vector of the magnetic field. This direction is specified by magnetic declination ($D$) and magnetic inclination ($I$). The types of the instruments used in this paper were as follows: (1) proton magnetometers EDA and PMG-1 and (2) DI-flux theodolite Zeiss Theo 015B furnished with magnetometer Elsec 810.

At most of the observation points, the azimuths of marks had to be determined in addition to the geomagnetic measurements. For this purpose observations of the Sun were used. The instrument employed for this purpose was the theodolite Zeiss Theo 010.

As the geomagnetic field is a vector field, three geomagnetic elements are required for determining it at each observation point. In this paper, elements $D$, $I$ and $F$ were chosen because they are the elements that were directly measured. If we chose another triad of elements, the measuring error would rise as a result of the conversion between the elements.

The measurements were carried out during the spring-to-autumn season of the year 2014 and their results were reduced to the 2014.5 epoch. The process of the reduction assumed that on the whole area of the country all the transient variations of the geomagnetic field are identical. The records of the geomagnetic field from the Hurbanovo Geomagnetic Observatory were utilized in this process.

The reduction was performed using the following formula:

$$E_{point,\,2014.5} = E_{point,\,t} - (E_{Hurbanovo,\,t} - E_{Hurbanovo,\,2014.5}), \tag{1}$$

where the meaning of the variables are as follows: $E_{point,\,2014.5}$ denotes the value of one of the geomagnetic elements $D$, $I$ or $F$ for the epoch 2014.5, $E_{point,\,t}$ stands for the same element but it is its value that was measured at the observation point at time $t$, $E_{Hurbanovo,\,t}$ is the value of the same element at the geomagnetic observatory Hurbanovo at the time of the measurement $t$, and $E_{Hurbanovo,\,2014.5}$ is the value of that element at Hurbanovo for the epoch 2014.5. The resulting values of $E_{point,\,2014.5}$ are reviewed in the following section.

To reveal the main features of the distribution of the geomagnetic field throughout the country, two basic approaches seem to be possible: (a) The first one needs to use a high number of observation points distributed regularly over the whole country. Calculating a polynomial model with the least-squares method, the high number of points is assumed to eliminate the local anomalies. Such an approach was used by *Dolinský et al. (2009)* in the magnetic survey for the 2007.5 epoch. (b) In the second approach, the observation points have to be located outside the known local anomalies, which were identified in a previous detailed magnetic survey. Here the elimination of the local anomalies is not based on the high number of observation points. This second approach is employed in our paper.

## 3. Results

The data that were measured at 12 observation points in the middle of the year 2014 and thereafter reduced to the epoch 2014.5 are listed in Table 1. The observation point Hurbanovo is the Hurbanovo Geomagnetic Observatory itself. The observation point Úbrež is a stabilized repeat station, at which the magnetic measurements have been repeated every two years. The rest of the observation points were provisional ground survey points, which

Table 1. Numerical results of the magnetic survey. The data are reduced to the 2014.5 epoch. The values from Bošany were excluded from calculating the model of the distribution of the geomagnetic field because they appeared to be anomalous.

| Observation point | Geographic coordinates | | Declination | Inclination | Total field |
|---|---|---|---|---|---|
| | Latitude | Longitude | | | [nT] |
| Hurbanovo | 47.880° | 18.200° | 4° 09.9′ | 64° 18.9′ | 48564.9 |
| Šamorín | 48.046° | 17.341° | 4° 04.6′ | 64° 30.1′ | 48515.7 |
| Očkov | 48.650° | 17.752° | 4° 06.1′ | 64° 58.0′ | 48746.9 |
| Bošany | 48.558° | 18.239° | 3° 32.8′ | 64° 58.9′ | 48739.1 |
| Makov | 49.358° | 18.432° | 4° 19.6′ | 65° 35.1′ | 49048.9 |
| Šuňava | 49.038° | 20.076° | 4° 42.7′ | 65° 24.7′ | 48976.4 |
| Úbrež | 48.790° | 22.125° | 5° 08.3′ | 65° 19.0′ | 49067.9 |
| Turčianske Kľačany | 49.117° | 18.957° | 4° 30.1′ | 65° 26.4′ | 48914.9 |
| Zborov | 49.377° | 21.328° | 5° 07.2′ | 65° 44.8′ | 49183.6 |
| Opavské Lazy | 48.211° | 19.168° | 4° 23.1′ | 64° 46.1′ | 48754.7 |
| Vyšný Skálnik | 48.458° | 19.968° | 4° 44.4′ | 65° 01.8′ | 48884.1 |
| Ladomirová | 49.320° | 21.632° | — | — | 49195.4 |

were not stabilized for the future use.

Which is striking in Table 1, is the anomalous value of magnetic declination at the observation point Bošany. The value was re-measured several times during several re-occupations, including re-measuring the azimuth of the mark. These repeated measurements confirmed that the measured value is true and the locality is probably a part of a relatively strong local anomaly belonging to the Tribeč Mountains.Checking thoroughly the map of isogones for the 2007.5 epoch by *Dolinský et al. (2009)* we found that the locality of Bošany is likely affected by the edge of the Central-Slovakian anomaly. As was decided in Section 2, the local anomalies have to be avoided. Therefore, the anomalous values of Bošany were excluded from calculating the model of the distribution of the geomagnetic field in the following section.

In Table 1, there are also missing values of declination and inclination for the observation point Ladomirová. The reason for this is not any local anomaly; it is merely caused by a failure in the measuring instrument (DI-flux theodolite). From this place only the value of the total field was used in this study. We do not expect that these missing values could perceptibly affect the model because there is another observation point (Zborov) close to Ladomirová, for which all three geomagnetic elements were determined.

### 3.1. First-degree polynomial model

The numerical results of the magnetic survey, which were presented above, were then processed statistically. It was found that the distributions of the geomagnetic field elements $D$, $I$ and $F$ can be expressed by the 1st-degree polynomial model:

$$D_{2014.5} = (4°11.4' \pm 1.6') + (5.0'/° \pm 1.8'/°).\Delta\varphi + \\ + (14.2'/° \pm 0.6'/°).\Delta\lambda\,, \quad (2)$$

$$I_{2014.5} = (64°23.9' \pm 1.2') + (47.7'/° \pm 1.4'/°).\Delta\varphi + \\ + (3.4'/° \pm 0.5'/°).\Delta\lambda\,, \quad (3)$$

$$F_{2014.5} = (48564\ \mathrm{nT} \pm 15\ \mathrm{nT}) + (279\ \mathrm{nT}/° \pm 17\ \mathrm{nT}/°).\Delta\varphi + \\ + (66.4\ \mathrm{nT}/° \pm 5.7\ \mathrm{nT}/°).\Delta\lambda\,. \quad (4)$$

In the above mentioned equations, $\Delta\varphi$ stands for the geographical latitude of the observation point referred to the latitude of the Hurbanovo Observatory.

Likewise, $\Delta\lambda$ is the geographical longitude of the observation point relative to the longitude of the Hurbanovo Observatory. They are given in degrees:

$$\Delta\varphi = \varphi_{point} - \varphi_{Hurbanovo} \tag{5}$$

$$\Delta\lambda = \lambda_{point} - \lambda_{Hurbanovo} \tag{6}$$

Here $\varphi_{Hurbanovo}$ and $\lambda_{Hurbanovo}$ are the geographical latitude and longitude of the Hurbanovo Geomagnetic Observatory. Likewise, $\varphi_{point}$ and $\lambda_{point}$ are the geographical latitude and longitude of the observation point in question. The regression coefficients in the Eqs. (2)–(4) are assessed by probable deviations:

$$\vartheta = 0.674 \ . \ \sigma, \tag{7}$$

where $\sigma$ means standard deviation.

Graphical representation of this 1st-degree polynomial model is shown on Fig. 1. Travelling from the western to the eastern part of Slovakia, magnetic declination changes from 3.9° to 5.3°. Magnetic inclination ranges from approximately 64.25° in the southwest to 65.8° in the northern part of the country. The total field grows from 48500 nT to more than 49200 nT.

In the next section the above mentioned model will be compared to the International Geomagnetic Reference Field (IGRF).

### 3.2. Comparing the polynomial model with the IGRF

In this section, the data that were determined for the epoch 2014.5 at 11 observation points by direct measurements are compared with two models: 1st-degree polynomial model and IGRF model. The former of the models was derived in the previous section of this paper. Information about the latter can be found on the webpage of the IAGA Division V-MOD, Geomagnetic Field Modelling[3].

No noticeable spatial relation over the country was found in the distribution of the differences between the polynomial-model data and the directly measured data. The same turned out to be true for the distribution of the

[3] http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html

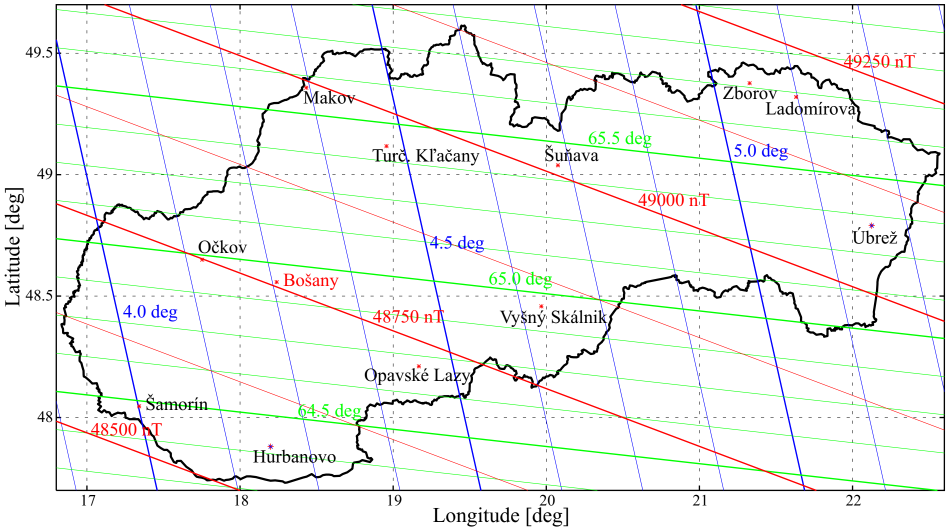


Fig. 1. Distribution of the geomagnetic elements in Slovakia for the epoch 2014.5 – the 1st-degree polynomial model described by Eqs. (2)–(4). The blue, green and red lines display the spatial distributions of $D$, $I$ and $F$, respectively. The positions of the observation points are indicated, too. The values of Bošany were excluded from calculating the model because they appeared to be anomalous. For Ladomirová only the value of the total field was considered. The observation points of Hurbanovo and Úbrež are stabilized while the other points are provisional.

differences between the IGRF data and the directly measured data. Accordingly, the statistics in this paper did not take into account the positions of the observation points. It must be noted here that the anomalous data of the observation point Bošany were also excluded from this part of the study.

The statistics for the differences between the two models and the directly measured data are presented in two tables. These two tables differ in the definition of the central tendency of the statistical data. Table 2 shows medians with median absolute deviations (MADs), while Table 3 presents arithmetic means with probable deviations. Here the MAD is defined as:

$$MAD = \text{median}_i(|\Delta_i - \text{median}_j(\Delta)_j|), \tag{8}$$

where $\Delta_i$ or $\Delta_j$ stands for the difference between a model and the directly measured value. The probable deviations ($\vartheta$) were calculated from standard deviations using Eq. (7).

For the purpose of this study, the median was expected to be a better measure for identifying the central tendency than the arithmetic mean. This is because the median is usually far less affected by outliers than the arithmetic mean. The geomagnetic data from some observation points might be influenced in some way by some undisclosed local magnetic anomalies and such data might act as potential outliers. Nevertheless, arithmetic means with probable deviations are also presented in this study because they represent a widely used concept. After all, both the measures led to the same decision about which model describes the spatial distribution of the geomagnetic elements more accurately. This comparison will be discussed in Section 4.

Table 2. The statistics for the differences between the models and the directly measured data: medians and median absolute deviations.

| | Declination | Inclination | Total field |
|---|---|---|---|
| Lin. model – measured data | $1.25' \pm 2.75'$ | $0.5' \pm 1.5'$ | 5 nT ± 35 nT |
| IGRF – measured data | $1.0' \pm 2.5'$ | $2.0' \pm 1.5'$ | 70 nT ± 20 nT |

Table 3. The statistics for the differences between the models and the directly measured data: arithmetic means and probable deviations.

| | Declination | Inclination | Total field |
|---|---|---|---|
| Lin. model – measured data | $2.0' \pm 2.4'$ | $0.45' \pm 1.7'$ | 3 nT ± 23 nT |
| IGRF – measured data | $0.9' \pm 2.2'$ | $0.75' \pm 2.1'$ | 57 nT ± 21 nT |

### 3.3. Secular variation between epochs 2007.5 and 2015.5

There is one more piece of information that could be obtained from the magnetic survey described in this paper. Comparing the results of this survey with the results of the detailed ground survey that was carried out in the 2007.5 epoch, the secular variation was calculated. That detailed survey was accomplished using a dense network of observation points, 121 points altogether. Therefore, it was easy to find points occupied in 2007, which were located at the same places (or at least very close to them) as the observation points of the 2014.5 survey.

Much like the situation in Section 3.2, no noticeable spatial relation over the country was found in the spatial distribution of the secular variation of the geomagnetic elements. Hence the secular variation was treated as homogeneous all over the country. The concrete values of the calculated secular variation are stored in Table 4, which again displays both kind of statistics: medians with MADs and arithmetic means with probable deviations. As was explained in Section 3.2, the medians with MADs should be considered the more decisive.

Table 4. Secular variations of the geomagnetic elements $D$, $I$ and $F$ between epochs 2007.5 and 2014.5.

| Sort of statistics | Declination | Inclination | Total field |
|---|---|---|---|
| Quantile | $7.2'$/yr ± $0.2'$/yr | $39''$/yr ± $12''$/yr | 31.7 nT/yr ± 0.9 nT/yr |
| Moment | $7.5'$/yr ± $0.6'$/yr | $43''$/yr ± $45.5''$/yr | 32.1 nT/yr ± 1.8 nT/yr |

## 4. Discussion and conclusions

In the sections above, the numerical results of the magnetic survey were presented in the form of a 1st-degree polynomial model for the distribution of the geomagnetic elements $D$, $I$ and $F$. The data and the model are related to the 2014.5 epoch and to the region of Slovakia. The polynomial model was then tested in such a way that the differences between it and the measured data were compared with differences between the IGRF and the measured data. This comparison showed the following findings:

- The 1st-degree polynomial model seems to describe the spatial distribution of magnetic declination worse than the IGRF model (see the first columns in Tables 2 and 3).
- The 1st-degree polynomial model describes the spatial distribution of magnetic inclination better than the IGRF model (see the middle columns in Tables 2 and 3).
- The 1st-degree polynomial model describes the spatial distribution of the total field better than the IGRF model (see the last columns in Tables 2 and 3).

The accuracy of the polynomial model for magnetic declination does not differ dramatically from the accuracy of model IGRF. The polynomial model thus still remains worthwhile for some practical purposes because using it is very easy – it can be expressed by a simple linear equation. When there is a need for the value of magnetic declination for a time instant other than 2014.5, the value of secular variation $7.2'/\mathrm{yr} \pm 0.2'/\mathrm{yr}$ can be used. However, if the magnetic declination needs to be determined with the best accuracy possible, use of the IGRF model should be recommended.

For magnetic inclination and total field, on the contrary, the polynomial model provided much better results than the IGRF model. In addition, for total field the IGRF model produced rather high bias: here the difference between the IGRF values and the directly measured values was found to be as much as 70 nT $\pm$ 20 nT. This comparison indicates that in these cases the presented 1st-degree polynomial model satisfactorily describes the distribution of the geomagnetic field in Slovakia. It can thus be recommended for calculating magnetic inclination and total field.

The data set that was used in this paper did not allow us to identify any spatial features concerning a spatial distribution of the differences between the IGRF and the directly measured data. However, using a wider data set of direct measurements could yet identify some spatial feature of these differences. An important task for the future research will be to search for such features. Knowledge about them could possibly improve future updates of the global model of the geomagnetic field.

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