THE REPRESENTATIVE RECENT SECULAR VARIATION OF THE GEOMAGNETIC FIELD ON THE CROATIAN TERRITORY

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ABSTRACT

The four consecutive geomagnetic surveys performed from 2004 to 2007 at Pokupsko (POKU) repeat station, which is located in the central part of Croatia, were depicted. The resulting geomagnetic field secular variation, and its time change, was chosen as being representative for the whole Croatian territory. In doing so, two models of data reduction using Tihany (THY), as the closest reference geomagnetic observatory were considered. First data reduction model assumed simply that the secular variation at the repeat station and observatory were the same all the time throughout the year for which the secular mean was calculated. Second data reduction model took into the consideration the difference in secular variation at both repeat station and observatory for the concerned year. In addition, the reduction to a quiet level, according to procedure used at Edinburgh, and in reference to Tihany and L'Aquila observatories, was performed. All three reductions methods were compared. Obtained geomagnetic field values, as well as its secular variation were compared to those computed from the global geomagnetic models. In addition, Mokrovićs' historical data were used in order to determine the geomagnetic field variation. Herewith, the first geomagnetic field secular variation obtained from terrestric surveys of the Republic of Croatia is presented.

Keywords: geomagnetic repeat station, geomagnetic data reduction, geomagnetic field secular variation

1 INTRODUCTION

Secular variation is defined as the first time derivative of the normal field, usually expressed as the annual change of a particular geomagnetic field element [1]. The term normal field describes the combination of the main field and static crust field that is determined through field surveys and subsequent data reduction as well as field modeling. Such a normal field for the territory of Croatia named Croatian Geomagnetic Normal Reference Field (CGNRF) is represented by 2^{nd} order polynomial in latitude and longitude for epoch 2004.5 [2]. In this paper the secular variation is estimated from reduced geomagnetic field observations at repeat station POKUpsko. This survey was undertaken as no recent secular variation based on the terrestrial geomagnetic observations was available for the Croatian territory.

2 POKUPSKO REPEAT STATION

In the absence of the national observatory, geomagnetic field data was provided through surveys carried out in the Croatian Geomagnetic Repeat Stations Network (CGRSN) established in 2004. At that time, the CGRSN consisted of eight stations evenly spread over the national territory. The CGRSN surveys were repeated in 2007 and 2008, and in 2008 the network was upgraded with two additional stations (Figure 1). No on-site variometer was used during the surveys. The Croatian Geomagnetic Repeat Stations Network design, IAGA criteria evaluation on locations as well as actual survey practice, was described in [3]. The

Pokupsko (POKU) repeat station with the longest series of consecutive surveys from 2004 until 2008 was positioned in the middle of Croatia. Due to the mentioned POKU was considered the representative for the estimation of secular variation over the territory of Croatia.

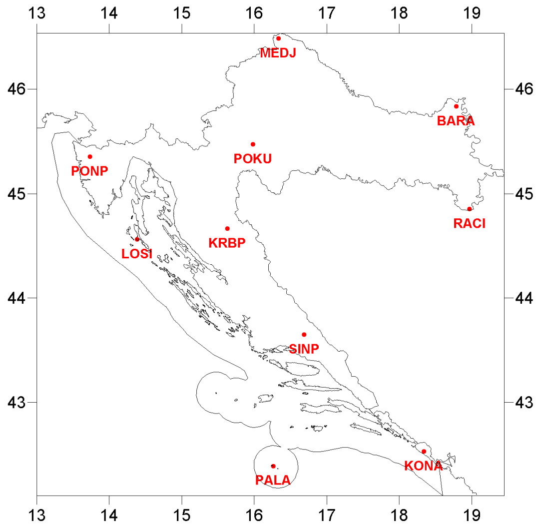

Figure 1: Croatian Geomagnetic Repeat Stations Network.

3 DATA REDUCTION

In order to obtain secular variation at the repeat station, the repeat station absolute observations must be reduced to the reference observatory (ies). Herewith three data reduction methods were used in sequel. The first method assumed that secular variations at repeat station and observatory were equal [1]. The second data reduction method assumed that the secular variation at repeat station and observatory were linear and different [1]. The Tihany (THY) reference observatory data were used for both reduction methods. THY observatory was chosen because of its closest distance to POKU repeat station (199 km). In comparison with L'Aquila (AQU) and Fuerstenfeldbruck (FUR) observatories, the THY was found as the most representative for reduction [4]. The third reduction method was to a quiet level [5] and involves THY and AQU data. The distance between POKU and AQU was much larger, 405 km.

3.1 Reduction Model I – equal secular variations at repeat station and observatory

The simple data reduction model assumed that geomagnetic field variation at the observatory was basically the same as on the repeat station,

$$E_{SV}^{epoch} = E_{OBS}^{epoch} + \left(E_{SV}^{t} - E_{OBS}^{t}\right), \qquad (1)$$

where

E_{OBS}^{epoch} is the geomagnetic element at observatory and mid year epoch,

E_{SV}^{t} is the element observed at repeat station SV at instant of time *t*,

E_{OBS}^{t} is the element observed at observatory at the same time *t*.

Model I data reduction method is suitable when reference observatory and repeat station are close, the electric conductivity differences between observatory and repeat station small, the magnetosphere activity and the time span (*t–epoch*) small [6].

THY observatory annual means were used in reductions of the geomagnetic elements *E* (C. András and B. Heilig, priv. comm., 2008). The declination *D*, inclination *I* and total intensity *F*, as well as variations were shown in Table 1. The reduced values scatter, given as $\max\{|E_{\max} - E_{\text{mean}}|, |E_{\min} - E_{\text{mean}}|\}$, was adopted as accuracy criterion. In 2004, 2005, 2006, and 2007 scatters of declination were 0.9', 0.8', 0.6' and 1', inclination 0.3', 0.1', 0.1', and 0.2', and total intensity 1.0 nT, 3.8 nT, 1.4 nT, and 1.7 nT, respectively.

Table 1: Model I - geomagnetic elements and variations at POKU.

Epoch	D [deg min]	SV [min/y]	SV' [min/y^2]	I [deg min]	SV [min/y]	SV' [min/y^2]	F [nT]	SV [nT/y]	SV' [nT/y^2]
2004.5	2 29.4			62 00.7			47434.3		
		2.5			0.7			24.6	
2005.5	2 31.9		3.6	62 01.4		-1.3	47458.9		9.9
		6.1			-0.6			34.5	
2006.5	2 38.0		0.3	62 00.8		0.4	47493.4		-6.3
		6.4			-0.2			28.2	
2007.5	2 44.4			62 00.6			47521.6		

3.2 Reduction Model II – linear and different secular variations at repeat station and observatory

In the second reduction model the secular variation was assumed to be linear but different at the observatory and at the repeat station [1]. Additional term *(a-b)* took into account secular variation difference between repeat station and observatory, leading to:

$$E_{SV}^{epoch} = E_{OBS}^{epoch} + \left(E_{SV}^{t} - E_{OBS}^{t}\right) + (a-b)\,, \qquad (2)$$

with

$$(a-b) = (dE_{SV}/dt - dE_{OBS}/dt)\cdot \Delta T\ , \qquad (3)$$

where

dE_{SV}/dt is the geomagnetic element's secular variation at the repeat station,

dE_{OBS}/dt is the geomagnetic element's secular variation at the observatory, and ΔT is the time span between mid year epoch and the instant of the observation *t*. If the instant of observation $t <$ epoch, then $\Delta T > 0$, and if $t >$ epoch then $\Delta T < 0$.

In order to apply Model II data reduction, the secular variations at both observatory and repeat station must be known in advance. The *(a – b)* term was estimated for each observation day and added to the secular mean value obtained by Model I, as reported in Table 2.

Table 2: Model II - geomagnetic elements at POKU.

Observation day	DOY	(a-b) [min]	D (Model II) [deg min]	(a-b) [min]	I (Model II) [deg min]	(a-b) [nT]	F (Model II) [nT]
02.06.2004.	154	-0.1	2 29.2	0.0	62 0.7	-0.6	47433.7
03.06.2005.	154	-0.1	2 31.2	0.0	62 1.4	0.1	47462.8
08.09.2005.	251	-0.1	2 32.4	n/a	n/a	0.3	47455.4
18.07.2006.	199	0.0	2 38.0	0.0	62 0.8	0.0	47493.3
17.10.2007.	290	0.2	2 44.6	0.1	62 0.7	-1.1	47520.5

From Table 2 it should be noted that the *(a – b)* term does not exceed 0.2' for *D*, 0.1' for *I*, and 1.1 nT for *F*, being less or equal to scatter values for 2004 – 2007 surveys, respectively. As expected, the largest correction term for *D* as well as for *I* occurred for observations taken on 17. October 2007. Also, the difference between *D* values reduced according to Model I for 03 June and 08 September 2005 is 1.25', while the difference between values reduced according to Model II is 1.17'. The difference between the total intensity reduced values according to Model I reduction for the observation days 03 June and 08 September 2005 is 7.5 nT. After the Model II data reduction implementation this difference decreased to 7.4 nT. Considering the usual mid-latitude observations' errors of 1' in declination and 0.5' in inclination [1] it was obvious that differences between Model I and Model II in presented case were not significant. Very good agreement between THY observatory and POKU repeat station geomagnetic elements secular variations led to the small difference between Model I and Model II data reduction. This indicated suitability of the THY observatory for POKU repeat station data reduction. The geomagnetic elements and variations according to Model II were shown in Table 3. In 2004, 2005, 2006, and 2007 corresponding scatters of declination are 0.9', 0.6', 0.6' and 1', inclination 0.3', 0.1', 0.1', and 0.2', and total intensity 1.0 nT, 3.7 nT, 1.4 nT, and 1.7 nT.

Table 3: Model II - geomagnetic elements and variations at POKU.

Epoch	D [deg min]	SV [min/y]	SV' [min/y^2]	I [deg min]	SV [min/y]	SV' [min/y^2]	F [nT]	SV [nT/y]	SV' [nT/y^2]
2004.5	2 29.2			62 0.7			47433.7		
		2.6			0.7			25.4	
2005.5	2 31.8		3.6	62 1.4		-1.3	47459.1		8.8
		6.2			-0.6			34.2	
2006.5	2 38.0		0.4	62 00.8		0.5	47493.3		-7.0
		6.6			-0.1			27.2	
2007.5	2 44.6			62 00.7			47520.5		

3.3 Reduction to a quiet level

The repeat station observations' reduction to a quiet level was carried out in reference to THY and AQU observatories. Quiet time values were selected by examining data from both observatories for the eleven-day period centered on the observation day. The quiet night-time value for each observatory was taken as the mean value of two hourly means either side of midnight from two days showing minimal external field disturbance [5]. Periods of minimal external field disturbance were selected by examining average standard deviation mean value between 22-23 UTC and 23-24 UTC periods, as well as Kp index values.

If observations of geomagnetic element E_{SV}^{t} at repeat station are made at the time *t* then its value reduced to a quiet level $E_{SV}^{t(q)}$ is:

$$E_{SV}^{t(q)} = E_{SV}^{t} + C\,, \tag{4}$$

where

$$C = \frac{\Delta\theta_2 \left[E_{OBS1}^{t(q)} - E_{OBS1}^{t}\right] + \Delta\theta_1 \left[E_{OBS2}^{t(q)} - E_{OBS2}^{t}\right]}{\Delta\theta_1 + \Delta\theta_2}\,, \tag{5}$$

θ_1 is the latitude of the observatory north of the station,
θ_2 is the latitude of the observatory south of the station,
θ_{SV} is the latitude of the repeat station,
$\Delta\theta_1 = \theta_1 - \theta_{SV}$,
$\Delta\theta_2 = \theta_{SV} - \theta_2$,
E_{OBS1}^{t} is the value of *E* at observatory north of the station at time *t,*
E_{OBS2}^{t} is the value of *E* at observatory south of the station at time *t,*
$E_{OBS1}^{t(q)}$ is the quiet level of *E* at observatory north of the station at time *t(q),*
$E_{OBS2}^{t(q)}$ is the quiet level of *E* at observatory south of the station at time *t(q).*

The correction term *C* in equation (4) was the weighted average of the element difference between quiet time and observation time on the repeat station for both observatories, where coordinate differences $\Delta\theta_1$ and $\Delta\theta_2$ were weights. This data reduction method, unlike two other did not load the reduced values with secular change spatial variation between the observatory and repeat station. In order to compare the reduced data of 2004 and 2005 when only few observation times were taken with Model I and Model II, the mean value was calculated and mean epoch was adopted. In the Quiet level model the reduction epoch did not correspond to the mid year epoch (Table 4), and the differences between two subsequent reduced values were divided with epoch difference in order to obtain variations of each geomagnetic element. In 2004, 2005, 2006, and 2007 corresponding scatters of declination were 0.7’, 1.4’, 0.4’ and 0.9’, inclination 0.3’, 0.5’, 0.1’, and 0.1’, and total intensity 0.8 nT, 1.4 nT, 7.6 nT, and 1.9 nT.

Table 4: Quiet level model - geomagnetic elements and variations at POKU.

Epoch	**D [deg min]**	**SV [min/y]**	**SV’ [min/y^2]**	**I [deg min]**	**SV [min/y]**	**SV’ [min/y^2]**	**F [nT]**	**SV [nT/y]**	**SV’ [nT/y^2]**
2004.4	2 28.1			61 59.6			47435.2		
		2.4			1.6			25.4	
2005.6	2 30.9		5.2	62 01.6		-3.6	47465.6		13.5
		7.6			-2.0			38.9	
2006.5	2 37.8		-1.2	61 59.7		2.6	47500.7		-15.2
		6.4			0.6			23.7	
2007.8	2 46.1			62 0.3			47531.5		

4 COMPARISON OF RESULTS

The purpose of comparison of different reduction solutions was to show the differences among them as well as to choose the representative method. Previous reduction models were also plotted against IGRF (International Geomagnetic Reference Field) global model [7]. Since IGRF contained long wavelength components, the difference between the obtained reduced data and IGRF model values could indicate a lithosphere contribution, not modeled external contributions as well as observations' errors.

4.1 Declination secular variation

As pointed out, Model I and II results shown on Figure 2 exhibited insignificant differences. The declination secular variation from the IGRF model was about 5.2 '/yr larger than secular variation obtained from other methods for the epoch 2005.0. Quiet level model declination secular variation is approx. 1.4 '/yr larger then the other models for the epoch 2006.0. All models gave similar results for the epoch 2007.0. The geomagnetic element's on left side of the following figures were given for the mid year epoch, annual variation on the right sides are given for the beginning year epochs.

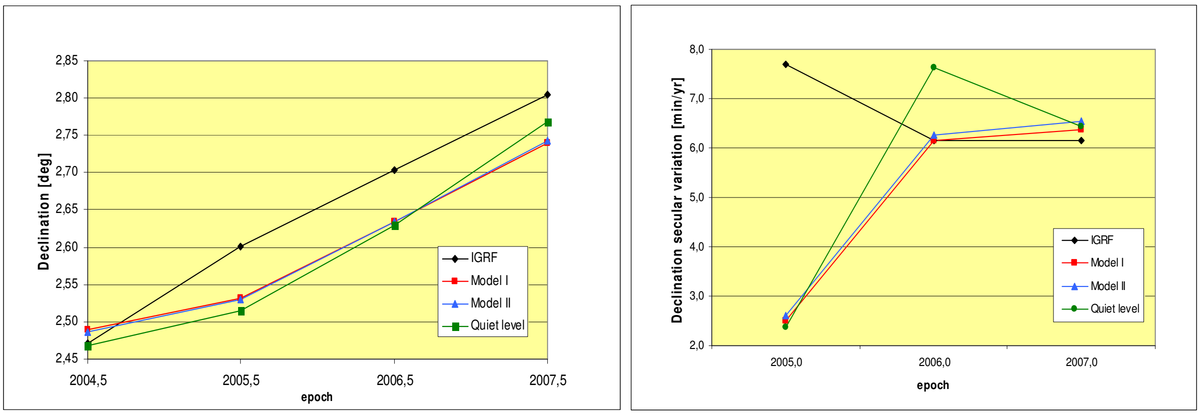

Figure 2: POKU declination (left) and its secular variation (right) (2004.5 – 2007.5).

4.2 Inclination secular variation

The reduction methods differences were shown on Figure 3 as well. Inclination secular variation obtained by Quiet level method was about 1'/yr larger than the other results for the epoch 2005.0 In the following epoch only Model I and II results fitted together while the difference between the IGRF and Quiet level model was approximately 2.6 '/yr. Model I and II led to similar but distinct results to IGRF and Quiet level model within 0.8 '/yr for the epoch 2007.0.

Although the differences between the three reduction methods were found, the secular variation results were not insignificant, Model I and II being smoother then Quiet level model, they showed similar tendency.

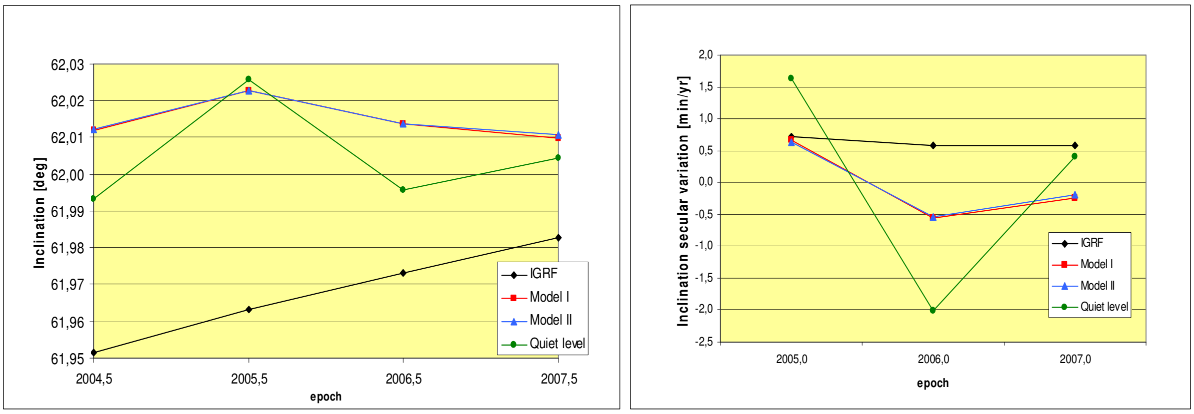

Figure 3: POKU inclination (left) and its secular variation (right) (2004.5 – 2007.5).

4.3 Total intensity secular variation

Similarly to declination and inclination, the best agreement was among Model I and II in the whole period 2005.0 - 2007.0 (Figure 4). The total intensity secular variation showed a large difference of 68.2 nT/yr between IGRF and the other methods for the epoch 2005.0. The secular variations were within the range of 4.6 nT and 12.9 nT for the epoch 2006.0 and 2007.0, respectively.

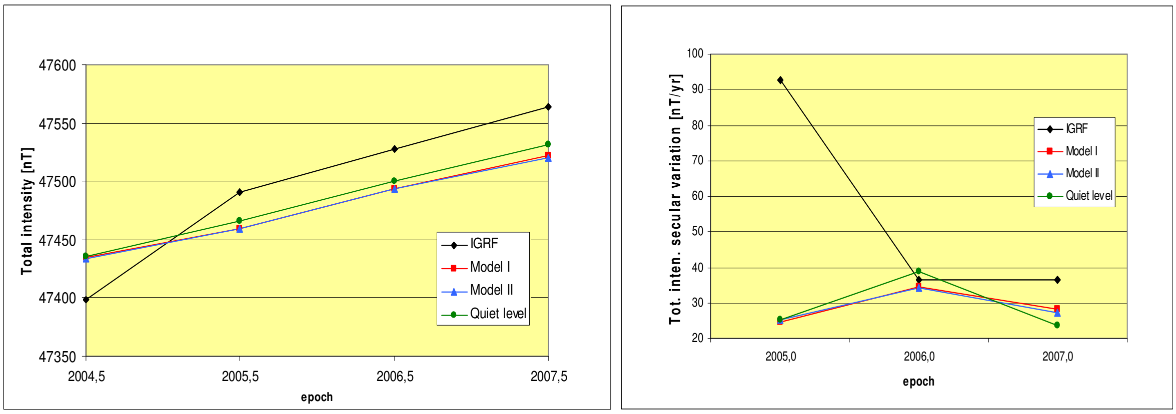

Figure 4: POKU total intensity (left) and its secular variation (right) (2004.5 – 2007.5).

4.4 Secular variation from historical data

The average annual change from 2004.5 to 2007.5 estimated from Model II was: 5.1'/yr for *D*, 0.0 '/yr for *I* and 29.0 nT/yr for *F* at POKU repeat station. On a larger scale, the average annual change from 1927.5 to 2007.5 were: 5.4 '/yr for *D*, 1.0 '/yr for *I* and 37.3 nT/yr for *F*, being the difference between epoch 1927.5 data and Model II data for the epoch 2007.5. It should be noted that epoch 1927.5 data included different data collected in period 1806 through 1918 with different observation methods and under various observation conditions [7], thus leading to a rough estimation of the annual change. Naturally, these average annual changes did not reveal erratic behavior of secular variation.

5 CONCLUSION

The POKU repeat station has been selected as a representative for the secular variation estimation over the Croatian territory because of its central position and existence of consecutive data sets in years 2004 - 2007. In order to quantify representative secular variation three data reduction methods were applied to the observational data. Model II generally showed the smallest declination scatter in comparison to Model I and Quiet level model. Inclination scatter was similar and small for all models. Total intensity scatter was similar for Model I and II and smaller then for Quiet level model. Particularly, Quiet level model showed larger declination and inclination scatter for the 2005.5 epoch, because it was obtained from two observation times average while for the other epochs the scatter was calculated from each reduced observation. Additionally, significantly larger Quiet level model scatter for epoch 2006.5 was likely influenced by the geomagnetic field difference between the repeat station and reference observatories. Due to the expected accuracy of the surveys, as well as generally smallest scatter in comparison to other methods, Model II was chosen as a representative data reduction method. Although Model II took into account the time span between the time of observation and mid year epoch, it was recommended to perform geomagnetic surveys close to the mid year. Similarities of Model I and II and their differences to Quiet level model were present in secular variations solutions as well. Since all three model solutions came from reduced observations, the large differences to IGRF were expected. Representative secular variation was thus obtained from Model II for the POKU repeat station and in period 2004.5 – 2007.5 amount to 5.1 ’/yr for declination, 0.0 ’/yr for inclination and 29.0 nT/yr for total intensity. Further improvements should include annual repeat stations network survey schedule, continuous geomagnetic field monitoring at future Croatian observatory, a non-linear secular variation reduction model as well as normal field modeling of the whole repeat stations network.

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