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Modeling the geomagnetic field over Croatia

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During the last years investigation of the geomagnetic field in Croatia has started and an effort to establish the geomagnetic observatory has been made. Based on the total field measured over the northern eastern part of Croatia, the suitable position for installing the geomagnetic observatory is proposed.

In this paper the core field behavior from 1961 to 2002 over the entire Croatian territory was investigated by exploiting different global models. Using a regional European model the secular variation over the country was calculated. The evolution of the core field at the potential location for installing the geomagnetic observatory was analyzed in detail. The calculated field variations follow the general core field variations over Europe and there are not variations due to different induced fields or other effects at the future observatory location.

This study contributes to the investigation of the potential observatory location and paves the way for better understanding of the geomagnetic field behavior over Croatia.

Keywords: geomagnetic secular variation, modeling, geomagnetic observatory

1. Introduction

1.1. The Earth's magnetic field

Measured at any point on the Earth's surface the geomagnetic field is a combination of several magnetic contributions generated by various sources.

More than 90% of the measured field is internal in origin and is generated in the Earth's outer fluid core. This part of geomagnetic field, known as core field (see e.g. Jacobs, 1987; Merill et al. 1998), is due to electric currents sustained by a geodynamo. The maximum intensity of the core field is around 60000 nT near the magnetic poles and around 25000 nT near the magnetic equator. Its variation over time scales of some months to some decades is referred to as secular variation (henceforth SV).

The sudden changes of the trend of SV are named geomagnetic jerks or secular variation impulses (Mandea et al., 2010) which occur.

The crustal field is related to the remanent and induced magnetization of the rocks within the crust (e.g. Mandea and Thèbault, 2007). The magnitude of the crustal field varies from fractions to hundreds of nT, but can reach values as high as several thousands of nT.

The external fields are produced by ionospheric and magnetospheric current systems (Campbell, 2003; Clark, 2000). The values of those fields at the Earth's surface are of few tens of nT, even few hundred to thousand nT during magnetic storms. There are also external fields induced by currents flowing within the Earth's crust and upper mantle. The external fields varies in space and time with periods less of second to the well known solar cycle (11 years) and its harmonics.

In this study I am interested in the core geomagnetic field and its variations.

1.2. Geomagnetic field models

By permanent measuring the field over a period of years it is possible to mathematically represent the magnetic field and its secular variation. To create an accurate field model, high-resolution data coverage is needed. Observatory and satellite data complement each other well to fully exploit the geomagnetic field. Depending of the modeling goals different combination of data sets are used. Different models try to fit and explain the observed geomagnetic field and its time variations on global as well as on regional scales.

Global modeling

For global modeling of the geomagnetic field the well-known technique, Spherical Harmonic Analysis (SHA), the procedure of representing a potential function by a sum of spherical harmonic functions, is widely used.

In the following I describe the global geomagnetic field models used in this study.

MAGSAT model

The model (Cain et al., 1989) is based on the available MAGSAT vector data complemented by observatory secular variation results from September 1979 to June 1980 and is centered on 1980.0. This was the first attempt to include significant parts of the lithospheric field in global spherical harmonic models and it has been expanded to degree 63 with secular variation estimates up to degree and order 10.

Ørsted secular variation model OSVM

The Ørsted secular variation model, OSVM (Olsen, 2002) is based on Ørsted scalar and vector data from March 1999 to September 2001 and observatory secular variation values. Satellite data are selected and corrected to minimize the influence of external fields. The model is expanded to spherical harmonic degree and order 29 with a secular variation description up to degree and order 13 and includes a description of the magnetospheric ring current.

POMME model

I used version 3.0 of the POtsdam Magnetic Model of the Earth, POMME (Maus et al., 2006). It is based on CHAMP satellite vector and scalar data from 2000.6 to 2005.7 centered on 2003.0 with secular variation and acceleration described by a Taylor series expansion of the core field coefficients up to degree and order 16. The accuracy of the internal field description is improved compared to the earlier versions by the larger amount of available data and improved data selection and correction for external fields. The static field is expanded to spherical harmonic degree and order 60 and a magnetospheric field description is part of the model.

CHAOS model

This model (Olsen et al., 2006) is based on CHAMP, Ørsted and SAC-C data measured between March 1999 and December 2005. CHAOS describes the core and crustal field up to degree and order 50 with a continuous spline representation of the coefficients up to degree and order 14 and a linear secular variation estimate for degrees 15 to 18. It is the first continuous model based on satellite data.

Comprehensive Model, CM4 model

The fourth version of the continuous Comprehensive Model, CM4 (Sabaka et al., 2004), covers the whole time interval from 1960 to 2002. It has been derived from quiet-time POGO, MAGSAT, Ørsted and CHAMP satellite data in combination with observatory hourly means. The internal field is expanded to spherical harmonic degree and order 60. The model also includes descriptions of various other field contributions originated in the ionosphere and magnetosphere as well as the fields induced below the Earth surface by the external source fields.

Regional modeling

The purpose of modern regional modeling is to describe the geomagnetic field over a portion of the Earth's surface, providing a better spatial resolution of the local field for areas of high data density.

In this study, I used the regional, *EU_MIX model* model built by Verbanac et al. (2009). This model is based on the European observatory data and is derived using the improved and regularized spherical cap harmonic analysis. For details about the data and model, see Verbanac (2007) and Verbanac et al. (2009). The EU_MIX is a continuous model and provides a detailed description of the secular variation and secular acceleration for Europe over the period 1961–2002.

1.3. Motivation

During the last years research of the geomagnetic field in Croatia has restarted after more than 50 years of no concrete activity and an effort to establish the geomagnetic observatory has been made (for details see Verbanac and Korte, 2006).

The measurements of the total field intensity strength were performed over the northern part of the country within the period 2003–2007.

The distributions of the declination, horizontal intensity, inclination, total field intensity, as well as the crustal and anomaly geomagnetic fields over the northern part of middle Croatia for the 2003.76 epoch, obtained using global Comprehensive CM4 model (Sabaka et al., 2004) and conducted measurements, were presented by Verbanac and Korte (2006).

Based on that analysis, the best location for installing the geomagnetic observatory (45.8° N, 16.6° E) was suggested.

Here, I extend this research by analyzing the geomagnetic field behavior over the entire Croatian region and over longer time span. The special attention is payed to the location chosen for installing the geomagnetic observatory. Note that it is very important to carefully check in as many as possible ways the observatory site, to ensure that it satisfies the standards proposed by geomagnetic community (Jankowski and Sucksdorff, 1996).

In this paper I aim to:

1) investigate the geomagnetic field behavior over the entire Croatian territory exploiting different models based on data from the Magsat, Ørsted, CHAMP and SAC-C satellites;

2) investigate the geomagnetic field evolution over the entire Croatian region using regional EU_MIX model, which is based on European observatory data;

3) examine the secular variation at the potential observatory site.

The paper is organized as follows. In the next section the data-sets are introduced. Then, I present the results obtained by different global models and regional model. These results are discussed and conclusion is drawn in the last section.

2. Data

The analysis is based on data sets obtained from five global models and one regional model. The data sets used to estimate the internal field contributions from global models (described in the introduction) were obtained from field models based on data from the satellites MAGSAT, ØRSTED, POGO, CHAMP and SAC-C, partly in combination with observatory data. Since the core field contributions is needed for the analysis, I used the internal field descriptions of each model up to spherical harmonic degree and order 14. The models were used for their center epoch: 1980.0, 2000.0, 2003.0, 2002.5 for

MAGSAT and CM4, OSVM, POMME and CHAOS, respectively. The data set from the regional EU_MIX model comprises the secular variation and secular acceleration (their *X*, *Y*, and *Z* component) for epoch 1980.5, and their time-series at the chosen potential observatory location over the entire time-span of the model validity, 1961–2002.

Note that with the spherical harmonic expansion used in the global models, the resolution is limited to about 2800 km. The regional EU_MIX model provides a better resolution, namely 1880 km. Further note that the rms misfit of the CM4 model to all the observatory data used for obtaining the EU_MIX model is 4 nT/year. The EU_MIX rms misfit to the data is reduced to 3.3 nT/year (Verbanac, 2007).

3. Results

3.1. Global models

Predicted values from all four global models were calculated on a regular grid of 1° × 1°, spanning the longitudinal region from 13° E to 20° E and latitudinal region from 42° N to 47° N.

The corresponding contour maps of the total field intensity are presented in Figure 1.

All figure panels show that the field is stronger in the norther than in the southern part of the country. This suits the general, dipol filed behavior. According to both MAGSAT and CM4 model, at epoch 1980 the field values changes from 46000 nT in the southern part of the country to 47100 nT in the northern part. The estimated field values from ØRSTED model reveals that at epoch 2000, field values changes from 46500 nT in the southern part of the country to 47600 nT in the northern part. CHAOS and POMME models give practically the same values for the total field intensity amounting for 46600 nT in the southern part of the country to 47700 nT in the northern part. According to all models, the gradient of the total field is about 30 nT per 1 degree of longitude and 300 nT per 1 degree of latitude. Assuming that the total field changes at equal rate from 1980 to 2003, the estimated annual change would amount for some 50 nT/year. However, it is obvious not a case as both CHAOS and POMME models give the same field estimations, although these two models differ for one year. More details about secular variations are derived from the regional EU_MIX model and are discussed in the following.

3.2. Regional, EU_MIX model

In Figure 2, I present contour maps of the computed secular variation, EU_MIX model (*X*, *Y* and *Z* components). The values were calculated on a regular grid of 1° × 1°, spanning the longitudinal region from 13° E to 20° E and latitudinal region from 42° N to 47° N. For details about modeling method and

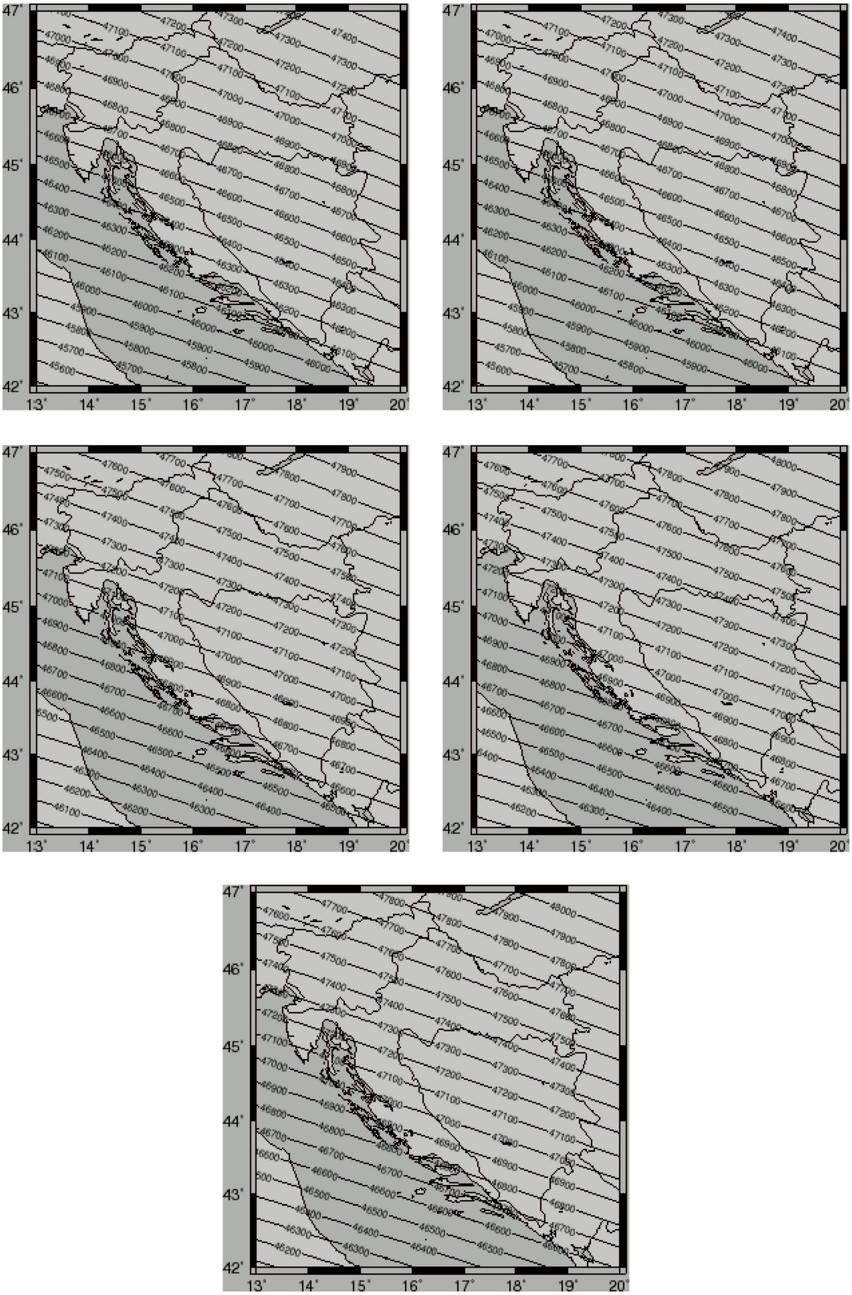

Figure 1. From top to bottom (and left to right): maps for the total field intensity in nT, computed from the MAGSAT (epoch 1980.0), CM4 (epoch 1980.0), OSVM (epoch 2000.0), CHAOS (epoch 2002.5) and POMME (epoch 2003.0) models.

parametrizations see Verbanac et al. (2009). I show maps for the epoch 1980.5, as a representative example. Note that this epoch lays almost in the middle of the interval of the model validity.

Both *X* and *Y* SV components are larger in the approx. SW part than in the approx. NE part of Croatia within one year. The differences are about 7 nT. In contrary, the SV *Z* is for a few nT larger in the E part than in the W part of the country.

I further use the advantage of the time continuity of the EU_MIX model to study the field evolution at the chosen location for installing the geomagnetic observatory. I produced the *X*, *Y* and *Z* SV time-series embracing period 1961–2002. The corresponding time-series are shown in Figure 3. All components show the variation of increases and decreasing pattern. Some variations are smooth, and some are rather abrupt.

The *X* component shows a very prominent SV change from epoch 1970.5 to epoch 1983.5. During this period the decrease of 28 nT/year are noticed. A few smaller and smoother changes (with local extrema around 1962.5, 1964.5, 1967.5, 1990.0, 1994.5, and 1998) are also seen with a maximal change of 10 nT/year.

In the *Y* component the rather large SV changes of around 20 nT/year (with local extrema around 1968.5, 1979, 1991, and 1996.9). The most largest of these changes in the SV field of order of 30 nT/year occurred between the epochs 1968.5 and 1979.

The *Z* component exhibits a very dynamic pattern with larger and smaller variations. Such behavior was expected since the EU_MIX model demonstrates the very dynamic SV changes in *Z*, in both time and space over all Europe. The *Z* component variations might contain external and induced field variations, although the observatory data included in the model were corrected by means of an empirical approach, described in detail by Verbanac et al. (2007).

Note that some of the years of remarkable changes in the SV field correspond to the years of abrupt SV changes seen over the European region

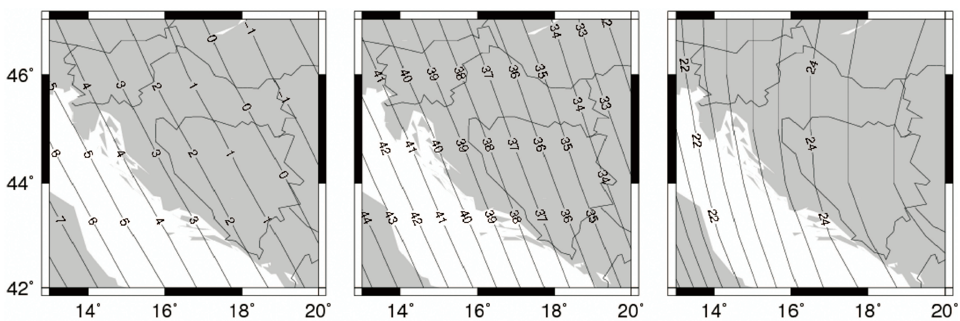

Figure 2. Maps of the *X* (left), *Y* (centre) and *Z* (right) secular variation components at epoch 1980.5 obtained from U_MIX model (SCHA with spatial and temporal regularization): Units nT/yr. Mercator map projection.

(Mandea et al., 2010; Verbanac et al., 2009). These epochs can be summarized as follows: for the *X* component around 1965, 1970, 1994; for *Y* component around 1969, 1996; for the *Z* around 1969, 1987. The well-known jerk of 1969 is clearly seen at this location in all three components.

In order to check the model results, for comparison I first calculated the SV of *X*, *Y* and *Z* components observed for the same period at Niemegk (NGK) geomagnetic observatory. I chosed NGK as representative example, since the

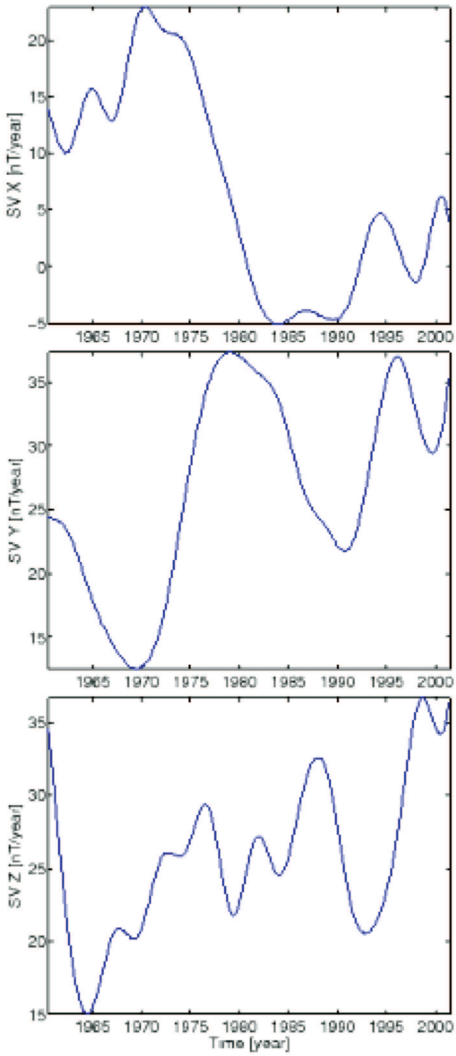

Figure 3. Time-series for *X* (first row), *Y* (second row) and *Z* (third row) SV components at observatory location (45.8° N, 16.6° E) computed from the EU_MIX model, in nT/year.

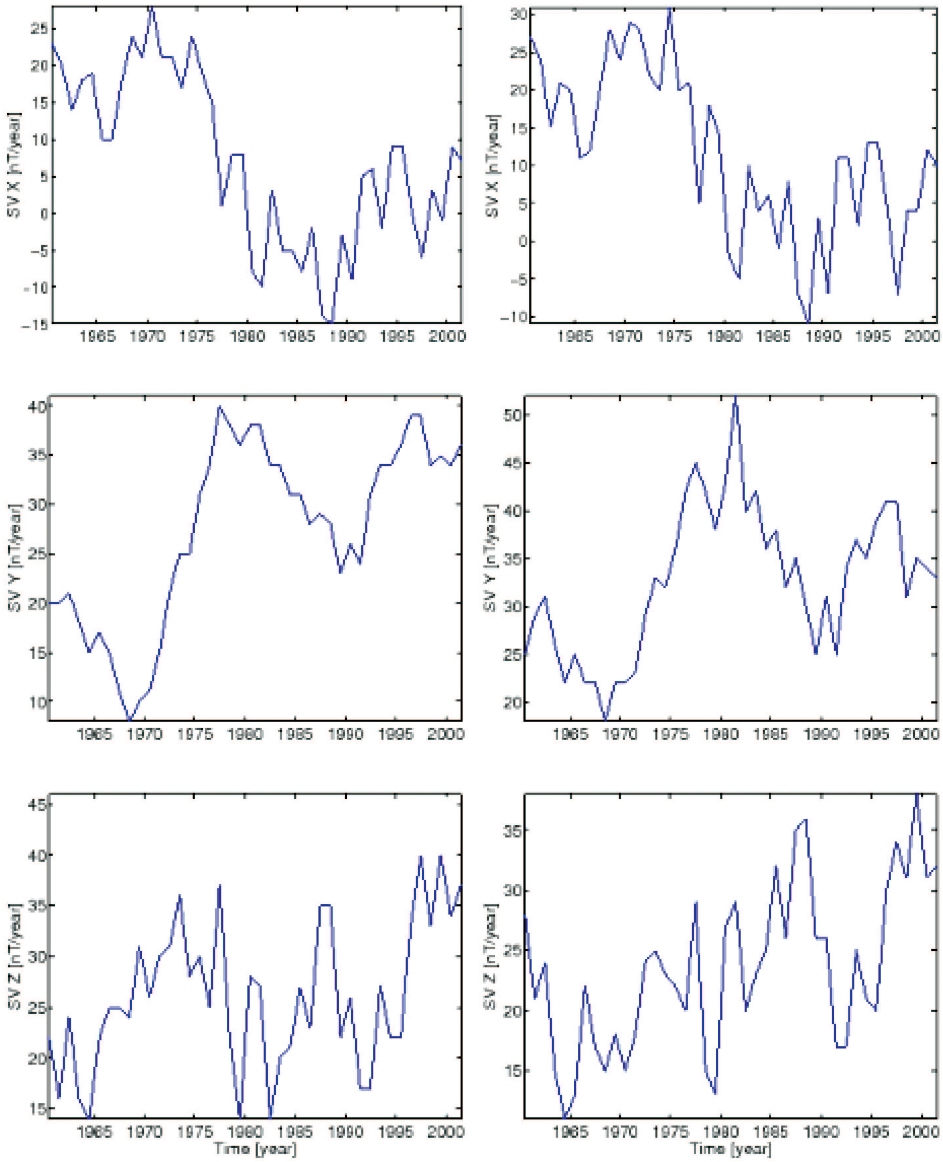

Figure 4. Time-series for *X* (first row), *Y* (second row) and *Z* (third row) SV components at NGK and AQU observatory locations, in nT/year.

data are of high quality, and they are very well fitted by EU_MIX model over the whole time span, and in all three components (for details see Verbanac et al., 2009). The annual means are collected from: http://www-app3.gfz-potsdam.de/obs/niemegk/ The time series are presented in Figure 4, left panels.

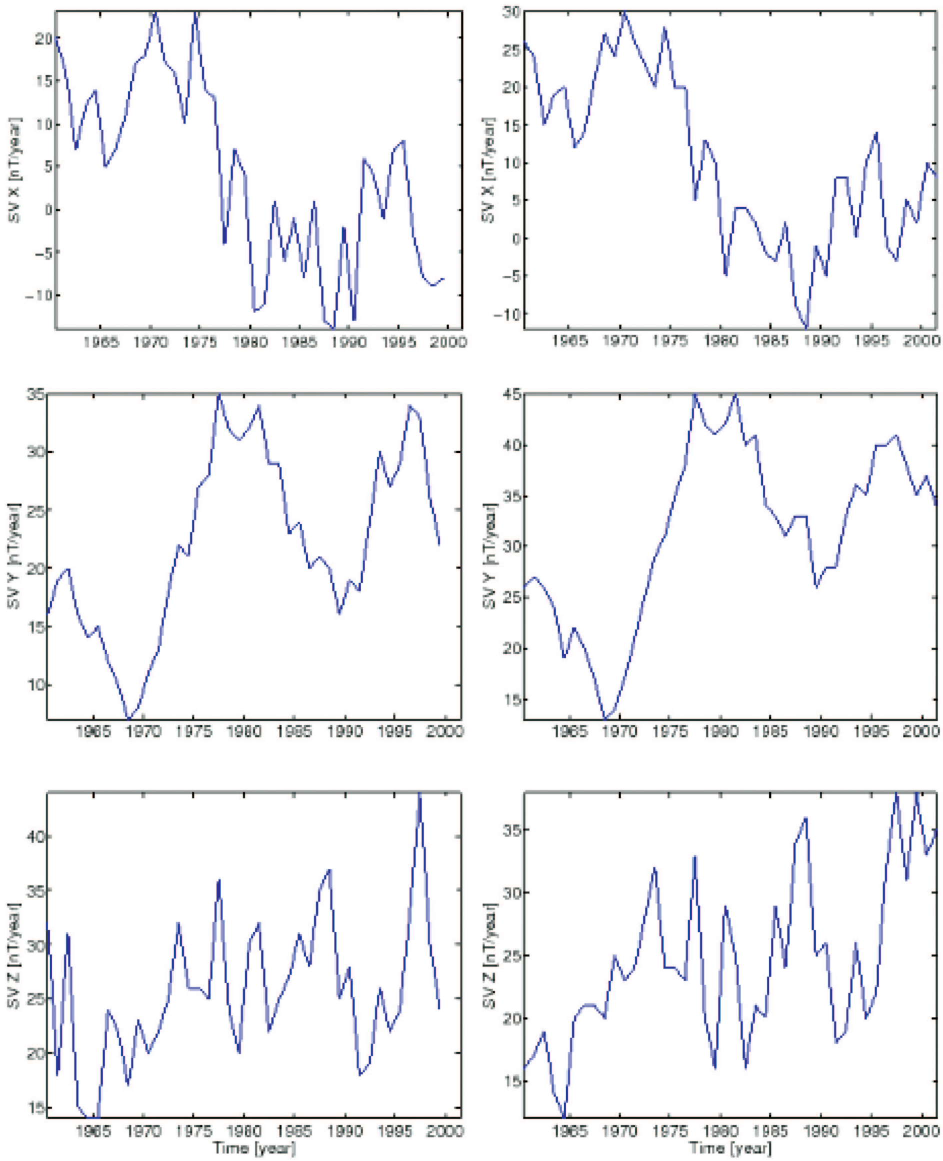

Figure 5. Time-series for *X* (first row), *Y* (second row) and *Z* (third row) SV components at GCK (left panels) and FUR (right panels) observatory locations, in nT/year.

Note that the curves are not smooth as in the case of the EU_MIX time series because the SV were computed from the annual mean values. All components exibit variations similar to those obtained from EU_MIX model that are shown in Figure 3. The SV curves track each other very well, and the epochs of significant changes of SV are matched. Further, in addition to NGK, I compared the EU_MIX model at observatory site with calculated SV of *X*, *Y* and *Z* components observed for the same period at AQU, GCK and FUR observatories. The annual means are collected from the World Data Center Edinburgh (http://www.geomag.bgs.ac.uk/gifs/ annual means.HTML). The time series are presented in Figure 4 right panels and in Figure 5. Comparison with EU_MIX time series again shows that all the curves exibit similar variations, with the change of decreasing and increasing trends occuring at same epochs. Moreover, note that even smaller variations observed at observatory places, are also predicted by EU_MIX model at observatory site in Croatia. For instance, in *Y* the decreasing of SV is seen around 1980. At observatory site the decline in value is slighter, since the model is continuous and data are somewhat smoothed in time and space (for details about modelling technique see Verbanac (2007) and Verbanac et al. (2009)).

Thus, we may conclude that during the studied period the observed changes in all components at the potential geomagnetic observatory site are caused by internal geomagnetic field. We further can assume that there are not variations due to different induced fields or other effect. This is very important for the geomagnetic observatory location. However, to ensure that no induction effects exist it would be preferred to run a variometer at that particular point for longer period (e.g. a year) and compare it to the nearest surounding observatories.

4. Counclusion

In this paper the geomagnetic core field behavior over the entire Croatian territory was investigated by exploiting different global models and one regional, European, model. The core field values were obtained for the epochs 1980.0, 2000.0, 2003.0, and 2002.5 for MAGSAT and CM4, OSVM, POMME, and CHAOS models, respectively. The secular variation was calculated from the regional EU_MIX model for the epoch 1980.5 which lays almost in the middle of the interval of the model validity. I further use the advantage of the time continuity of the EU_MIX model to study the field evolution over 40 years at the potential location for installing the geomagnetic observatory.

The results may be summarized as follows:

(1) All global model predictions revealed that the total field is stronger in the norther than in the southern part of the country with the gradient of about 30 nT per 1 degree of longitude and 300 nT per 1 degree of latitude.

(2) The computed secular variations of *X*, *Y*, and *Z* components for the epoch 1980.5 reveal larger change in the approx. SW part than in the approx. NE part of Croatia within one year in both *X* and *Y* components. The SV *Z* component has larger values in the eastern part than in the western part of the country.

(3) The produced *X*, *Y* and *Z* SV time-series embracing period 1961–2002 at the chosen observatory location reveal both smooth and abrupt variations. The most dynamic pattern is observed in *Z* component. These secular variations are consistent with the general European secular variations pattern (Verbanac et al., 2009).

(4) Some of the years of remarkable changes in the SV field correspond to the years of abrupt SV changes seen over the European region (Verbanac et al., 2009). These epochs can be summarized as follows: for the *X* component around 1965, 1970, 1994; for *Y* component around 1969, 1996; for the *Z* around 1969, 1987. The well-known jerk of 1969 is clearly seen at this location in all three components.

This study contributes to get an insight in the core field and its changes over the entire Croatian region for the period without measurements. This is especially important for the site considered as potential location for installing the geomagnetic observatory.

The results show that the calculated field variations follow the general core field variations over Europe and that at the particular point (observatory location) there are probably not variations due to different induced fields or other effects. The variations rather reflects the dynamical physical processes occuring in the Earth's core. However, to ensure that no induction effects exist we aim to run a variometer at that particular point for longer period (e.g. a year) and then compare it to the nearest surounding observatories.

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SAŽETAK

Modeliranje geomagnetskog polja nad Hrvatskom

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Tijekom posljednjih godina započeto je istraživanje geomagnetskog polja u Hrvatskoj i učinjeni su prvi koraci za osnivanje geomagnetskog opservatorija.

Na temelju izmjerenog ukupnog magnetskog polja u sjeveroistočnom djelu Hrvatske, predložena je lokacija za instaliranje geomagnetskog opservatorija.

U ovom radu proučeno je ponašanje unutrašnjeg magnetskog polja preko cijelog teritorija Hrvatske za razdoblje 1961.–2002. uporabom različitih globalnih modela. Uz pomoć regionalnog Europskog modela, izračunata je sekularna promjena polja u Hrvatskoj. Evolucija polja kore na potencijalnoj lokaciji za instaliranje geomagnetskog opservatorija detaljno je analizirana. Izračunate promjene polja slijede promjene polja jezgre u Europi. Nisu pronađene promjene radi različitih induciranih polja ili drugih efekata na lokaciji budućeg opservatorija.

Ovaj rad doprinosi proučavanju potencijalne lokacije geomagnetskog opservatorija i otvara put boljem razumijevanju ponašanja geomagnetskog polja na području Hrvatske.

Ključne riječi: geomagnetske sekularne promjene, modeliranje, geomagnetski opservatorij

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