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Preliminary Measurements of Geomagnetic-field Variations in Slovenia

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Abstract: The paper describes preliminary measurements of the Earth magnetic field made at the future geomagnetic observatory in Slovenia located at the bottom of the mountain peak Sinji Vrh above the town of Ajdovščina. Operation of the proton magnetometer has been verified for longer periods. This instrument is used to indicate the absolute value of the geomagnetic-field vector. These measurements provide the basis for continuous three-axis measurements of changes in the geomagnetic field as well as for evenly distributed, recurrent absolute measurements. Measuring results of the preliminary measurements of the absolute values of changes in the geomagnetic-field vector were treated as signals. The basic geophysical explanations were added to the results of data processing. Conclusions drawn from the preliminary measurements will be used for the future measuring equipment of the observatory necessary for its formal operational licensing and for its integration with the international information network.

Key words: geomagnetic observatory, geomagnetic measurements, proton magnetometer.

1 BUILDING A GEOMAGNETIC OBSERVATORY IN SLOVENIA

Construction of the geomagnetic observatory in Slovenia (hereinafter the "Observatory") is one of the activities of the Laboratory for Geomagnetism and Aeronomy of the Higher Education Centre of Sežana. The Laboratory was registered in January 2009 with ARRS in Ljubljana. Its activities had started two years before its registration [1]. The location under the mountain peak Sinji Vrh above Ajdovščina(φ= 045,90011° N, λ = 013,93895° E, h = 866 m) is an optimal site for an observatory (Figure 1). It was selected after three years of searching for a proper location and agreeing to terms with all parties affected by its construction [2].

Geomagnetic measuring data are directly used in eleven different areas of activities: navigation, geology and mining, geotechnology, archeology, telecommunications, energy and power engineering, seismology and meteorology, climatology and environment, transport, medicine and magnetobiology and biomagnetics. Accurate measurements of the geomagnetic field are used in drafting aeronautical and nautical charts needed for navigation. Transport would be less safe or even impossible without themwhen the satellite navigation systems are at standstill, e.g., during wars or solar winds. Magnetometers are used in geology and mining to detect natural gas, ore and oil deposits, geothermal wells and stocks of ground water. They are also used in energy and power engineering for registering changes in the geomagnetic field to determine their impact on oil and gas pipelines, overhead power lines and power transformers.

Figure 1.Temporary hut with a measuring pillar for absolute measurements of the geomagnetic field and astronomic observations at the site of future Observatory under the Sinji Vrh above Ajdovščina.

The process of measuring the geomagnetic field has been known for more than four centuries [3, 4], however, we are currently only at the start of carrying out such measurements at a new observatory currently being in its construction phase. Its operation will enable further research work in the field of geomagnetism and aeronomy on national and international projects and its

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integration into the INTERMAGNET (International Real-time Magnetic Observatory Network)international information network.

INTERMAGNET was established in 1987 as an international information network to exchanging measuring data obtained by geomagnetic observatories [5]. The network includes geomagnetic observatories from 44 states broadcasting their measuring data each minute into six nods. The nods in Paris (France) and Edinburgh (Scotland) are responsible for Europe.

2 COMPARISON AND PROCESSING OF MEASURED DATA

Measurements of the geomagnetic-field vector taken at the future Observatory were carried out using the Overhauser proton magnetometer GSM-19GW, serial number 7112566, manufactured by GEM Systems from Canada. In September 2009, at the observatory Royal Meteorologique de Belgique – Centre de Physique du Globe a Dourbes, Belgium, this instrument was used to compare measurement results. The comparison confirmed that the used magnetometer complies with international recommendations for the instrument for absolute measurements at the Observatory [6].

Preliminary variable measurements made at the Observatory site with the proton magnetometer started on 25th November 2010 and after five consecutive measuring-periods ended on 24th February 2011. The power supply for the instrument was provided by a 12 V, 110 Ah battery replaced with a new charged battery each time a measuring period had ended. The magnetometer was first tested for shortened sampling times, from 5 seconds to 1 second, then its location and location of its sensor and GPS antenna were tested and thereupon its operation was monitored. Each measuring result was registered in a static memory of the instrument using the ASCII code: the time designation in the UTC standard form, absolute value of the geomagnetic-field vector F(t) in 10^{-9}T and evaluation of the Signal Quality (SQ).

Measurements carried out during a solar wind enabled checking operation of the proton magnetometer. The solar wind was predicted and was caused by a mass ejection in a group of sunspots AR1158 on 15th February 2011 at an evaluated rate of X2 [7]. The mass ejection caused on the Earth a geomagnetic storm which reached Europe on 17th February 2011 in the afternoon hours (Figure 2).

In 2008, the Higher Education Centre of Sežana and the Grocka Geomagnetic Observatory in Serbia signed a bilateral agreement on business and technical and scientific cooperation. The agreement regulates exchange of measuring results obtained at the planned observatory site during the period of carrying out the preliminary measurements of variations in the geomagnetic field. Both observatory sites are located in the European mid latitudes and therefore they are geophysically comparable. Results of measurements of changes in the absolute value of the geomagnetic-field vector F(t) taken during the above mentioned geomagnetic storm (Figure 2) are also comparable. The differences are due to the different longitudes, geological structure of the terrain and current weather conditions.

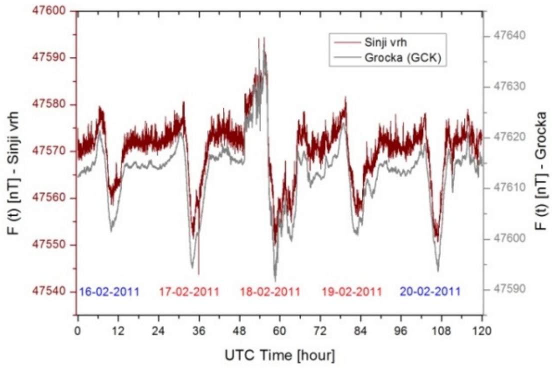

Figure 2.Registration of a magnetic storm caused by the Sun coronal mass ejection on 15-02-2011 at the planned observatory site in Slovenia and at the Grocka Geomagnetic Observatory (GCK) in Serbia.

Unlike is the case withother data processing digital signal processing deals with signals. The signals are mostly measuring data from the real world transmitted by various sensors. Digital signal processing may reduce their quantity, thus making them easier to recognize and access, or,in other words, they become usable. As for each technical and scientific area, for digital signal processing there have been special operational technology, mathematics and computer algorithms developed.

3 MEAN VALUE AND STANDARD DEVIATION

If all measurements are carried out in the same way and under the same conditions, then the most probable real value of the value measured is an arithmetical mean value μof all measurement results. The error of each measurement is its deviation from the most probable real value of the value measured. The sum of all errors for each group of measurements is equal to zero, and therefore the mean value of all equivalent measurement results is the one closest to the real value [8].

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$$

The mean value of signal μ[9] presents one-way, time-constant value describing exclusively one-way energy transmission. The alternating component of the signalwhich actually bears information will change around this mean value.

Varianceσ^2 or average absolute deviation is the sum of square values of deviations of the error from mean valueμ. As the variance is expressed in the square unit of the measure, standard deviation σmay be more understandable.

$$\sigma^2 = \frac{1}{N}\sum_{1}^{N}(x_i - \mu)^2$$

Standard deviation $\sigma$is the mean value of powers of alternating components. Sometimes the standard deviation itself is not needed; however, its proportion to the mean value is important. In these cases, the mean value is the actual value measured, and the standard deviation presents the noise and other interferences. The standard deviation proportion to the mean value is called signal-to-noise ratio SNR. SNR expressed in percentage is the coefficient of variation CV.

Table 1.Statistical processing of measurement results during the first three hours of the selected days of the third test cycle.

Day	Mean value	Standard deviationσ	Coefficient of variation CV
[dd.mm.yyy]	[nT]	[nT]	[%]
20.01.2011	47591,15	1,17	0,002
21.01.2011	47593,02	1,28	0,003
22.01.2011	47592,06	1,69	0,004
23.01.2011	47592,05	1,28	0,003
24.01.2011	47593,23	1,33	0,003
25.01.2011	385767,47	79585,00	20,630

Table 1 presents results of statistical processing of measurement results during the first three hours of selected days when the test measurements of the third cycle of the preliminary measurement at the Observatory site were carried out; the value measured was the absolute value of geomagnetic-field vector F(t). During this period, which lasted three weeks, from Wednesday 12/01/2011 to Wednesday 02/02/2011, the proton magnetometer increased automatically the time designation of the measurement three times: on 14/01/2011 for 2 seconds and later on the same day for 1 second, and on 19/01/2011 for 2 seconds. After the last skip in the time designation, it worked normally for five days and then changed the SQ coefficient from the normal value of 99 to 72 and the next day it transposed the date of the file registration in an improper way. Therefore, the measurements carried out from Thursday 20/01/2011 to Tuesday 25/01/2011 were analyzed in more detail.

During the measurements at the future Observatory site, the two proton magnetometers operated in parallel in order to reliably measure the change in the absolute value of the geomagnetic field vector. The magnetometers were regularly maintained and daily checked by statistical processing of the obtained measurement data during the first three hours of each measuring day. The new measuring day startedat midnight of the UTC time, when the sun is down in Slovenia and therefore under the lowest impact by the geomagnetic interferences from the universe.

4 SIGNAL CORRELATION AND DEPENDENCE

During signal processing, the measure for similarity between the two signals as a function of the time delay is cross correlation. This method is used to determine the entire signal on the basis of its known part. Cross correlation of signals is an operation similar to the function convolution often used in researching the system impact on its input signal [9, 10].

Cross correlation for linear functions f(t) and g(t) is:

$$\Phi_{fg} = (f * g)(t) = \int_{-\infty}^{\infty} f^*(\tau)g(t+\tau)d\tau,$$

Where f*(t) is a complex conjugate value of function f(t).Similarly, for discrete functions cross correlation is defined as:

$$\Phi_{fg} = (f * g)[n] = \sum_{m=-\infty}^{\infty} \lim_{N\to\infty} \frac{1}{2N+1} \sum_{n=-N}^{N} f[n]g[n + m] = \sum_{m=-\infty}^{\infty} f^*[m]g[n+m].$$

Instead of a complex spectrum, cross correlation may be presented as a variance. In signal processing, the variance provides oscillation around the mean value and is used as a measure of the power of all extant components:

$$\gamma_{fg} = (f * g)[n] = \lim_{N\to\infty} \frac{1}{2N+1} \sum_{n=-N}^{N} \left(f[n] - \overline{f[n]}\right)\left(g[n+m] - \overline{g[n]}\right).$$

Sometimes it may be necessary to present cross correlation as its coefficient. It can be calculated by normalizing cross correlation of the two signals, with the power of these two signals, setting the time delay as m = 0. Cross-correlation coefficient lies within the interval [-1; +1] and its value may be 0, which means that there is no connection between the signals.

$$l_{fg}[m] = \frac{\Phi_{fg}[m]}{[\Phi_{ff}[0].\, \Phi_{gg}[0]]^{1/2}}$$

Statistics uses the cross-correlation coefficient as r coefficient or the Pearson's coefficient [11]. The Pearson's correlation coefficient determines the mutual dependence of two variables, X and Y, with values between -1 and +1.

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

The algorithm calculating the cross-correlation coefficient was initially tested usinga step-by-step calculation and checking the results. Only after such verification was the algorithm included in the software for processing and storing the data measured.

5 VERIFICATION OF THE ALGORITHM DETERMINING THE CORRELATION COEFFICIENT

The data measured by the proton magnetometer during the third cycle of its testing were used in verification of the algorithm determining the correlation coefficient [12, 13]. A magnetically calm day of 20-01-2011 with the quality of measuring signal SQ = 99 was selected as a reference (Figure 3). For the reference day the correlation coefficient is r = 1.00000 (auto-correlation). For this series of measurements, the highest deviation from the reference day was recorded on 25-01-2011 (Figure 4) with the quality of measuring signal SQ = 72 and the correlation coefficient (cross correlation) r = -0.16289.

Table 2.Correlation coefficient for each day from the third test cycle

Day	Correlation*coefficient* r	
[dd.mm.yyyy]	Sinji vrh	Grocka (GCK)
20.01.2011	**1,00000**	0,92880
21.01.2011	0,73914	0,83943
22.01.2011	0,82041	0,84288
23.01.2011	0,80229	0,80662
24.01.2011	0,35404	**0,01337**
25.01.2011	**-0,16289**	0,55334

The correlation coefficient is a number that determines the similarity between two diurnal changes in the absolute value of the geomagnetic field (Table 2). In this example, these values are given as two discrete time functions,f(t) and g(t). Most of the calculated values of the correlation coefficient are positive r ≥ 0, or, the linear dependence of both functions is positive. This means that after the increase in the first time function, the second time function also increased; after the decrease in the first time function, the second time function also decreased. The correlation coefficient at the same time yields the dependence rate of the time functions. The higher the coefficient is, the higher is the dependence rate of both time functions.

Both the mean value of the signal and the standard deviation (Table 1) predicted the poor measurement taken on 25-01-2011, and in accordance with this,thecorrelation coefficient indicated a negative value r = - 0.16289 (Table 2). The measurements made on that day had no similarity with the reference measurements made on 20-01-2011. Therefore, the correlation coefficients for the measurements at the Grocka Geomagnetic Observatory were also calculated. The calculation shows that on 24-01-2011 the measurement results deviated a great deal from the reference measurement results despite being evaluated as SQ = 99.

The basic time function for further calculation of the correlation coefficient may be the measurement of the change in the geomagnetic field in a selected day during a magnetically calm period or previous day. At the end of the day, upon completion of each measurement, the appropriate correlation coefficient should be saved in the file for the current month or it may be included in the name of a file including the measuring data.

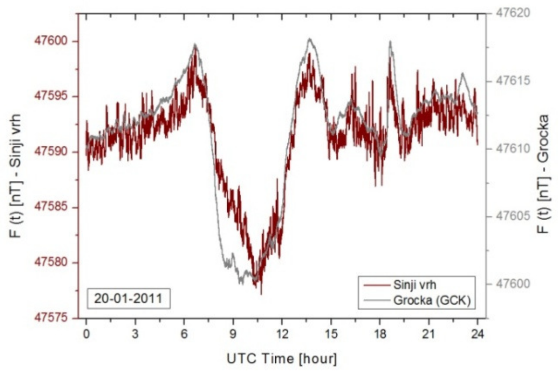

Figure 3. Change in the absolute value of geomagnetic field F(t) on a selected reference day during the third cycle of the test measurements.

6 FOURIER TRANSFORM AND FREQUENCY ANALYSIS

The computer calculation of convolution, cross correlation, auto-correlation and correlation may cause problems as it lasts very long because the matrix with all samples of the treated signals is very complex and there are many mutual products to be calculated [9, 14]. This can be solved by using substitute numbers with a floating zero, ordinary numbers of a limited length or a dedicated computer, customized for such calculations.

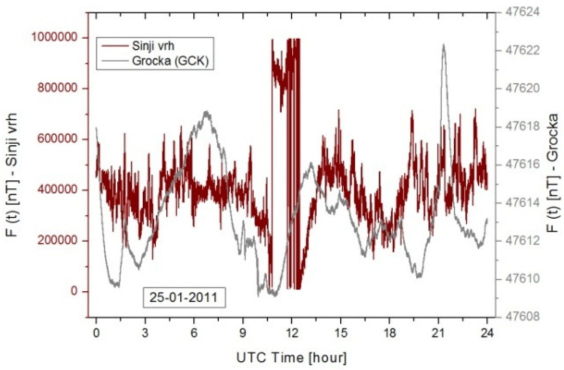

Figure 4. Change in the absolute value of geomagnetic field F(t) during the third cycle of test measurements on the day with the quality of measuring signal SQ = 72.

The best way to increase the speed of signal operations is to selectbetter algorithms. By using transformation from the time into the frequency domain, the time of calculation is reduced and the obtained result is the same. The Fast Fourier transformation has very demanding algorithms that are interesting when researching and comparing the frequency spectra of exceptional dynamic phenomena of the geomagnetic field and when researching their impact on our lives [15].

7 CONCLUSIONS

The importance of simultaneous processing of measurement results in the form of signals, i.e. calculation of mean value μof the signal and standard deviation σ(Table 1), as well as of verification of the algorithm used in determination of the correlation coefficient r (Table 2) is very clear. A comparison and processing of the measured values showed that the selected location for the future observatory is suitable to fulfill its purpose. It is important that absolute measurements are used in selecting an appropriate way of measurement-data processing by taking into consideration specifics of the measurements of changes in the geomagnetic field at the planned Observatory site occurring because of the geologic type of the ground (Figure 2).

To determine the environmentalimpacton the geomagnetic measurements at the observatory site, the following measuring equipment enabling automatic measurements should be used:

- Meteorological station at the Observatory site to determine how changes in weather states correlate with those in the geomagnetic field,
- Hydrographic station at the source of the river Hubelj located at the height of 200m above the sea level, and
- Acceleration meter to determine seismic impacts on the geomagnetic measurements.

The Geomagnetic Observatory planned to be constructed at the bottom of the mountain peak Sinji vrh above the town of Ajdovščina and its future development will considerably contribute to further development of the knowledge about geomagnetism of the Higher Education Centre of Sežana and will be an important achievement in the national level, too. In progressive countries, measurements of the geomagnetic field are of equal importance as the meteorological, hydrological and seismic ones.

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Damir Deželjin is about to complete his master's studies at the Faculty of Mathematics, Sciences and Information Technologies, University of Primorska, Koper, Slovenia. In the last ten years, his effort has been towards bringing the information technologyinto practice. He cooperates with the Laboratory for Geomagnetism and Aeronomy at the Higher Education Centre of Sežana in field of measuring data acquisition, transmission and processing.

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