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Zentralanstalt für Meteorologie und Geodynamik

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Special Issue: IAGA Workshop 2018

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Conrad Observatory

Scientific contributions to the XVIIIth Workshop on Geomagnetic Observatory Instruments, Data Acquisition and Processing of the International Association of Geomagnetism and Aeronomy (IAGA) organized by the ZAMG team at the Conrad Observatory in June 2018.

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Preface

The Conrad Observatory has become a recognized center for international activities around geomagnetic data. Three international events were held at and organized by the Conrad Observatory in 2018. The XVIIIth IAGA Workshop, the IAGA Observatory Summer School for young observers and the INTERMAGNET committee meeting were held at the observatory. During the workshop the participants were able to check their instruments for instrumentation errors. Data acquisition and processing for this took place at the Conrad Observatory and at ZAMG. The young observers were able to attend special courses for handling and care of instrumentation, data quality checking, acquisition and processing held by experienced observers from all over the world. The INTERMAGNET committee had the opportunity to negotiate new standards for one second magnetic data recorded at the observatories around the world.

This special issue of the Conrad Observatory Journal contains many reports of research groups attending these events presenting results of research campaigns and equipment developments.

Beside these events many other projects, research campaigns and system developments were conducted at the Conrad Observatory in the most recent years which should be mentioned here.

Together with the Space Research Institute, Austrian Academy of Science, a new calibration *Merritt Coil System* could be established at the observatory. This is a very valuable feature for the calibration of new sensors, especially satellite magnetometers as used on the ESA JUICE mission. Regional magnetometer stations were developed and set up for a better understanding of space weather and its consequences. Two PhD students finished their thesis in 2018.

I congratulate the team of the Conrad Observatory for their excellent work.

In this spirit,

Michael Staudinger
Director of the Central Institute for Meteorology and Geodynamics

XVIIIth IAGA workshop at the Conrad Observatory

Local Organisation Comittee

Figure 1: Participants of the IAGA workshop and the Summer School at the Conrad Observatory near Muggendorf, Austria.

In June 2018, earth magnetic field researchers from all over the world met at the Conrad Observatory in Austria. Three events were organized there: The XVIIIth IAGA Workshop, the IAGA Observatory Summer School for young Observers, and a meeting of the INTERMAGNET Committee. Summer School and the IAGA Workshop on Geomagnetic Observatory Instruments, Data Acquisition and Processing took place at the Conrad Observatory of the Zentralanstalt für Meteorologie und Geodynamik (ZAMG), Austria.
The IAGA Observatory summer school was organized in the days before the IAGA Workshop for the first time, with the aim of providing young technicians and scientists as well as new observers with a good basic understanding of a wide range of observatory topics. Altogether 23 participants, sponsored by the LOC participated. The summer school provided an in-depth course on DI measurements, instrumentation and data processing with accompanying practical sessions given by experts in the specific fields: Alan Berarducci, Tim White and Chris Turbitt.
The IAGA Workshop started on 24. June. The event attracted 110 participants from 36 different countries from all over the world. There were made 123 DI measurements by 32 different observers on four pillars at the tunnel system of the Conrad Observatory. In total 39 oral presentations were given and 35 posters were presented. Alan Thomson from the British Geological Survey gave an invited talk during the opening ceremony. Beside the poster sessions, an excursion to a winery and BBQ evening provided also an excellent opportunity for the geomagnetic research community for discussions about the latest research findings, new development work, methods and measurement procedures.
Following the workshop, the INTERMAGNET meeting took place. INTERMAGNET defines observatory quality standards, examines their data and certifies them.
23 members of operations and executive committee, as well as 5 guests met on the Hohe Warte at the ZAMG. Reports from the respective working groups, decisions on the certification and a revision of the work instructions were the main topics of this three-day meeting.

Figure 2: Instrument presentation during the workshop in the Observatories laboratories,

Summer School and Workshop would not be possible without the generous financial support of our sponsors. We are particularly grateful to the following companies, institutions and agencies:

- Bundesimmobiliengesellschaft m.b.H
- emc elektromanagement & construction g.m.b.h.
- GEM Systems
- Gustav Klein GmbH & Co KG
- International Association of Geomagnetism and Aeronomy IAGA
- Niederösterreichische Landesregierung
- ÖSTERREICHISCHE BUNDESFORSTE AG
- ÖSTU-STETTIN Hoch- und Tiefbau GmbH

The grants where used to cover the accommodation for young scientists during the workshop and waiving fees for participants.

The LOC:
Roman Leonhardt, Barbara Leichter, Ramon Egli, Richard Kornfeld, Andrea Draxler, Niko Kompein, Rachel Bailey, Irene Herzog, Richard Mandl, Patrick Arneitz, Jennifer Deim, Peter Melichar

Zentralanstalt für Meteorologie und Geodynamik, Hohe Warte 38, 1190 Wien, Austria

Corresponding author:
Roman Leonhardt
Conrad Observatory
Zentralanstalt für Meteorologie und Geodynamik
Hohe Warte 38, A-1190 Wien
Tel.: +43 1 36026 2507
e-mail: roman.leonhardt@zamg.ac.at

Content

Applications

Coupled Dark State Magnetometer for the China Seismo Electromagnetic Satellite

A. Pollinger, R. Lammegger, W. Magnes, I. Jernej, C. Hagen, M. Ellmeier, M. Leichtfried, C. Kürbisch, R. Wallner, G. Fremuth, C. Amtmann, M. Delva and G. Prattes

On 2 February 2018, after 9 years of development, the instrument was successfully launched into a low Earth orbit. This is the first demonstration of the CDSM measurement principle in space.

The Coupled Dark State Magnetometer (CDSM) is an optically pumped scalar magnetometer based on two-photon spectroscopy of free alkali atoms. The magnetic field measurement is based on the Zeeman effect which is the splitting of a spectral line into several components in the presence of a quasi-static magnetic field. Additionally, the CDSM uses several coherent population trapping (CPT) resonances in parallel in order to reduce systematic errors, e.g. the sensor temperature dependence. CPT inherently allows omni-directional measurements. This leads to a simple, all-optical sensor design without double cell units, excitation coils or electro-mechanical parts. The measurement principle was discovered in 2008 [1] and since then the two involved institutes have developed the instrument for future space missions [2].

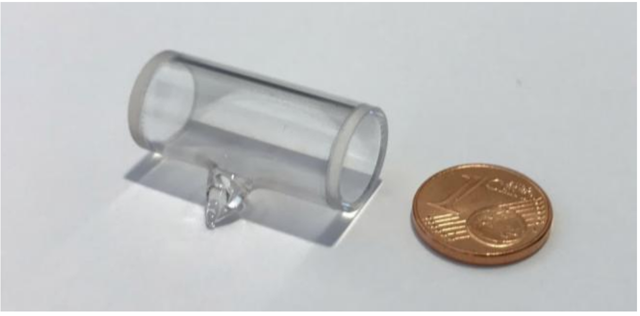

Figure 1: The CDSM uses laser light to probe rubidium atoms in this glass cylinder in order to gain information of the surrounding magnetic field.

Key parameters of the CDSM such as sensor-heading characteristic, accuracy, power spectral density of the detection noise and sensor temperature dependence were experimentally determined at the Conrad Observatory of the Central Institute for Meteorology and Geodynamics in Austria and partly at the Fragment Mountain Weak Magnetic Laboratory of the National Institute of Metrology in China.

The flight model is characterized by an accuracy of 0.19 nT (σ), a detection noise of 50 pTrms at 1 s integration time, a mass of 1672 g and an in-Earth orbit measured power consumption of 3394 mW [2].

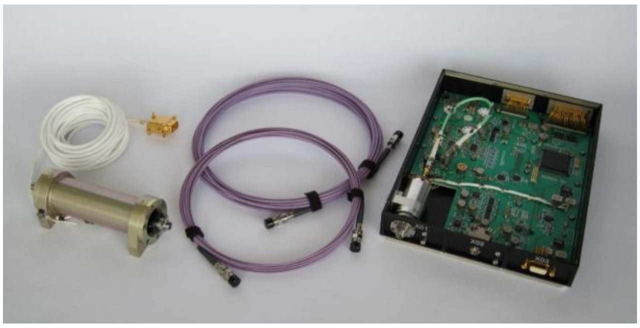

Figure 2: The flight model consists of a mixed signal electronics board and the laser unit mounted in the instrument box (right). The sensor unit (left) is located at the tip of a boom outside of the satellite and is connected with two fibres (middle) and the thermal control cable.

The China Seismo-Electromagnetic Satellite (CSES), also known as Zhangheng-1, investigates natural electromagnetic phenomena and possible applications for earthquake monitoring from space in a polar, sun-synchronous, low Earth orbit. CSES was launched in February 2018 and has a nominal mission lifetime of 5 years.

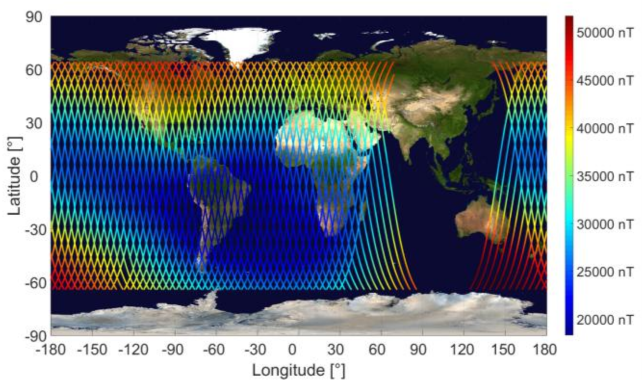

Figure 3: Since March 2018, the CDSM measures the magnetic field of Earth aboard CSES in a low Earth orbit.

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Author:

A. Pollinger[1,2], R. Lammegger[1], W. Magnes[2], I. Jernej[1], C. Hagen[2], M. Ellmeier[2], M. Leichtfried[2], C. Kürbisch[2], R. Wallner[2], G. Fremuth[2], C. Amtmann[1], M. Delva[2], G. Prattes[2]

1) Institute of Experimental Physics, Graz University of Technology, Austria

2) Space Research Institute, Austrian Academy of Sciences, Austria

Corresponding author:

Andreas Pollinger

Space Research Institute, Austrian Academy of Sciences

Schmiedlstraße 6, 8042 Graz, Austria

Tel.: +43 (316) 4120 569

e-mail: andreas.pollinger@oeaw.ac.at

A coupled dark state magnetometer developed for space missions

Christoph Amtmann, Roland Lammegger, Andreas Pollinger, Werner Magnes, Michaela Ellmeier, Christian Hagen, Irmgard Jernej and Martín Agú

The development of an optically pumped magnetometer for space missions is a challenging task considering the electrical, mechanical and thermal limitations and restrictions in a harsh environment. The coupled dark state magnetometer (CDSM) is a self calibrating, scalar magnetometer specifically designed for these challenges.

The coherent population trapping effect (CPT), within the hyper fine structure of the ^{87}Rb-D_1 line, allows a precise detection of magnetic fields. Several of these CPT resonances, in the form of Λ-systems, are excited and coupled simultaneously. In Figure 1, the two magnetically shifted (orange and green) Λ-systems are coupled to measure the magnetic field and to minimize external influences such as neon buffer gas pressure shift, sensor temperature shift and light shift. The blue Λ-system acts as a frequency reference for the CDSM's self calibration. The laser light's circular polarisation only excites Λ-systems according to the $m_F \pm 1$ selection rule. In Figure 1, the solid lines indicate excitations with σ^+ and the dotted lines excitations with σ^- polarised light.

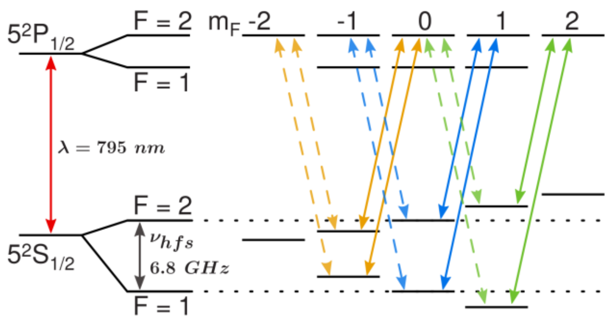

Figure 1: Excitation scheme of multiple Λ-systems within the hyper fine structure of the ^{87}Rb-D_1 line. The dotted and solid lines indicate resonances with different m_F quantum numbers.

For an omnidirectional sensitivity, additional CPT resonances (not shown in Figure 1) are exited depending on the angle between the magnetic field and the laser propagation axis.

The CDSM's current space ready flight model design is displayed in Figure 2. Optical fibres connect the ^{87}Rb sensor unit to the vertical cavity surface emitting laser (VCSEL) diode unit and the photodiode, both within the electronics unit. The laser current is FM-modulated with a 3.4 GHz signal to match the ground state hyper fine splitting with the first upper and lower sidebands to establish the Λ-systems. A blue resonance (Figure 1) stabilizes this GHz frequency. A field programmable gate array (FPGA) ensures the autonomous operation in space. Currently an accuracy below 0.2 nT is achieved.

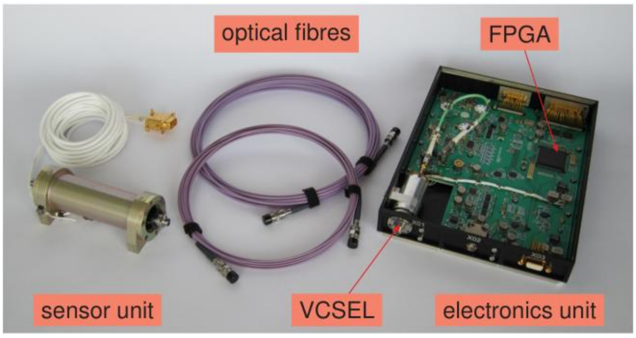

Figure 2: CSES flight model with its main components. From left to right: the vapour sensor unit, the optical fibres and the electronics box.

Since February 2018, the first CDSM version has been operating successfully in a low Earth orbit as part of the China seismo-electromagnetic satellite (CSES) mission. In 2022, the magnetometer will be launched with a newly designed sensor unit on board of the Jupiter icy moons explorer (JUICE) mission.

This new sensor design features a dual transition principle. The light is sent through the spectroscopic glass cell twice to compensate for different atomic transition rates due to the light's circular polarisation. Now both, the dotted and solid resonances are equally excited. This allows to optimise the accuracy and further reduces the external influences.

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Author:
C. Amtmann[1], R. Lammegger[1], A. Pollinger[1], W. Magnes[2], M. Ellmeier[2], C. Hagen[2], I. Jernej[2] and M. Agú[2]
1) Institute for Experimental Physics, Graz University of Technology
2) Space Research Institute, Austrian Academy of Sciences, Schmiedlstraße 6, 8042 Graz, Austria

Corresponding author:
Christoph Amtmann
Institute for Experimental Physics, Graz University of Technology, Petersgasse 16, 8010 Graz, Austria
e-mail: christoph.amtmann@tugraz.at

Accurate estimation of variometers' frequency response and synchronization errors

Andriy Marusenkov

The goal of the paper is to determine the transfer function and time-stamp accuracy of a LEMI-025 fluxgate variometer against the specifications of the INTERMAGNET one-second data standard. The results obtained by the two methods - modified impulse response analysis and direct measurements at selected frequencies - are entirely consistent with expected characteristics of the 61-point digital filter used for decimating 10 Hz variometer raw data to final 1-second values.

The two methods are used for testing compatibility of a variometer LEMI-025 with the INTEMAGNET one-second definitive data specifications (Turbitt et al., 2013) concerning time-stamp accuracy and frequency response in the pass and stop bands.

The first method is based on the approach described by Shanahan et al., 2009 - the impulse response (IR) of the system is estimated and then using the Fourier transform the amplitude and phase at any frequency could be calculated. The impulse response of 1 Hz data is estimated as the first differences of the overlaid instrument responses to phase-shifted impulse inputs, thus obtaining the same time resolution as if we are using 10 Hz data. This is achieved by using as input signals the sequence of 0.05 Hz square waveform oscillations delayed by 0.05, 0.15, ..., 0.95 s relatively to the top of an UTC second.

Another method is a set of the direct measurements of the system response to an input signal with a given frequency, so called a multiply frequency test.

For the both methods the same test bench (Fig. 1) is used to generate the packets of square or sine waveforms synchronized with an UTC second. In order to cancel out external magnetic signals, the sensor with a calibration coil is placed inside a magnetic shield.

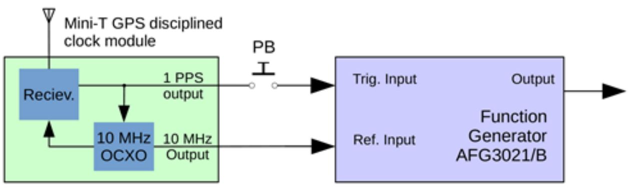

Figure 1: Test bench diagram

The group delay estimations in the band 0.02 to 0.5 Hz, obtained by the both methods, are within INTERMAGNET specifications of 0.01 s. The amplitude estimations as well as the response of the 61-point digital filter and the required limits are given in Fig. 2.

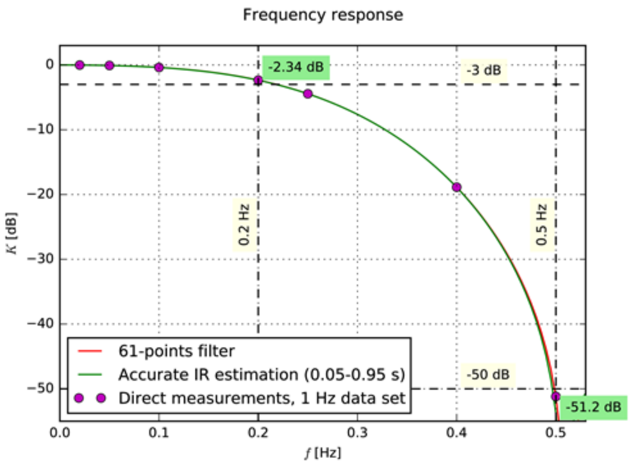

Figure 2: Amplitude vs. frequency response estimations

The impulse response method yields accurate results at the proper set of input signals. Frequency response estimations obtained by the two different approaches are mutually consistent. A variometer LEMI-025 with the 61-points filter meets INTERMAGNET requirements to 1-second data.

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Author:
Andriy Marusenkov[1]
1) LLC "LEMI"; Lviv Centre of Institute for Space Research, Lviv, Ukraine

Corresponding author:
Andriy Marusenkov
LLC "LEMI"; Lviv Centre of Institute for Space Research
Naukova 5A, 79060 Lviv, Ukraine
Tel.: +380 32 2540266
e-mail: marand@isr.lviv.ua

Absolute vector measurements based on the scalar Overhauser sensors POS

Vladimir Sapunov, Jean Rasson, Sergey Khomutov, Anatoly Soloviev, Pavel Borodin, Oleg Kusonsky, Boris Kuzmenko, Alexey Denisov, Dmitriy Saveliev, Valiliy Saveliev, Sergey Kiselev, Evgenii Narkhov, Alex Sapunov

Due to the high absolute precision (up to 0.2 nT) and stability (<0.05 nT per year), the scalar Overhauser magnetometer POS-1 found wide application in the magnetic observatories and hazard monitoring systems. We present new modifications on our magnetometers for measuring the vertical component (POS-3) or the full vector (POS-4) based on the switching bias fields methods [1]. We discuss the long-term experience in their testing at the magnetic observatories ARS (Arti, IGF UB RAS) and PET (Paratunka, IKIR FEB RAS). The absolute accuracy of the measurement of the vertical component of 10-30 nT is achieved. This can be improved to 1-3 nT by use of a self-calibration. This was tested by comparing with a Diflux based on the nonmagnetic theodolite Theo-010. The vertical system titanium frame based on Garrett's Ø110x260 mm solenoid provides long-term stability up to 2 nT/year. The solenoid vertical axis was controlled by spirit levels of 30 angular seconds and with the help of a new high-precision non-magnetic 2D inclinometer providing accuracy of up to 1 arcsec, resolution 0.1 arcsec, temperature range of -40 + 60 C.

The creation of a new small-sized solenoid and Overhauser sensor with dimensions 50x100 mm mounted directly on the theodolite telescope similar to DIMOVER [2] is presented in the report. The primary results of the test, showing a sensitivity to the field modulus of 0.02 nT and better than 0.3 nT component along the axis of the solenoid are presented. The technique of self-calibration is developed based on determining the angles of misalignment of the telescope axis and the solenoid when the absolute measurements of the components of the field are measured for different angular orientations. It is assumed that the developed magnetometer and non-magnetic theodolite will be promising for use at stations. We have developed a method of self-locking based on determining angles of misalignment of the telescope axis and the solenoid, when the absolute values of the field components are measured for different angular orientations. We believe that the developed magnetometer and non-magnetic theodolite will become candidates for use at geomagnetic observatories and repeat stations.

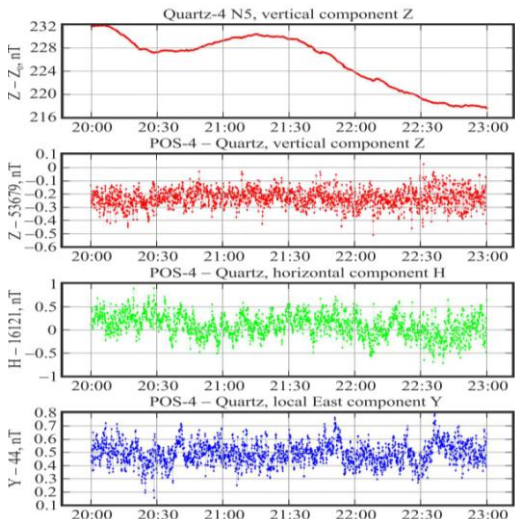

Figure 2: An example of Z variation made is Quartz-4 and POS-4 relative to Quartz

Figure 1: Vector magnetometer POS-4, POS-DIMOVER & non-magnetic theodolite

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Author:
V. Sapunov[1], J. Rasson[2], S. Khomutov[3], A. Soloviev[4], P. Borodin[5], O. Kusonsky[5], B. Kuzmenko[6], A. Denisov[1], D. Saveliev[1], V. Saveliev[1], S. Kiselev[1], E. Narkhov[1], A. Sapunov[1]
1) Ural Federal University, Quantum magnetometry laboratory (UrFU, Russia)
2) Institut Royal Meteorologique de Belgique (IRM, Belgium)
3) Institute of cosmophysical research and radio wave propagation (FEB RAS, Russia)
4) Geophysical Center of the Russian Academy of Sciences (GC RAS, Russia), Schmidt Institute of Physics of the Earth RAS (Russia)
5) ARS magnetic observatory of the Ural branch of the RAS (Arti UB RAS, Russia)
6) NTP Horizont LLC (Russia)

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Corresponding authors:
Vladimir Sapunov
Ural Federal University, Quantum magnetometry laboratory
Mira 21, 126, Ekaterinburg, Russia
Tel.: +79222042744
e-mail: vasapunov@urfu.ru, vasapunov@gmail.com

Evgenii Narkhov
Quntum Magnitec Pipe Test LLC
e-mail: narhoved.ftf@gmail.com

ELF receiver for EM waves beyond 46 Hz

Rudi Čop

At the PIA Geomagnetic Observatory (Piran, Slovenia) (hereinafter: the Observatory) we measure changes in the Earth's magnetic field according to the international recommendations with digital magnetometers with one-second sampling. Since we wanted to detect the noise sources in the geomagnetic field in frequency range from 0.05 Hz to 0.5 Hz, the antenna of the ELF receiver was first directed vertically. On the territory of Slovenia the Z component of the geomagnetic field is the noisiest one. We found that the frequency range from 5 Hz to 50 Hz contains electromagnetic disturbances of artificial origin. We then tried to determine, by the spectral analysis, their sources and the possible influence of these disturbances in the frequency range below 1 Hz.

From the measurements which took ten months, we selected three typical measurements in geomagnetically calm days: 5 July 2017 (Figure 1) and 11 November 2017, all time from 08:10 to 08:20 UTC. The mean value of the output voltage from the ELF receiver changes with the time and direction of the B-antenna axes. This is due to the change in the operating temperature of the low noise operating amplifier at the pre-amplification stage.

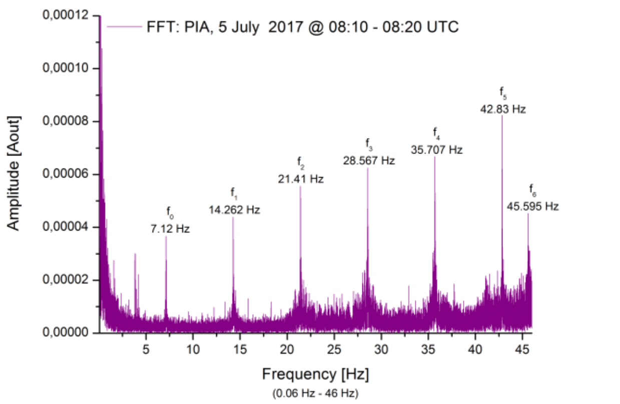

Figure 1: Spectral analysis of the ELF receiver data on 5 July 2017 between 08:10 and 08:20 UTC in the frequency range from 0.06 Hz to 46 Hz.

The analysis of phenomena in the frequency range from 0.06 Hz to 46 Hz (Figure 1) does not yet reveal the true sources of the emerging frequencies. From the frequency f = 50 Hz, which is the frequency of the electro-energy network, the frequency f_5 is spaced by Δf = 7.1 Hz. The same distance exists between all other frequencies lower than f = 50 Hz. The sum of each pair of these frequencies $f_0 + f_5$, $f_1 + f_4$, $f_2 + f_3$ gives the value of the base frequency f = 50 Hz. These would be sub-harmonic frequencies. However, it is not possible to explain the source of the frequency f = 45.6 Hz and frequencies lower than 7.12 Hz.

The true source of the output frequencies in the frequency range from 0.06 Hz to 46 Hz is shown only when the considered frequency range is expanded to 360 Hz. There exist the odd and even higher harmonic frequencies from 100 Hz to 350 Hz, which are multiple fundamental harmonic frequencies f = 50 Hz. They are caused by electric currents. A more detailed frequency analysis from 1 Hz to 95 Hz shows the lower and upper bands. These two bands are the result of pulse-with modulation for asynchronous motor control. The degree of modulation of the example from 5 July (Figure 1) is equal to β = 1, and in the following case on 11 November 2017, $\beta > 1$.

On 29 May 2018, at 6:00 UTC, the supply of electricity was interrupted at the Observatory and in its wider surroundings. The nearest still operating consumers of electricity were at least 2 km far away from the Observatory. In the frequency range from 0.3 Hz to 360 Hz the upper and lower side band, due to pulse-width modulation, completely disappeared. On the frequency range from 0.05 Hz to 0.5 Hz the effect of such a switch-off is detected as a reduction of correlation between the mean values of all amplitudes in this frequency range and amplitudes of industrial frequency of f = 50 Hz.

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Different PWM Waveforms Generation for 3-Phase AC Induction Motor with XC164CS, 2006. Application Note AP16097. München (D): Infineon Technologies.

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Author:
Rudi Čop
Institute Sv. Peter, 6320 Sečovlje, Slovenia

Corresponding author:
Rudi Čop
Institute Sv. Peter, Sv. Peter 115, 6320 Sečovlje, Slovenia
Tel.: +386 51 644 022
e-mail: rudi@artal.si

DS-2 digital fluxset D/I instrument

László Hegymegi, János Szöllősy, Ádám Domján, Csaba Hegymegi

Observatories usually use automatic instrumentation for time variation recording but the absolute instrument used for baseline determination operated manually. This procedure is time consuming and has several possibilities to make mistakes. In our new absolute D/I instrument DS-2 optical angle reading system was replaced with a digital one. In order to increase angular precision new graduated disk was produced and applied. Magnetometer and angle reading data are transmitted to a tablet which is used as display and data collection system. At the same time the tablet can be used to calculate data for baseline correction.

Using experiences of DS-1 digital D/I theodolite a new instrument was designed and built. The base of the instrument is again a Zeiss theodolite where optical angle reading system is replaced with digital angle reader. The fluxset magnetometer electronics which is fixed on the telescope has an extra board to process data of digital angle encoders. Both data are transmitted via bluetooth to a tablet and when the telescope is adjusted to the desired position the operator should press a button on the remote commander and data are stored into the memory of the tablet together with GPS time (and coordinates) data.

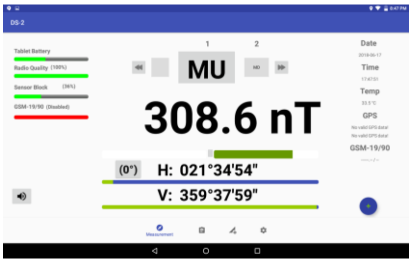

Figure 1: DS- 2 digital absolute instrument

Scalar magnetometer's serial data can be received directly by the tablet in real-time giving the possibility to calculate absolute components of the geomagnetic field vector. Data stored in the tablet can be copied to a memory card or uploaded via wifi to the server of the observatory. Data format can be xls or csv.

Android application running on the tablet has several usefool tools to help the operator's job. On the display can be found information In addition to the actual magnetometer output and angles on date, time, temperature of the of the instruent, geographical coordinates, battery charging status of the magnetometer and of the tablet. Also the next position of the telescope is shown. To speed up the measurement process after declination observations the mean value is calculated and displayed.

Working parameters can be entered by the tablet. There is also possibility to enter here measurement identification data as place, operator's name etc.

All instrumentation is running from battery at least for six hours. To charge 12 V DC or 230 V (115 V) can be used.

We carried out absolute observations with DS-2 in parallel to classical optical instruments equipped DTU and Bartington magnetometers (354459 and 153567). Measurement errors are in the same range.

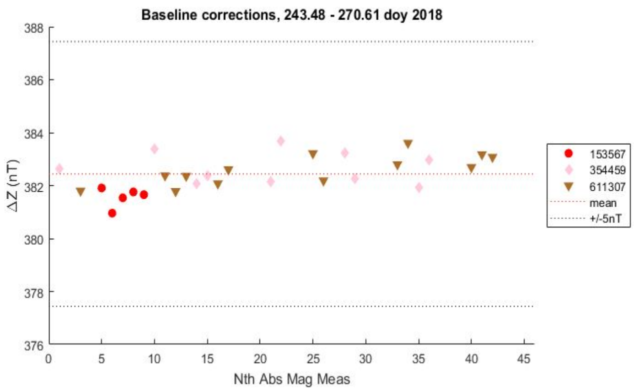

Figure 2: sample data of comparision

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Author:
L.. Hegymegi[1], J.Szöllősy[2], Á. Domján[1], Cs. Hegymegi[1]
1) Mingeo Ltd, Budapest, Hungary
2) Independent contractor, Hungary

Corresponding author:
László Hegymegi
Mingeo Ltd.
Ráskai Lea utca 20, Budapest, H-2040, Hungary
Tel.: +36 (30) 9715934
e-mail: hegymegi@mingeo.com

Determination of rotation angles and geographic orientations in geomagnetic observatory instruments using digital camera images

László Merényi, László Hegymegi, Ádám Domján

A digital image-based method is suggested as a possible alternative way for angle and orientation measurements in geomagnetic observatories and in field measurements. The suggested method is contact-free, fast and continuous, the results are immediately in digital form: these are some of the advantages compared to the optical theodolite readings. It offers some ways to relate the relative measurements to geographic reference orientations. Calibration procedures and straightforward digital algorithms are available to efficiently reduce the effects of the potential error sources, like the non-parallelisms between the plane of rotation, the recorded objects plane, the lens and the image sensor.

At absolute geomagnetic measurements, the rotations of a magnetometer sensor and a reference geographic orientation must be accurately measured. In this application the measuring device must be non-magnetic that complicates the instrument design and the realization of the measurement. In today's practice non-magnetic optical theodolites are used for this purpose, the operation of which requires experienced observers.

Photogrammetry techniques are used for a long time to determine the position of objects. Taking repeated exposures, the movements and rotations of the objects can also be estimated.

Figure 1: Multi-parallel line pattern fixed on the top of a Zeiss theodolite

As the camera can be far from the sensor, the set-up can be made non-magnetic. Recognizing this fact, we started a project to try to develop a camera-based method that can be used together or in lieu of the theodolite measurements. After some first tests, we have elaborated and selected a computational method that is a bit different from the classical photogrammetry and digital image processing methods. A multi-parallel line pattern is fixed on a rotable magnetometer sensor holder. A camera continuously records this pattern and a computer program processes the grayscale images in real time.

The angle of an image is determined by finding the angle along which the standard deviation of the image pixel values is the minimum. This angle practically corresponds to the average of the angles of individual lines. With this type of averaging, the errors due to the final pixel resolution and to the pixel noise could be greatly reduced.

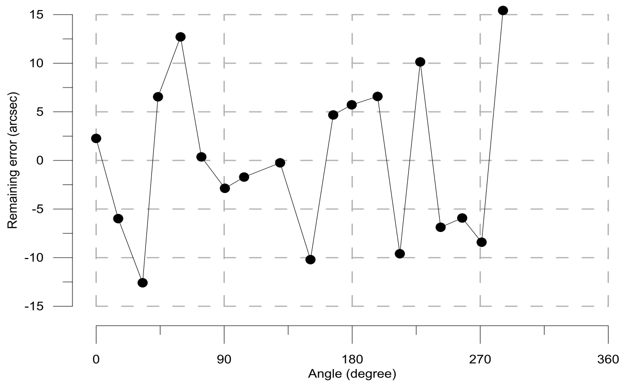

Figure 2: The differences between the theodolite readings and the angles determined by the method, after applying corrections from a calibration

Fig. 2. shows the results of one of our tests, made by the instrument seen in Fig. 1. and a commercial CCTV camera. The recent accuracy is about ±15 arcsec, after making a calibration that is required to get the 0° position and to remove errors due to the non-parallelism in the system. We are on the way to improve the accuracy by using, e.g. lens calibration, professional photogrammetry cameras, complex patterns and better calibration procedures.

Using free-hanging strings and Sunlight shadows of free-hanging strings projected on a horizontal surface as line patterns, the vertical and True north can be determined, then used as references for inclination and declination measurements. We are also testing these possibilities.

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Author:

L. Merényi[1] L. Hegymegi[1], Á. Domján[1]

1) Mingeo Ltd., Budapest, Hungary

Corresponding author:

László Merényi

Mingeo Ltd.

Ráskai Lea utca 20., 1142 Budapest, Hungary

Tel.: +36 (30) 648 32132

e-mail: lmerenyi@mingeo.hu

First results of the GyroDIF at the Livingston Island Geomagnetic Observatory, Antarctica

Santiago Marsal, Joan Miquel Torta, Juan José Curto, Antoni Segarra, Miquel Ibañez, Alexandre Gonsette

The 2017-2018 Antarctic survey at the Livingston Island geomagnetic observatory (LIV) has been devoted to deploying and testing the GyroDIF, an automatic DIflux developed by the Royal Meteorological Institute based on a gyroscope (aka gyro) to refer the declination (D) to the true north. We compare the baselines of the magnetic field elements obtained with the GyroDIF with those arising from a manual DIflux theodolite. The GyroDIF-based magnetic inclination (I) baseline compares well with manual determinations; however, the D baselines from both instruments are more divergent due to the low resolution of the gyroscope and an additional magneto-optical effect affecting the true north measurements.

The LIV Observatory (62.662° S, 60.395° W) is operative since 1996. It is equipped with a 3-axis fluxgate (FGE), a proton vector magnetometer, a scalar magnetometer and a DIflux. Although it is only manned during the austral summer, power availability allows continuous recording of the variometers and satellite transmission of 1-min data. In January 2018 a GyroDIF has been set up to provide absolute measurements all year round (Fig. 1). Its operation is similar to that of the manual DIflux, but true north referencing is based on an integrated gyro. Installation details can be found in Marsal et al. (2017).

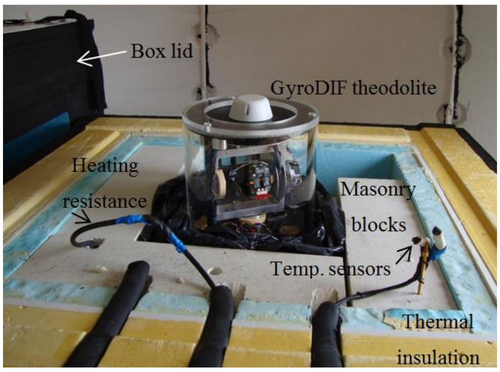

Figure 1: GyroDIF within its thermally insulated box at LIV.

The gyro is a fiber optic sensor noting the projection of the Earth's rotation vector along its axis. To compensate the gyro bias and collimation errors, the sensor up/down positions are performed scanning the full horizontal circle in 10° intervals. Combining their output in different ways we get the Earth's angular speed along the gyro axis and the cited errors. Once the circle is swept, the first combination provides a cosine curve whose phase gives the true north position. Such measurements, however, reveal a   0.1°, translating into 40 nT in Y. Reducing this uncertainty below 2 nT requires applying a Gaussian filter over a time window spanning one month of true north data. Monitoring of the gyro bias also reveals anomalous data arising from unstable temperature.

Fig. 2 shows a comparison of our FGE baselines over the last survey, obtained from the DIflux on one hand (red dots), and from the GyroDIF on the other (blue dots). The two sets of the H and Z baselines are in good agreement, indicating accurate GyroDIF I measurements. However, the D-derived E (magnetic East) baseline, obtained after combining the magnetic and the gyro data, deserves some comments: a) the large dispersion of the blue dots around the filtered value is a result of the aforementioned large   of the true north measurements; b) the large offset between both datasets results from a biased value of the true north position. The reason is probably related to a coupling between the gyro optics and the magnetic field itself, known as magneto-optical effect (under study). Such an offset is expected to be nearly constant over the next surveys, in which case it may be corrected.

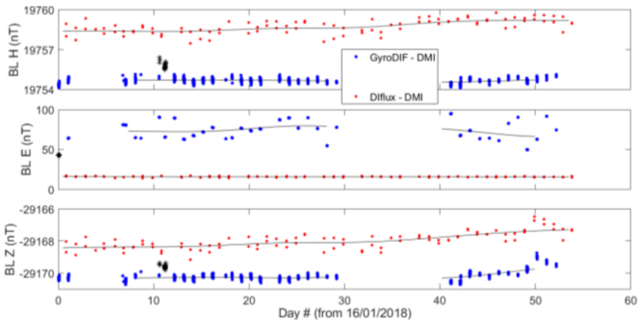

Figure 2: Comparison of baselines of H, E and Z components for the LIV FGE, obtained from the DIflux (red dots) and from the GyroDIF (blue dots).

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Marsal, S., Curto, J. J., Torta, J. M., Gonsette, A., Favà, V., Rasson, J., Ibañez, M., and Cid, Ò., 2017. An automatic DI-flux at the Livingston Island geomagnetic observatory, Antarctica: requirements and lessons learned. Geosci. Instrum. Method. Data Syst., 6, 269-277, https://doi.org/10.5194/gi-6-269-2017, 2017.

Author:

S. Marsal[1], J. M. Torta[1], J. J. Curto[1], A. Segarra[1], M. Ibañez[1], A. Gonsette[2]
1) Observatori de l'Ebre (OE), Univ. Ramon Llull – CSIC, Roquetes, Spain
2) Institut Royal Météorologique (IRM), Centre de Physique du Globe, Viroinval (Dourbes), Belgium

Corresponding author:

Santiago Marsal
Observatori de l'Ebre (OE), Univ. Ramon Llull – CSIC
Horta Alta 38, 43520 Roquetes, Spain
e-mail: smarsal@obsebre.es

Development of a constant-temperature box for variometers

Ramon Egli, Richard Kornfeld, Roman Leonhardt, Barbara Leichter

The temperature stabilization required for reliable variometer measurements is difficult to achieve in the field. Possible solutions include instrument burial, or the use of containers with active or passive temperature regulation. We have chosen the latter and developed a transportable, thermally insulated box (1×1×0.7 m). The heating power required by active temperature regulation is inversely proportional to the thermal conductivity λ of the insulating layers. On the other hand, passive regulation is best achieved by minimizing the thermal diffusivity. These needs have been fulfilled with a composite 3-layer insulation, whereby each layer fills the ~10 cm space between 4 concentric boxes. The external and internal layers are filled with rigid foam blocks, while the middle layer is filled on-site with ~300 l water, which provides the thermal capacity required by passive insulation. The empty system can be hand-lifted.

The box has 3 cable connections for instrument operation, heating, and temperature monitoring with sensors (colour disks, Fig. 1) outside, inside the three insulating layers, and inside the variometer-hosting inner box, respectively.

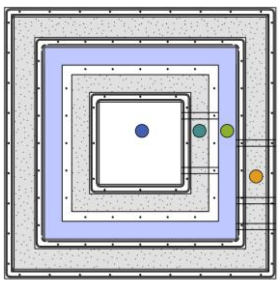

Figure 1: Top view of the insulated container (water in blue) and position of the 5 temperature sensors.

A first performance test has been performed between April and June, with the box directly exposed to the sun. The external sensor recorded daily temperature variations of >16°C, while the maximum daily variation of the inner box did not exceed 0.3°C (Fig. 2).

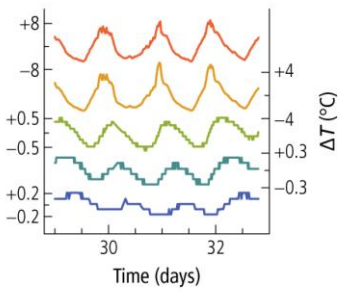

Figure 2: Temperature variations measured by the 5 sensors (same color code as in Fig. 1) during 5 days.

The insulation performance has been modelled by solving the 1-D heat equation with following unknown parameters: the heat transfer coefficient ha to the surrounding air, the effective thermal conductivity λ of the foam blocks, and the heat transfer coefficient h_w between water and the surrounding layers, including heat transmission across the box walls (water is assumed to mix, as deduced from the difference between cooling and warming rates in Fig. 2).

Realistic model parameters (λ = 0.28 W/m·K, h_a = 9 W/m^{2}K, h_w = 4 W/m^{2}K) have been obtained by minimizing the relative difference between predicted sinusoidal daily variations and the mean daily variations recorded by the sensors. The modelled attenuation of periodic temperature variations matches the damping coefficients estimated from a Fourier analysis of the actual temperature records, for periods ranging from 1 day to 1 month (Fig. 3). The passive ≈100-fold attenuation of daily variations enables a satisfactory variometer operation with absolute measurements taken weekly to correct the drift produced by residual temperature variations. The estimated inner box heating power needed to compensate a 20°C temperature variation is <3 W for a 1-day period, and 30W for a 5-day period.

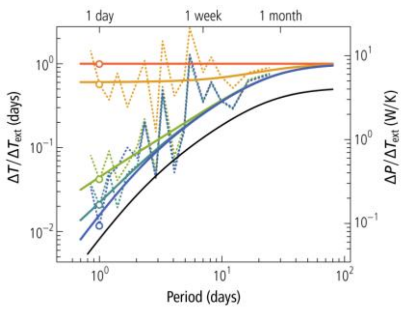

Figure 3: Attenuation of sinusoidal temperature variations recorded by the 5 sensors as a function of their period (dashed lines obtained with Fourier analysis), compared with the corresponding model curves (solid lines). The expected heating power required to fully compensate a 1 K-external temperature variation is shown by the black curve.

These preliminary tests represent a worst-case scenario, since several foam blocks were missing, and the black box was directly exposed to the sunlight.

Author:
R. Egli[1], R. Kornfeld[1], R. Leonhardt[1], B. Leichter[1]
1) Central Institute for Meteorology and Geodynamics, Vienna, Austria

Corresponding author:
Ramon Egli
Central Institute for Meteorology and Geodynamics
Hohe Warte 38, 1190 Vienna, Austria
Tel.: +43 (1) 36026/2503
e-mail: ramon.egli@zamg.ac.at

How to treat the Zeiss THEO 010 and 020 nonmagnetic theodolites

Jürgen Matzka, Thomas Wenger, Jörg Krüger, Achim Morschhauser, Carsten Müller-Brettschneider

Almost all geomagnetic observatories rely on steel-free Zeiss THEO 010 and 020 theodolites for the absolute measurement of geomagnetic declination and inclination. Keeping the presently available instruments in good condition is highly relevant for the geomagnetism community. Here, we present some guidance on operation, storage and maintenance. The user manual we find to be a valuable, possible overlooked, source of information.

Production of the THEO 010 and 020 theodolites by Carl Zeiss Jena commenced in 1971 and stopped around 1990. Special nonmagnetic and steel-free versions for use with magnetic compasses and for special measurements are mentioned in the user manual and around 500 such pieces have originally been built by Zeiss. THEO 010 and 020 that were subsequently converted steel-free are still commercially available today. The information given here is based on our experience (JK was responsible for final control and adjustment of THEO 010 and 020 at Carl Zeiss Jena), the user manual, and discussions with colleagues during the IAGA Workshop at the Conrad Observatory.

In contrast to the normal version, the nonmagnetic theodolites have no ball-bearing in the vertical axis system and therefore should be greased more often, say every 2 to 5 years. A hole in the grease film can cause irreparable damage to the nonmagnetic axis system (cold welding). Insufficient greasing makes the alidade sluggish, more harder to rotate. Due to grease and air bubbles in the vertical axis system, there should be a small vertical mechanical play between alidade and tribrach.

Operation. The instrument can be used between -25° C and +45° C. The user manual recommends to always make the final turn with the fine tuning knobs in clockwise direction for the horizontal circle and in counter-clockwise direction for the vertical circle. The spring plates of the tribrach should be fixed to the pillar.

Storage and transport. For storage and transport in the box, usually the clamps should be slightly tightened. However, for a theodolite with a fluxgate sensor on top that only tightly fits into the transport box, it might be more wise to leave the clamps open. Mechanical shocks should be avoided as they can lead to circle errors that need adjustment, or even instrument damage. After horizontal storage, the alidade should be slowly rotated a few times in both directions to redistribute the grease. Storing the instrument above +45° C rapidly weakens the cement keeping optical parts (lenses, circles, scales) and the spirit levels in place and leads to severe de-adjustment of the instrument. High temperatures also adversely affect the grease. If the instrument is stored in a small building, a car, or the transport box and exposed to direct sunlight without ventilation, then temperatures exceeding 45° C could easily be reached. Don't store a humid or dusty instrument in the transport box. Never use strong direct heating to dry the instrument. For short breaks during outdoor work, cover the instrument to protect it from rain and dust. Operate and store the instrument in a ventilated room protected from sunlight and rain. When bringing a theodolite from a cold to a warm room, let it temperate slowly inside the transport box. Growth of fungus deteriorates the optics, especially when humidity exceeds 75 % for extended periods and temperatures are above 15 °C. Use a well-ventilated, bright room for storing the instrument (e.g. operate sometimes a small ventilator close the theodolite, though remove it during observations; store smaller parts in a glass cabinet with slightly (5 K) increased temperature or with a desiccant).

Maintenance. The instrument should only be opened, disassembled and greased by a specialist. All original spare parts for THEO 010 and 020 were transferred from Carl Zeiss Jena to the company Wiethüchter in the early 1990ies and from there to Wenger-Wiethüchter in Jena around 2000. However, no spare nonmagnetic vertical axes exist. Our community would profit from sharing such specialised spare parts to make sure that a maximum number of high-quality instruments remains operational.

Acknowledgement. We acknowledge valuable discussions with our colleagues at the IAGA Workshop 2018 at the Conrad Observatory, especially with A. Berarducci, L. Hegymegi, A. Lewis, T. Raita and C. Turbitt.

Authors:
J. Matzka[1], T. Wenger[2], J. Krüger[2], A. Morschhauser[1], C. Müller-Brettschneider[1]
1) GFZ German Research Centre For Geosciences, Potsdam, Germany
2) Wenger-Wiethüchter Vermessungstechnik, Jena, Germany
info@wenger-vermessungstechnik.de

Corresponding author:
Jürgen Matzka
GFZ German Research Centre for Geosciences
Telegrafenberg, 14473 Potsdam, Germany
Tel.: +49 (0)33843/624-18
e-mail: jmat@gfz-potsdam.de

A low-power data logger system for 1 second INTERMAGNET data

Achim Morschhauser, Jürgen Matzka, Jürgen Haseloff, Oliver Bronkalla, Carsten Müller-Brettschneider

Geomagnetic observatories are currently facing requirements that cannot be easily implemented with most existing observatory data logger systems. These include real-time data transmission even from remote locations, high sampling rates and digital filtering, and delivery of data according to the INTERMAGNET 1 second standard. We believe that these challenges can best be handled in a community effort, and present the current state of an open-source data logger system.

Introduction. The design criteria of the data logger system include modularity and flexibility for use with different observatory settings, low power consumption for operation at remote locations, and the use of mostly standard low-cost hardware components. It consists of an open-source software package that runs on POSIX-compatible systems, and a Raspberry Pi platform [1]. We see this system as a good basis to address current challenges regarding geomagnetic observatory data acquisition, and we encourage international participation in further development, improvement, and usage. For this purpose, the software is open-source and freely available at a Git repository [2].

Software. The software includes functionality for serial port communication, digital filters, accurate timestamping, and drivers for common geomagnetic sensors and A/D converters (e.g. GEMSystems, ObsDAQ).

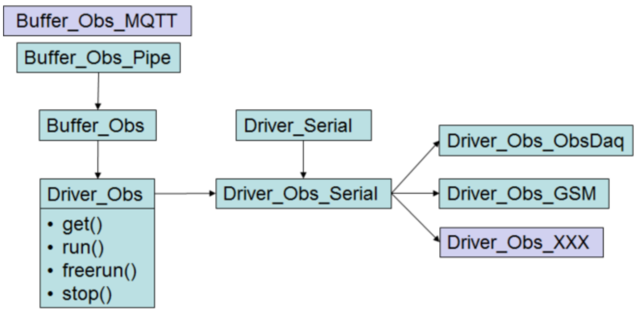

Figure 1: Example class diagram for instrument drivers and communication of the C++ datalogger software.

The datalogging software is developed in C++ using the object-oriented approach. This allows to run the software on many platforms, and makes the code modular and flexible. For example, as shown in Fig. 1, a generic abstract class <Driver_Obs> defines some interface methods for taking single or continuous measurements, and for storing calibration constants. For serial communication, the class <Driver_Obs_Serial> is available that implements <Driver_Obs> and that can be expanded to work with different geomagnetic instruments.

Hardware. Our implementation of the data logger system is built around a RaspberryPi embedded platform. However, we note that the software package is independent from this hardware solution, and can easily be adapted to work with an alternate system. Fig. 2 shows the hardware components including USB to serial port adapters for communication with most geomagnetic instrumentation, a fibre-optical media converter (FMC) for transmitting the data, and a real-time clock and GPS module for accurate time synchronization.

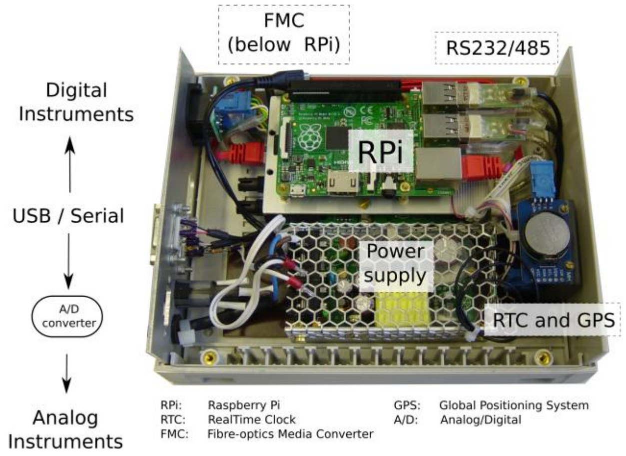

Figure 2: Layout of the RaspberryPi datalogger system as installed, e.g., at the observatories of Tatuoca (TTB) and Tristan da Cunha (TDC). Main hardware components and interfaces are labeled.

Outlook. The RaspberryPi datalogger hardware as shown in Fig. 2 has been successfully installed at the geomagnetic observatories of Wingst (WNG), Tatuoca (TTB) and Tristan da Cunha (TDC). The software package is under continuous development, and we invite the community for testing and contributing [1]. In the near future, we plan to add more precise timestamping and support for a wider range of instruments.

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Authors:

A. Morschhauser[1], J. Matzka[1], J. Haseloff[1], O. Bronkalla[1], C. Müller-Brettschneider[1]

1) GFZ German Research Centre For Geosciences, Potsdam, Germany

Corresponding author:

Achim Morschhauser
GFZ German Research Centre For Geosciences
Telegrafenberg, 14473 Potsdam, Germany
Tel.: +49 (0)33843/624-14
e-mail: mors@gfz-potsdam.de

Differential Magnetometer System in Support of Space Weather Impact Modelling

Martyn, T.P., Swan. A.P., Taylor, T.L., Turbitt, C.W

The impact of Geomagnetically Induced Currents (GIC) caused by severe space weather events on ground-based infrastructure is a well known phenomenon that, in extreme cases, has led to significant disruption to power supplies and technologies. The Space Weather Impact on Ground-based Systems (SWIGS) project comprises four work packages directed towards improving understanding and forecasting of GIC; including the impact on infrastructure such as power lines, pipelines and railways. The lack of readily available GIC data from network operators presently limits the verification of GIC modelling in the UK power grid, hence, the British Geological Survey (BGS) plans to deploy a number of remote monitoring sites close to grounded nodes in the UK power distribution network.

The proposed monitor is based on a differential magnetic variometer system deployed on the Southern African power grid in 2013 & 2015 (Matandirotya, E., et. al. 2016). The sites provide proxy measurements of the induced currents in the adjacent high-voltage overhead lines. The project specification required the recording of time-stamped one-second samples, transmitting in near real-time from a set of six sites, self-sufficient in power for up to six months. The bandwidth of interest of the study is between 10 and 10,000 seconds and the required resolution of signal is of the order 1nT.

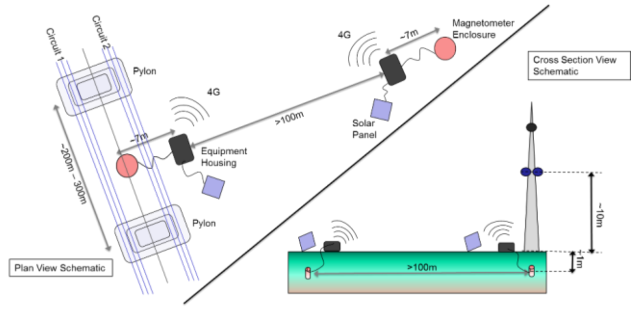

Figure 1: Schematic of the Differential Magnetometer System

The final design for each system comprises a Sensys FGM3D magnetometer used with an Earth Data EDR209 3 channel digitiser. Data is transmitted via a Teltonika RUT955 4G router and the system is powered by 2x90Ah batteries recharged by a 270W solar panel via a charge regulator. Temperature stability is achieved by burying the magnetometer to a depth of ~1m. To minimise development time, the data collection system is based around the well established and robust Seedlink protocol favoured by seismology. Three data channels (x,y,z) are recorded at 1Hz and two auxiliary channels; temperature and battery voltage are sampled once per minute.

The manufacturer specifications of the Sensys FGM3D variometer meet the scientific requirements whilst being affordable to the project budget. The noise floor and impulse response of the system were tested at the BGS' Eskdalemuir Observatory using a mu metal shield. The impulse response was simulated using an on/off step current with a period of 1800s (A. Swan, et. al. 2016). A maximum attenuation of -0.1dB was calculated within the frequency band of interest. The noise floor was calculated over 10 periods of 600 seconds in the shield. The system was found to have a noise floor of <0.02nT√Hz within the frequency 0.1 to 0.5Hz.

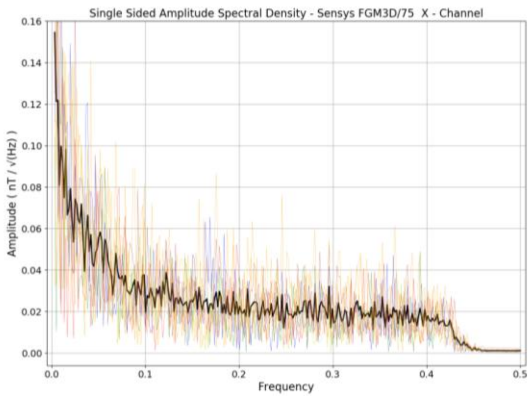

Figure 2: Sensys FGM3G Noise Floor Test performed in a mu metal shield

To date, systems have been deployed at 3 sites across the UK. The systems have been resilient to in-field conditions surviving both summer storms and livestock. The solar panel and battery system has been sufficient to return batteries to full charge within 45 minutes of sunrise. Over a 3-hour period, in certain conditions, a temperature variation of >4°C has been recorded. This is outside the 1 °C / 3 hour specification. Further development to insulate the magnetometer is required.

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Author:
Martyn, T.P., Swan. A.P., Taylor, T.L., Turbitt, C.W
Geomagnetism Team, British Geological Survey

Corresponding author:
Martyn, T.P
Geomagnetism Team, British Geological Survey, The Lyell Centre, Riccarton, Edinburgh EH14 4AP,
Tel: ++44 131 650 0207
tmartyn@bgs.ac.uk<mailto:tmartyn@bgs.ac.uk>

Mechanical and optical tests of Zeiss THEO 010 and 020 nonmagnetic theodolites during the IAGA workshop 2018 at Conrad Observatory

Jürgen Matzka, Thomas Wenger, Jörg Krüger, Achim Morschhauser

During the IAGA workshop 2018 at Conrad observatory, 30 nonmagnetic theodolites of the Zeiss THEO series were tested for their mechanical and optical properties. Next to an inspection of the instruments, the horizontal circle error (collimation error) and the vertical circle error were determined with the help of a surveyor's level. While half of the instruments were fine, the others were in need of adjustment or repair. Typical problems requiring repair are sluggish vertical axes and mechanical problems of the coaxial fine-tuning. Typical adjustment problems are the position of the image in the microscope and collimation and vertical circle errors.

The tests were performed by JK who was responsible for final control and adjustment at Carl Zeiss Jena. The tests started by mounting the theodolite on a tripod opposite of a surveyor's level (Figure 1) and a first visual inspection of the instrument.

Figure 1: Test of a steel-free converted Zeiss THEO 020A theodolite during the IAGA Workshop 2018. From left to right: Alan Berarducci, Jörg Krüger, Theo 020A, Carl Zeiss Jena Ni 002 collimator with green light source at ocular.

Mechanical inspection. First, the mechanical play of the vertical axis system was tested by slightly lifting the alidade up from the tribrach. Then, the vertical and horizontal axis rotation were tested for sluggishness. The clamps were tested by moving the alidade/telescope slightly under clamped conditions (a click-sound indicates proper clamp adjustment). The fine-tuning was tested, it should be easy to rotate and a click-sound should be heard when reaching the fine-tuning limit. The tuning of the micrometre plate (010 only) was tested.

Optical inspection. The optical images in the microscope were checked to have the right lateral position, size and focus. The images were checked for irregular structures that arise from degenerated glue of the optical parts, from fungus, or from dust/water/oil droplets.

Test with surveyor's level. A Zeiss Ni 002, the most accurate surveyor's level (compensator) by Carl Zeiss Jena (0.2 mm on 1 km or 0.04'' deviation) was used to determine horizontal (collimation) or vertical circle errors of the theodolites tested (Figure 1). By looking with the telescope to be tested into the objective of the Ni 002, a cross hair identical to the THEO cross hair can be seen. A tilt of the cross hair and an error of the vertical index can be diagnosed by this method. The angular difference between face left/face right (sensor up/sensor down) observations of that cross hair is noted. Small errors could be corrected by adjusting the cross hair of the THEO. In this process, all spirit levels were adjusted.

Results. About half of the instruments were found to be ok, while the other half needs adjustment or repair. Recommendations on the treatment of Zeiss THEO theodolites are given in Matzka et al., 2018.

Documentation and outlook. We documented all test results and the participants were informed about the results at the workshop and/or by email. We regard this article as a first step and hope to come up with a more comprehensive test strategy and documentation during the next workshop, based on the experience at the Conrad Observatory 2018 workshop.

Acknowledgement. We received valuable support for the tests by ZAMG and Conrad Observatory.

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Matzka et al., 2018. How to treat the Zeiss THEO 010 and 020 nonmagnetic theodolites. This volume.

Author:
J. Matzka[1], T. Wenger[2], J. Krüger[2], A. Morschhauser[1]
1) GFZ German Research Centre For Geosciences, Potsdam, Germany
2) Wenger-Wiethüchter Vermessungstechnik, Jena, Germany
info@wenger-vermessungstechnik.de

Corresponding author:
Jürgen Matzka
GFZ German Research Centre for Geosciences
Telegrafenberg, 14473 Potsdam, Germany
Tel.: +49 (0)33843/624-18
e-mail: jmat@gfz-potsdam.de

MARTAS - Real time data acquisition and data transfer

Leonhardt, R., Mandl, R., Bailey, R., Kornfeld, R., and Egli, R.

Figure 1: Connection box with mobile MARTAS system, unbreakable power supply (battery not shown), lightning protection, remote control.

MARTAS (MagPy's real time acquisition system) is a python software to read data from various instruments, to locally store/buffer this data on any provided storage medium, and contemporary broadcast data in real-time based on state-of-the-art IOT (Internet Of Things) techniques for remote usage. MARTAS consists of a core which handles storage, broad-casting, treatment of data objects, and a library which contains communication routines for supported instruments. MARTAS is designed as an universal acquisition routine, running on basically every hardware, from very lightweight, low-power systems like backbone, raspberry pi, up to full server-grade network integrated computers.

MARTAS supports basically every network environment from single local installation without or only periodical internet access, towards fully de-centrally organized networks in which MARTAS broadcast data to an external broker which in turn is accessed by an independent data collector. Data broadcasting is performed by the MQTT protocol, supporting handshaking (all quality-of-service levels), authentication and SSL encryption. Data acquisition, broadcasting and its collection/analysis can be split up on multiple hardware systems, but also run on a single IPC. Altogether four process groups supported by MARTAS can be distinguished.

1. Acquisition: MARTAS collects data from e.g. serial connectors, converts the data to a general data object, buffers the data on a storage medium (e.g. SD) and publishes data via MQTT to a broker using a defined topic.
2. Broker: The broker handles authentication and data access.
3. Collector: A collector receives that data stream in real-time and e.g. stores the data objects in files or databases.
4. ANALYSIS: analysis processes access data streams and perform automated/manual analysis like outlier detection, delta value calculation, and many more.

MARTAS is easy to install, simple to configure and, for developers, easy to extend. A full MARTAS system comes along with an UPS, lightning protection, completely independent monitoring based on NAGIOS (cite), remote configuration possibilities and as web-based graphical visualization of data. All components are optional. Furthermore, basic collection routines are included. MARTAS can interact with MagPy which allows for automated processing and analysis.

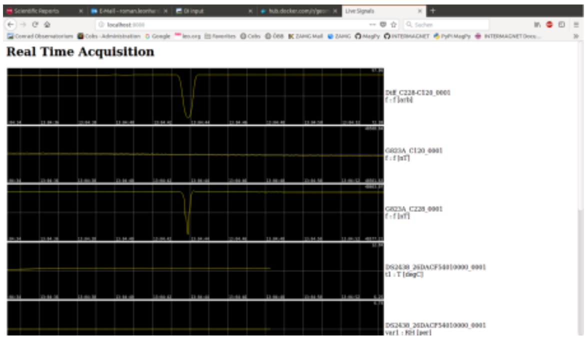

Figure 2: The collector routine, coming along with MARTAS, can be used to subscribe to topics on multiple brokers and organize and visualize incoming data.

Currently MARTAS supports the following geomagnetic instruments: GEM systems GSM19 GEM systems GSM90 overhauzer GP20S3 potassium mag Geometrics G823A Caesium mag Quantum POS1 overhauzer mag LEMI L025, L036 and other variometers)

Authors:
Roman Leonhardt, Richard Mandl, Rachel Bailey, Richard Kornfeld, Ramon Egli

Zentralanstalt für Meteorologie und Geodynamik, Hohe Warte 38, 1190 Wien, Austria

Corresponding author:
Roman Leonhardt
Conrad Observatory
Zentralanstalt für Meteorologie und Geodynamik
Hohe Warte 38, A-1190 Wien
Tel.: +43 1 36026 2507
e-mail: roman.leonhardt@zamg.ac.at

Edea, Cameroon: The Opening of a New Geomagnetic Observatory

Benoit Heumez, Vincent Lesur, Ted Luc, Kader Telali, Xavier Lalanne

A new geomagnetic observatory that produce vector data sampled every second has been implemented in Edea, in the southwest of Cameroon since April 2018. It is situated at 2600Km of the nearest magnetic observatory, TSU, Namibia. Following the closure of Bangui observatory, Edea area is an important site for magnetic measurements. The observatory is roughly at a symmetric location to M'bour observatory relative to the magnetic equator. It is too far to the south for studying the equatorial electrojet but its data carry important information on the behaviour of the core and external (ionospheric, magnetospheric) fields in this region. This presentation focused on how the observatory was planned, built and installed, how the local staff was trained and the equipment was set to deliver real-time data sampled every second.

Following the closure of Bangui (BNG) observatory in Central African Republic in 2012 and the opening of a light railway service in Addis Ababa, Ethiopia that led to the closure of Addis Ababa observatory (AAE) in 2015, we started to look for a new site. A collaborating institute was found in Cameroon, IRGM (Institute of Geological and Mining Research).

The observatory was pre-built at the French national magnetic observatory in Chambon-la-forêt, and shipped just before the installation on site at Edea, Cameroon, in April 2018. 3 observers, on site 24h/7, were trained for absolute measurements and basic maintenance.

The site location is situated at 2600Km of the nearest magnetic observatory, TSU, Namibia.

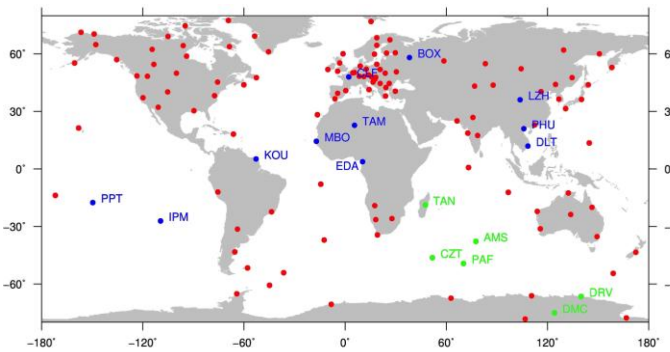

Figure 1: Map showing INTERMAGNET observatories including, in blue, Institut de Physique du Globe de Paris (IPGP) network, in green, Ecole et Observatoires de Science de la Terre (EOST) network.

The absolute and vectorial sensor pillars are fully decoupled from the concrete stab supporting the shelter. One set of instruments (scalar Geomag SM100 + vector LEMI-035) is installed in a fiberglass container with thermal inertia obtained by adding 500 litres of water. The sensors and electronics in this container are therefore in the same environment. 28 V DC sensors are feeding from the main building through a coaxial cable and data communication is through optical fibre.

A 2.5m(L) x 2.5m (l) x 2.1 m (h) absolute shelter made with fiberglass with a plastic opaque dome was installed.

The temperature gets extreme in the absolute shelter during the day. This led to the installation of a light source for the azimut mark and a battery-powered theodolite light for late/early measures when the temperature is cooler.

Figure 2: Left: picture of Edea observatory site showing the container with the sensors at the back and the absolute hut at the front. Right: picture of the absolute pillar in the absolute hut.

As a result, the observatory delivers real-time data sampled every second calibrated by a weekly absolute measure. The few first months of raw data show large disturbances on the vectorial magnetometer that needs further investigations. Those disturbances can be due to the proximity of the scalar magnetometer, insufficient grounding or power instability. The few baseline observations done so far are not yet exploitable. Further training of observers is needed.

These issues will be addressed in February 2019 during our next visit to Cameroon.

EDA is only few months old, we hope to reach INTERMAGNET quality soon to apply for membership during 2019.

Authors:
B. Heumez, V. Lesur, T. Luc, K. Telali, X. Lalanne
Institut de Physique du Globe de Paris, 1, rue Jussieu - 75238 Paris cedex 05, France

Corresponding author:
Benoit Heumez
Observatoire Magnétique
Carrefour des 8 routes, 45340 Chambon la forêt- France
Tel.: +33 (0) 238339501
e-mail: heumez@ipgp.fr

The revision of archival magnetic data of the observatories of IKIR FEB RAS: actuality, progress and prospects

Sergey Y. Khomutov, Irina N. Khomutova, Igor S. Solovev, Svetlana Y. Papsheva

The archives of the magnetic data of the observatories "Magadan" MGD, "Cape Schmidt" CPS, "Khabarovsk" KHB, "Paratunka" PET and "Yuzhno Sakhalinsk" YSS of IKIR FEB RAS, presented at WDC and INTERMAGNET and in local database of observatories, are considered. The hourly value datasets of MGD and PET in WDC contain the errors such as spikes and jumps and gaps for some years. Some available old data of CPS and KHB for past year are not published. Main progress with magnetic measurements is associated with INTERMAGNET status of observatories MGD, KHB and PET after 2011. A significant achievement was obtaining the digital images of analogue magnetograms of MGD (1998-2005, WDC for STP, Moscow) and PET (1967-2006, under financial support of VarSITI project). Revision of old magnetic data of IKIR observatories is necessary because they continue to be important for the scientific community. The work is carried out in the following areas: (a) the checking of hourly data, available in WDC, the correction of spikes and jumps; (b) the filling of gaps in analogue data using the images of magnetograms; (c) the filling of gaps using the some digital data, available after 2000.

Status of old magnetic data of observatories of IKIR FEB RAS (Figure 1):

1) data were published in WDC, but with errors (the checking and correction are needed);

2) data were published in WDC, but with gaps (the prepared data can be at observatory in local archives, the revision is needed);

3) the data has not been published (raw data can be at observatory, full processing is required, see Figure 2).

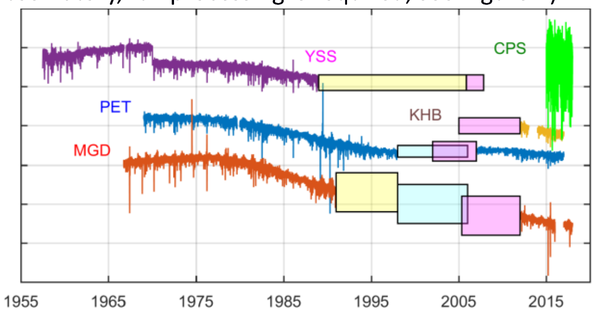

Figure 1: Status of magnetic data of observatories of IKIR FEB RAS (hourly values of horizontal component). Data up to 1998 are presented in the WDC (Edinburgh, Moscow), data of KHB, MGD and PET since 2007-2012 are presented in INTERMAGNET. The pink box shows periods with digital magnetometers, the blue box shows the presence of analog magnetograms (or their images), the yellow box indicates periods with an unknown data state.

The main problems:

(a) a lot of noise of unknown nature, which can not be removed by software – manual processing is required;

(b) there is no information about the temperature in the variation pavilion (there are single readings on the spirit thermometer during the photopaper changing);

(c) there is no detailed information about the methods of absolute observations and the obtained results, including the change from QHM to DIflux. It is assumed joint processing of hourly data from analogue magnetograms and digital data during the periods of joint measurements.

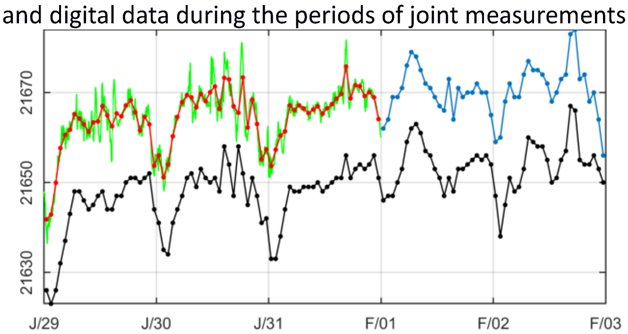

Figure 2: Example of filling of the gaps in the data of the observatory PET during 01-31 January, 1997 (horizontal component H,nT). Green curve—minute data obtained by digitization of the analog magnetograms (see Khomutov and Khomutova, 2016); red curve — hourly data calculated from minute values; blue curve — hourly values obtained by manual processing of magnetograms (from WDC); black curve — hourly data of observatory MMB (from WDC, for comparison).

One of the results – hourly data for 1991, 1996-1997 from the local archive of the Observatory "Paratunka" PET were checked and corrected. The missing data for January 1996 and January 1997 were obtained by digitization of analog magnetograms (Khomutov and Khomutova, 2016). The corrected files were transferred to the WDC (Edinburgh, Moscow).

This work was supported by Russian Science Foundation Grant No.14-11-00194.

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Author:
Sergey Y. Khomutov[1], Irina N. Khomutova[1], Igor S. Solovev[1], Svetlana Y. Papsheva[2]
1) Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS, Paratunka, Kamchatka, Russia
2) Kamchatka State Technical University, Petropavlovsk-Kamchatskiy, Russia

Corresponding author:
Sergey Y. Khomutov
Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS
Mirnaya str. 7, Paratunka, Kamchatka, 684034, Russia
Tel.: +8 (41531) 33193
e-mail: Khomutov@ikir.ru

The intercomparison of the scalar magnetometers at the Geophysical Observatory Arti, September 2017

Oleg A. Kusonsky, Sergey Y. Khomutov, Pavel B. Borodin, Vladimir A. Sapunov, Dmitry V. Savel'ev, Vasily D. Savel'ev, Evgeny D. Narkhov, Lev A. Murav'ev, Alexey Y. Gvozdarev, Ivan A. Nuzhdaev, Arkady V. Ovcharenko, Alexey S. Bebnev

On September 21-22, 2017 at the Geophysical Observatory Arti, Institute of Geophysics (Ekaterinburg), a intercomparison of scalar magnetometers was carried out. Main tasks were (1) to make an estimation of the systematic error of the absolute scalar magnetometers, using Overhauser scalar magnetometer POS-1 N11 (Quantum Magnetometry Laboratory of Ural Federal University, Yekaterinburg) as reference; (2) to get an experience of scalar magnetometer intercomparison technology and to train of the participants; (3) to organize the communication of the specialists who are engaged by observatory and field magnetic measurements; (4) to discuss the problems of magnetic observatories and Russian magnetometry in general. 11 magnetologists from institutes and universities of the Urals, Kamchatka and Altay took part in the work. 10 scalar magnetometers were presented to intercomparison, including 3 - GSM-19W, 4 - POS-1, 1 - Scintrex SM-5, 1 - Geometrix G-859.

Special area at observatory Arti was prepared at glade near magnetic pavilions. Four wooden pillars with diameter about 0.4 meters were installed. Height of underground and overground parts of pillar have height is about 1 and 1.5 meters, accordingly. One pair of pillars was selected as main (Figure 1) and second pair was used in addition. Distances between pillar are 11.5 and 12.5 meters. Before preparing for magnetic measurements this area was checked for uniformity of field.

Figure 1: Intercomparison of scalar magnetometers GSM-19W (remote pillar) and POS-1 (near pillar). The supports were used to install the sensors in fixed place.

Good synchronization of timers by GPS was provided. Method of intercomparison was in accordance with (Jankowski and Sucksdorff, 1996; Rasson, 2004). Results are presented in Table 1. Reference magnetometer POS-1 N11 was verified at D.I.Mendeleev Institute for Metrology (VNIIM) on May 12, 2016.

Magnetometer (Institute)	N	dFsys (std), nT	dFgrad (std), nT
GSM-19W (PET, IKIR)	5	-0.43 (0.05)	+0.85 (0.05)
GSM-19W (IVS)	5	-0.32 (0.04)	+0.79 (0.04)
GSM-19W (KamGU)	5	-0.66 (0.07)	+0.76 (0.04)
POS-1 (IGF)	5	+0.11 (0.02)	+1.03 (0.03)
POS-1 (GASU)	5	+0.34 (0.04)	+0.97 (0.05)
POS-1 (IGF)	5	+0.23 (0.02)	+0.76 (0.01)
POS-1–aero (QML UrFU)	5	-0.02 (0.02)	+0.95 (0.05)
POS-4 (QML UrFU) – bad data	4	-0.26 (0.34)	+1.12 (0.09)
Scintrex SM-5 (IGF)	5	+2.63 (0.03)	+0.60 (0.02)
Geometrix G-859 (IGF) 1st day	3	+4.33 (0.03)	+0.75 (0.01)
Geometrix G-859 (IGF) 2nd day	5	+4.45 (0.05)	+0.77 (0.01)

Table 1: Results of intercomparison: N - number of sets (set is measurements during 1.5 minutes at every pillars), dFsys is offset of tested magnetometer from reference magnetometer POS-1 N11, dFgrad is difference of F between pillars. Standard deviation is presented in parentheses.

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Author:

O.A. Kusonsky[1], S.Y. Khomutov[2], P.B. Borodin[1], V.A. Sapunov[3], D.V. Savel'ev[3], V.D. Savel'ev[3], E.D. Narkhov[3], L.A. Murav'ev[1], A.Y. Gvozdarev[4], I.A. Nuzhdaev[5], A.V. Ovcharenko[1], A.S. Bebnev[1]

(1) Institute of Geophysics UB RAS, Ekaterinburg, Russia; (2) Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS, Paratunka, Kamchatka, Russia; (3) Quantum magnetometry laboratory, Ural Federal University, Ekaterinburg, Russia; (4) Gorno-Altay State University, Altay Republic, Russia; (5) Institute of Volcanology and Seismology FEB RAS, Petropavlovsk-Kamchatsky, Russia

Corresponding author:

Sergey Y. Khomutov
Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS
Mirnaya str. 7, Paratunka, Kamchatka, 684034, Russia
Tel.: +8 (41531) 33193
e-mail: Khomutov@ikir.ru

Review of the geomagnetic field research activities in Lithuania

Romuald Obuchovski

Lithuania is successfully integrated in the European geomagnetic field research activities. Six secular variation research stations were established in 1999 and precise geomagnetic field measurements were performed there in 1999, 2001, 2004, 2007 and 2016. Obtained diurnal magnetic field variations at measuring station and neighbouring observatories were analysed. All measurements are reduced to the mean of the year using data from geomagnetic observatory of Belsk. Based on the measured data the analysis of geomagnetic field parameter secular changes was performed. The Institute of Geodesy has acquired modern equipment for geomagnetic field measurements in 2012. The equipment consists of two units of antimagnetic theodolite Theo010B with D/I FLUXGATE magnetometer, dIdD magnetometer and ENVI PRO magnetometer/gradiometer.

Research of geomagnetic field parameter secular variations

There was no geomagnetic observatory in Lithuania till 2017, therefore geomagnetic field parameter secular variations were researched at secular variation research stations (repeat stations). Periodic measurements at permanent research stations are essential for research of long-term variations of geomagnetic field. In Lithuania such research is periodically performed at 6 stations of special construction.

In 2012, the Institute of Geodesy has acquired modern equipment for geomagnetic field measurements. The equipment consists of two units of antimagnetic theodolite Theo010B with D/I FLUXGATE magnetometer, dIdD magnetometer and ENVI PRO magnetometer/gradiometer.

New geomagnetic observatory in Aukštadvaris

Geomagnetic observatory was established in Aukštadvaris in 2017 by the Institute of Geodesy, Vilnius Gediminas Technical University. The observatory is located away from larger settlements and intensive traffic roads, surrounded with the forests in the neighbouhood of VGTU practice base camp (Fig. 1).

Figure 1. Location of observatory in Aukštadvaris

The building is built of wood. Other building materials were carefully selected and checked on the influence to magnetic field. Basement of the building was made of cement reinforced with fiberglass. Area of the building 36 m^2, with a cellar of 11 m^2. Outside view of building is shown in figure 2.

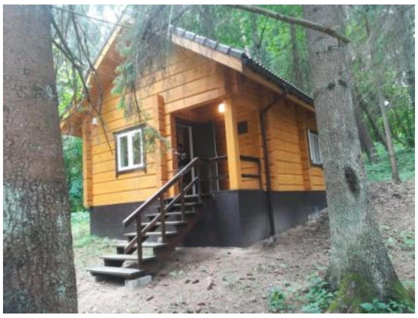

Figure 2. Outside view of observatory

Absolute observations of geomagnetic field parameters are performed with theodolite *Theo010B* with *D/I FLUXGATE* magnetometer on pillar especially established for this purpose. Sighting directions were selected outside of observatory building, Astronomic azimuth using GNSS RTK observations was determined to these directions.

Problems should to be solved

Observations in Aukštadvaris were started in July 2017. Comparison observations with neighboring Belsk observatory shows, that are problems with DidD magnetometer orientation in Aukštadvaris. It is necessary to perform detailed research related with base stability. Also problems of uninterruptable power supply and internet data streaming should be solved. We also lack experience of operating equipment, data processing and interpreting.

Author:
R. Obuchovski [1, 2]
1) Institute of Geodesy, Vilnius Gediminas Technical University, Vilnius, Lithuania
2) Department of Geodesy and Cartography, Vilnius Gediminas Technical University, Vilnius, Lithuania

Corresponding author:
Romuald Obuchovski
Institute of Geodesy
Sauletekio al. 11, Vilnius, Lithuania
Tel.: +37052744705
e-mail: romuald.obuchovski@vgtu.lt

The Magnetic Observatory of Coimbra (COI): operating status and future developments

Paulo Ribeiro, M. Alexandra Pais, Anna L. Morozova

The Magnetic Observatory of Coimbra (COI) was founded in 1864. Currently operated by the Geophysical and Astronomical Observatory of the University of Coimbra, it is one of the oldest observatories in operation in the world and the only one in Portugal mainland. Besides giving a brief account of its long history, instruments and routines, this presentation aimed to characterize the geomagnetic series currently observed in COI, and to present its master plans for future development.

The Magnetic Observatory of Coimbra (COI) was founded in 1864 (Fig. 1). Currently operated by the Geophysical and Astronomical Observatory of University of Coimbra, is one of the oldest observatories in operation in the world and the only one in Portugal mainland. Due to the increasing urbanization during the first quarter of the 20th century, the observatory was relocated to its current site (*Alto da Baleia*) in 1932. The first years in *Alto da Baleia* suffered from very flawed operation and all observations ended up being interrupted around 1941 due to the difficult years of World War. Magnetic observatory routines were resumed nearly the end of 1951 on a methodical and more accurate basis (Pais and Miranda, 1995).

By the late 1980s, the COI data began showing again some non-negligible perturbations mainly related to the aging and drift of instruments. Part of these problems and limitations were overcome in 2007 by replacing the complete old set of instruments with a modern digital fluxgate variometer (a DMI model FGE, suspended version) and a standard pair of absolute instruments (a DI-flux based on a Bartington fluxgate MAG01H sensor mounted on a MG2KP Theodolite and an Overhauser GSM-90F1 scalar magnetometer). This upgrading resulted in a healthier base-line stability and in a clear quality improvement of the monthly and annual data series as demonstrated by the lowering variance of their first time-differences (Morozova et al., 2014). Nonetheless, the ongoing city growth continued to critically threaten the good functioning and quality of observatory data, in particular the high frequency signal. This can be a limitation for some space weather studies.

Figure 1: The official commemorative stamp of the 150th anniversary of foundation of the Meteorological and Magnetic Observatory of the University of Coimbra (MMOUC): old drawing of the MMOUC's main building; issued in 2014 by *Correios de Portugal* (CTT).

Besides giving a brief account of its long history, instruments and routines, this presentation aimed to characterize the geomagnetic series currently observed in COI (available at the WDC for Geomagnetism, Edinburgh), and to present its master plans for future development, which will comprise the relocation of the observatory to a rural area near Coimbra, and the application to integrate the INTERMAGNET network.

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Author:
Paulo Ribeiro[1,2] M. Alexandra Pais[2,3] Anna L. Morozova[2]
1) Geophysical and Astronomical Observatory, University of Coimbra, Portugal
2) CITEUC, Geophysical and Astronomical Observatory, University of Coimbra, Portugal
3) Department of Physics, University of Coimbra, Portugal

Corresponding author:
Paulo Ribeiro
Geophysical and Astronomical Observatory of University of Coimbra
Rua do Observatório, Almas de Freire - Santa Clara
3040-004 Coimbra, Portugal
Tel.: +351 239 802 373
e-mail: pribeiro@ci.uc.pt

New datasets from South American equatorial magnetic observatories

Gabriel B. Soares, Jürgen Matzka, Henning Lilienkamp, Domingo Rosales, Katia Pinheiro

Here we describe two geomagnetic time series from the South American magnetic observatories Huancayo (Peru) and Tatuoca (Brazil) that are affected by both the equatorial electrojet (due to their proximity to the magnetic equator) and the South Atlantic Magnetic Anomaly. We have filled in gaps and removed errors in the hourly values from Huancayo for 1922 to 2001 and we recovered and calibrated minute mean data from Tatuoca for 2008 to 2016.

The geomagnetic observatory Huancayo in Peru (IAGA code HUA, latitude 12.05° S, longitude 75.30° W, altitude 3313 m) is in operation since March 1st, 1922. The magnetic equator (the line around the globe where the geomagnetic field is horizontal) remained very close to it during its entire period of operation. More information on HUA's early history and its establishment can be found in Johnston et al. (1948). Here we detail the processing of a HUA dataset containing geomagnetic records from 1922 to 2002.

The HUA dataset consists of horizontal, declination and vertical components (H, D and Z) hourly mean values, obtained from two different sources: the World Data Center (WDC) Kyoto and recently digitized handwritten tables (DHT) with data that were previously unavailable. The DHT data fills considerable gaps in the WDC data for the 1960ies, 1970ies and 1980ies (see Figure 1). These two subsets partially overlap in the 1960ies. Here, we provide a final combined WDC-DHT dataset for HUA from 1922 (installation of HUA) to 2001, as HUA became a member of INTERMAGNET (International Real-time Magnetic Observatory Network) in 2002. We have processed all three components of WDC and DHT data, correcting typos, spikes, jumps and we combined them into one final dataset. Furthermore, we also describe the DHT digitisation process and our criteria to decide between the WDC and DHT sets in the overlap periods.

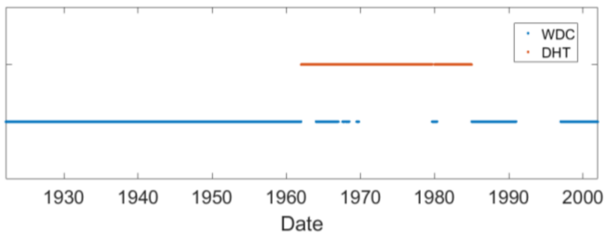

Figure 1: Timeline with WDC and DHT data availability.

While HUA is an equatorial magnetic station since its installation, the geomagnetic observatory Tatuoca in Brazil (IAGA code TTB, latitude 1.20° S, longitude 48.51° W, altitude 10 m) only became an equatorial station in the last decade, although it has been operated since 1957 by Observatório Nacional (and also by the German Research Centre for Geosciences since 2015, as detailed in Morschhauser et al., 2017). This is due to the strong secular variation of the vertical component in the Brazilian sector that leads to a significant movement of the magnetic equator.

Thus, only part of TTB time series (which is longer than 60 years) is a record of the equatorial electrojet ionospheric current. Here we present the 2008-2016 dataset, as the magnetic equator crossed TTB location in March 2013. This is a processed and calibrated dataset that contains minute means and derived hourly mean values of X, Y and Z components. Two different data subsets were produced according to the observed noise level.

Concerning the removal of artificial disturbances, two versions of the dataset were produced: one in which events of spikes and periods of noise of more than 3 nT (peak to peak) were systematically removed from the records; and a second subset where noise that exceeded 1 nT (peak to peak, by visually checking raw variation 1Hz data magnetograms) was removed from the records, if the noise was not attenuated during the filtering of the 1 Hz data to minute means.

Up to now, both HUA and TTB datasets described in this work were not provided to the scientific community in a final digital format. Thus, our aim is to provide both datasets to the WDC for Geomagnetism, Edinburgh (http://www.wdc.bgs.ac.uk/) and to the GFZ Data Services (http://dataservices.gfz-potsdam.de/portal/). This would allow new scientific investigations regarding the South American magnetic equator region.

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Author:
G. B. Soares[1], J. Matzka[2], H. Lilienkamp[2,3], D. Rosales[4], K. Pinheiro[1]
(1) Geophysics Department, Observatório Nacional, 20921-400 Rio de Janeiro, Brazil. (2) GFZ German Research Centre for Geosciences, 14473 Potsdam, Germany. (3) Institute of Earth and Environmental Sciences, University of Potsdam, Germany. (4) Instituto Geofísico Del Perú, Huancayo Geomagnetic Observatory, Peru.

Corresponding author:
Gabriel B. Soares
Observatório Nacional
Rua General José Cristino 77, 20921-400, Rio de Janeiro, Brazil
Tel.: +55 (21) 986217908
e-mail: gabrielsoares@on.br

The Scott Base Geomagnetic Observatory

Tanja Petersen

The Scott Base Geomagnetic Observatory (SBA), operated by GNS Science with support provided by Antarctica New Zealand, is continuously monitoring the changes of the Earth's magnetic field within the Southern polar regions as an important contributor to the INTERMAGNET global magnetic observatory network. With the current technology, a measurement of variations in strength and direction of the magnetic field is automatically being taken every second by magnetometers located inside the two small "geomag" huts at Scott Base. The data are being processed and submitted to INTERMAGNET on an hourly basis. Increased accuracy and areal extension of the SBA data set is gained by magnetic surveys at Cape Evans and Lake Vanda, which were first conducted in 1911 and 1974, respectively, and are repeated about every 5 years. The scientific value of SBA needs to be become more widely recognised within New Zealand; to ensure the observatories continuation, we need to explain and highlight their significance on a global scale.

The Southern Hemisphere is an area that is only sparsely covered by INTERMAGNET geomagnetic observatories (IMOs). The Scott Base Observatory (SBA), established in 1958, is located on Ross Island, Antarctica. The two "geomag" huts (Fig.1) are placed on volcanic rocks within a small area between the ocean and Scott Base.

Figure 1: Data continuously recorded in the Variometer Hut (left) every second are corrected to match the absolute observations conducted once a week by a Scott Base technician in the Absolute Hut (right). The huts are located on volcanic rock and next to the ocean (white background).

The noise caused by electromagnetic interference and power supply voltage variations (Fig 2.) is small compared to natural variations in the magnetic field. The surface rocks around Scott Base are highly magnetised and their magnetic properties have significant temperature coefficients. The temperature variation between summer and winter are large, causing seasonally varying localised gradients in the magnetic field; baseline values differ by ~50 nT between seasons. Repeat magnetic measurements conducted every five years away from Scott Base become important for obtaining a more robust picture of changes in the Earth's magnetic field in the Ross Sea region. The two sites are located on dry rock: Cape Evans was first measured in 1911-12 by the Scott expedition, measurements at Lake Vanda are dating back to 1974.

The remote location of SBA together with the long-term record of observations adds value to the global network. About 80,000 SBA daily files were downloaded for scientific use from INTERMAGNET in 2017.

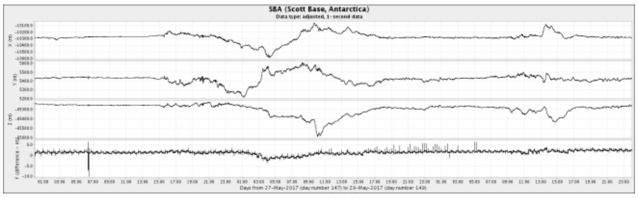

Figure 2: Three days of SBA 1-second data [nT]. XYZ are recorded by a FGE fluxgate magnetometer. F difference (the total field F', calculated from XYZ, minus F recorded independently by an Overhauser proton magnetometer) is a data quality indicator: the large spike is caused by a person entering the hut, the small ones by the nearby ionosonde and the frequent steps are due to an on/off heater system.

Scientists around the globe and within New Zealand use data from IMOs to study our Earth's protective shield, its interactions with the ionosphere, and the impact geomagnetic storms could potentially have on our modern society [e.g., Mac Manus et al. 2017; Rodger et al. 2017]. The International Geomagnetic Reference Model (IGRF) and World Magnetic Model (WMM), largescale representations of the Earth's magnetic field, are calculated from measurements made at IMOs and by satellites. The IGRF is used for applications in Space Physics, Exploration Geology/Geophysics, Deep Earth Geophysics, and Biology studies of animal migration. The WMM provides course correction for the world's smartphones, navigational systems of ships & airplanes, and geological applications such as drilling and mining.

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Author:
T. Petersen[1]
1) GNS Science, Avalon, New Zealand

Corresponding author:
Tanja Petersen
GNS Science, 1 Fairway Drive, Avalon, Lower Hutt, New Zealand
Tel.: +64-4-570 1444
E-mail: t.petersen@gns.cri.nz

Geomagnetic field secular variation changes at the European magnetic observatories

M.Orlyuk, Yu.Sumaruk, A.Neska

Secular variations of the geomagnetic field, have two components, the first one from the internal sources and the second one from the external sources. The internal sources secular variations are nearly constant in time but have different values for every observatory. The amplitude and sign of the external sources component is highly correlated to the amplitude and sign of the large scale magnetic field variations of the Sun and to the amplitude and sign of the mean annual southern component of the interplanetary magnetic field.

There exist a dense network of geomagnetic observatories at the European continent that have long series of observations of the absolute values of the geomagnetic field, which allow us to investigate changes in time short-period variations: eleven, twenty-two, and long-period (60-, 80-, 100-years-old) variations.

Figure 1 illustrates SV(H) component at European observatories. Changes of SV(H) at all observatories are in phase, but curves of SV(H) are shifted on vertical axis. It means that they are created by two sources. Changes on vertical axis connected with internal source. Change on horizontal axis connected with external sources. SV are smoothed by three and eleven years running means. It means we excluded the short period of secular variations.

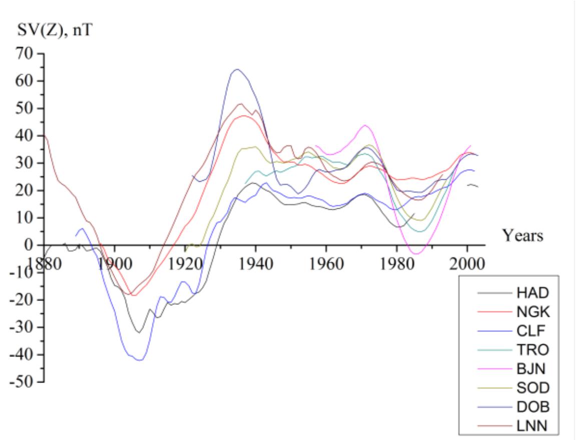

Figure 1: SV(H) component at European observatories

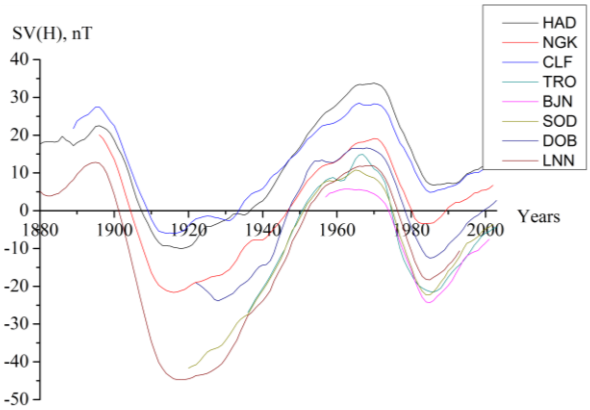

Figure 2: changes SV(Z) at European observatories

Figure 2 shows changes SV(Z) at European observatories. The changes in SV(H) and SV(Z) are wave-like. The amplitudes of oscillations SV(Z) were increasing with the latitude of the observatory, and SV(H) - with decreasing latitude. In vertical component we can detect fluctuations with periods of 22 and 80 years. The amplitudes of 22-year oscillations increase with increasing latitudes of the observatory. Obviously, this is a manifestation of the 22-year-Hale cycle of solar activity.

On the studied time interval, there is a clear decrease in the amplitude of oscillations over time. There are two subintervals of SV(H) oscillations. The first subinterval lasted from the 1880s to the beginning of the 1960's. The duration of the subinterval was about 80 years. The second subinterval began in the 1960's and will end in the early of the 21st century, its duration will be about 50-60 years. We see a decrease in the amplitude of oscillations SV over time and the duration of subintervals. Such changes are observed for solar and geomagnetic activity.

Author:
M.Orlyuk, Yu.Sumaruk, A.Neska
Institute of Geophysics of the NAS of Ukraine

Corresponding author:
M.Orlyuk
Institute of Geophysics of the NAS of Ukraine 32, Palladin Ave., 03680, Kyiv-142,
Geomagnetism Department
Tel.: +380(44)4242340
Fax: +380(44)4502520

The CONRAD Observatory in Austria – A Design Challenge

Peter Melichar

The Austrian Seismological Service was established at the ZAMG in 1904, Victor Conrad was appointed as the first head. He became Professor of Cosmic Physics at the Franz Joseph University in Czernowitz, crown land Bukovina, in 1910. Conrad emigrated with his wife Ida to the USA in 1939. He taught inter alia at Harvard University in Cambridge, Mass. untiringly until the age of 80. Ida Conrad, who passed away in 1969, conferred in her will a legacy to the ZAMG, with the wish that „ ... from the estate a building will be erected, serving geophysical and meteorological research, and will be named after Victor Conrad." The generous legacy of Ida Conrad and subsidies from the Province of Lower Austria made it possible to set up the CONRAD Observatory at an excellent location. This external financial support was the starting point for the implementation of this ambitious project by the Ministry of Science and Research.

In 1975, Peter Melichar was commissioned by the ZAMG (Central Institute for Meteorology and Geodynamics) to find a suitable site for a new geophysical observatory. The order included design and structuring of the observatory to meet the specific needs for a research center for seismology, gravimetry and geomagnetism. In 1978/79, a suitable site was found in Lower Austria on the Trafelberg at 1,100 meters above sea level. The essential criteria for the location are (i) that it is free from interference from natural and artificial sources, and (ii) that the location has a geological underground with spacious largely non-magnetic rocks. To be independent from seasonal fluctuations, an underground construction was chosen for the design, which makes the observatory operation independent of weather conditions. In the tunnel system, the temperature of + 7 ° Celsius remains constant. This is a real gift the mountain offers and it provides ideal conditions for highly sensitive sensors and electronics, leading to a significant reduction in thermal low noise.

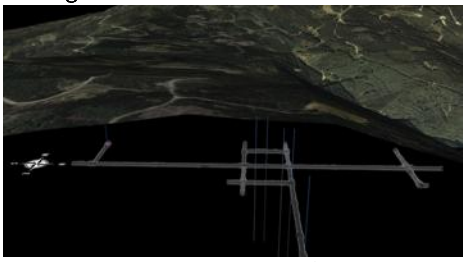

Figure 1: Tunnel System of the Geomagnetic Observatory

The GMO tunnel system was built by the Austrian company ÖSTU STETTIN using a special nonmagnetic construction technique. The CONRAD Observatory, with its two separated underground sections SGO and GMO, has a total tunnel length of 1,166 m with a total of eight boreholes reaching up to 200-meter depth accessible from the tunnel floor. The central heart of the GMO is the 3D gradiometer magnetometer system from GEM Systems, Canada. In its configuration, it is currently the world's most sensitive measurement system of its kind. It includes two horizontal gradiometers in north-south and east-west directions as well as a vertical gradiometer. The maximum extension on the three axes x, y and z is 200 meters each. Measurements in the Femto-Tesla range are now carried out with the 9 potassium sensors that make up the gradiometer. Everyone knows that earthquakes cannot (yet) be reliably predicted, but it is known that due to the pressure build-up in the earth's crust just shortly before an earthquake happens very small electromagnetic signals are generated in the rock masses. This leads to induction and piezoelectric effects, which then cause extremely small changes in the current systems of the ionosphere. Due to the extreme resolution of the 3D gradiometer in the GMO, these magnetic precursor effects may be recorded and analysed for the first time.

The opening ceremony of the SGO took place on 23 May 2002. It is used for research and development in seismology and gravimetry, as well as for applied sciences. The opening ceremony of the GMO - a center for geomagnetic research and development - took place on 21 May 2014. From the beginning, the goal was to establish the CONRAD Observatory as an international research center and meeting place for the science community!

Figure 2: The GMO Building on Trafelberg in Lower Austria

Author:
Peter Melichar
Central Institute for Meteorology and Geodynamics, Austria

Corresponding author:
Peter Melichar
Neugebäudestraße 51,
A - 1110 Vienna, Austria
e-mail: peter.melichar1@aon.at

Scanning historical magnetograms kept in the archives of the Institute of Geophysics Polish Ac. of Sc.

Jan Reda, Jan Kozlakiewicz, Mariusz Neska, Pawel Czubak

The archival resources in the Institute of Geophysics PAS comprehend a large amount of analog magnetograms recorded in the geomagnetic observatories Świder (SWI), Hel (HLP), Belsk (BEL), Hornsund (HRN, Spitsbergen), and Arctowski (ARC, Antarctica). The oldest magnetograms are from Świder observatory which started its work in 1920. The last Polish observatories to stop analog recordings were Hornsund and Arctowski in 1995. Analog recordings were conducted in different ways. In most cases, recordings were made on photographic paper. However, there were also used chart recorders equipped with a pen. For about two years we have been performing a systematic scanning of historical magnetograms now.

All the Polish geomagnetic observatories started their work with analog recordings. The Swider Observatory was the first one; it started its activity in 1920. Geomagnetic observations conducted by Swider were taken over in 1965 by the Central Geophysical Observatory at Belsk, which has been working until today. The table below summarises the historical analog recordings conducted by Polish observatories associated in IAGA.

Observatory	Location	Period of analog recordings
Świder (SWI)	Central Poland	1920-1975
Belsk (BEL)	Central Poland	1966-1987
Hel (HLP)	Northern Poland	1957-1996
Hornsund (HRN)	Spitsbergen	1978-1996
Arctowski (ARC)	Antarctica	1978-1996

In most cases, analog recordings were conducted on photographic paper. Different variometers were used for recordings, such as La Cour, Mating Wiesenberg, Schulze, but most of all with Bobrov quartz torsion variometers.

Figure 1. The working place for scanning in Belsk Observatory.

Moreover, on the basis of the Bobrov variometer, a PSM magnetometer was developed in Belsk Observatory in 1978. It produced voltage analog signals proportional to the changes of the geomagnetic field. Hornsund and Arctowski observatories recorded analog signals using pen recorders.

In 2016, a laboratory for scanning historical geophysical recordings was established in Belsk. It is equipped with a few nice scanners. For scanning archival magnetograms, we are using a MAP MASTER type flatbed A0 scanner made in Germany. The working place for scanning is shown in Fig. 1.

After many tests and analyses, it was decided to carry out scanning at the resolution of 600 pixels/inch. This corresponds to the horizontal resolution of 1 pixel/7.5sec and the vertical resolution of 1 pixel/85pT for most of the scanned magnetograms. The scans are saved in TIF format which supports lossless compression.

So far, ca. 12 000 magnetograms have been scanned, among them all magnetograms of Set No 1 from Belsk for the period 1966-1987. In a longer time horizon we plan a conversion of scanned bitmaps to digital time series.

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Authors:
Reda J., Kozlakiewicz J., Neska M., Czubak P.
Institute of Geophysics Polish Academy of Sciences, Warsaw, Poland

Corresponding author:
Jan Reda
Central Geophysical Observatory at Belsk, 05-622 Belsk,Duzy, Poland, Tel. +48 48 6610830, Email: jreda@igf.edu.pl

Bi-national cooperation project for the development of regional magnetic models and charts in Central America

Ana Caccavari-Garza, Gerardo Cifuentes-Nava, Esteban Hernández-Quintero, Jorge Brenes, Armando Ayala.

In the 70's several measurements had been performed in Central America by the Geophysics Institute, UNAM: magnetic repeat stations where visited, and magnetic Declination, Inclination and Intensity where obtained. In this project we takes up these important studies and we work together to occupy an adequate number of magnetic repeat stations in the area (Costa Rica and Mexico) with two purposes principal: update data for regional geomagnetic field models (Southeast of Mexico and Central America); and the exchange of techniques for measurement, processing, and publication of the results in the corresponding catalogs and magnetic charts.

Historically, Mexico and Costa Rica have studied the geomagnetic field and its variations in the region since the 19th century. In the 70's several measurements had been performed in Central America by the Geophysics Institute, UNAM (Sandoval, 1950; Cañón-Amaro, 1991). 29 magnetic repeat stations where visited and Declination, Inclination and Intensity were obtained (Fig.1).

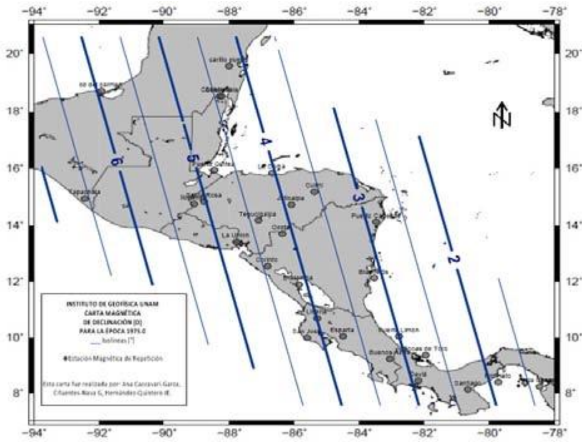
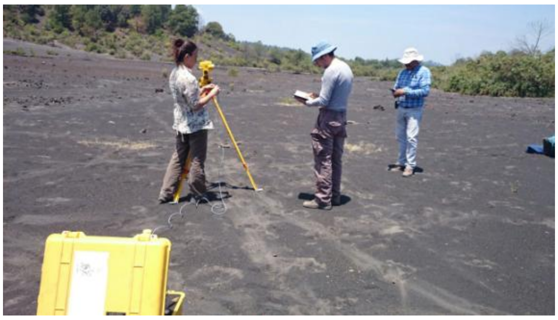


Figure 1: Magnetic declination chart 1975; made with data of Cañón-Amaro, 1991

In Costa Rica, systematic observations of the magnetic field began in 1898 by H. Pittier, who published the first isogonic chart in the area. In 1978 a most detailed study of the magnetic field of Costa Rica was performed and updated later by G. Leandro in 1984. In other hand, in Mexico, the first magnetic observations were made at the end of the 16th century by Cavendish in 1576 in La Paz, B.C. The first Magnetic chart was made in a specific study conducted by the Carnegie Institute in Washington, in 1906. Since 1947, the year in which the IGEF (Geophysics Institute of the UNAM) is founded, it is in charge of publishing the Magnetic Letters for the Mexican Republic, as well as a couple of catalogs with the magnetic values of the Mexican Republic and Central America from 1587-1991. In 2010 Declination, Inclination and Intensity chart were published. These studies have been interrupted in recent years in both countries due to problems of lack of logistical and financial support; as well as the relocation of the Chiripa Magnetic Observatory this year.



Since April 2018, 18 magnetic stations in Costa Rica were visited and magnetic data are being processed in collaboration with Mexico. Also in Mexico some magnetic stations have being visited (Fig. 2) and some are going to be visited in next months. We are working in the development of a regional magnetic charts for Mexico and Central America.

Figure 2. Magnetic repeat station Paricutin, Michoacán, Mexico.

The recovery of the magnetic measurements in the 70's and some others in the region of Central America and the present work, will allow to analyze the secular variation in the area. This project resulted in an interesting exercise in collaboration between different Latin American countries and is a contribution to number studies in geomagnetism in the region.

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Author:

Ana Caccavari-Garza[1], Gerardo Cifuentes-Nava [1], Esteban Hernandez-Quintero[1], Jorge Brenes[2], Armando Ayala[2].

1) Instituto de Geofísica, Universidad Nacional Autónoma de México, México

2) Instituto Costarricense de Electricidad, Costa Rica

Corresponding author:

Ana Caccavari-Garza Instituto de Geofísica, Universidad Nacional Autónoma de México Av. Universidad 3000. Ciudad Universitaria. CP.04510, Cd. Mx. México. Tel.: +52 (55) 56224149 e-mail: anacg@igeofisica.unam.mx

Characteristics of 1 second baselines from Hyderabad and Choutuppal Magnetic Observatories, India

N. Phani Chandrasekhar, K. Chandra Shakar Rao and L. Manjula

Many INTERMAGNET Geomagnetic Observatories are graduating from 1 min definitive data to 1s definitive data. The quality of this new data is very sensitive to the precision and stability of the vector and scalar magnetometers as well as the Declination-Inclination magnetometer used in each Observatory. The effect of small amplitude local fluctuations of the natural and man-made electromagnetic environment around the magnetometers is substantial with the higher frequency of measurement and the noise often affects the quality of the baselines. In this study, we compare such baselines obtained with different magnetometers at Hyderabad and Choutuppal Magnetic Observatories, India.

Magnetic observatories record long-term vector and scalar data and the network of these Observatories (INTERMAGNET) produce complete information about the changes in the spatial and temporal characteristics of the Earth's magnetic field. Due to very high demand from the geomagnetic community for various space weather applications, most of the Magnetic Observatories are now recording 1s data (Chandrasekhar et al. 2017).

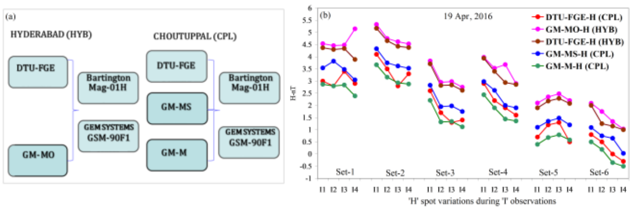

Figure 1: (a) Magnetometers used for the experimental study; (b) Deviations in H-spot variations in magnetometers during absolute observations on a quiet day

For any Observatory, the stability of baselines is a crucial factor; the baseline deviations have to be at least one order less than the long period weak signals (Anil et al. 2017).The accuracy of the baselines are directly impacted by the quality of the 1s data from the various magnetometers.

With the aim of producing 1s definitive data from Choutuppal (CPL) Observatory in the near future, we performed a few experiments under temperature controlled environment to understand the nature of baselines from 1s magnetic measurements at Hyderabad (HYB) and Choutuppal (CPL) Observatories using similar and different magnetometers over a period of 4 months (Mar-Jun, 2016). Details of the magnetometers used for the study at each Observatory are shown in Fig 1a and discussed in detail (Chandrasekhar et al. 2017). 'H' spot variations during the time of D-I observations for 6 sets between the magnetometers on one quiet day is shown in Fig 1b (where I1-I4 are Inclination readings). It is evident from Fig 1b that the 'H' variation trends are relatively same and have a scatter of 0.5nT between the DTU systems deployed at HYB and CPL Observatories and 0.8 nT between the GM systems (MS and MO), whereas in GM-M, variations are confined to 0.2nT range. From 4 months of observations, we found that the drift in baselines are found to be maximum in suspended systems (DTU-FGE, GM-MO and GM-MS, ±0.8 nT) than unsuspended GM-M (±0.3 nT), (Fig 2) and are directly proportional to the obtained deviations in spot variations. DTU-FGE systems show controlled variations than GM systems. It is also evident that baselines at HYB and CPL Observatories show relatively same trend with few exceptions. Being aware of factors mentioned above, is critical for generation of 1s definitive data and a longer time series is required to evaluate the differences in spot variations between the systems, proposed as a future study.

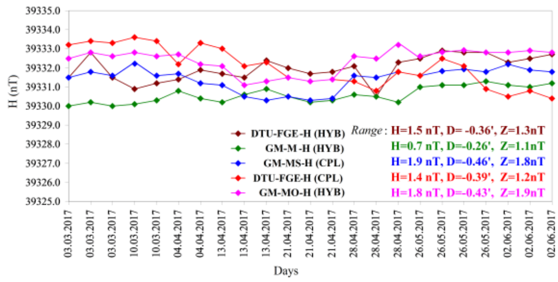

Figure 2: Baseline variations in H-component and the observed differences in D and Z components between the magnetometers.

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Author:s
N. Phani Chandrasekhar[1], K. Chandra Shakar Rao[1], L. Manjula[1]
1) CSIR-National Geophysical Research Institute, Hyderabad, India

Corresponding author:
Phani Chandrasekhar
CSIR-National Geophysical Research Institute, Hyderabad, 500007, India
Tel.: +91 40 23434737, e-mail: phaninelapatla@gmail.com

Complex geophysical investigations on the site of Tihany observatory

András Csontos, Péter Tildy

The appearance of a little systematic baseline instability with large spatial differences motivates us to perform a detailed geophysical survey on the site of Tihany observatory including electric resistivity tomography (ERT), geomagnetic measurements and susceptibility measurements. Soil samples were also collected based on the measurement results, on them an X-ray powder diffraction (XRD) measurement was completed to identify the minerals of the sediments. After these investigations deposits with different magnetic properties could be linked to structures created by hydrothermal processes.

Tihany Geophysical Observatory was founded in Tihany National Park on the peninsula of Lake Balaton, Hungary. The volcanic origin of Tihany peninsula has been repeatedly studied. Phreatomagmatic eruptions occurred in the area approximately 7-7.5 million years ago. According to the survey the NW-part of the peninsula shows the existence of strong anomalies of volcanic rocks, but in the SE region, where hot springs appeared previously, the spatial variation of the geomagnetic field was relatively week. That is why the place of the observatory was selected in the SE region of the peninsula near to the top of a geyser cone.

The knowledge of the distribution of crust anomalies near to the geomagnetic recording systems can be important for observers. In order to determinate the distribution of different deposits, as the first step geophysical surveys were performed.

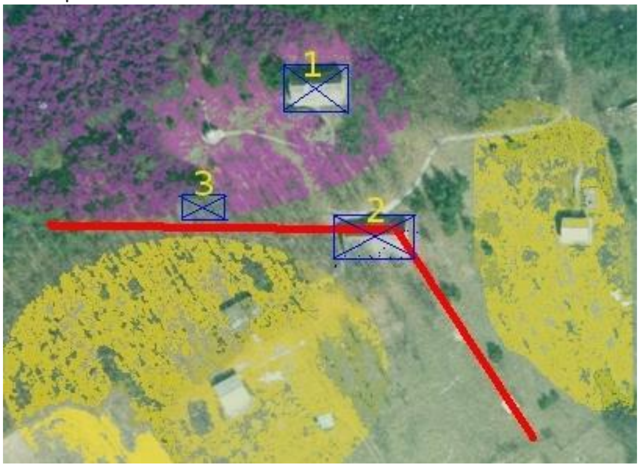

Figure 1: The picture shows the ground of Tihany observatory. The red lines are the fractures where the eruptions of hot water occurred. They separate the geological characteristics.of the site i.e. rocky (purple) and clayey (yellow) areas. The blue rectangles are the places of geomagnetic measurements. 1 marks the absolute house, 2 marks the variation house and 3 marks a new underground hut.

As results of ERT and geomagnetic surveys we could separate different types of sediments based on resistivity contrast and magnetic properties. Reverse magnetization was observed by geomagnetic survey.

Perhaps these areas are the marks of eruptions of hot water. Eruption(s) may occurred near tectonic lines or other fractures. (Csontos et al., 2017) The detected structures separate the ground of the observatory also into a rocky and a clayey part. (Fig.1)

According to XRD measurements we can characterize the above described geological formations which were mostly created by geochemical processes:

1.) The minerals of the rock are mostly hydrocalcite (40%) and dolomite (44%). This rock is free from the magnetic minerals.

2.) Clayey deposit is practically a mixture of different minerals. We could find smectite, quartz, illite+muskovite, calcite and chlorite with relatively high percentage in the samples. Goethite (α-FeOOH) was also reported in the deposit but we can not exclude the appearance of further type of magnetic mineral in the ground.

Along the fractures (Fig.1) the susceptibility map of the surface shows structures, i.e. parallel to the fractures we can measure relatively high susceptibility values. These can be marks of lode. After heavy mineral separation X-ray powder diffraction measurement detected maghemite, hematite and goethite in the samples of these deposits. The appearance of maghemite can be the reason of the relatively high susceptibility.

We could identify the structures of deposits created by hydrothermal processes and minerals of different facies so the impoundment of magnetic anomalies of the crust were performed. As a consequence of our study we verified, that the absolute control of the geomagnetic observatory is not influenced by strong crust anomalies.

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Author:
A. Csontos[1]. P. Tildy[1]
1) Mining an Geological Survey of Hungary

Corresponding author:
András Csontos
Mining an Geological Survey of Hungary, Tihany Geophysical Observatory
H-8230 Tihany, Kossuth u. 91., Hungary
Tel.: +36 (87) 448-501
e-mail: csontos.andras@mbfsz.gov.hu

Current practice of the Hungarian Repeat station surveys: measurement, data processing, interpretation

Péter Kovács, András Csontos, Gergely Vadász, Balázs Heilig

In Hungary, the tradition of the geomagnetic survey campaigns dates back to the middle of the nineteenth century. Between 1950 and 1995, Hungary's vector magnetic components have been surveyed periodically, every 15 years, on the so-called country survey (CS) network comprising 300 stations. In 1965, a repeat-station (RS) network was also installed in order to monitor the spatial distribution of the secular change of the magnetic field and to regularly update the field measured in the dense CS network. In the paper, we present the RS network of Hungary, and our recent improvements applied in the measurement technique and data processing.

The RS network of Hungary (H-RS) is shown in Figure 1 (Aczél, Stomfai, 1969). The network comprises 13 stations that are located on non-anomalous sites. The re-occupation period of H-RS is 2 years, in accordance with the recommendation of MagNetE. We use one-axial fluxgate magnetometer mounted on the telescope of a Theo020A Zeiss theodolite to measure the magnetic declination and inclination (in the null mode, see Newitt et al., 1996), and GSM 19 Overhauser type of magnetometer to record the total field. In each station, the measurements are carried out in the morning and afternoon hours in consecutive days in order to minimize the error of the temporal reduction. Basically, the temporal reduction is carried out with the use of the magnetic recording of the Tihany Observatory (THY). Additionally, we also install a three-component DIDD magnetometer in the Baradla cave (near to Aggtelek RS) and use its record for the reduction of the nearby measurements (see Fig. 1.). The limestone cave environment ensures low level of magnetic and mechanical noise, as well as temperature stability.

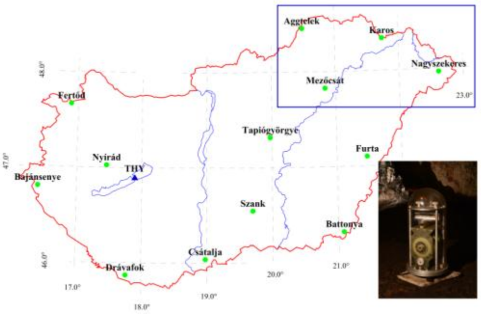

Figure 1: The Hungarian repeat station network (H-RS). The picture shows the on-site DIDD variometer installed near to Aggtelek station. The blue rectangle represents the area where the on-site recording is applied in the data reduction.

It is shown, that, by applying the on-site recording, the gain in the temporal reduction accuracy can exceed 2 nT in X, Y or Z components, depending on the geomagnetic activity conditions.

The normal field models of Hungary are compiled by the first- or second-order polynomial of the geographic coordinates. The polynomial fitting is carried out separately for each of the vector component, thus this solution ignores the Laplace's condition. To avoid this shortcoming, recently, we have developed a Matlab code for the application of the adjusted spherical harmonic analysis (ASHA), introduced by De Santis (1992) for the modelling of the geomagnetic field for a spherical cap domain. To improve the model accuracy for Hungary, we involve RS and observatory data of neighbouring countries, from the database of WDC for Geomagnetism. Moreover, in empty area we also set up "virtual stations" and filled them with magnetic values derived from the recent IGRF model (Thébault et al., 2015).

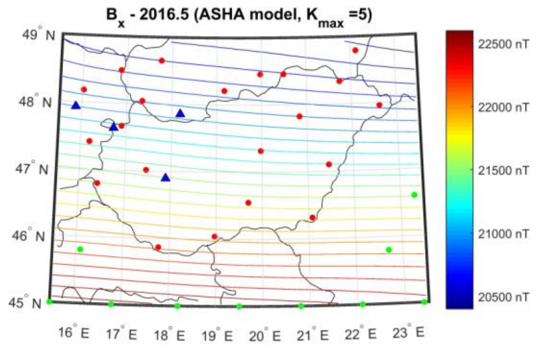

Figure 2: The X component model field for Hungary compiled according to ASHA (see text). The red dots, blue triangles and green dots show the locations of repeat stations, observatories and "virtual stations" (see text), respectively, from where data have been used in the model computation.

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Author:
P. Kovács[1], A. Csontos[1], G. Vadász[2], B. Heilig[1]
1) Mining and Geological Survey of Hungary, Budapest, Hungary
2) Eötvös Loránd University, Faculty of Science, Institute of Physics, Budapest, Hungary

Corresponding author:
Péter Kovács
Mining and Geological Survey of Hungary
Columbus str. 17-23, 1145 Budapest, Hungary, Tel.: +36 (1) 252 4999
e-mail: kovacs.peter@mbfsz.gov.hu

Magnetotelluric Measurements at Geomagnetic Observatories

Jake Morris, Greg Lucas

Space weather interacts with the geomagnetic field to induce geoelectric fields within the Earth. These geoelectric fields have the potential to adversely affect electric power grids. The U.S. Geological Survey (USGS) is currently deploying magnetotelluric (MT) systems at ground-based USGS geomagnetic observatories, which simultaneously measure both the geoelectric and magnetic fields. The geoelectric field varies as a result of the regional geology and the magnitude of the magnetic field. MT measurements will provide geoelectric field data in a broad region around each magnetic observatory. Data from these measurements will be used to calculate realistic regional geoelectric fields using three-dimensional (3D) impedance functions to produce potential hazard maps useful for assessing risk to electric power grids.

Geomagnetic storms induce geoelectric fields within the interior of the Earth that lead to geomagnetically induced currents (GICs) within power grids. GICs can lead to anomalies and faults within power transmission systems and were the cause of the Hydro-Québec power system collapse [Bolduc, 2002]. This has led to increasing interest in the relationship of geoelectric fields with electrical systems in recent years.

Real-time monitoring of geoelectric fields is currently undertaken at only a few geomagnetic observatories throughout the world, including the United States Geological Survey's (USGS) Boulder geomagnetic observatory [Blum et al. 2017]. These installations require permanent infrastructure and support staff to calibrate and monitor the facilities, which can be prohibitively expensive to install at every geomagnetic facility that an institute operates. Rather than installing permanent monitoring stations at all of the observatories, the USGS is beginning to conduct temporary magnetotelluric field deployments at all of their observatories.

The magnetotelluric method simultaneously measures the magnetic and electric fields, which can then be analysed to determine the conductivity structure at each observatory arising from the underlying geology. The impedance, derived from the conductivity structure, will only change over geologic time-scales, meaning that it doesn't need to be continually monitored. Once the impedance near a geomagnetic observatory is determined, it can be used to estimate geoelectric fields that would have been realized in that location.

This year we have deployed magnetotelluric stations to the Fresno (FRN), Tucson (TUC), and Newport (NEW) geomagnetic observatories and calculated the local impedance of the Earth at each site. These impedances can then be convolved with the long historic record of geomagnetic field data at each site to produce estimated geoelectric fields. Figure 1 shows the predicted geoelectric field at the Fresno (FRN) geomagnetic observatory during the 2003 Halloween Storm.

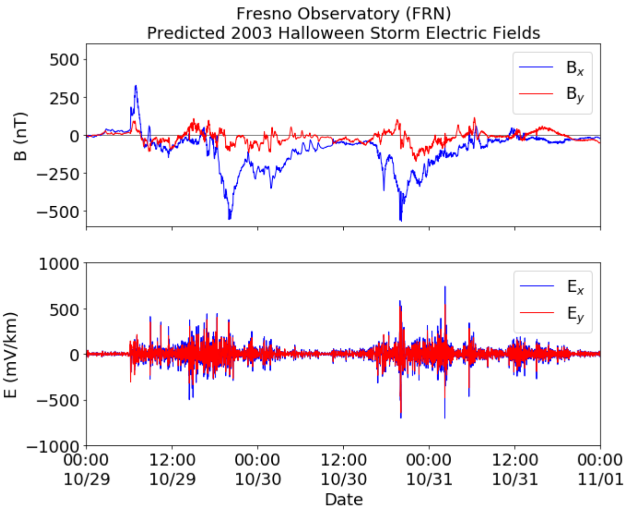

Figure 1: The measured magnetic field at geomagnetic observatories can be combined with local magnetotelluric measurements to make predictions of the local electric field during historic geomagnetic storms.

These temporary magnetotelluric deployments to geomagnetic observatories with long-duration high-quality magnetic field measurements provides a method to generate estimates of local geoelectric fields that would have been realized during historic geomagnetic storms. It also provides a method to predict the real-time geoelectric fields local to the observatories that can be used by utility companies to make informed decisions about operating their transmission network.

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Author:
J. Morris[1] G. Lucas[1]
1) United States Geological Survey, Geomagnetism Program, Golden, Colorado, United States

Corresponding author:
Jake Morris
USGS Geomagnetism Program
1711 Illinois St, Golden, CO, USA, 80401
Tel.: +1 (303) 273-8603
e-mail: jakemor@usgs.gov

The interpretation of magnetic noise component in lunar sample magnetic measurement. (15445)

Tereza Kamenikova, Gunther Kletetschka

The paleomagnetic measurements of the lunar samples were based on Natural Remanent Magnetization (NRM) basis. There was developed methods, analyzing NRM without heating process needs. [1] Magnetic characteristics are based on magnetic minerals involved in sample, their grain size, temperature, strain and aspect ratio. [2, 3] There are existing two ways for the crustal rock sample how to record the paleomagnetic information. The chemical process when magnetic grain is growing through the blocking volume of homogeneously distributed magnetic dipoles. The magnetic minerals will interact with the magnetic field, in case the field will be present at the stationary temperature. This process is called chemical remanent magnetization (CRM). The second process is going on, in case the cooling magnetic grain passing the blocking temperature by constant volume, when fluctuation of the magnetic moments interacts with the external magnetic field, in case the field is present. This process is called thermal remanent magnetization (TRM). These processes having both the same similar efficiency for contribution the paleofield remanent capacity [4].

For the presented work was used a new method which don't involve the heating and capture the amount of magnetic noise in the Lunar samples. This method is based on this logic. In case the sample A has not seen magnetic field, when was formed. The sample should be completely demagnetized and have a magnetic background M(A) On behalf of this properties, the AF (alternating field) demagnetization would be in constant for any of the AF demagnetizing level. The first step of our approach is to take sample A and demagnetize it by 1 mT, 10 mT, 100 mT, 1000 mT and the overall magnetization M(A(AF)) should be constant magnetic background [5].

When the sample is saturated by pulse or constant magnetic field, all magnetic domains of the sample converging into one magnetic dipole. The magnetic instrumentation is giving maximum MS(A) magnetic level. The monotonous magnetic decay is given in case the sample is step-wise demagnetized, curve itself pointing from its saturated value down to demagnetized state MS(A(AF)). Dividing these two sequences M(A(AF))/MS(A(AF)) essentially means that when function which is constant is divided by decreasing monotonously decreasing function, that overall result is function that monotonously increases. And this monotonous trend is central for our test for magnetic noise presence in lunar samples [5].

The lunar rocks magnetic carrier is mostly iron minerals [6]. In case these minerals contain superparamagnetic grains, they are vulnerable to viscous magnetization when is exposed to geomagnetic field. Carriers of this magnetization have very low magnetic coercivity. Such magnetization is removed when demagnetizing the sample by using the lowest amplitude of the demagnetizing alternating field (usually up to 5 mT) [5].

We tested sample of lunar breccia chipped by Apollo 15 mission. The sample 15445.277 was fragmented. We had 7 subsamples, one thin section, one of these subsamples contained only dust as a residue from separation for control of magnetic noise (Fig. 1).

The noise/viscosity detection procedure was applied for all fragments. The results displayed monotonously increasing function as expected. The 4 fragments and thin section showed a magnetic noise only (monotonously increasing function), 2 fragments with the highest sample masses were induced by viscous magnetization and 2 fragments contained superparamagnetic component overprinted on magnetic noise. It was possible to show with magnetic data from the other 5 sub-fragments without SP that they contain magnetic noise and did not record any level of magnetic field during their formation [5].

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Author:
T. Kamenikova[1,2] G. Kletetschka[1,2,3]
1) Institute of Geology, Academy of Sciences of the Czech Republic, Czech Republic
2) Faculty of Science, Charles University, Czech Republic
3) Department of Geology and Geophysics, University of Alaska Fairbanks, USA

Corresponding author:
Tereza Kamenikova
Albertov 6, Faculty of Science, Charles University, Prague, 128 43, Czech Republic
e-mail: kamenikt@natur.cuni.cz

Precise measurement of the magnetic field vector with moving carriers

Fedir Dudkin, Valery Korepanov, Vira Pronenko, Andrii Pristai

The use of flux-gate magnetometers onboard mobile carriers faces a number of difficulties that limit their implementation in the practice of geophysical research. This is due to the fact that the measurements of rather weak magnetic anomalies are executed in the presence of strong Earth's magnetic field which creates great interference unavoidably arising when the vector magnetometer rotates during its movement. The analysis of this factor is made and the way to eliminate such errors is discussed.

The geophysical research of Earth's crust structure requires measurements of the Earth's magnetic field vector variations at big areas. Normally, this is made with flux-gate magnetometers (FGMs) in numerous stationary positions to cover all the area. To decrease time and money expenses, recently the attempts are known to do this with the help of moving carriers. In spite that the existing FGM parameters allow their using for magnetic survey with moving platforms, this faces a number of difficulties that limit their implementation in the practice of geophysical research. This is due to the fact that FGM produces three component measurements results in the presence of strong Earth's magnetic field $\mathbf{B}_0$ (the absolute value $|\mathbf{B}_0|$ can reach 67 000 nT), and when the FGM rotates during its movement, great interference is unavoidably arising. To this, EM interference and vibration from the copter motor is the important factor which limits the magnetometer sensitivity level in wide frequency band. The last problem can be solved by proper interference filtration and use of elastic construction design of suspended (towed) FGM. One may believe that the calculation of the magnetic field module after the measured components may allow overcoming the first problem, at least making FGM use competitive to scalar magnetometers. But detailed study showed that even small deflections α_{ij} of FGM sensors from mutual orthogonality (≤0.1 degrees) and non-identities k_i of transfer function of measuring channels (≤0.1%) can lead to "pseudo" anomalies appearance in module values at sensors rotation what is the essential factor which limits the FGM application in practice. The module B calculations results are illustrated below, where the appearing changes are given for dB, dB/d▯ and dB/dθ at B=50000 nT and simultaneous deviations of angles from orthogonality α_{12}=89.9°, α_{23}= α_{13}=90.1° and transfer functions non-identity values k_1=1, k_2=1-5·10^{-4}, k_3=1-10^{-3}. This may create errors up to dB=80 nT, dB/dφ=2 nT/deg and dB/dθ=2.5 nT/deg (see Figure).

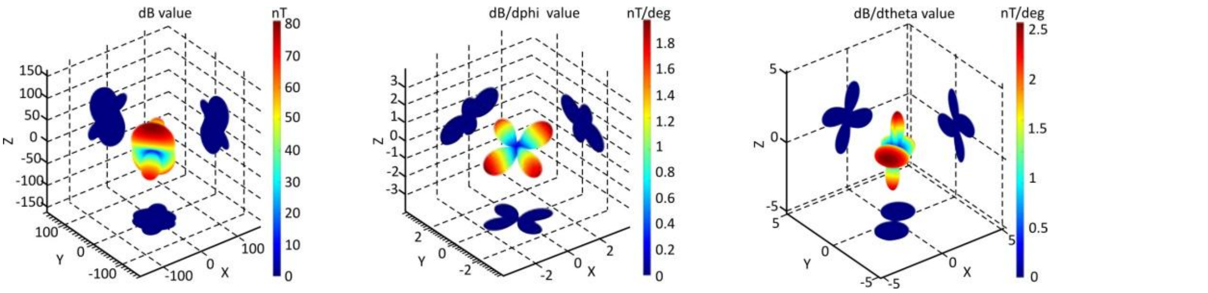

Figure: The possible dB, dB/dφ and dB/dθ errors at B=50000 nT and simultaneous deviations α_{12}=89.9°, α_{23}= α_{13}=90.1°, k_1=1, k_2=1-5·10^{-4}, k_3=1-10^{-3}.

Basing on our calculations, we may estimate the requirements to the sensors non-uniformity errors in order dB(φ, θ) parameter values would be at the level of natural interference - by conservative estimation, do not exceeding 1 nT. Thus, required error should be decreased up to 10^{-3} of angular degree and the control of the magnetic channels transformation coefficient should be at the level 2·10^{-5}, i. e. 0.002%. These conditions require a new approach to FGM application in the dynamic measurements of small anomalies in the Earth's magnetic field. Possible solution is to develop the method to determine the real FGM channels mutual orthogonality deflection and transformation factors non-identity with given precision and to introduce corresponding corrections at data processing. This method is under development now.

Author:
F. Dudkin, V. Korepanov, V. Pronenko, A. Pristai
Laboratory for Electromagnetic Innovations , Lviv, Ukraine

Corresponding author:
Valery Korepanov
Laboratory for Electromagnetic Innovations, Naukova 5-A, 79060 Lviv, Ukraine
Tel.: +380 (32) 2639163
e-mail: vakor@isr.lviv.u

Rapid mid-latitude magnetic storms recorded by old observatories

Fridrich Valach, Pavel Hejda, Josef Bochníček, Miloš Revallo, Magdaléna Váczyová

Recently, a new insight into the mechanism of the Carrington magnetic storm was published, which identified the field aligned currents as the main cause of this well-known event. The new idea seems to be a promising alternative to the generally accepted theory, in which the ring current is the main cause of the low- and mid-latitude magnetic storms. In our contribution, two records of rapid mid-latitude magnetic storms are discussed which were recorded by historical magnetic observatories (years 1848 and 1872). The profiles of the horizontal component show that, instead of the ring current, some currents related to the auroral oval or field aligned currents (FACs) probably played an important role in the development of these interesting geomagnetic variations.

The classic concept of great mid-latitude geomagnetic disturbances is that they are the magnetic storms and are caused by the ring current. Recently, however, Cid et al. (2015) showed that the immensely large decrease of horizontal intensity (H) that was observed at Colaba during the well-known violent variation on 2/9/1859 was probably caused by the FACs.

Here we present two other profiles of the horizontal component that were observed in the middle of the 19th century. Their "recovery phases" seem to be too rapid to be caused by the decay of the ring current.

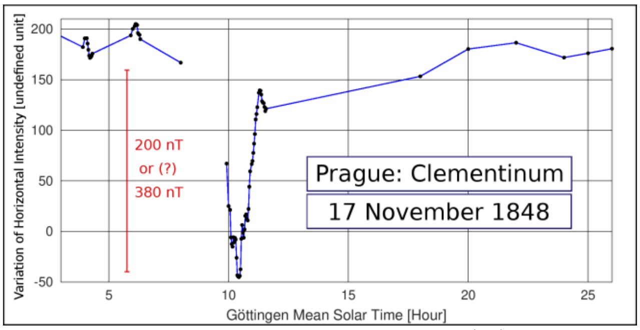

Figure 1: The magnetic variation observed in Prague on 17/11/1848. The vertical scale for the H component has not yet been unambiguously determined.

A pronounced negative variation was observed in Prague (Clementinum) on 17/11/1848 (Fig. 1). This very fast variation with depression more than 200 nT occurred at 23:20 MLT. The most likely interpretation of this event is that it might be caused by the substorm electrojet. Alternatively, its cause might be upward FACs. The magnetic variation was accompanied by an intense aurora, which indicates the presence of auroral oval in mid-latitudes. The GIC effect from this phenomenon affected a telegraph line in Italy.

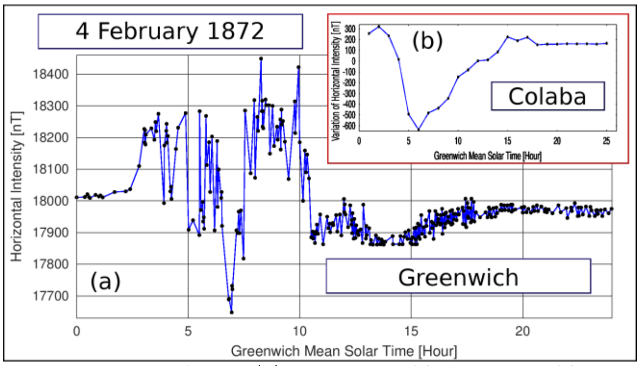

Figure 2: The H-profiles on 4/2/1872 recorded at (a) Greenwich and (b) Colaba.

Very strong auroras accompanied the variations of the H component (Fig. 2a) which were recorded by the Greenwich observatory on 4/2/1872. Maximum depression of H occurred at 19:02 MLT. Interestingly, the 1-hour means of H from Colaba (India) exhibit a profile which well resembles the classic ring-current storm. Provided that the auroral oval reached the location of Greenwich during the storm, the positive variations of H recorded in Greenwich both before and after 19:00 MLT (compared to the H-profile of Colaba) could probably be interpreted as a result of the eastward electrojet.

This study is aimed to support the idea that the non-ring-current magnetic disturbances at mid-latitudes might be much more important than hitherto thought.

Acknowledgmens:
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Author:
F. Valach[1], P. Hejda[2], J. Bochníček[2], M. Revallo[3], M. Váczyová[1]
1) Geomagnetic Observatory, Earth Science Institute, Slovak Academy of Sciences, Hurbanovo, Slovakia
2) Institute of Geophysics, Czech Academy of Sciences, Prague, Czech Republic
3) Earth Science Institute, Slovak Academy of Sciences, Bratislava, Slovakia

Corresponding author:
Fridrich Valach
Geomagnetic Observatory, Earth Science Institute, Slovak Academy of Sciences
Komárňanská 108, 947 01 Hurbanovo, Slovakia
Tel.: +421 35 760 22 11
e-mail: fridrich@geomag.sk

Ukrainian Regional Magnetic Map: the results of calculations of the geomagnetic field components for the Epoch 2015

M. Orlyuk, A. Marchenko, A. Romenets, M. Bakarjieva

Method to calculate power and angular components of induction vector of the Earth's magnetic field is proposed. This method is grounded on the development of 3D model of the Earth's crust and following calculation by it of northern (ΔB_{ax}), eastern (ΔB_{ay}) and vertical (ΔB_{az}) components of anomalous magnetic field that together with corresponding components (B_{0x}, B_{0y}, B_{0z}) of normal field enable to define full values of B_x -, B_y -, B_z - components of the Earth's magnetic field. Using them the value of horizontal component (B_H) as well as the angles of declination D and inclination I of geomagnetic field are calculated. The values of power and angular components of B magnetic field on the territory of Ukraine for the Epoch 2015 year (IGRF-12) are calculated. The contribution into magnetic declination D and inclination I of its normal (D_0, I_0) and anomalous (ΔD, ΔI) components is estimated.

The internal Earth's magnetic field is the vector sum of the core field (main magnetic field) B_0 and lithospheric magnetic field ΔB. Software complex for calculate induction vector of magnetic sources was created. In this case it is proposed for the first time to calculate magnetic field ΔB_M from the magnetic model of the Earth's crust. These field ΔB_M is corresponding to anomaly ΔB. Using known values of the Earth's magnetic field components it is easy to calculate corresponding magnetic field components ΔB_{Mx}, ΔB_{My}, ΔB_{Mz}

Full vector components *B* are estimated as

$$B = B_0 + \Delta B_M,\quad B_x = B_{0x} + \Delta B_{Mx},\quad B_y = B_{0y} + \Delta B_{My},\quad B_z = B_{0z} + \Delta B_{Mz}$$

$$B_H = \sqrt{B_x^2 + B_y^2} \qquad D = \arccos\,(B_x / B_H) \qquad I = \arcsin\,(B_z / B)$$

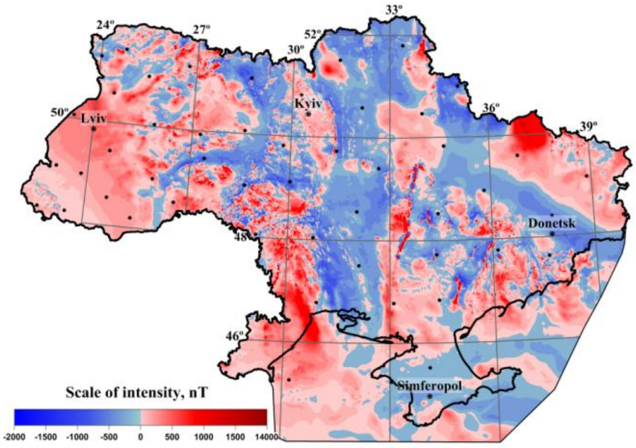

Figure 1: Magnetic Anomaly Map of Ukraine [Nechaeva et al., 2002; Orlyuk et al., 2015]

3D magnetic model of the territory of Ukraine is represented by 230 magnetic sources. The sources of magnetic anomalies are located at depths from 1 to 10 km (sources of local magnetic anomalies) and 7-10 ÷ 30-45 km (sources of regional anomalies). Their magnetization varies from 0.1 A/m to 10.0 A/m. The sources of Kursk and Kryvyi Rig anomalies have a magnetization more than 10.0 A/m. The values of the geomagnetic field components B_x, B_y, B_z, B_H, D and I are calculated for the Epoch 2015.

According to calculations the power components of the geomagnetic field have the following limits: Northern B_x = (17440 ÷ 25260) nT, Eastern B_y = (-2200 ÷ 7400) nT; Vertical B_z = 42700 ÷ 52700 nT, Horizontal B_H = (18000÷ 25600) nT. Magnetic declination D in the territory of Ukraine varies from -5,4° to 20.6° (Fig. 2), and magnetic inclination I from 61,1° to 69,1°. According to the results of calculation, anomaly of power and angular components of geomagnetic field are observed in areas of intense magnetic anomalies of the regional and local ranks.

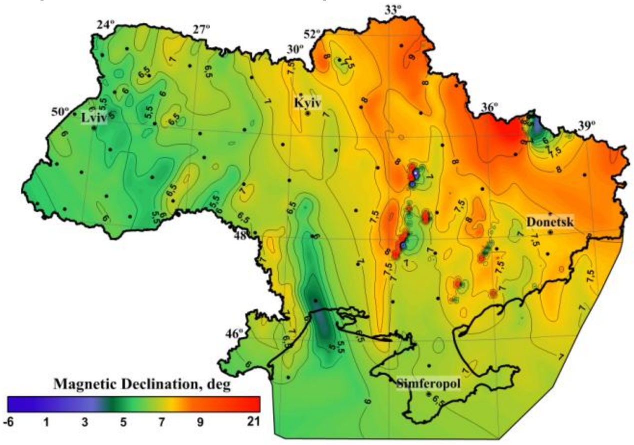

Figure 2: Magnetic declination in the territory of Ukraine for the epoch 2015.

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Author:

M. Orlyuk[1], A. Marchenko[1], A. Romenets[1], M. Bakarjieva[1]

1) Institute of Geophysics by S.I.Subbotin name, Kyiv Ukraine,

Corresponding author:

Mykhailo Orlyuk

Institute of Geophysics by S.I.Subbotin name, Palladin, av. 32, Kiev, 03680, Ukraine, tel. (044) 424-23-40, E-mail: orlyuk@igph.kiev.ua, orliuk@ukr.net

The Study About Registered Solar, Geomagnetic and Ionospheric Storms

Spomenko J. Mihajlović, Milena Cukavac, Elra Hasanagić, Rudi Čop, Lazo Pekevsk, Jovica Jankovic, Miodrag Rašić

Conditions in space or solar weather often can be determined by activity of CMEs emission (Coronal Mass Ejections), or by eruptions of coronal plasma and energy. Solar weather is changed as is changed number of registered solar storms, number and speed of magnetic clouds and if they were observed by moderate or intensive magnetic storms.These are changes in the speed and power of the Solar Wind, the appearance of intense solar flares, which are associated with the emission of Coronal Mass Ejections (CMEs) and the radiation of coronal holes (CH). The geo-effective impact of solar-geomagnetic disturbances will be analyzed on the case of three solar, geomagnetic and ionospheric storms (Geomagnetic storm in January 2012 and St. Patrick Day Magnetic storm in 2013 and 2015).

On St. Patrick's Day, 17th March 2015 maximum change in the value of the index of geomagnetic activity were registered [D_{ST} / dt = -228 nT]. Due to the date of registration of this disorder, this geomagnetic storm is called Saint Patrick geomagnetic storm. Start or appearance of St. Patrik geomagnetic storm was determined by registering SSC (A) impulse / 04 45 UT; 17th March 2015./. The magnitude of sudden impulse of SSC (A) was as follows: dX = + 38 nT/ min; dY = + 7.9 nT / min (SSC - Sudden Storm Commencement). Registered signal, "sudden impulse", announced geomagnetic storm, which had a maximum change of horizontal component intensity of the geomagnetic field around [dX = 174 nT] and has registered a maximal period of three hours index geomagnetic activities of Kp = 7. Figure 1. shows the distribution of three-hour indices geomagnetic activity in the period of duration St. Patrick's Day Magnetic storm.

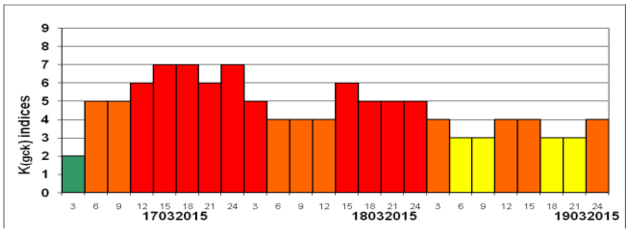

Figure 1: Local three-hours geomagnetic activity indices, Date: 17-19. March 2015, Geomagnetic Observatory Grocka (GCK)

According to the rank, regarding the maximum value of D_{ST} index of geomagnetic storm, Sv. Patrick was one of the most intense storm registered in the 24th solar cycle. St. Patrick Magnetic storm, from 17th to 19th March 2015, registered at the Geomagnetic observatory Grocka (GCK), is shown in Figure 2. Solar and magnetic weather phenomena (*solar weather & magnetic weather*) and the emerging solar-geophysical processes and events (solar, geomagnetic and electromagnetic storms), generated changes in processes and movements in the Earth's atmosphere. Geo-effective impact of geomagnetic storm St. Patrick was observed at the level of the dynamics and structure of atmospheric and meteorological changes, from 16th to 22th March 2015.

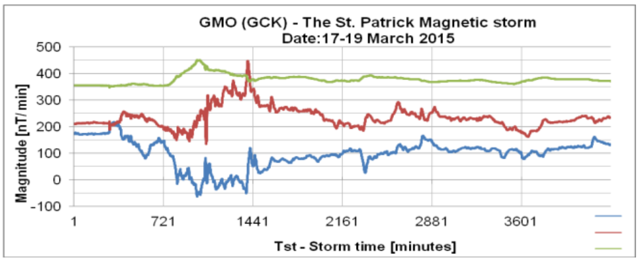

Figure 2: Magnetic Storm St. Patrick, date: 17-19. March 2015, Geomagnetic Observatory Grocka (GCK)

Analyzing the relationship between the solar and geomagnetic activity indices and the wind speed in the Hurricane Nathan (which appeared in this period), it has been found that there are statistically significant correlations. When viewing cross-correlations of mentioned indices of the solar and geomagnetic activities on the one hand and the wind speeds in the Hurricane Nathan on the other hand, the correlation increases, wherein the maximum correlation is achieved when the wind speeds are `shifted`, that is, when they lag 36 hours behind the indicators of the solar and geomagnetic activities.

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Author:
Spomenko J. Mihajlović [1], Milena Cukavac[1], Elra Hasanagić[1], Rudi Čop[2], Lazo Pekevski[3], Jovica Jankovic[1], Miodrag Rašić[1]

(1) Republic Geodetic Authority
(2) Zavod Terra Viva, Sečovlje, Slovenija
(3) University “Sts. Cyril and Methodius”, Seismological Observatory, Skopje, Macedonia

Corresponding author:
Spomenko J. Mihajlović
Republic Geodetic Authority
Center for Geomagnetism and Aeronomy
“Milutin Milanković“
Put za Umčare 3, 11306 Grocka, Belgrade, Serbia
Tel.: +381 (11) 8520242
e-mail: mihas@orion.rs

Using observatory, differential magnetometer and magneto-telluric data for modelling geomagnetically induced currents in Spain

J Miquel Torta, Santi Marsal, Juan J Curto, Oscar Cid, Juanjo Ledo, Alex Marcuello, Pilar Queralt, Anna Martí, Joan Campanyà

The lessons learnt from all our analyses on the threat posed by geomagnetically induced currents (GICs) to the Spanish 400 kV power grid are used in a new project for establishing a series of local MT surveys to properly map the geoelectric field, enabling the matching between the model predictions and actual GIC measurements across the entire Spanish territory. The number of GIC measurements are also planned to be increased by indirectly obtaining them with the deployment of magnetometers under some selected power lines, in contrast with the more usual way of measuring the current in the neutrals of the transformers at substations, and thus avoiding the necessity of interfering with the power companies.

The modelling of GICs in Spain was started by taking the plane wave assumption for the external current source, an homogeneous Earth conductivity for the induction problem, and the Lehtinen and Pirjola method for the engineering problem (Torta et al., 2014). We also used 1-D depth-conductivity models, but they did not perform substantially better than the homogenous Earth approach. To improve the first model, in Torta et al. (2017) we interpolated the geomagnetic variations from the records of several observatories with the Spherical Elementary Current Systems (SECS) technique. We also performed magneto-telluric (MT) measurements in the vicinity of the substation from which we have GIC measurements and showed that the regional geoelectrical response is strongly affected by the Mediterranean Sea. In that case, a high model accuracy was obtained when using the empirical surface impedance, adopting either a 2-D approach or the full impedance tensor.

To continue developing modelling improvements, we have just started with a new project aimed at addressing the characterization of GICs in the Iberian Peninsula by means of a multidisciplinary approach. We first plan to characterize the magnetospheric and ionospheric sources that generate the greatest GICs. To do that, we will exploit our recent experience on the use of SECS to map the polar current systems associated with the geomagnetic sudden commencements on the St. Patrick's Day storms (Marsal et al., 2017). To characterize the internal sources, we will define a geoelectric model by integrating previous MT soundings and new data to determine how the 3D structure of the subsurface resistivity affects the GICs. Finally, new GIC intensities at critical locations will be obtained by differential magnetometry (the GIC is estimated from the difference between the variations of the magnetic field recorded under a power line, and the same variations but recorded some distance away, where the magnetic field of the GIC has no effect). We will deploy several stations across the country, measuring GICs under different power lines during several weeks or months. We have already installed a couple of magnetometers under a 400 kV line close to Ebre observatory. To detect the GIC effects, we first found the orientation angles, the scale values and the bias fields by minimizing the vector of residuals from a least squares fit to the one-minute data recorded at both places during the quietest days. Then, we rotated those residuals to the directions parallel and perpendicular to the power line, and obtained the induced current from Biot-Savart law, according to the line wire-to-wire distance, their height and the distance of the magnetometer from them. Figure 1 displays the GIC signal obtained for one of the very few slightly disturbed days during the last season. It correlates reasonably well with that obtained with our model for the same line.

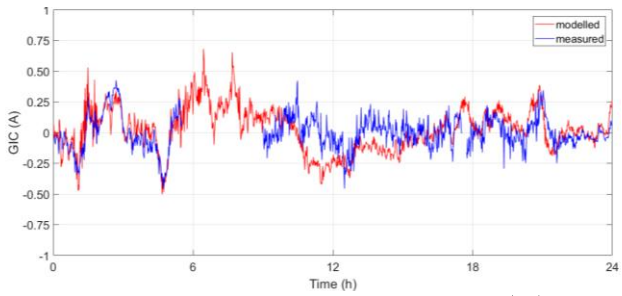

Figure 1: GIC measured and modelled signals obtained for 18/06/2018.

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Author:

J.M. Torta[1], S. Marsal[1], J.J. Curto[1], O. Cid[1], J. Ledo[2], A. Marcuello[2], P. Queralt[2], A. Martí[2], J. Campanyà[3]

1) Observatori de l'Ebre, (OE), CSIC - Univ. Ramon Llull, Roquetes, Spain

2) Institut Geomodels, Universitat de Barcelona, Barcelona, Spain

3) School of Physics, Trinity College Dublin, Ireland

Corresponding author:

Joan Miquel Torta

Observatori de l'Ebre

Horta Alta, 38, 43520 Roquetes, Spain

Tel.: +34 977500511

e-mail: jmtorta@obsebre.es

Effect of Space Weather observed in the Czech oil pipeline network

Pavel Hejda, Josef Pek

Buried pipelines are equipped with a cathodic protection system which keeps the pipeline at a negative potential of about 1 to 2 volts in relation to the ground, in order to prevent corrosion. The pipe to soil voltage is monitored at cathodic protection stations. As the pipelines are long electric conductors they respond to geomagnetically induced currents (GIC). The impact of geomagnetic disturbances on the pipe to soil (PtoS) voltage was studied, based on the data from 20 stations on the Czech pipelines recorded in the period 2005 – 2017. Whereas the signal of strong magnetic storms is quite pronounced in some stations, it was often overprinted by technical disturbances, like strange currents by DC supplied railways.

The strong effect of Halloween geomagnetic storms on the GIC in the Czech oil pipelines was demonstrated by Hejda & Bochníček (2005). In the present work we report a systematic study based on the data recorded in 20 stations on the Czech pipelines in the period 2005 – 2017.

The primary test was based on comparison of the PtoS voltage with the plane wave model of the geoelectric field. We assumed that large range of geoelectric field E should bear large range of PtoS voltage. Relation between daily maxima of hourly ranges of E and PtoS voltage was thus tested. However, the results showed significant relation only on 3 of 20 stations.

The test thus indicated that

- either the most parts of pipelines are insensitive to the changes of geomagnetic field
- or there are other stronger sources of disturbances of PtoS voltage.

To understand better this phenomenon, E and PtoS variation for the most disturbed days was inspected. The case of 17th March 2015 is presented below.

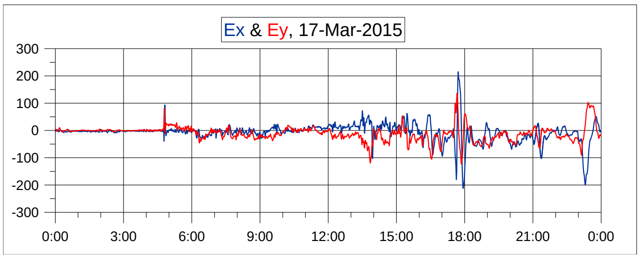

Figure 1: Plane wave model of horizontal components of geoelectric field based on the observations of geomagnetic field at Budkov Observatory on 17th March 2015

It showed out that the geomagnetic signal was mixed with technical disturbances. They include strange current generated by DC powered railways, industrial and urban noise, crossing with other pipelines, etc. The recorded PtoS voltage can be also influenced by the quality of pipeline coating. One must further take into account that the cathodic protection system works for recovering the original state (especially in case of changes towards positive PtoS voltage).

Two examples are shown. Station MLV29 is situated in a magnetically quiet place close to German boundary. Station M1604 is close to the DC supplied railway east of Prague. In this case the PtoS voltage monitors the traffic on the railway.

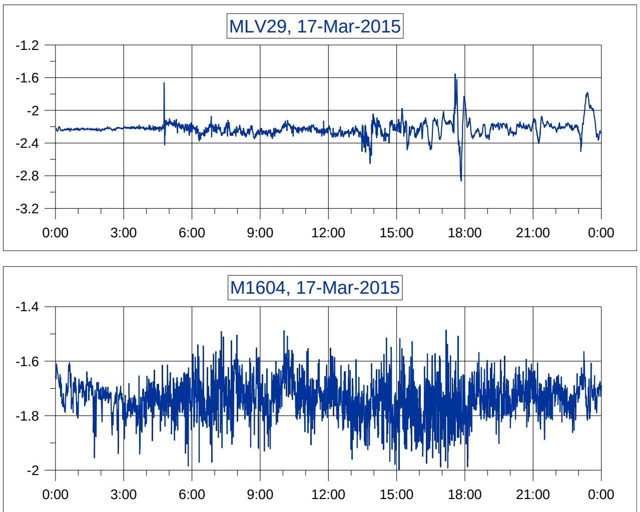

Figure 2: PtoS voltage recorded at stations MLV29 and M1604 on 17th March 2015

Acknowledgements:

The data of the PtoS voltage were released by courtesy of the join-stock company MERO ČR a.s., the data owner. This research was supported by the grant 17-19877S of the National Science Foundation of the Czech Republic.

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Authors:
P. Hejda, J. Pek
Institute of Geophysics, Czech Academy of Sciences, Prague, Czech Republic

Corresponding author:
Pavel Hejda
Institute of Geophysics, Czech Academy of Sciences
Bocni II/1401, Prague, 14100 Czech Republic
Tel.: +420 267103339
e-mail: ph@ig.cas.cz

Using magnetic observatory data to investigate the longitudinal and seasonal variability of the counter electrojet

Gabriel B. Soares, Yosuke Yamazaki, Jürgen Matzka, Katia Pinheiro, Atul Kulkarni, Akimasa Yoshikawa

The equatorial electrojet (EEJ) is an eastward ionospheric current system that occasionally reverses during morning and afternoon hours, leading to periods of westward current in the ionospheric E-region known as counter electrojet (CEJ). Here, we present the first analysis of CEJ based on an extensive ground-based dataset for the Brazilian sector (data from 2008 to 2018) and we compare it to the Peruvian, African, Indian and Philippine sectors.

Data from magnetic observatories placed near the magnetic equator can be used to study the equatorial electrojet (EEJ) and its reversal, the so-called counter electrojet (CEJ). The EEJ is an ionospheric current that flows eastwards at E-region heights within a narrow band of about 4° from the magnetic equator. It causes an enhancement of the normal daily Sq variations in the geomagnetic horizontal component H. The westward current during CEJ events can last for a few hours and causes a depression in the H values. One method to isolate the EEJ/CEJ signal from other external and internal sources of the geomagnetic field is by taking the difference of H measured at an equatorial station and at a low-latitude station with a similar longitude, but outside the influence of the EEJ (Stolle et al., 2008). Here, we consider only geomagnetically quiet periods (Kp <= 3o).

In this work we provide the longitudinal and seasonal variability of morning and afternoon CEJ events (MCEJ and ACEJ, respectively) by using geomagnetic data from the Peruvian sector: Huancayo observatory (HUA, INTERMAGNET) and Piura station (PIU, LISN network), the Brazilian sector: Tatuoca (TTB, Observatório Nacional) and Kourou (KOU, INTERMAGNET) observatories, the African sector: Samogossoni station (SAM, WAMNET network) and Tamanrasset observatory (TAM, INTERMAGNET), the Indian sector: Tirunelveli (TIR, WDC-Mumbai) and Alibag (ABG, INTERMAGNET) observatories, and the Asian sector: Davao (DAV, MAGDAS network) and Muntilupa (MUT, MAGDAS network) stations. All stations are shown in Figure 1, in addition to the position of the magnetic equator for different epochs. Figure 2 shows the total MCEJ and ACEJ occurrence rates for all longitude sectors. The white boxes with numbers represent the respective MCEJ (left) and ACEJ (right) occurrence rates. The CEJ longitudinal dependence is evident, with the highest rates observed for the Brazilian sector.

In addition, we found a CEJ dependence on solar flux and lunar phase in the Brazilian sector similar to that observed for the Peruvian sector. Concerning the CEJ climatology, Singh et al. (2018) indicated the ACEJ modulation by non-migrating tides. However, we performed simulations with the EEJM-2 and TIEGCM models (not shown here) which indicate that the longitudinal differences of both MCEJ and ACEJ climatologies found in our results are strongly related to the EEJ modulation by atmospheric winds (affected by both tidal non-migrating and migrating oscillations).

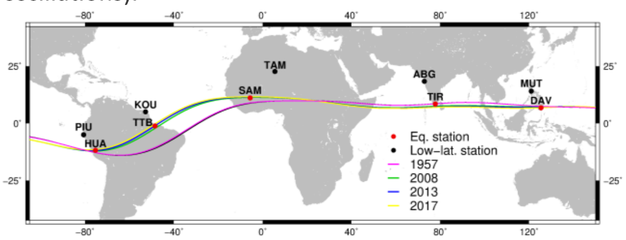

Figure 1: Location map of the equatorial and low-latitude magnetic observatories and stations used in this study. The magnetic equator lines for 1957, 2008, 2013, 2017 were calculated by using the IGRF-12 model.

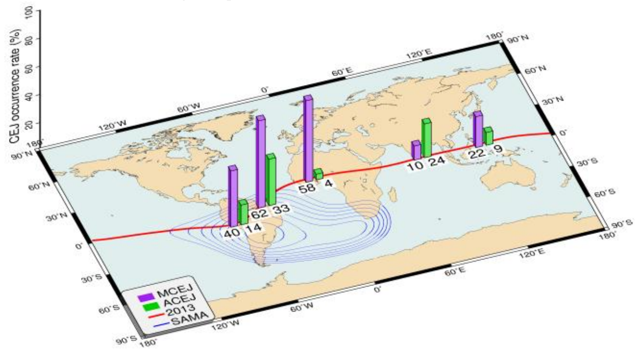

Figure 2: Total CEJ occurrence rates (in %) for MCEJ (purple) and ACEJ (green), for the Peruvian (HUA), Brazilian (TTB), African (SAM), Indian (TIR) and Philippine (DAV) sectors. Magnetic equator for 2013 is shown in red. SAMA (blue lines) contours are shown (inner contour: 23000 nT, outer contour: 30000 nT).

Lastly, we emphasize that a better understanding of the mechanisms that control the longitudinal difference of CEJ occurrences is important for further studies of the whole EEJ/CEJ system.

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Author:

G. B. Soares[1], Y. Yamazaki[2], J. Matzka[2], K. Pinheiro[1], A. Kulkarni[3], A. Yoshikawa[4]

(1) Geophysics Department, Observatório Nacional, 20921-400 Rio de Janeiro, Brazil. (2) GFZ German Research Centre for Geosciences, 14473 Potsdam, Germany. (3) Indian Institute of Geomagnetism, India. (4) International Center for Space Weather Science and Education, Kyushu University, Japan.

Corresponding author:

Gabriel B. Soares
Observatório Nacional
Rua General José Cristino 77, 20921-400, Rio de Janeiro, Brazil
Tel.: +55 (21) 986217908
e-mail: gabrielsoares@on.br

Solar flare effect of 6 September 2017. An analysis using Spherical Elementary Current Systems.

Juan José Curto, Santiago Marsal

For the first time, we analysed the temporal evolution of a Solar Flare Effect (Sfe) event, that of 6 September 2017, by using the technique of Spherical Elementary Current Systems (SECS). Thus we were able to follow the temporal evolution of the current system during the Sfe lifetime. At the beginning, a sharp increase in current intensities occurred driven by the hard X rays which at that moment were dominant. Then, a slow decay followed the advent of soft X and EUV rays. Sfe modelled current systems appeared abnormally displaced in longitude with respect to the subsolar point. During the whole event, both vortices remained static and no significant shift was detected. A clear prevalence of the northern hemisphere was observed although the event occurred during the equinox.

The Sun emitted two big solar flares on the morning of 6 Sept. 2017. The first one, classified as an X2.2 flare, peaked at 9:10 UT, while the second one was classified as X9.3 and peaked at 11:58 UT. This day, Ebre observatory and most European and American magnetic observatories detected two Sfe events due to their favourable location respect to the Sun (Figure 1).

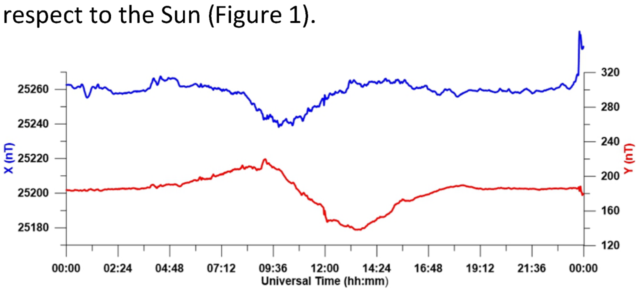

Figure 1: Magnetogram corresponding to Ebre magnetic station (41.0º N, 0.3º E) for 6 September 2017 showing X (true north component; blue line) and Y (east component; red line). In the Y component, an initial increase (eastward deflection) around 9:00 UT is followed by a subsequent decrease (westward deflection) around 12:00 UT.

The amplitude of the Sfe was found at each of these stations after removing the Sq field. This was obtained by linearly interpolating between the initial and the final Sfe time and was used as input for the SECS computation. SECS is an equivalent source method aimed at explaining the observed ground magnetic variations in terms of its current sources in the ionosphere and in the subsurface. The technique was developed by Amm and Viljanen (1999), modelling a current system from the superposition of elementary currents originating from a network of poles. Marsal et al. (2017) used this technique to map the polar current systems associated with a geomagnetic sudden commencement. In this work we applied this technique for the first time to analyse the temporal evolution of the Sfe event that happened at noon time. As a result, a sequence of snapshots covering the whole duration of the event was obtained. Figure 2 presents the snapshot corresponding to the moment of maximum.

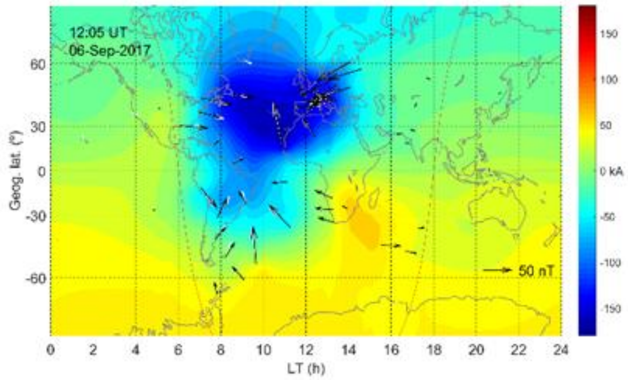

Figure 2: SECS-derived equivalent current system flowing at ionospheric heights at the moment of the maximum. Black arrows represent the measured Sfe field, while white arrows show the modelled Sfe field using the SECS technique. The dotted red line represents the terminator.

The most outstanding features revealed by this study were: a) Unlike other cases, the analysed current system was very static in time, the shape of the current vortices remained stable and their position did not shift substantially; b) The Sfe current system was found away from the subsolar point meridian, with a faint Southern focus noticeably shifted towards East; c) The Northern vortex was clearly dominant; it was slightly shifted towards west, and its area presented a certain eccentricity in the zonal direction.

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Author:
J. J. Curto[1] S. Marsal[1]
1) Observatori de l'Ebre, (OE) CSIC - URL, Roquetes, Spain.

Corresponding author:
Juan José Curto
Observatori de l'Ebre, (OE) CSIC-URL
C/ Horta Alta, 38, 43520 Roquetes, Spain
Tel.: +34 (1) 977500511
e-mail: jjcurto@obsebre.es

Tracing of a magnetic anomaly body

LIM, Mutaek[1*], PARK, Youngsue[1], JUNG, Hyunkey[1], SHIN, Younghong[1], RIM, Hyoungrea[2], and PARK, Changseok[1]

If we attach an attitude acquiring equipment to the common frame on which the magnetic sensor and the attitude acquiring equipment are installed, aligned to coincide with each other, then we can rotate the acquired three component magnetic field data around each of the three axes of the common frame's coordinate system with the amount of the acquired three attitudes, i. e. yaw, pitch, roll. The components data as the result of rotation are now the same as we can get when we have measured the invariant magnetic field data with the frame reoriented to coincide with the geographical coordinate system. We used quaternion multiplication or quaternion rotation to get the relation between two coordinate systems. Once we calculated that relation between each sensor's coordinate system and the geographical coordinate system we applied quaternion rotation to the time series data from each sensor (xn(t), yn(t), zn(t)) and we got the time series data for each sensor (nn(t), en(t), dn(t)) as if we measured on new coordinate system reoriented to the geographical coordinate system. We are now doing inversion processing with CGLS (conjugate gradient least squares) algorithm by using three component magnetic field data acquired on a sensor array composed of three fluxgate magnetometers and reoriented to geographical coordinate system. The expected result of inversion will give us the possibility to trace the position of a magnetic anomaly body along time with superiority of performance of three components magnetic field data to scalar magnetic field data.

The possibility to trace the position of a magnetic anomaly body along time is very useful. But till now the tracing have been done mainly by using only the scalar magnetic data because of the difficulty to acquire the attitude data of the sensor body frame's coordinate system. If we attach an attitude acquiring equipment to the common frame on which the three component magnetic sensor and that attitude acquiring equipment are installed, aligned to coincide with each other, then we can rotate the acquired three component magnetic field data around each of the three axes of the common frame's coordinate system with the amount of the acquired three attitudes, i. e. yaw, pitch, roll. The components data as the result of rotation will be the same as we can get when we have measured the invariant magnetic field data with the frame reoriented to coincide with the geographical coordinate system. We applied quaternion multiplication or quaternion rotation to get the relation between two coordinate systems.

We deployed a sensor array composed of three fluxgate magnetometers, irregularly positioned intentionally and got time series of magnetic field data for each sensor (xn(t), yn(t), zn(t)). Once we calculated that relation between each sensor's coordinate system and the geographical coordinate system by using quaternion rotation, we calculated the time series data for each sensor (nn(t), en(t), dn(t)). To get the necessary data for quaternion rotation we did a set of absolute magnetic measurement near the sensor array with the help of the continuous three components data of CYG (Cheongyang) Magnetic Observatory, one of IMO (InterMagnet Magnetic Observatory) Network.

We are doing inversion processing with CGLS (conjugate gradient least squares) algorithm by using three component magnetic field data acquired on a sensor array composed of three fluxgate magnetometers and reoriented to geographical coordinate system. The expected result of inversion will give us the possibility to trace the position of a magnetic anomaly body along time with superiority of performance of three components magnetic field data to scalar magnetic field data.

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Author:
LIM, Mutaek[1], PARK, Youngsue[1], JUNG, Hyunkey[1], SHIN, Younghong[1], RIM, Hyoungrea[2], and PARK, Changseok[1]
1) Korea Institute of Geoscience and Mineral Resources , Daejeon, Korea
2) Busan National University, Busan, Korea

Corresponding author:
LIM, Mutaek
Korea Institute of Geoscience and Mineral Resources , Daejeon, Korea
124, Gwahak-ro, Yuseong-gu, Daejeon, 1190 Vienna, Austria
Tel.: +82 42 868 3157
e-mail: limmt@kigam.re.kr

Rapid fluctuations of Earth's outer core - Towards a better detection with ground-based magnetic observations

Seiki Asari, Ingo Wardinski

We investigate detectability of the interannual fluctuations of Earth's fluid core motion without using recent satellite magnetic observations. From ground-based monthly mean data for 1957.0-2015.4 we develop a new magnetic model, C^{3}FM2.x, to be inverted for a core flow model. Fluctuations of the core angular momentum (CAM) associated with this "ground-based" flow model are then evaluated by comparing them to those based on "satellite" flow model derived from CHAOS-6.x2. Fluctuations of the length-of-day (LOD) predicted from the both models show comparable coherencies with the 6-year oscillation of the observed LOD. This implies that the phase of the rapid CAM fluctuations can be as well detectable even in the earlier times of C^{3}FM2.x as in the recent satellite era. We also discuss a need to optimise the magnetic model by improving the monthly dataset that significantly contain interannual signals from the magnetospheric sources.

Magnetic measurements by recent satellite missions have made it possible to reliably extract interannual fluctuations of the core magnetic field (~2 nT/yr at Earth surface). As a hypothesis to explain them, a presence of the 6-year torsional Alfvén waves has been suggested, which is supported as well by the corresponding oscillation in the LOD observation [1]. However, inferred waves depend crucially on models of the magnetic field variation employed [2].

We assess the use of ground-based magnetic models for detecting the tiny interannual core signals. A temporally continuous magnetic field model C^{3}FM2.x is developed that encompasses both the satellite era (1999-) and pre-satellite era. It is estimated with the same modelling method as for C^{3}FM2 [3] from an updated monthly dataset created by avaraging all hourly mean data from magnetic stations available for 1957.0-2015.4. The model is characterised by its temporal parametrisation with order 6 B-splines at 1.4-year interval, allowing a higher time variability than other pre-satellite magnetic models.

A core flow model is built from C^{3}FM2.x by imposing a weak quasi-geostrophy assumption [2]. Following [1,2,4], the CAM variation is then calculated and translated into a prediction of the LOD variation. Fig. 1 shows its time derivative in comparison with those predicted from recent satellite magnetic model CHAOS-6.x2 and calculated from the observation. The predictions are roughly in phase with the observed 6-year oscillation, and interestingly enough, seem correlated even after 2010, where the oscillation is irregular. The C^{3}FM2.x prediction also shows significant coherency with the interannual LOD observation in the pre-satellite era, as may be expected from its dataset distributed roughly evenly in time.

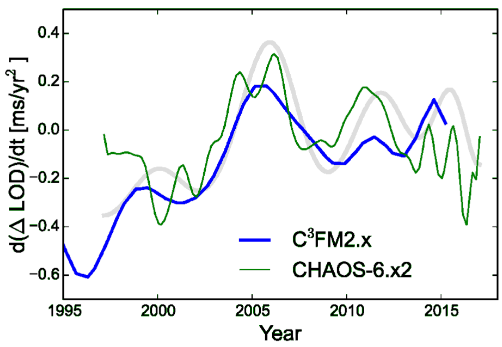

Figure 1: Time derivatives of the observed (gray) and predicted LOD fluctuations.

We note that ground-based magnetic models can still result in rapid CAM fluctuations agreeing relatively poorly with the observed LOD phase [4]. For a more precise detection, it would be necessarily to maximally eliminate interannual contributions of the magnetospheric currents, which we think still contaminate C^{3}FM2.x. A careful strategy for dataset cleaning should be implemented, for instance, by referring to the Dst index or its alternative indices [5].

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Author:
S. Asari[1] I. Wardinski[2]
1) Kakioka Magnetic Observatory, Japan Meteorological Agency, Ishioka, Japan
2) Laboratoire de Planétologie et Géodynamique, Université de Nantes, Nantes, France

Corresponding author:
Seiki Asari
Kakioka Magnetic Observatory
Kakioka 595, 315-0116 Ishioka, Japan
Tel.: +81 (299) 43 6721
e-mail: asari@kakioka-jma.go.jp

Wavelet spectral analysis of the ENIGMA magnetometer array time series and solar wind conditions around the strongest magnetic storms of solar cycle 24

Adamantia-Zoe Boutsi, Georgios Balasis

Magnetic storms are undoubtedly among the most important phenomena in space physics and also a central subject of space weather. Here we study the Earth's magnetic field time variations measured by ENIGMA for 2015, when the three strongest magnetic storms of solar cycle 24 occurred in March, June and December, along with the corresponding solar wind parameters and geomagnetic activity indices. We apply spectral analysis techniques based on wavelet transforms and calculate the Hurst exponent of these time series.

The HellENIc GeoMagnetic Array (ENIGMA) is a network of 4 ground-based magnetometer stations in the areas of Trikala, Attica, Lakonia and Lasithi in Greece that provides measurements for the study of geomagnetic pulsations, resulting from the solar wind - magnetosphere coupling. ENIGMA is a SuperMAG contributor that enables effective remote sensing of geospace dynamics and the study of space weather effects on the ground (i.e. Geomagnetically Induced Currents - GIC).

The wavelet transform identifies the temporal evolution of the signal's spectral content, i.e. various frequencies, and thus should in principle be capable of separating the various field source contributions. For the analysis we used the algorithm developed by Torrence and Compo (1998). The geomagnetic activity index used as a proxy is the SYM-H. The solar wind parameters were obtained from the OMNIweb database.

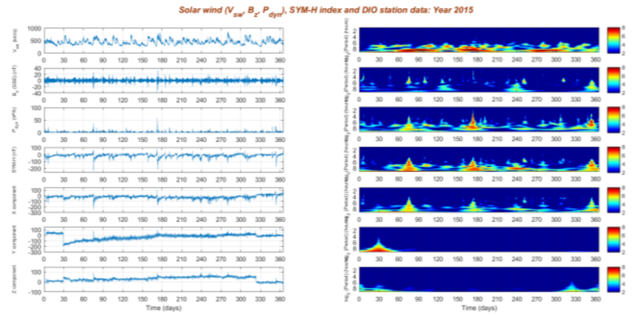

Figure 1: (From top to bottom) Depiction of the time series and respective wavelet power spectra of the solar wind parameters (Plasma Velocity, Dynamic Pressure, IMF's Bz component), the SYM-H index and the x, y and z components of the Earth's magnetic field as measured by the ENIGMA Dionysos (DIO) station.

The comparative Fig. 1 shows that the intensity of the three major storms of 2015 is clearly depicted in the SYM-H, Pdyn and the x-component of the Earth's magnetic field panels. The spectral analysis on the By and Bz components reveals a strong dependence on "steps" in the time series, for which special attention must be given.

Next, we calculate the Hurst exponent, H, for the time series presented in Fig. 1. We note that when 0<H<0.5 the time series has anti-persistent properties, which means that if the fluctuations increase with time, it is likely to decrease in the interval immediately following and vice versa. Physically, this implies that fluctuations tend to induce stability within the system (negative feedback mechanism). If H takes values in the interval (0.5 1) the signal exhibits persistent properties, which means that if the amplitude of the fluctuations increases with time, it is likely to continue increasing in the immediately next interval. Namely, the underlying dynamics is governed by a positive feedback mechanism [Balasis et al., 2006].

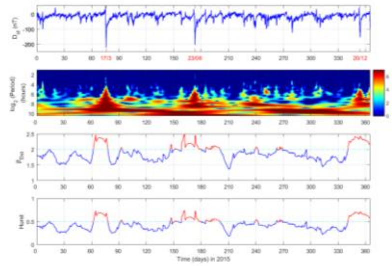

Figure 2: (From top to bottom) Depiction of the Dst index time series, its wavelet transform, the β exponent and the linearly correlated to it Hurst exponent. Blue color corresponds to values less than 0.5 and red color to values above 0.5.

In Fig. 2 we present the calculated Hurst values for the Dst geomagnetic activity index. Our results show the existence of two different patterns: (i) a pattern associated with the intense magnetic storms, which is characterized by higher Hurst values; (ii) a pattern associated with the quiet-time magnetosphere, which is characterized by lower Hurst values.

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Authors:
Z. Boutsi[1,2] G. Balasis[1]
1) Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, Greece
2) Section of Astrophysics, Astronomy and Mechanics, Department of Physics, National and Kapodistrian University of Athens, Greece

Corresponding author:
Zoe Boutsi
Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens
Metaxa & Vas. Pavlou, Penteli, 15236 Athens, Greece
Tel.: (+30) 210 8109183, e-mail: zboutsi@noa.gr

Magnetic field secular variations in Ukraine on the base of RS network observations

Valentyn Maksymchuk , Mykhajlo Orlyuk

Accordingly to results of geomagnetic observations on the Ukrainian RS the map of secular variations for 2005-2010 yrs. was plotted. Spatial structure is characterized by existence of anomalous zones, which are confined to active seismic areas of Ukraine.

Geomagnetic observations on the repeat stations (RS) network let us obtain information about absolute values of magnetic field components, which are the base for normal magnetic field maps plotting. At the same time repeat observations on the RS network allow us to obtain magnetic field secular variations (SV) data and information about their spatial structure. The area under study covers the entire territory of Ukraine that extends 18 degrees in EW direction and 8 degrees in NS direction, which cause a problem for normal geomagnetic field representation and its SV mapping is very actual for Ukraine.

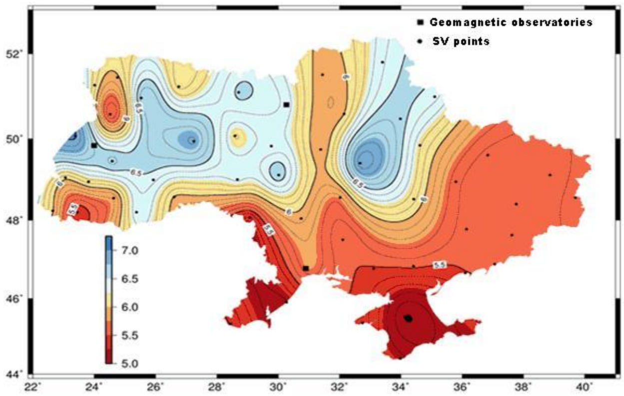

Figure 1: Map of secular variation of magnetic declination D (min/y) during 2005-2010 in Ukraine.

In 2018 SV network in Ukraine consists from 78 points (approximately 1 RS point in 8,000 sq.km). Additionally, three geomagnetic observatories (Kyiv, Lviv, Odesa) are located on the territory of Ukraine. Recent RS network was founded during 2003-2004 yrs. and the first cycle of observations was carried out. Repeat observations were done during 2010-2011 yrs. Those results were used as a base for maps of secular variations for X, Y, Z, F, D components for 2005-2011 years. Especially complex SV spatial structure in all magnetic field components was revealed.

Few anomalous zones of D (Fig.1) and F (Fig.2) SV morphology in Ukraine are defined. Minimum values of SV F field are obtained in Transcarpathians (28 nT/per year), Volyno-Podillya (30 nT/per year), Crimea Peninsula (30 nT/per year) (Fig.2). Central and Eastern parts of Ukraine are characterized by mosaic SV structure of F field with some isometric anomalies, supported only by one RS point.

Comparison of SV spatial structure, based on the RS points data and IGRF model shows essential differences. Deviation from IGRF model for F component was defined in active seismic regions of Carpathians and Crimea (-2-3 nT/per year), for Volyno-Podillya and Donbass (2-3 nT/per year). The same time close correlation of SV anomalies structure with anomalous magnetic field can be observed. It underlines that Earth's lithosphere sources have an impact into magnetic field SV.

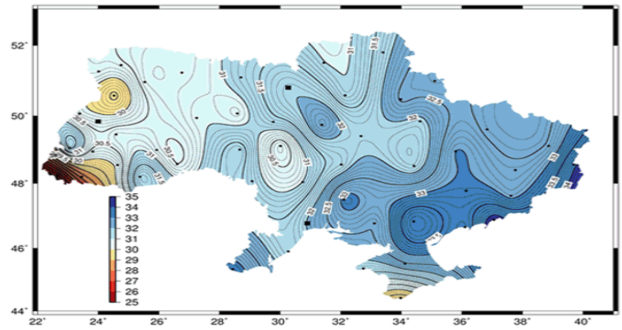

Figure 2: Map of secular variation of geomagnetic field F(nT/y) during за 2005-2010 in Ukraine

The next cycle of geomagnetic observations on the Ukrainian RS network is planned in 2019-2020 yrs.

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Author:

V.Maksymchuk [1] M.Orlyuk [2]

1)Carpathian Branch of S.I.Subbotin's Institute of Geophysics, NAS of Ukraine, Lviv, Ukraine

2) S.I.Subbotin's Institute of Geophysics, NAS of Ukraine, Kyiv, Ukraine

Corresponding author:

Valentyn Maksymchuk

Carpathian Branch of S.I.Subbotin's Institute of Geophysics, National Academy of Sciences of Ukraine, Lviv, Ukraine

Naukova 3-B, 79060 Lviv, Ukraine

Tel.: +38 (032) 264 8563

e-mail: vmaksymchuk@cb-igph.lviv.ua







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