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New Concepts in Geomagnetic Observatories Operation

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Abstract

Using the IAGA definition of a geomagnetic observatory and a wish list from geomagnetic data users, we look into new ways to fulfill these requirements using the new developments in absolute and variometric instrumentation. We try to project how future observatories will look like, especially considering the new automatic instruments which will soon be forthcoming.

1. Introduction

When looking for innovative ideas for Geomagnetic Observatories (GO), it is of course useful to ask the question: what is wanted from magnetic observatories? Part of the answer is to be delivered by the GO's data users and another part is to be found in the IAGA definition of a GO: "A Geomagnetic Observatory is a place where the geomagnetic vector has been observed for an extended period of time".

"Extended" in this context means at least one year, so that annual means of three independent components of the geomagnetic vector can be computed. Therefore one of the most important requirements for a GO is its ability to operate in the long term. Whereas this goal has been attained in many GO's, others have had trouble in maintaining the observations over an extended portion of time. It is therefore a logical way to go to investigate how this long life can be attained.

The IAGA mention of "place" in the GO definition has its importance too: it is to be chosen so that the GO's are evenly distributed on the globe. Some innovative concepts to solve this problem should be found based on new automated equipment and a rational approach in the collaboration with host countries where observatories are in need.

Additionally, it is clear that the user wants observations of good quality, without gaps in the time series. How can we innovatively attack the problem?

Last and independently of the IAGA definition, there is nowadays a user base interested in data sampled faster, up to 1/s.

2. User Driven new Geomagnetic Observatory Concepts

INTERMAGNET decided in 2003 at its Dourbes meeting to create a new recording standard based on a 1 second means data acquisition. The first requirements for such a geomagnetic data acquisition system were compiled during an INTERMAGNET survey investigating the needs of the scientific community using geomagnetic time series data (Love 2006). They are given in Table 1.

From the survey it appears that a timing accuracy of 0.01 s is required, so that a GPS or equivalent timing method must be used. The amplitude and phase response of the magnetometer must be carefully shaped and checked. The resolution should be not less than 0.01 nT. This list of requirements probably means that 1-minute means INTERMAGNET data acquisition systems cannot fit them: 16 bits ADC's have simply not the dynamic range. On the other hand, the 0.01 nT noise applies not only to the instrumentation but also to the site noise. This means that the deployment of 1 s INTERMAGNET systems is worth the effort only in GO sporting very low noise magnetic characteristics.

Some new prototype instruments are being developed right now for a sampling at 1 Hz. See the article "New INTERMAGNET Fluxgate Magnetometer" by Korepanov *et al*. in this issue for the first realization of a fast sampling variometer according to standards set by INTERMAGNET.

Table 1

1-second INTERMAGNET standards: results of survey

User	Data Resol [nT]	Data Accuracy	Filter Preferences	Time Accuracy	Time Position
Chulliat	0.001	NA	Gaussian digital	0.001 s	Centered on UT sec
Engebretson	0.1	NA		0.1 s	Centered on UT sec
Fraser	0.1	NA	Uniform phase	GPS	No preference
McPherron	0.01		Good phase	0.001 s	
Hughes	0.01-0.003	NA	Digital is ideal	0.05 s	Centered on UT sec
Moldwin	0.1	NA		0.001 s	Centered on UT sec
Masahito	> 0.1			0.1-0.01 s	
Waterman	0.01	NA	Digital	0.1-0.05 s	Centered on UT sec
Consensus	0.01	NA	Digital	0.01 s	Centered on UT sec

3. Data Quality

But fast data acquisition is not the only way for innovation. The quality of the recorded data is a primary concern for the observer and user. Good data is obtained through the agency of various factors like: low noise as produced by the instrument or the site environment, adequately monitored baseline changes, accurate timing, the absence of gaps in the time series, the absence of spikes, etc. Another item concerning data quality is global coverage. An observatory which fills a gap in the global coverage is improving the representation one can make of the geomagnetic field and is therefore decreasing the “noise” in the field picture. A good time series should also be available in the long term. Finally, nowadays good data also means that it should be rapidly and easily accessible.

4. New Concepts for Improving Observatories and Their Data

New concepts must try to find ways to improve:

- The global distribution of GO’s by looking into possibilities to provide more observatories where they are scarce: in developing countries and oceanic areas
- Promotion of long term operations by making GO’s more affordable. Therefore we must look into ways to provide operation with low cost in manpower, maintenance and processing. The setup of GO's with low sensitivity to cultural and industrial development and well protected against vandalism will also enhance the durability of a GO.

4.1 Global distribution: Focus on developing countries (DC)

It is important to realize that DC’s often provide very low noise sites (important for fast sampled data). Therefore, helping DC’s to improve and install geomagnetic observatories often leads to win-win situations: the target country will have good data, leading to better services to the socio-economic community (safe navigation using magnetic compass), while the worldwide scientific community will benefit from better global coverage and lower noise data. Training of observatory staff may also contribute to a reduction in the digital divide.

Experience and past failures have shown the importance of receiving full collaboration from the on site staff, and that careful planning is a must, even if it is sometimes difficult. As a rule we should try to maximize the use of existing infrastructure, especially real estate. In order to provide the normally expensive observatory equipment, older equipment, accurate but deemed obsolete can be refurbished, recalibrated and usefully redeployed without large funding. In general, there is no need to automate too much the observation procedures, as staff are often numerous.

4.2 Global distribution: Need for automatic observatories

As one of the main concerns is the installation of new observatories where they are missing, it will be necessary to automate GO’s so as to: permit operation in hardly accessible places, to reduce costs and to improve accuracy where qualified human observers are not forthcoming.

5. Different Approaches for Obtaining Automation of Observatories

5.1 Precise variometer set-up

Setting-up of a very precise variometer is an obvious approach to automate. An absolute measurement (non-automated) close to this variometer will determine once and for all (or very infrequently) its baselines and orientation.

By "very precise" we mean that the scale factor is known at the 0.1% or better level and that the orthogonality is OK or can be corrected for. We mean also that it is stable so that the long term drift is nil or linear, that it is temperature-insensitive and that the variometer is maintained in a fixed orientation (stable pillars). Last, the variometer should be installed in a clean geomagnetic environment.

There is a flaw however: there is no way to check if the baseline and orientation remains constant otherwise than by doing an absolute measurement.

An automatic observatory along these lines could be successful for careful installations of precise full-field variometers for which a correction matrix is known in a well protected environment and with baseline checks every year.

5.2 Automate DIflux

The idea is to robotize the full absolute measurement protocol: automate DIflux and Modulus measurements. A nearby variometer runs in parallel, also in automatic mode. Modulus automatic measurements are already a reality. DIflux measurements are hard to implement in an automatic way because of the following difficult tasks:

- realize nonmagnetic robotic action for moving the fluxgate over 360° around both vertical and horizontal axes as well as fine positioning in any orientation,
- realize non-magnetic digital angle measurement,
- realize automatic target sightings or equivalent.

Early attempts to automate the DIflux in our lab started in the late 1980′ies with the design of several prototypes: The first proto used a motorized custom theodolite with digital encoders and with removable telescope. This early device allowed to validate the idea and to establish that a basic accuracy at the 3 second of arc level or better was possible. A second prototype was built in the 1990′ies: it was a modified nonmagnetic Ruska theodolite with digital encoders but was not motorized. This device was demonstrated in the Uppsala IAGA assembly in 1997 and participated in the geomagnetic instrument intercomparison workshop in Huancayo, Peru (Veliz Castillo and Rasson 1998). Both those instruments allowed the Automatic Diflux concept to mature and the motto became: keep it simple! Therefore, the following concepts were introduced:

- Realization that the telescope can be removed altogether;
- Use laser instead of telescope. Magnetic parts in laser would have no effect on accuracy (Gilbert and Rasson 1998);
- Alternatively, a sunshot can be performed also in automatic mode using a simple sensitive optical device using a split photoelectric cell. This does

away with the need for a far away target. Using this automatic device and a reduction using UT1 instead of UTC allows an accuracy of the azimuth determination by sunshot at the level of 1 second of arc or better;

- Use of piezoelectric motors (with high quality ceramic bearings). They have no noticeable magnetic signature in the idle or rotating state. Moreover, they have an high holding torque when idle;
- The rotating load is so small that the motor bearings double as theodolite axis bearings;
- Dual encoders at 180° ensure high angular accuracy.

In the early 2000′ies, work on a third prototype was initiated along those new concepts. A working model has been presented in this workshop in the absolute house of Belsk observatory. Please refer to the paper “Presentation of the Prototype of an Automated DIFlux” by van Loo and Rasson in this volume for technical details on this device.

6. Designing the Future Geomagnetic Observatories

6.1 Future GO’s should be built to last

The future design of magnetic observatories, as they are to last for the longest possible time, should therefore take into account:

- avoidance of cultural noise, present and future:
  - Direct field perturbations like those caused by magnetic objects (cars on nearby road, effect of magnets in appliances),
  - Ground current effects. DC ground currents are able to travel on long distances and the effects are extremely difficult to foresee and to protect against. They are surely associated with railway lines, faulty mains connections and power stations.
- Limited funding available. The interruption of the GO funding is a frequent reason for stopping the operation of an observatory. Therefore, low operation costs are a basic way to maintain long term funding.
- Possibility of vandalism, robbery. As the future GO may very well be an unattended estate, the possibilities of these kinds of unpleasant actions are very likely. Many observatories have been broken into in the past, and the effects are almost always catastrophic: damage or destruction of the geomagnetic instruments, buildings left with open access. The cost and time and data loss is often huge as replacement of the equipment is difficult: the repair team often lives in another continent.

Some ways to discourage vandalism are:

- Make the GO difficult to access and to break into.
- Make it look very dull, uninteresting and worthless.

6.2 *So how will they look like?*

We try to foresee how the future GO will look in our opinion. The traditional separation between variometric and absolute instruments will be upheld. Continuously recording XYZ Variometer and PPM will be deployed in an “install and forget” approach. An automatic Diflux will be operating as a companion.

The traditional threesome of observatory buildings will be replaced by a single column like building (see Fig. 1) featuring small chambers where the automatic equipment is set-up. The top is equipped with a radome wherein the automatic Diflux is installed. This provides convenient access for the Diflux to the sunrays as it sits above the treetop level. The lower part of the column has a small room for the data acquisition, power and communications equipment. The height for the structure is tentatively set at 30 m. This kind of facility, which could be made of nonmagnetically armed concrete, should be affordable. A piece of land not bigger than 40×40 m should be sufficient to host it.

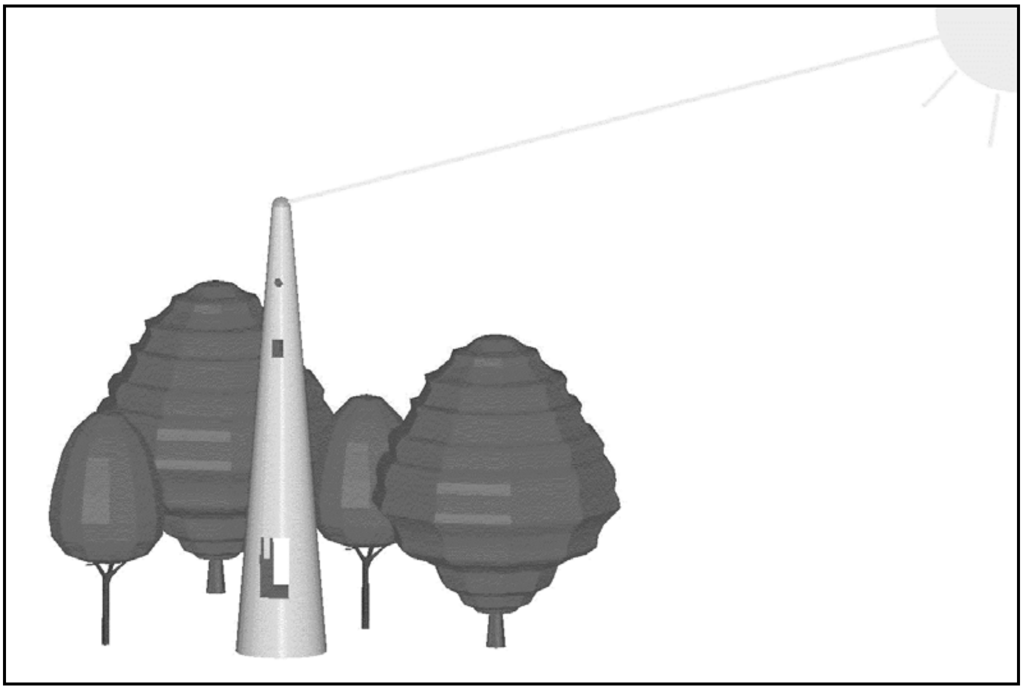

Fig. 1. How could a future geomagnetic observatory look like? This picture shows several concepts for an unattended GO: An automatic DIflux is installed on top of the pillar like structure and gets its orientation from sightings on the sun. Directly below a PPM and an XYZ variometer are operating in an “install and forget” configuration. The elevated position protects against unauthorized access, allows unobstructed reception of the sunrays and may attenuate perturbations originating in ground currents.

For finding the North Geographic reference direction it will use a sunshot with GPS timing (corrected to UT1 for accuracy) instead of usual target. The elevated position will also render the measurements less susceptible to contamination by cultural noise. It will moreover render unauthorized access difficult preventing vandalism and break-in. The high pillar structure will be equipped with continuous 2 axis tilt monitoring. Data access will be via web interface.

6.3 How will sea-bottom magnetic observatories look like?

One notable difference with a surface observatory is the inability to use astronomical or GNSS fixes to get the True North and time: At 4000 m water depth an observer cannot use sunshots or GPS because the salt water column will let no electromagnetic waves through. Therefore the only way we know of to find True North is to use a so-called gyroscopic North Seeker. Here a gyroscopic device sensing the Earth's rotation and oriented by the pull of gravity will have its rapid rotation axis precess around the True North direction. Existing commercial North seekers are reasonably non-magnetic and have a North pointing accuracy of about 20 second of arc if suitable precautions are taken and enough observation time is allowed for.

Therefore sea-bottom GO's must be completely automatic, they will use automatic Diflux combined with a North Seeker (gyrotheodolite). There is also the possibility to merge the Diflux and DI variometer by having two orthogonal fluxgate operating on the Diflux (Chave *et al*. 1995).

7. Conclusions

New concepts for magnetic observatories will allow improved world coverage of the observations by:

- Rational approach to instrumentation, management and funding in Developing Countries,
- Introduction of fully automated observations where necessary by way of:
  - Automated Diflux and other equipments,
  - Ultra stable variometers in well protected environments.

Automation of Declination/Inclination measurement brings a new concept in magnetic observatories and will solve the challenge of sea-floor magnetic observatories.

User driven development of fast data acquisition leads to renew the concepts for fast sampling variometers.

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