DI3 – A NEW PROCEDURE FOR ABSOLUTE DIRECTIONAL MEASUREMENTS

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ABSTRACT

The standard observatory procedure for determining a geomagnetic field's declination and inclination absolutely is the DI-flux measurement. The instrument consists of a non-magnetic theodolite equipped with a single-axis fluxgate magnetometer. Additionally, a scalar magnetometer is needed to provide all three components of the field. Using only 12 measurement steps, all systematic errors can be accounted for, but if only one of the readings is wrong, the whole measurement has to be rejected. We use a three-component sensor on top of the theodolites telescope. By performing more measurement steps, we gain much better control of the whole procedure: As the magnetometer can be fully calibrated by rotating about two independent directions, every combined reading of magnetometer output and theodolite angles provides the absolute field vector. We predefined a set of angle positions that the observer has to try to achieve. To further simplify the measurement procedure, the observer is guided by a pocket pc, in which he has only to confirm the theodolite position. The magnetic field is then stored automatically, together with the horizontal and vertical angles. The DI3 measurement is periodically performed at the Niemegk Observatory, allowing for a direct comparison with the traditional measurements.

Keywords: Absolute measurements, Magnetometer

1 INTRODUCTION

Presently, in most geomagnetic observatories, absolute directional measurements are conducted by means of a DI-flux magnetometer. Developed by Kring Lauridsen in 1985, this instrument, consisting of a non-magnetic theodolite equipped with a single-axis fluxgate magnetometer, allows for the determination of the field's declination and inclination while all possible error sources are cancelled out by the measurement procedure (Kring Lauridsen, 1985). Furthermore, the procedure allows calculation of the sensor offset and misalignment at the same time, which is valuable in controlling its stability (Matzka & Hansen, 2007).

Nonetheless, this well-tested, broadly employed technique has several disadvantages. First and maybe most important, all sets of measured angles, timestamps, and magnetometer readings are required to calculate the field's declination and inclination. If only one reading is erroneous, the whole measurement becomes useless and has to be performed again. Second, the procedure is very sensitive to the skill of the observer. This can become problematic if the absolute measurement is conducted by a lay person in a remote observatory where the staff is instructed only seldomly and is not aware of its contribution to reliable magnetic field data. An observer at a 'mother' observatory, who is responsible for the data processing, must frequently completely dismiss a measurement and thus put up with gaps in the base line determination. Finally, the procedure as it was invented a quarter of a century ago is no longer up-to-date: It is more desirable to record the data in a digital format directly instead of filling a measurement protocol by hand and then typing all readings into a computer.

With our DI3 technique, we address all those drawbacks and meet the challenge to improve the traditional method. For this purpose, we equipped a theodolite with a vector instead of a single axis sensor. It is obvious that the increased information from a three component magnetometer must have an advantage when compared to that of a one component instrument. The main benefits have been presented in Hemshorn et al. (2009a). In addition, we linked the magnetometer via Bluetooth to a commercial hand held computer that guided through the adjusted measurement procedure and collected and stored all data digitally including angle readings,

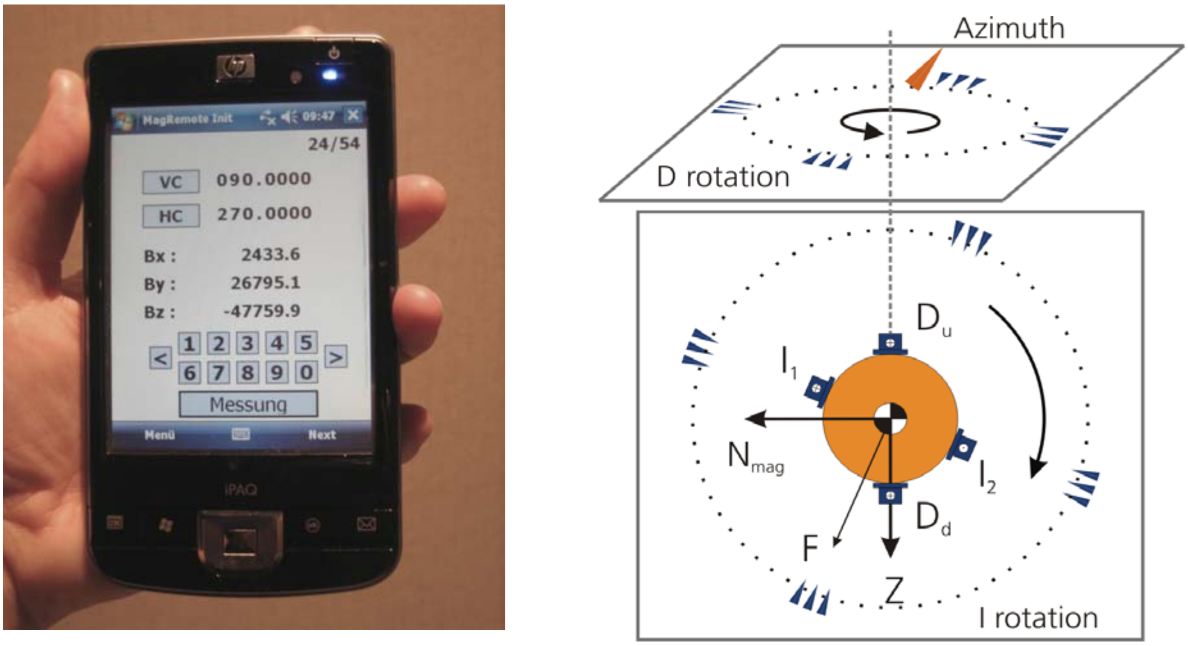

Figure 1. The PDA guiding through the measurement procedure (left) and a schematic illustration of the measurement positions (right)

magnetometer outputs, and timestamps.

In this paper, we first present the components necessary for setting up a DI3 instrument and explain the suggested measurement procedure. The data processing steps are given afterwards together with exemplary results obtained from measurements at the Niemegk Observatory and during the IAGA workshop in Changchun. At the end, we summarize our experiences and conclude with some remarks about possible future improvements.

2 COMPONENTS AND PROCEDURE

We relied on a high-accuracy non-magnetic theodolite as used in the standard DI-flux method, in our case a Zeiss 020B. A vector fluxgate sensor was mounted on top of the telescope. Experiences with that type of 3D magnetometers for absolute measurement have already been gained with our automated system GAUSS, which has been continuously measuring for more than two years in Niemegk. This sensor has a range of +/- 50000 nT and is highly linear. In our case, this is a strong requirement since all three magnetometer axes are turned around in the full Earth field.

A personal digital assistant (PDA) guides the observer through the measurement and permits the direct digitisation of all data. We decided on a Hewlett and Packard iPAQ 214 that offers a Bluetooth port to connect to the magnetometer. The operating system Windows mobile offers the possibility to run custom-written programs. With the Microsoft developer tool kit[1], C# routines can be written and compiled. Both magnetometer and PDA can be run on batteries lasting for more than three procedures after charging.

Considering the procedure, we favoured a more symmetric version than the one presented in Hemshorn et al. (2009a). We start by pointing the azimuth mark with sensor up and down (positions 1 and 2). In both positions, the exact horizontal angle towards the mark and the arbitrary vertical angle of the theodolite position are read and typed into the PDA. The vertical angle is recorded here because the magnetometer output is also stored for increased redundancy in the magnetic field determination together with the angles at the simple push of a

1 See: http://msdn.microsoft.com/en-us/library/bb158496.aspx

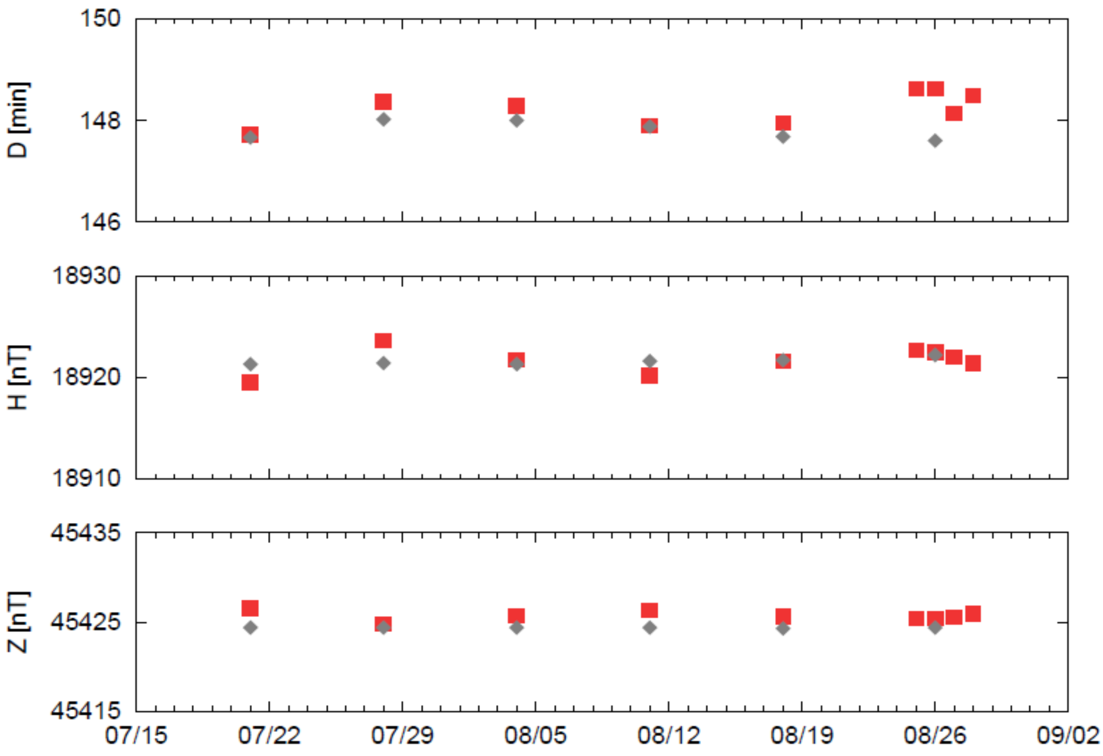

Figure 2. Baseline from the Niemegk Observatory. Red squares show baseline values obtained from DI3 measurements; the black line is derived from standard DI-flux measurements.

button. For the next steps, the telescope is set exactly horizontal with the sensor below the telescope (vertical circle VC=90°), and measurements are taken at 12 different positions as marked in Figure 1. The observer only has to set the theodolite's angles as they are dictated by the PDA and push the button. As for the traditional method, the same is repeated with the sensor above the telescope. Then a second azimuth pointing is done, again also recording the arbitrary horizontal angle and magnetometer output. Similarly to the traditional method, the horizontal angle is then fixed, and the inclination rotation is performed (2x12 settings with opposite horizontal angle). We have prescribed a horizontal circle position close to the magnetic field direction, similar to the positions used in the traditional method, but the DI3 method works with a vertical rotation about any arbitrary horizontal setting of the instrument. The procedure ends with a third azimuth pointing so that we have measurements in 54 positions (2+ 2x12 +2 +2x12+2) where each data line consists of a time stamp, the theodolite's horizontal and vertical angle, and the three magnetic components.

Altogether, this procedure takes about 30 min, which is less than twice as long as the standard one, but it provides much higher redundancy in a user-friendly absolute measurement.

3 DATA PROCESSING AND FIRST RESULTS

One of our aims is to shift some of the complexity from the observer to the data processing. Hence, several calculation steps are required to obtain the final set of 54 absolute measurements from the initial data set.

We start with the scalar calibration of the sensor. With the help of additional scalar data, e.g., from the observatories' Overhauser instrument, the vector magnetometer can be fully calibrated including the determination of the sensor non-orthogonality, scale values and offsets (cf. Auster et al., 2002). The next step is the calculation of the sensor misalignment angles with the help of equations 2 and 3 from Hemshorn et al. (2009b). These angles are used to rotate the magnetic field values into a coordinate system aligned with the telescope axis. Exploiting the theodolite's angle readings and the known azimuth value, we can rotate the whole measurement set towards the geographic reference frame. Taking into account the field variation, the 54 absolute vector measurements are reduced to the starting time, and the final base line results are obtained as averages of all 54 values. The standard deviation of these averages illustrates the quality of the measurement. In case individual erroneous readings occurred, e.g., if the theodolite was not set exactly to one of the angles prescribed by our protocol, those can be identified as clear outliers and can then be ignored in the averaging. We have developed an Excel sheet for the data processing, which is available on request.

Using this procedure, we conducted a test series from July 2010 to September 2010 at the Niemegk Observatory. The comparison of the results to the standard observatory baseline is shown in Figure 2. We obtained very good agreement with most of the DI measurements, with only some deviation in the declination measurements, before leaving for the IAGA workshop in Changchun.

During the measurement session during the workshop, we benefited from four measurement slots. The results published by Wang (2011, this issue), show that our instrument can easily compete with the standard method.

4 CONCLUSION AND OUTLOOK

We have shown that the presented DI3 system consisting of a theodolite equipped with a three-component magnetometer and completed with a commercial PDA is useful to perform enhanced, reliable absolute magnetic measurements.

The first measurement series at Niemegk has shown the feasibility and the comparison measurements in Changchun the competitiveness of the method. The large number of 54 discrete absolute measurements per procedure is the main advantage. It allows rejection of single erroneous measurements and hence reduces the demands on the observer. Even if some of the measurement readings are clearly wrong, reliable absolute results may still be obtained by a remote specialist doing the data processing by simply rejecting data rows with outlying values. Furthermore, the high number of absolutes permits calculation of the standard deviation of the result, giving an insight in the reliability of the result. As all steps are guided by the PDA, measurements can easily be handled by non-professional observers.

Test series are planned to investigate the sensitivity of the procedure to systematic errors, such as bad levelling or existing field gradients. We expect that the DI3 procedure can significantly facilitate baseline control and improve data quality for remote geomagnetic observatories where observations are done by lay persons and data processing is done remotely.

Figure 3. Presentation of the instrument during the IAGA workshop in Changchun.

5 ACKNOWLEDGEMENTS

We would like to thank our Chinese colleagues who provided all necessary data and assistance for baseline calculation at the Changchun Observatory. The theodolite that we used was on loan from our Danish colleagues. The regular measurements of Martin Fredow and Katrin Tornow at the Niemegk Observatory are greatly acknowledged. Oliver Bronkalla provided scripts and help for easy variation reduction and baseline comparison at Niemegk.

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