DI3: DI-Flux measurements with a three-component fluxgate

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Abstract

DI-Flux instruments, used for absolutely determining the Earth's magnetic field components, consist of a non-magnetic theodolite usually equipped with a single-axis fluxgate sensor.
Because of recent space missions, three-component fluxgate sensors are small enough to fit on the telescope of a theodolite and can measure the Earth's magnetic field with an adequate linearity. One can presume that the additional magnetic information should contribute to an improved measurement result.
Performing the standard procedure of declination and inclination readings in the four possible orientations of the sensor allows one to calibrate and align the fluxgate sensor completely. Transformed into the theodolite coordinate system, each set of magnetic field and angle readings provides the complete field vector in the geographic reference system, which leads to a welcome redundancy. With this redundancy, random errors can be minimised, and systematic effects can be separated during data processing. This should ease some of the difficulties of precision in the measurement procedure with a one-component sensor. Such a simplification of absolute measurements is highly desirable for observatories without permanent, well-trained staff where laypersons perform the observations.

Instrumentation and Procedure

We mounted a vector-compensated fluxgate sensor, provided by TU Braunschweig controlled by a Magson digital fluxgate electronics on top of a Zeiss 020B theodolite (see Figure 1), and performed a measurement procedure similar to the traditional one. Without exploiting the angle readings, we can

Figure 1: Zeiss theodolite equipped with a three-component fluxgate magnetometer.

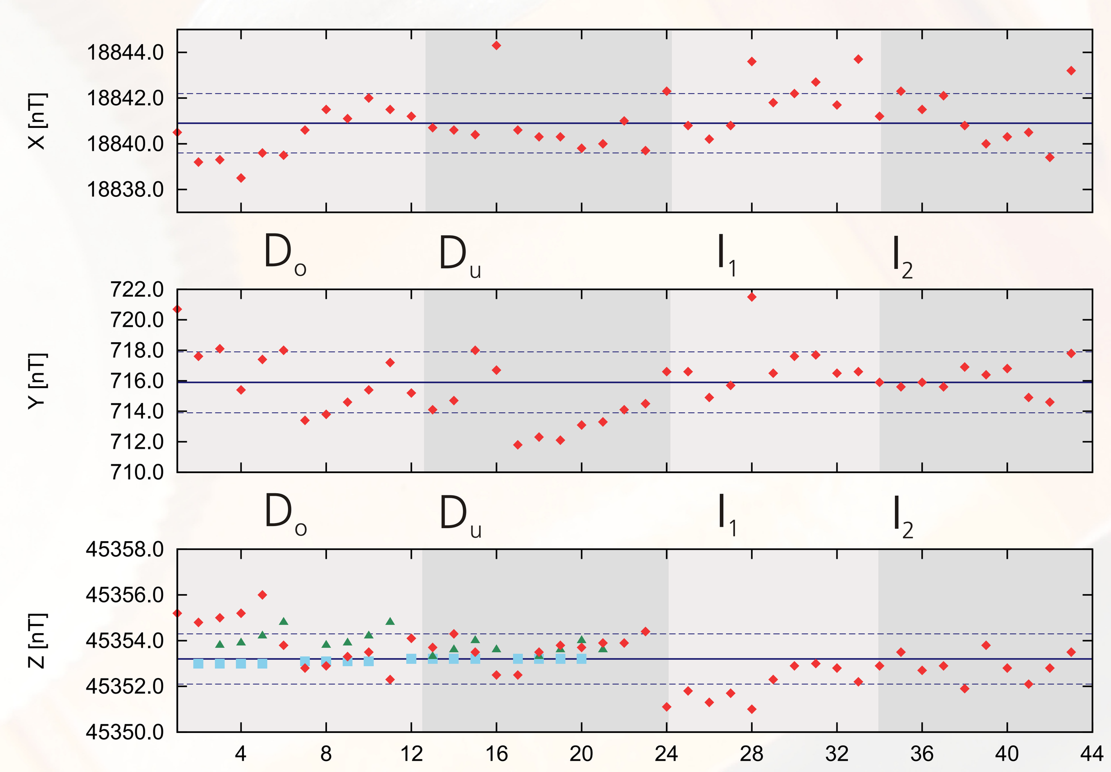
- Calibrate the sensor completely (i.e. determine offsets, scale values and orthogonality) by turning it about two independent axes (cf. Auster et al (2002)).
- Calculate the field along the direction of rotation by using three measurement positions.
- Derive the rotation matrix to transform the magnetometer readings into the coordinate system defined by the theodolite by aligning one magnetometer axis (Z for D-rotation and X for I rotation) with the rotation axis.

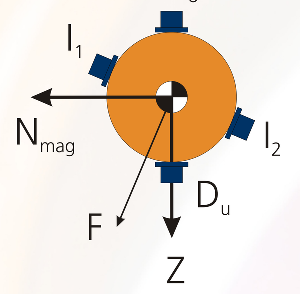
Thus, every single measurement position (comprised of angle readings and magnetometer outputs) becomes an absolute measurement. Measurements can be taken at arbitrary angle combinations. The observer does not have to search the angle where the sensor is perpendicular to the field but can move to discrete, simple angles.
We agreed on a procedure for measuring at the field at azimuth mark direction before and after D rotation, at 4 subsequent positions (0.05 gon steps) close to the telescope orientations perpendicular to F, and at one angle between these positions (altogether 44 readings). Other procedures are possible and can be optimised with regard to the local field conditions and observers' preferences.

Advantages

The use of a three-component magnetometer for a standard DI measurement has numerous advantages:

1. The large number of absolute measurements during one sequence can help reduce random measurement errors (e.g., angle reading errors). Figure 2 shows the result for all three components derived from one measurement procedure where variation reduction is already included. When a Zeiss 020B the standard deviation of the measurement set varies between 1nT and 5nT. By increasing number of measurements per sequence, the confidence for the mean value increases. Performing a standard DI-Flux procedure, in contrast, causes random errors to accumulate because each reading is necessary to calculate D and I.





Measurement results	Inclination of sensor towards telescope
X_{mean} = 18840.9nT ±1.3nT	0.504° about X
Y_{mean} = 715.9nT ± 2.0nT	-0.008° about Y
Z_{mean} = 45353.2nT ± 1.1nT	0.602° about Z

Calibration Parameters

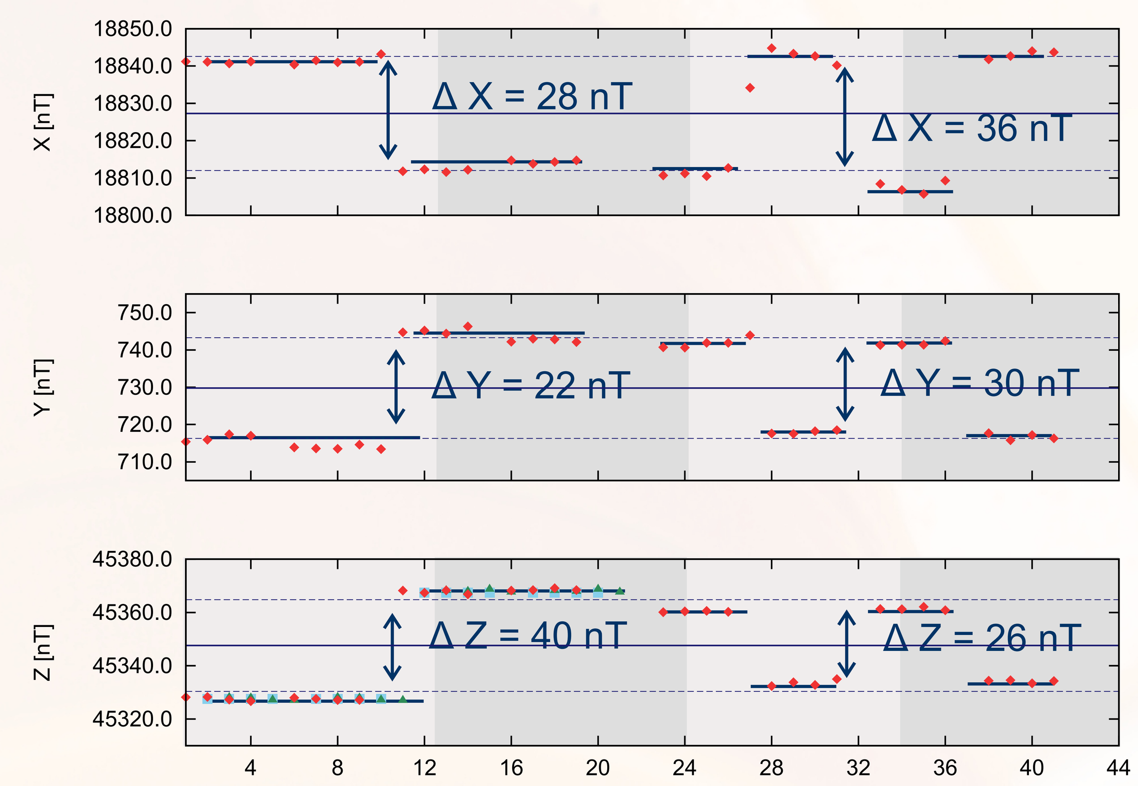
Offset	Scale Value	Orthogonality
-0.9 nT	0.99988	-0.007235
-1 nT	0.99988	0.003904
-2.8 nT	0.999833	0.007868

Figure 2: Results of all 44 absolute measurements during one sequence (shown in red) performed on May 22, 2008. Blue and green triangles indicate the Z component calculated from the rotation about the vertical axis. The solid lines indicate the mean value, dashed lines the standard deviation. The background color represents the measurement steps: declination with sensor up and down (D_u, D_d) and inclination (I_1, I_2) readings.

2. Fatal errors like typos of angle readings can easily be detected, and those measurement points can be removed without losing the absolute measurement. This makes the procedure less vulnerable to errors of less trained observers.

Figure 3: An artificial field gradient has been applied on the sensor position using a Helmholtz system where both coils are connected serially in identical direction.

3. Systematic errors, such as field gradients between upper and lower sensor positions, can be separated by the DI3 method. With the standard DI-Flux method field gradients in only one direction can be discovered. To prove this, we took measurements with additional artificial field gradients (see below). Perturbing field gradients can be easily detected.



	Δ X	Δ Y	Δ Z
D_o D_u	± 14 nT	± 11 nT	± 20 nT
I_1 I_2	± 18 nT	± 15 nT	± 13 nT

Figure 4: Results of all 44 absolute measurements with applied disturbing field. Differences between different measurement positions (sensor on top or below; sensor further to the north or south) can clearly be seen in every component.

4. Preferred angle adjustments can be determined after the azimuth mark reading automatically because the approximate orientation between the pillar / azimuth mark system and the magnetic field vector is fixed. Therefore, measurement angles can be predicted by the sequence control automatically for each pillar. This is a further step to make the measurement more error tolerant.

5. Finally, with implementing a 3D fluxgate sensor we offer no disadvantage to observers who prefer the traditional method. By using only one axis, the DI flux method can be applied as usual.

Conclusions

Using a three-component instead of a single-axis sensor increases the redundancy and thus the accuracy of a DI-fluxgate measurement. Systematic errors can be detected. Wrong values can be dropped and random errors can be minimised with increasing number of angle readings.
The requirements on the observer are relaxed: Time, magnetometer output and variometer readings are recorded automatically. Angle readings are only necessary at discrete (rounded) angles.
The requirements on the theodolite quality can be relaxed as well. Measurements with Zeiss 020B theodolites equipped with a 3D fluxgate sensor are competitive.

Acknowledgments

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