

Author's final response

Answers to comments of H.-U. Auster:

Comment 1:

Please add a more specific test checking the precision of the angular readings. One option could be that you measure the field component for arbitrary angular settings (within the fluxgate range of +/-3000nT) and compare it with the nominal field component calculated for the angles. The field vector should be known in an observatory at any time, and the setup parameter (orientation vs. azimuth mark, fluxgate offset, fluxgate orientation) are known from at least one absolute measurement with the DS-1 system.

Author's response:

Not exactly the proposed check was carried out but absolute measurement using the inverse method proposed by (Brunke and Matzka, 2017), where the readings were taken in different telescope position and results were similar to the results got using the conventional method. This suggests that there is no problem with the angular precision. Anyway a detailed angular reading precision test is in preparation.

Author's changes in manuscript:

At page 7 line 17 the "[We also plan to check the instrument according to the ISO 17123-3 standard. \(ISO 17123-3:2001\)](#)" sentence was inserted.

Comment 2:

Reducing the influence of the nearby electronics (including battery and RF unit) to a level below 1nT is a remarkable achievement. For more confidence, results of a magnetic characterization of the electronics should be added which should includes remanent and induced (electronics might contain soft magnetic material) contributions as well as the effect of perm and deperm.

Author's response:

The electronics box have remanent magnetization which is less than 20 nT in total from 1 cm distance. However the electronics is mounted on the telescope, and therefore its effect is canceled out. We have not tested yet the induced magnetism of the electronic box. Our one day test suggests its effect could be small if there is any. Perm and deperm procedure was not carried out.

Author's changes in manuscript:

At page 3 line 5 the “Owing to this design the ~~small (< 1 nT)~~ magnetic effect of the ~~of the~~ printed circuit board ~~and battery~~ in the electronic box is cancelled by measurements taken in four positions, because it rotates with the telescope - (Gilbert and Rasson, 1998). ~~We suppose that the box has not any induced magnetism however it was not tested yet.~~” sentences were augmented and revised.

Comment 3:

Using the single component fluxgate sensor for absolute measurements by the residual method with larger deviations from zero crossing (as indicated in Figure 2) the author should mention how he eliminates non linearity errors and scale values uncertainties because only offset and alignment errors are vanished by the DI-Flux measurement procedure.

Author's response:

The single component FluxSet sensor is linear inside its operating range. On (new) Figure 2 we can see that the FluxSet magnetometer is linear inside the +/-3000 nT operation range and the maximum difference of observations is 3.2nT from the calculated line, while the PPM reading variations were maximum 2 nT during the measurements. Every DS-1 instrument's scale factor is determined and stored in its non volatile memory. This value has to be checked from time to time.

Author's changes in manuscript:

A (new) Figure 2 was added, with its caption text. At page 3 line 2 the “~~In this range the magnetometer is linear as it is shown on Figure 2.~~” sentence was inserted.

Answers to comments of A. Gonsette:

Comment 1:

Chapter 2 is a little light. In particular, authors do not give any information about the modified theodolite performances. The angular accuracy according to a specific norm (e.g. ISO 17-123) is not given.

Author's response:

The ISO 17123 specific norm is not yet available for us. It is under purchase. When we will have, then the angular accuracy measurement will be performed accordingly.

Author's changes in manuscript:

At page 7 line 17 the "We also plan to check the instrument according to the ISO 17123-3 standard. (ISO 17123-3:2001)" sentence was inserted.

Comment 2:

The pendulum has been modified in order to host the V-circle reading head. What is the effect on the tilt compensation?

Author's response:

The tilt compensation was checked and the modification had no any effect on it.

Author's changes in manuscript:

At page 2 line 7 the "This modification has not any influence on the smooth operation of the pendulum, which was proved experimentally." sentence was inserted.

Comment 3:

Does the temperature have an impact on the angle reading?

Author's response:

There is in a built in temperature sensor to monitor temperature changes but we did not experienced any temperature effect on the angle reading.

Author's changes in manuscript:

There was no change added.

Comment 4:

The FluxSet sensor remains somehow exotic for the magnetic observatory community. Authors have mentioned it in the title and should therefore spend little energy for a (short) description. What is the difference between a FluxSet and a more conventional Fluxgate?

Author's response:

Chapter 2 was revised and a short description of the FluxSet magnetometer was added.

Author's changes in manuscript:

At page 2 line 9 the " The DS-1 instrument is built with FluxSet magnetometer. Its operating principle is similar to the pulse-position type fluxgate magnetometer. Practical advantage of these

magnetometers that their signal can be easily converted into a binary signal and the measurement of magnetic fields is reduced to a high precision time measurement through the displacement of the magnetisation curve produced by the external field. The magnetometer measures the axial magnetic field at the probe. The transverse sensitivity is negligible. The probe of the device is a small size coil around a high permeability (one mm wide) amorphous metal strip.” sentences were inserted.

Comment 5:

Page 2: “Owing to this design...because it rotates with the telescope.” This is not evident for the reader. Author should include an experiment or a reference: (Gilbert D and Rasson JL, (1998). Effect on Dflux Measuring Accuracy due to a Magnet located on it, Proceedings of the VIth Workshop on Geomagnetic Observatory Instruments, Data Acquisition and Processing, Scientific Technical Report STR98/21, pp168-171, GeoForschungsZentrum Potsdam.)

Author's response:

We put the corresponding reference into that paragraph.

Author's changes in manuscript:

At page 3 line 5 the “Owing to this design the ~~small (< 1 nT)~~ magnetic effect of the ~~of the~~ printed circuit board ~~and battery~~ in the electronic box is cancelled by measurements taken in four positions, because it rotates with the telescope : (Gilbert and Rasson, 1998).” sentence was revised.

Comment 6:

Moreover, it is true if and only if the magnetization remains constant during the whole set of 4 measurements. Is it the case?

Author's response:

It is supposed that the remanent magnetization of the electronics box during the measurements remains constant as it can change mainly with changing temperature but this is nearly constant during the short period of one absolute measurement.

Author's changes in manuscript:

There was no change added.

Comment 7:

Page 3 line 6: What is the minimum distance between DIM and CPU? What is the CPU magnetic signature at 1meter when it is switched on? What is the tablet impact?

Author's response:

The minimum distance between the electronic unit, tablet and the FluxSet sensor is 2m. From that distance the effect of both units is below 0.5 nT.

Author's changes in manuscript:

At page 3 line 14 the “It has some steel parts therefore ~~it~~ its magnetic effect from 1 and 2 meter is 3.0 and 0.3 nT, respectively. It must be placed ~~a few~~ at least 2 meters away from the absolute pillar.” sentences were corrected and augmented. At page 3 line 17 the “A large screen tablet is included in the package of DS-1 equipment. ~~However, the magnetic effect of which is 3.5 and 0.5 nT from 1 and 2 meter. Instead of this tablet,~~ the user can use his any WiFi capable device ~~web browser functionality which has web browser.~~” sentences were corrected and augmented.

Comment 8:

Chapter 3: The authors should give some details about the measurement procedure (p4-11). Residual or zero method? What sequence?

Author's response:

All absolute magnetic measurement were measured by the null method. The utilized sequences were mentioned in page 4 line 11.

Author's changes in manuscript:

At page 4 line 3 the “ **Basically should be used like a classical DIM.**” sentence was added.

Comment 9:

Also, neither a variometer description nor the reference instrument description are present. Are DS-1 and ref-DIM on the same pillar?

Author's response:

The registration of geomagnetic field variations is carried out by two sets of triaxial fluxgate magnetometers, namely by the ARGOS and the DRXX systems at NCK observatory. The NCK observatory main absolute instrument is a Zeiss THEO 010B theodolite equipped with DTU single axis fluxgate magnetometer model G. The measurements were taken the same pillar.

Author's changes in manuscript:

At page 4 line 8 the “The reference instrument was NCK’s main absolute instrument, a ZEISS THE 010B equipped with DMI G type fluxgate magnetometer.” sentence was augmented. At page 5 line 6 the “The instruments were installed on the same absolute pillar of the NCK observatory” sentence was added. At page 5 line 9 “At NCK the registration of geomagnetic field variations is carried out by two sets of triaxial fluxgate magnetometers, namely by the ARGOS and the DRXX systems. (Ádám et al., 2009) The other two observatories’ variometer data were downloaded from the INTERMAGNET website.” sentences were added.

Comment 10:

A robust comparison between two DIM is made by computing a variometer baselines for more than 1 day. Then baselines are compared. Such elementary validation test is not present in the paper. Fig 3 E-H are just a few points (3x2 points for reference instrument) plot. Authors promise a one-year comparison as future work. Maybe they could already provide 1 or 2 weeks comparison.

Author's response:

The long term comparison test measurements are in progress. There is no 2 week comparison test yet.

Author's changes in manuscript:

There was no change added.

Comment 11:

Page 5: Why the duplicated MDIIDM scheme?

Author's response:

The NCK stuff use the MDIIDM scheme. With their instrument we measured with their standard in order to they can put the raw data into their absolute processing program. With the DS-1 we measured with IAGA 2016 Dourbes format.

Author's changes in manuscript:

At page 4 line 11 the “~~The observers followed the~~ At the NCK measurement procedures the duplicate, symmetrical scheme (MDIIDM, M stands for the Azimuth (mira azimuth (mark), D is the declination angle, I is the inclination angle) is used to produce a set of readings with the reference instrument, in order to easily identify any error as this is the usual measurement routine at NCK. Typical operators require about 20-25 minutes to complete one measurement series. ~~On the 2016 IAGA Observatory Workshop in Dourbes this schema with both instrument. However with the DS-1~~ the simplified scheme (MDIM) was used like at the 2016

IAGA Observatory Workshop in Dourbes. The use of different schemas ~~was complicated analysis~~ made the analysis more complicated, but it ~~did not affect the outcome of the results as the NGK main instrument's absolute data could be converted into (MDIM) format~~ had no effect on the results." sentences were revised.

Comment 12:

Is 20-25 min for the traditional DIM or for the DS-1?

Author's response:

The duplicate symmetrical MDIIDM schema and the simplified MDIM schema take to 20-25 and 15-18 minutes to complete them also DS-1 and the reference instrument, respectively.

Author's changes in manuscript:

At page 4 line 15 the "Typical operators require about 20-25 minutes to complete ~~one measurement series~~ this schema with both instrument." sentence was added.

Comment 13:

Could authors detail the handwork gain compared to traditional instruments?

Author's response:

In the DS-1 the telescope is used for mark sightings adjustment only. There is no need to read the circle readings, because you see the telescope positions on the tablet. You do not need to go around the pillar during the whole measurement. You do not need to handle the cable of the magnetometer. You do not need to write on any data just to push a button on the remote controller. After the measurement do not need to digitize the measurement protocol, since it is in digital form already.

Author's changes in manuscript:

There is no change added.

Author's self corrections:

In the (new) Figure 4, table 2 and the body text the ΔF was replaced with ΔH , since this is the appropriate notation for the horizontal baseline corrections.