Solving the orientation problem for an automatic magnetic observatory

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Comments from Chris Turbitt, British Geological Survey

Overall:

This paper outlines a calibration method, and a study off the associated errors, to determine the rotation matrices between the magnetic axes of a magnetometer and the geographical frame whilst the magnetometer remains in-situ at an absolute magnetic observatory. The study has been carried out in the response to the need to further automate geomagnetic monitoring, with the goal of improving the geographical distribution of INTERMAGNET quality absolute magnetic observatories.

Specifically the authors describe a theoretical procedure to orient the magnetic axes of a tri-axial magnetometer-variometer in the geographical reference frame, given that other magnetometer parameters (scale values, offsets, linearity, etc.) have been predetermined through an alternate calibration process – a so-called internal calibration. The sensor orientation is determined by comparison to a reference measurements of the magnetic field vector (classical absolute measurements) whilst the magnetometer-variometer is installed on an observatory pillar.

Further to this, the authors statistically demonstrate through the use of observatory and simulated data that errors in the estimates of the rotation matrices introduced as a result of absolute measurement error and the limited range of the calibrating fields do not result, under typical geomagnetic field variations, in significant errors to the subsequent measured vector. This study and its conclusions are sufficiently novel and of relevance to the geomagnetic observatory community and publication is recommended.

Comments:

The authors' conclusion that following a calibration as outlined, an observatory can operate as an automatic observatory fitting INTERMAGNET standards for time scales of years is theoretically demonstrated in the paper (albeit to a 2nT accuracy rather than the 1nT stated in the abstract), under the simulated conditions set out in the paper. The practical problems of operating an absolute magnetic observatory – stabilising instrument and environment parameters – are only lightly discussed yet are known to significantly influence absolute data accuracy. The effect of assumptions made by the authors, such as an accurate internal calibration, on the proposed calibration process are not quantified in the paper although these are non-trivial problems for the typical variometers (i.e. non full-field magnetometers) employed at the majority of absolute magnetic observatories currently in operation. It is not clear whether statements such as 'this error ... is a direct function of the errors on the absolute measurements' (line 341:10) can be made when no other errors are considered. For example, what would be the consequence if the equality in line 343:9 was invalid or if V(t) in Eq. (3) had an error term?

The authors' remark on the requirement of long-term accuracy over short-term accuracy for specific application (line 449:20) is acknowledged, although this and the 99% rule in line 349:2 are not in line with the current INTERMAGNET standards referenced in the paper.

Nonetheless, this is a worthwhile and interesting study and the proposed method, error analysis and subsequent findings offer a valuable contribution to the feasibility of long-term, automated, absolute magnetic observatories in isolated locations.

Recommendations for minor corrections:

1. Line 341:4 indices 1, 2, 3 if measured vector should be superscript
2. Line 342:6 implies that the magnetometer components (V) are measured and scaled error free i.e. equation (3) should have hat notation.
3. Definition of epsilon in lines 342:19 and 343:2 are inconsistent. Perhaps epsilon in line 342:19 needs a 'j' superscript?
4. Lines 345:3, 346:14, 346:18 & 350:26 should refer to Eq. (8) rather than Eq. (9).
5. The equation referred to in line 345:6 is the equation at line 324:19, rather than Eq. (3).
6. Recommend 'more diverse in direction the Bk are' rather than 'further apart the Bk are' in line 345:21.
7. Line 347:1, use 'mixed product' or 'vector triple product' rather than 'mixt product'.
8. If I understand Figure 3 correctly, this is a plot against an aperture index of the average and maximum effect on the calibration error (|V'-V|) of a 0.75nT absolute error on the 720 Bk triplets for all simulated V(t) with a variation vector (v) of 50nT. If this is the case, then should the references to |deltaB|av and |deltaB|max in Section 5.2 be replaced with |deltaV|av and |deltaV|max i.e. the calibration error? Otherwise, the calibration error (defined in line 345:3) is ambiguous. It may be that |deltaB| refers to the error in the calculated field, derived from V' and V, in which case |deltaB| and |deltaV| would be approximately equal if e1, e2 & e3 were near orthogonal. If this is the case, then this could be stated for clarification.
9. 'Univoqually' in line 347:2 replaced with 'unequivocally'.
10. Should the '1441' in line 347:14 read '1440 x 365'?
11. Consideration could be given to plotting Figures 4 & 5 as cumulative distributions in order that the statement in line 347:16 can be more readily observed i.e. for epsilonb=0.75, the probability of the error being >2nT is less than (say) 30%.
12. Replace 'in the last but one paragraph' with 'in Sect. 5.2'?
13. Line 348:21 should read 'Figure 11 is an example of the effect of changing alpha' rather than 'Figure 11 is an example of the effect of changing t0'
14. Colour references in the figure captions 7-10 should be changed from black/grey to blue/red.
15. Line 350:3 should denote the start of the Appendix.