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Using the diamagnetic cavity to determine a temperature dependent offset model

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1 Introduction

To accurately measure the magnetic field at the comet, the sensor temperature dependent offset of the magnetic field sensor RPCMAG-OB und RPCMAG-IB need to be determined. This may be done on ground, however, for the Rosetta sensors this temperature model is limited to -60°C= 213K due to the lack of advanced temperature calibration equipment at the time of calibration. Therefore, the offset determination needs to be done inflight, either by established methods like Hedgecock (Alfvén waves) or the mirror mode method (compressible waves). Alternatively the magnetic field may be calibrated if the spacecraft is situated in a region with known magnetic field strength and/or direction. Here we use the diamagnetic cavity, a region that is formed around a high activity comet and that should be entirely field free. This implies that if this region is detected in the data, either using certain magnetic field signatures or other RPC instruments, the measured field should be zero in all components. If this is not the case, the remaining field is associated with an offset from either the temperature dependence of the sensor or spacecraft interference fields.

There are several problems with this method that need to be solved. For one, it seems, that at least in some components, there is an additional temporal drift of the offset that needs to be corrected simultaneously with the temperature dependence. Additionally, the temperature dependence is highly non-linear. Lastly, the spacecraft was only located in the diamagnetic cavity for about 16 hours from April 2015 to February 2016. This limits the amount of data points significantly and gives only a limited range of temperature values.

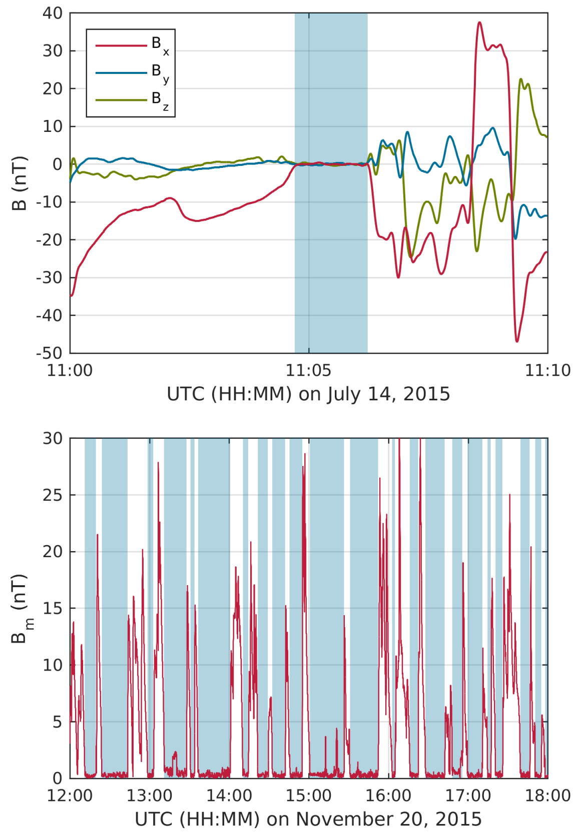

Figure 1: Example of the diamagnetic cavity observations. This data has already been corrected for the offset, however the intervals in the diamagnetic cavity are clearly visible as the field is unusually stable for a long time. From Goetz et al. (2016).

2 Method

First the intervals in the diamagnetic cavity need to be identified. This has been done and published in Goetz et al. (2016). Then the data set that is used to determine the offset needs to be chosen. To make sure that the calibration is performed on unaltered data, the basis is chosen to be raw data in instrument coordinates. This is uncalibrated and in counts. This data has the following name in the archive: RPCMAG150801T0000_RAW_OB_M3.TAB where OB/IB indicates the sensor (outboard/inboard) and M3 denotes the mode. M3 is burst mode, meaning OB is sampling at 20 vectors/s and IB at 1 vector/s. M2 is normal mode, meaning OB is sampling at 1 vector/s and IB is sampling at 1/32 vectors/s. Then the following steps are undertaken to determine the offset:

1. Calculate real physical units from counts, using the conversion given in:Richter (2015)
2. Apply a sixth order butterworth lowpass with cutoff at 1.2 Hz for burst mode OB data and resample to 1 Hz. This needs to be done to get rid of the reaction wheel signatures and has the advantage that the burst and normal mode datasets can be merged. The same advantage leads us to interpolate the normal mode IB data to 1 Hz.
3. Using the cavity event list published in Goetz et al. (2016), the offset is calculated for 32 s intervals inside the cavity, this corresponds to sensor temperature values (which is sampled with a frequency of 1/32 Hz).
4. Using the time, temperature and offset values for one component, a first 2D fit is calculated. It is assumed that the temperature and time dependence of the offset is linear. The resulting fit is shown in Figures 2 and 3.
5. This fit is then subtracted from the offset values.
6. The remaining values are binned in temperature (bin size: 1 K, range: 155 K to 210 K) and the median offset is calculated for each temperature interval. All intervals are interpolated and a smoothing average of sample size 10 is applied. This prevents sharp increases or decreases in the field for the case that the temperature changes rapidly. The fit is shown in Figures 4 and 5.

The two fits can then be used to calibrate the data.

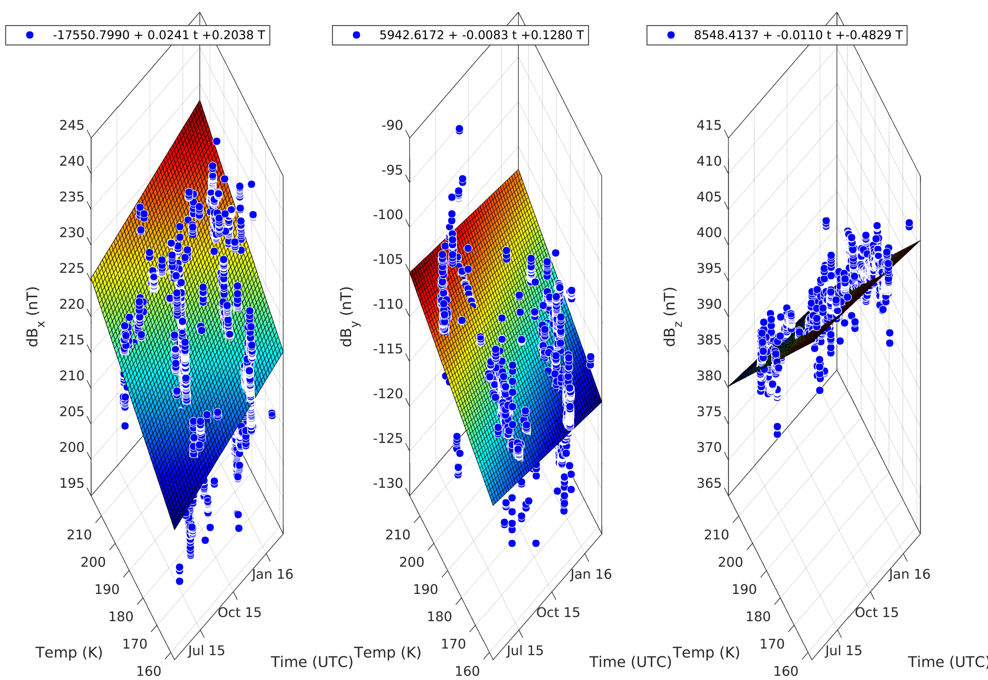

Figure 2: OB. 2D fit and data, the fit function is given in the legend.

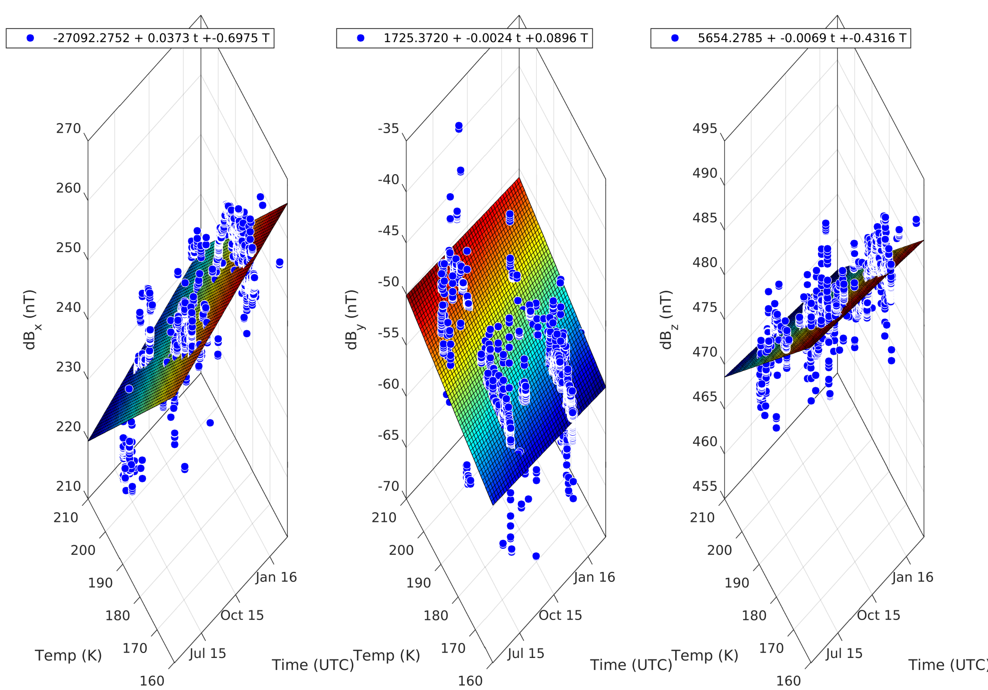

Figure 3: IB. 2D fit and data, the fit function is given in the legend.

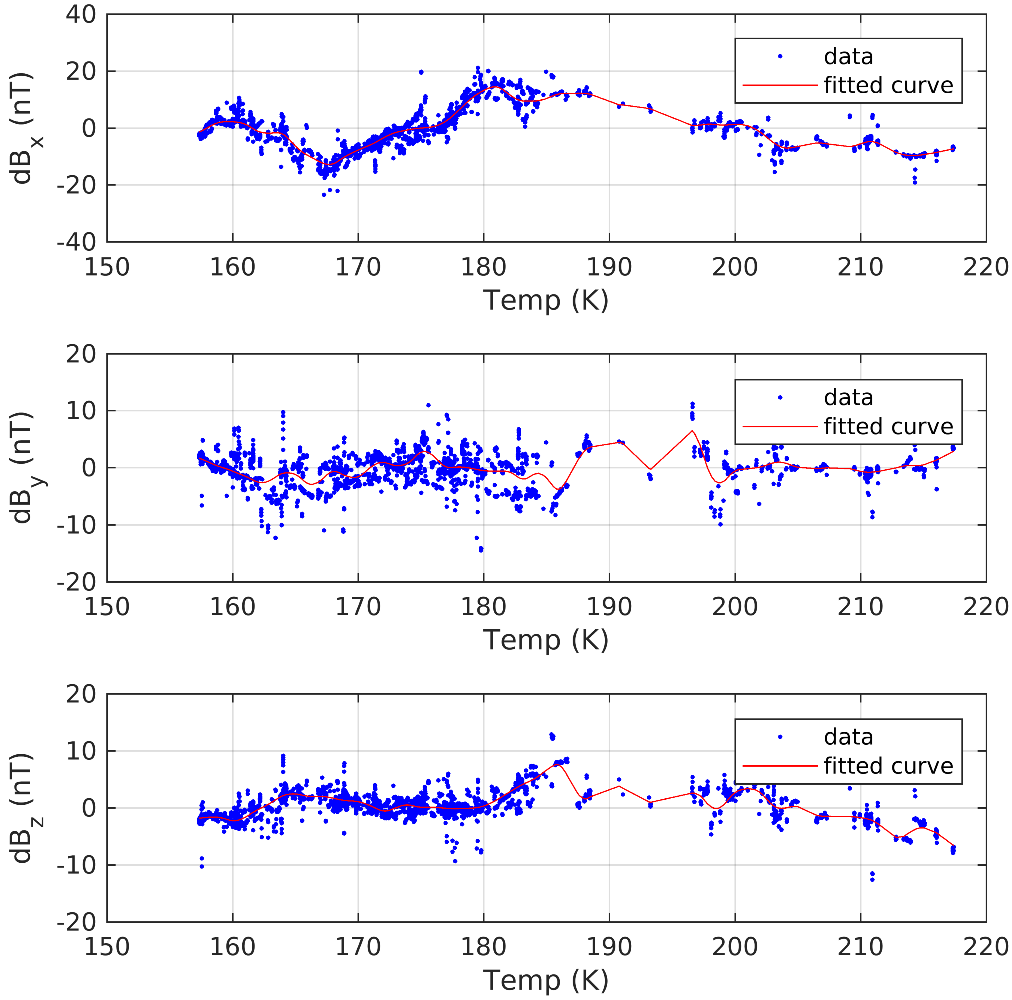

Figure 4: OB. Temperature interpolation after binning.

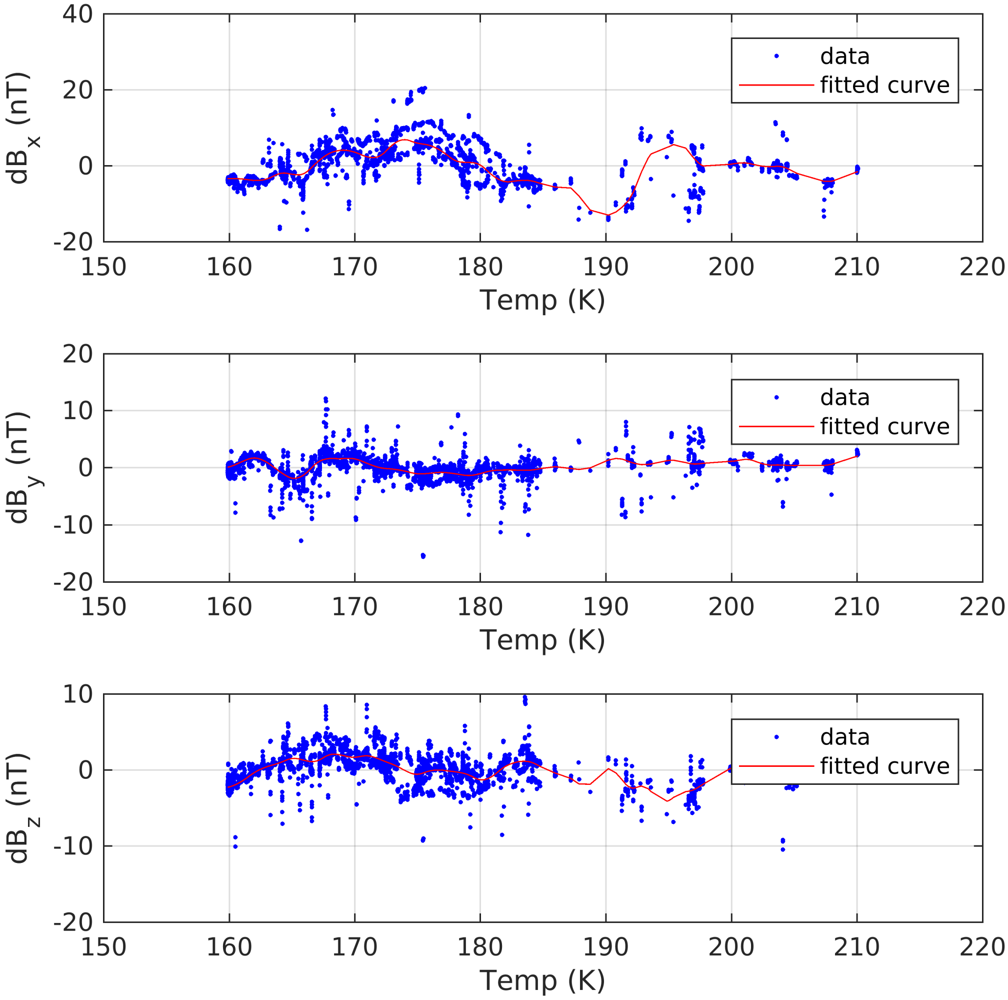

Figure 5: IB. Temperature interpolation after binning.

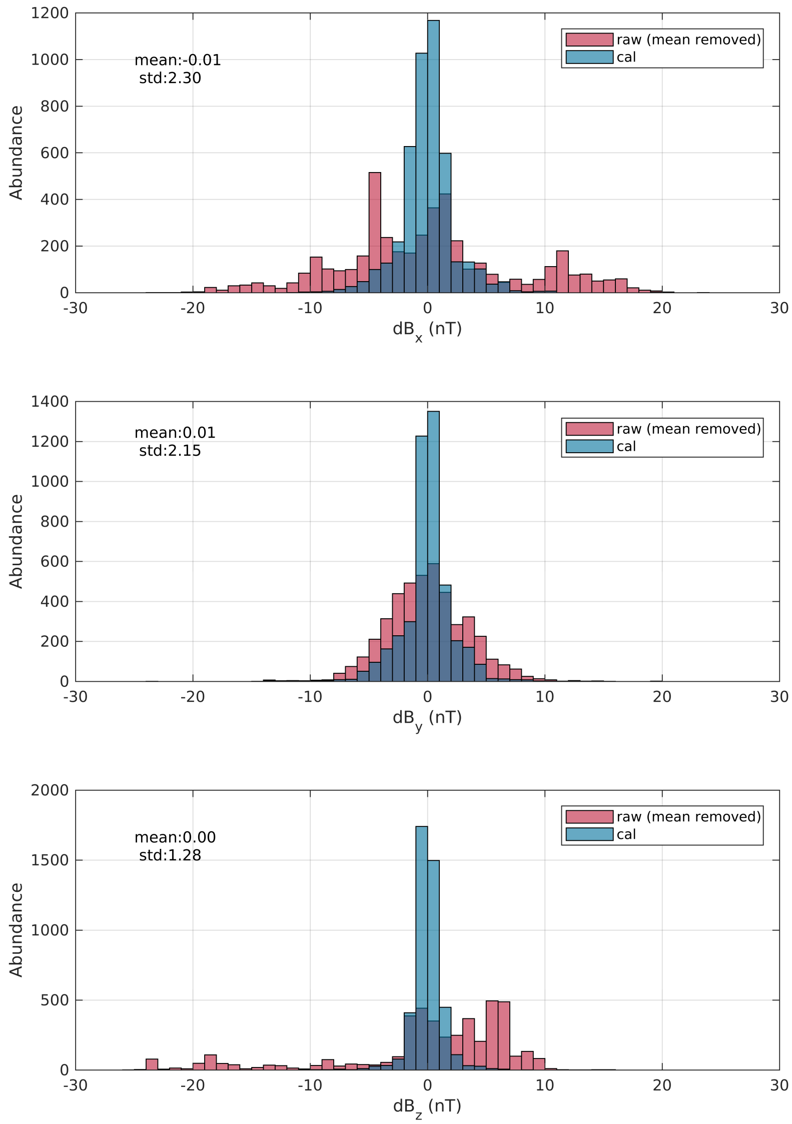

Figure 6: OB. Result. Ideally all values should be zero, which is not the case. However, the distribution after calibration is significantly more focused at zero. For comparison the mean was removed from the raw data.

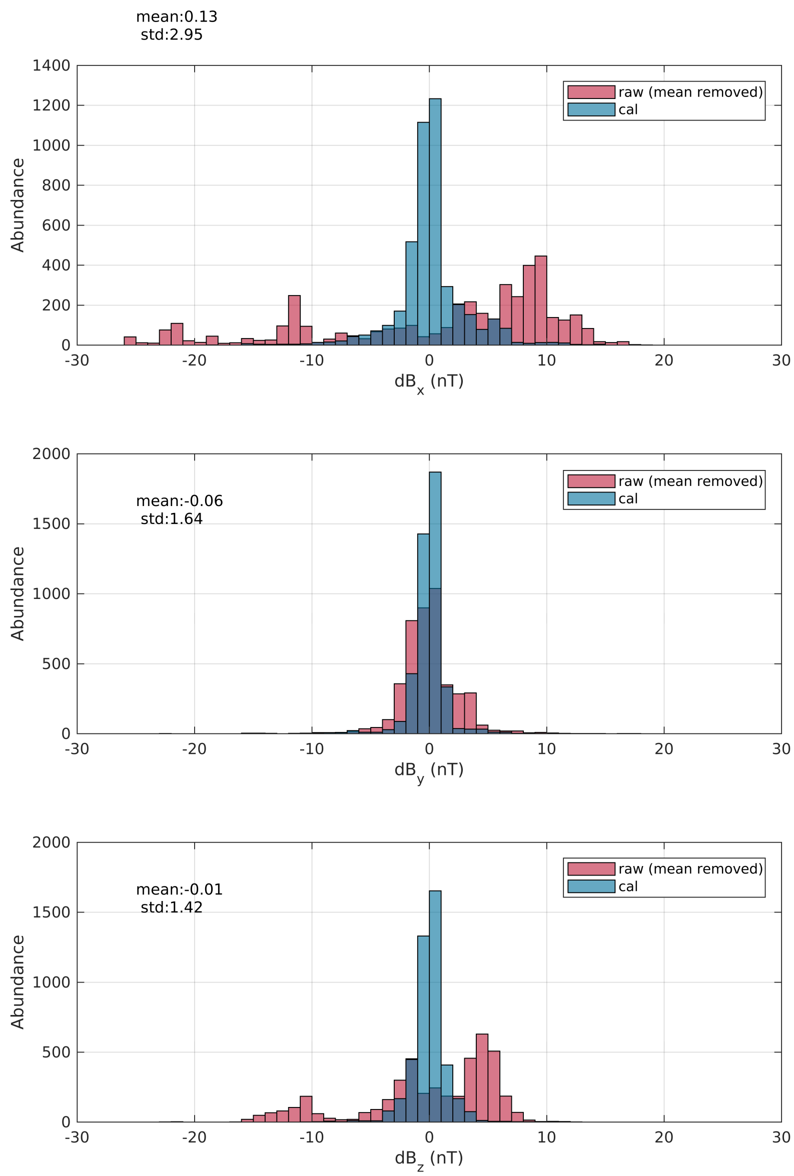

Figure 7: IB. Result. Ideally all values should be zero, which is not the case. However, the distribution after calibration is significantly more focused at zero. For comparison the mean was removed from the raw data.

3 Results and verification

The result of the calibration is shown in Figures 6 and 7. Although the second interpolated fit is only valid in the temperature range from 155 K to 210 K, the first fit may be used for all data, although it may become inaccurate if the time and temperature deviated too far from what was used in the fit.

The determined offset still varies significantly from zero. However, this is the result of short-time spacecraft interference that cannot be modeled.

The goodness of the calibration may be tested using spacecraft slews. Theoretically, the true magnetic field observations should not be affected by spacecraft slews analyzed in a spacecraft fixed system. Also the observation should not be affected by a slew analyzed in a plasma fixed coordinate system like CK or CSEQ, if the s/c residual field is zero and the magnetometer offsets are determined correctly. If, however, the s/c residual field is not zero or the magnetometer offsets are wrong, i.e. the sum of s/c-residual field and magnetometer offset suggest a non vanishing field, the analysis of the magnetic field in a plasma fixed frame would show a rotation-structure correlated to the actual slew. Thus, minimizing such a rotation-structure could be used to find the right sum of offsets and s/c-residual field.

Figures 8, 9 and 10 show three testcases. The goal is to verify how far from the temperature and time range that was used to correct the data, the temperature curve for the offset still works. Table 1 summarizes the parameters that the test cases fulfill. The correct calibration is only achieved if the sensor temperature is within the models constraints (case 1). Otherwise, the magnetic field offset that the model predicts is not accurate enough. However, close examination of cases 2 and 3 show that the closer to the model cutoff the temperature is, the more accurate the magnetic field offset is. It should also be noted that for times that are much larger than the last diamagnetic cavity interval, the magnetic field offset predicted will be distorted (case 3).

#	correct time range	correct temperature range
1	✓	✓
2	-	-
3	N/A	N/A

Table 1: Comparison of the Testcases: ✓ — Conditions are fulfilled, - — situation worse, as present conditions near model limits, N/A —model not applicable, because limits are exceeded.

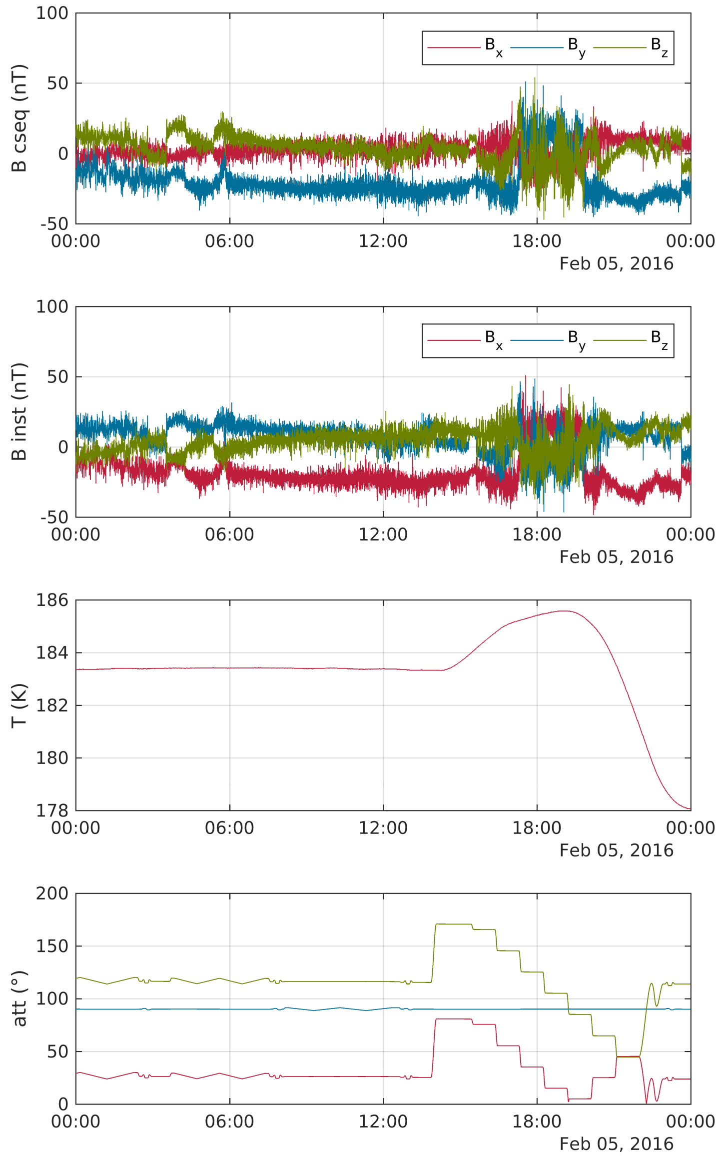

Figure 8: Test case 1. The figure shows the magnetic field components in CSEQ (plasma fixed) in the first panel, and in instrument fixed coordinates in the second panel. The third and fourth panel show the sensor temperature and spacecraft attitude. The changes in attitude do not correlate to any structure in the magnetic field in CSEQ coordinates, we therefore conclude that the magnetic field calibration is sufficiently accurate.

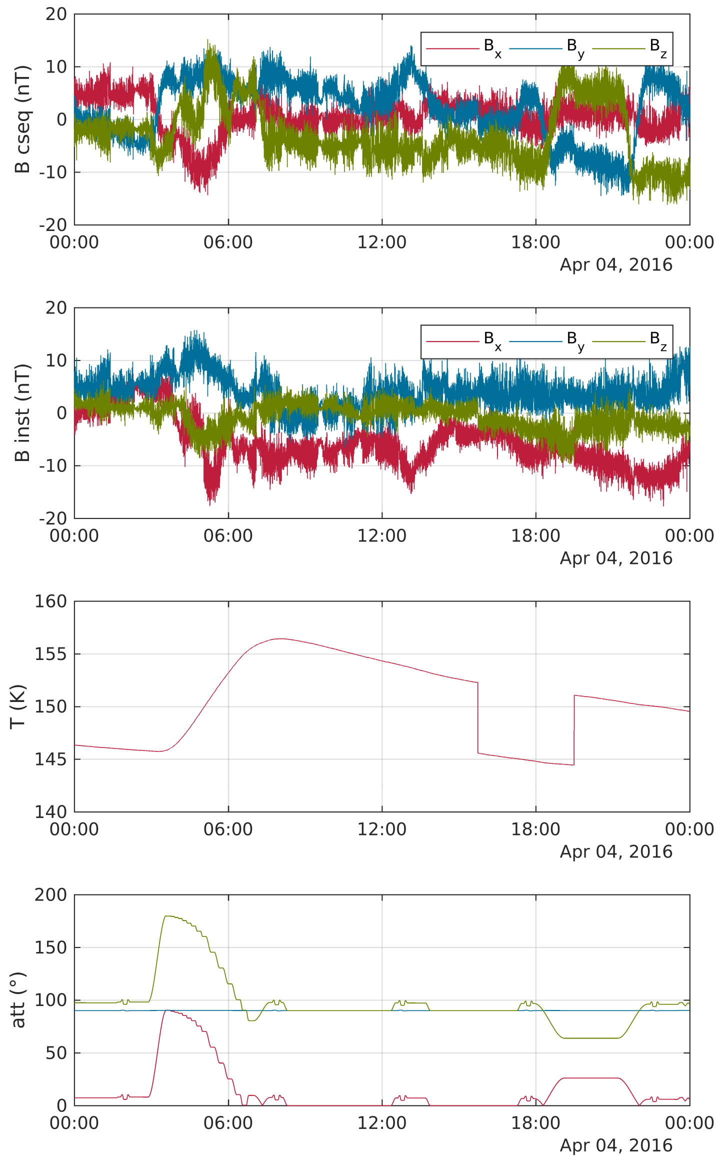

Figure 9: Test case 2. The figure shows the magnetic field components in CSEQ (plasma fixed) in the first panel, and in instrument fixed coordinates in the second panel. The third and fourth panel show the sensor temperature and spacecraft attitude. The changes in attitude correlate with changes in magnetic field in CSEQ. This is related to the fact that the sensor temperature is below the threshold that the model applicable for (155K). Additionally there is an anomaly in the sensor temperature that is related to a spacecraft voltage change. This also leads to a jump in the magnetic field.

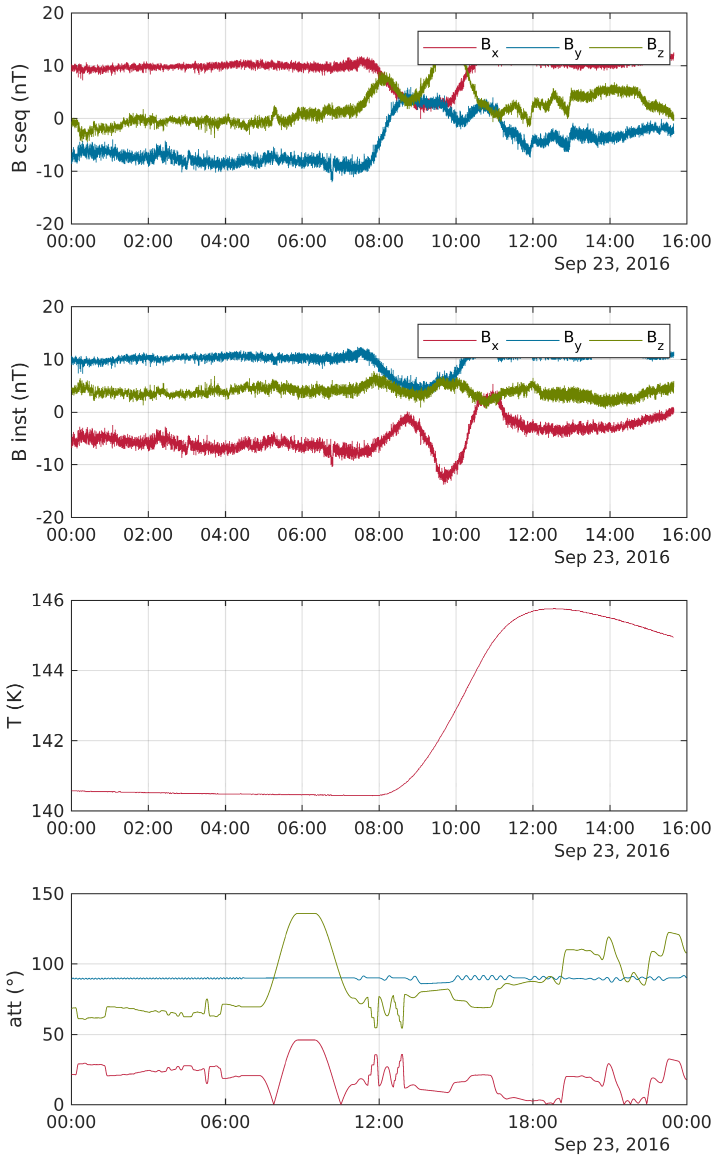

Figure 10: Test case 3. The figure shows the magnetic field components in CSEQ (plasma fixed) in the first panel, and in instrument fixed coordinates in the second panel. The third and fourth panel show the sensor temperature and spacecraft attitude. The changes in attitude correlate to the magnetic field changes in CSEQ. The model is not applicable due to low sensor temperatures.

4 Data product

This calibration has not yet been implemented in the pipeline, as the plan is to resubmit the data set only at the end of the archiving processes and other methods may improve upon the temperature curve.

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