Influence of sensor noise levels on magnetometer calibration

Gerlinde Timmermann, Dragos Constantinescu, Patrick Kolhey, Ingo Richter, Hans-Ulrich Auster, Ferdinand Plaschke
TU Braunschweig | Institute of Geophysics and Extraterrestrial Physics, Faculty of Electrical Engineering, Information Technoloy, Physics, Germany
gerlinde.timmermann@tu-braunschweig.de | Telefon +49 (0) 531 391 - 5230

1. Abstract

Magnetometers are prime instruments of scientific spacecraft targeting the space plasma environments of solar system bodies. Despite extensive ground calibration efforts, regular inflight calibration activities of these magnetometers have shown to be crucial to maintain necessary data quality levels over time. Classically, 12 parameters influence the calibration: 3 gain values, 6 angles defining magnetic sensor orientations, and 3 zero level offsets that correspond to instrument outputs in vanishing ambient fields. Particularly in low fields, accurate choice of offset levels are of utmost importance. To achieve this, measurements of Alfvénic fluctuations in the solar wind are typically used. We investigate the influence of sensor noise levels on the accuracy of different calibration parameters, particularly on the offsets, using MMS magnetic field measurements.

2. Noise Data and Methods

- Magnetic field data from a fluxgate magnetometer measured in a magnetically shielded environment over night
- Calculate the power spectral density (PSD) with a discrete Fourier transform according to:

$$P(f_k) = \frac{2\,\Delta t}{3N} \sum_{x,y,z} \left| \sum_{m=0}^{N-1} B_{xyz,m} \exp\left\{-2\pi i \ \frac{mk}{N}\right\} \right|^2$$

N: number of sampling points, Δt: sampling period

- Calculate the 5th, 10th, 25th, 50th, 75th, 90th, and 95th quantile
- Downsample to 1 Hz, split into 1 min intervals, detrend linearly

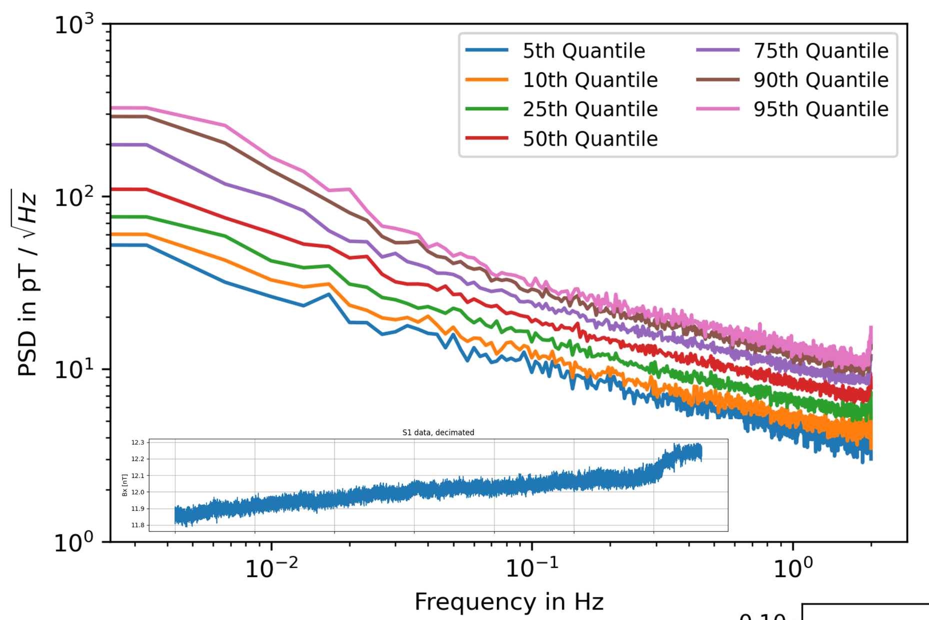

Fig. 1:
PSD of fluxgate magnetometer in shielded environment over night, insert: B_x of FGM

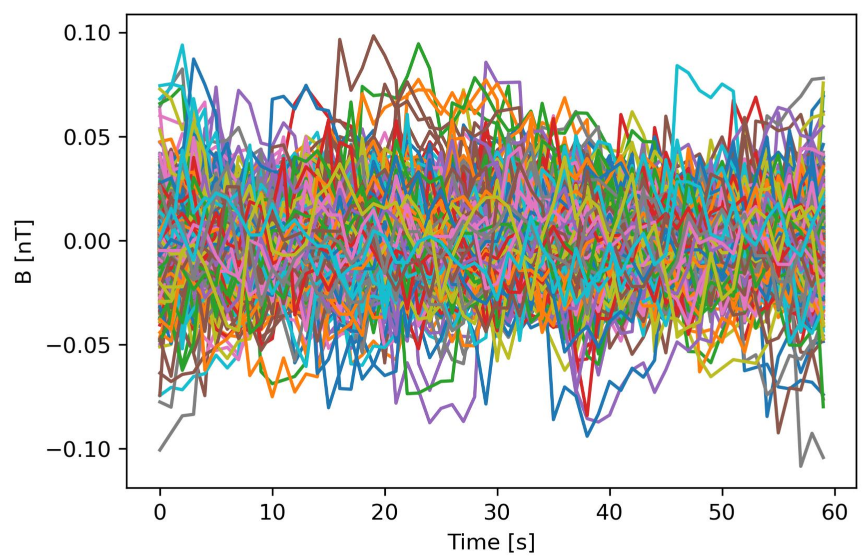

Fig. 2:
detrended 1 min intervals of FGM data

3. Magnetic Field: Data and Methods

- Use well-calibrated 8 Hz magnetic field data from NASA's Magnetospheric Multiscale Mission (MMS)
- despun major principal axis of inertia (DMPA) Coordinate system: x-y plane is spin plane, positive z points north, aligned with spacecraft spin axis
- MMS 1 survey data in DMPA from dayside extended mission phase 3B is used between Dec 1st and Dec 31st 2017
- according to [1] dividing of data into 1 min intervals, downsampling to 1 Hz to reduce computational efforts
- Identify offsets with Hedgecock method [2] by minimizing standard deviation $\sqrt{\sum |\mathbf{B} - \boldsymbol{O}|^2}$ for solar wind intervals with $|\mathbf{B}|$ < 10 nT
- Only take offsets with -10 nT < O_x, O_y, O_z < 10 nT and only take intervals where B is fluctuating: $\sigma(B) > \sigma_c = 0.075$
- δ = width of kernel density estimation (KDE) result in nT at 90% peak value (only intervals with Alfvénic fluctuations)

4. Results

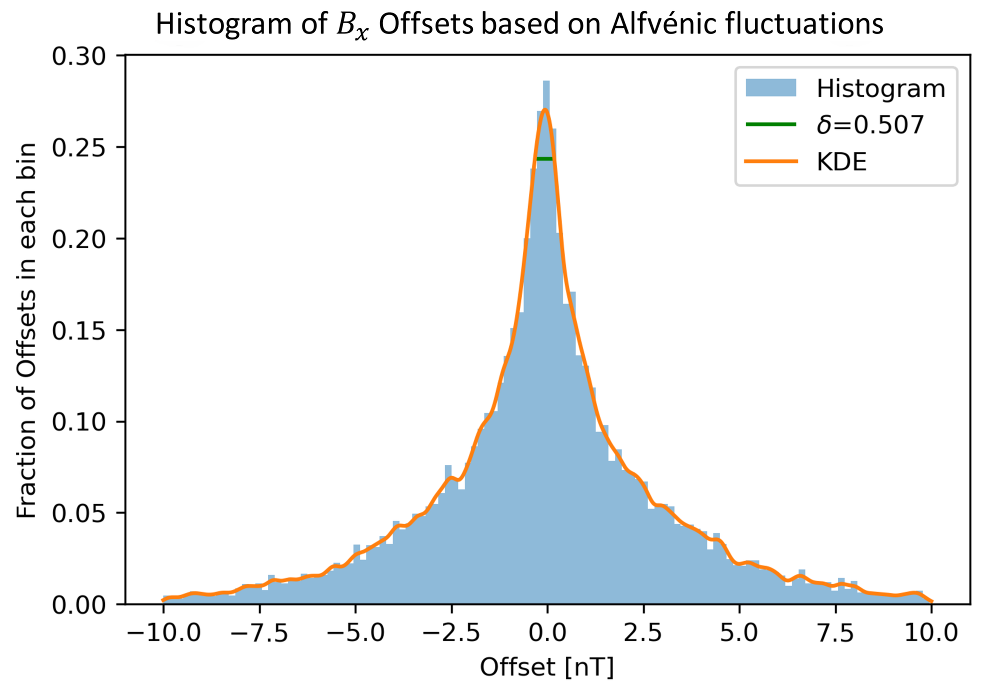

Fig. 3

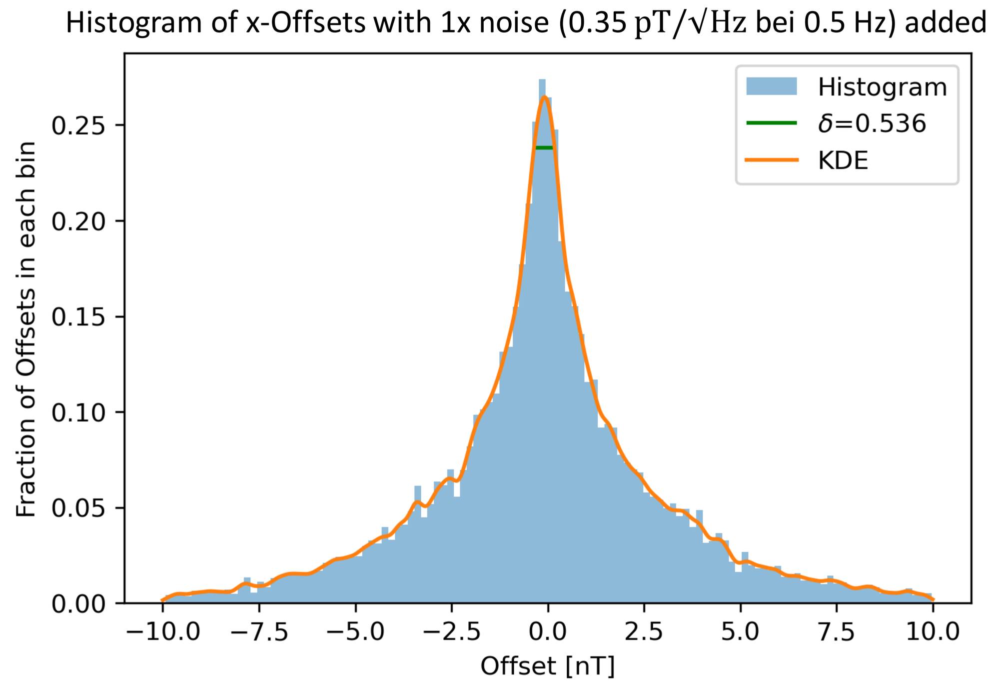

Fig. 4

4. Results - continued

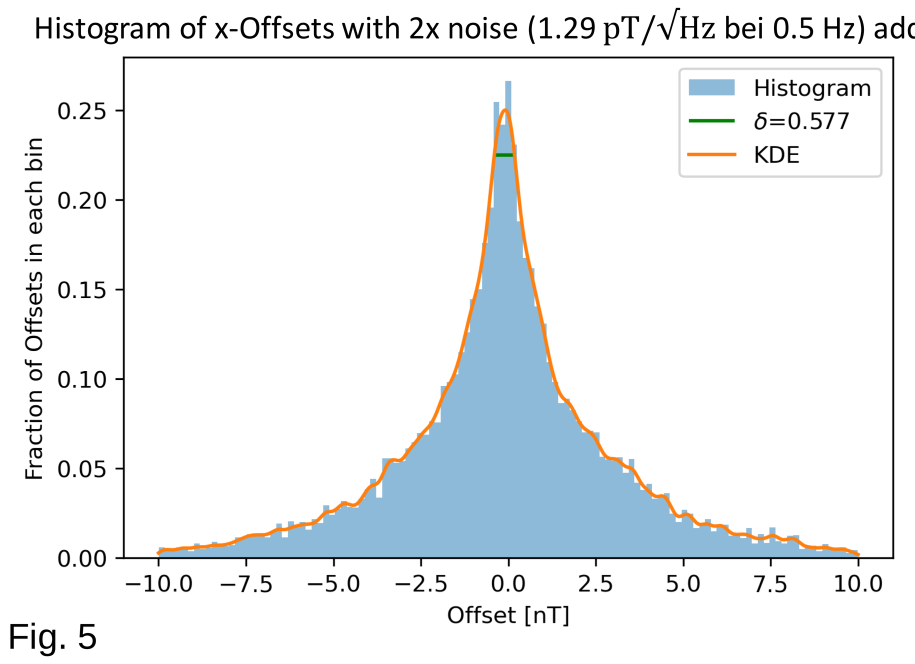

Fig. 5

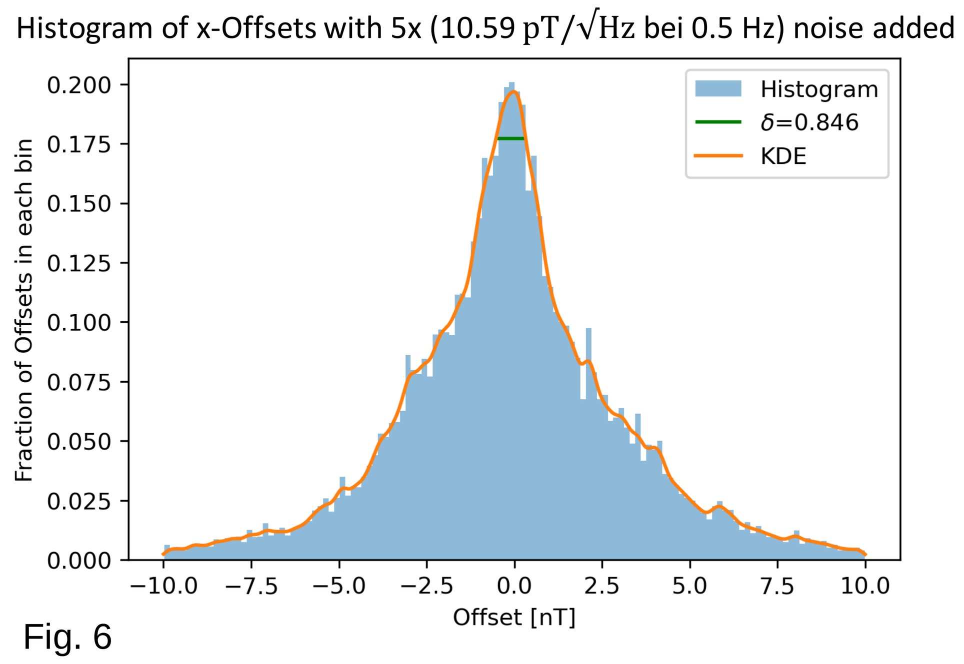

Fig. 6

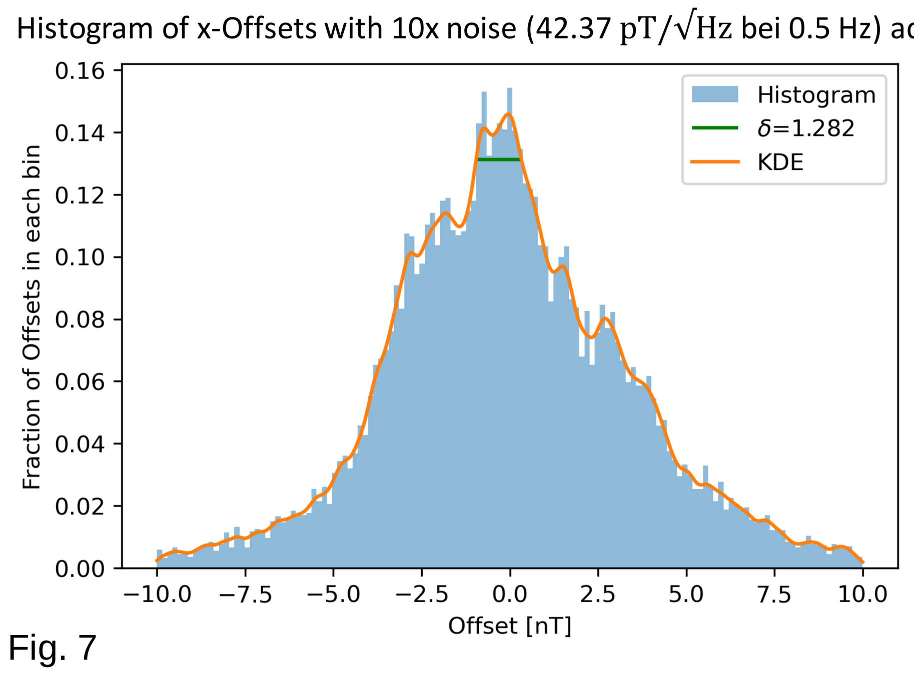

Fig. 7

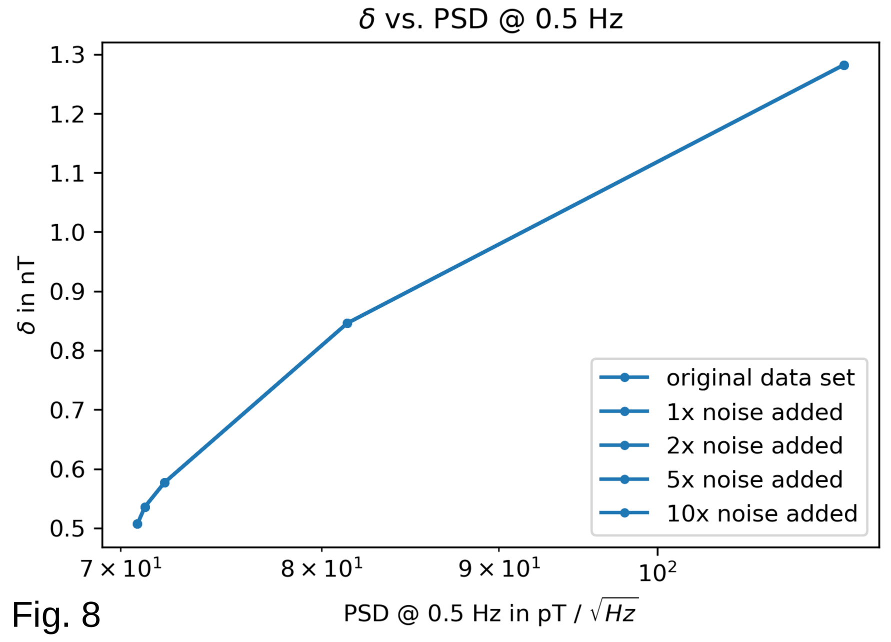

Fig. 8

5. Discussion and Conclusions

- The histogram of original data resembels a sharp bell curve, δ = 0.507 (Fig. 3)
- The offsets are changing when noise is added → bell curve widens, δ increases
- Noise added one or two times changes δ by less than 0.1 nT (Fig. 4+5), five times more noise changes δ by more than 0.3 nT (Fig. 6), adding 10 times noise more than doubles δ and peak of KDE shifts to the left (Fig. 7)
- Adding noise can lead to challenges in determining accurate offset values
- Fig. 8 shows the PSD levels depending on the added noise at 0.5 Hz
- Fig. 9 shows the noise levels (calculated as described in section 2) of an AMR magnetometer: at 0.5 Hz it has a value of 200 pT
- If the magnetometer has already a high noise level, determining the offsets won't be possible

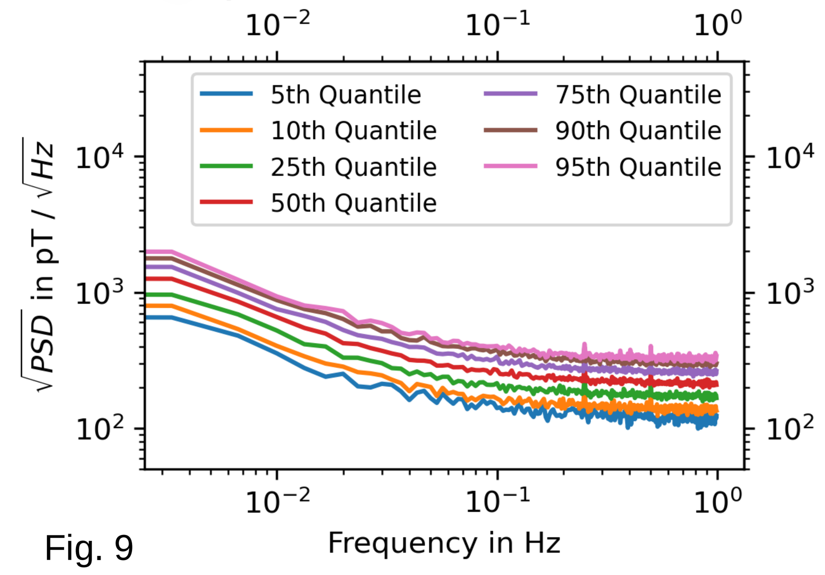

Fig. 9

Acknowledgements

This project is supported by the Federal Ministry of Economic Affairs and Climate Actions (BMWK) on the basis of a decision by the German Bundestag.

Technische Universität Braunschweig

References
[1] Plaschke, F.: Solar wind sufficient for FGM offsets, Geosc. Instrum. Method. Data Syst., 8, 285-291, 2019
[2] Hedgecock, P.C.: A correlation technique for magnetometer zero level determination, Space Science Instruments, 1, 83-90, 1975

IGEP TU Braunschweig | Institut für Geophysik und extraterrestrische Physik

EGU General Assembly 2025

This presentation participates in OSPP – Outstanding Student & PhD candidate Presentation contest

Sharing is encouraged