Answers to the comments from Anonymous Referee #1

We thank the referee very much for their time and their detailed comments! We are sure the proposed changes will improve the paper. In the following, we will address each point separately.

General comments:

"The paper does not answer the question of how the noise characteristics of the devices selected for analysis compare with various other FGM and AMR magnetometers in terms of this parameter. So it is not comparison of "different magnetometer types" as the paper title declares, but rather a case study of the two FGM and AMR instruments for space applications."
"The paper's title suggests a broader scope than what's actually covered in the paper."

The title was changed to "Comparison of noise levels of two magnetometer types and their suitability for different space environments" to represent we only used two magnetometers and different space regions. Additionally, we made it clearer that the FGM used is state-of-the-art and thus comparable to others (page 3, line 80).

"In general noise level of fluxgate and search coil sensors depends on physical dimensions of their magnetic cores: the larger the core, the lower the noise level. How do the dimensions of the sensors in question compare?"
The size of the ring cores of the FGMs used is 13 mm (for XZ direction) and 18 mm (for YZ direction) (analog to the ring cores used in Auster et al., 2008). This was also added in the paper (line 81f.)

The AMR hybrid sensor has a volume of 1.67 cm³ with a 16 mm diameter and 8.3 mm height. (Leitner et al., 2015) This was also added in the paper (line 87).

"What will the noise level of the FGM instrument be if its sensor is reduced to the size of the AMR sensor? Or what will the noise level of the AMR magnetometer be if its sensor is increased to the size of the FGM sensor?"
It is of course true that there is a correlation between the general noise level of an FGM instrument and the physical dimensions of its magnetic core. Of comparable influence are the impacts on the noise level due to production variation, excitation power, feedback noise, winding numbers or pickup tuning, to name a few. In addition, bigger fluxgates are heavier and need more power, making them disadvantaged for use in space applications.

Nevertheless, this study was not targeting a full parameter study of fluxgate sensors, but to illustrate the usability of the presented instruments for different space environments.

It is a valid point to say the AMR and the FGM used are of different sizes. AMR magnetometers are smaller than FGMs and need less power. However, they are based on thin films in the micrometer range that give them their uniqe properties. Increasing the AMR to the size of the FGM would make them lose the thin film specific desired behavior, so they would not yield the same functionality as before. Additionally, these components would not be off-the-shelf available anymore and thus increase the price, which is a key selling point for using AMR magnetometers in the first place (low cost).

There is work being done on so-called fluxgate on chip, see e.g. Ma et al., 2024 (600 µm ring core) or Lu et al., 2014 (less than 1 mm wide core). These come with higher noise levels than the fluxgate sensor used in this paper (61-87 pT/Hz1/2 at 1 Hz depending on direction in Ma et al., 2024; 50 pT/Hz1/2 @ 1 Hz with 50 Hz excitation and 790 pT/Hz1/2 @ 1 Hz with 25 Hz excitation in Lu et al., 2014), but they are mostly still lower than the noise levels of the AMR magnetometer presented in this study. Furthermore, we think going into such detail of the different sizes of magnetometers is – though quite interesting – out of the scope of this paper.

"The overall presentation of the research results is well structured, but some statements and formulations are not sufficiently clear. Abbreviations, symbols and units are fairly defined and used."

We checked again for consistency in abbreviations, symbol usage, and units and made corrections/ adjustments where necessary.

Specific comments:

page 4, lines 112-114:
"In my opinion, this sentence is not clear enough. It would be helpful to explain its meaning in more detail and provide a link to a specific subsection (or subsections) in the article instead of "as seen later"."

The sentence was changed and a link to the results section is now given.
Additionally, this lets small variations of individual measurements fade into the background noise level, so all disturbances seen are either from the spacecraft or a result of general space phenomena (as seen in section 3) .

page 4, lines 121-123:
"Please explain the rule used to calculate the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles of the PSD square roots."

An explanation for the percentiles is now included in the text.
Here, the 5th percentile corresponds to the value that is equal to 5% of the maximum value at each frequency, the 10th percentile corresponds to the value that is equal to 10% of the maximum value at each frequency and so forth.

page 11, lines 232-234:
"It appears that the article (Hooge et al., 1981) does not directly discuss 1/f noise in fluxgate magnetic sensors. (…) The topic of FGM magnetic noise (MN) is discussed in the paper Korepanov et al., 2001, see Section 2, p. 138: (…)"

Thank you very much for pointing out a better source for a comparison value of spectral slope! The old one has been replaced.

Technical Corrections:
page 5, Table 1 and lines 136-138, page 12, line 242:
"The values of the amplitude spectral density of FGM and AMR magnetometers at 1 mHz (77.91 and 1277.36) and AMR at 1 Hz (157.09) in Table1 are different in comparison with values at these frequencies on the plots in Fig.1, 2, A1, A2 (110-115 at 1mHz for FGM, 2100 at 1 mHz and 210 at 1 Hz for AMR). It appears that the values (77.91 and 1277.36) in column

$P(f)_{1/2}$ @ 3 mHz (1 mHz) of Table 1 are actually given at 3 mHz, not 1 mHz as stated in the Table 1 capture and line 134. The noise level of AMR magnetometer also mentioned later (page 11, line 237) as 157 pT/$Hz_{1/2}$ at 0.5 Hz is also in contradiction with plots in Figures 1(b), 2, A1, A2."

The unmatching values of Table I and the caption/text have been corrected.

"Neither 157, nor 210 pT/$Hz_{1/2}$ at 1 Hz does not corresponds to the overall instrument noise density 100 pT/$Hz_{1/2}$ at 1 Hz specified in Table IV "SOSMAG AMR Instrument Spec" of the paper (Leitner et al., 2015)."

I got the measurement data from A. Valavanoglou (as shown in the reference list), if plotted one can see it is not the exact same measurement as used in Leitner et al. (2015) (difference in levels of B and temperature). Nevertheless, they are from sensors developed for SOSMAG. The noise levels of 210 pT/Hz1/2 are in the same order of magnitude as given in the paper (100 pT/Hz1/2), thus saying "an AMR magnetometer as used in SOSMAG" seems - in our opinion - appropriate.

"In addition, all amplitude spectral density values in Table 1 are unnecessarily precise. In my opinion, these numbers can be rounded to 1 pT without any loss of information."

The values have been rounded to 1 pT.

page 11, lines 236-239:

"What means expression "at lower frequencies"? Lower than what and why "not suitable"?"

The expression "at lower frequencies" has been specified as well as the meaning of "not suitable". Since this is at quite a high level, this AMR magnetometer is not suitable for scientific measurements at frequencies below 1 Hz, since the noise floor is higher than the lowest expected signals. There exist other AMRs with lower noise floors as described in Brown et al. (2012).

"Taking into account spectral slopes of the natural phenomena (-1.81 … -1.36 at $f<0.1$ Hz) and that of the AMR magnetometer ($\alpha=-1.02$ at $f<0.03$) the lower frequency, the higher signal/noise ratio is expected. Thus, at a sufficiently low frequency, the signal-to-noise ratio becomes suitable for measuring natural signals, doesn't it?"

We agree that in theory, at sufficiently low frequencies the SNR of an AMR should become suitable for measuring natural signals. However, the lowest frequency is given by the length of the time interval measured. For this study, the time intervals of the natural signal measurements were chosen to be 5 min long, giving a minimum frequency of 3.3 mHz. Also, it needs to be taken into account that the length of the time intervals is restricted by how long a spacecraft can dwell in the space region under consideration. This is restricted by the spacecraft's velocity, which is usually in the one digit km/s range, given e.g. for a THEMIS satellite an orbit period of about 26 h. In this time period, it will cross several space regions. If it was staying in only one space region, this would yield frequencies in the µHz range. At last, the offset stability for AMR magnetometer cannot be assumed to be constant for long time periods. (see Schulz et al., 2019)

References

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