Author response to referee #2

The authors thank Anonymous referee #2 for their detailed comments on the manuscript. We will take the comments into account when revising the manuscript. In this document we provide responses to each of the referee's comments (formatted as italics in indented paragraphs and grouped together when appropriate).

> *Please do not use the term "offset" in connection with the measured magnetic field value, p. 2, line 46. It is very confusing considering that this term is reserved for quantifying the systematic error of the sensor. Replace it with, for example, the term "contribution" or similar. Likewise, the term "despun coordinate" is inappropriate and very confusing.*
>
> *If I understand it correctly, the projections of the BSA field component measured along the spin axis onto the axes of the other sensors represent that permanent, non-removable contribution. However, this does not exhibit sinusoidal behavior with the ω_{spin} frequency, as stated on p.2, line 47. This is also evidenced by relation (2), where the only time dependence of this contribution is related to the time variability $B_{\mathrm{SA}} = B_{\mathrm{SA}}(t)$. Please clarify this part of the text.*

We agree that the wording of this paragraph is unfortunate and does not explain the situation well. We will rephrase this paragraph, replacing the wording "spin tone" with "projected spin axis contribution". We will also rename the variable from B_{ST} to B_{pSA} throughout the manuscript.

> *For the sensor configuration as described in Abstract and Introduction, the second step in the coordinate transformation is redundant because the probe spin axis coincides with the Pz-axis, as it is depicted in Figure 1(a). The presentation of Figure 1(b) and the matrix Σ (which actually should be an identity) is very confusing for the reader. Please remove this contribution to the explanation, or present it as a general case of rotating the sensor design with appropriate commentary for the current case.*

We agree that the description of the sensor system needs improvement. Accordingly, we added a third panel, Fig. 1(c), to illustrate the angle α between spin plane sensor axes S1 and S2 and the spin axis (see Fig. 1). However, we kindly disagree that the Pz-axis and the spin axis coincide which should be visible in Fig. 1(b) with the spin axis in black and the Pz-axis in blue.

In the revised manuscript we will explain the sensor system and transformation between the different

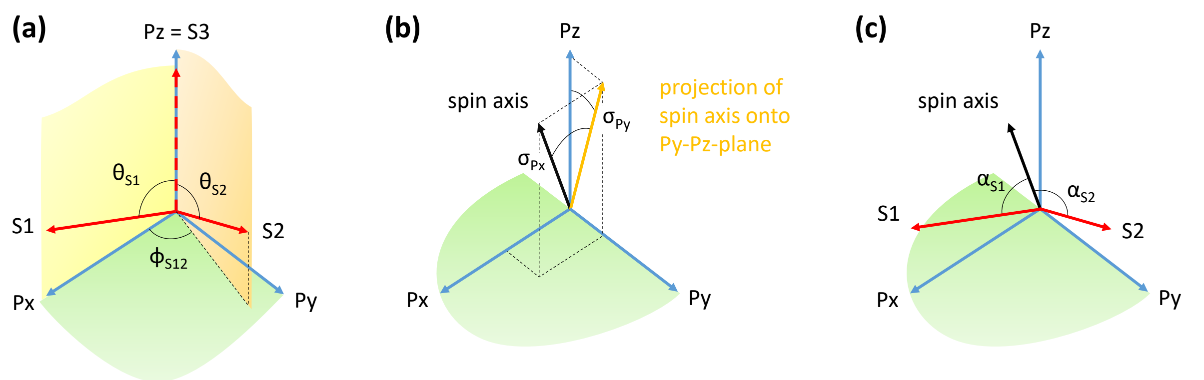

Figure 1: Updated sketch of sensor coordinate system. The panel c) shows the angles α_{S1} and α_{S1} between spin axis and spin plane sensors.

coordinate systems in more detail.

> *Please justify the use of the transformation $\mathbf{\Phi}$, apparently $\phi_{\mathrm{a}} = \phi_{\mathrm{a}}(t)$.*

There were no requirements for the orientation of the FGM instrument onboard the THEMIS spacecraft [see Auster et al., 2008]. Therefore the rotation around the spin axis just comes from the position of the FGM onboard the spacecraft, and ϕ_{a} is needed to get from the sensor system to a physical meaningful coordinate system. In Fig. 2 we present the evolution of all 9 calibration parameter for THE over the mission duration. As can be seen in Fig. 2(g) ϕ_a stays quiet constant the whole time.

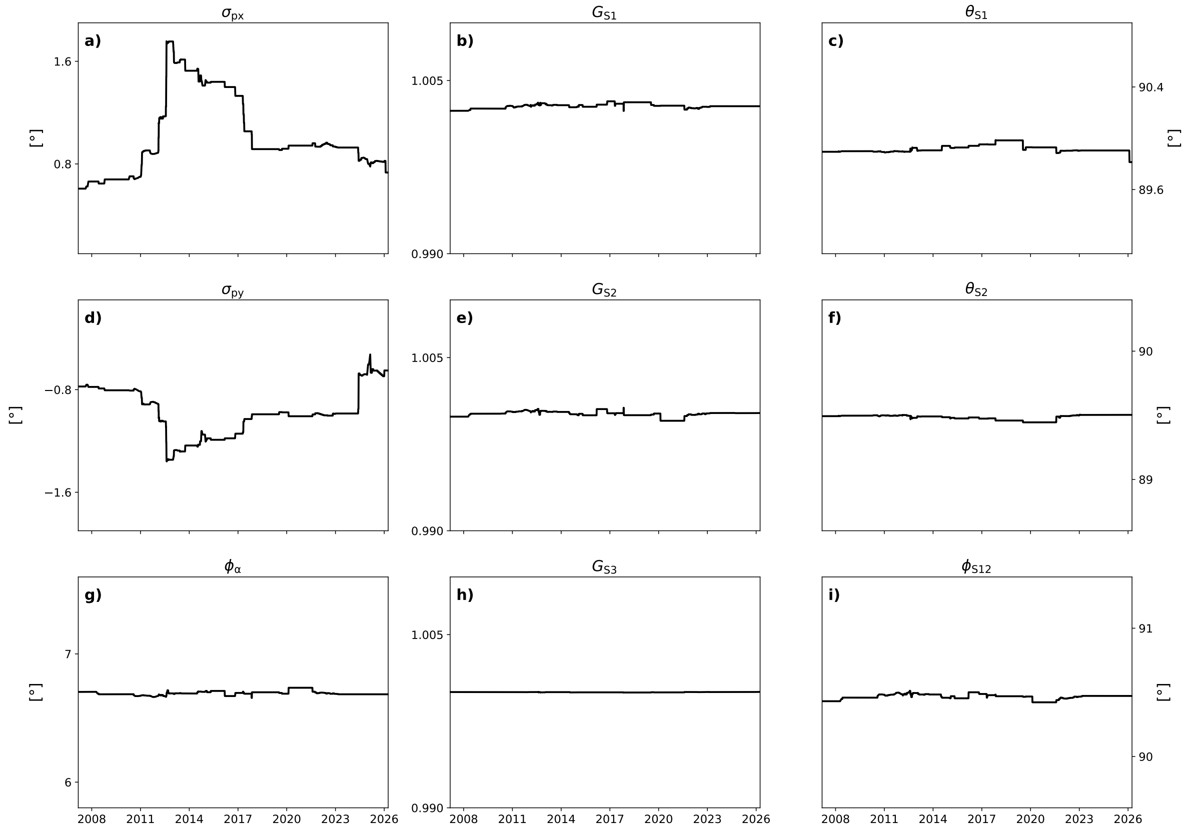

Figure 2: Evolution of calibration parameter: σ_px, σ_py, and ϕ_α are the rotation angles around the orthogonalized sensor axes (c.f. with blue coordinate system Fig. 1 in the manuscript or Fig. 1 in this reponse). G_S1, G_S2, and G_S3 are the gains along the sensor axes. θ_S1, θ_S1, and ϕ_S12 are the internal sensor angles as described in Fig. 1 in the manuscript.

> *It is appropriate to present the conversion by the* $\mathbf{G}$ *matrix first, since this is applied to the data that has not yet been transformed.*

We agree and will reorder the presentation of the matrices.

> *The origin of relation (8) is unclear, the angles* α_Si *apparently* $\alpha_\mathrm{S1} = 90° - \theta_\mathrm{S1}$, $\alpha_\mathrm{S2} = 90° - \theta_\mathrm{S2}$ *(what is* α_S3 *?). Please provide the derivation and explain also with regard to the reservation in point 1.*

We agree that the angles α_S1, α_S2 and α_S3 have not been introduced well. They are the angles between the sensor axes S1, S2 and S3 and the spin axis, respectively. As mentioned above, we will add a third panel to Fig. 1 and will expand the explanation of the sensor system. Eq. 8 is simply the projection of the spin axis onto the sensor axes, yielding the angles between spin axis and sensor axes.

> *Please specify that formula (11) is applied to (9) and (10) individually. From the fitting procedure, I assume, the unknown values* $A_1, B_1(t), C_1, D_1(t), \varphi_1$ *and* $A_2, B_2(t), C_2, D_2(t), \varphi_2$ *arise and the value* $B_\mathrm{ST}(t)$ *is common to both expressions. Please demonstrate in detail how this is achieved. In relation (11) also correct for the linear increase in amplitude with time.*

We agree that we have to be more precise. We will clearly point out that A, B, C, D and φ are free fitting parameter, whereas ω_s is provided by the state file of THE.
Applying the fit to both spin plane sensor axes data we will result in two independent estimates for B_pSA (formerly B_ST, see comment above). Referee #1 pointed out, that we used t in Eq. 11 and

Eq. 13 although they are not the same. Therefore we will replace t with τ in Eq. 11 with τ ranging from 0 to $2.5T_{\mathrm{spin}}$. To obtain one B_{pSA} value for one fit window, we are then using the central average $B_{\mathrm{pSA}} = B_{\mathrm{pSA}}(\tau = 1.25T_{\mathrm{spin}})$. We will expand the description of the method and will fix the aforementioned inconsistencies.
In the revised manuscript we will rewrite this paragraph in will add more details and explanations.

> *p. 5, line 111: You now have recalculated the components B_{raw1} and B_{raw2} (and not (B_{S1} and B_{S2}), according to relations (9) and (10). Please consider the designation for raw data and treated data and be consistent in their use in the following text.*

We agree that we need to be more precise and careful when naming variables. In this sentence, we intended to inform the reader that we calculate B_{pSA} independently for both spin plane sensor axes, as mentioned in the comment above, with details on the implementation to follow later in the manuscript. We will revise this paragraph to avoid confusion and resolve inconsistencies in the naming of our variables.

> *p.5, line 115: An average reader is not familiar with the devices you mention. This requires a more thorough description of the functionality of the device whose data you use, and possibly also a picture with a description.*

We can add a more detailed description, but we would prefer not to include another image, since it is already included in the cited work and this manuscript will contain many illustrations nonetheless.

> *p.5, line 120: Please provide an example of this procedure using relations (12) and (13) with specific values and a specific result and with an appropriate comment.*

We will include a figure and an explanation to illustrate the fitting and shifting process in detail. This is exemplary shown in Fig. 3.

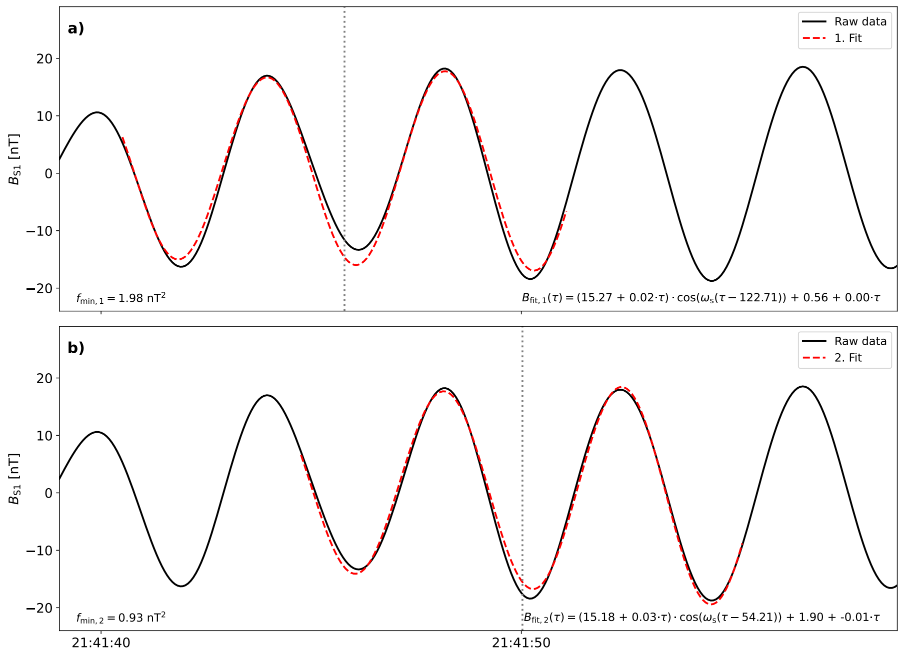

Figure 3: Two consecutive fits applied to the modified raw data (black) to calculate B_{pSA}. The dashed red lines represent the applied fit which is only defined where drawn. The fit in panel b) is shifted by one spin period compared to the one in a). In addition, at the bottom we present the f_{min} values and the fitting parameter for each fit.

> *What is the origin of the amplitude $A(t)$ in the weight function $w(t)$, p. 6, line 126? What are the criteria for its magnitude? Please, provide details.*

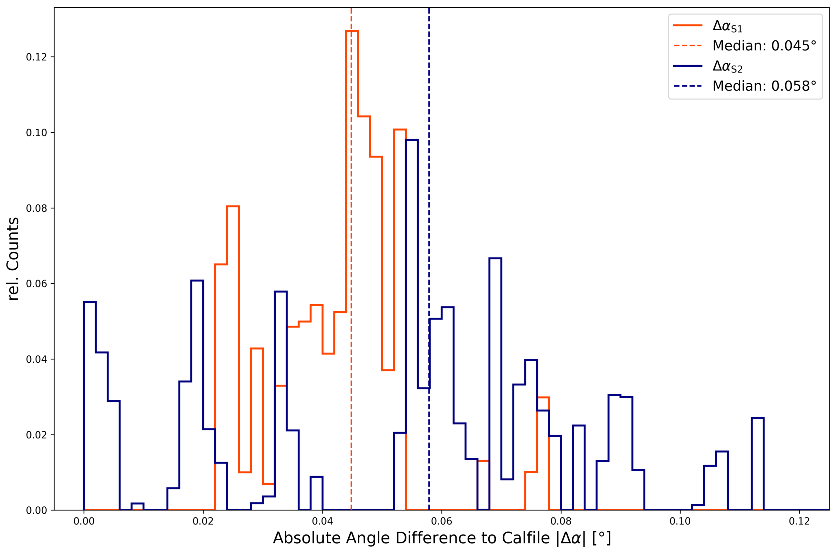

Figure 4: Difference between α values from comparison of model field and B_{pSA} and values from the calibration matrix.

The parameter $A(t)$ stems from the idea to not down weight intervals with large magnetic fields. But since $A(t)$ is not changing meaningful over the duration we average (1 minute), we changed the weighting to $1/f_{\mathrm{min}}$ and include a scaling with time distance.

> *The angle α (α_{S1}, α_{S1}) does not come from measurements or from the derivation of the matrix C - on the contrary, it must enter the calculations as a data known from the technical settings of the device. Please clarify this fact on p. 6, 7. If this is not the case, I consider it impossible to solve the considered problem - then the equation (2) has all input quantities unknown.*

We derive the angle α by comparing our recovered projected spin axis contribution B_{pSA} with the model field near perigee. We assume that this provides a sufficiently accurate estimate, since the model field is a good approximation of the actual field near perigee. To verify this, we compared our estimated α values with those from the calibration matrix over a three-year period from 2017 to 2020. This is shown in Fig. 4.

As can be seen from the histogram, the angles differ only minimally, with median values of 0.045° and 0.058° for α_{S1} and α_{S1}, respectively. We agree that we need to be more precise in our wording and will revise the relevant sections of the manuscripts accordingly.

> *Please increase the size of the images.*

We will increase the size of the images.

> *Please add information regarding the data's affiliation to the period and probe in the description of Figures 5 and 6 (as well as to the other figures).*

We will add the information.

> *Conclusions: Please, design the optimal geometric arrangement of the sensor axes and justify it.*

We agree that this statement should not be made without adequate justification. As referee #1 also noted, we must first analyze the implications for the calibration method currently in use, as well as the errors and accuracy of the parameters. Since this would go outside the scope of this work, we will soften the statement.

> *Minor corrections:*
>
> > *p.1, l.3: ...including a set of fluxgate magnetometers that measure...*

p.1, l.21: ...predefined rate denoted as Tspin... please correct. Provide the value.

p.2, l.36: ...six orientation angles... please, explain or correct.

1. We kindly disagree, since there is only fluxgate magnetometer on each spacecraft.
2. We will provide a range since T_{spin} changed during the duration of the mission.
3. We will briefly mention the orientation angles and will refer to the section 2.1 where we explain the geometry in more detail.

References

Auster, H., Glassmeier, K., Magnes, W., andW. Baumjohann, O. A., Constantinescu, D., Fischer, D., Fornacon, K., Georgescu, E., Harvey, P., Hillenmaier, O., Kroth, R., Ludlam, M., Narita, Y., Nakamura, R., Okrafka, K., Plaschke, F., Richter, I., Schwarzl, H., Stoll, B., Valavanoglou, A., and Wiedemann, M. (2008). The themis fluxgate magnetometer. *Space Sci. Rev.*, 141:235–264.