Response to Reviewer 1:

We extend our sincere gratitude to the reviewer for their insightful comments, which have significantly guided us in strengthening our manuscript. In response to the reviewer's suggestions, we have revised the manuscript, with changes highlighted in blue text in the revised manuscript. Below, we provide detailed responses to each of the reviewer's comments.

One could also argue that your title is too generic or even misleading. After all, your own observations exclusively focus on the magnetic field, but (somewhat surprisingly) ignore plasma effects like e.g., the role of the solar wind pressure, possible magnetopause boundary layers, transport mechanisms etc. This should be reflected in the title.

....

We have now updated the title to better align with the focus of the current study.

....

Major concerns

My major concern about the paper is the methodology (or possibly the explanation or my understanding of the methodology). Rather than actually observing magnetopause crossings, you seem to rely on deviations between the measured field and a model field (IGRF). Plasma or particle aspects, e.g, plasma or thermal pressure are largely ignored. This raises several questions that should be addressed:

1) From my understanding, you identify the magnetopause as the region where deltaBz is 0, i.e., the measured and modeled magnetic fields are identical along the Z axis (line 106, and marked with cyan contours in the plot). How does this signify the magnetopause? Does it not only show where the model (IGRF) agrees with measurements? Some elaboration is needed here.

....

We acknowledge the referee's observation that at the location where $\Delta B_{Z}=0$, the observed and modeled magnetic fields are identical, i.e., $B_{Z}^{Observed}= B_{Z}^{IGRF}$ at the magnetopause.

To avoid confusion, we have now included plots of the observed B_{Z} without the IGRF subtraction in the revised manuscript. This addition will provide a clear representation of the magnetic field variations and the location of the magnetopause.

Our primary objective was to determine the average location of the magnetopause during substorm phases, and whether or not we subtracted the IGRF did not affect the behavior of the magnetopause during these events.

……….

2) Your figure 1 shows maps of these magnetic field deviations. Here, I am critical to the use of IGRF outside of the magnetopause. Your map covers up to 20 Re sunward, i.e., well outside the typical magnetopause and well into the magnetosheath, or possibly into the pristine solar wind plasma region. How valid is the IGRF here ?

………..

Beyond $X > \sim 10$ R_E on the dayside, the internal magnetic field is zero, and only the external (modeled) magnetic field is displayed. As our analysis focuses on the location of magnetopause, we are not concerned with the external field in the solar wind, and we did not discuss it in this study.

Although, earlier we subtracted the IGRF from all observed BZ values for the sake of consistency only. But now in the revised manuscript we plotted observed Bz without IGRF subtraction in Figure 1, 2 and obtained same results.

………..

3) The color scale in Figure 1 is not really ideal to illustrate deviations, but in my eyes, the most pronounced feature is the red region (i.e., largest negative deviation between measured field and IGRF) close to Earth. This is unclear to me. I would expect that the best agreement would be close to Earth where IGRF is a much better representation of the model field than e.g., in the solar wind. I know that this is outside your focus region, and you mask it out in later plots. Still, this is an eye catcher of this plot and needs to be explained (even if you do not show it visually).

………….

Sorry for the confusion.

The region near the Earth appears to be predominantly influenced by the modeled field (IGRF), as indicated by the presence of negative magnetic field values. The exact reason for this dominance is currently unclear and requires further investigation.

In the revised manuscript, we have chosen to mask the region within 4 R_E (Earth radii) around the Earth, as depicted in Figures 1 and 2 of revised manuscript. This decision was made because this particular region contains high dipole field values, which are not the primary focus of our study. By masking this region, we can direct our attention and analysis towards the specific aspects that are relevant to our research objectives.

....

4) There are also a couple of inconsistencies regarding the position of the magnetopause and the underlying reason for this. I think the effects of motion due to reconnection (i., e the actual reconnection process) and magnetopause motion due to pressure imbalance are mixed up at times, or not fully consistent with existing knowledge. See details below.

....

There are a number of studies who identified inward motion of magnetopause during southward/northward IMF. The motion of the magnetopause is a dynamic interplay between the IMF, particularly its Bz component, and the solar wind dynamic pressure. Changes in these factors lead to the contraction or expansion of the magnetopause.
$tsyganenko and Sibeck (1994),
fairfield (1971),
sibeck (1991),
Shue et al., (1997),
Aubry et al., (1970)$

....

Minor issues

During reading of the paper I came across a number of minor issues that should be addressed. Number given refer to line numbers the draft.

9: '..the magnetopause undergoes a significant compression..'. I doubt that the dayside magnetpause can be much compressed, i.e., get thinner; I think you mean motion or inward/outward displacement here.

…………

Sorry for the confusion. we were trying to say that the magnetopause moves significantly towards Earth. Now we rephrased the sentence in the revised manuscript.

………….

20: You should specify 'dayside' magnetopause here; it is unlikely that the flanks of the magnetopause can be shifted to geosynchronous distance. Also, I do not think that erosion due to reconnection can significantly move the magnetopause. The inward motion is more likely cause by enhanced dayside pressure; In the conceptual Dungey cycle, flux just circulate, so flux tubes eroded in the dayside are replenished by the return convection.

……….

Sorry for the confusion. We have now corrected the sentence and provided the appropriate references.

……….

49: I suggest to remove 'boundary'. I think you mean magnetopause (which is a boundary in itself, and should not be confused with magnetopause boundary layers, which are layers of plasma adjacent to the magnetopause. You do not use plasma observations in your study) here.

………..

Now we have removed the misleading word in revised manuscript.

………..

50: I would have emphasized that all your measurements are from the low latitudes (equatorial orbits).

....

Yes, the orbits of the RBSP, THEMIS and MMS satellites are near the equatorial plane, which corresponds to low latitudes. These missions are designed to investigate key processes in the magnetosphere, many of which occur in the near-equatorial plane.

....

55: The number of substorms is repeated many times (e.g.,lines 55,78,95...), but when discussing phases (lines 100-105), the numbers do not add up. Please check.

....

We have corrected in the revised manuscript.

....

65: What does 'higher-altitude orbit' mean?

....

For a magnetospheric satellite in an elliptical orbit, altitude can be related to the apogee (farthest point from Earth) of the orbit.
For MMS, we used near-equatorial, higher-altitude orbit with apogee ~30 RE, THEMIS has apogees of ~ 12 RE and RBSP ~6 RE. Now we mentioned their apogees in the text to avoid confusion.

....

88: repeated information. See line 73.

....

Now we have removed the repeated sentence.

....

91: '..small scale deviations due to substorm processes..'. Deviations from the IGRF model can also be caused buy other processes than substorms. As noted above, I also question the validity of the IGRF model close to the magnetopause.

………..

We have now plotted the observed magnetic field (without IGRF subtraction) in Figures 1 and 2 and updated the text accordingly in the revised manuscript.

……….

95: Unnecessary repetition of number of substorms.

……….

Now corrected

……….

Fig 1: I think this figure is misleading. The color coding indicate strong deviations (red color) from IGRF close to Earth (where one would expect the best agreement). Although this is not your main focus region, it may indicate a flaw in calculations or measurements, and should be investigated and explained.

………..

Now we have plotted observed Bz (without IGRF subtraction) in Figure 1, 2 and mask the region within 4 R_E in order to avoid confusion related to the strong deviations (red color) from IGRF close to Earth.

………..

139: '..during this phase..'. Which phase of the substorm is discussed here ?

……….

Now corrected.

……….

141: 'As the magnetosheath…'. I do not understand this sentenced. Particles can be reflected at shocks and boundaries, but I have never heard about reflection of a magnetic field. Likewise, I have a hard time understanding the next few lines. The discussion about the ring current, R2 currents (which, to my knowledge usually designate ionospheric field aligned currents closing at the magnetopause) is somewhat confusing. Can it be improved ?

……….

Sorry for the confusion. By the sentence "reflection of a magnetic field." we mean to say that "this is an indication of an IMF maximum….". Now we have rephrased that sentence.

We have now removed the misleading sentence related to the R2 current in the revised manuscript.

………

158: I do not fully understand why the substorm recovery phase would imply a further compression of the magnetopause, and it is not consistent with your statement in line 8 (abstract, where you use the therm 'relaxation')

……….

Sorry for the confusion and now we have corrected that sentence in the revised manuscript. Notably, our findings show outward motion of magnetopause during substorm recover phase.

………

169, 174: You here discuss displacements of the order of a a few 100 km. I would be very careful when interpreting such small numbers - they are most likely well below the uncertainty in methodology or model output.

………..

We agree with the reviewer's observation that the displacements of the order of a few 100 km is very small, but the tendency of magnetopause moving outward during

substorm recovery phase, clearly visible in in-situ measurements (Figure \ref{fig:difference} e, f), is supported by the Shue model as well (Table 1).

....

203: Regarding standoff distance and Fig 3. From my interpretation, the motion is almost insignificant, and this statement is also inconsistent with the above comment and line 159 "..recovery phase..implying further inward motion..."

....

We have corrected the statement on line 159, ensuring it aligns with the statements on lines 203.

....

222: "..decrease in standoff distance due to..flux erosion..driven by reconnection". I think a better explanation is needed. The subsolar magnetopause is typically less than 1000 km thick (e.g., MMS results from Paschmann et al, JGR, 2018). The inward dispacements reported here are much larger than this, and I think it is more correct to say that a change in pressure balance, rather than the reconnection process itself cause this displacement of the magnetopause.

....

We have removed the sentence to prevent any confusion and elaborated it more in the revised manuscript.

....

Table 1: This table gives the impression that the standoff distance is solely governed by IMF Bz, but what about the solar wind dynamic pressure and other parameters?

....

It is well-known that changes in the magnetopause location arise due to variations in the IMF B_Z, dynamic pressure, and other factors. However, its position is heavily influenced by solar wind pressure. We studied separately the variation of r_0 with respect to changes in solar wind dynamic pressure. For pressures ≤ 2 nPa, r_0 is approximately 10.7 R_E during pre-onset and 10.73 R_E near the substorm end. For higher pressures (≥ 5 nPa), r_0 is about 8.6 R_E during pre-onset and 8.7 R_E near the substorm end. This indicates that solar wind pressure has a more significant effect on the magnetopause location than the IMF B_Z. However, similar to the results for IMF B_Z changes, the variation in r_0 during substorm phases is minimal and thus figure not shown in this study.

……..

278: This is the summary, but this paragraph starts with a fairly detailed interpretation of Figure 1 again , including references to single panels and details that partly repeats the earlier descriptions starting around line 95. I suggest to simplify and to synthesize the text here.

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Thank you for your suggestion. I have now revised the discussion and summary to make it more concise and clear. Please see the revised version in the revised manuscript.

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