Response to Reviewer 2:

We would like to thank the reviewer very much for providing insightful comments which guided us strengthen our manuscript. Based on the comments of the reviewer, we have revised the manuscript. Please find below our detailed responses to each of reviewer's comment.

Major comments:

1. Overall, the method for identifying the magnetopause location is very simplistic, potentially overly simplistic. The average magnetopause location is identified using the Shue model, which is parameterized by quantities from the solar wind only and does not account for, e.g., variations in the internal magnetospheric pressure.

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Reply: We agree with the reviewer that the Shue model relies exclusively on solar wind parameters and was not initially designed to account for variations in internal magnetospheric pressure or substorms. Despite this limitation, we opted to use the Shue model in this study due to its simplicity and reliable measurement technique, enabling us to simply estimate the average distance of the magnetopause from the centre of the Earth and its shape at various substorm times. Its predictions offer valuable contextual insights for interpreting the statistics derived from the magnetopause using multi-spacecraft data.

Selecting to use a model based on solar wind parameters only as a reference allows us to examine the changes in the internal state of the magnetosphere during substorms, and its impacts on the magnetopause position. Without such a reference value, it would be difficult to know whether the position is affected by solar wind conditions or by substorm-associated changes in the magnetosphere. ....

2. An observed magnetopause location is extracted from contours of the difference between the average measured magnetic field and the IGRF. It is not clear why this method is chosen as sharp gradients of plasma density, plasma beta, changes in the composition of minor ions, etc. are more commonly used – and arguably superior – identifiers. (While the ion composition is not measured by THEMIS, it is by MMS and Van Allen Probes). The study does not provide an adequate justification of the choice of methodology, i.e., a justification that the choice of data and models are useful for studying fundamental physical processes (erosion / compression / etc?)

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Reply: We agree with the reviewer that methods such as magnetopause crossings, sharp gradients in plasma density and plasma beta, and changes in minor ion composition are commonly used to determine the magnetopause location. However, in this study, we relied on identifying sharp gradients in the observed magnetic field, which effectively serves the same purpose. Magnetic field data, readily available from all the space missions (THEMIS, MMS, RBSP), provid a consistent and reliable means of analysis. In contrast, studying magnetopause location using ion composition data posed challenges due to its unavailability across all these spacecraft.

Additionally, 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.

Using time series during magnetopause crossings to examine the magnetopause position is possible, but that methodology does not allow for binning the data with respect to substorm phase, as the crossings occur at random time intervals. The statistical method employing all data and seeing where the field changes from that dominated by magnetospheric currents to one that is dominated by the IMF is the only way to discern the relatively short time intervals separating the substorm phases.

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3. Line 103 throughout: “In the five-year study period, the magnetic field measurements correspond to approximately 1502 substorms during northward IMF conditions and 3458 substorms during southward IMF conditions and 116 without both orientations.” More information is needed in this section to explain how the northward vs southward IMF categorization is performed. It is not until section 6 that I found the explanation “The initial step involves computing the average of the IMF BZ for each substorm (from onset to recovery end)”.

Furthermore, the authors should justify this choice. For instance, if the IMF is southward or small during the growth phase but northward on average, erosion of the low-latitude magnetospheric field may still contribute to the magnetopause location.

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Reply: The first step involves aggregating magnetic field measurements from all satellites over the five-year period, resulting in nearly 15 million data points when averaged over 1-minute intervals. This magnetic field data is combined with solar wind data, specifically the IMF B_Z and dynamic pressure, obtained from the OMNI database and also averaged over 1 minute. We utilize a list of substorms and develop an algorithm to identify the time intervals from the onset to the end of each substorm. This approach enables us to compute the average of IMF B_Z for each substorm period (from onset to recovery end), offering insight into the typical value of IMF B_Z during each event. We then filter the data based on IMF B_Z values, distinguishing between IMF $B_Z > 0$ (northward IMF) and IMF $B_Z < 0$ (southward IMF). This allows us to estimate the number of substorms occurring under both northward and southward IMF conditions. During the study period from January 1, 2016, to December 31, 2020, we observed a total of 5,077 isolated substorms. Of these, the majority (3,458) occurred during periods of southward IMF, compared to 1,502 substorms during northward IMF. Additionally, 116 substorms occurred independently of any IMF changes.

The justification for choosing substorms during northward/southward IMF B_Z is that there is a strong correlation between IMF B_Z and the occurrence of magnetospheric substorms. The more prolonged and intense southward IMF B_Z, the more energy is transferred into the magnetosphere, leading to more frequent and intense substorms. When the IMF B_Z is northward, the probability of substorm occurrence is lower. However, substorms can still occur, often due to other processes or prior build-up of energy in the magnetotail.

The erosion of the magnetospheric field is linked to the IMF's orientation, which could indeed impact the magnetopause location (although small) through magnetic reconnection (lines 20, 30). By separating data based on IMF $B_Z < 0$, we can monitor the magnetopause location specifically during southward IMF conditions. Similarly, analyzing data with IMF $Bz > 0$ allows us to examine the magnetopause location during only northward IMF, avoiding confusion between the two scenarios.

We have included this text in the revised manuscript.

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4. Fig. 1: It would be useful to understand how many magnetic field measurements / data points are available per bin. The differences in the spatial distributions of the "B" parameter are very subtle from one substorm phase to the next. Is the coverage sufficient to call these differences physical?

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Reply: Each panel in Figures 1 and 2 consists of 820 bins, but the number of data points per bin varies. In the panels showing in Figures 1a, 1c, 1e for northward IMF, the number of data points in the bins ranges from 0 (lighter bins) to a maximum of 351 (darker bins). In contrast, the panels depicting in Figures 1b, 1d, 1f for southward IMF contain more data points per bin, with counts ranging from 0 to a maximum of 700, reflecting the higher number of substorms during southward IMF periods.

As illustrated in Figure 1, the magnetopause displacements during substorm phases are minimal. However, the outward movement of the magnetopause during the substorm recovery phase is clearly evident in the in-situ measurements (Figure 1e, 1f). This outward shift is also prominently displayed in Figure 2e, 2f, where the red color indicates an increase in the magnetic field. The Shue model further supports and confirms this tendency of the magnetopause movement, as shown in Table 1. The subtle variations in the spatial distributions of the ΔB parameter from one substorm phase to another are indeed a critical aspect of our findings. We emphasize that while these differences may appear minor, they are derived from a comprehensive dataset collected over a five-year period, which includes a significant number of substorm events. This extensive dataset enhances the reliability of our observations and supports the assertion that these differences are physical rather than artifacts of limited data coverage.

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Minor comments:

1. Line 36: "Substorms are transient phenomena that occur in the Earth's magnetotail, storing and releasing solar wind energy through an explosive process". The second sentence in this paragraph is a more accurate introduction of substorms. It is not correct that substorms are phenomena in the magnetotail (exclusively).

.... Reply: Now we have corrected the misleading sentence in the revised manuscript as "Substorms are dynamic and transient phenomena that play a crucial role in the Earth's magnetosphere, storing solar wind energy and then releasing it through an explosive process"

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In addition to addressing the reviewer's comments, we have made further edits to the manuscript in response to the first reviewer, with all changes highlighted in blue.