# Response to Referee Comment 1

Yann Pfau-Kempf on behalf of all co-authors

March 28, 2025

We thank the referee for the kind words and constructive review which will help us improve the paper. We reply point-by-point below (*in italics*).

Line 41: The authors use the term flux rope for both FTE and plasmoid, but what about Kelvin Helmholtz vortices? They are not mentioned until the very last paragraph in the conclusions. If they are, or are not included in the 'flux rope' definition here it should be mentioned.
*We will clarify that flux ropes can form as part of the development of the Kelvin-Helmholtz instability, as observed e.g. by Hwang et al. (2020)* `https://doi.org/10.1029/2019JA027665`.

Figure1: Have you looked at the boundary points in terms of the points which fail only one of either R+ or R-? They would be the edges of the flux rope structure and might be regions of interest themselves.
*These points will certainly be of interest in more focussed studies on particular flux ropes, but they would clutter the figures in this work too much. Any point along the field line would be a one-sided detection, thus flagging significantly larger volumes than just the vicinity of the flux rope.*

Line 115: Why 'significantly larger than the domain size'? I would assume if the traced point leaves the domain then surely the point is not flux rope.
*As explained in Section 2.3, due to the discretisation it is possible some traces keep circling around a certain region for long distances, hence the need for such termination conditions.*

Line 145: How is the fraction of omitted cells decided? Is it random, or geometric conditions set by the user?
*This is left to the appreciation of the user. In our runs, at most 0.05% of cells were left unresolved for the full-domain tracing yet it was ensured all flux-rope detections had completed. This reduced the time spent on the tracing algorithm by an estimated 30–50%. We will add a mention of this in the text.*

Line 165: What radius are the field aligned currents coupled from? The data availability statement notes the large size of the output data, but it may beneficial to upload a simulation parameter input file ( or text file summarizing the simulation input parameters) for future comparisons.

*The coupling radius is set to 5.6* $R_\mathrm{E}$ *in this run, we will add this information to the text. The dataset including the configuration files is now publicly available and we will include the reference to it.*

`http://urn.fi/urn:nbn:fi:att:3ce0f038-2c69-4c7c-8f67-7a71e9e57b56`

Figure 2: This is where a quantified measure could be helpful. In the snapshot it's clear there are more points identified with a larger Rcutoff, and at least one flux rope is missing between 3Rc and 7Rc. What I would like to see is what is the total flux rope volume for each of these panels? This could then be included in the video or even shown as a time series with a curve for each Rc setting. It could help justify the selection of Rcutoff = 7Rc.

*This is a good suggestion. We propose to include the figure below and discuss it. It shows the total volume of the detected simulation cells as a function of time for various* $R_\mathrm{cutoff}$ *in panel (a) and as a function of* $R_\mathrm{cutoff}$ *for various times. These show that there is a range of suitable values around 7. A much lower cutoff value (below 5–6) leads to significantly less volume detected, whereas much higher values (beyond 8) lead to a rapid increase in the detected volume.*

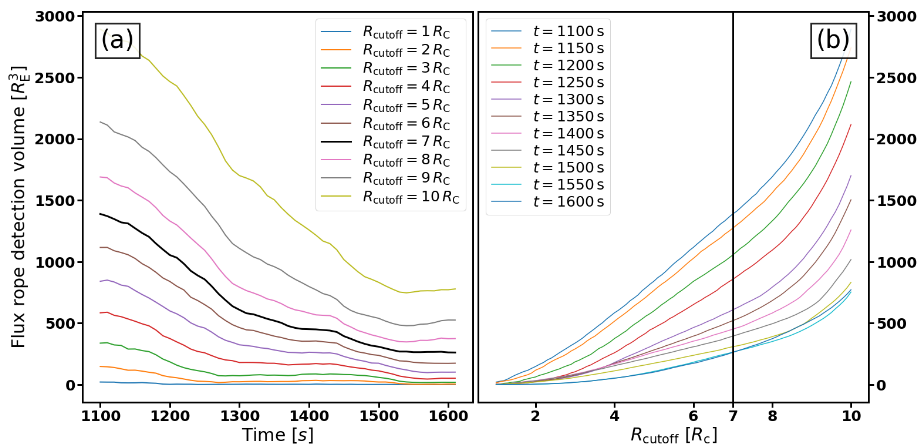


Figure 4: The + and circles in panels e and f are difficult to distinguish between.

*We will change the markers used to distinguish them better.*

Line 245: With both the yellow circle O points and the green flux rope points, perhaps the coverage of the O points (within some distance threshold) could be reported here and used as validation. It could be reported as a percentage over time, again for the different choices of Rcutoff to show that 7Rc performs the best.

*Without an adaptation of the distance threshold around O lines due to varying scales, we think this would be too crude an approach. On the other hand, a more rigorous comparison would in the end require some determination of the volume surrounding either O lines or detected cells* *(this study's method), by tracing or other proxies (like Paul et al., 2022), which we would rather leave for upcoming studies. We think the spatio-temporal correspondence of the yellow circle O markers and the regions detected in green is sufficient as a cross-validation at this stage.*

Figure 5: The satellite traces may show a better structure crossing if put into LMN coordinates.
*The "traditional" LMN coordinate system based on the normal direction to the magnetopause is difficult to determine in this case as the magnetopause has a rather complicated shape. However performing a Minimum Variance Analysis in order to single out the component with least variation allows to extract the flux rope's signature more clearly and we will include this in the figure.*

Figure 6: I believe the X and Y scaling (horizontal axes) is different between some panels in the same column. This made it difficult to understand the point about the cross section shrinking. It would improve comparison between panels in a single column to have the scales the same.
*The frames are scaled to best highlight the flux rope structure, especially with the magnetic field stream lines. It would be harder to make out with the larger frame of the top panels for the lower ones. We will add a reference scale on the plots to guide the eye and better illustrate the varying frame sizes.*

Figure 7: Great use of perspective to summarize the flux rope detection results. Again, could be improved with an indication of how many flux ropes were found for each contour level. If identifying contiguous flux ropes is not currently possible, at least the total number of points (or volume of all points?).
*We have not yet developed a method to identify and track single flux ropes. However, we think it would make the figure difficult to construct and understand when adding the information of the coverage volume that would sum over spatial dimensions as well as time.*

Line 349: Figure 7 demonstrates that no dayside flux ropes survive to X=0, but is there a gradient or a sudden cutoff? If it is reconnection eroding the structure, maybe larger FTEs make it further downstream before vanishing?
*As can be seen in Figure 4 and especially the Supplementary Material Animation 1 indeed larger FTEs survive a little longer along the magnetopause, so it is not completely abrupt, but given the steep inclination of the magnetopause it is indeed so that all FTEs in the noon sector erode away between 4 and 0* $R_\mathrm{E}$.

Line 351: "any section of the flux rope presenting a magnetic field configuration anti-parallel to the lobe magnetic field will erode away due to magnetic reconnection." Consider rewording slightly. The results only show a single flux rope that has its anti-parallel portion eroded, while every flux rope with such conditions could experience such erosion, it was not shown that this occurs in every instance. If the results do show this, then that should be included explicitly in the results section.

*We are led to this interpretation through the combined evidence of the FTEs eroding through reconnection at high-$|z|$ in Figure 4/Supplementary Material Animation 1 and Figure 7, the case study shown in Figure 6, and other flank flux ropes we have investigated but not shown here. We will reword this paragraph to better reflect this.*

Line 356: Can it be estimated from these results what percentage of flux ropes are vanishing over the poles vs surviving downstream? Does it match some geometric ratio of the portion of the dayside X line length?

*See next response.*

Line 377: Similar to above, it's mentioned that 'such a prediction would be perilous'. While I agree that a single simulation should not be over-extrapolated, the results can certainly be reported. How many low latitude flux ropes were found for this time interval? How does that compare to the number that vanished over the poles? The answer will be limited to this simulation setup, but nonetheless interesting.

*In a global-scale, fluid-like picture a simplified geometric argument could be likely made. However e.g. Figure 2, and our previous work (Pfau-Kempf et al., 2020, `https://doi.org/10.1063/5.0020685`), show that the geometry of the reconnection site is non-trivial and leads to intricate structures such as the curved flux rope from Figure 5/Supplementary Material Animation 2. Once a method is developed to characterise flux ropes as distinct objects, it will be easier to try and address this issue by investigating the shape and orientation of the flux ropes and their evolution as a function of time and magnetopause clock angle.*

*We however suggest to provide an estimate of the rates of occurrence based on the figures and animations of this work. From Supplementary Material Animation 1 one can estimate that 6 (5) FTEs vanish over the North (South) cusp over the interval of 539 s, yielding an occurrence rate of about 1 FTE per 100 s per hemisphere. In Figure 3, one can identify 4–5 flux ropes between 0 and $-100\,R_\mathrm{E}$ on each flank, while Figure 6 provides an estimate of the transport velocity, namely 30 $R_\mathrm{E}$ in 300 s, or $100\,R_\mathrm{E}$ in 1000 s, which means that there is one flank flux rope passing by in about 200–250 s on each flank. This compares remarkably well with the observations of Eastwood et al. (2012) so we will include this estimate in the discussion.*

Line 397: Does this imply that there may be holes that form in the field of flux rope points? Will this then make it more difficult to identify individual contiguous flux rope structures?

*Indeed, theoretically the curvature radius is very large at the centre of a flux rope with axial field and the method may not flag that region as sufficiently rolled up. In practice, with the discretisation of the model setup taken into account, we do not expect this to lead to significant holes. Refining* *the identification of contiguous structures with local proxies should yield robust results. We will clarify the discussion in this respect.*

Line 449: How would this method tell the difference between a rolled up KH vortex and a low latitude flux rope which has been carried downstream?
*This tracing method by itself does not characterise flux ropes further. But it serves as a starting point to identify individual flux ropes as distinct objects, as mentioned above. Further information such as the forward or backward end points of the field lines could be used to discriminate between the low-latitude flux ropes and KH vortices, or heat flux signatures (e.g. Tarvus et al., 2023, https://doi.org/10.3847/1538-4357/ad697a). We will add these considerations to that paragraph.*