Reply to the Referee comments by Dr. Alexandra Fogg:

We would like to thank Dr. Fogg for carefully reading the manuscript and sharing helpful comments and suggestions. The manuscript will be revised accordingly. Please see below our response to each of your comments and suggestions.

In this paper, the authors present Swarm density data during the Starlink loss event of February 2022. They also present some data showing the timeline of tracking by NORAD, including orbital altitudes. They conclude that none of the previously presented mechanisms can account for the satellite losses.

The paper is generally well-written with few typographical errors. I include major and minor comments below. Thank you for inviting me to review this paper, I would be happy to review it again if needed.

- Thank you. We will carefully look for any typographical errors and correct them. All your major and minor comments will be addressed in the revised manuscript.

Major comments

1. Overall I felt the paper was a bit light on citations, and detailed description. I think in general a more detailed discussion of the implications/results of the work is needed to really emphasize the impact. I indicate some places where discussion needs expansion in the minor comments.

- Thank you for pointing these out. We will improve the citations and descriptions in the manuscript to emphasize the impacts of the results.

2. Just a note for the editor to consider. I am not sure whether this paper fits within the remit of NPG? On the NPG website (https://www.nonlinear-processes-in-geophysics.net/about/aims_and_scope.html) is says the journal "solicits **disruptive and innovative concepts and methodologies**, as well as original applications of these to address the ubiquitous complexity in geoscience systems". Although this paper has merit in terms of new data etc, I am not sure if it is presenting any new concepts/methodologies. Perhaps the authors could comment on this.

- Although this comment was directed to the Editor, we would like to emphasize that our article is pointing to an unexplained cause of a large loss of satellites. The physics behind the losses is not explained by any of the already proposed mechanisms. The real cause for such a large loss may lead to a new physical process acting in the high atmosphere that could be vital to our technologic space based devices. Such an event with so many spacecrafts would be a nice opportunity to understand the satellite loss

mechanisms, since the individual data for all those spacecraft may provide a space resolution not seen before during a disturbed event.

Minor comments

1. Lines 19-26. Please could you consider including some more recent citations for storm work. For example, work by Walach et al (2019, https://doi.org/10.1029/2019JA026816) suggests an expansion to perhaps even 40deg latitude.
   - Thank you for the reference. This will be discussed in the revised manuscript.

2. On line 34 you note that there are three published scenarios (Tsurutani, Dang, and Fang), but you don't describe them. Please briefly describe what each of those papers propose, since this is key to your paper.
   - The description of the mechanisms proposed by those papers was in the section 8, around line 240. But since you mentioned, we noticed that it may lack for a first-time reader of our article. We have included a short description of each one in the introduction. Thank you.

3. Section 2 is quite light on references. You assert lots of facts about the scenarios – please could you include citations for these. If no papers are available, a webpage citation for where you got the information will suffice.
   - Thank you for the suggestion. We have included suitable citations to the stated facts.

4. Line 75: how did you determine the onset time of this flare / CME eruption? It appears to be from a list – please cite where you got it from.
   - The CME eruption is estimated based on the ICME velocity observed. This information is used to identify the flares observed by GOES X-ray sensor. We now have made it clear to the reader in the text and include the references.

5. Line 79: did you investigate the driver of the second storm? Is it driven by the same CME event?
   - The interplanetary driver of the second storm is another magnetic cloud. A detailed discussion of the driver has been included. However, it was not possible to clearly identify a flare in the Sun that could be the origin of this event.

6. Line 82: for sudden impulse, please briefly describe what this event is rather than assert it. You should also cite Araki 1994 (doi 10.1029/GM081p0183).
   - Thank you. The paper is now cited, and we included a short explanation about the SI in the text.

7. Lines 80-99. In your description of the passing solar wind / storm events, it's very factual. I think this description would not be clear to someone who isn't an expert in storms etc. If possible, please could you link your descriptions to the figure – e.g. on line 87 you note the fluxrope signature. Please describe what a characteristic fluxrope signature looks like (including citation) and link back to where you see this in your figure. Please do similar for each of the signatures you discuss.
- Thank you for the suggestion. We have included a detailed definition and descriptions (with suitable references) for all major interplanetary structures.

8. Fig 1: it could be worth including a vertical line / shaded region which indicates the Starlink launch window. Also, you could indicate storm phases from a published list (e.g. Walach 2019 mentioned above).
- Thanks. We have updated the figure accordingly, including an arrow on the top of the figure to indicate the time of the Starlink launch.

9. Line 100. Please provide citations for the Swarm mission, data, and orbital characteristics.
- Thanks. The original reference for Swarm mission is "Swarm - The Earth's magnetic field and environment explorers. ESA report for mission selection (SP1269/6), April 2004". We have updated the text and included the reference in the paper.

10. Fig 2. Your choice of colour bar is not colourblind-friendly, and doesn't seem to be perceptively uniform. I would recommend changing the colourbar, and if not, at a minimum you could provide another panel which shows a timeseries of average density across some latitude window.
- Thank you very much for your suggestion. We have processed the figures again to use a colormap colourblind-friendly.

11. Line 125. I make it over 130% - you may as well state the exact percentage here.
- We have included exact values of the dayside and nightside ionospheric densities, as suggested.

12. Table 1: what is the cause of the 28.6% failure for launch number 76? Just a sentence with citation here as it's an obvious outlier with second biggest failure rate.
- This launch (Group 6-1) had several changes compared with the previous satellites. It was the first launch of larger, upgraded Starlink V2 Mini satellites with four times the bandwidth of previous models (so the reduced number of satellite compared with the previous launches, around 50). Also, it was the first use of a Argon-fueled Hall-effect thruster in space. Space-X also made changes in the tension rods to avoid release them in space. So, with those large changes, the number of losses was larger. We have placed a mark in this launch and the explanation in the Figure Caption. Thanks.

13. Line 155 “Some of these remaining 6 were also lost after a few tracking”. This sentence doesn’t quite make sense, please rephrase.
- The statement has been revised to “Some of these 6 surviving satellites were also lost after a few tracking”. Thank you.

14. Fig 3: I think the caption should be more descriptive, including: noting the numbers are “NORAD” numbers, explaining what the different coloured arrows mean, noting that the timeseries is SYM-H, etc. Please follow the descriptive style of your previous figure captions.
- Thank you for the suggestion. The figure caption has been updated/revised accordingly.

15. Fig 4 and 5: Please make the fontsize bigger, and perhaps make the figure the same width as the text. Lots of detail to be seen! It could be informative to put some indication of storm times on these panels (or perhaps just overplot SYM-H?).
- Thanks for the suggestions. The figures have been updated, as suggested.

16. Line 221: typographical error: survived->survive
- Corrected.

17. Line 222-223: you comment here about the wide variety of fates for the satellites. This is an interesting point. From my understanding of your introduction to Starlink launch procedures, they are ejected in different directions from the launch vehicle. Could that mean they are e.g. impacting the enhanced atmosphere at a different angle / time / velocity etc. Is there any correlation between the spacecraft that were lost and there position in the launch vehicle?
- We certainly considered this possibility. However, it is not possible to connect each satellite to the stack where it was attached. The telemetry data from the first moment after the release could indicate the direction, but this data is not public.

18. Line 235 – Please could you expand on this point rejecting Tsurutani 2022’s mechanism. If there was an enhanced density at 500 km, could there be enhanced densities below as well?
Yes, this is possible. But we feel that the density increase would be small and would not lead to a rapid loss of satellites.

19. Line 241 – missing year on Dang citation.
Corrected.

20. Line 250 – 254. How does your work contribute to / back up this theory? If not, what does your study suggest is the cause of the loss?

- Kakoti et al. (2023) showed different effects in Ionosphere and Thermosphere due to storms and substorms in different regions and altitudes. They used both ground and satellite observations, mainly TEC data, which are integrated in the whole column. In their conclusion, they also mention some possible mechanisms that could possibly lead to these disturbances ("Low-latitude ionospheric electric field/EEJ variation on 4 February could be related to the DDE, PPE field, and magnetospheric convection related to the substorm."). We believe that both our and their studies would benefit from local data from the telemetry of the lost satellites to pinpoint what is the driver of those changes in ionosphere, allowing us to create a complete scenario from the interplanetary disturbances to the ionospheric changes that lead to the satellite losses.

21. Section 8 – I would like to see a clear statement of what your work suggests the cause of the loss is. Could it be a combination of all the effects stated by previous authors? It was not an enormous storm, but did a bunch of small effects work together to create a tricky situation?

- To answer this is beyond the scope of the present work. It is possible but in our current thinking it is not probable. The very rapid loss of the Starlink satellites indicates that perhaps something more drastic has happened.

22. Line 262: the possibility of collisions causing the losses is remote – why? Citation for this? Could the geomagnetic conditions increase the possibility of this?

- As mentioned before, it is a possibility but we cannot affirm this due to the lack of telemetry data. Private communication with people related to the business mention the probability exist but is small.