

Reply to Referee 1

We thank the referee for careful reading of the manuscript and constructive suggestions. Below are our responses to the comments in red.

In the revised version, the authors have clarified that the phenomena investigated are not necessarily ULF signals themselves but rather the rapid geomagnetic variations in the ULF regimes. They have also expanded the introduction section by including a discussion of reconnection-related phenomena, such as flux transfer events. In addition, the title has been revised, and a new Figure 1 has been added to illustrate more clearly the phenomena investigated in this study. These revisions have significantly improved the manuscript. Nevertheless, several statements newly introduced in the revised version still appear to be awkward or unclear. This referee believes that further revision is necessary, particularly with respect to the following points.

1. Title: Please consider slightly revising the title for improved readability. For example, "High-latitude dayside rapid variations observed with ground magnetometers in Greenland."

Thank you for this suggestion, based on the response from both referees, we will update the title to the following: *High latitude, dayside rapid geomagnetic variations observed with ground-based magnetometers in Greenland*

2. First two sentences in the Abstract: Please consider revising the opening sentences of the Abstract. For example: We identify a previously unrecognized population of rapid geomagnetic variations associated with cusp dynamics. These variations produce distinct summertime signatures in the high-latitude ground magnetometer observations near the cusp.

Thank you for your suggestion, we have modified the abstract accordingly.

3. New subsection 2.1: The manuscript is introduced as a statistical study of rapid variations in the ULF regimes. However, Section 2.1 states that the proposed metric cannot distinguish ULF waves from other transient phenomena and should instead be interpreted as a measure of broadband geomagnetic signals. While acknowledging this limitation is important, the current presentation gives the impression that the scope of the study changes in Section 2.1. Rather than describing the authors' "initial intention", this referee suggests defining the metric from the outset as a measure of rapid geomagnetic variability within the selected frequency band and revising the corresponding text accordingly, so that the scientific objective remains consistent throughout the manuscript.

This is a good point. We will modify the text on L99 so that we define our metric earlier on in the following way: *The resulting metric, the smoothed signal $[[X_{ULF}]]_{10}$, is presented as the red curve in Fig. 1 (e) and is calculated as follows:....* In addition, we will modify the text in section 2.1 L107-109 as follows: *The "ULF" tag indicates the frequency band from which our metric extracts its information. In order to avoid confusion, it should be emphasised that it is not possible to separate ULF waves from other transient phenomena solely by using $[[X_{ULF}]]_{10}$.*

4. Lines 277 to 278 (Conclusions): Please consider revising "our study encourages a renewed search for cusp related ULF waves" to "our results motivate renewed investigations of cusp-related ULF waves."

That's a good suggestion, we will replace the first part of line 277 with the suggested text.

5. Lines 307-309 (Concluding paragraph): The concluding paragraph is generally clear, but several expressions could be improved. "Interesting features" is somewhat subjective and could be replaced with a more neutral expression. Likewise, "connected to the presence of ULF-like signals" could be expressed more concisely. The final sentence is also somewhat awkward because of the repeated use of "as well as". A more direct expression, such as "combining ground-based radar and satellite observations" would improve readability. In addition, the conclusion would be strengthened by briefly explaining why case studies are specifically needed, for example, to investigate the underlying physical mechanisms.

Thank you for these comments. We will update the text in L307-309 to the following: *We have identified several features connected to the presence of ULF-like signals at very high latitudes in the vicinity of the cusp. These deserve further investigation using ground-based radars and satellite data.*

Reply to Referee 2

We thank the referee for careful reading of the manuscript and constructive suggestions. Below are our responses to the comments in red.

Comments on Reply to Referee 2 Thank you for considering my comments so thoroughly. I have just have some further minor points then it should be ready for publication.

5 Regarding the title: ‘rapid variations’ is vague. Variations in what? ‘rapid geomagnetic variations’ is more precise.

Thank you for this suggestion. Based on the feedback from both referees, we will update the title to the following: *High latitude, dayside rapid geomagnetic variations observed with ground-based magnetometers in Greenland*

Regarding my second major comment, you state it is a ‘well known fact that the precipitation in the cusp is soft and hardly ionizes the E-region,’. If so, please provide references. It isn’t clear in your response what references you have added.

10 Appropriate references relating to this are on line 287 and onwards in the conclusion of the manuscript. In addition, we have added some additional text and the same references on line 198 where Fig. 5 is discussed: ... *where electron precipitation is soft ($< \sim 220$ eV) (Newell and Meng, 1988), and, thus, energy is deposited in the F-region above ~ 200 km, rather than lower in the ionosphere (Mantas and Walker, 1976; Banks et al., 1974).*

I do like Figures 1 and 2 in your reply. I’m glad they are included.

15 Thank you for your constructive feedback.

L74: ‘We are unsure what exactly the referee means.’ What I was trying to say was if you took the results from one of your stations, say STF, and could bin them by whether STF was on open or closed field lines, would this change the results. For example, do you get more detections when STF is on open field lines instead of closed? I appreciate there is ambiguity in determining which side of the OCB a given station is on. I think these results could be interesting. You have your Feldstein
20 model so even just using this to tag

Although we do not perform any binning according to open vs. closed field lines in this work, the location of the OCB is discussed with appropriate references on lines 215-236. We will bring the referee’s thoughts on this with us, for further investigations in the future.

Regarding my comment 7, I like this explanation. Make sure a comment on these lines is in the new script.

25 We will add the following text as we describe fig. 2 after line 141: *Field line resonances (FLRs) are often observed in the 45–600 s period range and are caused by compressional plasma waves (e.g., Samson et al. 1992 and reference therein). Considering that the station NAQ is in the very southern part of the auroral zone (64 degrees geomagnetic latitude), we do not expect this location to see the bulk of FLRs. They would appear more frequently deeper inside the auroral zone, towards the poleward edge of the aurora oval, where field lines map to regions close to the magnetopause in the dawn and dusk sectors.*
30 *Only during enhanced geomagnetic activity would we see them, and by scrutinizing Fig. 2(d), we in fact see a weak indication*

of this at around 6 and 18 MLT. At STF (Fig. 2(c)), we do observe a candidate signal of FLRs around this window more frequently.

Regarding your answer to my comment 11, you say the solar illumination increases. UV? X-ray? Be clear.

35 For clarification, we will add the following text to line 191: *The steady increase in the conductivity from year to year is caused by the simultaneous increase in the solar illumination as described by F10.7, which is a proxy of solar extreme ultra-violet radiation (EUV), (see Fig. 1F) as we approach solar maximum.*

Regarding comments 14/15, I think my confusion was regarding which mantle you were talking about. The ‘plasma mantle’ , or the hot rocky mantle under our feet! No harm in clarification.

40 Thank you for clarifying this. We will add the following text to line 248: ... *the absence of $[|X_{ULF}|]_{10}$ signals close to magnetic midnight at this latitude indicates that the ionosphere north of the station stops receiving such signals when the local magnetic field lines map into the magnetospheric plasma mantle.*

Regarding typographic comment 2 about ‘many to come.’ This implies to me references from the future, which I don’t think is allowed. You don’t need to put anything there at all, as you’ve put e.g. at the start. So just (e.g. ref1, ref2, ref3) is fine.

45 We removed "many to come" and replaced it with some additional references: Jacobs et al., 1964; Jacobs, 1970; Brekke et al., 1987.