Major comment

A general remark: I wonder how valid the MLT trend is at late dawn hours? Figure 2 shows that the number of data points in MLT bin 08 is rather small. I get the impression that Figure 5 has given guidance for the formula of Eq. 2, which inherently assumes the trend of increasing energy to cover also the late dawn sector. Do the already known properties of chorus waves or Arase observations support the trend to cover also early prenoon sector (with the recognition that the analysis by Ito et al., covers dawn sector until MLT 6). Furthermore, is there any risk that the energy estimates in the MLT bin 08 are somehow contaminated by illumination of the rising Sun?.

Response:

We agree that the 8 MLT bin is statistically less constrained due to the reduced number of observations. To assess its influence, we performed a sensitivity test by excluding the 8 MLT bin from the analysis. The post-midnight hardening remains present, with P($\beta_2 > 0$) = 0.91), compared to 0.97 when including this bin. This demonstrates that the late-dawn observations strengthen the statistical constraint but do not artificially generate the trend.

We will clarify in the revised manuscript that the 8 MLT bin should be interpreted with caution due to its lower statistical weight. We also note that statistical studies of chorus waves (e.g. Meredith et al. (2020)) show that chorus activity extends beyond the dawn sector toward pre-noon MLTs, supporting the physical plausibility of an extended hardening trend.

Regarding potential solar contamination, we performed an additional sensitivity test by retaining only spectra acquired under strict astronomical-night conditions, defined here as solar zenith angle larger than 108° (Sun more than 18° below the horizon). This filtering reduces the number of late-dawn events, especially in the 8 MLT bin. The Bayesian fit applied to this restricted dataset gives P$(\beta_2 > 0) = 0.99)$, compared with 0.97 in the original full-dataset analysis.

We also note that any residual high-altitude contribution to the 630.0 nm red-line emission would increase the red-to-blue ratio. In the lookup-table framework used here, this would bias the inferred characteristic energy toward lower values. Such an effect would therefore not explain an artificial increase of the inferred energy toward late dawn.

Minor comments

Line 28, Lorentz factor: This may not be a familiar term for all readers. Please, give a more detailed explanation for it.

We will give more details indeed.

Line 62, characteristic energies of electron precipitation causing optical pulsations: Extending the range to several hundreds of keV may not be appropriate here, because at those energy levels precipitation is a more relevant factor in D-layer chemistry than in auroral observations.

Indeed, we will correct this in the manuscript. Moreover, we will specifically cite Tesema et al. (2020) for discussing about several hundreds of keV electrons, relevant for the D-layer

Line 84, introduction of the ASIS at Tromsö: It would be good to give here also the relationship between UT and MLT for Tromsö, because it helps the reader to interpret some data plots later in this manuscript (e.g. Figs 1, 3, and 4)

The ASIS instrument has always been located at the Skibotn observatory, with the approximate relationship between UT and MLT at Skibotn (MLT $\approx$ UT + 2.5 h)

Line 102, classification by Nanjo et al.: Besides the auroral categories, it would be good to mention something about the AI-code capability to make distinction between cloudy conditions with background auroras and diffuse auroras.

We will clarify that the AI-based classification distinguishes diffuse aurora from other categories, including cloudy conditions and background auroral structures. In addition, a confidence threshold of 75% is applied to ensure robust event selection.

ines 127-128 introduction of the GLOW and Transsolo: The concept "stream" may not be familiar for all readers. Please clarify.

We will clarify the meaning of the term "stream" in the context of the kinetic transport models.

Figure 4, panel a: Colors in the strip showing AI categorization are confusing because they do not match with the colors given in the legend on the right side of the panel.

Sorry about that, this will be done

Equation 2: It becomes later clear in the text that "breakpoint" in the formula refers to MLT=4, but it would be good to mention it explicitly already here when introducing the formula. The "+" sign at the end of the formula is mysterious.

Indeed, this will be done, and the "+" sign removed

Lines 187-188: I guess that this is textbook material, but if possible with reasonable effort it would be nice to have a reference for the statement of 1.4826xMAD corresponding to the Gaussian-equivalent standard deviation.

We will add indeed a reference

Section 4.2, magnetospheric memory: The decision to discuss lags of 2 and 24 hours sounds a bit arbitrary... Is there a specific reason to select those two lag times? The conclusion of AE index exceeding 300 nT during the 24-hour period prior to pulsations to be a characteristic feature for the observed MLT trend is, in my opinion, somewhat weak, because ≥24h periods of continuous AE<300 nT are rather rare.

We thank the referee for this comment. We agree that the 24-hour interval is not strongly discriminant, as prolonged periods with AE < 300 nT are indeed relatively rare. Consequently, we have removed the 24-hour analysis from the revised manuscript.

To address related concerns also raised by Referee 2, we propose the following revised text in italic for Section 4.2:

4.2 AE over preceding time intervals

To test whether the observed MLT-dependent hardening depends only on the instantaneous geomagnetic context, we also examined the AE index over preceding intervals of 2 h and 6 h relative to each spectrograph measurement. This extends the type of analysis proposed by Hosokawa and Ogawa (2015) to a continuous spectroscopic dataset, while keeping AE as a proxy of geomagnetic context rather than as a diagnostic of the underlying scattering mechanism. The main result is that the post-midnight hardening remains visible even when the activity level is defined from AE over the preceding hours rather than from AE at the exact observation time.

For a 2-h preceding interval, the number of events classified as quiet (AE $<$ 100 nT) drops from 8167 to 2596. This indicates that many spectra recorded under low instantaneous AE are in fact preceded within the previous two hours by enhanced geomagnetic activity. As a consequence, the Bayesian posterior probability for a positive slope in the AE $<$ 100 nT class decreases from 0.996 (lag = 0 h) to about 0.75, while the class $100 \leq$ AE $<$ 300 nT shows a strengthened slope with $P(\beta_2 > 0) \approx 0.98$*. This redistribution does not contradict the main trend; rather, it shows that many intervals with low instantaneous Ae do not correspond to genuinely quiet conditions, but to a magnetospheric context still influenced by earlier activity. Intervals that remain in the AE $<$ 100 nT class even with a 2-h preceding interval therefore represent weakly preconditioned conditions, for which the positive energy–MLT trend is less clearly expressed.*

For a 6-h preceding interval, consistent with the timescale used by Hosokawa and Ogawa (2015) to characterize preceding substorm activity, the redistribution of events among AE classes becomes even more pronounced. In particular, the number of events classified as AE $<$ 100 nT is strongly reduced, indicating that most intervals with low instantaneous AE are preceded by enhanced geomagnetic activity within the previous several hours. At this timescale, the AE-based classification becomes less *discriminant, especially for the quiet class. Nevertheless, the post-midnight hardening remains visible. The trend is strongest for intermediate AE levels, with $P(\beta_2 > 0) \approx 0.997$, and more dispersed for highly active periods ($P(\beta_2 > 0) \approx 0.83$).*

Overall, these results show that the MLT-dependent hardening is not captured by instantaneous AE alone, and that its statistical expression depends on the broader geomagnetic context over timescales of several hours. In this sense, the AE analysis is used here to test the robustness of the spectroscopic MLT trend under different activity conditions, rather than to distinguish between specific precipitation mechanisms.

References

Hosokawa, K. and Ogawa, Y.: Ionospheric variation during pulsating aurora, Journal of Geophysical Research (Space Physics), 120, 5943–5957, https://doi.org/10.1002/2015JA021401, 2015.

Meredith, N. P., Horne, R. B., Bortnik, J., Li, W., Shen, X., Vellante, M., Piersanti, M., Magnes, W., Nakamura, R., and Santolík, O.: Global Model of Whistler Mode Chorus in the Near-Equatorial Region: Dependence on Geomagnetic Activity, Geophysical Research Letters, 47, e2020GL087 311, https://doi.org/10.1029/2020GL087311, 2020.

Tesema, F., Partamies, N., Kataoka, R., and Ogawa, Y.: Statistical study of diffuse aurora and its relation to substorm activity, Journal of Geophysical Research: Space Physics, 125, e2020JA028 037, https://doi.org/10.1029/2020JA028037, 2020.