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Interactive comment on "Electron precipitation characteristics during isolated, compound and multi-night substorm events" *by* Noora Partamies et al.

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We thank the referee for careful reading of the manuscript and raising important items for further clarification. Below are our responses to each comment, with comments in *italic*.

Point-by-point responses:

1. *The Introduction section nicely reviews the recent studies related to the evolution of magnetospheric/precipitating electrons during episodes of auroral substorm.*

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Discussion paper

However, it is a bit difficult to pick up "what is unknown in this research area? and what will be revealed in the current paper." This reviewer suggests the authors to pin-point the target of current study somewhere in the Introduction section.
The aim of the current study needs to be clear. It is the question of the precipitation during different types of substorms and during the evolution of a substorm, which has not been addressed by previous studies. At the end of the introduction this will be phrased as: "Our aim with this study is to investigate whether all substorms are equally influential to the neutral atmosphere, or whether the intensity, duration or internal structure of the substorms can be used to differentiate events which have a significant atmospheric impact from those which only have a negligible impact."

2. *I am confused of the difference between the IL and IL$_{asc}$ indices. My understanding is that IL is the local AL index made from the entire IMAGE network while IL$_{asc}$ is a similar local AL value but only with data from Lapland stations of IMAGE, is this correct?*
This is correct. IL is the local AL index based on data from the entire IMAGE network, and IL_{asc} only includes data from the 5 Lapland auroral camera stations. This is explained at the end of the section 2.1. For brevity we use the term "IL index" to refer to IL_{asc}, which may cause some confusion but we will re-phrase this in a clearer way in the revised version.

3. *In the current method, the expansion phase onset is defined as the start time of negative bay in the AL index. This reviewer well understands that this is the only possible way to identify the onset time from the AL time-series. At the same time, however, I suspect that this onset timing is slightly earlier than that of actual "optical" onset. Such a systematic delay can be seen in the examples in Figures 1 and 2. Do the authors have any discussion on the difference between the optical and magnetic onset?*
Absolutely correct. There is a small temporal difference between the "magnetic

onset" and the "optical onset" or the auroral breakup. This was discussed by Partamies et al. (2015) where they concluded that the time delay is typically of the order of a minute. As their result was based on optical aurora and the changes in the auroral structures (from arcs to more complex forms), the time delay may not be exactly the same between the magnetic onset and the onset of energetic precipitation (seen as CNA). This will be mentioned in the new version of the manuscript in connection to Figure 2.

4. *There is a difference in the response of CNA between the case example of an isolated substorm in Figure 1 and the superposed-epoch analysis one in Figure 4 (left). The CNA absorption has a maximum value at the minimum of AL in the case example, but it is largest at the expansion phase onset in the superposed-epoch analysis one. Could the authors provide some comments on this difference somewhere in the manuscript?*
   This is a good point. The example events in Figure 1 and 2 are plotted with 1-min temporal resolution, while the superposed epoch curves have an hourly resolution. Since the expansion phases are often short (less than an hour), the epoch evolution shows the maximum CNA at the epoch onset. This temporal resolution issue will be clarified in the revised text: "Note that the hourly resolution of the superposed epoch analysis places the maximum CNA values at the onset hour, although in higher resolution data they tend to occur around the minimum IL time, as seen in Figure 1."

5. *Figure 7: How close was the overpass of the DMSP/NOAA satellite? I presume that the satellite obtained multiple spectra during one specific overpass. Did the authors simply integrate all the spectra and generated one representative one? I would just like to know how the spectra from the satellites were corrected and integrated.*
   The DMSP/NOAA overpasses were searched within the common FoV of the Lapland ASCs and all the spectra are overpass-averaged spectra. These things will

be clarified in the new version of the manuscript: "Each spectrum in the figure is an average over an individual overpass, where an overpass is defined as a conjugate with the common field-of-view of Lapland auroral cameras, as described by Tesema et al. (2020)."

6. *What is the "boundary fluxes of the pulsating aurora"? This reviewer is just unable to understand the meaning of "boundary."*
   That is indeed a confusing statement. The boundary fluxes are the upper and lower envelope flux curves for the pulsating aurora as determined in the statistical study of Tesema et al. (2020). We will use this more precise terminology in the new version.

7. *Is there any orbital bias in the MLT coverage of DMSP/NOAA overpasses? Some previous studies implied that the energy of precipitating electrons causing pulsating aurorae tends to be harder in the later MLT (i.e., in the late morning sector). In this study, if the satellites only cover local time sectors, say before 03 MLT, the flux during the recovery phase might have been underestimated.*
   There is an MLT bias of DMSP/NOAA overpasses, as described by Tesema et al. (2020), where they suggest that the hardening of the precipitation only takes place after about 06:30 MLT and is largely due to the decay of softer precipitation. It is unlikely to observe recovery phases that late in MLT. It is rather only pulsating aurora that is often seen after about 4 MLT, and during most of those events the magnetic deflection has already recovered. This comment will be added in the discussion.

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