Authors' response to reviewers' comments on "Simulated seasonal impact on middle atmospheric ozone from high-energy electron precipitation related to pulsating aurorae" by Verronen et al.

Please find below our answers (in blue) to the comments (in black).

Response to the comments of Referee #3 (Allison Jaynes)

General Comments: This manuscript analyzes the seasonal impacts of energetic precipitation from pulsating aurora by integrating realistic energy spectrums and spatial extents of precipitation into WACCM simulations including lower ionospheric chemistry. The results clearly show the descent of NO_x to lower altitudes in the winter, which causes a significant portion of the ozone loss. There are also clear differences between the southern and northern hemispheres, due to variations in the polar vortex. This study is a very nice example of the effect that energetic electrons from pulsating aurora can have on the atmosphere and furthers our understanding of this important topic. I have included some comments and suggestions below for consideration, which I hope can be addressed for the final submission.

Response to general comments: We would like to thank the reviewer for her positive comments and appreciate the time devoted to the evaluation of our paper.

Specific comments:

Line 53: Add citation for "with a median duration of about 2–4 hours"

Response: The citation is Tesema et al. (2020), we have added it in the revised manuscript.

Line 56: Add citation for "PsA decays slower than the geomagnetic activity recovers"

Response: The citation is Partamies et al. (2017), we have added it in the revised manuscript.

Lines 192-195 & Figure 2: The difference between electron density in thermo-PsA and no-PsA compared to full-PsA and no-PsA is not clear in Figure 2. Essentially, these sentences are commenting on the clear difference between Figures 2e and 2i, but with the current color scale, that difference is not perceptible. There may be a slight bit of darker green in Figure 2e from 70-80 km (or up to 100 km in the winter) but it is certainly not clear and I had to really look several times and read this section closely to see there was a difference. Is it possible to change the color scale in just these two panels to a monochromatic one or else zoom in on this altitude range to get a better use of the rainbow scale to show the difference?

Response: Indeed, the electron density difference below 85 km is not quantitatively clear from Figures 2e and 3e, although qualitatively there is an obvious response down to about 63 km in the full-PsA simulation. The D-region electron density response to PsA-EEP ranges from very small in nighttime (when majority of the negative charge below about 80 km is held by ions) to 10^3 – 10^4 cm^{-3} increase in daytime. In hourly time resolution, the daytime increases are not very clear from the Figure.

Since electron density response is not the main focus of the paper, and the hourly resolution works well for other species, we have decided to keep the figures the same. Nevertheless, we see now that the text was not very clear on "what should be compared with what" (comparing the response in the full-PsA simulation to that in the thermo-PsA simulation means comparison between panels e and i, and this is what we discuss in the text.) Therefore, in the revised manuscript, we have

clarified the text to address the reviewer's comment and now give the magnitude of the D-region electron density response in the text.

Figures 5 & 6: Is there a white trace in panels a and c on Figures 5 and 6? Either the white is not visible due to the mostly white background, or you did not perform the 30-day mean of the black line, which should be noted.

Response: True, in Figures 5 and 6, the panels a and c do not present the 30-day averages because the response is clear from the hourly data. We have corrected the figure captions.

Figure 5: In panels a and c, the cyan line does not look like a 30-day running mean. Granted, we cannot see the full data for difference between thermo-PsA and no-PsA, but it does not look similar (as smooth) to Figs 4a, 4c, 6a, 6c. If there is a reason for this, please comment on it in the text, or point to it if I missed it.

Response: Thank you for pointing this out. Indeed, it is not the 30-day average but the hourly difference. As noted above, we did not include the 30-day averages here because the response is clear from the hourly data. We have corrected the figure caption.

Overall comment: Is it reasonable to estimate a total % difference integrated over time or spatial region or both? I see the utility of showing a figure such as Figure 24, but it doesn't give an indication of over the entire winter, say, how much of a contribution is this input of PsA- EEP. Similarly for the entire NH or SH region. Perhaps an analysis of the difference in integrals of the time series shown in Figures 4, 5, 6. This may give a better overall context for the differences due to PsA-EEP over a season.

Response: Both the temporal and spatial integration could be done in many different ways. Currently we do show altitude-integrated responses and also 30-day averages in Figures 4–6. Because the background concentrations vary considerably (panels a-d in Figures 2 and 3) and the responses at individual altitudes have different temporal characteristics (e.g. panels e-h in Figures 2 and 3) over the year (or over the winter period), we prefer to show the relative differences in Figures 4–6 as 30-day averages rather than integrated over longer time periods.

Grammar and spelling:

Line 29: "atmospheric ionization rates due to precipitation of solar protons,"
Line 167: "In wintertime, the largest concentrations. . ."
Line 194: ". . . removal of the ionization. . ."
Line 205: double "are" in "between the NH and SH are seen. . ."
Line 229: "In the NH, the peak increase. . ."
Line 245: remove "of" in "because of less variability in the polar vortex dynamics. . ."

Response: We have corrected grammar and spelling as suggested.