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Editor Daniel Whiter
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Dear Daniel Whiter

Thank you for taking the time to find reviewers for the paper. The reply to the first reviewer has been added at the end.

Regarding you comments:

Figure 6 In addition to the changes made to this section for reviewer #1 we have changed the caption to:
A plot of the brightness in Rayleighs of the emission from the $(0, 0)$ *band of the* N_2^+ *1NG system at* 391.4 nm *from the RENU2 blue photometer vs time after launch. Also shown are the Strickland model predictions (see text) for the* N_2^+ *1NG system at* 391.4 nm *dayglow (solid line) and for the* N_2^+ *1NG system at* 391.4 nm *dayglow plus the* N_2^+ *1NG system at* 391.4 nm *emission due to the auroral precipitation. A time after launch of* 200 s *corresponds to 07:37:30 UT while* 700 s *corresponds to 07:45:40 UT.*
As pointed out in the paper, the referenced GRL paper includes the additional plots.

Spelling Thank you, it has been corrected

Dates *13th of December 2015* and similar have been changed to: *13 December 2015*.
Dates following the international standard (YYYY-MM-DD, IS0 8601) have been changed to (dd month yyyy), except in figures where it is kept for sorting and clarity.
UT has been changed to UTC

Kind regards
Pål Ellingsen

Copied response to reviewer #1

Thank you for taking the time to review our submission *Observations of sunlit $N_2{}^+$ aurora at high altitudes during the RENU2 flight* . This response will reference each paragraph individually.

Paragraph 3 The referee is correct in assessing that the stated 40% is from the calculations in 4.1.3, though that calculation uses electron precipitation measurements taken by the rocket. Doing such a calculation with only ground data would be more speculative, as the input electron precipitation would not be known.

Paragraph 4 The track of the rocket is projected onto the MSP data in figure 7 (we acknowledge that figure 7 contains a lot of data). As the rocket flew east of the observatory as shown in figure 1, projecting that path onto all-sky images would introduce some geometric affects. A rough position in the images could be shown in the video, though as the camera is not geometrically corrected, the position would be uncertain within some degrees. Additionally as the referee correctly states, the rocket (due to its uncertainties during launch), did not fly close to magnetic zenith for the observatory, making it harder to determine which field lines in the All-sky image it crossed. I would be hesitant to project the whole path on one or two images, as it would give an incorrect view of the aurora at any given point of the rocket pass.

Paragraph 5

We agree that there is clearly some discrepancy between what is seen in the MSP and what is measured by the rocket and this is expected, as the rocket flew east of the observatory. Therefore this paper does not try to directly relate MSP intensities to the measured electron energies, but rather looks into what the solar EUV contribution is to the nitrogen emissions (using space and rocket measurements). The ground measurements are used to look into the preceding effects and the hight distribution of the nitrogen emissions. These are then qualitatively compared to the measurements taken by the RENU2 rocket.

The ideal case would of course be that the rocket flew very close to magnetic zenith above the observatory, though this is hard to achieve with the current precision of the rockets in use. If a rocket (or maybe a cubesat) did fly there, it would allow for direct comparisons of emissions on the ground and electrons detected.

Paragraph 6 - 8

We will be adding some new text from line 183:

The field of view of the photometers was 3.2 degree and the instrument was pointed in the zenith although the rocket spun and some glint was observed as described in Hecht et al. (2019). The photometer bandpass was narrow enough, at about 3 nm full-width at half maximum, to isolate the (0,0) band.

To model the data two long-established models were used, AURIC (Strickland et al., 1999) which completely modelled the dayglow and B3C (Strickland et al., 1993) to model the auroral output. For the $N_2{}^+$ emission resonant scattering of sunlight off $N_2{}^+$ ions dominated the emission for most of the flight.

We still feel that the reader will need to read Hecht et al. 2019 for the details. The added text includes some details about the photometer including field of view. The two models are long-established and we have added references to their descriptions.

1. ”The caption states it is dayglow plus emission due to auroral precipitation, but the

axis label is 391.4 nm brightness.”

- Our answer is that these come from the outputs of the models

2. ”At these heights and at such low energies there will be minimal contribution from other emissions, but some discussion of these important factors is needed.”
   - We are a bit unclear on what is asked here (these plots are from model outputs):
3. Statement on line 194
   - The statement on line 194 is a result for modelling.
4. ”The scattered contribution is dependent on shadow height, height of observation and energy of precipitation. How all of these factors affect the statement is important to know.”
   - Again this is calculated by AURIC.
5. ”At line 198 is it stated ‘there are clear increases that correspond to model predictions ...’ ; however, these correspondences are not clear, so more direct evidence is needed of these instances.”
   - Between 550 and 600 s the model predicts increases in the green and blue signals that are due to strong auroral precipitation and are clearly seen in the figure.
6. ”It is claimed (line 200) that the most noticeable aspect of the data is the increase in emissions after 500 seconds, which is not reflected in the model. If there is indeed a clear difference between the data and model during this time it needs to be presented more clearly so that the obvious nature of the feature is evident.”
   - It appears very clear to us that there is a sharp increase in the 391.4 emission at 500 s that is not seen (say in the green emission) and not reflected in the model.
7. ” At this time there is a large increase in the flux of low energy electrons, so an increase in brightness of emissions which result from low energies might be expected at these heights.”
   - The model does not predict a measurable increase in either the green or blue emissions at 500 s.
8. ”If there is indeed no increase in 630.0 nm emission at this time, how is this explained?”
   - The Hecht et al 2019 paper suggests that these are very short-lived bursts that are not seen in 6300 because of the long-lifetime of that emission.
9. ”A breakdown of the model results is of importance for any conclusions that are drawn. On reading Hecht et al 2019, there appears to be some increase in both 630.0 nm and 557.7 nm emission from the model at this time, so the authors need to provide more details in the present paper.”
   - There is no increase in either the blue or green emissions at 500 to 510 s.
10. However, given the height and position of the rocket, the most likely emission would indeed be the resonant scattered 391.4 nm.
    - Yes we agree here.

Paragraph 9

1. Where is the crucial information about the analysis of the raw photometer data? How have the profiles of the scans been integrated? How has a background been

subtracted?

- 3.1 states that the measured valued background subtracted and averaged over two scans, and converted from counts to Rayleigh via calibration. In the analysis there is no integration. It is unclear what is meant with *raw photometer data*, the photometer gives out a voltage pulse which is collected by a counter, though this does not belong in the paper (as the function of an A/D converter in a CMOS camera chips doesn't belong).

2. Looking at individual scans, is the scattered contribution visible as an increase in brightness above the shadow line at any time, especially when scanning through an arc? Interpreting such data, however, would be complicated by the occurrence of more than one arc in each scan. And if there are several auroral features within each scan how is the brightness measurement interpreted? The only angle where the true comparison can be made about the relative brightnesses at any time is in the zenith. Since this is not the case here, more justification for the method in the light of the inherent uncertainties is needed.

   - If one was able to measure under each field line (i.e. having a chain of observatories) this could be determined. In the MSP data from one observatory, any attempt at doing this for individual scans would be plagued by overlap from different heights. One might expect to see something like this is a large statistical study with several years worth of data, which is outside of scope of this study. In this study what is looked at is the correlation between emissions for different wavelengths over a given scan. If the emission scans correlate, their "shape" is the "same" allowing for the conclusion that they should have been emitted within the same volume. When they don not correlate one can draw the conclusions that they come from different volumes.

Paragraph 10

It is unclear which rigorous analysis is missing. The analysis here is base on a statistical analysis which asses the uncertainties through the correlation coefficient. We do not understand what is meant with "The uncertainties in the correlations need to be assessed quantitatively" as the correlation coefficient is in itself a quantitative measurement of the uncertainties. A coefficient of 1 would mean a perfect correlation, reducing it towards 0 makes it less and less correlated (likely that they are the same).

Paragraph 11

We are hoping the Godbole paper is published soon. We can supply it to the referee if desired.

Minor points

64 Can't see any difference

71 Sentence removed

103 Reference removed.

104 Thanks

125 Thanks

147 Agreed, clarified to: $\ldots\lambda = 50$ *nm based on the invariability of the photoionisation cross section from approximately 30 nm to 70 nm ...*

166 Agreed. Changed to: ..., *means that in solar EUV conditions one should be careful* *in classifying EUV as the only production mechanism for $N_2{}^+$, as an increase in the precipitating electrons can drive the production of $N_2{}^+$ as well.*

172 Changed to: *A process not included in the estimation here,...*

187 Removed somewhat as it was a poor choice of words.

191 Added: *In the absence of precipitation dayglow emission is observed from resonance scattering from ambient N2+ ions produced by solar photons or photoelectrons but this is a minor portion of the observed emission.*

198 Added: *As noted in Hecht et al. (2019) the short-lived nature of some of the intense precipitation could affect some of the observations of the auroral emissions. In particular the OI(630 nm) emission intensity was well below the model predictions. But emissions with short lifetimes (well below a second) are not affected.*