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Reply on RC2

Mizuki Fukizawa et al.

Author comment on "Reconstruction of precipitating electrons and three-dimensional structure of a pulsating auroral patch from monochromatic auroral images obtained from multiple observation points" by Mizuki Fukizawa et al., Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2022-5-AC2, 2022

Referee Comment :

This paper describes work done to reconstruct the 3D volume emission rate of a pulsating aurora patch, determine the altitude and vertical thickness of the patch, as well as the horizontal distribution of the characteristic energy and flux of the electron precipitation producing the pulsating aurora. Overall the manuscript is well written and the work is worthy of publication. I have some questions for the authors and suggest some minor corrections below. I also suggest the authors consider what is the most important result from the work. Currently it comes across to me as if the technical process of obtaining the results is the most important aspect of the work, but I wonder if the finding that "the horizontal distribution of E_c was neither uniform nor stable" is at least as important, if not more important. If they authors agree, I suggest they draw more attention to the scientific results (as opposed to the technical process, which is nevertheless impressive) in the abstract and conclusions.

Reply :

On 00:53:38 UT, the characteristic energy of precipitating electron flux is high at the southwestern edge of the PsA patch (Figure 3). One of the possible mechanisms to enhance the characteristic energy at the edge is the field aligned current (FAC). It had been believed that there is no FAC in the PsA patch because the PsA patch have no shear motion which is observed in the discrete aurora (Davis, 1978). However, several studies reported the FAC associated with PsA patches (Fujii et al., 1985; Gillies et al., 2015; Hosokawa and Ogawa, 2010). If the upward and downward FACs flow at the edge of the PsA path, the potential drop associated with the upward FAC can accelerate precipitating electrons and enhance their characteristic energy (Sato et al., 2004). The energy spectra of precipitating electrons observed by rockets and satellite does not show the field-aligned acceleration by the potential drop, but Shepherd and Fälthammar (1980) suggested the existence of the potential drop in the lower E region whose altitude is lower than that measured by rockets and satellites. The 3-D current structure in the PsA patch is out of scope of this study, but it will be reconstructed using ACT and the EISCAT_3D radar in future. We will add these explanations in the text.

References:

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Hosokawa, K. and Ogawa, Y.: Pedersen current carried by electrons in auroral D-region, Geophys. Res. Lett., 37(18), 1–5, doi:10.1029/2010GL044746, 2010.

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Shepherd, G. G. and Fälthammar, C.-G.: Implications of extreme thinness of pulsating auroral structures, J. Geophys. Res. Sp. Phys., 85(A1), 217–218, doi:10.1029/ja085ia01p00217, 1980.

Minor comments:

Comment 1:

Line 51: What is a “typical” field of view?

Reply 1:

The word “typical” was not appropriate expression. We would like to explain that the field of view of the three cameras were overlapped. So, we will revise the word “typical” to “common”.

Comment 2:

Line 56: Did all four WMI CCD cameras have 427.8 nm filters? What exactly do you mean by compositing auroral images from these cameras?

Reply 2:

Yes, they did. All four WMI CCD cameras had 427.8 nm filters. We composited auroral images from these cameras to improve the signal-to-noise ratio.

Comment 3:

Line 63: I think there's a mistake with the energy range here, are you sure it should be 300 eV to 100 eV? Also, I think it would help readers unfamiliar with the method if you could add a very brief explanation of what the energy axis actually means, before stating its range.

Reply 3:

It is a mistake. The energy range was 300 eV to 100 keV. Also, we will add the explanation as follows: "The energy axis contains the information about the auroral emission altitude. This is because high-energy electrons can penetrate at lower altitudes and cause auroral emission."

Comment 4:

Line 75: Determination of the inverse covariance matrix – you say this is the standard deviation from each auroral image, but the standard deviation over which dimension? Do you mean the standard deviation of the 1024 pixel intensities in the 32x32 region? I think this could be explained more clearly.

Reply 4:

The standard deviation was determined using the following procedure: First, we calculated the mean value and standard deviation in the central 5 × 5-pixel region for 20 images: Second, we derived a regression line between the mean value and standard deviation: Finally, we converted the grey level at each pixel to the standard deviation using the equation of the derived regression line. We will add this explanation to the text.

Comment 5:

Line 80: c_{SKB} fixed at 1 – should each camera not have a different value, to account for their absolute intensity calibration? Or do you already use calibrated images? Also in the next sentence you say c_j was different for each camera, which contradicts $c_{SKB} = 1$, and in the conclusions say you included the relative sensitivity between ASCs, which also contradicts $c_{SKB} = 1$ I think.

Reply 5:

We have already used calibrated images. However, the absolute value of each camera did not completely correspond. Therefore, we modified grey levels at KIL and SKB to correspond those at SKB (i.e., $c_{SKB} = 1$).

Comment 6:

Line 81: "during" should be "for".

Reply 6:

Thank you for pointing it out. I will revise it.

Comment 7:

Line 90: I think forming the plural of delta this way could be confusing – it's probably better to write "over 5 values of δ(...), which were..." (replacing "δ(...)" with the relevant

symbols).

Reply 7:

Thank you for your suggestion. We will revise "5 □□(□□,□□,□□,□□)s" to "5 values of □□(□□,□□,□□,□□)".

Comment 8:

Line 95: Is it valid to assume a constant background in all voxels? Should there not be a strong altitude dependence, if the background is diffuse auroral emission? Presumably the breakdown of this assumption in the altitude dimension would result in an error in the VER altitude profile of the PsA? Perhaps you could comment on this in the paper, or even better see if the altitude profile of the background could be determined from the "off" pulsating periods (although I understand this may be very challenging).

Reply 8:

In our analysis, we assumed that the volume emission rate (VER) was uniform not only horizontally but also vertically (i.e., at all voxels). However, even if the VER depends on the altitude, the altitude dependence does not affect our reconstruction results. The reason is explained in the following paragraph.

The linear integration of the VER in the vertical direction (i.e., the zenith angle θ = 0°) can be written as

$$\Lambda_0 = \int L(z)\, dz \ , \quad \text{(R1)}$$

where $L(z)$ is the altitude-dependent VER. When it is assumed that diffuse auroras are uniform horizontally, the liner integration of the VER at the zenith angle can be written as

$$\Lambda(\theta) = \int L(z)\, dz \,/\, \cos\theta = \Lambda_0 \,/\, \cos\theta = (constant) \,/\, \cos\theta. \quad \text{(R2)}$$

This indicates that the horizontal distribution of the background emission intensity (i.e., diffuse aurora) in the auroral image depends only on the zenith angle θ and does not depend on the altitude distribution of the VER. When we subtracted the background emission image from the observed auroral image, we determined the constant value in Eq. (R2) so as to fit Λ(θ) to the background emission intensity. Therefore, the altitude distribution of the diffuse aurora does not affect the reconstruction results.

On line 99, we will add the following sentences:

"In this analysis, we assumed that the diffuse aurora had the uniform VER in all voxels, but the VER of the diffuse aurora generally depends on the altitude. However, it should be noted that the altitude dependence of the VER does not affect the analysis result. This is because the horizontal distribution of the background emission intensity (i.e., diffuse aurora) in the auroral image depends only on the zenith angle (□cosθ) and does not depend on the altitude distribution of the VER, if the VER is horizontally uniform."

Comment 9:

Sect 3.1: Why is the error in the northwest different to the rest of the edge of the patch? On line 129 you say that part of the reconstruction from the observed images is expected to be underestimated, but does the error depend on the patch location and size? i.e. if you repeated the reconstruction from pseudo images with the patch in a different location, would the horizontal distribution of error change?

Reply 9:

The error depends on the patch location and size. We prepared the pseudo auroral images in which the auroral patch has similar location and size with observed one. Therefore, we expected that the reconstruction result from the observed images had a similar error with that from the pseudo images.

Comment 10:

Fig 4: How were the errors in Figures 4d and 4f determined? These are different to the errors in Figure 2.

Reply 10:

In Figure 2, we calculated the error between the model and reconstruction result of volume emission rate. We also derived peak altitudes and altitude widths of the volume emission rate for the model and reconstruction result. The errors between them are shown in Figure 4.

Comment 11:

Line 149: "residual squared sum" should be "sum of the squares of the residuals".

Reply 11:

Thank you for pointing it out. We will revise it.

Comment 12:

Line 148: I believe Movie S1 should be Movie A1, but if not please can you add a link or reference.

Reply 12:

Thank you for pointing it out. We will revise the name "Movie A1" to "Movie S1".

Comment 13:

Line 158: "see Appendix" should be "see Appendix B".

Reply 13:

Thank you for pointing it out. We will revise it.

Comment 14:

Line 175: It took me a few moments to understand your point here. I think what you are saying is that the time-dependent continuity equation must be solved to determine the electron density, it cannot be determined instantaneously from the VER (which I agree with). I suggest rewording the last few sentences of this paragraph to make it clearer, probably removing "time derivative term" in favor of some other wording. Also I suggest adding the word "even" on line 174 - "... to some extent even after the auroral emission intensity decreased..."

Reply 14:

Thank you for your suggestion. I will revise the last few sentences of this paragraph by removing "time derivative term" and adding the word "even" on line 174 as follows:

Line 174–178: "We noted that the electron density was reconstructed correctly to some extent even after the auroral emission intensity decreased at 00:53:40 UT. This correct reconstruction is due to consideration of the time change in the continuity equation. The electron density would seem to have rapidly decreased after 00:53:40 UT if the time change were not considered. This result suggests that the time change should be considered ($dn / dt \neq 0$ in Eq. (4)) when using the continuity equation to derive electron densities associated with PsAs."

Comment 15:

I don't think Appendix A is mentioned in the main text, but probably it should be, I guess in section 3.3.

Reply 15:

Thank you for pointing it out. We will revise the sentence on line 147 as follows:

Line 147: "The peak altitude of the PsA patch was also estimated by a different (Appendix A)."

Comment 16:

Please note that the filename for Movie A1 is confusingly Movie S1 – probably they are in fact the same thing?

Reply 16:

Yes, it is the same thing. We will revise the name "Movie A1" to "Movie S1".

Comment 17:

Line 206: "residual squared sum" should be "sum of the squares of the residuals".

Reply 17:

Thank you for pointing it out. We will revise it.