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Interactive comment on "Estimating the fate of oxygen ion outflow from the high altitude cusp" *by* Patrik Krcelic et al.

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Answers to the referee

We thank the reviewer for careful reading of the manuscript, and for providing valuable suggestions for improvement. Straightforward changes such as grammar, are changed in manuscript, and are not additionally commented. In following section we firstly repeat the comments from reviewer and than provide our response to the comments.

1 Comments and Author response

1.1 Main comments

It is not clear to me why you try to restrict to cusps and plasma mantle outflows. Is your method not valid outside of these regions? Why?

Method is valid in the polar cups as well, but in the polar caps the oxygen ion energies (and therefore parallel velocities) are much smaller and the ions get captured in the near Earth plasmasheet and ring current. The main concern of this paper is, what happens with oxygen ions from cusps and plasma mantle as it is thought that they all escape the magnetosphere.

CODIF obtains a full 3D velocity vector. Why do you choose to use v_{par} from CODIF and $E \times B v_{perp}$ from EDI? You could use v_{perp} from CODIF instead, right? I agree this assumes that O+ is frozen-in, which may not be always the case. At the very least,you should compare v_{perp} from EDI with v_{perp} from CODIF when both measurements are available, and maybe also with v_{perp} from HIA. I would be curious to see if your Figure 6 (right) is very different when computed using v_{perp} from CODIF or HIA.

There is a big difference between the EDI and CODIF perpendicular velocity data. The CODIF perpendicular velocities have similar values to CODIF parallel velocities. This velocities go up to $120\ km/s$, and are definitely not from the convection. EDI data give values of around $15\ km/s$ which is what we expect convection to be. At this point we do not know how to explain the CODIF perpendicular velocity measured in the cusps.

Another main concern to me is if the dataset you use corresponds truly to cusps observations. For EDI you use TS96 to decide if you are in the cusps or not only, right? You should check other parameters as well when available, as for instance plasma beta.For CODIF dataset you do a much more accurate filtering of your dataset.

The plasma beta number is not always available when we have EDI data. We have decided to analyse each dataset separately and than combine the average values to get our estimate.

1.2 Detailed comments

Introduction. Global models, eg Glocer et al. 2009 (Modeling ionospheric outflows and their impact on the magnetosphere, initial results) should be discussed somewhere in

the manuscript. Other works that potentially should be cited, discussed and compared to this study:

Slapak and Nilsson 2018 'The Oxygen Ion Circulation in The Outer Terrestrial Magnetosphere and Its Dependenceon Geomagnetic Activity'

Liao et al. 2010 'Statistical study of O+ transport from the cusp to the lobes with Cluster CODIF data'

The mentioned papers are now added to introduction.

P3. 11-13 In which parameter space? Dst? GSM coordinates?

Yes we used GSM coordinates and Dst values to combine the data. We have decided to remove the phrasing "parameter space" in manuscript to avoid confusion.

P4.3 Please include the reference to the newer model that you decide not to use, for completeness.

The references to the newer models are now included.

P5.1 '448 hours are from the cusps'. Do you infer cusp/no cusp of each 1 min EDI measurement using TS96 with its corresponding Kp index? Could you be a bit more precise on how do you get this number?

Yes, we have labeled all EDI minute measurements as "cusp/no cusp" using T96 model, and got the total number of the one minute measurements inside cusps. The better explanation is given in the new version of the manuscript.

P5.4 'good quality EDI'. Can you specify you criteria for 'good quality'?

"good quality EDI" is an label given by "Cluster Science Archive (CSA)", and there are a series of the criteria explained in the doi$= 10.1007/978 - 90 - 481 - 3499 - 1_5$;. The criteria are mostly statistical (χ^2 analysis is the most important one), and most of the scientific work is done using this data without getting too much into other two labels "caution" and "bad" data. A short explanation is included in the manuscript.

P5.8 Do you impose $R > 6\ R_E$ as for CODIF? Please specify.

Yes, we impose the $R > 6\ R_E$ as for CODIF and it is now specified in the new version of the manuscript.

P5.9 Please include the parameters you used for computing Shue98 (Pd and Bz).

For Shue98 we used the parameters $B_z = -1\ nT$, and $p_{DYN} = 2\ nPa$, and are now included into the manuscript.

P5.14 'Jan-June' Is this because during July-Dec Cluster does not cross the region of interest for this study? Would be equivalent to say you used all available data in 2001-2005? Please clarify if there is another reason to use Jan-June only.

Yes, during the months Jun-July are the only periods when Cluster crosses the areas of interest. We have changed it to "all available data in years $2001 - 2005$ as you suggested.

P5.17 How do you get beta? Do you use CODIF or HIA for the ion pressure? Do you account for the contributions of all species or only H+?

Plasma beta number is calculated from both H^+ and O^+ populations, and is it included into the new version of the manuscript.

P6.1-9 The description of the method to choose CODIF data is a bit confusing. You do not mention the word 'cusps', but this is the O+ population you are interested in,right? Plasma mantle $< - >$ cusp, here? Which energy range of CODIF do you use to compute v_par? Is cluster in the cusps/plasma mantle according to TS96 for all the measurements you select from CODIF?

For the analysis the full coverage of the CODIF instrument was used, but oxygen ion measurements are in the range $100\ eV$-$4\ keV$. We did not check the data using TS96 model as we did for EDI dataset.

P6.19 Could you comment on the drawbacks of this criterium ($100\ R_E$)? The X line position is not well defined, and can be significantly lower during disturbed conditions.

We have added the comments on the drawback of the position of the distant X-line criterium in the new version of the manuscript.

P6.18-30 I do not understand how do you 'trace' your outflows. Could you explain a bit more what you (Haaland, Li) do for propagating the outflows to the tail?

The method we use is based on the tracing of the ions along the field line using the TS96 model, and moving the field lines with each time step order to simulate the convection. We used the CODIF data to move the ions along the field line in each time step and EDI data to move the field line accordingly. The result is a total path of the ions (along the moving field line).

P8.7 'in the cusp regions'. Based on TS96?

Yes we have here based the cusp regions on the T96 model. This specification is added to the new version of the manuscript.

P10.12. this is a very crude simplification, although I understand it is difficult to do better given the current knowledge of the distant tail. The shortcomings of this approach need to be discussed, though.

The shortcomings of the used regions are now commented in the new version of the manuscript.

P11.3. To me, a very interesting result would be what is the average O+ flux in the cusps. Why do you not give this number and prefer to give relative amounts only? Slapak et al. 2017 does provide this number, right? Please include it also in this manuscript. It would be interesting also to see how it compares to other independent estimations of the O+ outflow in the cusps.

The average values of the cusp oxygen outflow is $\approx 1.05 \times 10^{10}\ m^2\ s^{-1}$, and is now added into the manuscript.

Table 1. You average over many years of data. I recommend including std deviation to these quantities, which I suspect may be large.

The purpose of the "Table 1" is to give the values we have used in our model. Adding the standard deviations into this table might be confusing to some readers.

P12.8-9 "Quartile" is not appropriate here.

Word "quartile" is now removed and the sentence is rephrased.

Table 3. The consideration $XGSE = -100\ R_E$may not be accurate for high-activity($Dst < -20\ nT$) periods. Include Dst units.

Dst units in "Table 3" are now added. The accuracy of specific results are commented in section "Discussion", as the values seems to be to high and is probably not accurate.