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

Anonymous Referee #2

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SUMMARY This work uses several years of in-situ observations made by Cluster to estimate the relative amount of O+ cusp outflow that is lost versus the amount that is re-circulated in the Earth's magnetosphere. They use a combination of two instruments to infer the average parallel and convection velocity of O+ in the cusps. Then, they compute whether the averaged outflows should end up in the dayside magnetosheath, distant tail beyond 100 R_e, or closer tail. They find that 52 - 82 % (table 3) of the O+ outflow is lost, and the rest is re-circulated to the magnetosphere. They also discuss their results as a function of Dst index.

Overall evaluation

Main comments

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Discussion paper

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?

Your results are provided as a function of position in GSM. They way you ensure they correspond to cusp / plasma mantle is not fully clear to me (see below).

CODIF obtains a full 3D velocity vector. Why do you choose to use v_par from CODIF and ExB∼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.

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.

English grammar needs to be revised.

Overall, I find interest in this study, but further clarifications are required in the text, figures and tables. The Introduction and referencing may be missing relevant recent studies.

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 TerrestrialMagnetosphere and Its Dependenceon Geomagnetic Activity'

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

P2.5 remove comma

P2.8 'has been analyzed' in detail?

P2.12 For given solar wind condtions...

P2.13 The convection velocity scales with magnetic field –> with the inverse of magnetic field magnitude?

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

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

P5.1 '448 hours are from the cusps'. D 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?

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

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

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

P5.11 'ware'

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.

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+?

P6.5 O+ densities in both...

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?

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.

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?

P7.8 will retain

P7.17 considered

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

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.

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.

P11.10 an measurements

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

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

P15.5 the high-altitude

P15.6 ..., as shown by...

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

P17.5 magnetosheath

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