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Interactive comment on "Terrestrial ion circulation in space" *by* Masatoshi Yamauchi

Anonymous Referee #1

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This manuscript is reported to be based on the Bartels Medal Lecture given by Dr. Yamauchi at the 2019 EGU Assembly in April. As such, it has an undeniable legitimacy and gravitas and should be published. I learned a lot from reviewing it.

This reviewer is unfamiliar with the details of the Medal citation or the charge to the speaker for the presentation. However, the identified focus seems narrow to me. It begins by identifying as a focus "findings by Cluster that are not covered by review papers on circulations [itemized reviews]."

The list of reviews is missing a few significant ones that should be included, e.g. Lotko, 2007, Moore and Horwitz, 2007, Maggiolo 2016.Most if not all of the identified reviews are at least a decade old, so it would seem more appropriate to focus the paper as a review of this important topic in space science, with significant recent developments from all relevant missions, as well as relevant theory papers.

The manuscript has some significant problems ranging from cosmetic and language to substantive, as described below. These should be addressed in a revision.

The top level issue concerns the referencing in this paper. It cites 22 papers with Yamauchi as first author and an additional 12 with him as co-author, out of about 125 -130 papers cited. Some of the self-authored papers do not appear fully relevant to the present paper. For example: Yamauchi et al. 1996b, 1996c, 2006a, 2006b, 2009b, 2018a, Ohtani et al., 1995, Lundin et al. 1995, Ebihara et al., 2001. A balance should be struck in self-referencing, making sure all are strictly relevant to the present paper.

Meanwhile the manuscript fails to cite a number of relevant papers on the following topics: * Outflow flux correlation with solar wind parameters, e.g. Pollock et al., 1990 JGR, Moore et al., 1999 GRL. * Ion trajectory simulations of the the magnetosphere in idealized fields, e.g. Delcourt et al. 1990 JGR and a number of more recent papers. * Ion trajectory simulations with ionospheric ions in MHD fields, e.g. Fok et al. 2010 JGR, Moore et al., 2009 JGR, and related others. * Multifluid global circulation models with outflow in MHD fields, e.g. Glocer et al., 2009 JGR, Garcia-Sage et al., 2015 JGR, Brambles, et al. 2011 JGR, Wiltberger 2010 JGR.

With attention to those and the following issues, this paper will indeed serve the space science community well as a comprehensive review of relevant recent work on the title topic.

COSMETIC ISSUES: Technical editing for English usage is recommended for this paper, but here are some examples of the many issues.

L9: “in the other *hemisphere*?

L12: “unanswered questions”?

L16: “than that entering the magnetotail”?

L25: specie => species

L39: “wide circulation, ranging from the tail. . .”?

L46: Sue => Su

L210: “a mixture of different ions”?

L227: “to deconvolve different sources. . .”?

L300: sever => “severe”

L536: “ionospheric cusp, which is the destination for the entire mass-loading area.”?

L601: convolute => “mix together”

L613: “have wide aspects” =>“extend broadly”, physic =>physics

L622: “needed to explore the questions raised by these observations”?

L633: un-understood => poorly understood

CONTENT ISSUES:

Introduction section:

The rationale given for a focus on ions to the exclusion of electrons strikes this reviewer as questionable. Electrons and ions are inseparable because of quasi neutrality and the ambipolar electric field, such that electron heating also leads directly to ion escape [Strangeway et al., 2005]. Acknowledging that would not change much about the paper, but it seems so important that it should be at least discussed.

Outline:

An outline is given at the outset, which begins well, but then singles out the inner magnetosphere for selective treatment. It seems that this should be treated as one of the several significant “destinations of the outflow”, rather than occupying its own major section. For example, total loss from the system may be a more important destination.

Sec.2 Outflow: The statement that cold filling flows have “never been directly detected”

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is incorrect. See for example, Singh and Horwitz [1992 JGR], Watanabe et al., [1992 JGR], and others.

This statement: "...but most of them have high O+ outflow flux with much higher velocity than this cold supersonic outflow, and they are actually the suprathermal described below, including the apogee observation by Su et al. (1998)" is also incorrect. The polar wind at high altitude [Moore et al., 1997 Science] is inescapably mixed by the velocity filtering effect with auroral zone outflows, but these are readily discriminated by their higher energy and temperature, as summarized in the cited review by Moore et al. 1999.

The space devoted to the Freja (Figure 2) and Viking (Figure 14) observations of suprathermal and hot outflows seems inconsistent with the stated focus on "findings by Cluster. . .not otherwise reviewed [itemized reviews]." These could be condensed out of the paper by citing appropriate papers, since it is neither recent nor from Cluster. With a current figure count of 17, and many data figures, the paper is perhaps a bit overloaded with graphics at present.

The claim in lines 88-91 that ". . .the value is underestimated (by Su et al.) because the upper energy threshold of the instrument was 350 eV" is incorrect. Simultaneous observations by TIMAS at higher energies established that the core distribution was within the energy range for the events analyzed. The complementarity of these two instruments is well illustrated in Cladis et al. 1999 JGR.

Fig.3 is only cited far out of sequence in the text of line 554, p.28. Discussion of Fig. 3 should note that it agrees fairly well with earlier findings from DE1 (Pollock et al. 1990 JGR), Polar (Moore et al. 1999 GRL), and perhaps Geotail (Nose et al., 2005). It's not clear if these papers are covered by the reviews cited, and so should be cited in relation to this figure and paper by Schilling.

Destinations of outflow:

3.4 Secondary destinations?

Figure 5 (mislabeled Fig. 6 in Table 1) should better highlight the distinct difference between outflows from the auroral zones (day and night) and from the polar cap at higher latitudes, and the plasma trough region at lower latitudes, together with the velocity filtering effect that spreads the slower outflows relative to the faster auroral outflows. Also, the plasmasphere label “detach” should perhaps be on the dayside where the Plasmaspheric plume forms through the circulation effect, and detached blobs often are created [with references to Grebowsky 1970, Chappell 1972 and the IMAGE mission, Sandel et al.]

4 Inner magnetosphere:

Figures 7,8,9 get very short descriptions in line 220, and are simply pointed to in cited papers, so do not seem necessary in this review. Or perhaps a single example would do in place of three.

Figure 11 is quite striking and important, showing how low energy and high energy populations mix and become combined, while being dispersed by the velocity filtering effect.

4.4 Direct injection: This topic remains somewhat controversial, and the discussion should present both sides of the argument, with citations. The statement is made that these ions having the field aligned appearance of an outflow need not be inside the source/loss cone because of pitch angle diffusion. However, to demonstrate that this is the case requires observations of equal or higher fluxes inside the source/loss cone on the same flux tubes. The reviewer is not aware of such observations, but if they exist, they should certainly be cited here.

4.7 Loss Process: An effort is made here to explain how loss to the magnetosheath can occur “without reconnection”, seemingly suggesting that reconnection would not work to explain such leakage, despite the existence of a huge recent body of observations

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from Polar [Chandler et al., 1999 JGR, 2003 JGR, 2008 GRL] and MMS [Burch et al. 2016, Torbert et al., 2018, many others] showing that reconnection is a common occurrence, on the dayside magnetopause, leading to mixing of magnetosheath and cold ionospheric plasmas. In fact, an entire subcategory of MMS research has investigated in detail the ingestion and acceleration of cold terrestrial ions into dayside reconnection diffusion regions [Toledo-Redondo 2016 GRL]. This reviewer suggests that a critique of reconnection at the dayside magnetopause is beyond the scope of this manuscript and should not be tackled, implied or even suggested.

5 Consequences:

5.2 O+ escape effects on solar wind interaction: here the suggestion is made that the presence of O+ escaping from the magnetosphere can have a significant dynamic effect on the system as it is picked up to solar wind motion, by mass loading it down, and can thereby affect the energetics of the interaction as suggested in cited papers.

The discussion after Figure 16 cites the reconnection mechanisms of Dungey and Axford and Hines. However, Axford and Hines explored mainly a “viscous” interaction and ignored reconnection if my memory is correct. Suggest deleting that reference in the context of reconnection.

Considering the discussion of mass flux and reconnection rate, reference should be made here to the MMS papers on this topic, e.g. the most recent, [Fuselier et al. 2019 JGR] and perhaps some key references therein. The Vasyliunas [1995] concept of two nested dayside boundaries is new to me, but it doesn’t seem applicable to a layered separation of magnetosheath, magnetospheric, and cold ionospheric plasmas. On the other hand, an inner boundary separating solar from terrestrial plasmas has been termed the “geopause” by Moore and Delcourt 1995 Reviews Geophysics. Also it has been used to organize global simulation work by Winglee 1998, 2002, and more recently by Wiltberger et al. 2015, Liemohn et al. 2016, and Glocer et al., 2018. It should be useful in the present paper when discussing inner and outer plasma boundaries.

The arguments leading to the conclusion of a need for a dedicated space mission to study these phenomena are well-posed and important and I applaud them.

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