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Interactive comment

Interactive comment on "Hybrid-Vlasov modelling of nightside auroral proton precipitation during southward interplanetary magnetic field conditions" *by* Maxime Grandin et al.

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We thank the Reviewer for their careful analysis of our manuscript as well as their constructive comments and suggestions. We provide our preliminary responses to the comments in blue, while the original text written by the Reviewer is shown in black.

The manuscript deals with the nightside proton precipitation, focusing on the perspective of the magnetosphere, by using Vlasiator, a global kinetic hybrid simulation of the near-Earth environment. The authors found a good agreement in terms of differential number fluxes and energies, compared to the empirical Hardy model. The proton precipitations are observed as burst events and, in some cases, they can be traced back

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Discussion paper

to the current sheet in the magnetotail and associated with depolarising flux bundles.

The paper brings interesting results and can be acceptable for publication after some clarifications.

1. In my opinion, the authors should justify the resolutions chosen for the simulation in terms of characteristic plasma quantities. In particular, in order to comment on the physical space resolution, what is the value for the ion inertial length? or Larmor radius? Since the proton precipitation is produced by the magnetic reconnection in the magnetotail, how thin is the current sheet? And, in a similar way, the authors should comment on the velocity space resolution. In this respect, what is the value for the Alfvén speed?

Thank you for this nice suggestion. We are indeed happy to provide these values and put them in perspective with the ordinary and velocity space resolutions. We can for instance provide such values in the solar wind (input) and in the transition region (at $X = -10R_E$, $Y = Z = 0$) at $t = 1800$ s (Fig. 2).

– Solar wind:
Ion inertial length $\lambda_d = 228$ km
Ion Larmor radius $r_L = 214$ km
Alfvén speed $v_A = 109$ km/s

– Transition region:
Ion inertial length $\lambda_d = 906$ km
Ion Larmor radius $r_L = 681$ km
Alfvén speed $v_A = 1596$ km/s

The real space resolution of 300 km in this run is therefore sufficient to resolve most of the proton kinetics, as was confirmed in a dedicated study by Pfau-Kempf et al. (2018, 10.3389/fphy.2018.00044).

The current sheet thickness was evaluated during this same run by Juusola et al.

(2018b, 10.5194/angeo-36-1027-2018) and is shown in Fig. 6 of their paper. In the region of interest for our study ($X > -20R_E$), Juusola et al. find that the plasma sheet thickness essentially lies within 0.1–0.2 R_E (i.e., just a few simulation cells).

The above values can be provided and discussed in a revised version of the manuscript.

2. In the inner boundary, protons are described with a static Maxwellian VDF. This means that here kinetic effects are neglected. However, the observed VDFs close to the inner boundary, for example in S2 (Fig.3), are strongly non Maxwellian during the precipitation. I am wondering if the imposed sharp change in the VDF could influence the results. Could the authors comment on this point?

The imposed static Maxwellian VDF at the inner boundary mostly affects the neighbouring cells through the calculation of translation and acceleration terms in the Vlasov equation. Since S2 is located about 15 cells away from the inner boundary, its stencil used for acceleration and translation do not reach the inner boundary. Given that, in addition, the plasma flows from S2 towards the inner boundary, potential diffusion effects are likely negligible in comparison with the bulk flow.

3. One of the hypotheses used to evaluate the directional differential particle flux is that 'protons remain attached to a given magnetic flux tube'. However, during a magnetic reconnection event this is not exactly true. Although the locations in the magnetosphere are chosen far from the X-point, I am wondering if the change in the magnetic topology can have effects also at these points for the analysis.

Since the locations of virtual spacecraft S1 and S2 are on closed field lines which do not further reconnect and are convected earthwards, there is no risk that the precipitating protons observed at S1 (or S2) are affected by magnetic reconnection before they reach the ionosphere. Hence, there should be no concerns regarding the validity of the hypothesis that the plasma observed at the virtual spacecraft remains attached to its magnetic flux tube until precipitating protons reach the ionosphere.

4. During the phase 2, the orbit of the NASA-MMS mission was chosen to spend time on the night side of the Earth's magnetosphere. Did the authors check if there are any datasets able to support their results?

Comparing our results with MMS data would indeed be interesting; however, we feel that this task would be beyond the scope of the present study, whose main aim is twofold: (i) present the methodology to evaluate proton precipitation in Vlasiator simulations, and (ii) discuss the nightside proton precipitation from a global perspective during a simulated event with southward IMF. A comparison of those results with observations could therefore be carried out in a follow-up study.

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