Ann. Geophys. Discuss.,
https://doi.org/10.5194/angeo-2020-13-RC1, 2020

Annales Geophysicae Discussions
Open Access

Interactive comment on "Asymmetries in the Earth's dayside magnetosheath: results from global hybrid-Vlasov simulations" *by* Lucile Turc et al.

Anonymous Referee #1

Received and published: 18 April 2020

Summary of the manuscript: Authors have studied magnetosheath dawn-dusk asymmetries of the magnetic field (B), proton number density (n) and plasma flow speed (V) in the 2-D global Vlasiator simulation and compared the results with statistics from the THEMIS observations. The main conclusion made by the authors is that while the polarity of the asymmetries agrees with the THEMIS results, the magnitudes are in disagreement because Vlasiator is run with one set of conditions, whereas spacecraft observations show cumulation of the observations from different solar wind conditions and IMF orientations.

Overall evaluation of the manuscript:

Unfortunately, in its present form I am unable to recommend this manuscript for publication in the scientific literature for the following reasons:

1) There are no original ideas or new scientifically valid results. There have been several past studies of the magnetosheath properties using both spacecraft data and different plasma approximation (e.g., MHD, hybrid, kinetic-simulations). Some of these have been cited but not all: The bow shock is not the only source for magnetosheath plasma. Also magnetopause processes are important that can transport magnetospheric particles into the magnetosheath. The study of the dawn-dusk asymmetries of B, n and V using spacecraft data has already been done. If the motivation is to solely test the code robustness, by using the study of dawn-dusk asymmetries as a validation effort against spacecraft data, a technical paper may be more suitable.

2) For scientific paper "more in depth" analysis of the physical mechanisms is required to address what differences are due to numerical issues, what are due to kinetic physics, and what are the mechanisms. For example, how are the magnetosheath densities > 4 explained, if solar wind density is 1? How are these results affected by grid-resolution.

3) The Methodology of the present paper is flawed so no accurate scientific conclusions can be made at this time. The authors' conclusion, that the disagreement with the data and simulation is due to the fact that simulation is run for one set of conditions, whereas spacecraft data contains the history of IMF and solar wind, is only one possible reason. Paper fails to discuss the other, more plausible and likely more significant reasons listed below:

i) Code is run with 750 km/s solar wind speed. This condition occurs rarely as the average solar wind speed is slightly less than 400 km/s. Therefore, it is not logical or scientifically justified to compare the runs with 750 km/s solar wind velocity with the spacecraft statistics collected in the magnetosheath, when the solar wind flow preceding the THEMIS data collection is about 400 km/s. With higher solar wind speeds, the shock compression becomes stronger and one would expect higher magnetic field strengths downstream of the quasi-perpendicular shock than for solar wind speeds of 400 km/s.

ii) The runs use upstream solar wind density of 1/cc, which would result in a maximum downstream density of about 4/cc downstream of quasi-perp shock. Assuming the values of 1- 4/cc, the ion inertial length would be 228 km to 114 km in the magnetosheath, respectively, and for higher densities these scales get even smaller. The paper does not describe what the coordinate-space resolution is used for the runs. In order to appropriately resolve the physical ion scales, the Vlasiator should use about 5 to 10 cells/ion inertial length, which requires coordinate space resolution at the minimum of about 20-40 km, otherwise the kinetic effects can artificially dominate at larger length scales than in the real system. Furthermore, if the ion inertial scale at the bow shock is not appropriately resolved, the results pertaining to kinetic shock physics are physically meaningless or exaggerated.

iii) Since the B, n and V are MHD quantities, authors should also run their case exactly with same parameters using the major global, state-of-the-art 3-D MHD codes available through Community Coordinated Modeling Center and compare their Vlasiator results with these.

Recommendation:

While I cannot recommend this paper for publication at this time, I hope the authors will use this feedback as an opportunity to improve the paper, and for transparency include additional missing information (e.g., the grid-resolution etc.). This work requires significant further code validation efforts in a global scale, where the effects of spatial grid-resolution are systematically studied, so that the results can be correctly interpreted.

Please see the specific comments below that need to be addressed after which the paper may eventually become suitable for scientific literature:

Specific comments:

1. Calculate the statistical solar wind and IMF condition from THEMIS statistics used in the paper.

2. Plot and show a spatial map in x-y -plane for each run of the i) ion inertial length, ii) ion gyro-radius and iii) plasma beta, and collect a mean, minimum and maximum values of these at the central magnetosheath where the statistics pertaining to study is being collected during the course of the simulation.

3. Re-run Vlasiator with the statistical conditions and with the appropriate resolution (whichever length-scale is the smallest). For plasma beta of 1, the both length-scales should be the same. Compare the results with those in the present manuscript.

4. Add details and benchmarking how the phase space velocity distributions are processed to calculate n and V in 2-D-plane (as one can cut a 3-D velocity distribution in infinite ways). Show how the processing of the velocity distribution functions affects the results. Convince the reader of the validity of this processing at different regions in the magnetosheath.

5. Re-run Vlasiator with a) old-set of parameters shown in this manuscript while appropriately resolving these length-scales and compare with the results from original resolution.

6. Ion and electron temperatures are an important quantity to demonstrate the dawn-dusk asymmetry. It will be very interesting to see these two parameters, and the perpendicular and parallel temperatures.

7. Since the majority of the quantities compared in this study can also be obtained by the MHD global simulation, I suggest the authors also run the same solar input in the CCMC to compare with all the other three major MHD models and show the advantage of Vlasiator results.

8. What is the “zebra stripes” structure on the dusk side, are those physical waves

(which wave-mode) or a grid oscillation?

9. From MHD the maximum shock compression ratio would give magnetosheath densities of 4/cc if the density in the solar wind is 1/cc. Here the maximum density in the magnetosheath is 6/cc. Is this a kinetic effect and what is the physical mechanism to generate that? How is the area of the > 4/cc density regions in the magnetosheath dependent on the ion gyro-radius/inertial scale and grid resolution when compared to MHD simulations that are run with the same parameters and same resolution?

Minor comments:

1. The Discussion and Conclusions are repetitive. This could be made more concise.

2. The referencing is inadequate. Authors should extend their citations to include some of the following. Please see previous global hybrid simulation studies of the magnetosheath (e.g. by Y. Lin et al. (2001-2020), H. Karimabadi et al., N. Omidi et al,) and several missing studies related to spacecraft observations and statistics of the various fore-shock transient that modify magnetosheath properties (e.g., F. Plaschke et al. (2013-2019), D. Turner at al., H. Hietala et al.(2009-2018), T. Liu et al.(2017-2019), H. Zhang et al. (2013-,) as well as leakage of magnetospheric particles into the magnetosheath by various processes (e.g., I. Cohen et al. 2017; K. Sorathia et al., 2019), and due to local magentosheath physics (e.g., P. Gary et al., 2006 A. Retino et al. 2007, D. Sundkvist et al. 2007, J. Soucek et al.(2008-2015), V. Genot et al. (2001-2009), T. Phan et al., 2018).

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