Asymmetries in the Earth’s dayside magnetosheath: results from global hybrid-Vlasov simulations

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THE MAGNETOSHEATH PLAYS A KEY ROLE IN SOLAR WIND-MAGNETOSPHERE COUPLING

At the interface between the solar wind and the magnetosphere, the magnetosheath is filled with shocked solar wind plasma.

The magnetosheath regulates the upstream conditions for magnetopause processes (reconnection, Kelvin-Helmholtz instability)
THE MAGNETOSHEATH PARAMETERS DISPLAY PRONOUNCED DAWN-DUSK ASYMMETRIES

- These asymmetries are mostly due to the different bow shock configuration on the dawn (quasi-parallel) and dusk (quasi-perpendicular) flanks during Parker-spiral IMF [Walsh et al., 2012; Dimmock & Nykyri, 2013; Dimmock et al., 2017]

- These asymmetries can influence plasma transport processes at the magnetopause, such as the KHI [Nykyri et al., 2017], and could partially explain the temperature asymmetry in the magnetotail [Wing et al., 2005; Dimmock et al., 2015]
• Hybrid-Vlasov model designed for global magnetospheric simulations
• Ions treated as velocity distribution functions, electrons are a charge-neutralizing fluid
• Most runs are currently 5D – 3D in velocity space and 2D in ordinary space
• Full description of the model: Palmroth et al. [2018]

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WE QUANTIFY MAGNETOSHEATH ASYMMETRIES IN A SET OF THREE VLASIATOR RUNS:

<table>
<thead>
<tr>
<th>Run name</th>
<th>Simulation plane</th>
<th>IMF cone angle $\theta_{Bx}$</th>
<th>IMF strength</th>
<th>$M_A$</th>
<th>$n_{SW}$ [cm$^{-3}$]</th>
<th>$V_{SW}$ [kms$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>$x - z$ plane</td>
<td>$45^\circ$</td>
<td>5 nT</td>
<td>6.9</td>
<td>1</td>
<td>$(-750,0,0)$</td>
</tr>
<tr>
<td>Run 2A</td>
<td>$x - y$ plane</td>
<td>$30^\circ$</td>
<td>5 nT</td>
<td>6.9</td>
<td>1</td>
<td>$(-750,0,0)$</td>
</tr>
<tr>
<td>Run 2B</td>
<td>$x - y$ plane</td>
<td>$30^\circ$</td>
<td>10 nT</td>
<td>3.5</td>
<td>1</td>
<td>$(-750,0,0)$</td>
</tr>
</tbody>
</table>

- Run 1: comparable with typical Parker-spiral IMF orientation
- Run 2A: lower cone angle
- Run 2B: lower Alfvén Mach number
We divide the magnetosheath in 18 azimuthal sectors (10° wide).

We delineate the inner and outer magnetosheath boundaries with a model of the same form as the Shue et al. [1997] magnetopause model.

We divide the magnetosheath into three sets of radial bins: inner, central and outer magnetosheath.

We calculate the average magnetosheath parameters in each magnetosheath bin by performing a spatial average, inside the bin, and a temporal average, over 150 s of the simulation.
- $B_{\text{Msheath}} \leq 4B_{\text{SW}}$ just downstream of the bow shock, consistent with MHD theory
- Larger field increase deeper in the magnetosheath due to the field lines piling up in front of the magnetosphere
- Weaker magnetic field compression in the low Alfvén Mach number run (Run 2B)

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MAGNETIC FIELD STRENGTH ASYMMETRY

- **Quasi-perpendicular-favoured asymmetry**, consistent with previous works [Walsh et al., 2012; Dimmock et al., 2017]

- Parker-spiral asymmetry level (in black) similar to that in the data (5-10% in Dimmock et al., 2017)

- More pronounced asymmetry when the cone angle is reduced from 45° to 30° because of the weak compression at the quasi-parallel shock

- Less pronounced asymmetry at low $M_A$ due to the reduced compression at the quasi-perpendicular shock
• Bulk velocity close to zero near the magnetopause nose and faster flows towards the flanks, as expected.

• **Large variability** of the velocity in the quasi-parallel magnetosheath, due to foreshock processes

• **Reduced variability** of the quasi-parallel magnetosheath velocity at low Alfvén Mach number

Turc et al., submitted to Annales Geophysicae
BULK VELOCITY ASYMMETRY

- **Quasi-perpendicular-favoured asymmetry**, consistent with previous works [Walsh et al., 2012; Dimmock et al., 2017].

- Parker-spiral asymmetry level slightly larger than in spacecraft measurements (5-10% in Dimmock et al., 2017)

- No significant change in the asymmetry level when changing the cone angle or the Alfvén Mach number

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• Magnetosheath density < 4 times the solar wind density in the quasi-perpendicular magnetosheath, consistent with MHD theory

• Large variability of the density in the quasi-parallel magnetosheath, due to foreshock processes

• Reduced density fluctuations at low Alfvén Mach number (Run 2B)
ION DENSITY ASYMMETRY

• Mostly quasi-parallel-favoured asymmetry, consistent with previous works [Paularena et al., 2001; Walsh et al., 2012; Dimmock et al., 2017]

• Large variability of the density asymmetry, even during completely steady upstream conditions → reverse polarity in some azimuthal bins

• Median value of the asymmetry closer to 0 at low Alfvén Mach number → less pronounced asymmetry overall, but with significant local variations

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CONCLUSIONS: VALIDATION OF THE SIMULATION RESULTS

The magnetosheath asymmetries in our Vlasiator runs are in good agreement with statistical spacecraft observations:

- Same polarity (quasi-perpendicular or quasi-parallel-favoured)
- Levels of asymmetry larger in the simulation, due to the single set of upstream conditions in each run ≠ compilation of observations with vastly different solar wind parameters [see also Walsh et al., 2012]

CONCLUSIONS: VARIABILITY OF MAGNETOSHEATH ASYMMETRIES

- When the cone angle is reduced from 45° to 30°, the magnetic field asymmetry is more pronounced, while the density and velocity asymmetry levels are unchanged.

- At low Alfvén Mach number, the magnetic field asymmetry level decreases, and the variability of the magnetosheath density and velocity is reduced, due to weaker foreshock processes.

- Large variability of the plasma density even for completely steady upstream conditions in our simulation, in particular in the quasi-parallel magnetosheath → could explain the vastly different levels of density asymmetry quantified in previous observational studies.