Investigating magnetopause dynamics using global magnetosphere simulation

COLLEGE OF ENGINEERING
AEROSPACE ENGINEERING
UNIVERSITY OF MICHIGAN

Austin Brenner [1], Tuija Pulkkinen[2]

[1] University of Michigan, Aerospace Engineering Department
[2] University of Michigan, Climate and Space Sciences and Engineering Department

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Intro

We develop new methods for processing 3D MHD data to directly quantify energy flux through the magnetopause and energy contained within the magnetosphere volume to better understand the system dynamics as a whole.

This study focuses on the second of a multi ICME impact event on Feb 18 2014 with Solar wind input as shown in Figure 1.

Methods

The Space Weather Modeling Framework (SWMF [1]) is used to simulate the Geospace environment and full 3D field data is saved at 1min resolution so that temporal dynamics of the magnetopause can be captured.

The magnetopause surface is identified at each output time using a combination of closed field line status indicator and β^* a modified plasma β incorporating both dynamic and thermal pressure in the numerator (hydrodynamic pressure). Previous studies have used flow line tracing and achieved similar results [2].

The total energy transfer vector $\vec{K}$ is used to quantify flux through the boundary and is split into contributions from electromagnetic energy (Poynting flux) $\vec{E}\times\vec{B}$, and hydrodynamic energy $(P_0)\ \vec{u}$. Each transfer vector is dotted with the surface unit normal to obtain the amount entering or leaving the system volume.

$$\vec{K} = \underbrace{\left(\frac{1}{2}\rho u^2 + \frac{\gamma}{\gamma-1}P + \frac{B^2}{\mu_0}\right)\vec{u}}_{P_0} - \underbrace{\frac{\vec{B}\circ\vec{u}}{\mu_0}\vec{B}}_{\vec{E}\times\vec{B}}$$

Results

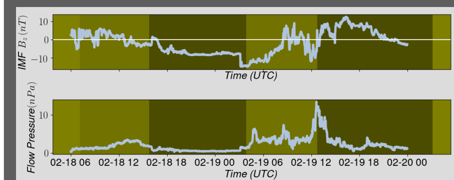


Figure 1: Solar wind B_z and Flow Pressure (ρu^2) for the event simulated. Data obtained from the WIND satellite. Shading indicates regions of the ICME identified using ground based magnetic perturbation observations

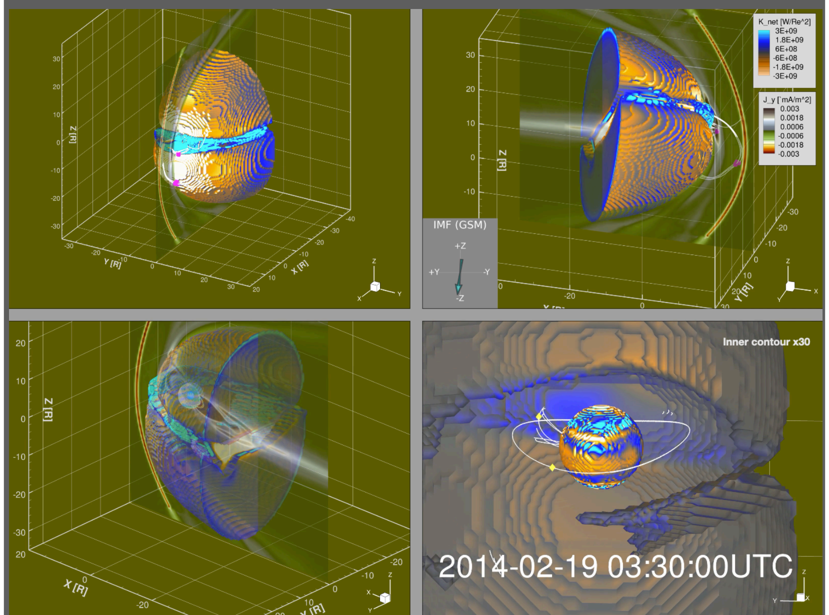
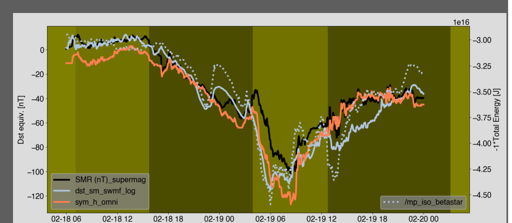


Figure 2: Multiple views of simulation output showing magnetopause surface and inner boundary at $r = 3R_e$ with contours showing $K_{injection}\,(-)$ and $K_{escape}\,(+)$. XZ slice shows contours of current density J_y illustrating the bowshock and magnetopause surface currents. The inner boundary contour levels are magnified by 30 to show the higher energy transfer density. Trajectories for various satellites along with positions shown with marker changes to indicate inside/outside magnetosphere. Trace comparisons are reserved for future work.

Figure 3: Comparison of simulated Dst with two observations (OMNI, SuperMAG)[3][4] showing simulation accuracy. RHS y axis normalized volume integrated energy shows good correlation between total energy and magnetic perturbation. This demonstrates the usefulness of tracing the system energy



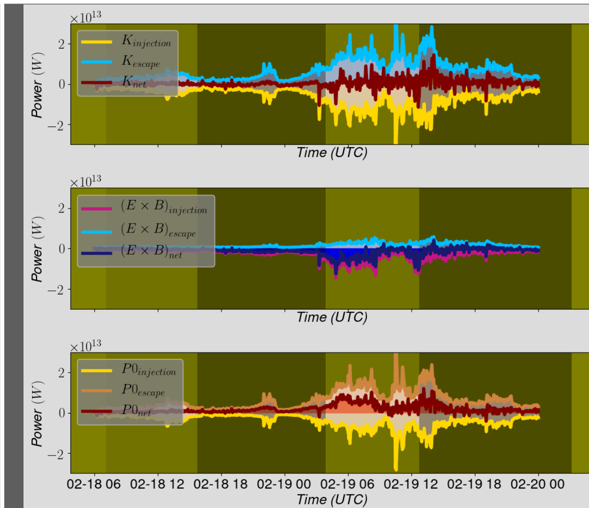


Figure 4: Panels show integrated energy flux through the outer surface boundary. Total energy flux (top), Poynting flux (mid), and hydrodynamic energy flux (bot) are shown with sign indicating injection (-) or escape (+) relative to the magnetosphere volume. It is clear that the magnetosphere is acting as an energy converter bringing in net electromagnetic energy and releasing net hydrodynamic energy. It is also clear that both types of energy are being transferred through the boundary at all times.

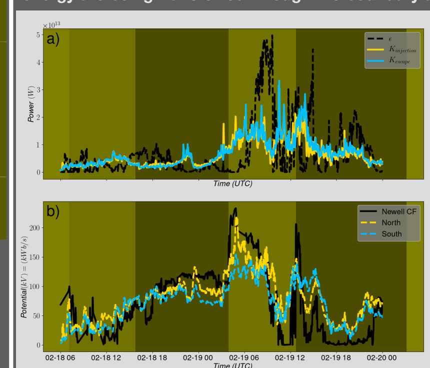


Figure 5: Two energy proxies are shown. a) Integrated total energy flux injected and escaping from the boundary compared with Akasofu ϵ parameter using $l_0 = 7R_e$ [5]. b) North and South Cross Polar Cap Potential (CPCP) from the simulation compared with Newell coupling function [6].

Conclusion

Strong correlation between volume energy state and magnetic perturbation. Integrated energy flux totals by type demonstrate energy conversion. Future studies to analyze spatial variations for both surface energy flux and volume energy.

References

[1] Tóth, G., et al. (2005), Space Weather Modeling Framework: A new tool for the space science community, *J. Geophys. Res.*, 110, A12226, doi:10.1029/2005JA011126.

[2] Palmroth, M., Pulkkinen, T.I., Janhunen, P., Wu, C.-C., 2003. Stormtime energy transfer in global MHD simulation. Journal of Geophysical Research 108 (A1), 1048, doi:10.1029/ 2002JA009446.

[3] NASA/GSFC's OMNI data set through OMNIWeb

[4] Gjerloev, J. W. (2012), The SuperMAG data processing technique, J. Geophys. Res., 117, A09213, doi:10.1029/2012JA017683.

[5] Paul Perreault, S. I. Akasofu, A study of geomagnetic storms, *Geophysical Journal International*, Volume 54, Issue 3, September 1978, Pages 547–573, https://doi.org/10.1111/j.1365-246X.1978.tb05494.x

[6] Newell, P. T. *et al.* (2007), A nearly universal solar wind-magnetosphere coupling function inferred from 10 magnetospheric state variables, *J. Geophys. Res.*, 112, A01206, doi:10.1029/2006JA012015.