Geomagnetic storm event simulation using a global MHD with adaptively embedded particle-in-cell (MHD-AEPIC) model

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PREEVENTS

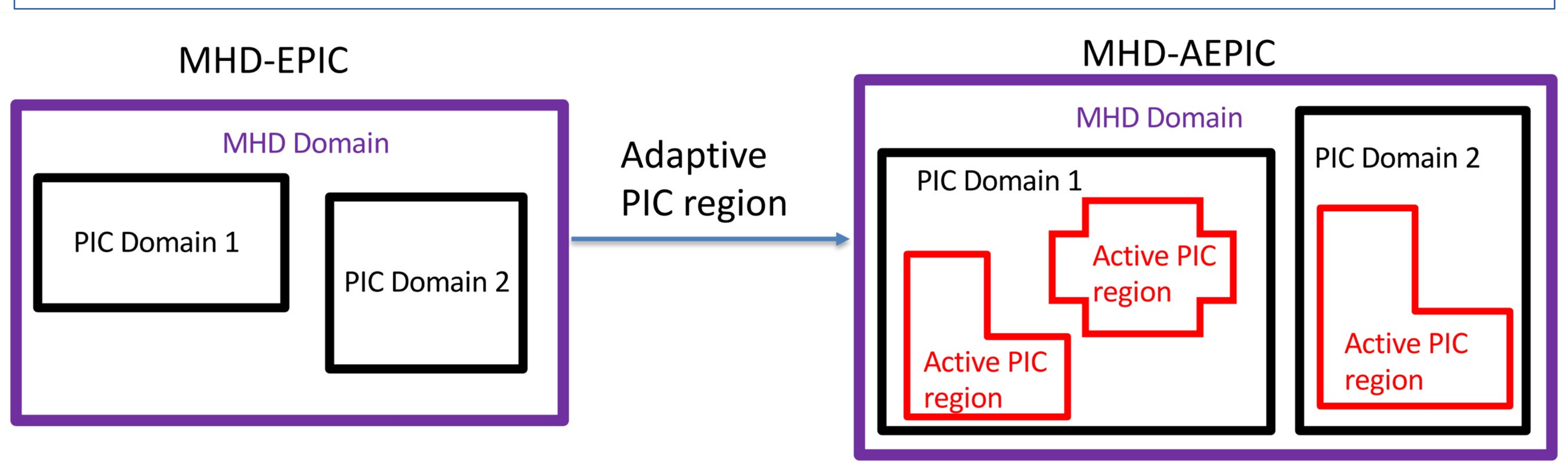
Introduction

❖ Kinetic Physics in Global Magnetosphere Simulation

- MHD-EPIC: two-way coupling between MHD and PIC models
- MHD-EPIC has been used to study the dayside magnetic reconnection (Chen et al. 2017)
- Applying MHD-EPIC to the tail is challenging: large PIC region is needed to cover the tail reconnection sites
- *MHD-AEPIC: dynamically adapt the PIC region during the runtime to minimize the computational cost*

Model Description

❖ FLexible Exascale Kinetic Simulator (FLEKS, Chen et al 2021)



- Gauss' law satisfying energy-conserving semi-implicit particle-in-cell method (GL-ECSIM)
- Particle resampling: splitting and merging
- Adaptation: PIC cells can be switched on/off

❖ Identifying reconnection sites for PIC

- Current density divided by perpendicular magnetic field:

$$c_1 = \frac{j^2}{|j \times B| + j\epsilon} \Delta x > 0.4$$

- Divergence of the magnetic field curvature

$$c_2 = [\nabla \cdot (b \cdot \nabla b)](\Delta x)^2 > \text{-}0.1$$

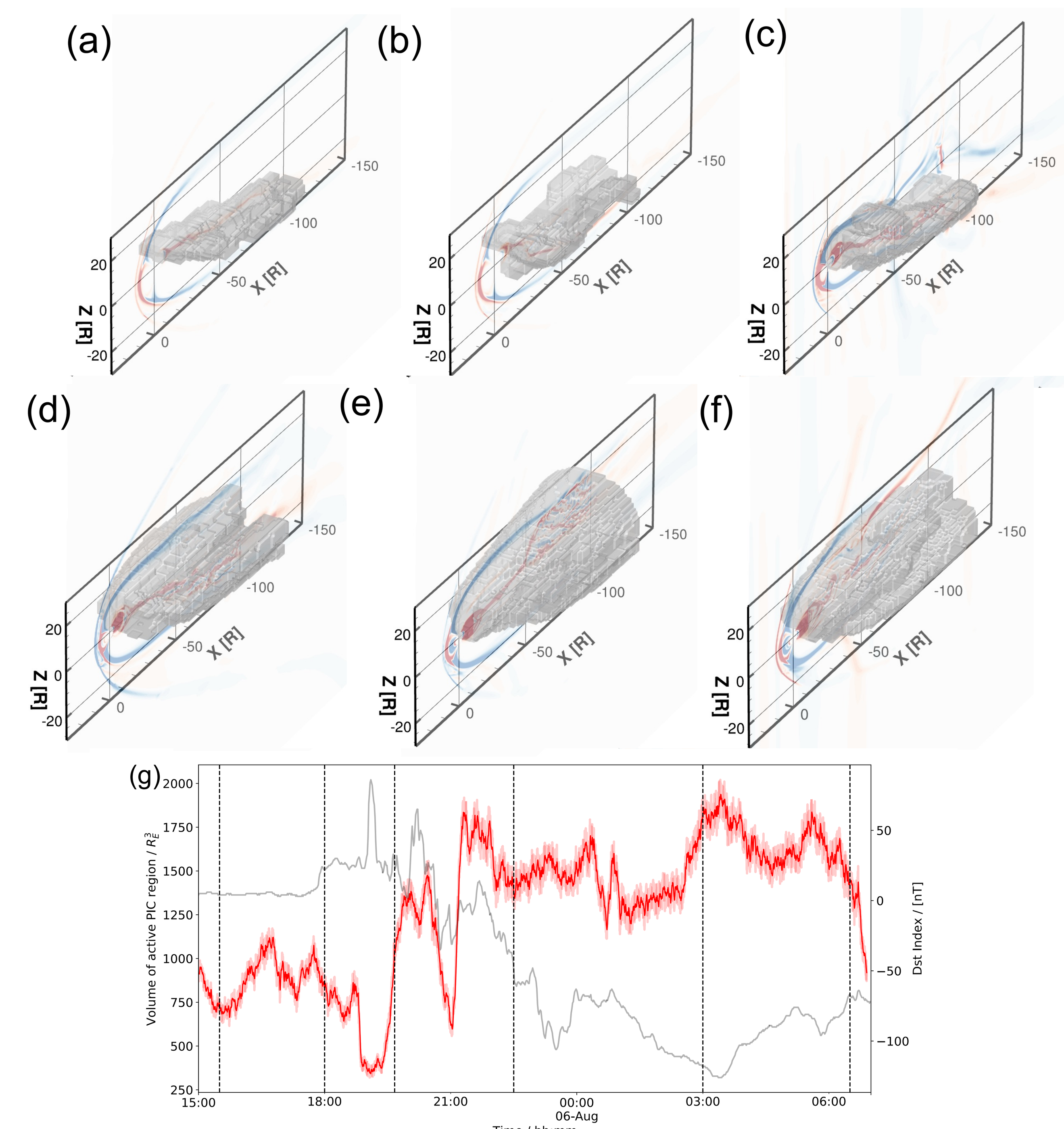
- Specific entropy

$$c_3 = \frac{p}{\rho^\gamma} > 0.02 \text{ nPa/(amu*cm}^{-3})^\gamma$$

c_1 identifies current sheet but ignores the guide field;
c_2 excludes O-lines;
c_3 restricts the PIC region to be inside the magnetosphere.

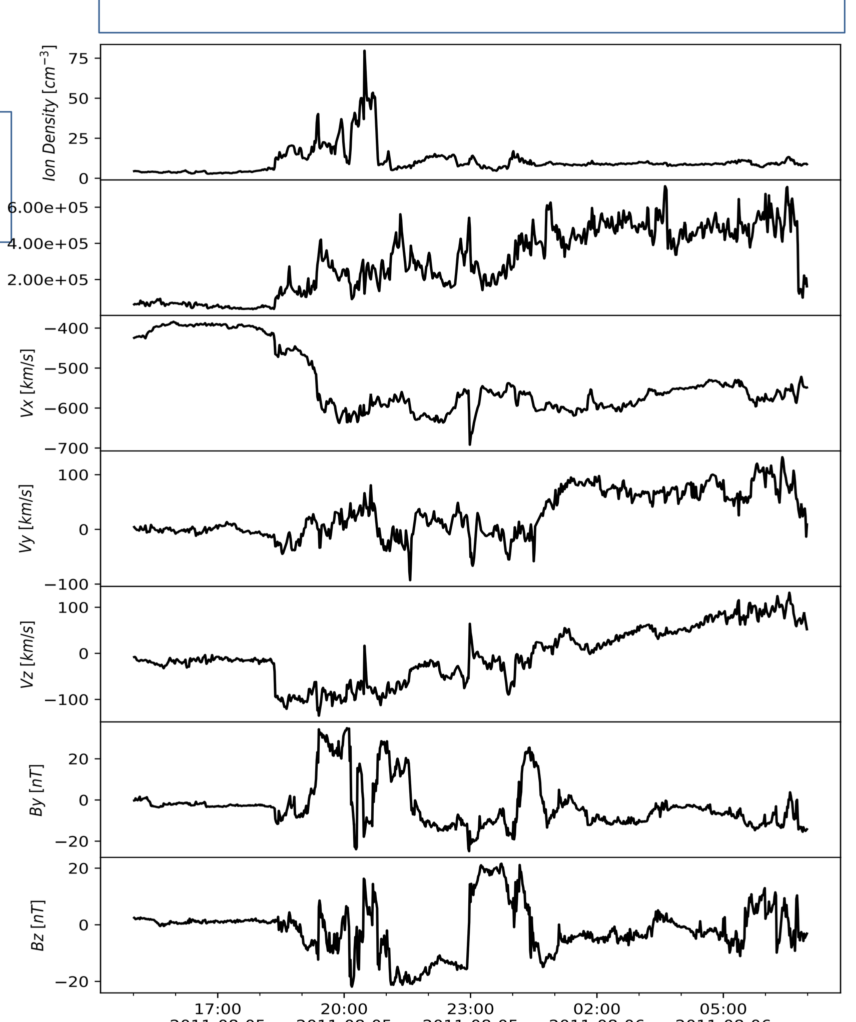
Dynamically adapting PIC domain

The grey iso-surfaces are the boundaries of the active PIC domain.



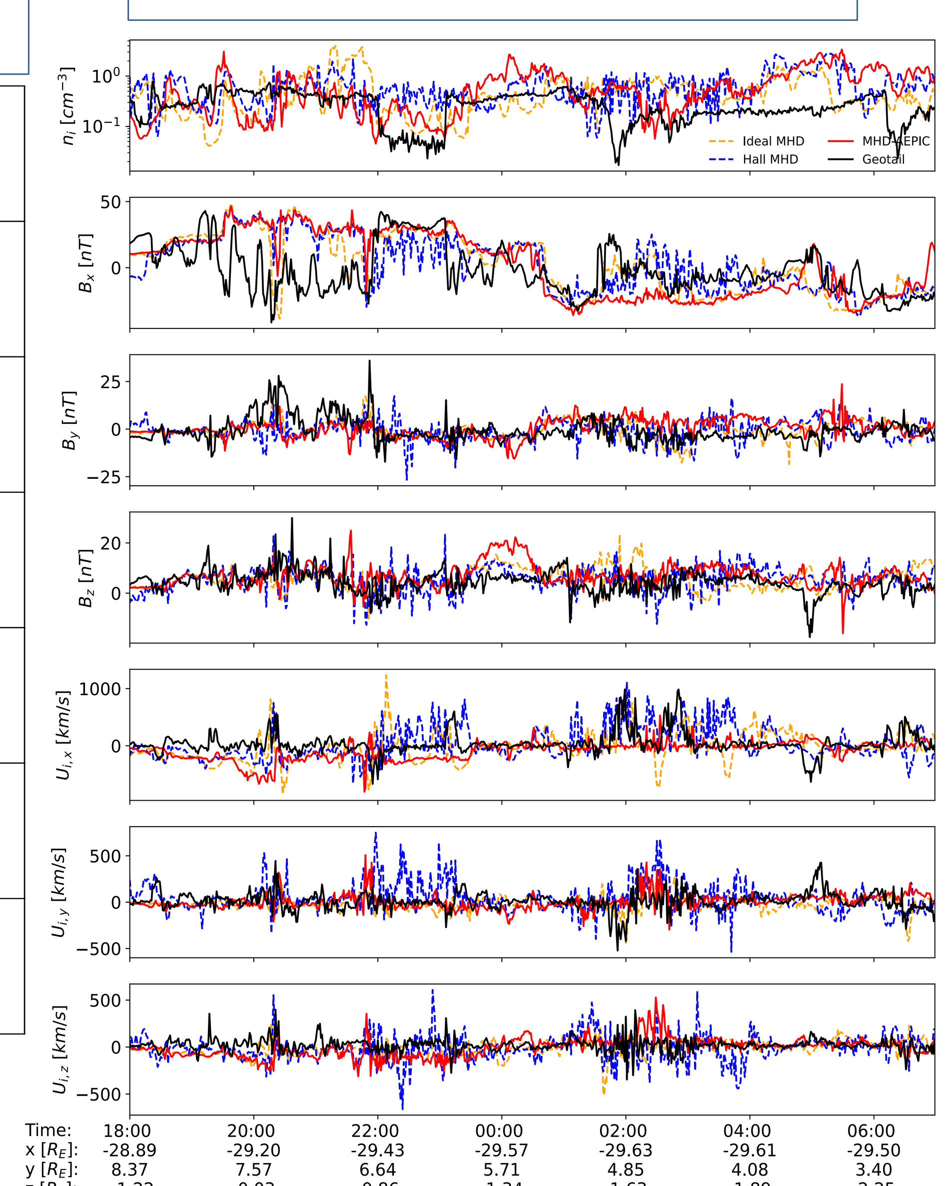
Geomagnetic Storm Simulation

❖ Selected storm event: 2011-08-05



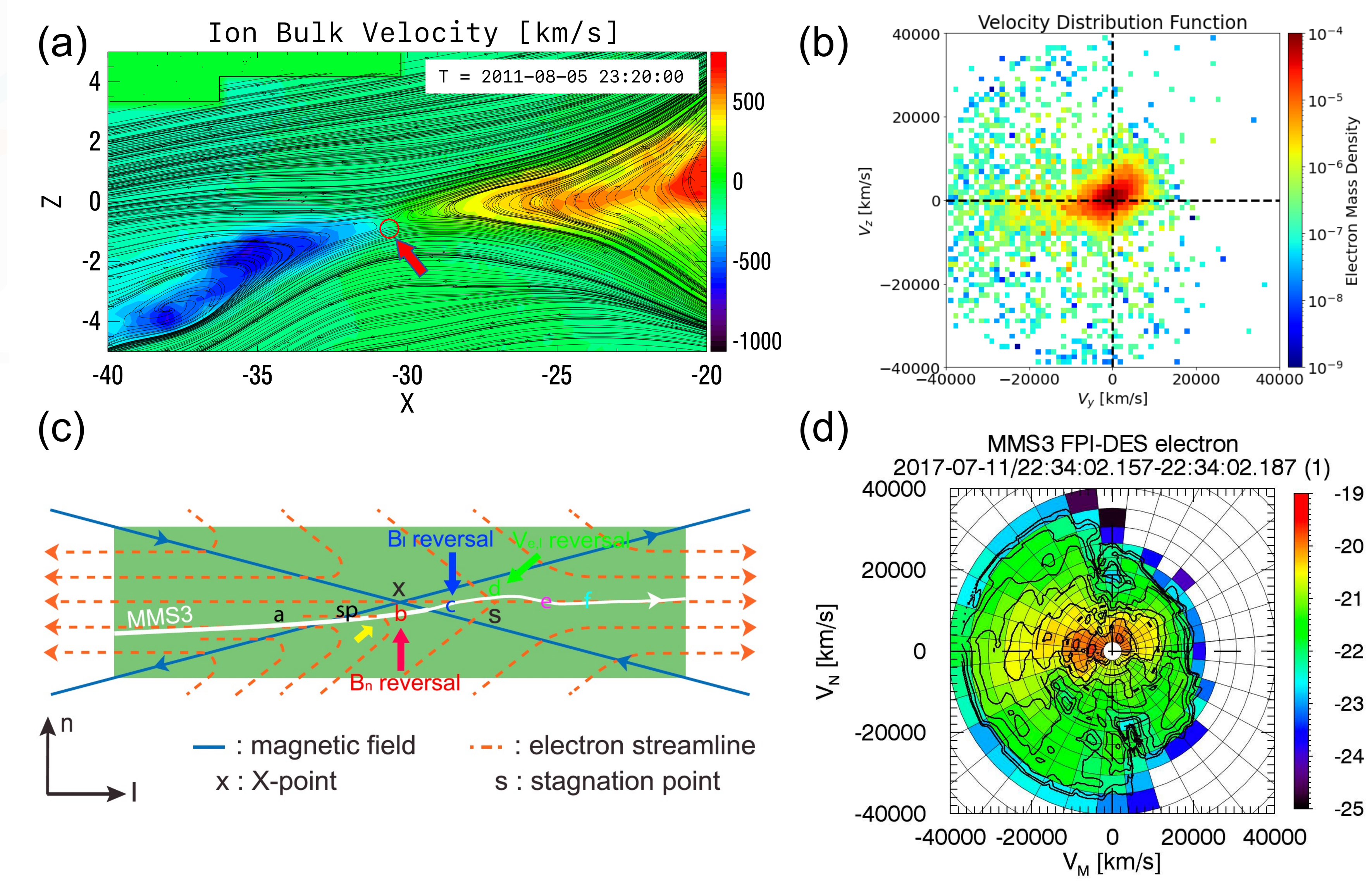
Two southward turnings of IMF happen at 18:30 on 2011-08-05 and 6 hours later.

❖ Geotail observation

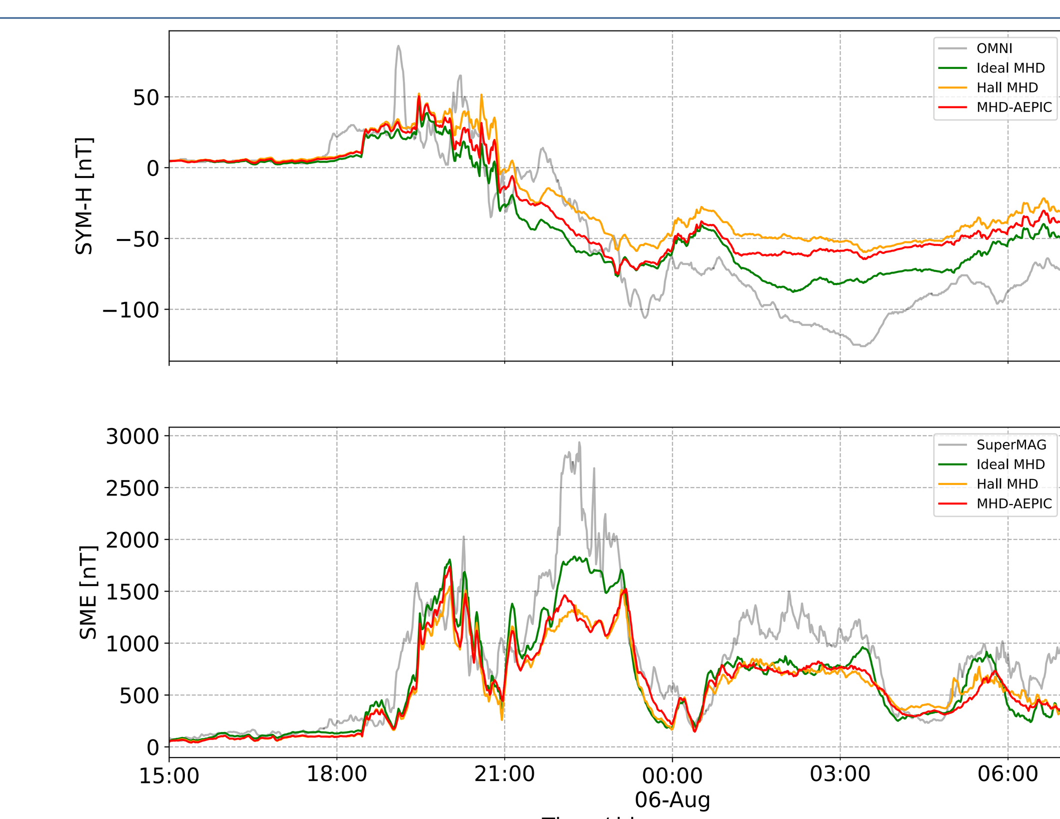


Results

❖ Reconnection event & Electron Velocity Distribution



❖ Dst Indexes from different models



Conclusions

- A brand new MHD with adaptively embedded particle-in-cell (MHD-AEPIC) model is introduced
- The new model makes it possible to perform a geomagnetic storm event simulation with electron physics for the first time
- The 16 h storm event takes ~255 h on 5600 CPU cores, the average volume of the active PIC patches is 1280 R_E^3, which is ~0.2% of a fixed PIC box: -100 < x < -10, -40 < y, z < 40 R_E
- The model results have good agreement with observations from the electron scale to the global scale

References

1. X. Wang, Y. Chen, and G. Toth. Global magnetohydrodynamic magnetosphere simulation with an adaptively embedded particle-in-cell model. Earth and Space Science Open Archive, page 21, 2021 doi:10.1002/essoar.10508044.2
2. Y. Chen, G. Toth, H. Zhou, and X. Wang. FLEKS: A flexible particle-in-cell code for multi-scale plasma simulations. Earth and Space Science Open Archive, page 27, 2021 doi:10.1002/essoar.10508070.1

Acknowledgements

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