Kaitlin Doublestein[1], Michael Liemohn[1], Daniel Welling[1]

Impact of Single Fluid and Multi-fluid MHD on GMD Forecasting: An Inner Boundary Condition Sensitivity Study

[1]Department of Climate and Space Science and Engineering, University of Michigan, Ann Arbor, USA

Objective

To show how inner boundary condition (IBC) settings affect simulation results, which in turn, impact geo magnetic disturbances (GMD) forecasting.

Single Fluid vs. Multifluid MHD Equations

Single Fluid:
- Protons and electrons
- No mass separation of other ion species
- Single energy equation solved
- No collision allowed
- Less computational demand

$$\frac{\partial \rho_m}{\partial t} + \nabla \cdot (\rho_m \mathbf{u}) = 0$$

$$\rho_m \frac{\partial \mathbf{u}}{\partial t} + \rho_m (\mathbf{u} \cdot \nabla) \mathbf{u} + \nabla p = \rho_m \mathbf{g} + \mathbf{j} \times \mathbf{B}$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla \times (\mathbf{u} \times \mathbf{B}) = -\eta_m \nabla^2 \mathbf{B}$$

$$\frac{3}{2}\frac{\partial p}{\partial t} + \frac{3}{2}(\mathbf{u} \cdot \nabla) p + \frac{5}{2} p (\nabla \cdot \mathbf{u}) = \frac{1}{\sigma_0} j^2$$

Multifluid:
- Multiple ion species and electrons can be accounted for
- Separate energy equations for different ion species
- More computationally demanding for solving the ideal MHD multiple times

$$\frac{\partial \rho_s}{\partial t} + \nabla \cdot (\rho_s \mathbf{u}_s) = S_{\rho_s},$$

$$\frac{\partial \rho_s \mathbf{u}_s}{\partial t} + \nabla \cdot (\rho_s \mathbf{u}_s \mathbf{u}_s + I p_s) = n_s q_s (\mathbf{u}_s - \mathbf{u}_+) \times \mathbf{B} + \frac{n_s q_s}{n_e e} (\mathbf{J} \times \mathbf{B} - \nabla p_e) + \mathbf{S}_{\rho_s \mathbf{u}_s},$$

$$\frac{\partial p_s}{\partial t} + \nabla \cdot (p_s \mathbf{u}_s) = -(\gamma - 1) p_s \nabla \cdot \mathbf{u}_s + S_{p_s},$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla \times (\mathbf{u}_+ \times \mathbf{B}) = 0,$$

Toth et al., 2009

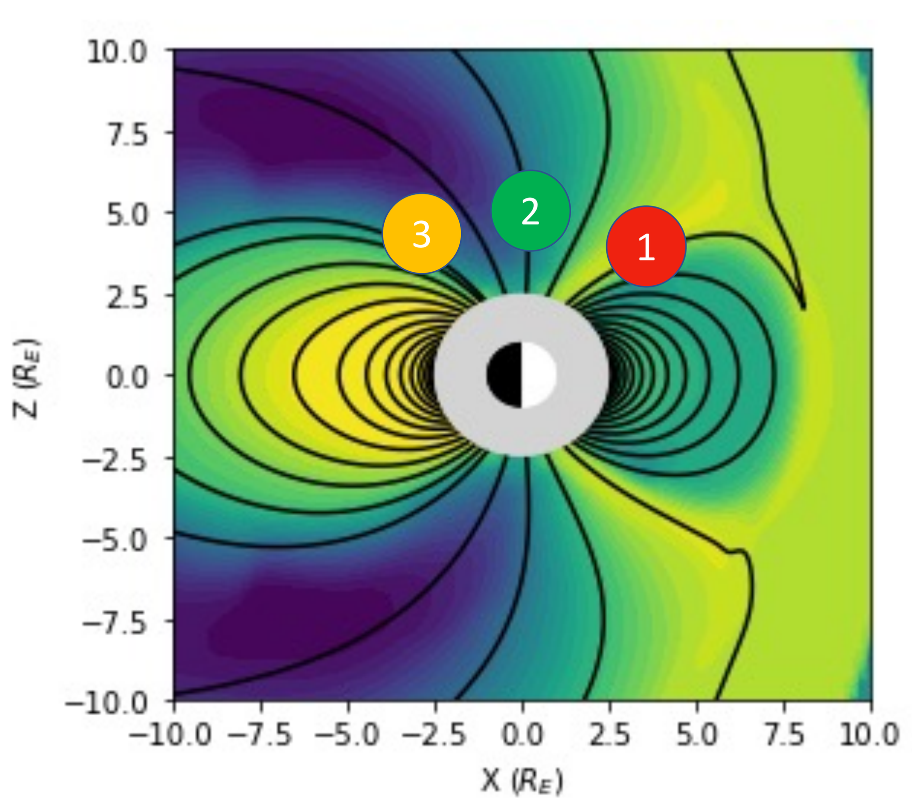
Importance: Allowing other ion species to exist in the MHD equations, this can impact reconnection rates, recovery rates post storm, and impact physics throughout the magnetosphere.

Methodology

Simulation set up:
+3 nT northward IMF B_z for 5 hours to -10 nT southward IMF B_z for 5 hours
Idealized run parameters, compared light, medium, heavy densities at inner boundary

- Coupled General Magnetosphere (GM) and Ionosphere Electrodynamics (IE) using the Space Weather Modeling Framework

Ion Outflow Regions of Interest

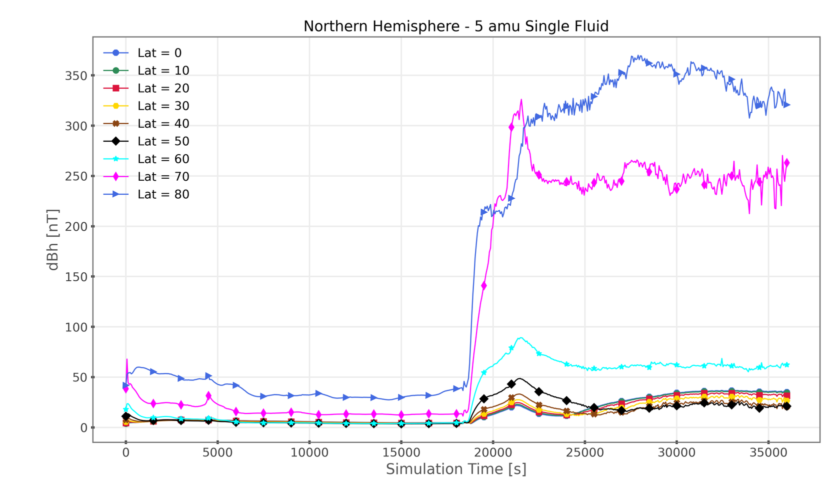


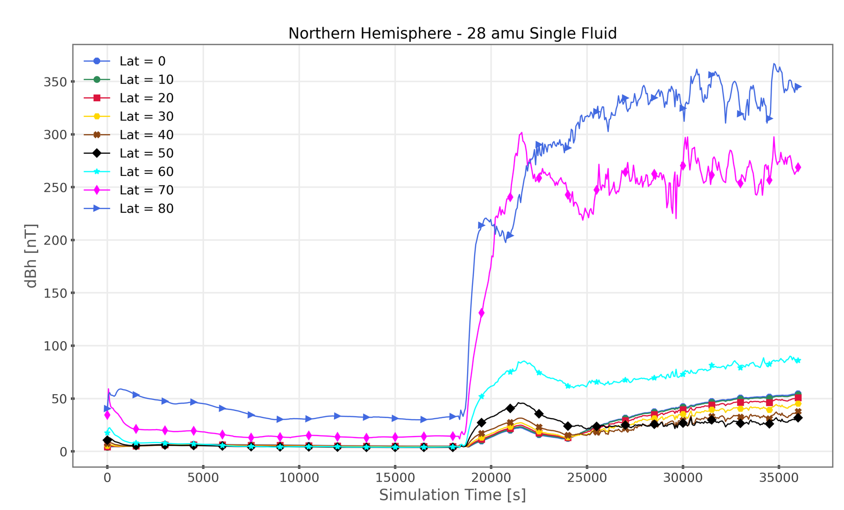
Regions of Interest:
1. Cusp Outflow
2. Auroral Outflow
3. Ring Current Outflow

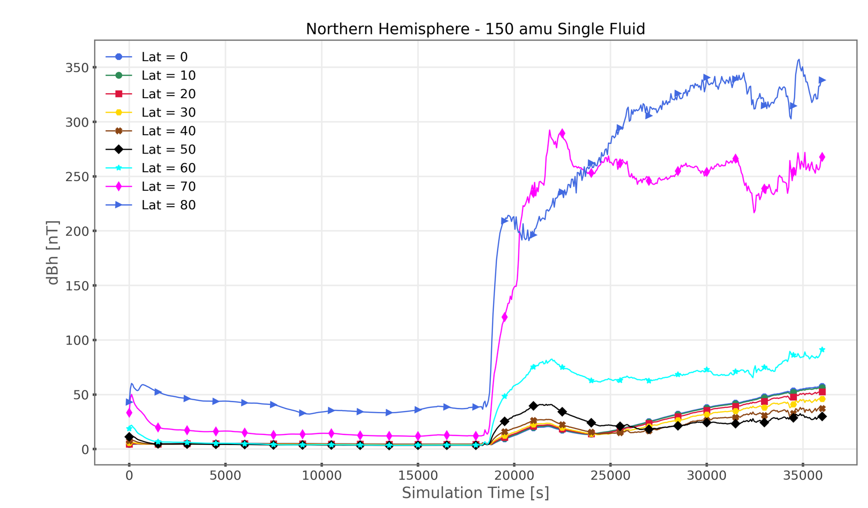
Results

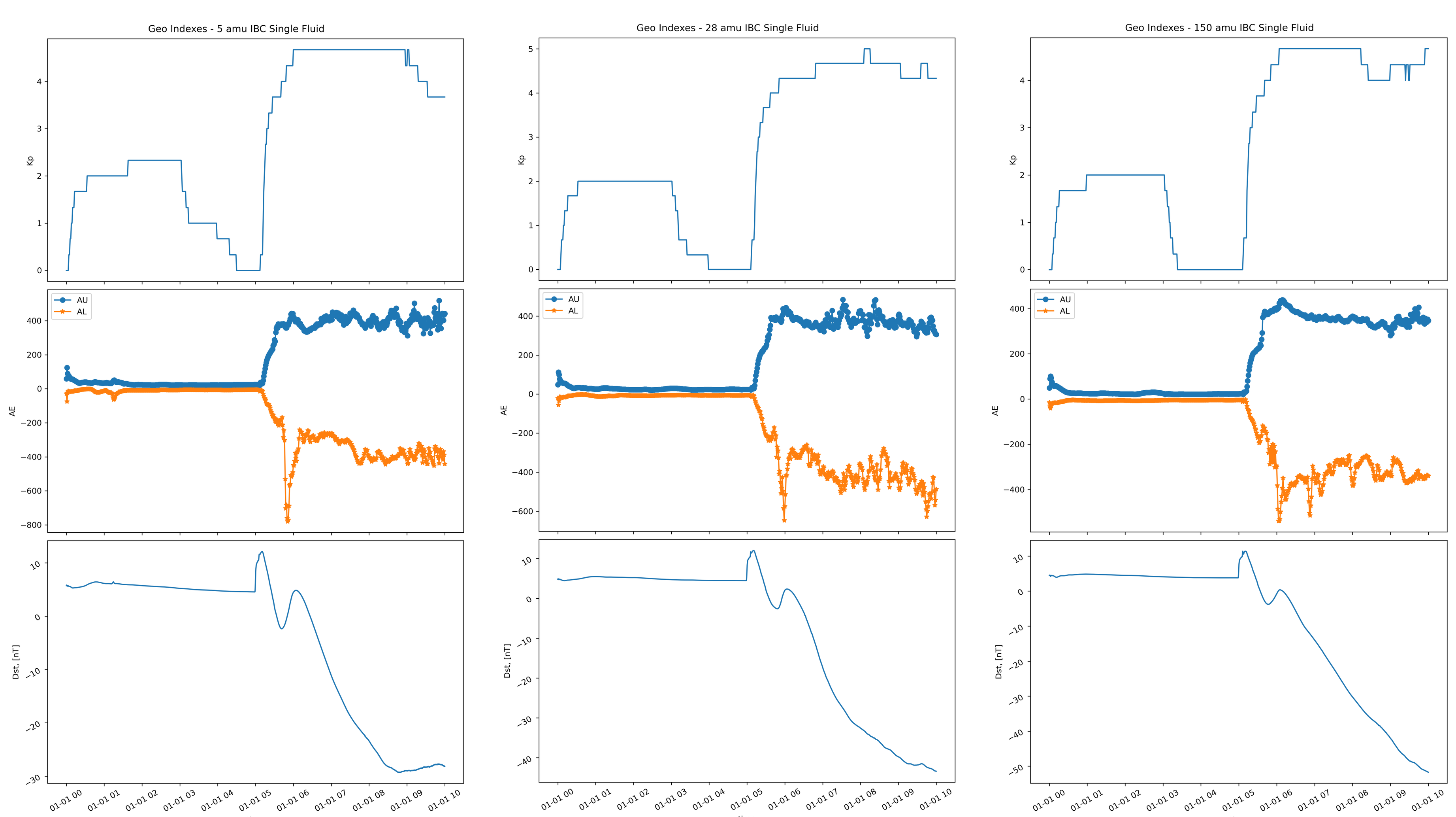
Three Densities – Idealized Runs

Three runs of low, standard, and high density at the inner boundary:
- Following plots show dBh averaged across a latitude region and the geomagnetic indices for the runs they correspond to

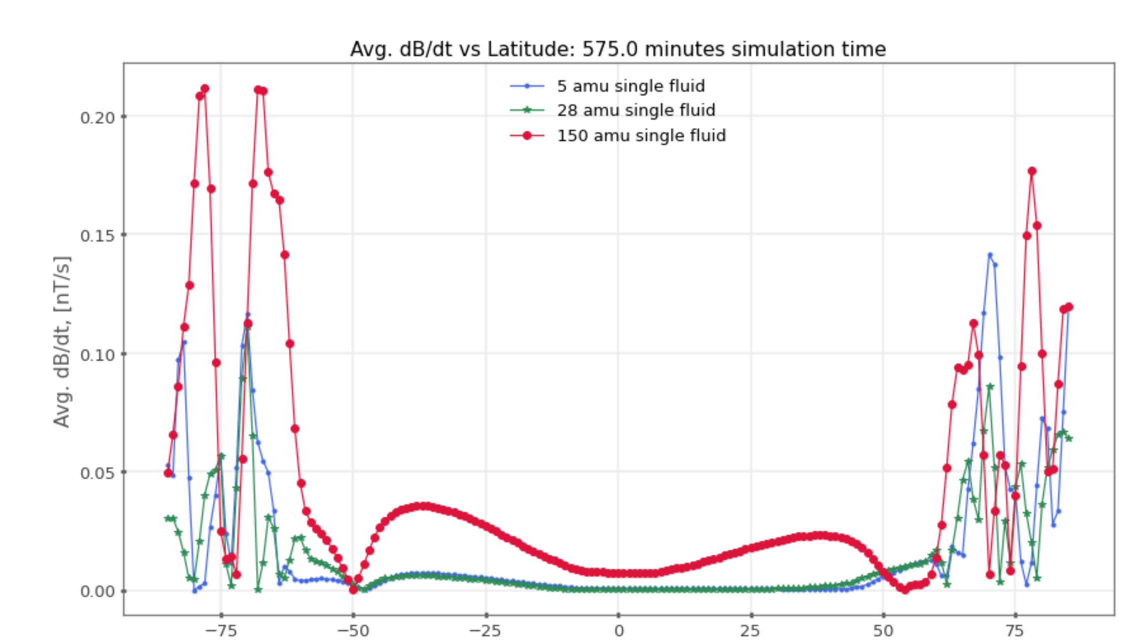








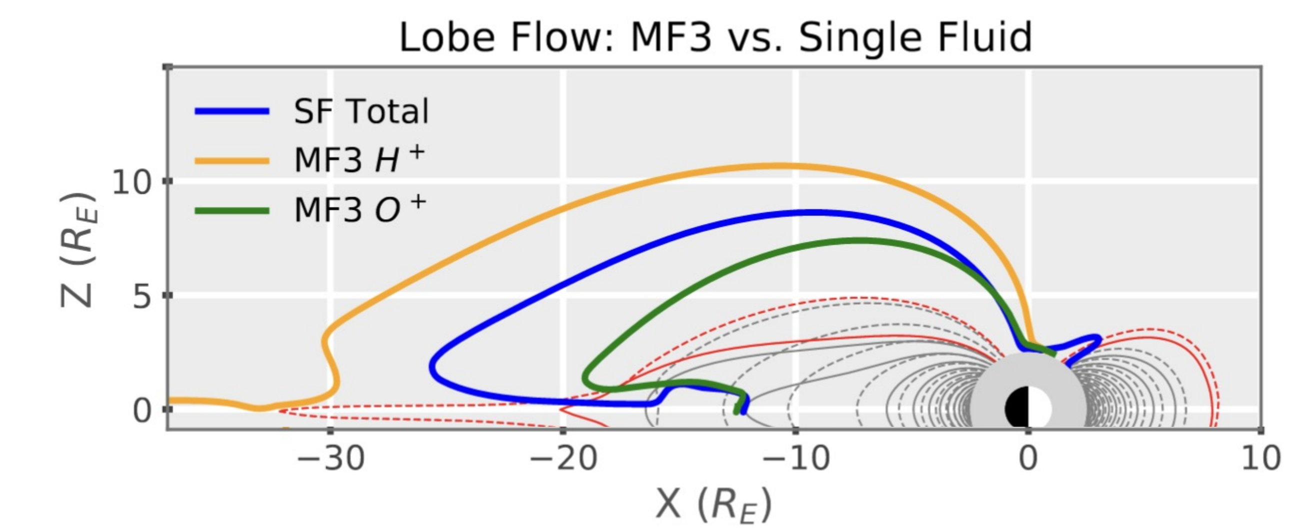
Averaged dB/dt for different densities



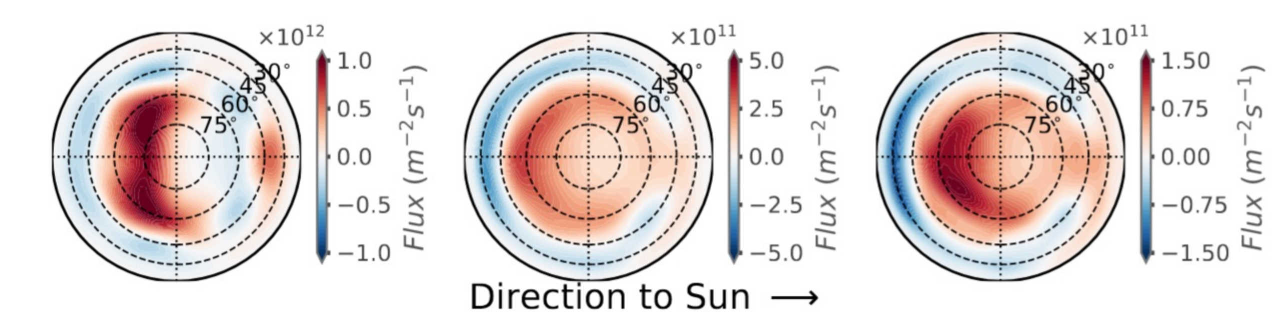
An increase in density leads to a further latitudinal extent!

Multifluid Impact

Multifluid:
- Multifluid run (shown below) indicates that with the presence of O^+, this will feed into the ring current, while H^+ will exit tailward.



The presence of O^+ will change the outflow pattern which dictates the ion trajectory throughout the magnetosphere



Conclusions

Increasing the inner boundary density impacts the latitudinal extent of the average dB/dt. This, in turn, affects GMD forecasting.

It is anticipated that multifluid MHD would further change these results by

Next Steps

Fully flush out multifluid extent of the impact on GMD operations
- Include other IBCs like parallel velocity, temperature, or different compositions on top of number density change.

Compare results to a simulated magnetometer station for a case study

Compare H^+/O^+ ratios during storm time to determine accuracy of single fluid to multifluid MHD for GMD forecasting operations improvement.

Contact Information

Email: kdoubles@umich.edu