

GEM Focus Group: Magnetic Reconnection In Global Modeling of the Magnetosphere

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Proposed FG term: 4 years

Abstract

Modeling of systems involving magnetic reconnection has generally employed one of two strategies: a bottom up strategy, and a top down one. The first is to attempt to include a reasonably complete generalized Ohm's law, but to use a highly idealized geometry to accurately simulate the microscale physics of reconnection in a localized way. The second is to employ realistic system geometry, as in a GGCM, but to employ *ad hoc* grid dependent or current dependent dissipation in order to achieve fast reconnection. This focus group will act to bring these approaches together by incorporating non-MHD effects, and seeking to understand the impact of newly recognized resistive MHD effects (namely plasmoids) in global modeling of the magnetosphere. This focus group would be part of the GGCM research area.

1. Description of Topic

Global MHD models succeed in reproducing many features of the Earth's magnetosphere. However, current computational tools fail to accurately model fast magnetic reconnection in the high Lundquist number (or collisionless) limit. In order to achieve fast reconnection in a global MHD code, modelers usually resort to an *ad hoc* localized or current dependent resistivity. Reconnection plays a pivotal role as a driver of magnetospheric dynamics. Since the reconnection phenomena obtained in a global MHD code are sensitive to the resistivity model, and potentially even to the computational grid, it is essential that we attack the problem of how to include the physics of collisionless magnetic reconnection in global MHD codes.

In the past decade, the reconnection community has come to a consensus that reconnection in numerical simulations can be fast if the so-called "Hall term" is included in the generalized Ohm's law. However, although the inclusion of Hall physics in a global code has been achieved recently (Tóth, 2008), it has yet to be explored in detail. In addition to the Hall effect, recent particle-in-cell (PIC) simulations in idealized geometries have found that in the limit of high Lundquist number, reconnecting current sheets are unstable to a super-Alfvénic plasmoid instability (Daughton *et al.*, 2009). This instability substantially increases the rate of reconnection, possibly allowing reconnection to become fast in high Lundquist number systems, even in the absence of Hall-term-related effects. This instability has also been studied in detail in the context of resistive MHD studies of reconnection (Loureiro *et al.*, 2007, Bhattacharjee *et al.*, 2009, and Cassak *et al.*, 2009). However, it has yet to be seen whether and how this plasmoid instability manifests itself in more realistic, 3D systems.

Additionally, local PIC simulations of reconnection have indicated that the off-diagonal, or *agyrotropic*, elements of the electron pressure tensor play a dominant role in the breaking of the frozen-in condition close to reconnection sites (Kuznetsova *et al.*, 2001).

In addition to electron pressure anisotropy, a recent study by Lê et al. (Lê *et al.*, 2009) has found that electron pressure *anisotropy* is of key importance in determining the geometry of the dissipation region. Preliminary results suggest that the kinetic physics associated with pressure anisotropy can be captured by suitably modified equations of state for parallel and perpendicular pressure (Lê, *et al.*, 2009). Fluid closures, which parameterize and encapsulate the underlying kinetic physics associated with the pressure anisotropy and anisotropy may be a fruitful way to more realistically model the physics of collisionless reconnection in global MHD codes, while avoiding the high computational expense of particle simulation.

We propose a GEM focus group, **Magnetic Reconnection in Global Modeling of the Magnetosphere**, to address these issues. This proposed group will continue the work done by the GGCM Methods and Modules focus group. The goals of this four-year focus group will be to: 1) Assess the ability of global MHD to accurately model fast magnetic reconnection in the magnetosphere; 2) Address the question of how local kinetic effects may be incorporated in global simulations with realistic geometries— either by coupling to a Hall model near field nulls or by modifying the fluid closure to include pressure tensor effects; 3) Study in detail the scaling of the rate of magnetic reconnection with respect to Lundquist number in global codes with resistivity. Can secondary plasmoids be generated in global resistive simulations in the limit of the highest currently reachable simulation Lundquist numbers? **These questions are timely because at least two GGCM models (SWMF and OpenGGCM) now have the ability to include the Hall term in simulations. Furthermore the computational resources now becoming available will allow higher resolution global studies, as well as larger size and 3D “local” simulations to be carried out than ever before.**

2. Relationship to other GEM focus groups

The problems addressed by our proposed focus group are directly relevant to those addressed by several existing and proposed focus groups. For example, the proposed focus group on the **Magnetosheath** (co-chairs S. Petrinec and K. Nykyri) is concerned with energy flux into the magnetosphere through the entire sheath—a considerable region of space. However our group will focus on the smallest scale processes in areas immediately around reconnection sites, which have a major influence on plasma energy flux. Our group will also complement the work of the **Plasma Entry into and within the Magnetotail** group (co-chairs A. Otto, J. Johnson, and S. Wing). Whereas these groups may focus on the larger scale properties of dayside and tail reconnection, our proposed group will focus on the kinetic scale details and the implications of the particular resistivity (or other dissipation) model employed in accurately modeling the physics of reconnection regions throughout the magnetosphere. Our group would benefit from joint sessions with these other groups.

3. Goals and deliverables

The first goal of our group will be to evaluate the ability of global MHD codes to accurately model fast reconnection in the magnetosphere. To this end, we will carry out a **Global MHD Lundquist Number Challenge** to answer the question of how reconnection in global codes scales in the limit of small uniform resistivity. Can the copious plasmoid formation seen in local simulations be achieved in global codes? How

do such plasmoids affect the flux of plasma and energy into the magnetosphere? How do they compare to observed flux transfer events in the magnetosphere?

Additionally we will conduct a detailed numerical study of alternative fluid closures which be able may capture the collisionless, kinetic physics of the electron dissipation region in the context of a fluid model for eventual inclusion in global models. This will address outstanding discrepancies between the current state of the art local, two-fluid and PIC simulations of magnetic reconnection, namely the presence of extended electron jets and the abundant formation of plasmoids in kinetic simulations.

4. Expected Activities

The focus group will meet each summer with 2-3 sessions at the GEM workshop and additionally at the pre-AGU mini conferences to discuss progress on its goals.

Presentations will be solicited on topics including:

- Scaling of reconnection with varying dissipation parameters in global codes using idealized model driving conditions.
- Impact of plasmoids and extended electron jets in reconnection in the global system.
- Scaling of reconnection with system size, dissipation parameters, and pressure tensor models in local simulations of reconnection.
- Statistical models and testing of statistical models of bursty, plasmoid dominated reconnection.
- Three-dimensional studies of collisionless or very-weakly collisional reconnection.
- Coupling of localized extended-MHD or kinetic models in global simulations.
- 3D Hall MHD reconnection in global simulations.
- Further testing of predictions regarding asymmetric reconnection.

References

- Daughton, W. *et al.* (2009), Transition from collisional to kinetic regimes in large-scale reconnection layers. *Phys. Rev. Lett.* **103** 065004.
- Loureiro, N. *et al.* (2007), Instability of Current Sheets and Formation of Plasmoid Chains. *Phys. Plas.* **14** 100703.
- Le, A. *et al.*, (2009), Equations of state for collisionless Guide-Field Reconnection. *Phys. Rev. Lett.* **102** 085001.
- Cassak, P. A. *et al.* (2009), Scaling of Sweet Parker Reconnection with secondary islands. *Phys. Plas.* **16** 120702.
- Bhattacharjee, A. *et al.* (2009), Fast reconnection in high-Lundquist-number plasmas due to the plasmoid Instability. *Phys. Plas.* **16** 112102.
- Tóth, G. (2008) Hall magnetohydrodynamics on block-adaptive grids, Vol. 227, Issue 14, 6967-6984.
- Kuznetsova, M. *et al.* (2001), Collisionless reconnection supported by nongyrotropic pressure effects in hybrid and particle simulations, *J. Geophys. Res.*, 106, 3799.