An Integrated Modeling Suite for Simulating the Core Induction and Kinetic Effects in Mercury’s Magnetosphere
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Introduction: Mercury, the innermost planet in the solar system, possesses a mini-magnetosphere arising from the interaction of its relatively weak internal field with the solar wind. Previous missions to Mercury, especially MESSENGER, have revealed many unique aspects of Mercury’s space environment. In particular, the planetary field is believed to be generated by dynamo action in a highly conducting core whose radius is about 80% of the planetary radius [1]. The close proximity of the core to Mercury’s surface and the magnetospheric boundaries suggests that the planetary interior has significant influences on the way Mercury responds to the forcing by the external solar wind [2]. Moreover, the ambient solar wind in the inner heliosphere that interacts with Mercury typically has a low Alfvénic Mach number (~2 - 4), implying that magnetopause reconnection at Mercury might occur with high efficiency. MESSENGER observations have indeed shown that reconnection in Mercury’s magnetosphere appears to be very intense, and the global dynamics is dominated by effects of reconnection [3].

A Global MHD Model with Coupled Interior: Understanding the coupled solar wind-magnetosphere-interior interaction at Mercury requires not only analysis of observations but also a modeling framework that is both comprehensive and inclusive. We have developed a global magnetohydrodynamics (MHD) model for Mercury in which the planetary interior is modeled as layers of different electrical conductivities that electromagnetically couple to the surrounding plasma environment [4]. This modeling capability allows us to characterize the dynamical response of Mercury to time-varying external conditions in a self-consistent manner. We have applied this new model to both idealized solar wind conditions and a set of extreme solar events (CMEs and High-speed Streams) observed by MESSENGER to quantify the induction effect at the core and the erosion effect from reconnection. Based on comparisons of our model results with MESSENGER observations, we find that induction and magnetopause reconnection appear to play an equally important role in determining the structure of Mercury’s dayside magnetosphere.

Resolving Kinetic Effects through a Coupled Fluid-kinetic Model (MHD-EPIC): Given that reconnection is the dominant driver of Mercury’s magnetospheric dynamics, we have developed a two-way coupled fluid-kinetic model for Mercury, MHD with Embedded Particle-in-Cell (MHD-EPIC) [5-7], which enables simulating reconnection at kinetic scales while simultaneously capturing large-scale effects of reconnection on a global magnetosphere. The MHD-EPIC model has been applied to Mercury to investigate reconnection-driven phenomena in the magnetotail, including the formation and characteristics of tail X-line, generation and propagation of plasmoids, and potential dawn-dusk asymmetries [8].

Figure-1: A 3D perspective of the coupled magnetosphere-interior system at Mercury. The colors represent the current density (J), the green traces show sample magnetic field lines, and Mercury’s interior is color-coded with the resistivity. The orange box shows the PIC-modeled region within the MHD model [8]. The figure is made based on results from the global model published in [4].

References: