Geophysical Research Abstracts
Vol. 12, EGU2010-5479, 2010
EGU General Assembly 2010

On Reconciling Magnetohydrodynamics, Drift Theory, and Kinetic Theory

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Within the context of convection within the magnetosphere, it is often argued that because magnetohydrodynamics (MHD) is a fluid theory it does not include the effects of particle drifts. Furthermore, MHD implicitly assumes that there are processes within the plasma that localize the plasma, such that time rates of change, for example, only depend on local gradients of the macrophysical quantities (e.g., density, pressure). Thus MHD does not allow for effects were particles with significantly different trajectories in configuration space contribute to the local bulk plasma parameters. Kinetic theory, were Liouville's theorem is used to determine the local distribution function based on the past history of particles within the phase space, does include such effects. But kinetic theory usually requires that the electric and magnetic fields that determine the trajectories be specified. If the resultant current within the plasma is sufficiently large, then the fields themselves must be modified, raising issues of self-consistency. Here we will demonstrate that to first order in the particle gyro-radius, MHD, drift theory, and kinetic theory all give the same result for the current density within the plasma: $\mathrm{j} \times \mathrm{B} = \nabla P$. Clearly in regions were there are steep gradients, MHD should be used with caution. But drift theory and kinetic theory may also have problems, since they require that the fields be specified in order to determine the drifts and currents. We will also discuss the role of heat flux, and argue that while a temperature gradient does result in an additional heat flux term that is missing from MHD, that term can be ignored, since it has zero divergence if the temperature gradient is parallel to the density gradient. Loss through precipitation or charge exchange is more likely to affect the energy content of a flux tube as the plasma convects within the magnetosphere.