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The Validity of the Frozen-in Condition for the Inner Magnetosphere

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Single fluid magnetohydrodynamics (MHD) uses the frozen-in condition to determine the electric field from the plasma flow velocity. The curl of this electric field is in turn used in Faraday's law to determine the time rate of change of the magnetic field. Within the MHD context the portion of the electric field given by a scalar potential is not important. However, models such as the Rice Convection Model (RCM) usually require the electric potential be specified as a boundary condition. Here we explore the validity of the frozen-in condition and show that within the MHD context, the frozen-in condition is valid provided the flows are barotropic, with the pressure gradient parallel to the density gradient. This is equivalent to isentropic flows. But simulations using the OpenGGCM model at the Community Coordinated Modeling Center show that the flow need not be barotropic. This suggests anomalous processes, such as reconnection, introduce density and pressure gradients that are not aligned. How much this changes the frozen-in condition is an open question, as it is a second-order effect. Nevertheless, this analysis emphasizes that the issue in merging the MHD and drift models may in part be associated with the fact that the potential electric field is not well constrained by the ideal frozen-in condition, with only the induction electric field being required to close the MHD equations. The next approximation is the frozen-in electron condition, which effectively assumes that the electron thermal pressure can be ignored, and this may provide a useful means for mapping MHD-derived electric fields to the drift domain.