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Plasma mixing and transport caused by the three-dimensional development of the Kelvin-Helmholtz instability

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The Kelvin-Helmholtz instability (KHI) is a key process for the transport of solar wind plasma into the Earth's magnetosphere across the magnetopause. When both magnetic and velocity shears coexists within a boundary as commonly seen at the magnetopause, the resulting KHI leads to generation of vortices and subsequent triggering of magnetic reconnection. Our recent 3D fully kinetic simulations of this vortex-induced reconnection (VIR) process for symmetric boundary layers demonstrated the copious formation of oblique magnetic flux ropes, which leads to a rapid mixing of the plasma within the vortex layer. THEMIS observations at the dusk-flank magnetopause indeed show similar features of flux ropes between observed KH vortices. More recently, we performed additional 3D fully kinetic simulations considering the effects of density and temperature asymmetries, which also commonly exist across the magnetopause. Past 2D simulations have shown that such asymmetries can lead to an excitation of secondary KH and Rayleigh-Taylor (RT) instabilities along the edge of the vortex in the absence of a finite magnetic field component (B_k) parallel to the k-vector of the KHI. Since B_k is expected to be finite at the magnetopause, here we explore the effect of B_k on the secondary KH/RT instabilities in 3D. We find that the suppression of the secondary instabilities due to B_k is an artifact of the 2D simulations, whereas in 3D the instabilities can grow over a range of oblique angles even when there is a finite B_k. These secondary instabilities give rise to turbulence, which gradually transports the solar wind plasma originally stored within the flow vortices deep into the magnetosphere. Simple estimates suggest that the reconnection-induced rapid mixing and the turbulent-induced gradual transport processes may contribute significantly to the formation of the Earth's low-latitude boundary layer (LLBL) and the cold-dense plasma sheet (CDPS) during prolonged periods of northward interplanetary-magnetic-field (IMF).