An MHD simulation study of the Kelvin-Helmholtz instability at the Martian ionopause with a day-to-night density gradient

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The effect of a day-to-night density gradient on the evolution of the Kelvin-Helmholtz instability (KHI) at the Martian ionopause is investigated using 2-D extended-local MHD simulations. The KHI is expected to play a major role in transporting mass, momentum and energy across the ionopause between the sheath flow and the Martian ionospheric plasmas, and is thus regarded as one of the candidate processes that have removed a huge amount of ions from Mars through its long history. Recent local MHD simulation studies have pointed out that a density gradient in the vertical direction significantly reduces its linear growth rate and its maximum growing wavelength mode becomes longer. A Longer wavelength mode makes KH vortices more inhomogeneous during the nonlinear phase [*Amerstorfer et al.*, 2010]. However, the actual ionopause has a density gradient not only in vertical but also in the horizontal (day-to-night) direction. In order to investigate the effects of a day-to-night density gradient, we have developed two extended-local MHD models by incorporating two elements of a global model, i.e., an aperiodic boundary condition and the day-to-night density gradient, into a local model.
Comparing the results of the aperiodic case (extended-local model without a day-to-night density gradient) with those of the periodic case (local model), we find two notable differences in the evolution of the KHI. Firstly, while the evolution of the main vortices group is mostly the same in both cases, that of the leading vortex is quite different[YK1] .[AS2] The main vortices group rises and its intrusion into two regions is symmetrical with the ionopause but the leading vortex does not enter the sheath region in the linear growth phase. On the other hand, the leading vortex seems to be squeezed by the sheath region while the main vortices group does not show such a squeezing like structure. Secondly, the ionospheric plasma in the aperiodic case is excavated about 1.5 times deeper. We find that these two differences are caused by the asymmetry in the structure of both sides of each vortex. When there is another vortex with a larger amplitude just downstream of a vortex, this structure behaves like a wall, the sheath flow will be stagnated by this wall-like structure. This stagnated sheath flow induces an enhanced vortex return flow, resulting in a deeper excavation of the ionospheric plasma. Previously, it has been thought that the mixing area will spread widely over time. The Deeper excavation of the leading vortex enhances mixing of ions. In addition, we also find the elongated filament structure is caused by the asymmetry in the structure of both sides of the vortex. A wall-like structure downstream side which mentioned above and an insufficient vortex motion on the leading (upstream) side of a KH vortex leads to vortex return flow and an imbalance between the pressure gradient force and the centrifugal force associated with the vortex motion. The vortex cannot keep its structure and will be an elongated filament. These asymmetries in the vortex structure are responsible for making two differences between the aperiodic and the periodic cases.
We also add the day-to-night density gradient to the aperiodic case by reference to MEX observation results [*Duru et al.*, 2008]. We find that the KHI is quickly excited in the downstream (low density) region. It has been thought that the KH wave propagates from upstream to downstream, i.e., one-way propagation. This excitation in the downstream indicates that the perturbations associated with the KH wave propagate not only to the downstream but also toward the opposite direction, with highly elongated filamentary structures in downstream.
In those simulations, we evaluate the effect of the day-to-night density gradient on the loss rate

of the ionospheric ions. We find that the day-to-night density gradient reduces the ions loss efficiency with 30-40%.

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