Ion acceleration by magnetic reconnection in the dayside ionospheres of unmagnetized planets

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We have examined magnetic reconnection in the dayside ionosphere of Venus and its application to other unmagnetized planets using a 2-D multi-species magnetohydrodynamic (MHD) model. Main object is to investigate the ionospheric ion acceleration and the escape processes associated with magnetic reconnection after an interplanetary magnetic field (IMF) reversal.
Magnetic reconnection is an efficient energy conversion process that converts the energy of magnetic field in an anti-parallel configuration into plasma kinetic and thermal energy. Thus, it is potentially important to accelerate and remove the ionospheric ions from unmagnetized planets and to understand the evolution of planetary atmospheres. Recently, magnetic reconnection has been observed around unmagnetized planets such as Venus and Mars [Eastwood et al., 2008; Halekas et al., 2009; Zhang et al., 2012; Hara et al., 2014; Harada et al., 2015]. However, there remain unsolved problems about magnetic reconnection after an IMF reversal; its spatiotemporal evolution and resulting atmospheric loss rate.
In this study, we performed three runs with different initial conditions. In order to examine the altitude where magnetic reconnection develops, different initial heights of the current sheet are given; 450 km (Run A), 360 km (Run B) and 260 km (Run C) altitudes. Our simulations showed that the fast magnetic reconnection called the plasmoid instability [Loureiro et al., 2007] occurs in Run A and Run B. On the other hand, the instability evolves slowly in Run C. From three runs, it is shown that the growth rate of the plasmoid instability is suppressed in the lower region of the ionosphere. For all cases, ionospheric plasmas are accelerated and ejected from the current sheet by magnetic reconnection. The averaged outflow velocities are 2.3 km/s for Run A, 2.8 km/s for Run B, and 0.4 km/s for Run C, respectively. It is indicated that the plasma is accelerated efficiently (up to 0.7-0.8 times the local Alfven velocity) in the upper ionosphere of Venus.
We also examined the O^+ loss rates due to magnetic reconnection after an IMF reversal in three runs. The transient O^+ loss rates are about 2.8×10^{25} ions/s for Run A, 2.3×10^{25} ions/s for Run B, and 5.5×10^{24} ions/s for Run C. This difference is attributed to the difference in the outflow velocity. It is suggested that the escape rate due to the reconnection decreases with a decreasing initial altitude. We have compared the O^+ loss rate due to magnetic reconnection with other escape processes, and concluded that the reconnection after an IMF reversal potentially contribute to oxygen loss if an IMF reversal frequently occurs.
Based on the simulation results and the theory of magnetic reconnection, we investigated the possible atmospheric loss by the magnetic reconnection after an IMF reversal at other unmagnetized planets. From an analytical estimation of the loss rate due to the reconnection after an IMF reversal, it is shown that the loss rate is proportional to local Alfven velocity and the number density of ionospheric ions. Using the parameter of the Martian ionosphere, we have estimated the O^+ loss rates as 8×10^{24} ions/s at the maximum. The estimated maximum loss rate is several ten times larger than that obtained from the Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft [Hara et al., 2015].

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