Mass-loading energy extraction from the solar wind to the planetary system and resultant additional ion escape

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Cluster statistics showed that ion loss rate from the open part of the polar magnetosphere increases exponential to Kp up to Kp=7 (Slapak et al., 2017). Cluster case studies for higher Kp indicate that the ion loss rate can be higher than the exponential extrapolation from the empirical relation for Kp<7 (Shillings et al., 2017).

According to these observations, the mass density of escaping O^+ can no longer be ignored with only 1% of number density ratio due to the mass ratio. In fact, Cluster observed substantial deceleration of the solar wind H^+ while acceleration of O^+ in plasma mantle. The conservation of anti-sunward momentum means, for inelastic mixing of O^+ into the H+ flow, that the kinetic energy is no longer conserved. The energy conversion rate, simply calculated from the momentum conservation, is proportional to total mass flux of O^+ (F_O) into the incident solar wind and to the square of the solar wind velocity (u_{sw}^2), and does not depend on the injection area or solar wind density. Applying the observed O^+ value and area, this means 10^{10-11} W, and is large enough to explain the electric current system flowing in the cusp region, which is the most intense current system in the dayside.

Since ion heating due to the Joule heating of the ionospheric current system is the main driver of the ion outflow, the entire cycle constitute a positive feedback energy extraction, explaining the observed exponential dependence of the escaping flux to Kp. Inversely, the solar wind dependence gives only near-linear dependence to the solar wind "coupling function", which is at most u_{sw}^4 but not exponential. Considering the ancient condition that corresponds to Kp=9-10, the mass-loading effect is extremely important in the atmospheric evolution.

The present positive feedback model with the mass-loading effect assumes that information of "deceleration" propagate upstream faster that the information of transversal electric field caused by O^+ deflection (shift of the guiding center), such that electric field by the H^+ deceleration appears before O^+ pickup motion. Otherwise, the model requires only the magnetic connectivity to the load: ionosphere for the Earth's case. This means that the concept should be applied to all unmagnetized body with sufficient ionosphere that can form a region (ionosphere or its equivalent) to consume the electric energy to heat ion.

One possible application is comet because Rosetta plasma observation showed strong deformation of the solar wind by the mass-loading effect (Nilsson et al., 2017). If the mass-loading region is magnetically connected to the region close to the cometary coma, extracted solar wind kinetic energy might alter the electric field inside the magnetosphere through ionosphere current closure, possibly accelerating O+ beyond the gyromotion. With Rosetta ICA instrument, we actually found cases with O^+ energization higher than the solar wind energy in the magnetosphere. We discuss the possible connection between the observed phenomena and the mass-loading energy extraction. If they are related, this would be another case that the mass loading is important in the atmospheric erosion.