Statistical study on the contribution of charge exchange to the decay of the storm-time ring current

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Several ion loss mechanisms have been proposed to explain the decay of the storm-time ring current. Although charge exchange is believed to be one of the most probable causes of the decay, there have been few observations that have been able to estimate its contribution quantitatively. In this paper, we statistically evaluate the contribution of charge exchange process to the decay of the storm-time ring current, using the flux of energetic neutral atoms (ENAs) with energy higher than 10 keV detected by the HENA imager onboard the IMAGE satellite.

The HENA imager detects ENAs which are generated when energetic, singly-charge ring-current ions charge exchange with neutral atoms and molecules in the upper atmosphere and exosphere. Since the energy loss in the charge exchange reaction is negligible, the ENA flux detected by HENA is appropriate for estimating the loss of ring-current energy via charge exchange. We estimate the energy loss with two different methods. In Method 1, we calculate energy loss within each line-of-sight of pixels of HENA and then sum over all pixels. This method requires knowledge of the distance from the satellite to the location of ENA production, which we do not know because the observed ENA flux is integrated along a line-of-sight. We assume that all ENAs were generated at the magnetic equator (Assumption 1) or at the spherical shell with a radial distance of 8 Re (Assumption 2). Assumption 2 gives the upper estimate of energy loss, because there are few ENAs produced at a radial distance greater than 8 Re. We also assume isotropic pitch angle distribution of the ring-current ions. In Method 2, we calculate the ENA flux through the unit surface area of the sphere with a radius of the geocentric distance of the IMAGE satellite. Under the assumption that the ENA flux is the same at any point over the sphere, the total energy of ENAs escaping from the sphere is estimated. We regard this total energy as the loss of ring-current energy via charge exchange.

We choose the recovery phase of magnetic storms from September 2001 to December 2002 that fulfill the criteria: The minimum Dst index is smaller than -50 nT, and IMAGE is located at a magnetic latitude higher than 60 degrees and at a radial distance greater than 6 Re. These criteria are satisfied by 105 one-hour intervals in 17 storms. Our results are summarized as follows: The energy loss rate is well correlated with the instantaneous Dst index; For a given instantaneous Dst index, the energy loss rate is independent of the decay rate of the ring current derived from the temporal variations in the Dst index; The contribution of charge exchange energy loss to the ring-current decay is large for the slow decay phase and small for the rapid decay phase. Both of the above two methods give almost similar results with the difference in the magnitude of a factor of two or three. These results suggest that energy loss via charge exchange is not large enough to account for the rapid decay of the ring current. We conclude that there are processes other than charge exchange that cause the rapid decay. The rapid decay is likely attributed to the outflow of ring-current ions from the magnetosphere and/or the precipitation of the ions into the atmosphere.