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# Observations of the ion upflow in the polar magnetosphere during geomagnetic storms

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Recent satellite observations have clarified that plasma outflows play an important role in abrupt changes in the ion composition in the plasmasheet and ring current during geomagnetic storms. However, the energy, flux, and trajectory of ion outflows remain unsolved due to the lack of observations of the ion upflows and outflows during geomagnetic storms. In the present study, we perform case studies of ion upflows during geomagnetic storms using the data observed by the Akebono and Polar satellites.

We use the electron density data observed by the plasma wave and sounder experiments (PWS), and the ion composition and field-aligned velocity observed by the suprathermal ion mass spectrometer (SMS) onboard the Akebono satellite in an altitude range of 275-10500 km. We used ion distribution function data observed by the thermal ion dynamics experiment (TIDE) onboard the Polar satellite in a geocentric distance range of 1.8-9 $R_E$.

First, we perform case studies for the geomagnetic storm events which occurred on March 30, and April 17, 1990, using the data from Akebono in an altitude range of 6000-10000 km. During the main phase of the March 30 storm, Akebono crossed the dayside polar region from dawn to dusk, and enhancement of the electron density was observed in the auroral zone and polar cap. The electron density increased more than 10 times than the quiet-time level. The SMS instrument measured ion upflows in the entire polar cap along the satellite path. Eighty percent of the upflowing ions were composed of oxygen and the upward velocities of oxygen along the field lines were 5-10 km/s which was about the same as the escape speed. The upflow flux of the oxygen ion mapped to 1000 km altitude corresponded to 1-4$*10^9$ /cm$^2$/s. During the main and recovery phases of the April 17 storm, Akebono crossed the dayside polar region from dawn to postnoon, and the electron density enhancement was observed for 12 hours in the auroral zone and dayside polar cap. The upflowing ions were dominated by oxygen ions and the upward velocities along the field lines of oxygen ions were 5 km/s. In contrast, in the dayside trough, there was no upflow flux of oxygen ion.

Next, we perform case studies of the geomagnetic storms which occurred on May 4, 1998, February 18, 1999, and April 6, 2000, using the data from Polar in an altitude range of 5000-40000 km. Ion velocities were calculated assuming the pure-oxygen plasma, since Akebono observation showed that the ion upflow during geomagnetic storms were dominated by oxygen. During the main phases of these storms, Polar crossed the southern polar region from night to dayside. Ion upflows had a maximum speed of 10 km/s in the dayside polar cap in an altitude range of 8000-15000 km. This speed is almost the same as the upflow velocity of oxygen observed by Akebono. During the main phase of the April 6 storm, Polar crossed the northern polar region from day to nightside, and observed ion upflows with a speed of about 15 km/s in the dayside polar cap in an altitude range of 40000-27000 km. In all these storms, the upward velocities are higher in the dayside than that in the nightside polar cap. The upward ion flux mapped to 1000 km altitude was typically of the order of $10^8$ /cm$^2$/s in the dayside polar cap, and the flux reached up to 1-15$*10^9$ /cm$^2$/s in and near the cusp and cleft regions. In the nightside polar cap, upward velocities were about 0 to -2 km/s, and the horizontal ion drift was directed to the nightside. These results show that the ions have large upward velocities and flux in the cusp, cleft, and dayside polar cap during geomagnetic storms. Since the downward flux is small in the nightside polar cap, most of the ions flowing upward in the dayside would flow into the magnetosphere. During the February 18 storm, the ions convecting anti-sunward in the polar cap reached the nightside auroral zone. The ions would be heated up to flow into the magnetotail.