The Polar Ion Outflow : Current understanding and future observations

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The geomagnetic field lines originating from the polar ionosphere are connected to the geomagnetic tail region on the nightside. Due to the large plasma pressure difference between the polar ionosphere and the distant magnetotail, plasma on such "open" field lines can escape from the ionosphere into the magnetotail. Such ion escape was initially predicted as a bulk subsonic flow of light thermal ions through plasma diffusion or thermal evaporation, and was subsequently suggested to be supersonic. Axford [1968] coined the term "polar wind" in analogy with the solar wind.

In addition to the polar wind, suprathermal and energetic ion outflows have been observed at high latitude. Yau and André [1997] classified the variety of outflows in the polar ionosphere into two categories: bulk ion flows with energies up to a few eV, such as the polar wind and auroral bulk upflow, and energetic ion outflows such as upward ion beams and conics, in which a portion of the ion population is accelerated to much higher energies, and upwelling ions in the cleft, which have typical energies up to a few tens of eV and characteristic temperatures of a few eV.

It is important to note that the various types of outflow populations in the polar ionosphere are sometimes mixed due to horizontal plasma transport, and ion energization processes at auroral latitudes or at times in the polar cap can accelerate the polar wind into an energetic ion outflow population. In particular, ion conics, ion beams, auroral bulk upflows, or upwelling ions (UWI) originating from the cusp or the cleft can be transported into the polar cap. Under southward IMF conditions when convection across the polar cap is predominantly anti-sunward, the UWI can appear as cleft ion fountain (CIF) in the polar cap, where they may be present at lower apparent temperatures than in the cleft due to velocity filtering effects, and contribute to the thermal ion population – and become a part of the ambipolar outflow.

In addition to the CIF, auroral bulk upflows, which are frequently observed by incoherent scatter (IS) radars and low-altitude satellites, are another important contributor of low-energy O+ ions to the polar wind ion population in the polar cap. From EISCAT during active periods, field-aligned bulk flows (mainly O+) from the topside auroral ionosphere were observed to start at a variable altitude and reach velocities of 1.5 km s-1 at 900-1500 km. In these observations, two types of upflow were identified: thermal flow that is associated with enhanced ion temperature, strong perpendicular electric field, and low electron density, and non-thermal flow that is associated with the auroral arc and enhanced electron temperature.

Such ion outflows are believed to play an important role in the removal of thermal plasma from the topside ionosphere due to its large number density. It is now generally accepted that there are two major sources of plasmas in the magnetosphere: ion outflows from the polar ionosphere, and direct or indirect entry of the solar wind plasma. The discovery of O+ ions in the magnetosphere revealed the ionosphere as an important source of magnetospheric plasma, and reflects the great amount of plasma provided by various plasma escape processes in the polar ionosphere.

Despite a long history of direct and indirect observations of the polar ion outflow, a well-established model which can be widely accepted has not been constructed. One of the reasons responsible for making the modeling difficult may be due to a mixture of various ion outflow processes described above. The outflow ions which experience several acceleration mechanisms for traveling from low to high altitudes may not be simply parameterized. In this presentation, we try to clarify characteristic feature of the ion outflow processes depending on the altitude and latitude, and propose necessary observations for better understanding.