On the source region of cold ions escaping from Earth's polar caps

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Every day, the Earth's atmosphere loses a significant amount of mass through ions escaping from the polar cap areas. Cold ions escaping along magnetic field lines constitute a significant part of the total ion outflow. In order to find out more about the source of the ion outflow, we have traced cold ions observed by the Cluster spacecraft in the magnetosphere down to the ionosphere. In the tracing, we take into account convection, centrifugal acceleration and gravity. From the data covering the years from 2001 to 2005, 103982 cases could be traced back to the topside ionosphere. Their origins are mapped with fluxes to show the primary outflow regions and their response to different geomagnetic conditions.

Introduction

The low kinetic and thermal energy ions(cold ions) in the magnetotail are difficult to measure because positive potential on the spacecraft keeps them away from the detectors. Recently, *Engwall et al* [2009] suggests that the cold ions compose a major part of terrestrial ion outflow by a new method(see below). Thus the dynamics of cold ion outflows dramatically dominate the ion outflow. To find the patterns of cold ion outflow from the Earth's ionosphere, we use the dataset derived from electric measurements to trace every recorded cold ion back to its source region. A statistical work according to different geomagnetic activities is based on the tracing work.

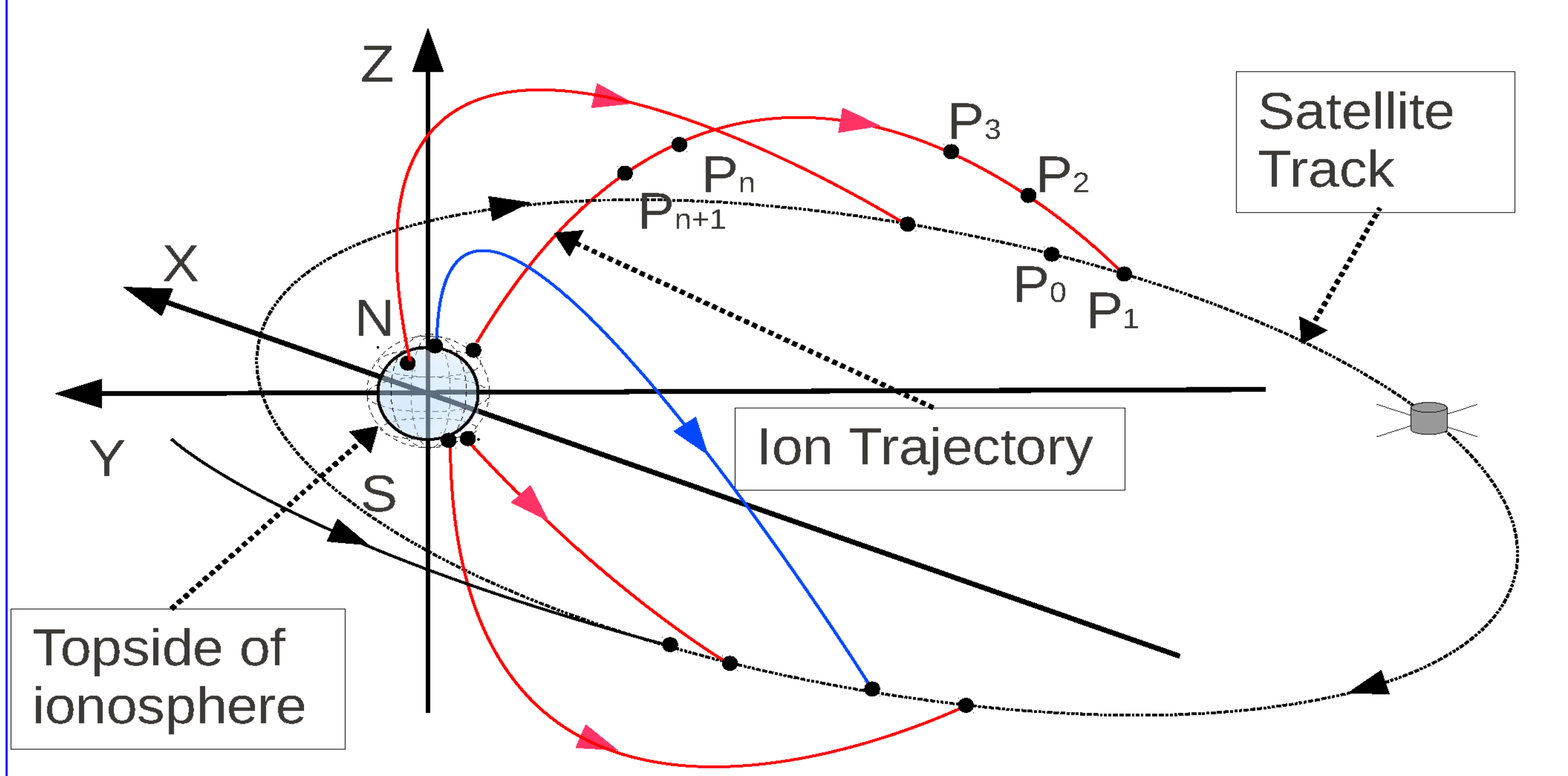
Methodology

The scattered ions could form an electric field behind the spacecraft when the spacecraft encounters cold, tenuous ion flow. This electric field derived by EDI and EFW on cluster allows us to access the parameters of those cold ions. The dataset from *Engwall et al*.[2009] including the velocities and density of cold ion is used in this work. The density is derived from a functional dependence between the spacecraft-probe potential and electron density density[*Pedersen et al*, 2008].

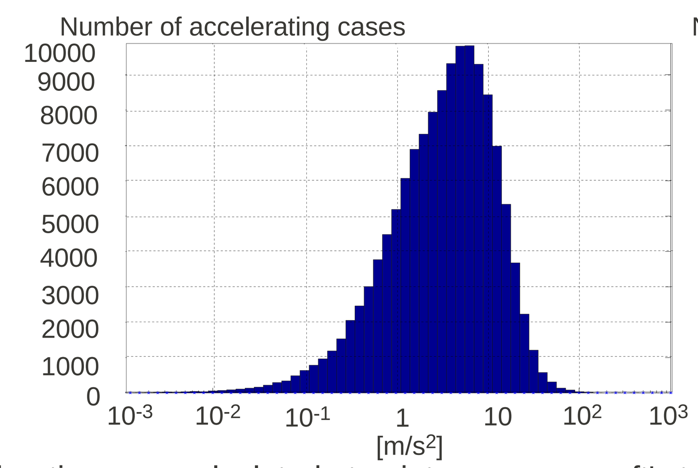
$$\vec{V}_i = V_{para} \cdot \hat{b} + \vec{V}_E$$
$$\vec{V}_E = \vec{E} \times \vec{B} / B^2$$
$$V_{para,n+1} = V_{para,n} - a \cdot t$$
$$a = \vec{V}_E \cdot \frac{d\hat{b}}{dt} + g_{para}$$
$$F_{n+1} = V_{para,n} \cdot n \sqrt{|\vec{B}_{n+1}| / |\vec{B}_n|}$$
$$\vec{V}_{E,n+1} = |\vec{V}_{E,n+1}| \sqrt{|\vec{B}_{n+1}| / |\vec{B}_n|} \hat{V}_{E,n+1}$$
$$\hat{V}_{E,n+1} = \vec{B}_{n+1} \times (\vec{E}_n \times \vec{B}_n) / |\vec{B}_{n+1} \times (\vec{E}_n \times \vec{B}_n)|$$
$$\vec{P}_{n+1} = \vec{P}_n - \vec{V}_i \cdot t$$

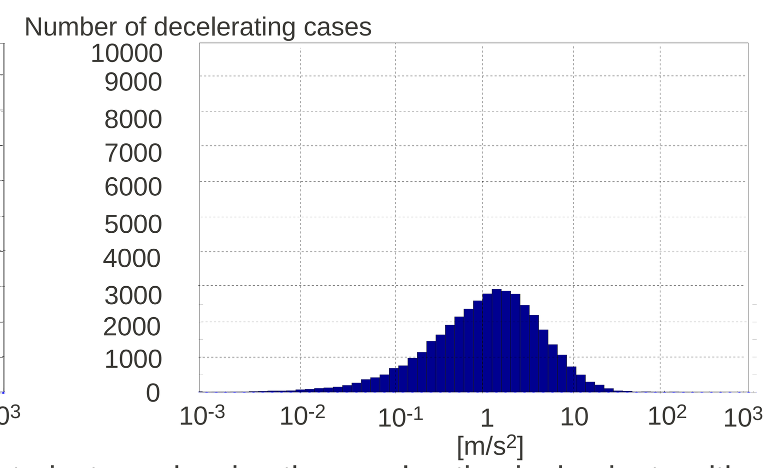
In this tracing work, we consider the velocities of cold ions' guiding center are composed of the velocity parallel to the magnetic field and the perpendicular velocity which caused by field line convection. The parallel velocity changes are primarily due to gravity and centrifugal acceleration[*Northrop*, 1963]. The perpendicular velocity changes in scale of the mapping factor in the magnetic tube.

Parameters from the dataset and magnetic model TS04 [Tsyganenko, 2005] are used to calculate the position of the ions step by step until their origins on the topside of ionosphere at altitude of ~1000Km.

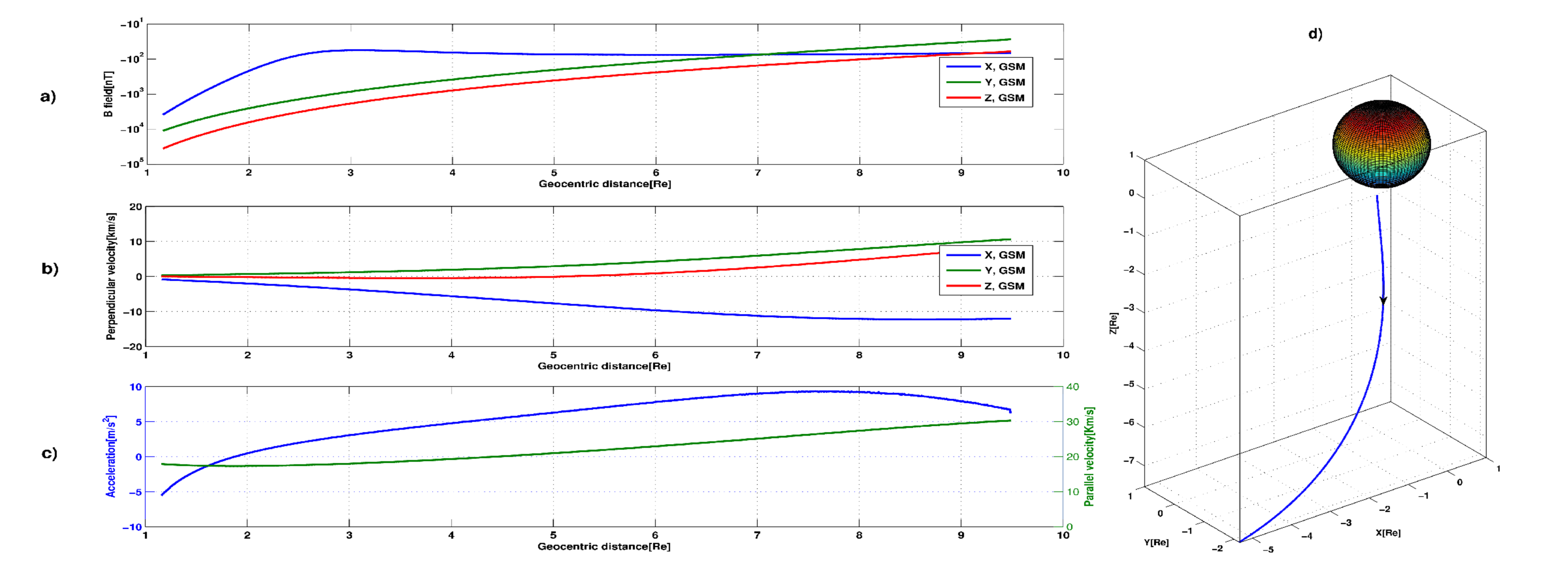


Data characteristics





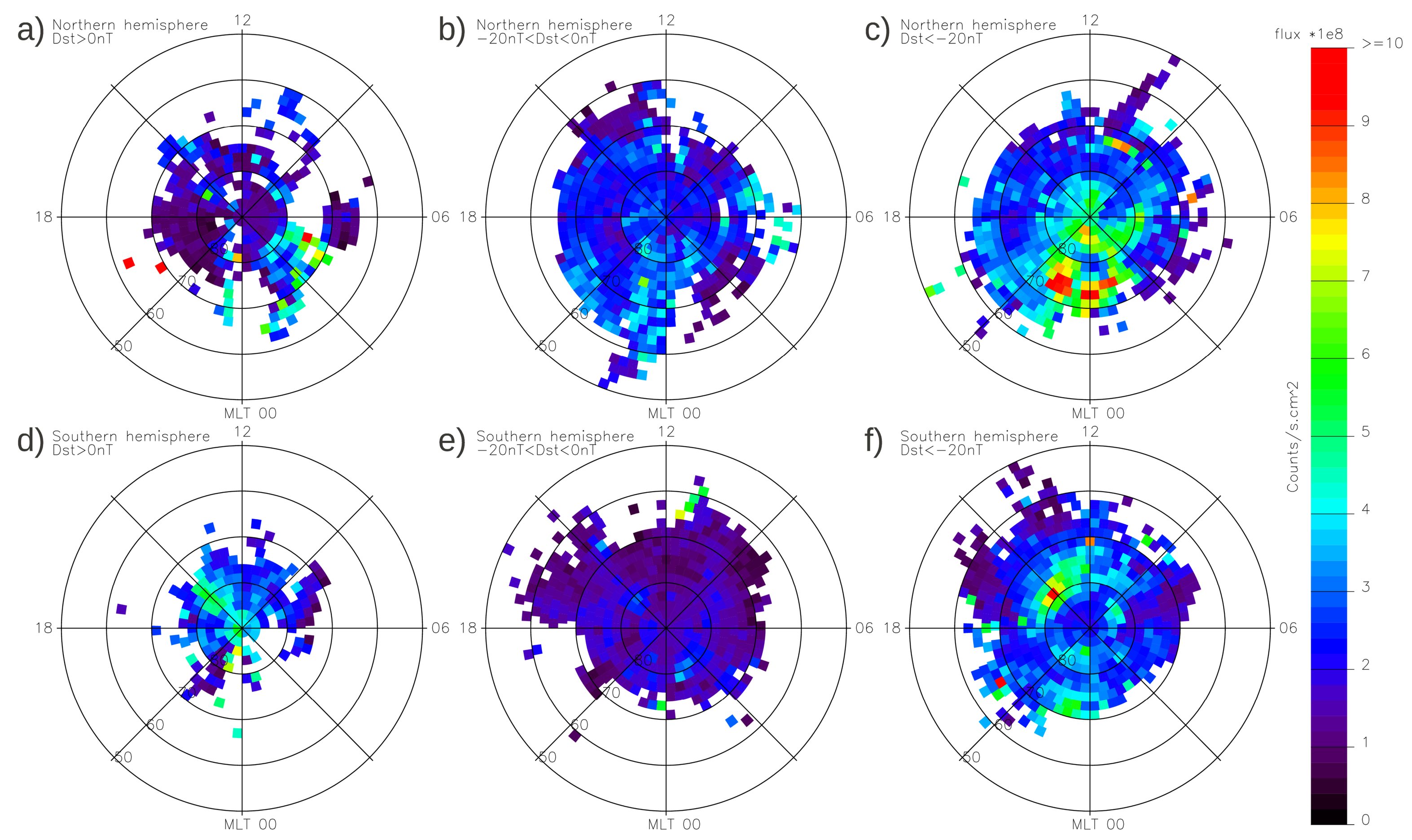
Accelerations are calculated at points on spacecraft's trajectory, showing the acceleration is dominate with the value on order of ~1m/s^2, while deceleration is of lower value. Other accelerations on ions' trajectories are calculated using magnetic field from model.



An example of cold ion's trajectory on the southern hemisphere. Panel a) and b) Magnetic field and perpendicular velocities in GSM on the trajectory. The abscissa is geocentric distance starting at altitude of 1000km and end up with 9.5 Re from the centre of the Earth. Panel c) Acceleration and parallel velocity change along the trajectory. Panel d) An overview of this trajectory in GSM calculated by tracing technique. The traveling time is 2440s with landing point at topside of ionosphere:[-63.9°,12.95MLT] in AACGM.

Observations

From the calculation, 58418 cases could be traced to the northern hemisphere and 45564 to the southern hemisphere. Their positions given by magnetic local time and latitude in Altitude adjustment corrected geomagnetic (AACGM) coordinates are plotted with color coded, magnetic field aligned fluxes.



The polar regions are divided into grids with equivalent area of around 65000 km^2. The figure above suggests that cold ion outflows mostly happen at positions with magnetic latitude higher than 60 degrees. The fluxes are order of 10^8/cm^2·s with higher fluxes locating at various positions which reveals miscellaneous mechanisms experienced by the cold ions.

Contracted polar cap during magnetic quiet time

The quiet condition typically exists when the IMF is northward (see table), The polar caps for both hemispheres get smaller. In the table, the outflow areas for different activities (on order of 10^7 km^2) are obtained by adding all the coloured grids, and the total outflow rates(on order of 10^{26} count/s) are summed up the outflow rate of each grid.

Expanded polar cap during magnetic storm time

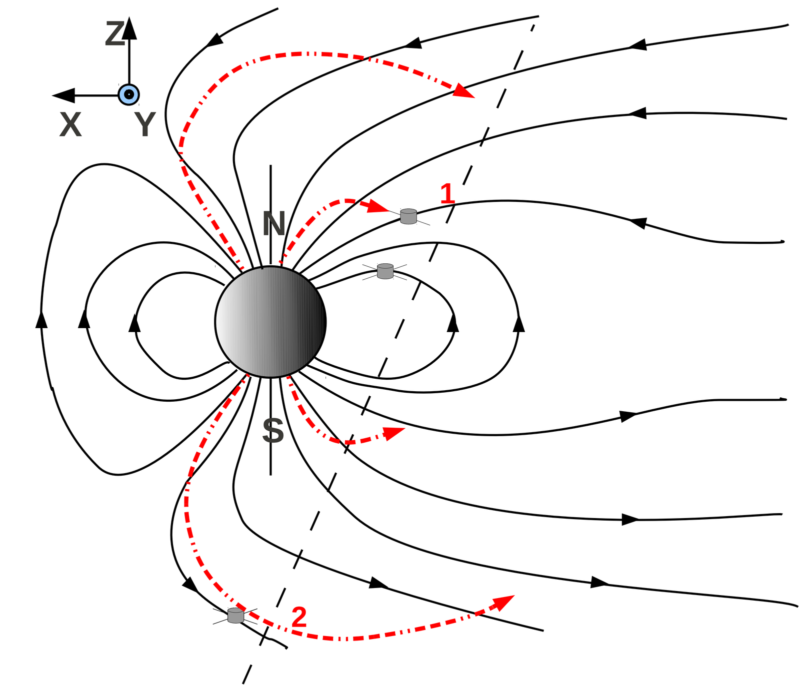
The disturbed time associates southern IMF which opens the field lines at dayside, the opened field lines convect across noon-midnight and tailward through both dusk and dawn flanks. On the other hand, the open field lines travel to magnetotail consist a large mount of magnetospheric convections by which we determine the source region. With those convections, the outflow regions get larger all the magnetic local time and expand to latitude as low as 60°.

Averages from the data set Engwall et al. [2006] for three different geomagnetic activity levels in both hemispheres as shown in figure 3 and calculated areas of outflow regions, together with total outflow fluxes.
1. Quiet = Dst above 0nT, Moderate = Dst between -20nT and 0nT, Storm = Dst below -20 nT.
2. Outflow areas are summed up with all the coloured grids in the same condition and hemisphere.
3. Total outflow rates are summed up with all outflow rate in coloured grids.

		Averaged parameters of solar wind indices											
	Activity[1]	AE [nT]	Dst [nT]	Kp	Bx [nT]	By [nT]	Bz [nT]	n_H [cm^{-3}]	V_{sw} [Km·s^{-1}]	F_{107} [10^{-22}W·s·m^{-2}]	P_{dyn} [nPa]	Outflow area [2] [Km^2]	total outflow[3] [counts·s^{-1}]
Northern hemisphere	Quiet	125.4	6.9	1.5	2.4	-2.5	0.4	9.9	396.5	139.9	2.9	1.62×10^7	3.19×10^{25}
	Moderate	200.0	-11.0	2.2	1.1	-1.2	-0.1	5.3	426.4	160.1	1.8	2.82×10^7	6.76×10^{25}
	Storm	448.8	-41.6	3.5	-0.7	2.1	-1.4	5.6	470.8	183.7	2.4	2.85×10^7	9.50×10^{25}
Southern hemisphere	Quiet	196.0	3.2	1.9	-0.2	0.5	0.9	7.9	399.1	165.2	2.4	9.2×10^6	2.51×10^{25}
	Moderate	200.5	-10.6	1.8	0.4	-0.3	-0.5	4.7	436.2	139.6	1.6	2.56×10^7	3.80×10^{25}
	Storm	386.3	-43.6	3.0	-1.3	-0.8	-1.0	5.8	445.2	175.1	2.2	2.79×10^7	7.56×10^{25}

Homogeneous outflow during moderate time

This work suggests a homogeneous outflow from both northern and southern hemisphere during moderate time. Many outflow regions emanating cold ions with fluxes range from 1×10^8 /cm^2 ·s to 4×10^8 /cm^2 ·s. The higher flux regions are located at the same positions as other conditions. The corresponding density map showing the same pattern suggests that it is the density of cold ion mainly influence the outflow and the outflow changes its intensities in response to different conditions. But the main outflow regions remain the same through the change of geomagnetic activities.



Cold ions from aurora/cusp regions can be detected by spacecraft at lower/higher altitude.

Outflow from the auroral zone and cusp

In the southern hemisphere, resource of slightly higher fluxes emerge at (~15MLT,76° ~84°), suggesting a possible outflow from cusp. The aurora region and cusp are observed on different hemispheres. A further analysis found the data for southern hemisphere are recorded at an average altitude 2 Re higher than that for northern hemisphere. If the asymmetry does not commonly happen for cold ion outflow, this suggests:
1) the cold ions from aurora region could not travel to higher altitudes;
2) the cold ions from cusp region could travel to higher altitude through dayside;
3) before convecting to equatorward, cold ions from different regions could travel to different altitudes.

Summary and conclusions

We used the cold ion data consisting of 172817 samples from the magnetosphere to calculate their origin in the ionosphere. About 110000 calculating results are used for statistical work. The rest cold ions with possible source in solar wind needs future work. The statistics presented above show:
1. The outflow source region for cold ions is contracted during magnetic quiet time;
2. This region expand to lower latitude with enhanced fluxes during disturbed time;
3. Other regions including cusp and aurora region also contribute the source for cold ions;
4. Cold ions from different regions escape into magnetosphere with different fates.

References
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