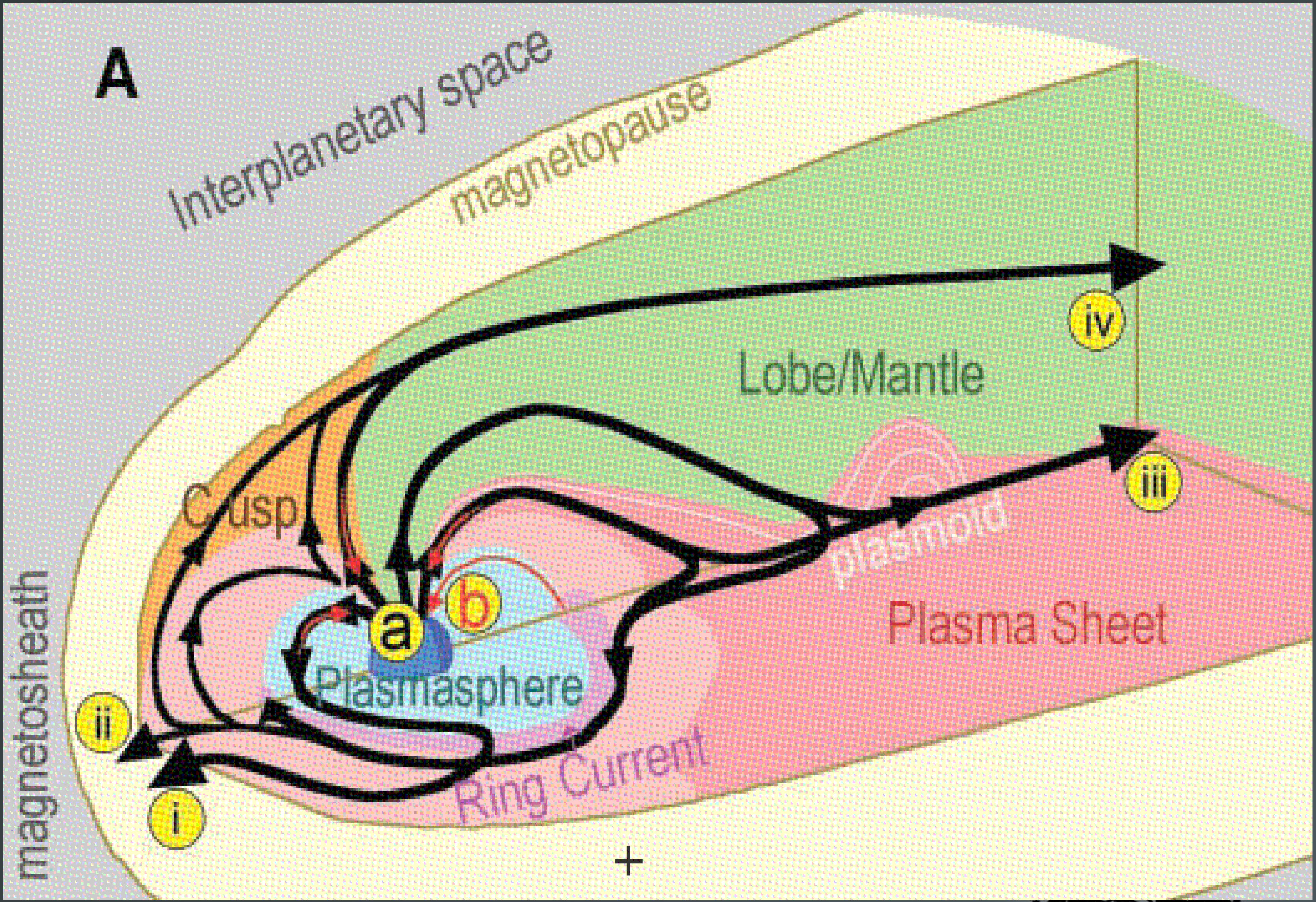
The source and fate of cold ion outflows from the Earth's ionosphere

Kun Li, Stein Haaland, Anders Eriksson, Mats Andre, Erik Engwall, Yong Wei

Ionospheric escape in the magnetosphere



[Matsui et al. 1999]

A big challenge

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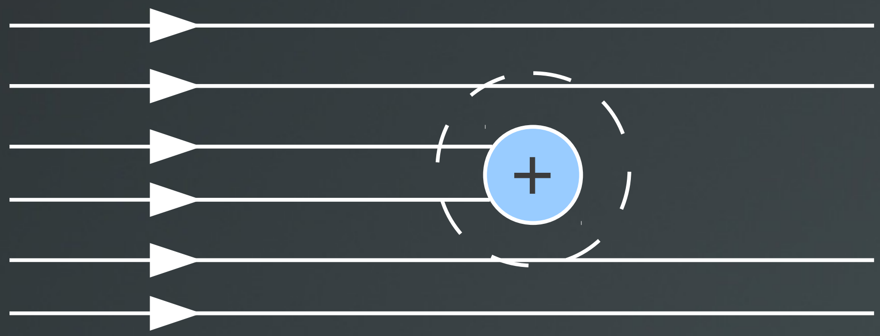
The Ionosphere as a Fully Adequate Source of Plasma for the Earth's Magnetosphere

C. R. CHAPPELL, T. E. MOORE, AND J. H. WAITE, JR.

Space Science Laboratory, NASA Marshall Space Flight Center, Huntsville, Alabama

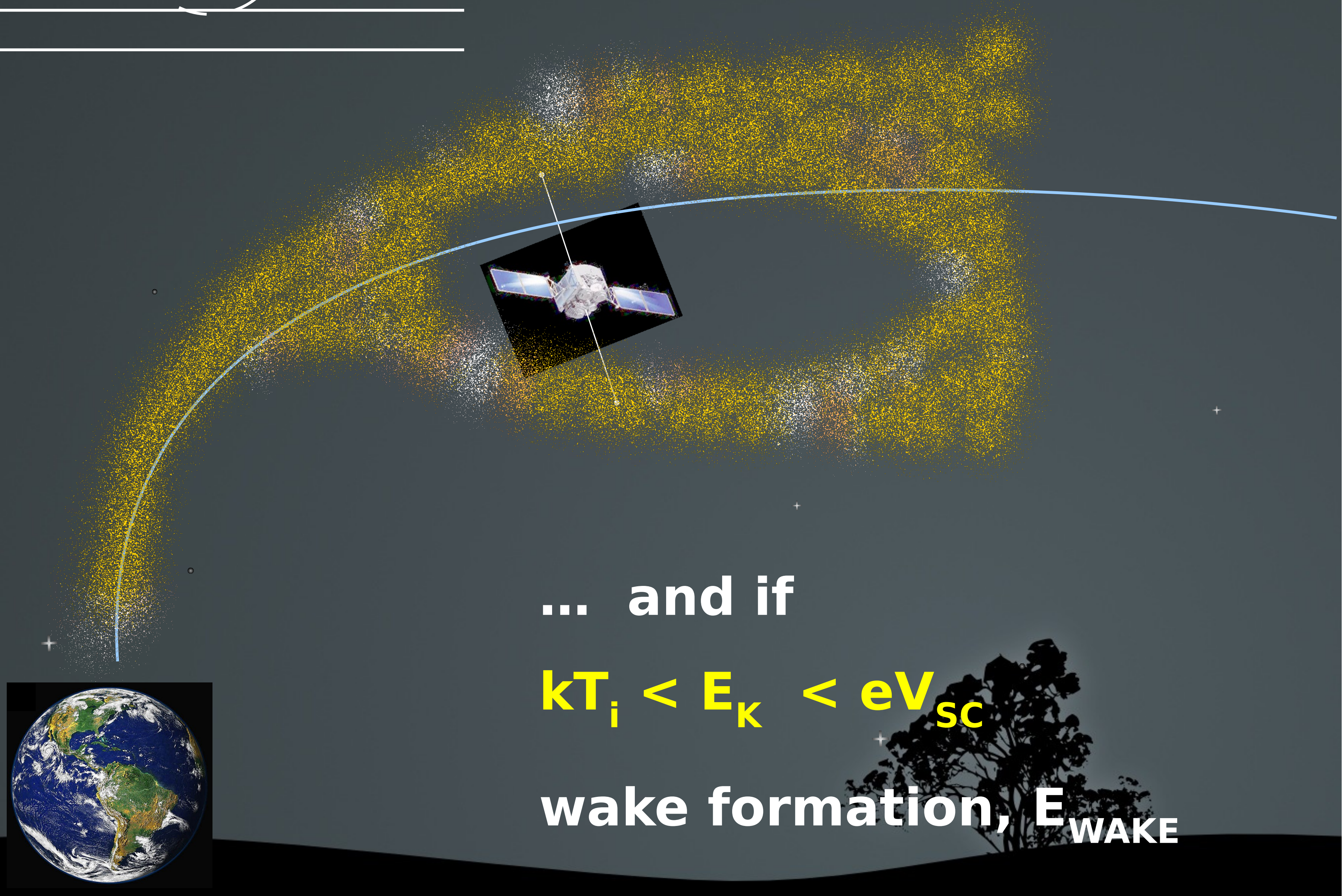
A series of recent measurements of the outflow of ionization from the ionosphere have further heightened our awareness of the strength of the ionospheric source of magnetospheric plasmas. In this paper the ionospheric contribution of the polar wind and cleft ion fountain at energies less than 10 eV has been added to the previously measured sources; this total ion outflow has then been used to calculate the resulting ion density in the different internal regions of the earth's magnetosphere: plasmasphere, plasma trough, plasma sheet, and magnetotail lobes. Using estimated volumes for these regions and an ion residence time characteristic of each region, we have found that the observed magnetospheric densities can be attained in all cases with no contribution from the solar wind plasma. In the case of the plasma sheet the ionospherically supplied density is more than enough to match the observations and even suggests an invisible component of low energy plasma (<10 eV) which has never been observed. A detailed comparison between the calculated ionospheric source effects in the plasma sheet and those recently measured by ISEE shows excellent agreement and suggests a direct polar low-energy ion source for the plasma sheet which has remained unmeasured because of spacecraft potential effects. Although the solar wind is clearly the earth's magnetospheric energy source and energetic solar wind ions are observed in the magnetosphere, these calculations suggest the possibility that the ionospheric source alone is sufficient to supply the entire magnetospheric plasma content under all geomagnetic conditions.

Wake formation



If $E_K >> eV_{SC}$, $E_K > kT_i$,

Narrow wake

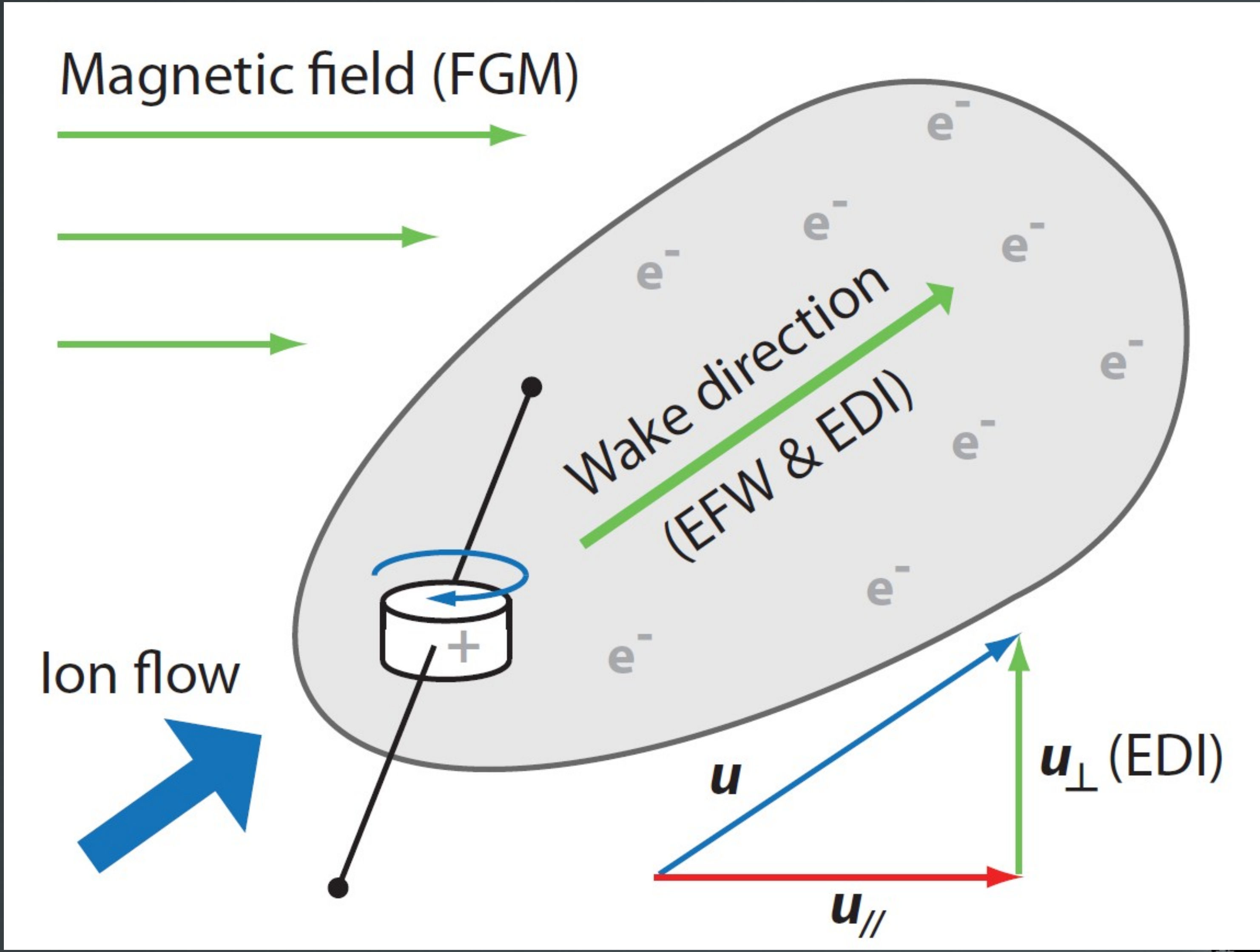


… and if

$kT_i < E_K < eV_{SC}$

wake formation, E_{WAKE}

New data with solution



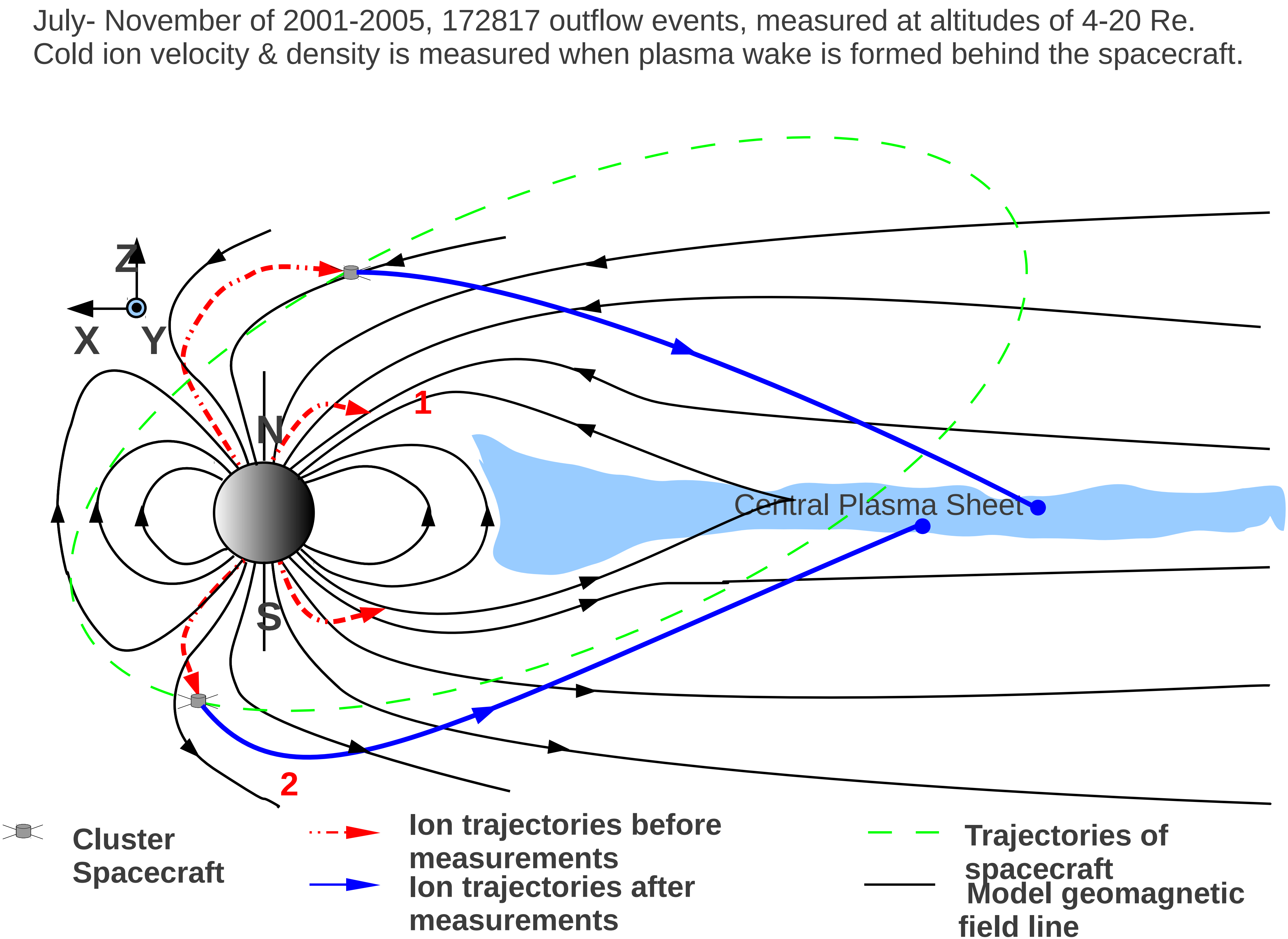
Using data from Cluster spacecraft

FGM: Flux Gate Magnetometer

EFW: Electric Field and Wave experiment

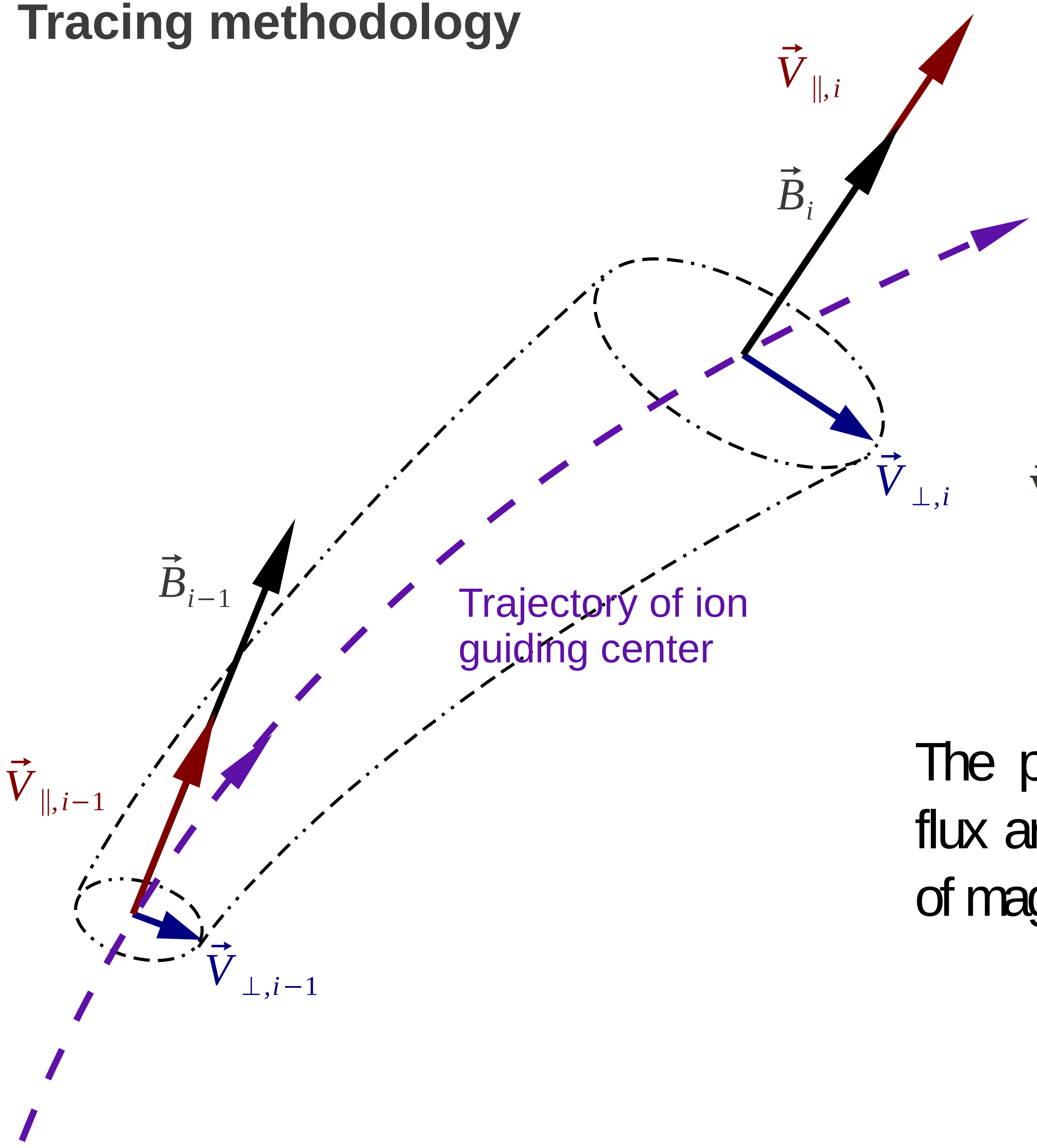
EDI: Electron Drift Instrument

Engwall et. al[2009b]
Ann. Geophys.



July- November of 2001-2005, 172817 outflow events, measured at altitudes of 4-20 Re.
Cold ion velocity & density is measured when plasma wake is formed behind the spacecraft.
Z
X
Y
N
S
1
2
Central Plasma Sheet
Cluster Spacecraft
Ion trajectories before measurements
Ion trajectories after measurements
Trajectories of spacecraft
Model geomagnetic field line

Tracing methodology



$$\vec{\mathbf{P}}_{\mathbf{i}} = \vec{\mathbf{P}}_{\mathbf{i}-1} + \vec{\mathbf{V}}_{\mathbf{i}-1} \Delta \mathbf{t}$$

$$\vec{\mathbf{V}}_{\mathbf{i}} = \vec{\mathbf{V}}_{\mathbf{para,i}} + \vec{\mathbf{V}}_{\mathbf{perp,i}}$$

$$\vec{\mathbf{V}}_{\mathbf{para,i}} = \vec{\mathbf{V}}_{\mathbf{para,i}-1} + \mathbf{a}_{\mathbf{i}-1} \Delta \mathbf{t}$$

$$\mathbf{a}_{\mathbf{i}} = \vec{\mathbf{V}}_{\mathbf{perp,i}} \cdot \frac{\mathbf{d}\hat{\mathbf{b}}}{\mathbf{dt}} + \mathbf{g}_{\mathbf{para,i}}$$

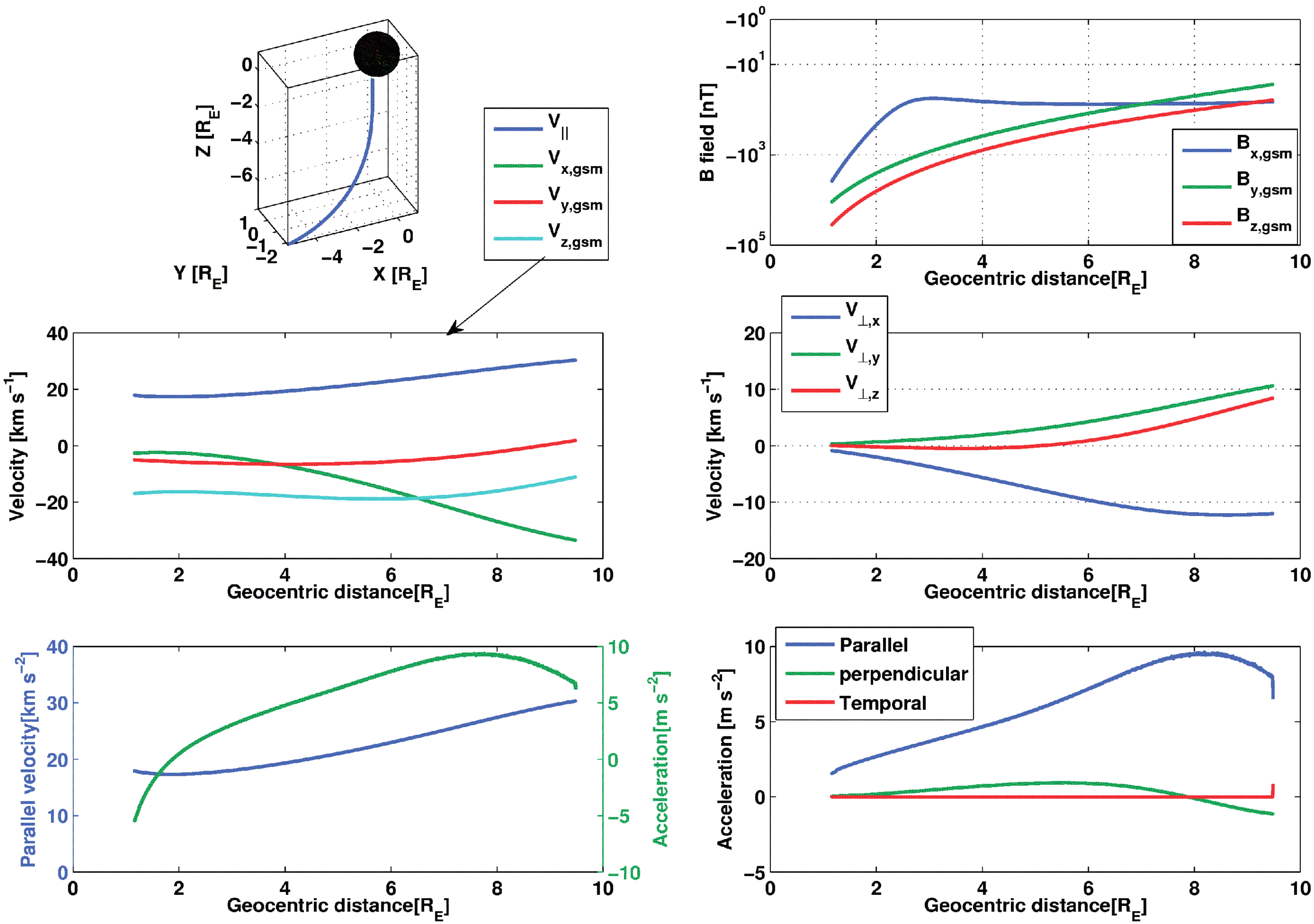
$$\vec{\mathbf{V}}_{\mathbf{perp,i}} = |\vec{\mathbf{V}}_{\mathbf{perp,i}-1}| \frac{(\vec{\mathbf{B}}_{\mathbf{i}-1} \times \vec{\mathbf{V}}_{\mathbf{perp,i}-1}) \times \vec{\mathbf{B}}_{\mathbf{i}}}{|(\vec{\mathbf{B}}_{\mathbf{i}-1} \times \vec{\mathbf{V}}_{\mathbf{perp,i}-1}) \times \vec{\mathbf{B}}_{\mathbf{i}}|}$$

$$\vec{\mathbf{F}}_{\mathbf{i}} = |\vec{\mathbf{F}}_{\mathbf{SC}}| \frac{|\vec{\mathbf{B}}_{\mathbf{i}}|}{|\vec{\mathbf{B}}_{\mathbf{SC}}|} \hat{\mathbf{b}}_{\mathbf{i}}$$

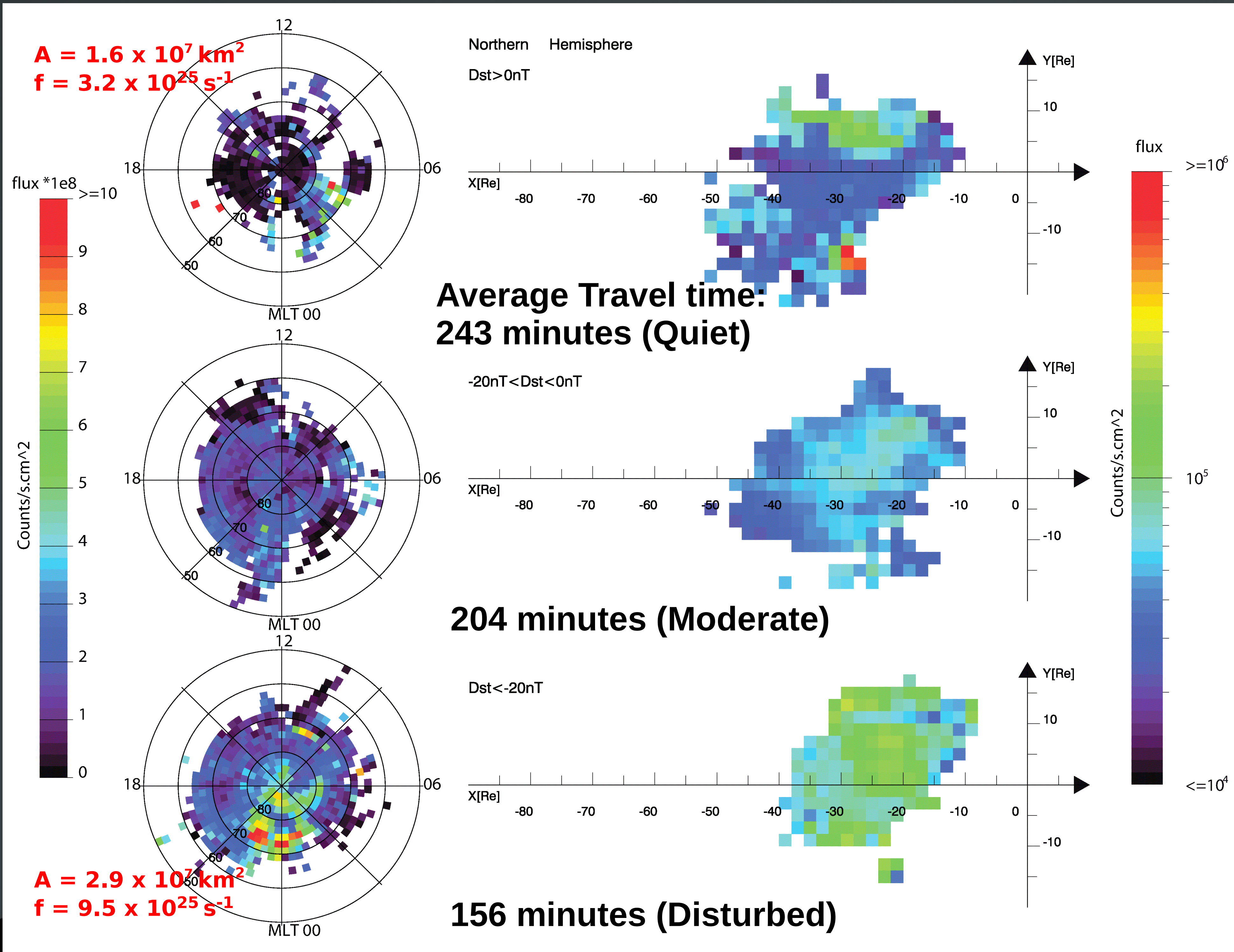
The perpendicular velocity and ion flux are scaled by the cross section of magnetic flux tube.

Trajectory Calculation

$$\frac{dv_{\parallel}}{dt} = \vec{v}_E \cdot \frac{d\,\hat{b}}{ds} - \vec{g}$$



Observation: Dst dependence (Northern hemisphere)

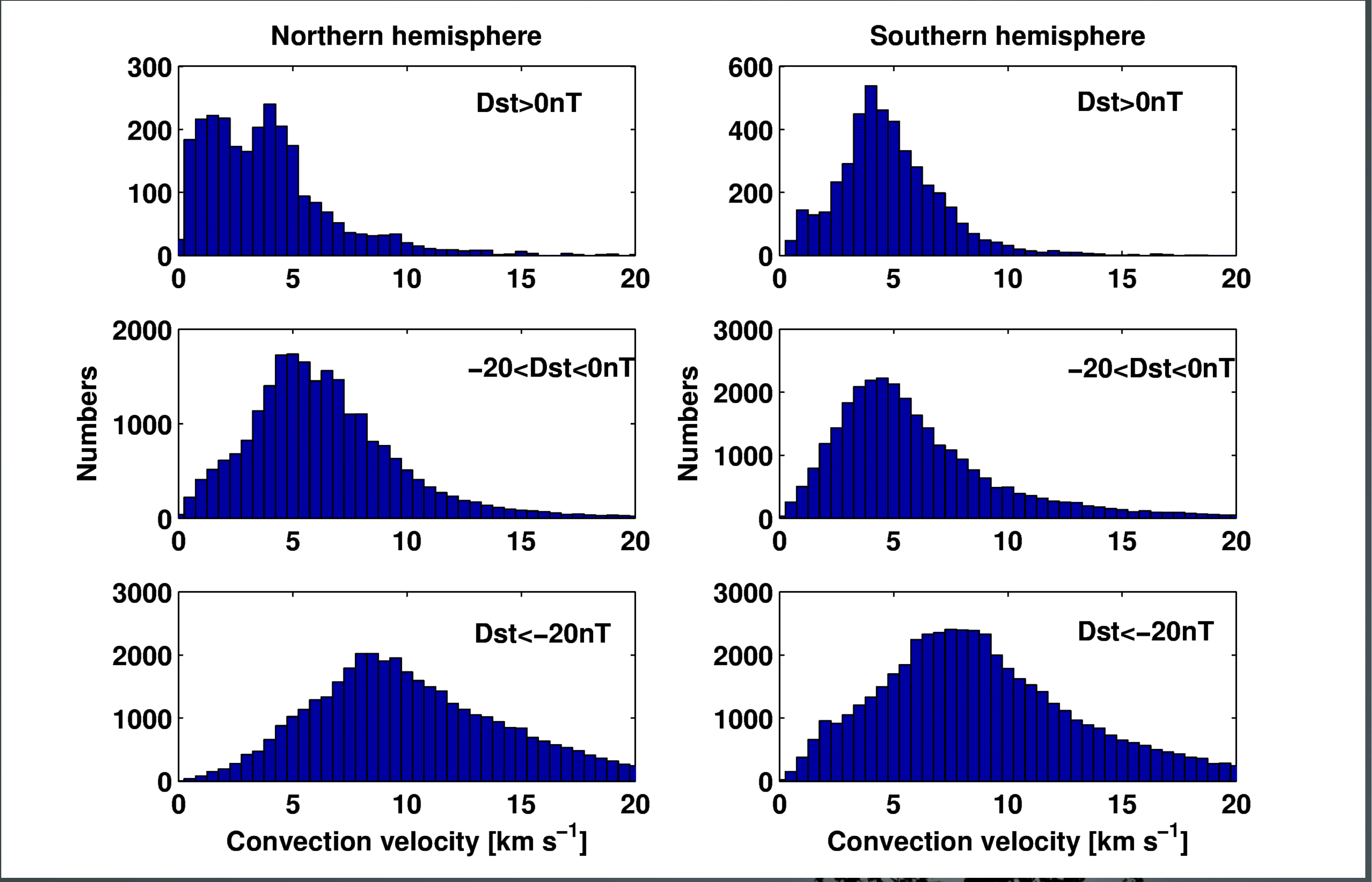


Convection velocity distribution

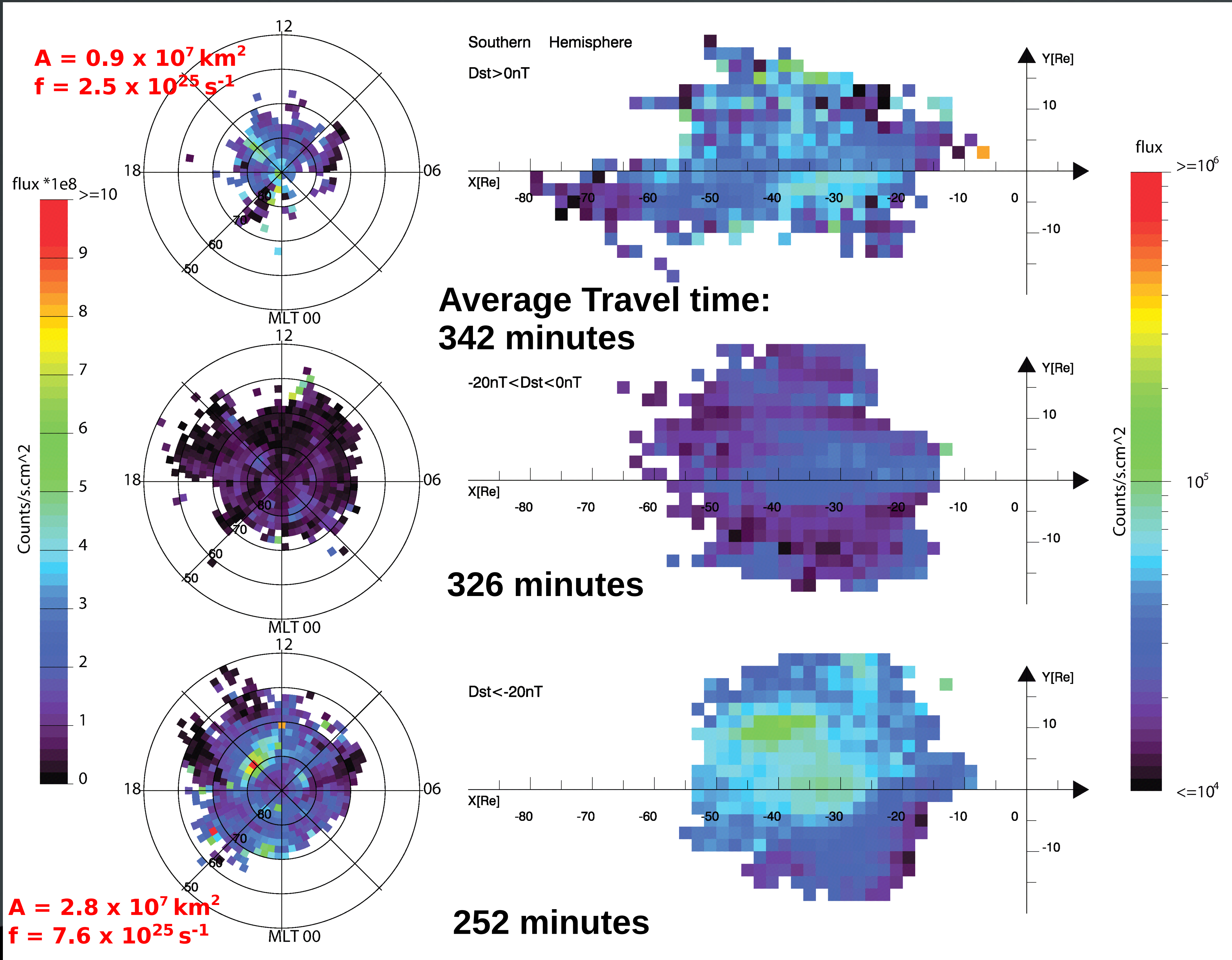
Quiet

Moderate

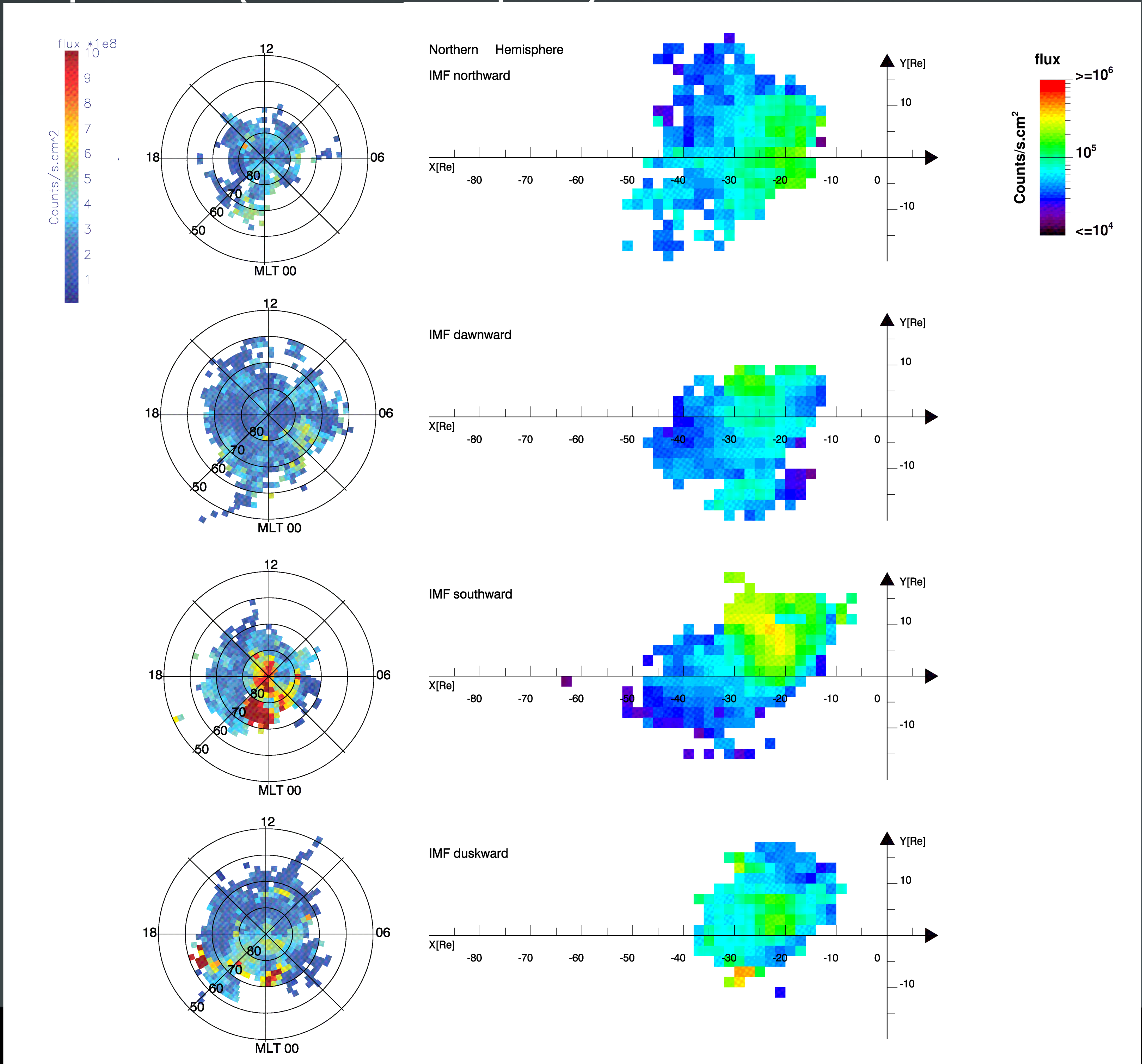
Disturbed



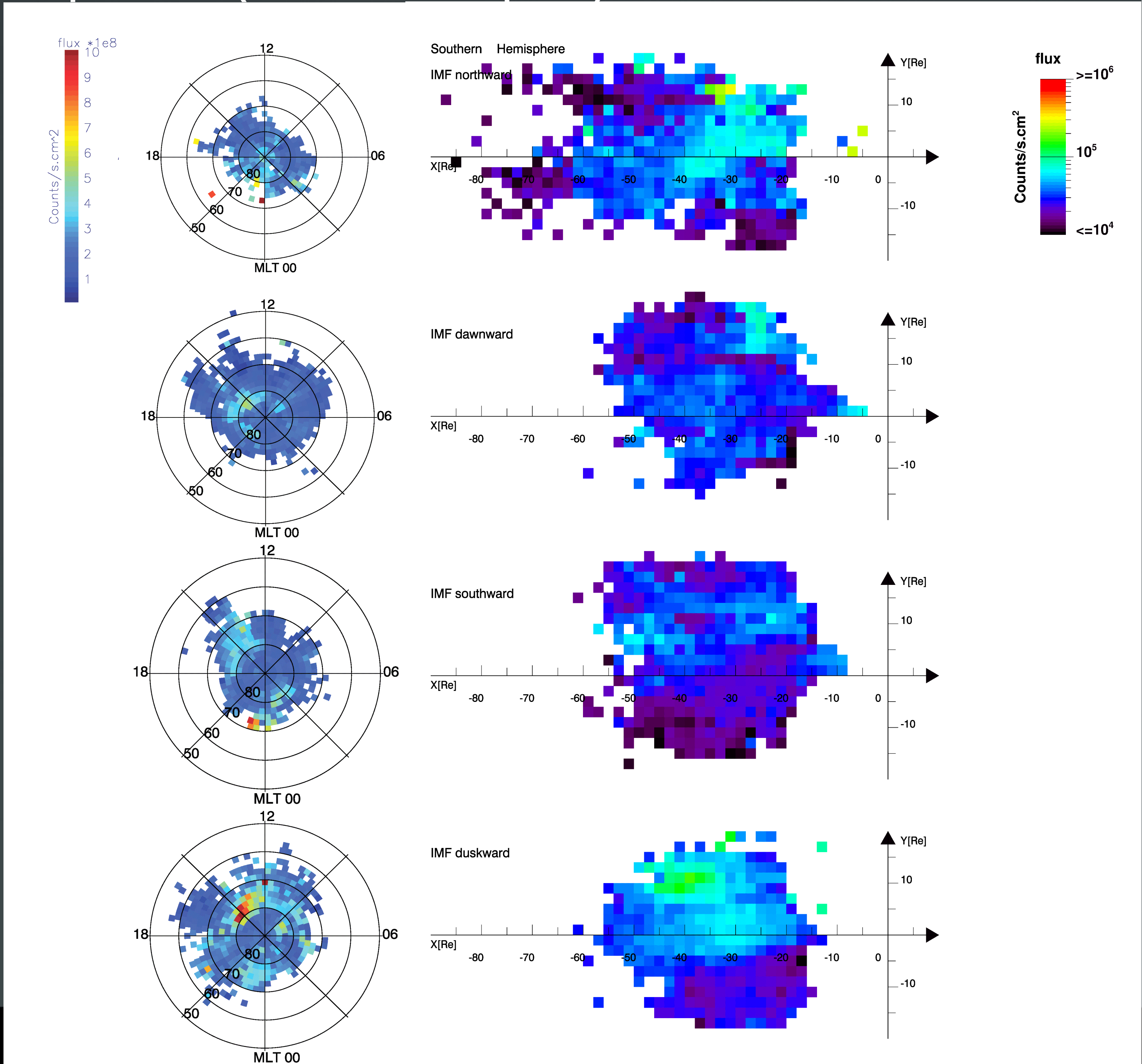
Observation: Dst dependence (Southern hemisphere)



Observation: IMF dependence (Northern hemisphere)



Observation: IMF dependence (Southern hemisphere)



Conclusion

1. Fate region could be contracted during geomagnetic disturbed time due to high convection velocity;

2. Total flux on CPS during disturbed time could be enhanced because of more outflow from ionosphere;

3. Dawn-dusk asymmetry for cold ion fate region on CPS was observed for different IMF directions;

4. A persistent dawn-dawn asymmetry for cold deposition region on plasma sheet is revealed.

5. High fluxes on plasma sheet does not correspond to high fluxes on the source region, and it can be highly mixed by outflows from various region on ionosphere.

6. Fluxes enhanced by high solar wind dynamic pressure is dominated by outflow from day-side ionosphere.