Magnetospheric Science with the SWARM Mission

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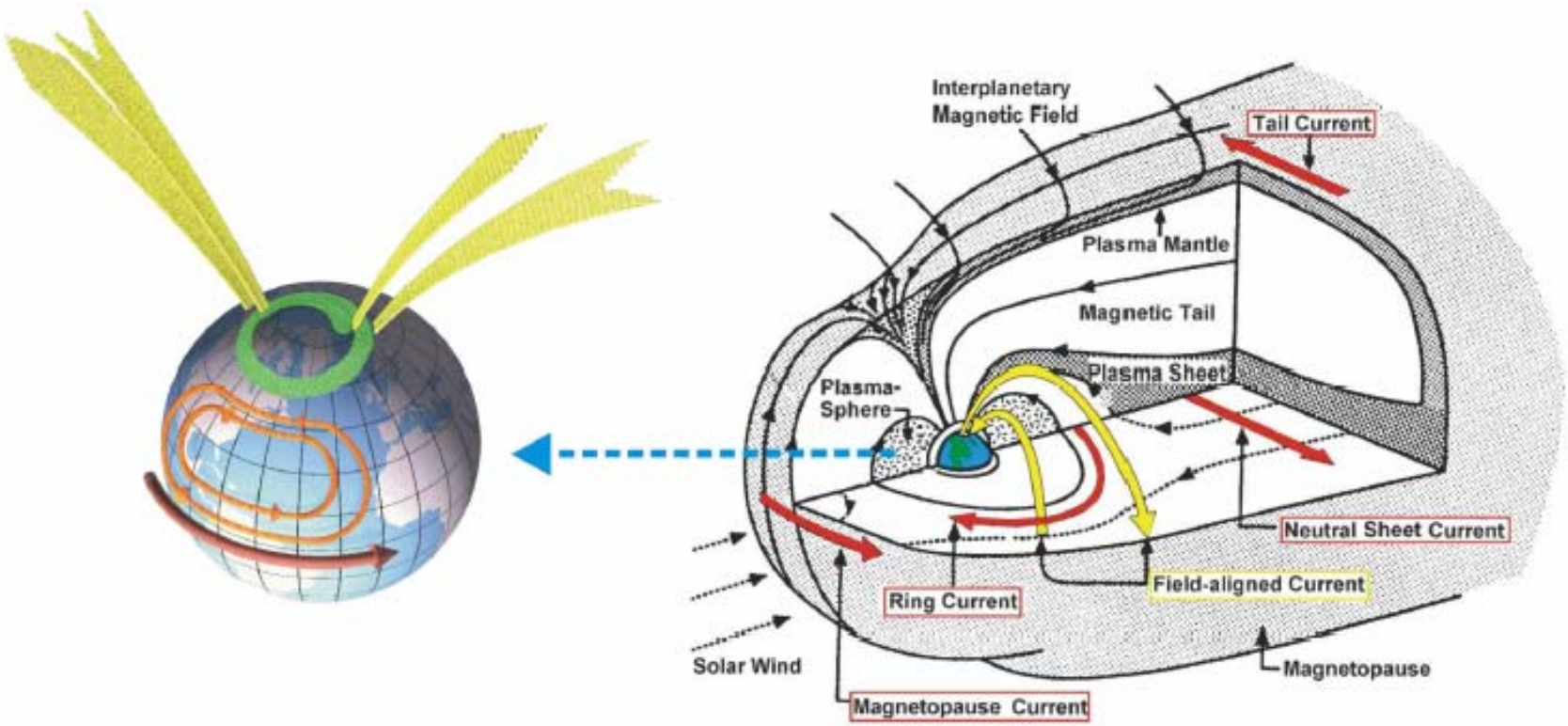
Objectives

- ***Introduce M-I coupling and the role of field-aligned currents***
- ***Review current state of understanding***
- ***Collect open science questions***
- ***Present some further thoughts***

Overview only
- somewhat simplified
- material based on work of many individuals

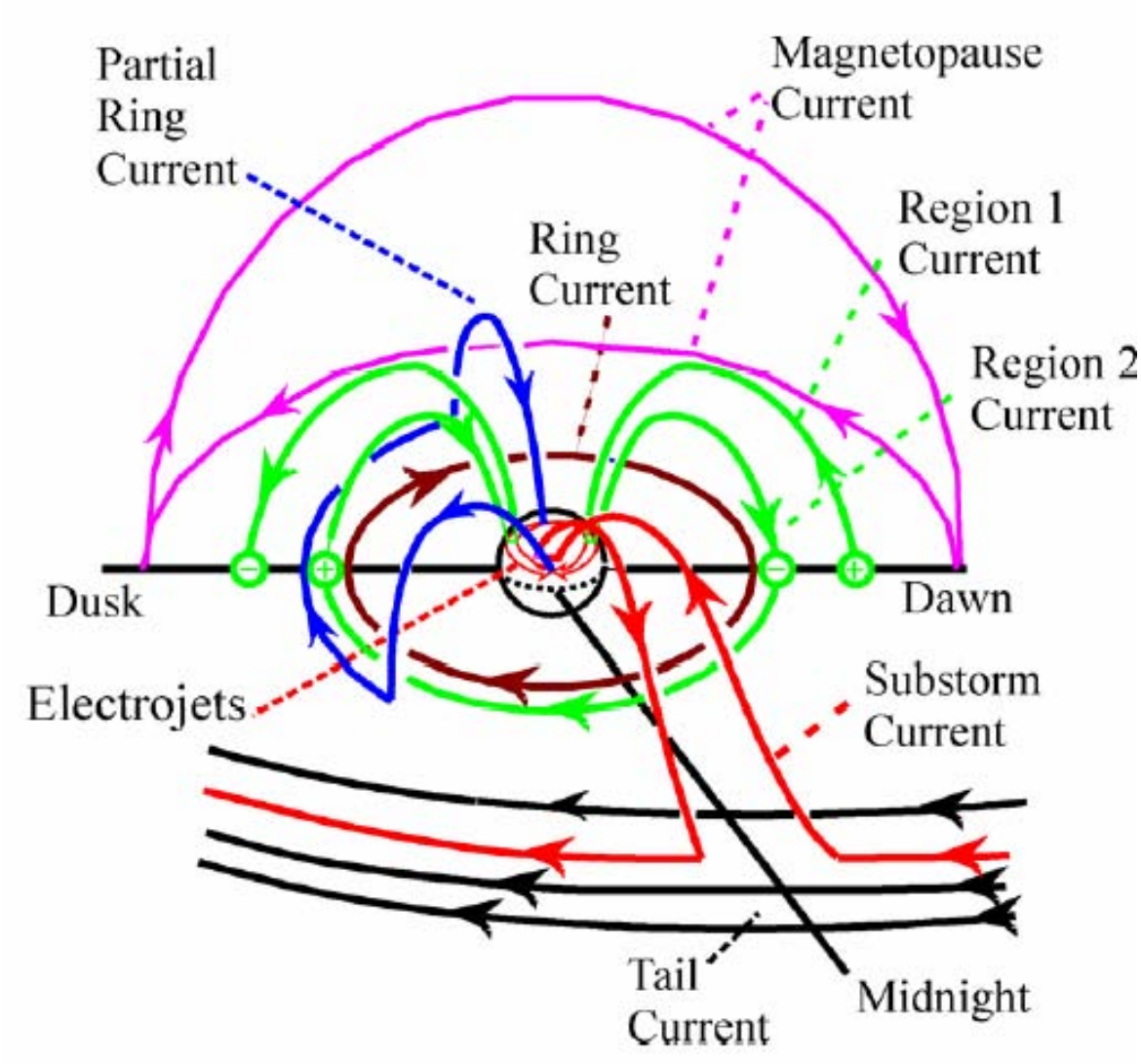
Introduction to M-I Coupling



The interaction between magnetosphere and ionosphere is mediated by (field-aligned) current flows between the domains

SWARM WWW site

Detailed Current Morphology



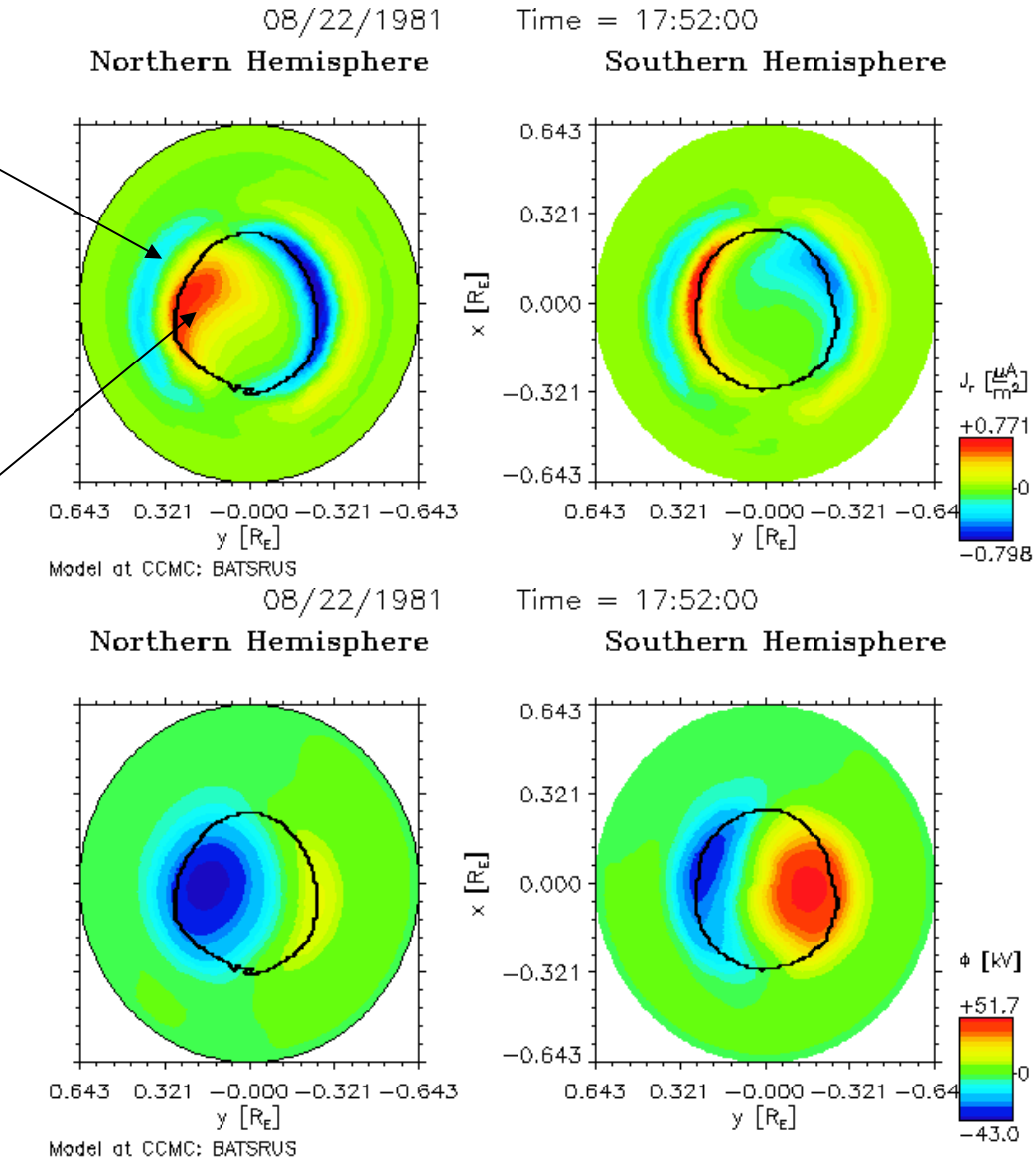
R. McPherron

Will focus on Region 1 currents…

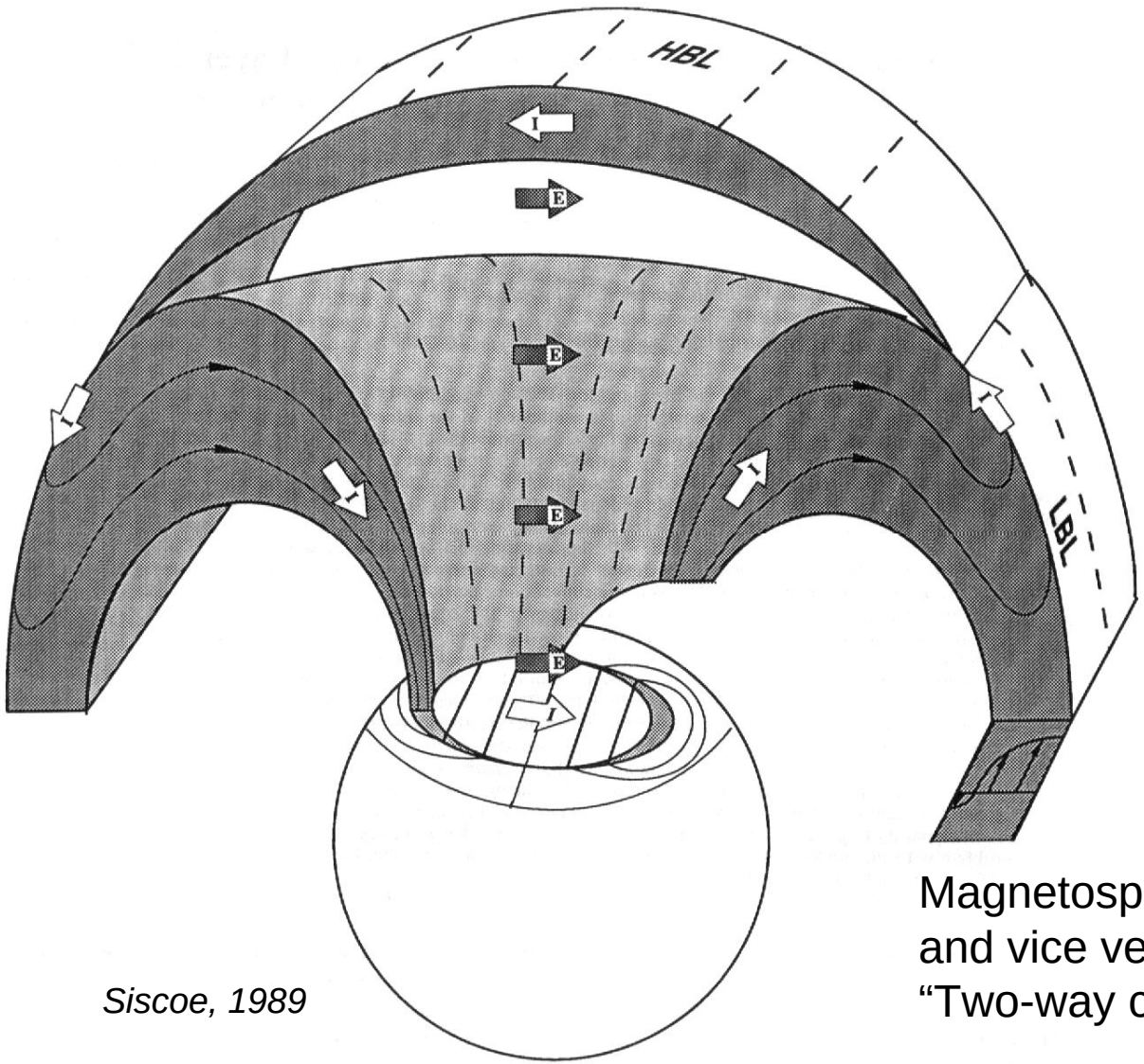
Currents and Ionospheric E Fields

Region 2

Region 1



Interaction Physics



Siscoe, 1989

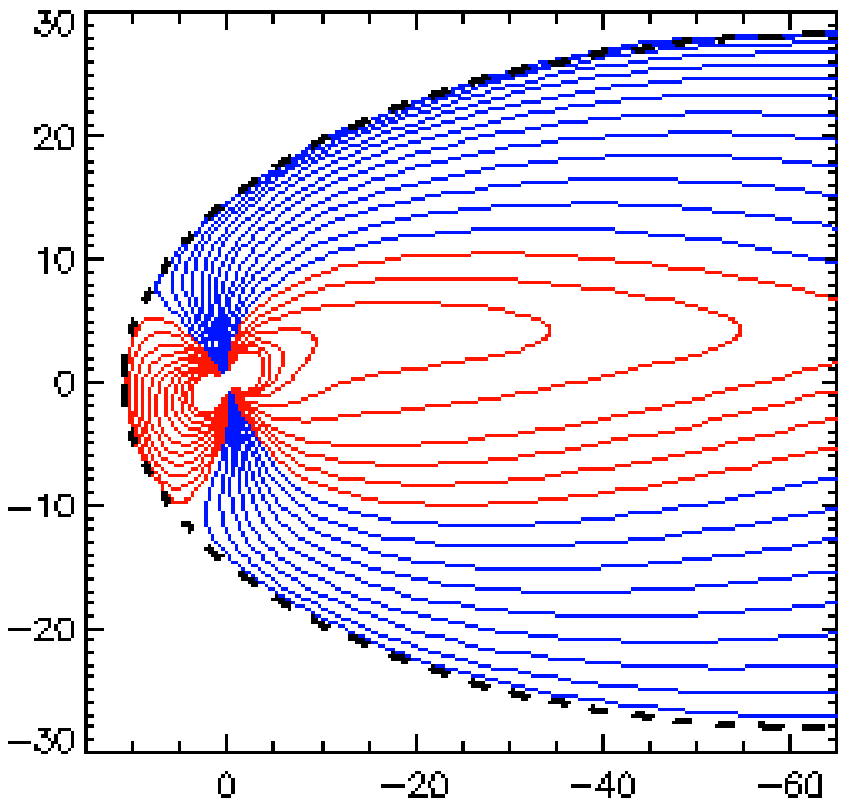
- Currents are generated in magnetosphere
- Currents close in the (resistive) ionosphere
- Ionospheric electric fields (potentials) are applied to geomagnetic field lines

Magnetosphere changes ionosphere and vice versa
“Two-way coupling”

The Magnetospheric Side

•Currents are associated with by shears and gradients in the magnetic field

•Field-aligned currents require shears in the magnetic field



A “planar” magnetosphere has no field-aligned currents

Deriving Currents

$$\rho \frac{d\vec{v}}{dt} = \vec{j} \times \vec{B} - \nabla p$$

$$\vec{j}_{\perp} = \frac{\nabla p \times \vec{B}}{B^2}$$

$$j_{\parallel} = -\int \frac{ds}{B} \nabla \cdot \vec{j}_{\perp} = -\int \frac{ds}{B} \nabla \cdot \frac{\nabla p \times \vec{B}}{B^2}$$

Currents related to plasma distribution

$$\frac{\partial \vec{B}}{\partial t} = -\nabla \times \left(\vec{v} \times \vec{B} \right)$$

$$\frac{\partial \vec{j}}{\partial t} = -\nabla \times \nabla \times \left(\vec{v} \times \vec{B} \right)$$

Changes by plasma flows, dynamical effects

Current distribution indicative of dynamics and its effects

The Basic Idea of FAC Generation

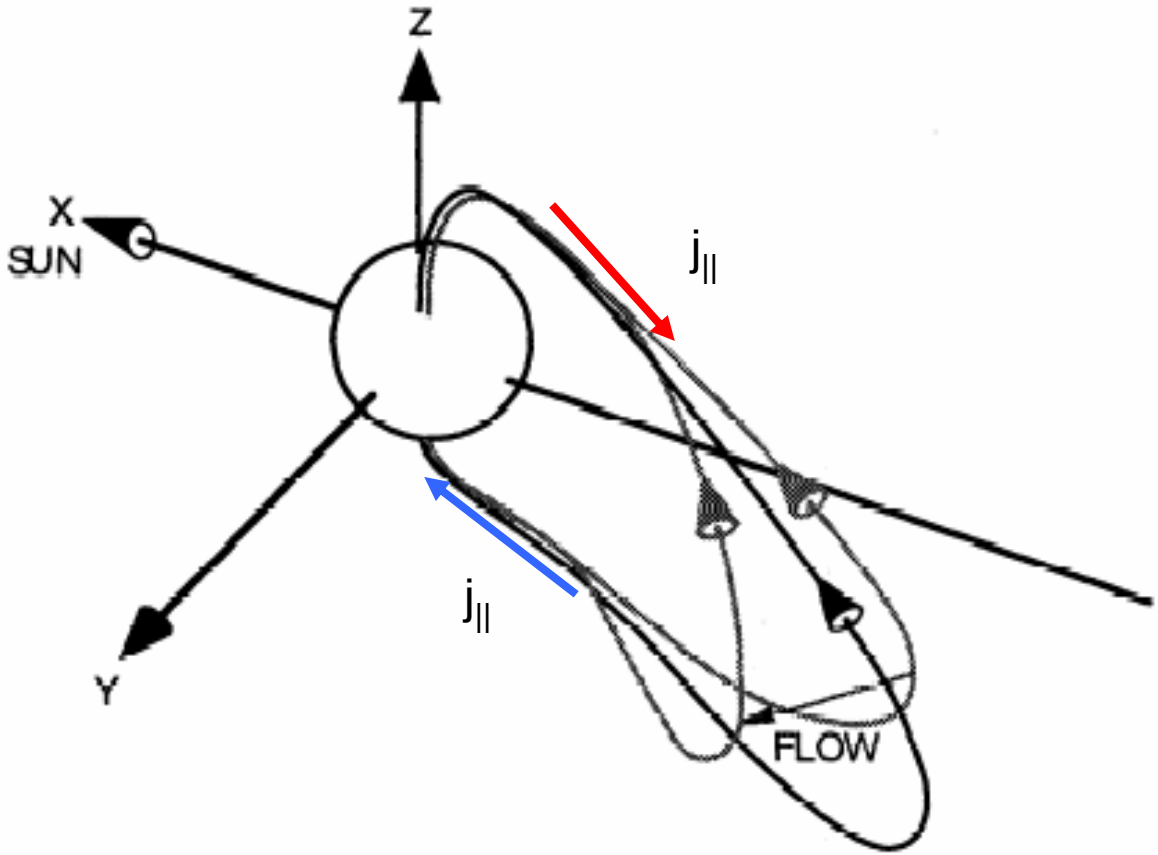
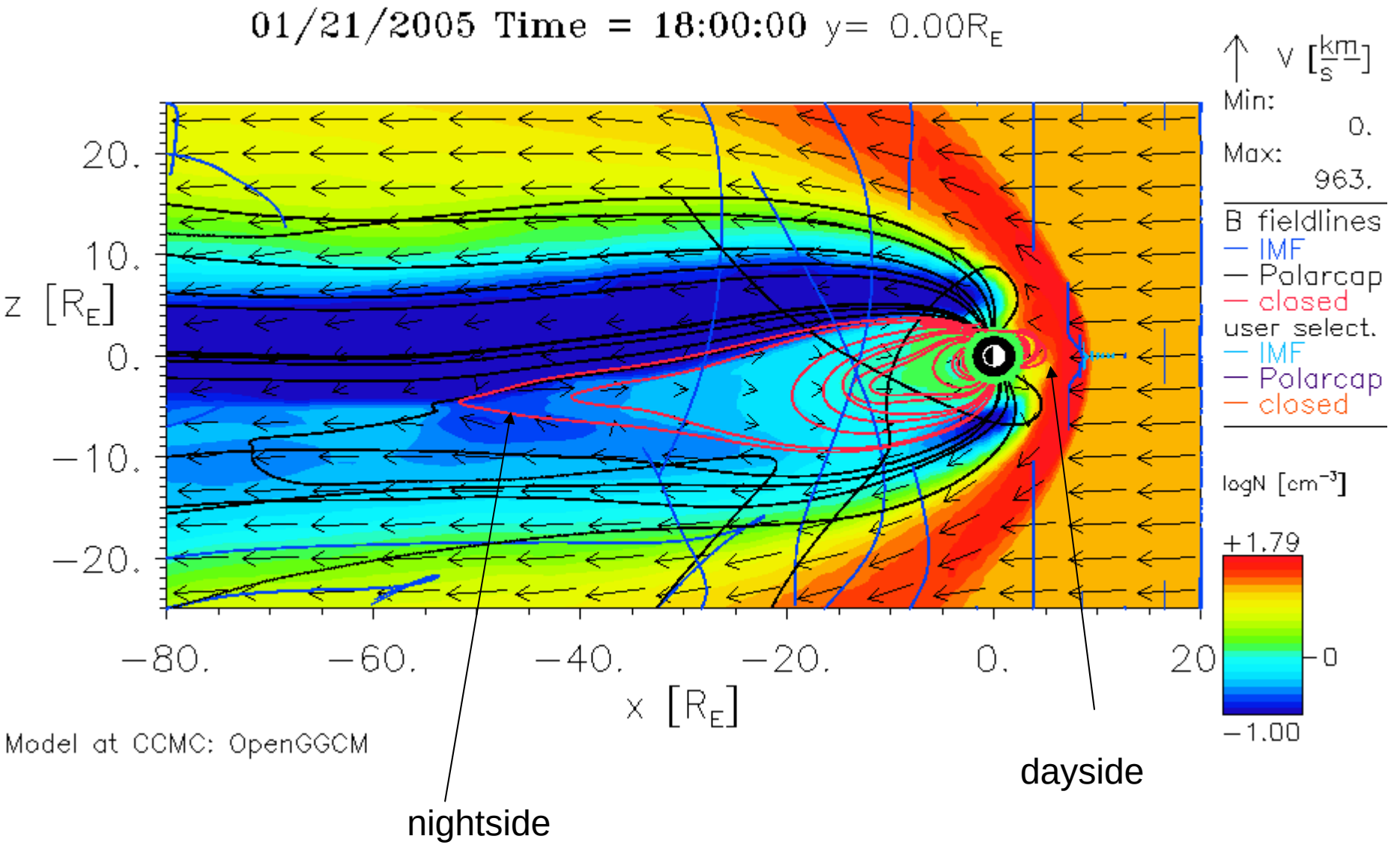


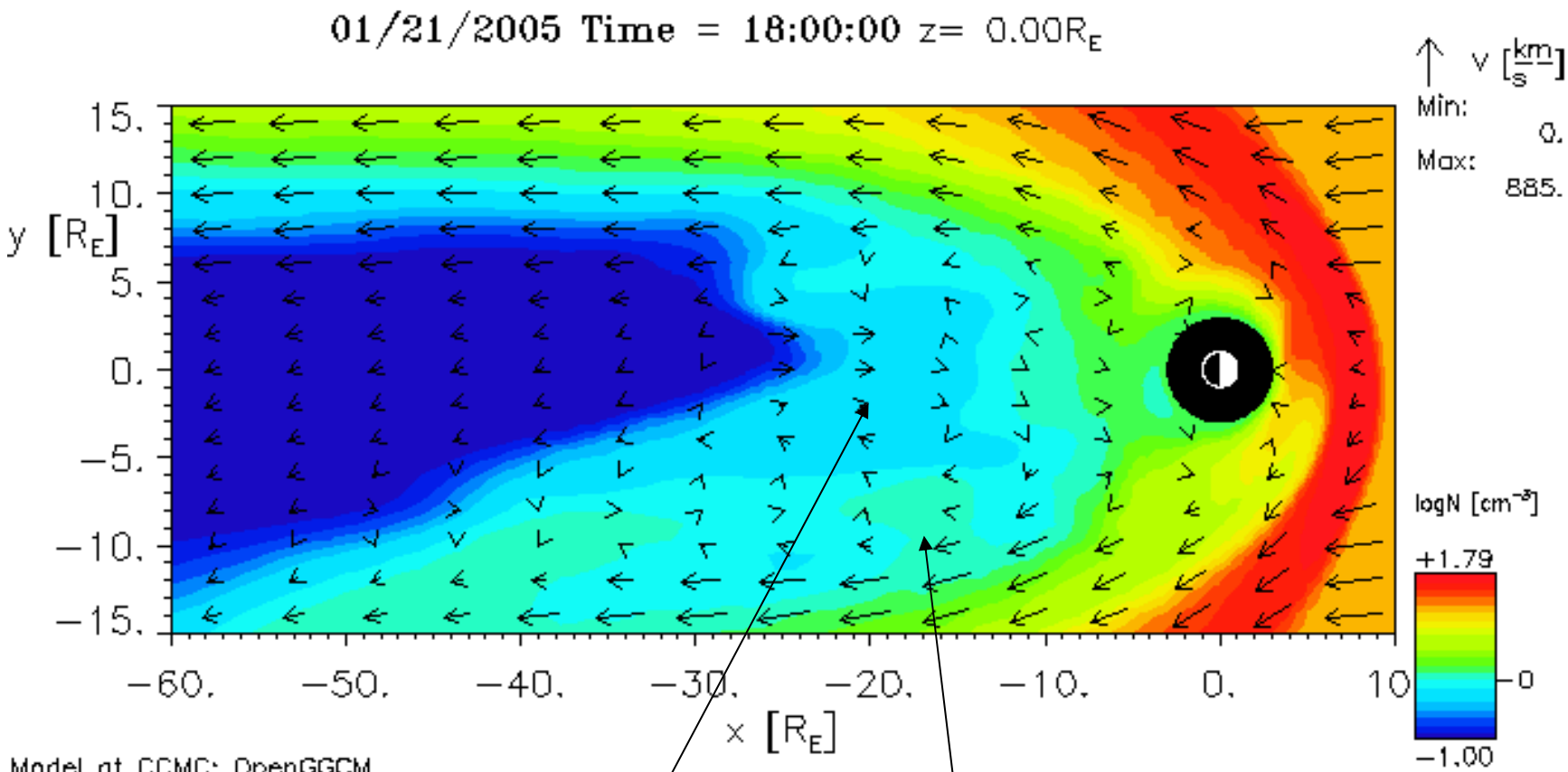
Figure 9. Perspective view of field lines (schematic) representing the generation of field-aligned currents by shear flow away from midnight. The flow, affecting only the shorter field line, causes a bending and an increase in B_y.

Birn and Hesse, 1996

Location of Flows



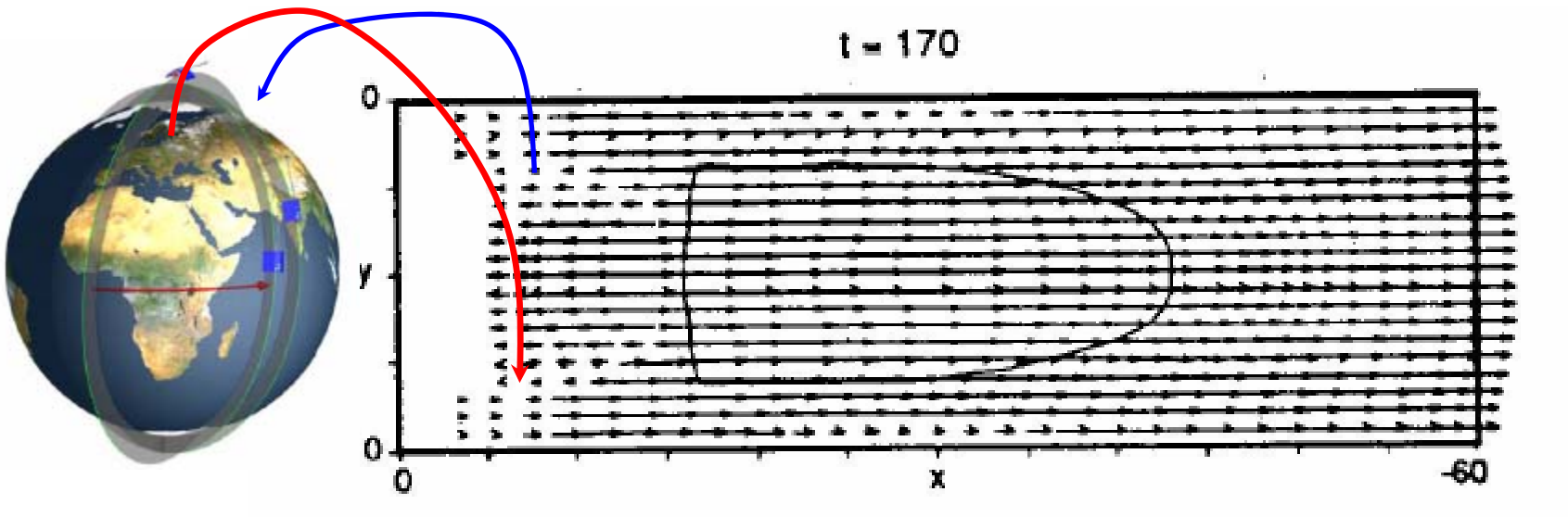
Location of Flows



nightside

Flanks

Generating Magnetic Shear

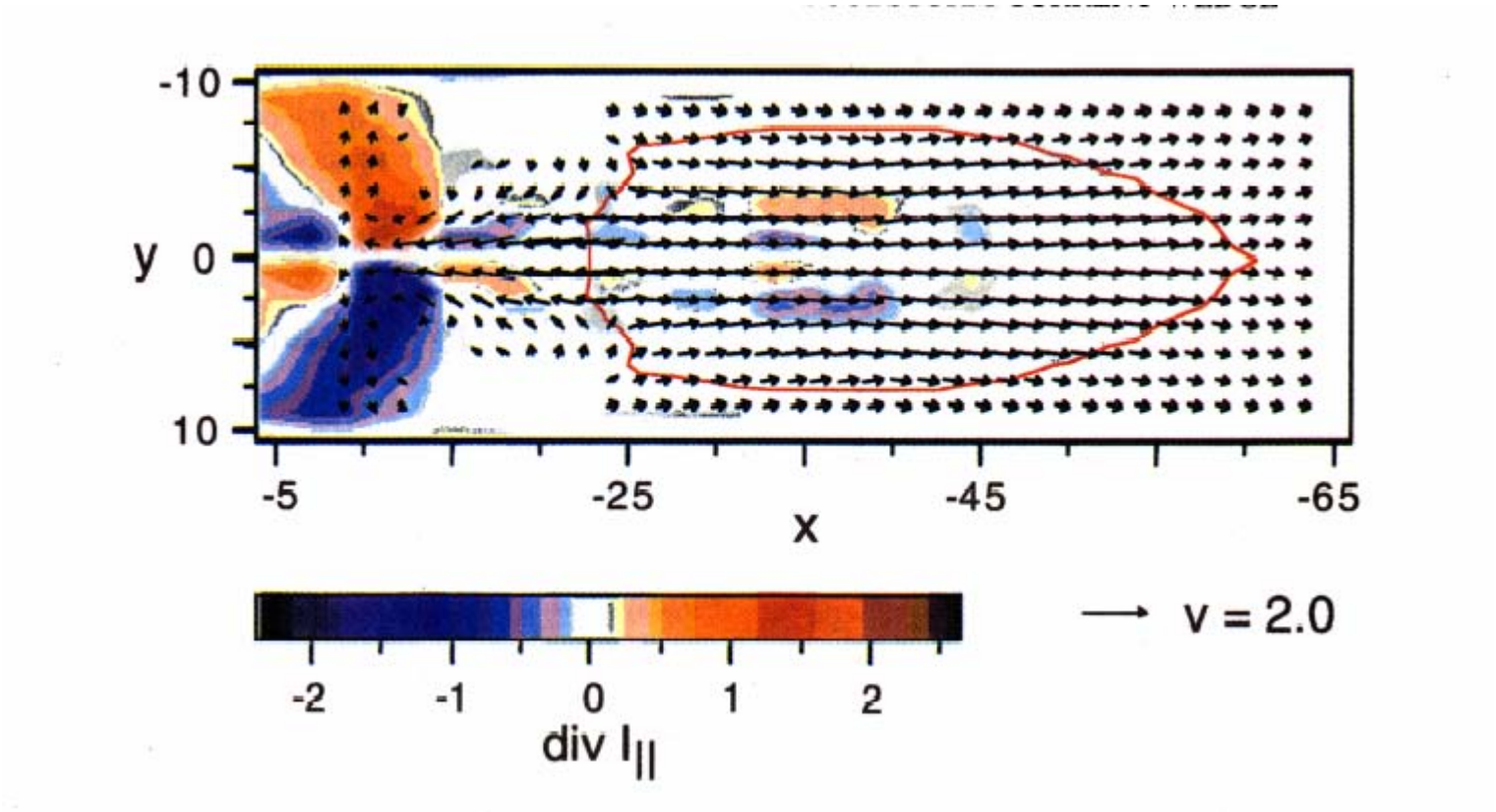


Flow gradients shear the magnetic field,

FAC result

Hesse and Birn, 1991

Height-integrated FAC Divergence



Region 1 Current Structure

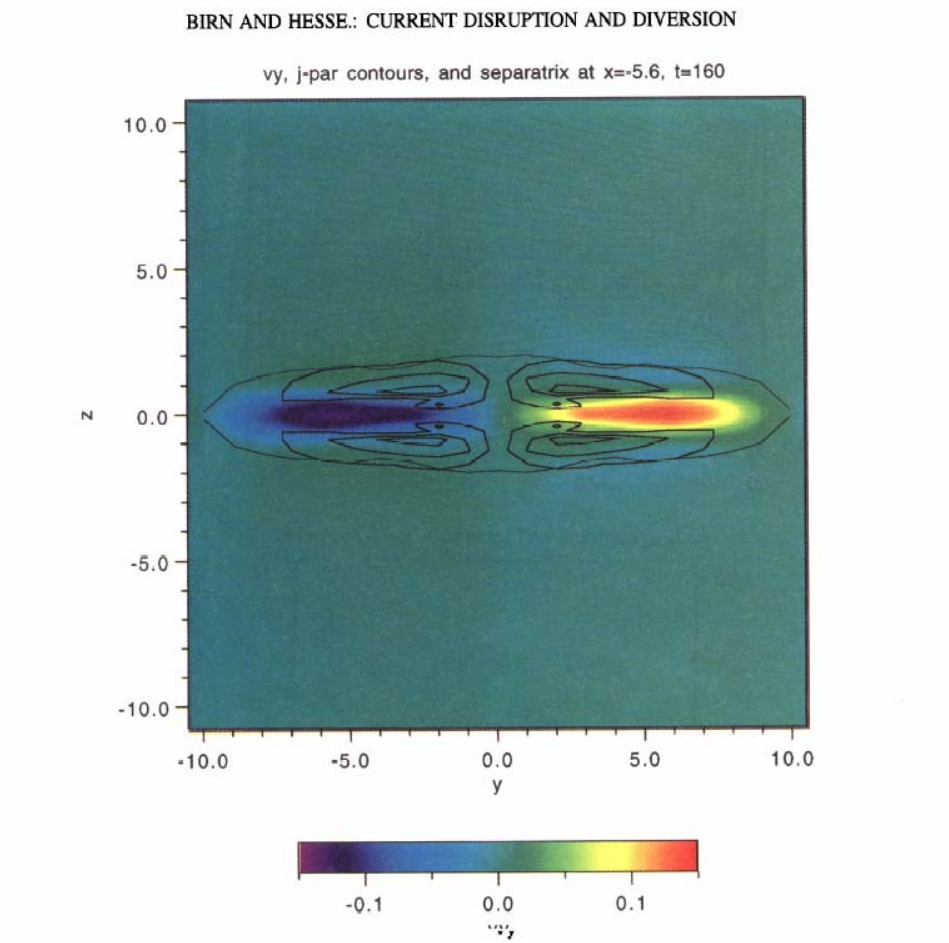
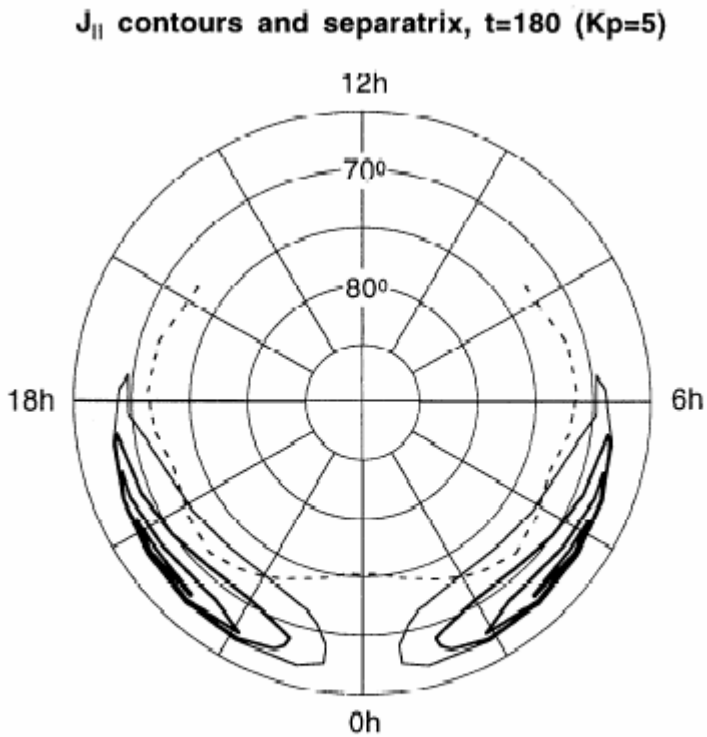


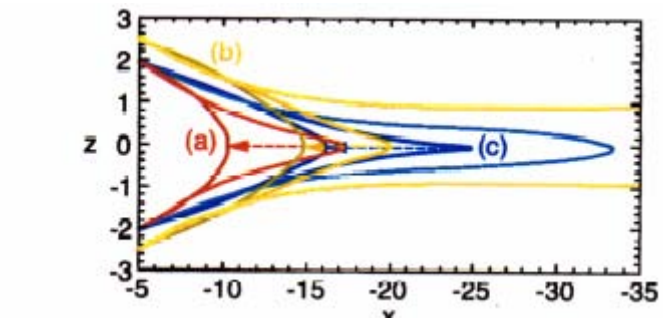
Plate 4. Magnitude of the cross-tail flow speed v_y (color coded) at $x = -5.6$ and $t = 160$. The shorter closed contours are contours of constant field-aligned current density (region 1 type), and the wide contour represents the boundary between open and closed field lines.

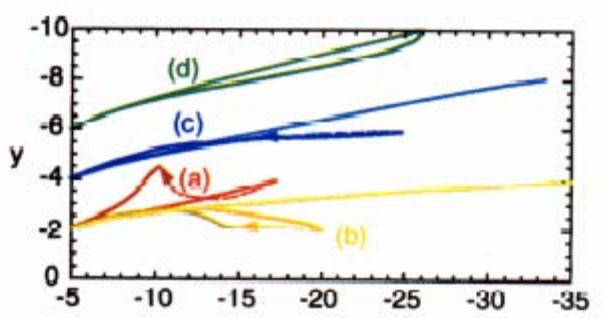


igure 8. Field-aligned current contours (solid lines) and mag-
tic separatrix (dashed line) of Figure 9 mapped to the Earth
ing the *Tsyganenko* [1987] magnetic field model for $Kp = 5$.
fter *Birn and Hesse* [1991c].

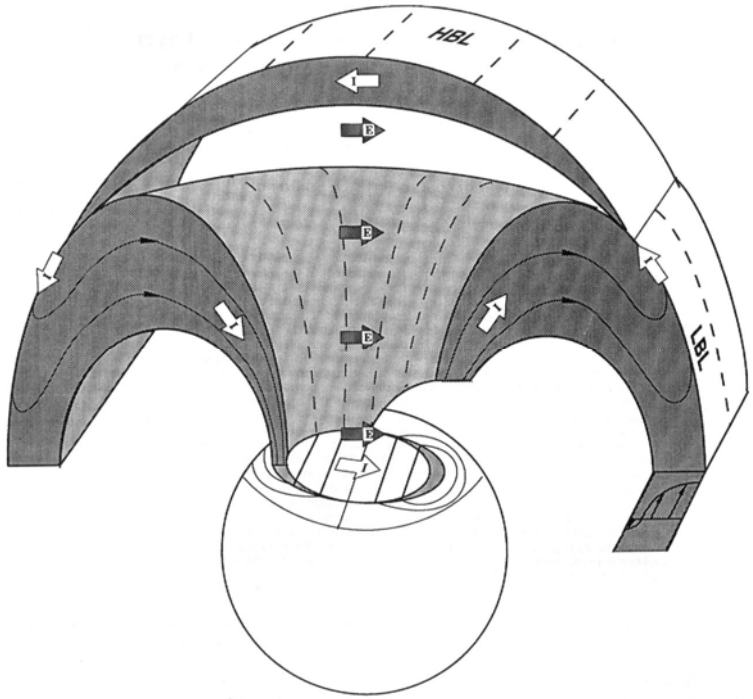
Summary of Magnetospheric Side

- ***Magnetospheric flows create or change field-aligned current systems***
- ***Field-aligned currents are associated with magnetic shear***
- ***Field-aligned current location is remote indicator of dynamic processes***





Ionospheric Electric Field Generation



- Current flow
- Neutral flow/friction

-> heating

$$\mathbf{J}_h = \vec{\vec{\Sigma}} \cdot \left(-\vec{\nabla}\Phi\right) + \left(\vec{\vec{\Sigma}} \cdot \vec{\mathbf{v}}_n\right) \times \vec{\mathbf{B}}$$

Field-line-integrated current (includes both hemispheres)

Field-line-integrated Conductivity (both hemispheres)

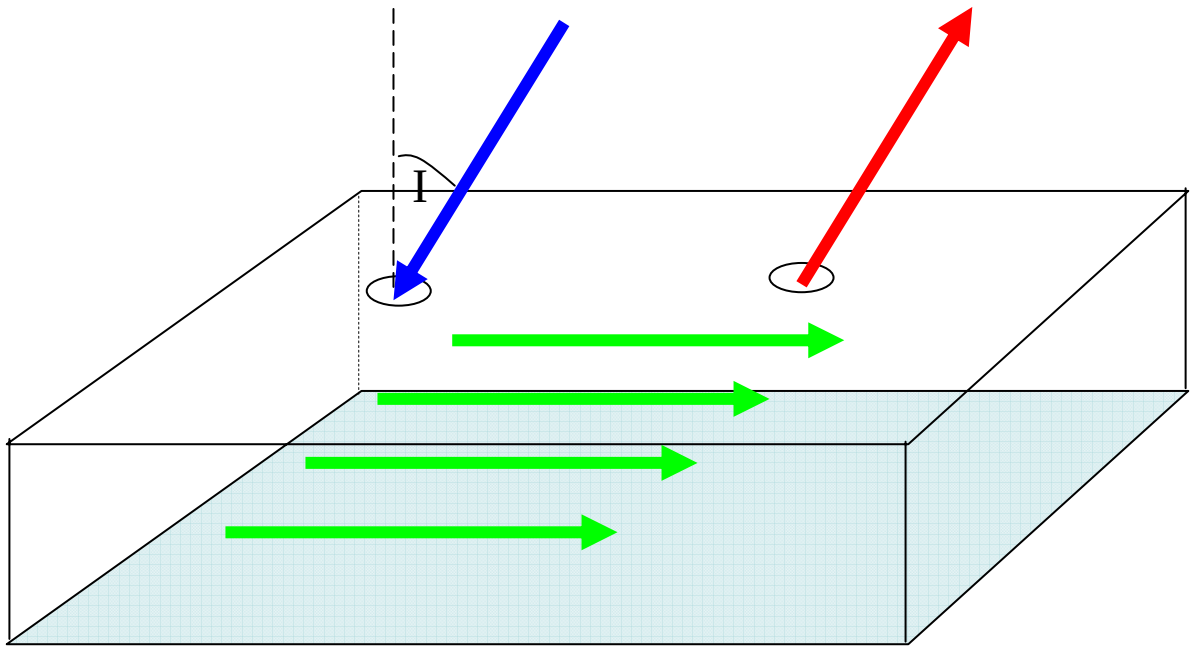
Field-line integrals of products of Hall and Pedersen conductivities and neutral winds

$$\vec{\nabla} \cdot \vec{\mathbf{J}}_h = J_{\parallel} \sin(I)$$

Total Ionospheric Dissipation/Generation

$$\int dV\vec{E}\cdot\vec{j} = -\int dV\nabla\phi\cdot\vec{j} = -\int dV\nabla\cdot\left(\phi\vec{j}\right) = -\oint dS\vec{n}\cdot\vec{j}\phi$$

$$\approx -\int dS\ \ \phi j_{\parallel}\cos(I)$$



ionospheric layer

FAC and electric fields determine total ionospheric energy deposition (-> heating)

What do we really know about FAC structure?

Is Life Therefore Simple?

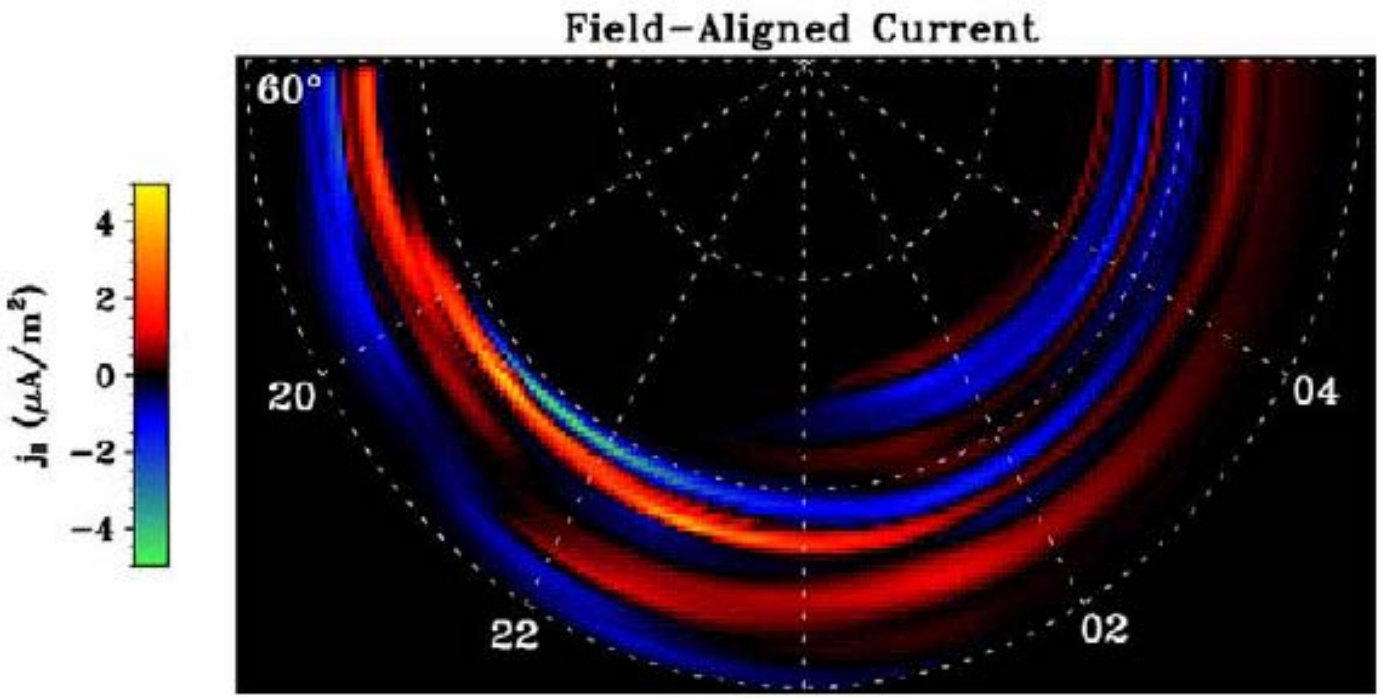


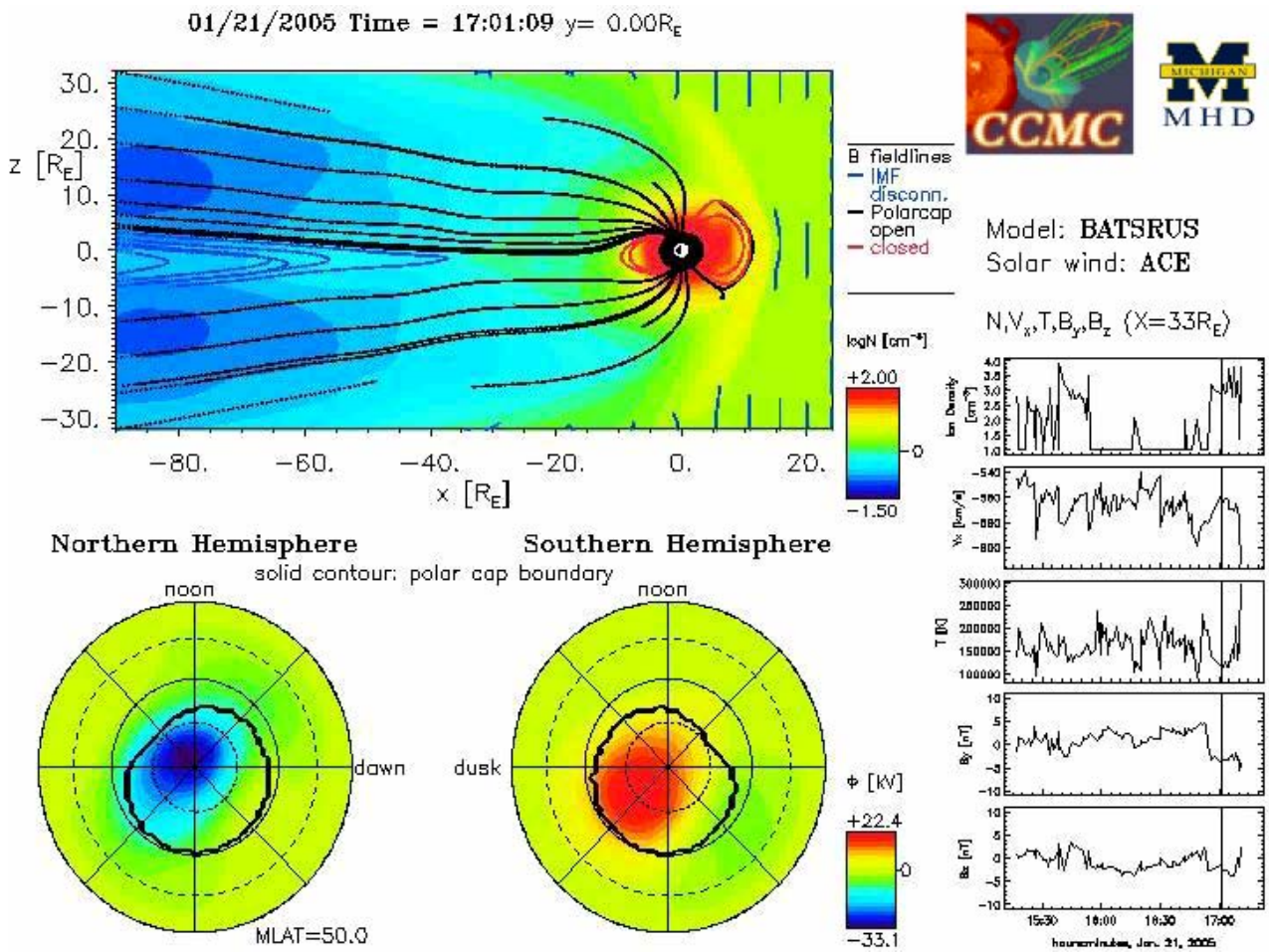
Figure 4. Field-aligned currents derived from the divergence of the height-integrated ionospheric currents shown in Figure 3.

-average field-aligned current structure-

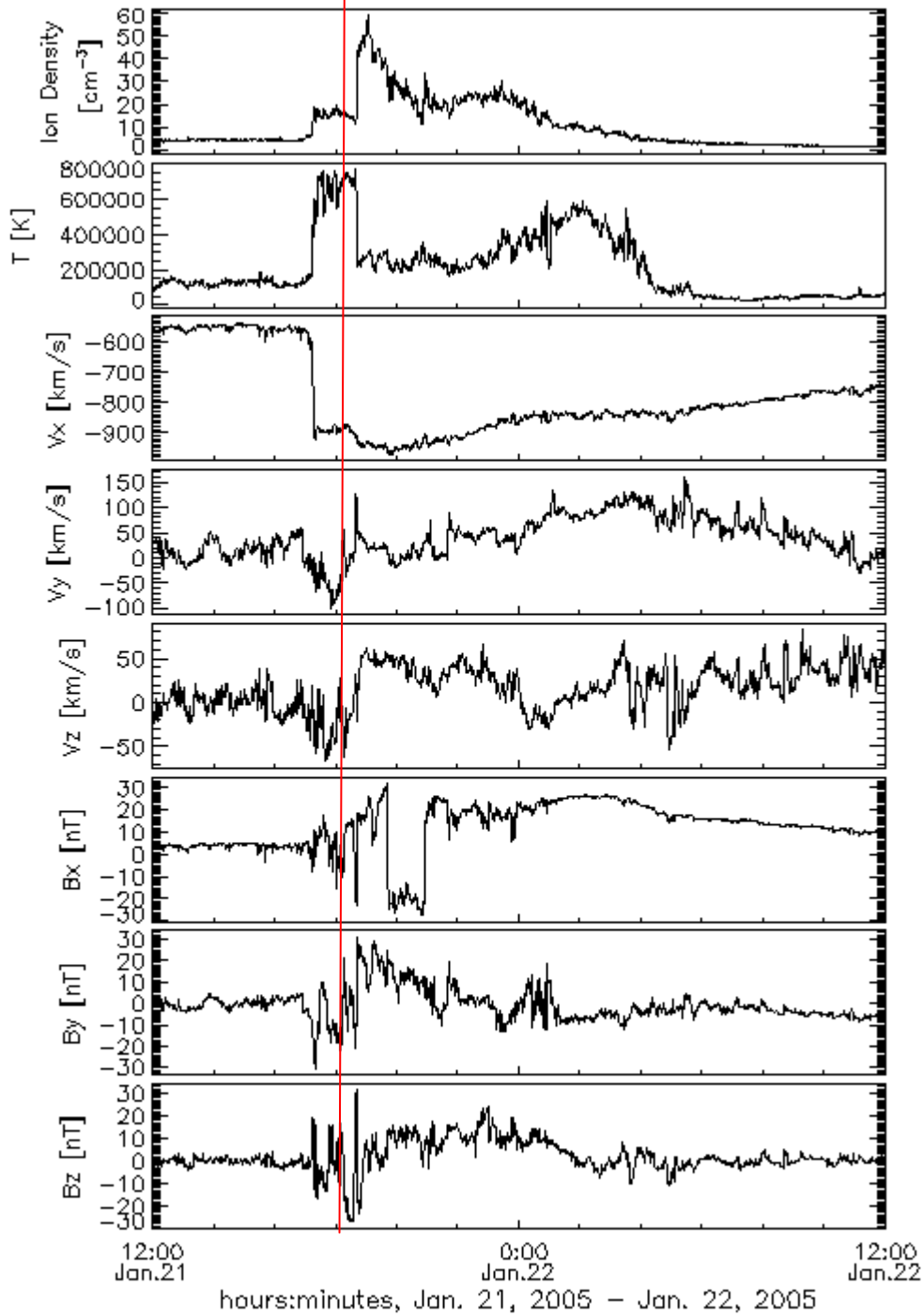
Gjerloev and Hoffman

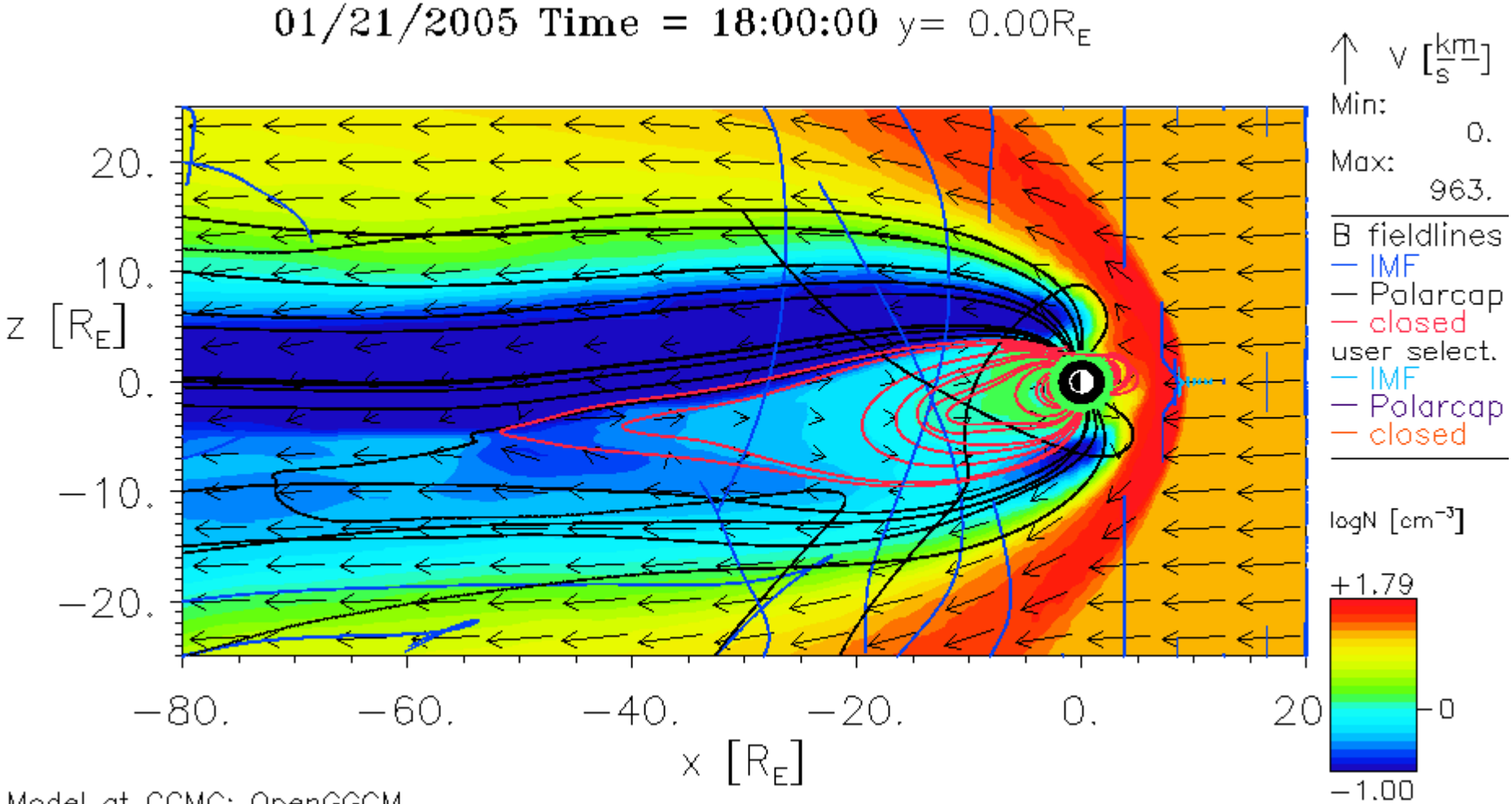
Jan 21, 2005

Click here to play movie (avi) file

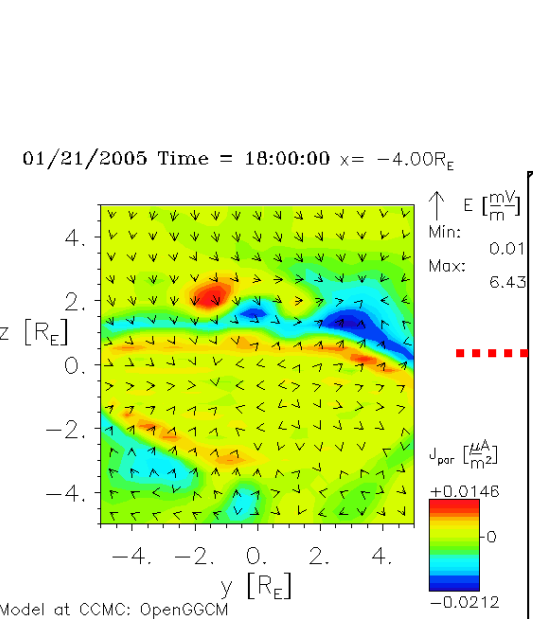


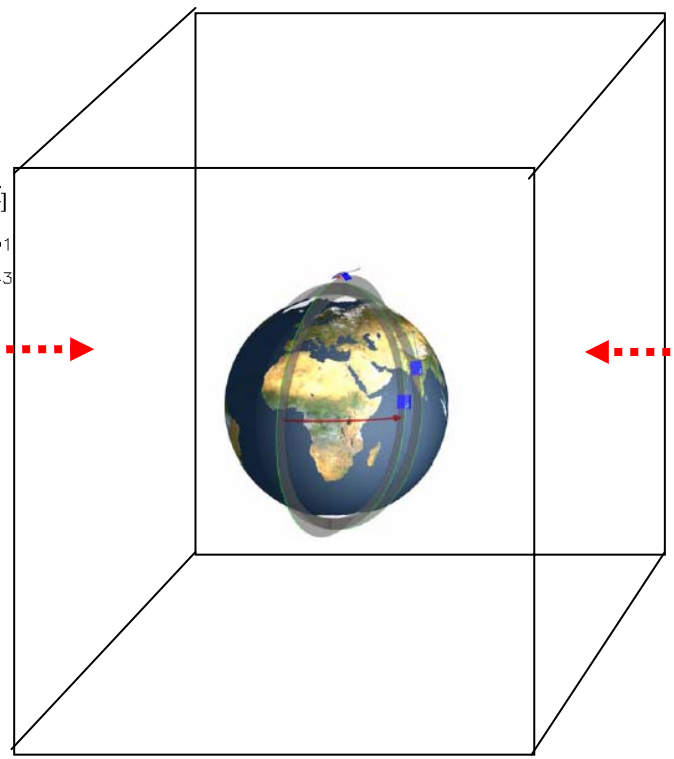
Calculation at CCMC, http://ccmc.gsfc.nasa.gov

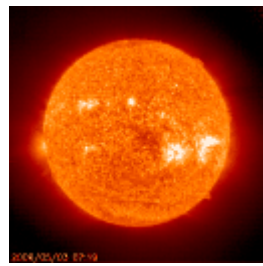

Ion Density [cm⁻³]
60
50
40
30
20
10
0
T [K]
800000
600000
400000
200000
0
Vx [km/s]
−600
−700
−800
−900
Vy [km/s]
150
100
50
0
−50
−100
Vz [km/s]
50
0
−50
Bx [nT]
30
20
10
0
−10
−20
−30
By [nT]
30
20
10
0
−10
−20
−30
Bz [nT]
30
20
10
0
−10
−20
−30
12:00
Jan.21
0:00
Jan.22
12:00
Jan.22
hours:minutes, Jan. 21, 2005 − Jan. 22, 2005

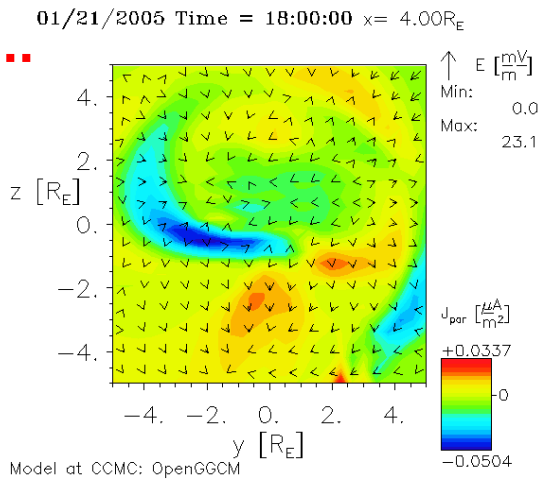

01/21/2005 Time = 18:00:00 y= 0.00R_E
V [km/s]
Min:
0.
Max:
963.
B fieldlines
IMF
Polarcap
closed
user select.
IMF
Polarcap
closed
logN [cm^-3]
+1.79
0
-1.00
20.
10.
0.
-10.
-20.
z [R_E]
-80.
-60.
-40.
-20.
0.
20
x [R_E]
Model at CCMC: OpenGGCM

Field-aligned Currents from Model



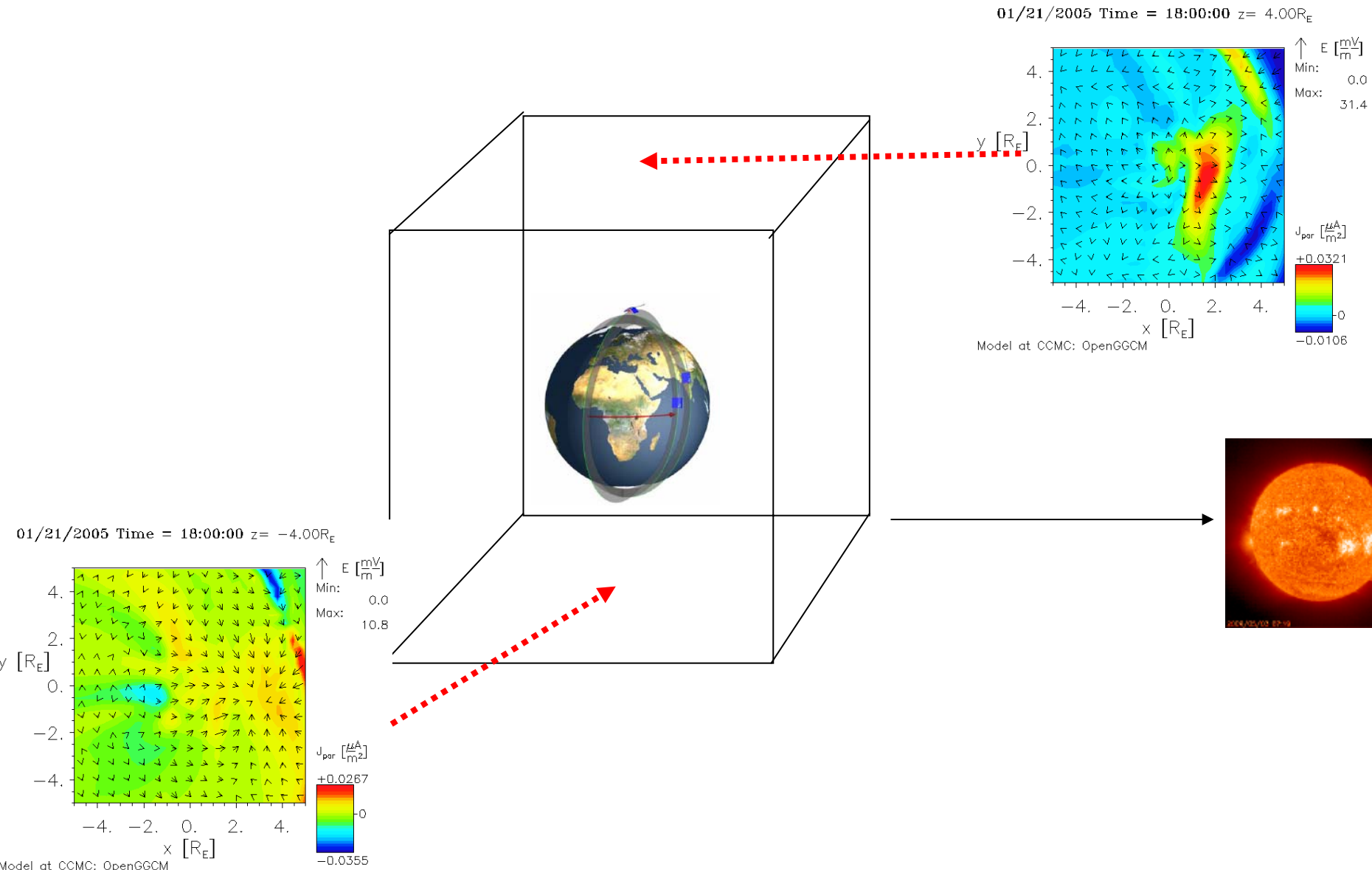




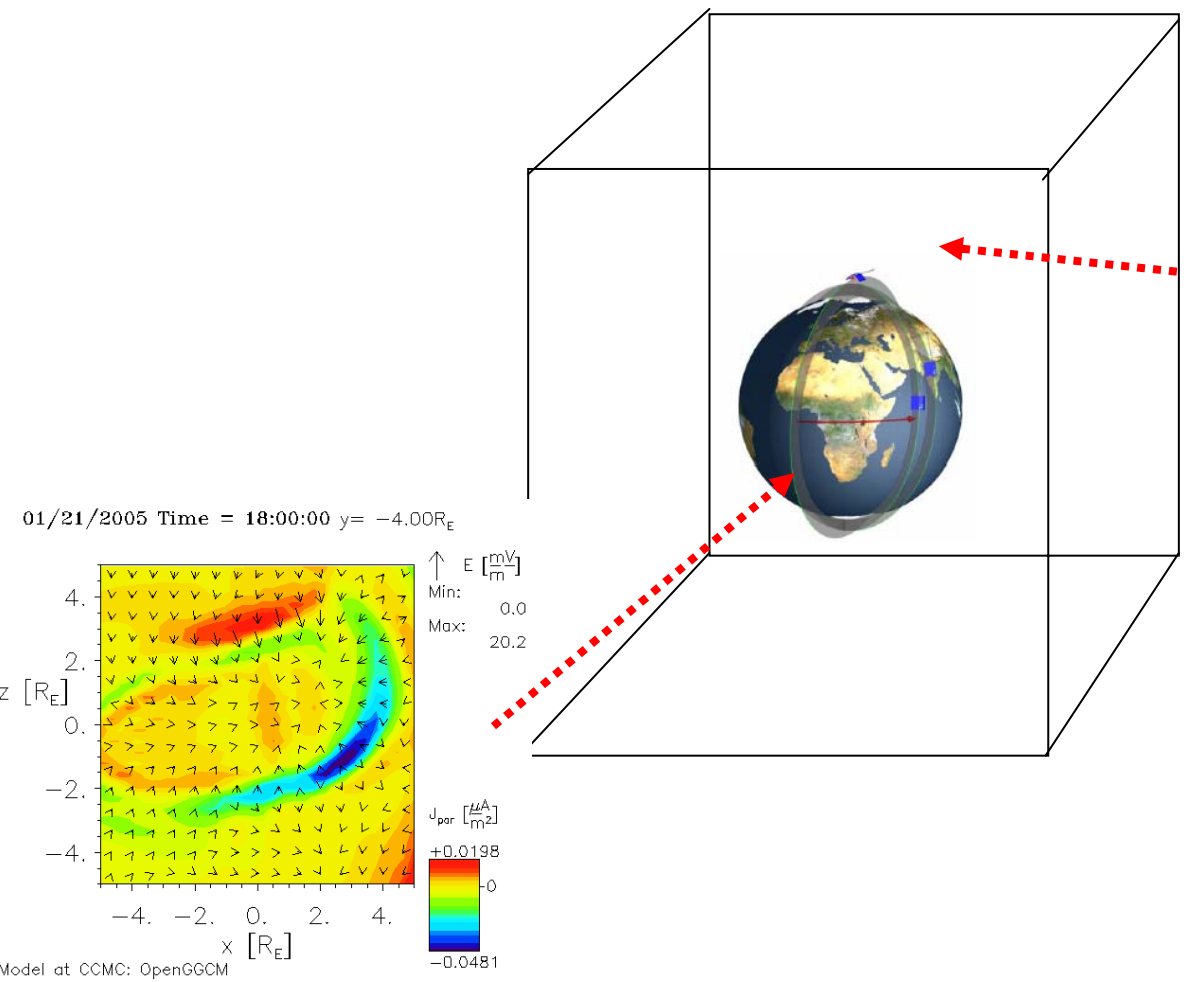


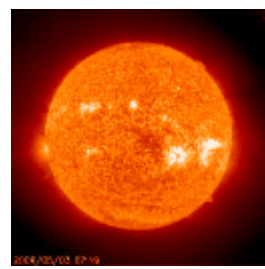
+/- $4R_E$

Field-aligned Currents from Model

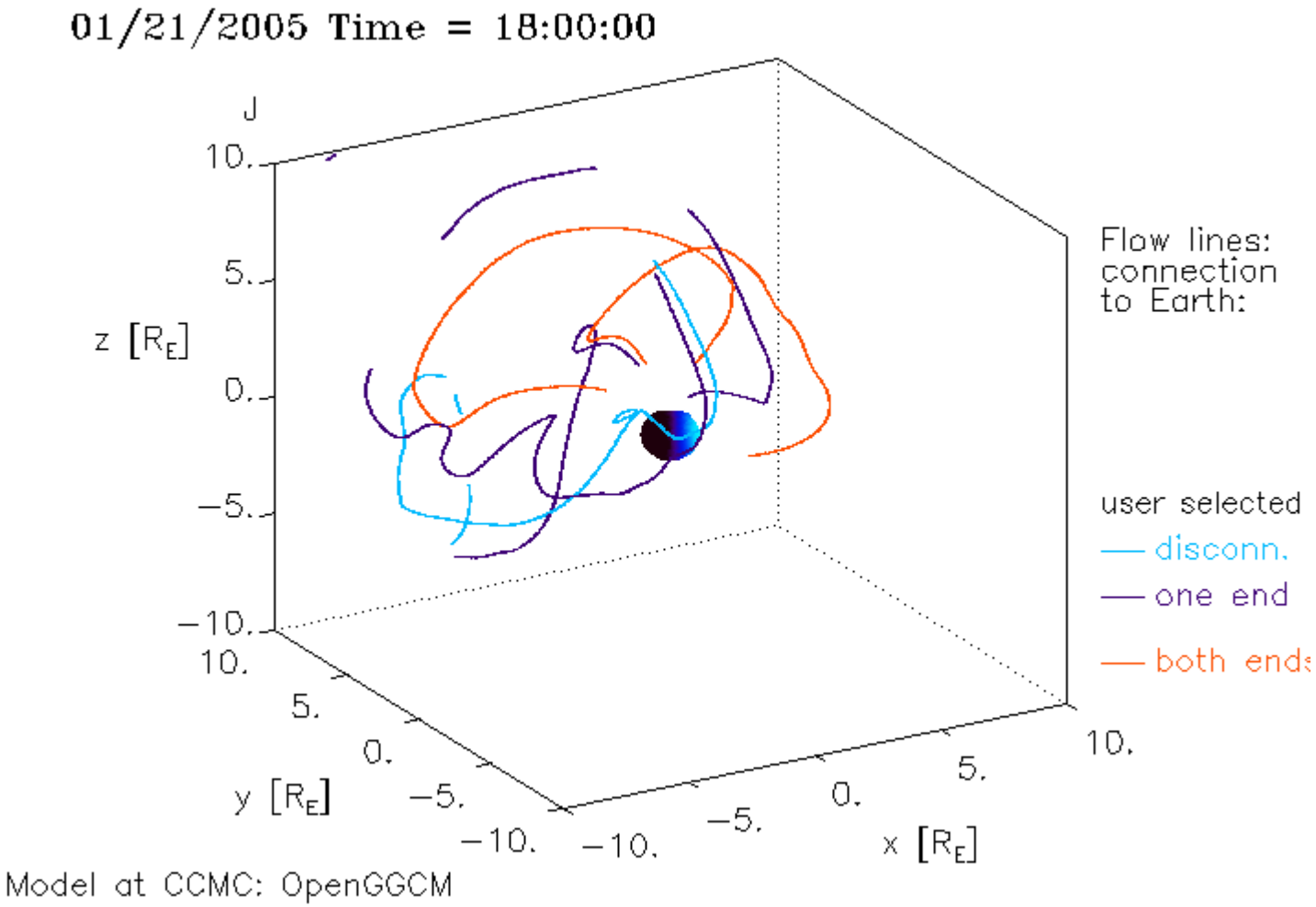


Field-aligned Currents from Model





Field-aligned Currents from Model



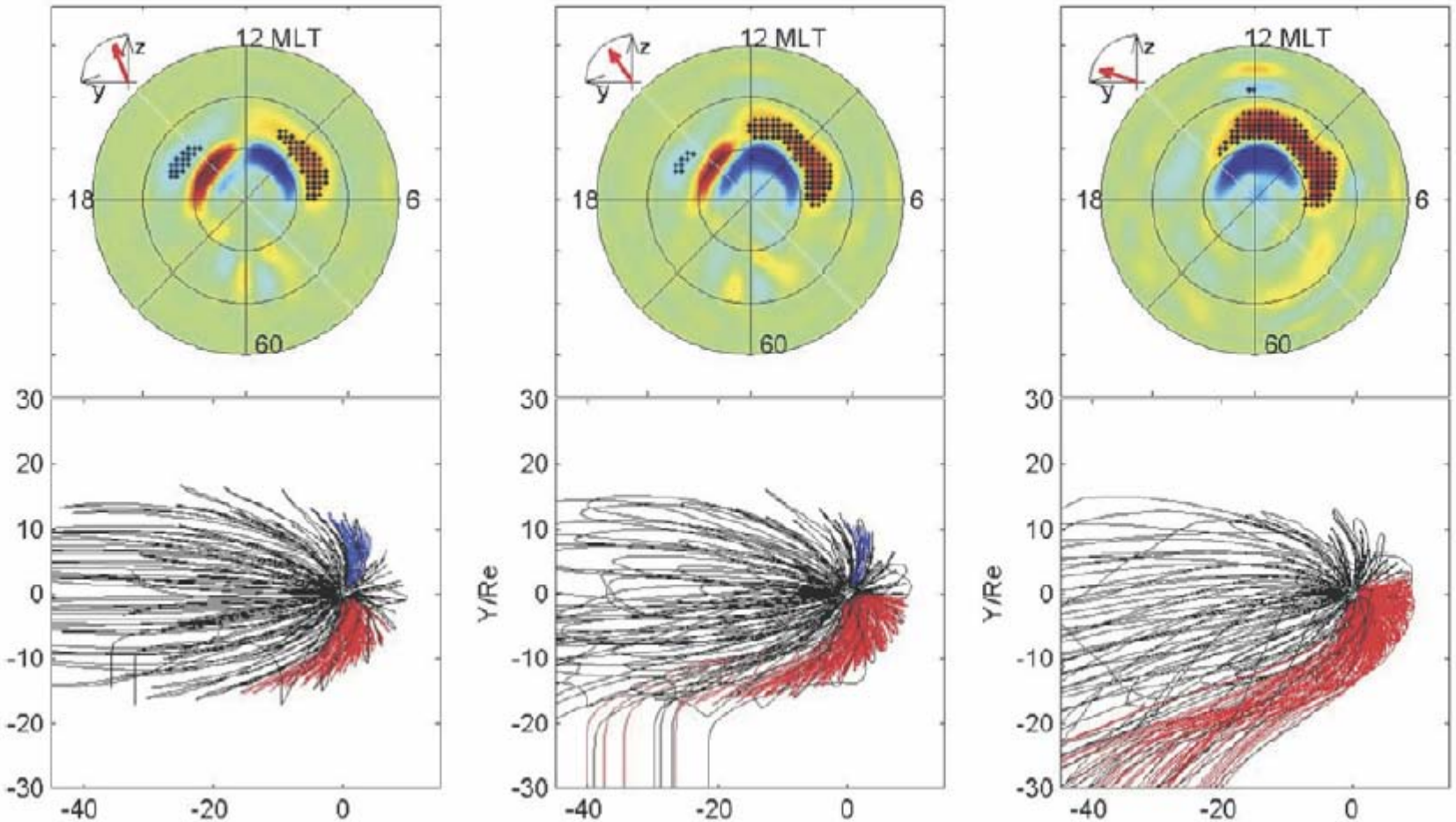
Much more complex than cartoons!

Limitations of Prior Investigations

- ***Single satellite -> need thin-sheet approximation, statistics***
- ***Orbit in fixed local time -> no global coverage***
- ***Accuracy of measurements***
- ***Accurate knowledge of zero-order geomagnetic field***

SWARM overcomes these issues simultaneously

Observation – Model Comparison



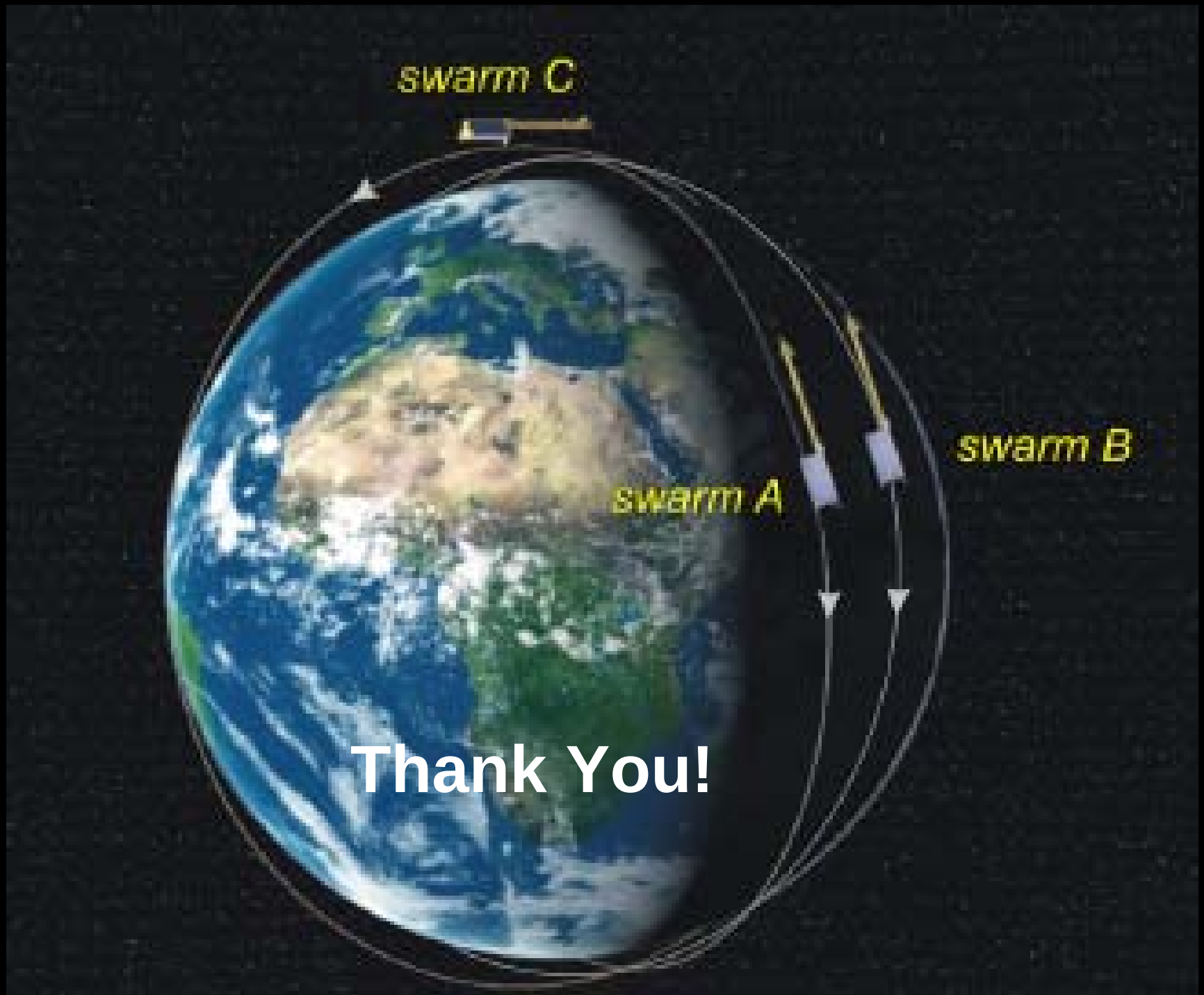
Vennerstrom et al.

Models available at CCMC – http://ccmc.gsfc.nasa.gov

Research would benefit greatly from
ready access to data and to data products (e.g., FAC patterns)

Final Thoughts

- ***Precise assessment of FAC structure (as well as ionospheric closure currents) remains outstanding science problem***
- ***Ready and easy data access essential for research success – data center***
- ***Synergy with modeling offers context, data analysis support, and assimilation opportunities***
- ***SWARM offers unique opportunity to magnetospheric research – expect exciting new research***



Thank You!