Does geospace exercise self control?

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MFLFM Study Group

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1 2 3

Systems Thinking

The *whole* is greater than the sum of the parts.

– Aristotle

?

… a *framework* based on the belief that the component parts of a system can best be understood in the context of relationships with each other and with other systems, rather than in isolation.

– Wikipedia

A system is what a system is *doing*. And we had better not say what a system is.

– Tom Mandel

Systems Thinking

The overall name of these interrelated structures is system. The motorcycle is a system … a system of concepts worked out in steel. There's no part in it, no shape in it that is not in someone's mind. I've noticed that people who have never worked with steel have trouble seeing this – that the motorcycle is primarily *a mental phenomenon*.

– Robert Pirsig

Zen and the Art of Motorcycle Maintenance

Systems Thinking

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Zen and the Art of Motorcycle Maintenance

Systems Thinking

The overall name of these interrelated structures is system. The magnetosphere is a system … a system of concepts worked out in plasma. There's no part in it, no shape in it that is not in someone's mind. I've noticed that people who have never worked with plasmas have trouble seeing this – that the magnetosphere is primarily *a mental phenomenon*.

– Motorcycle-Magnetosphere Equivalency

Zen and the Art of Magnetosphere Maintenance

Systems Thinking

- holistic → integration, synthesis
- framework → relational
- doing → behavioral
- mental → conceptual

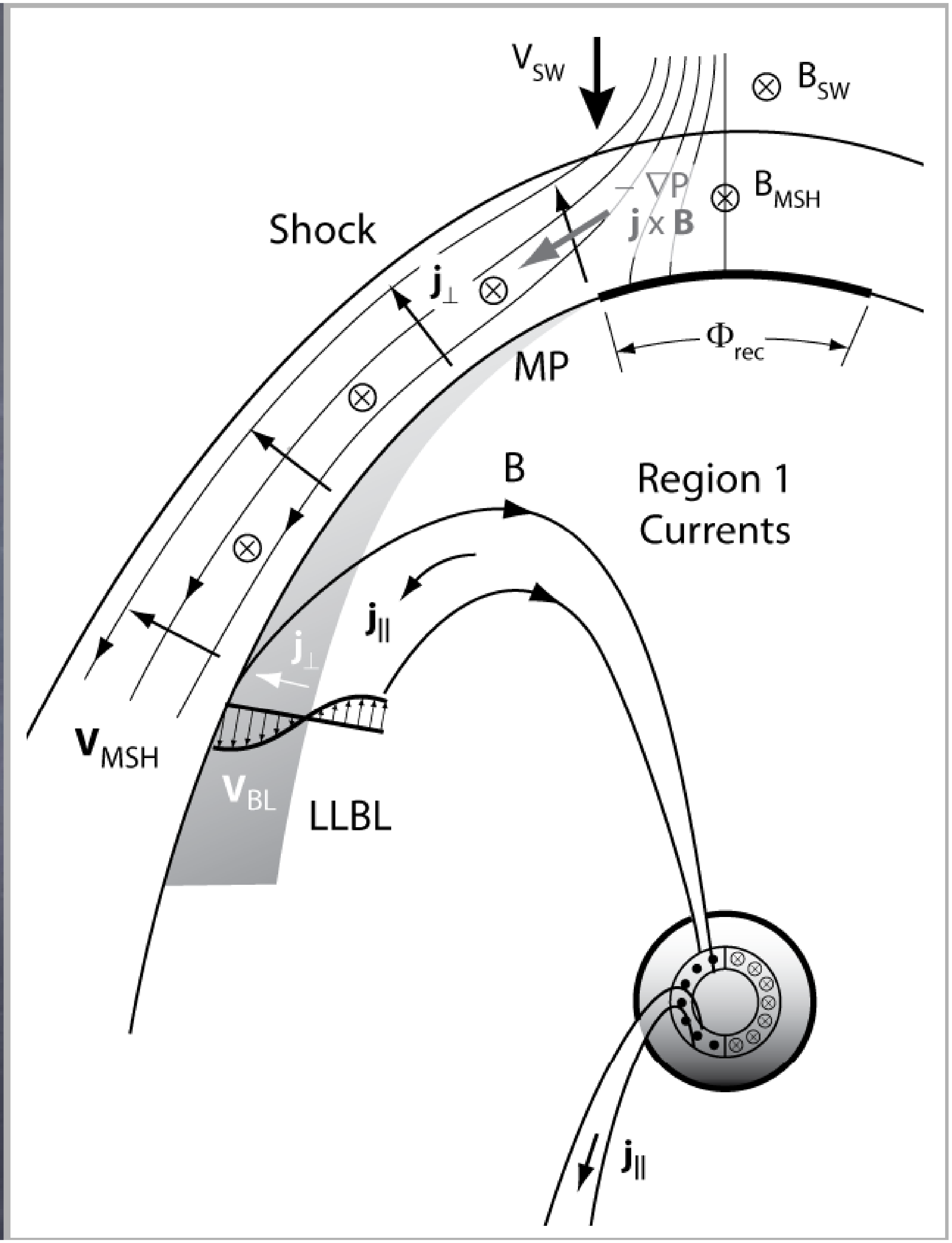
Geospace System

|||

Coupled SW, Magnetosphere, Ionosphere, Thermosphere

<u>Limits</u>

- **M_A, β >> 1 (HD)**
  $-\nabla P$ dominant
- **M_A, $\beta \gtrsim 1$ (MHD)**
  $j \times B$ dominant



$$j_{\parallel} = -B\int_s^n \nabla\cdot\vec{\mathbf{j}}_{\perp}\,\frac{ds}{B}$$

LLBL

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LLBL → MAGNETOSHEATH

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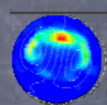
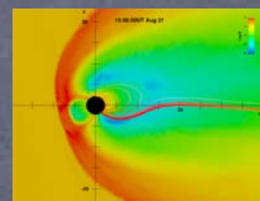
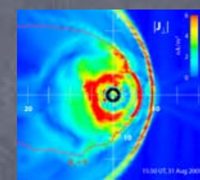
MAGNETOSPHERE







$$j_{\parallel} = -\nabla\cdot\vec{\mathbf{J}}_{\mathrm{P}}$$

MAGNETOSHEATH

$$\vec{\mathbf{J}}_{\mathrm{P}} = \nabla\cdot\overleftrightarrow{\mathbf{\Sigma}}\cdot\vec{\mathbf{E}}_{\mathrm{PC}}$$

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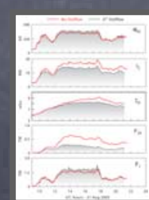
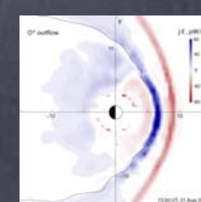
IONOSPHERE



MAGNETOPAUSE



$$\vec{\mathbf{E}}_{\mathrm{PC}} \rightarrow \Phi_{\mathrm{PC}}$$

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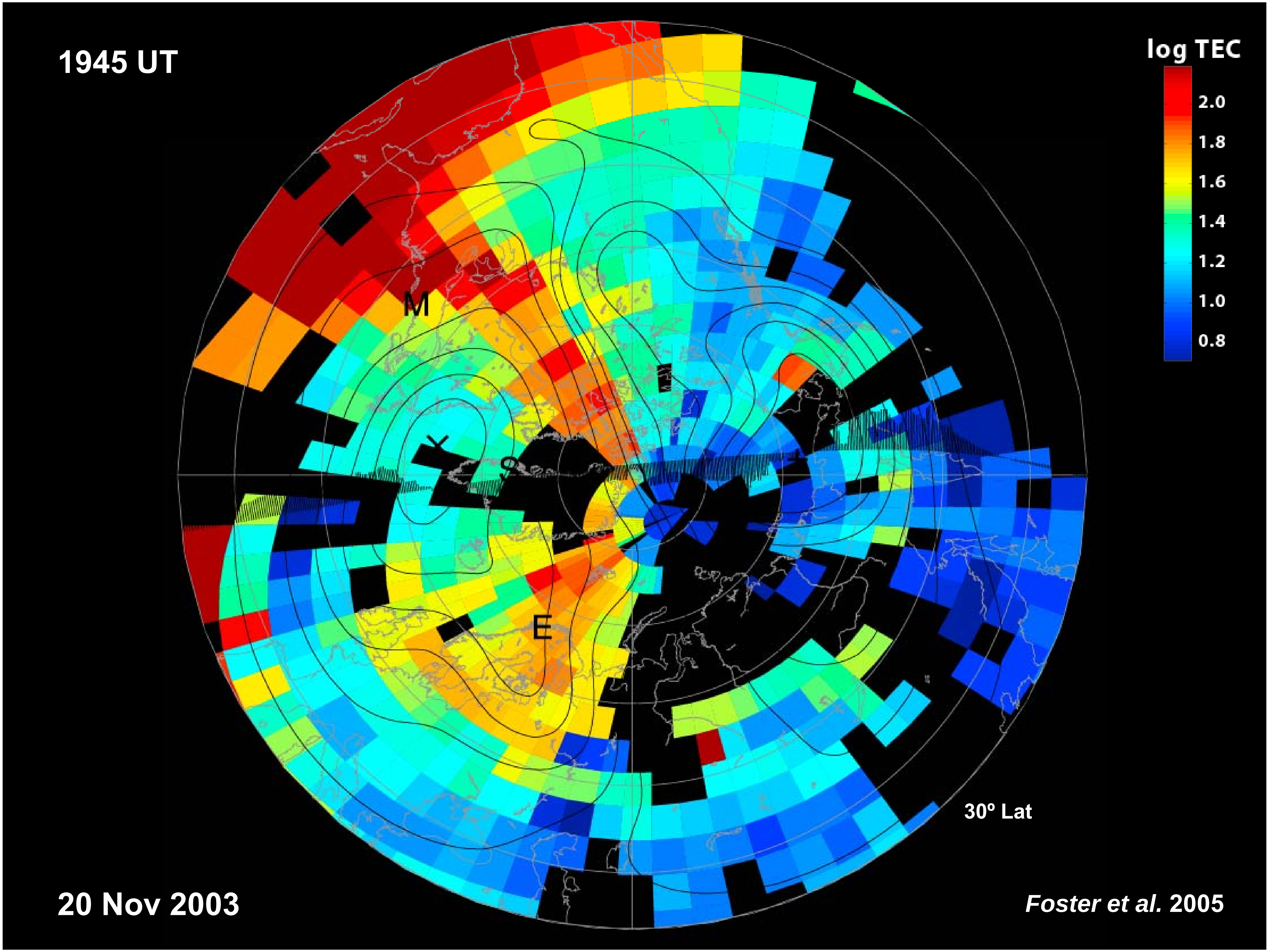
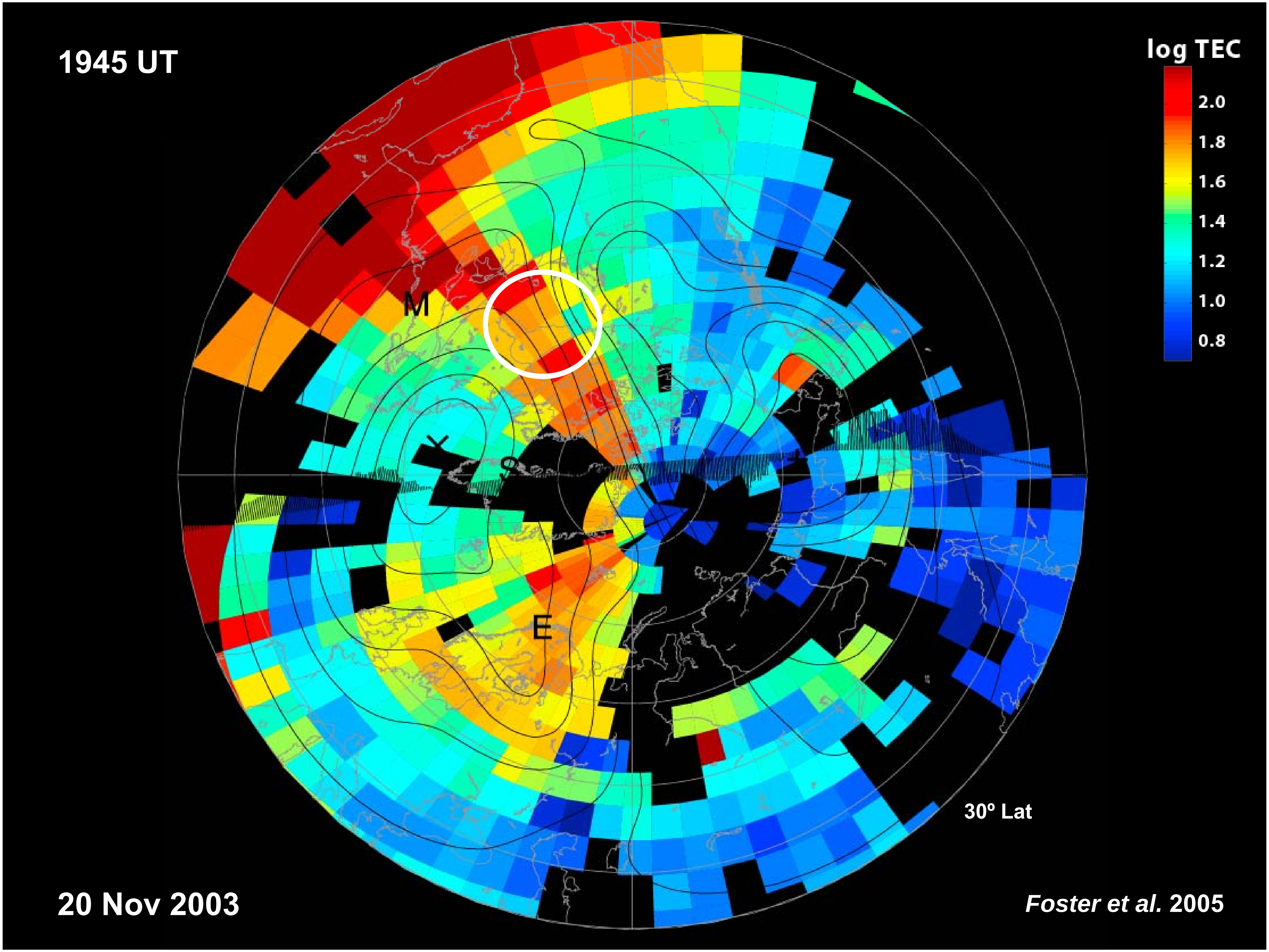

1945 UT
log TEC
2.0
1.8
1.6
1.4
1.2
1.0
0.8
M
E
30º Lat
20 Nov 2003
Foster et al. 2005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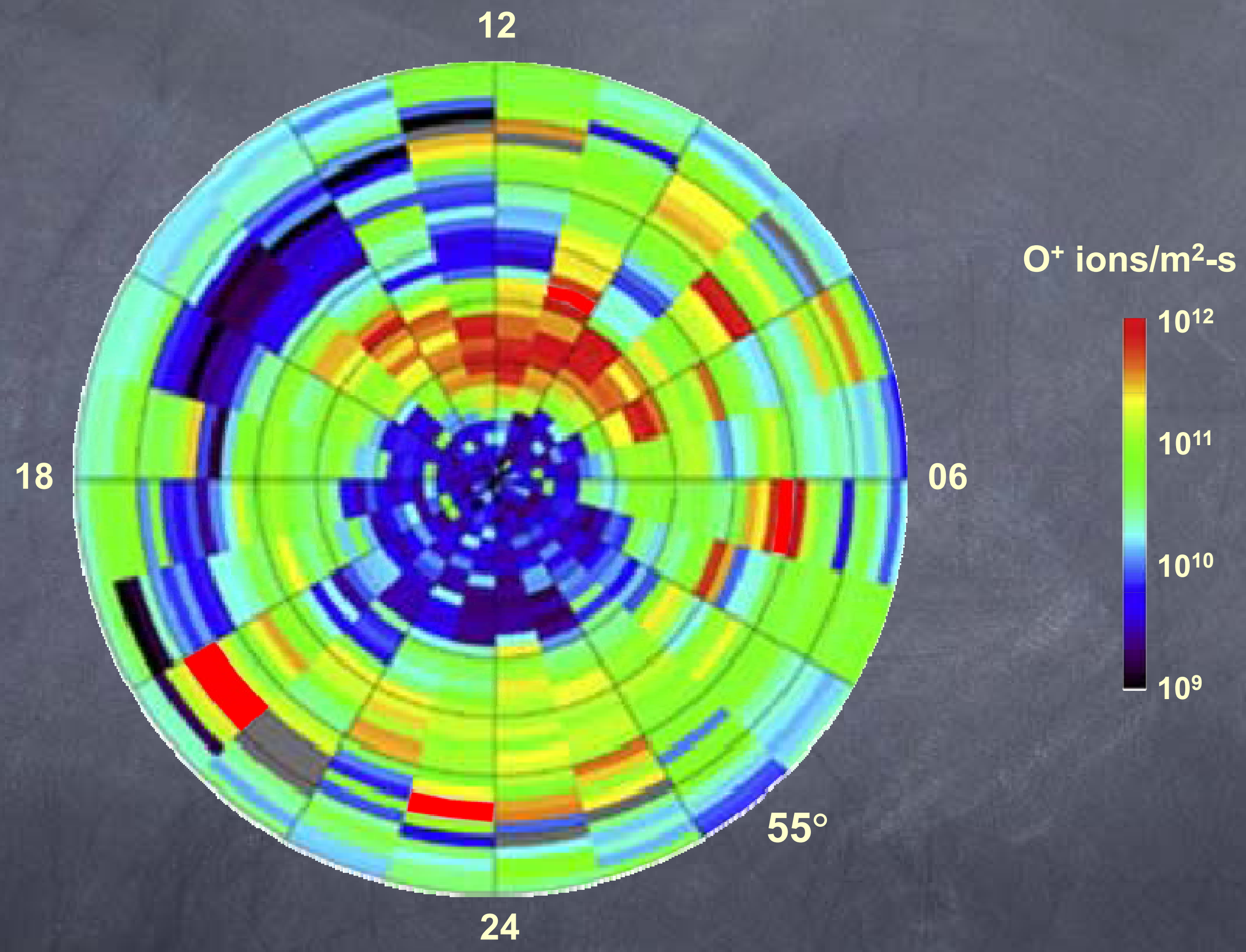
O^+ Outflow Flux

(15 eV – 33 keV)

Southern Summer 1997-98



Polar / 7600 km

Lennartsson et al. 2004

Outflow Mechanics

guiding center equations $(\varepsilon \square v_{\perp}/\omega_c \ell \square 1/\omega_c \tau \square\ 1)$

ambipolar field

centrifugal force

collisional drag

$$\frac{dv_{\square}}{dt} = \frac{eE_{\square}}{m} - \mu \nabla_{\square} B + \vec{v}_E \cdot D_t \vec{b} - \vec{g} \cdot \vec{b} - \nu_c v_{\square}$$

(ponderomotive)

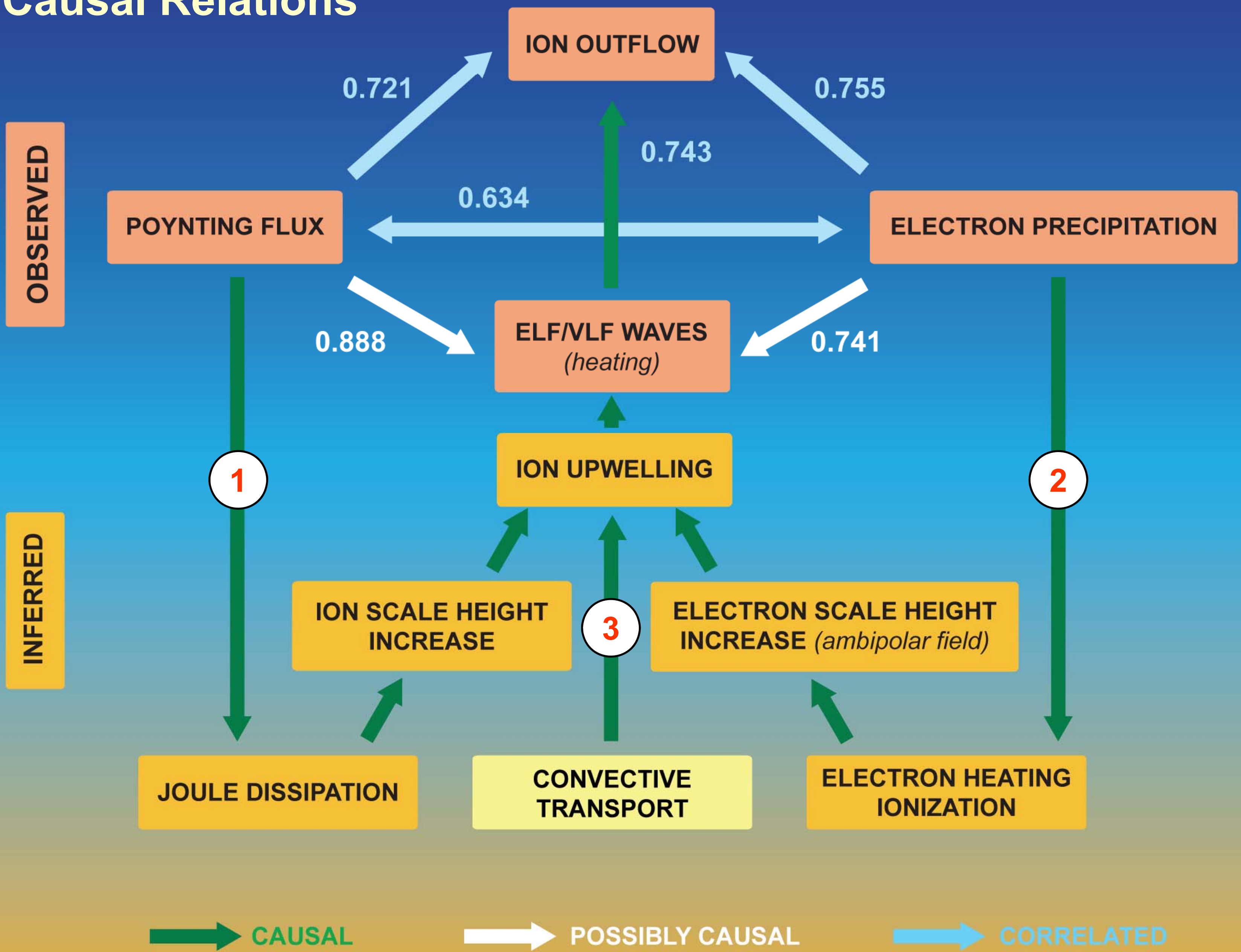
mirror force

gravity

$$D_t \mu = 0 \quad \text{where} \quad \mu = \frac{v_{\perp}^2}{2B}$$

$$D_t \equiv \frac{\partial}{\partial t} + (v_{\square} \vec{b} + \vec{v}_E) \cdot \nabla, \quad \vec{v}_E = \vec{E} \times \vec{b} / B$$

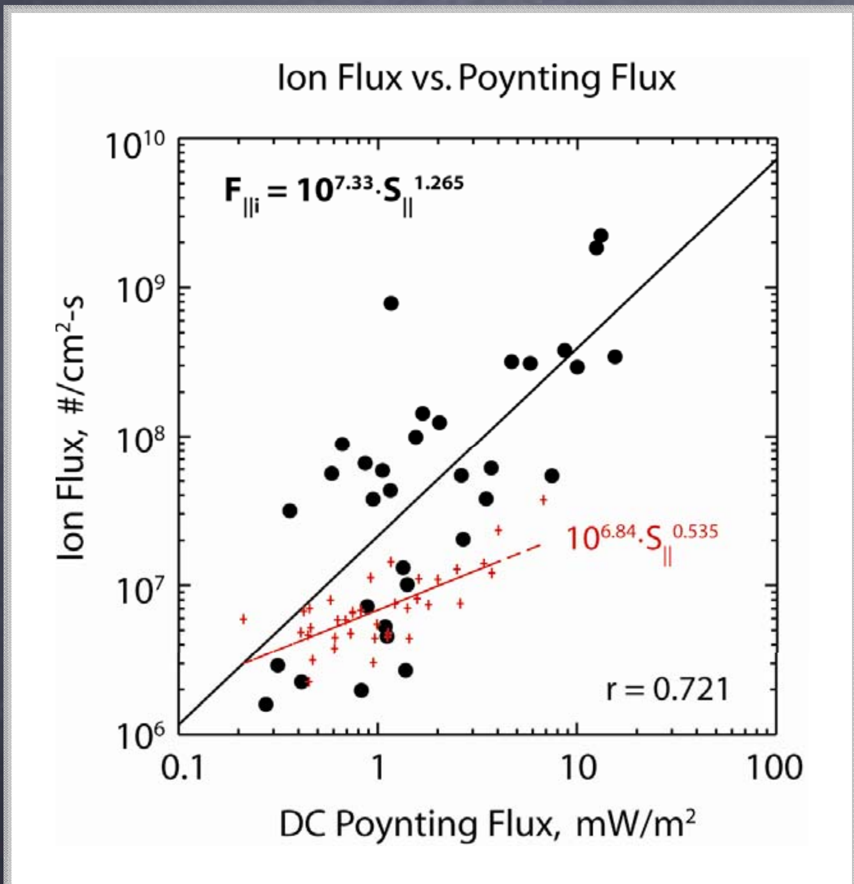
Causal Relations

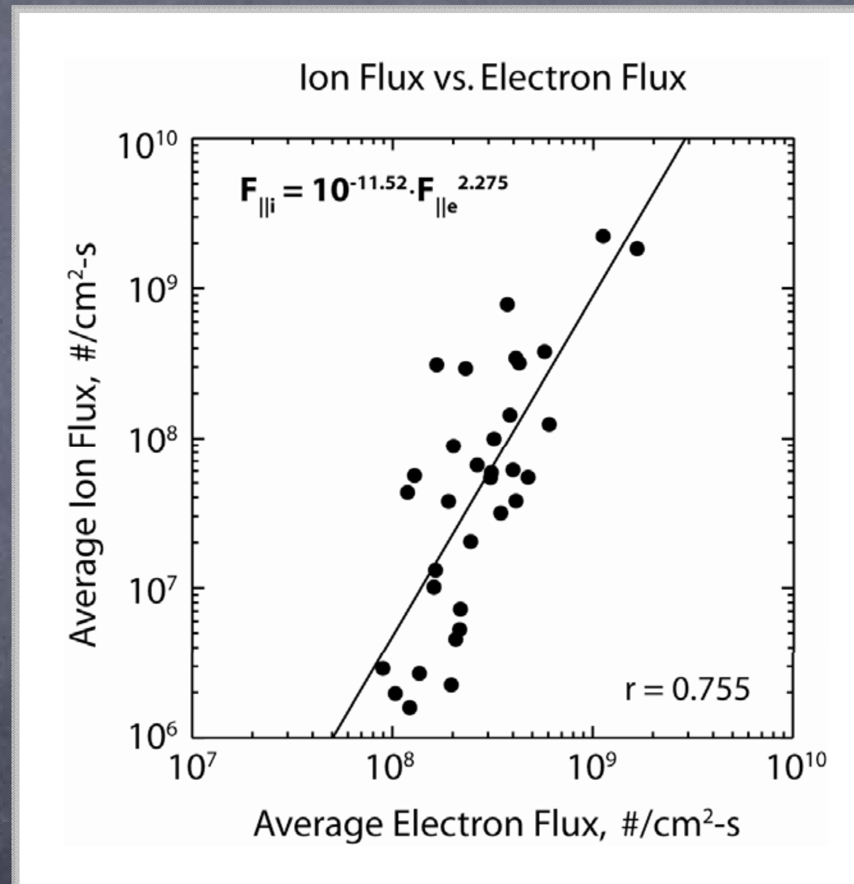


Strangeway et al. 2005

Empirical Model for Ionospheric Outflow

FAST data near 4000-km altitude in the low-altitude cusp

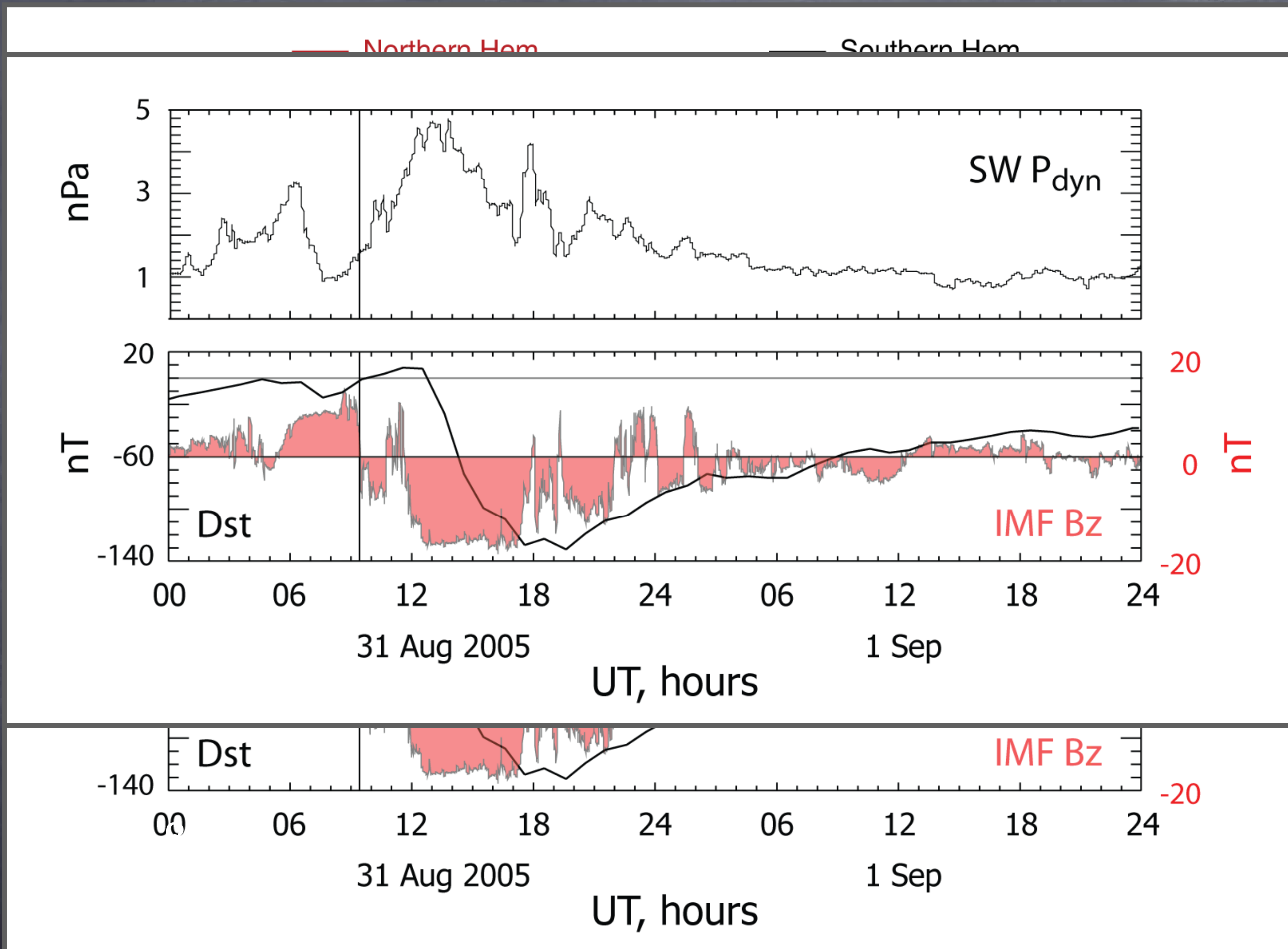




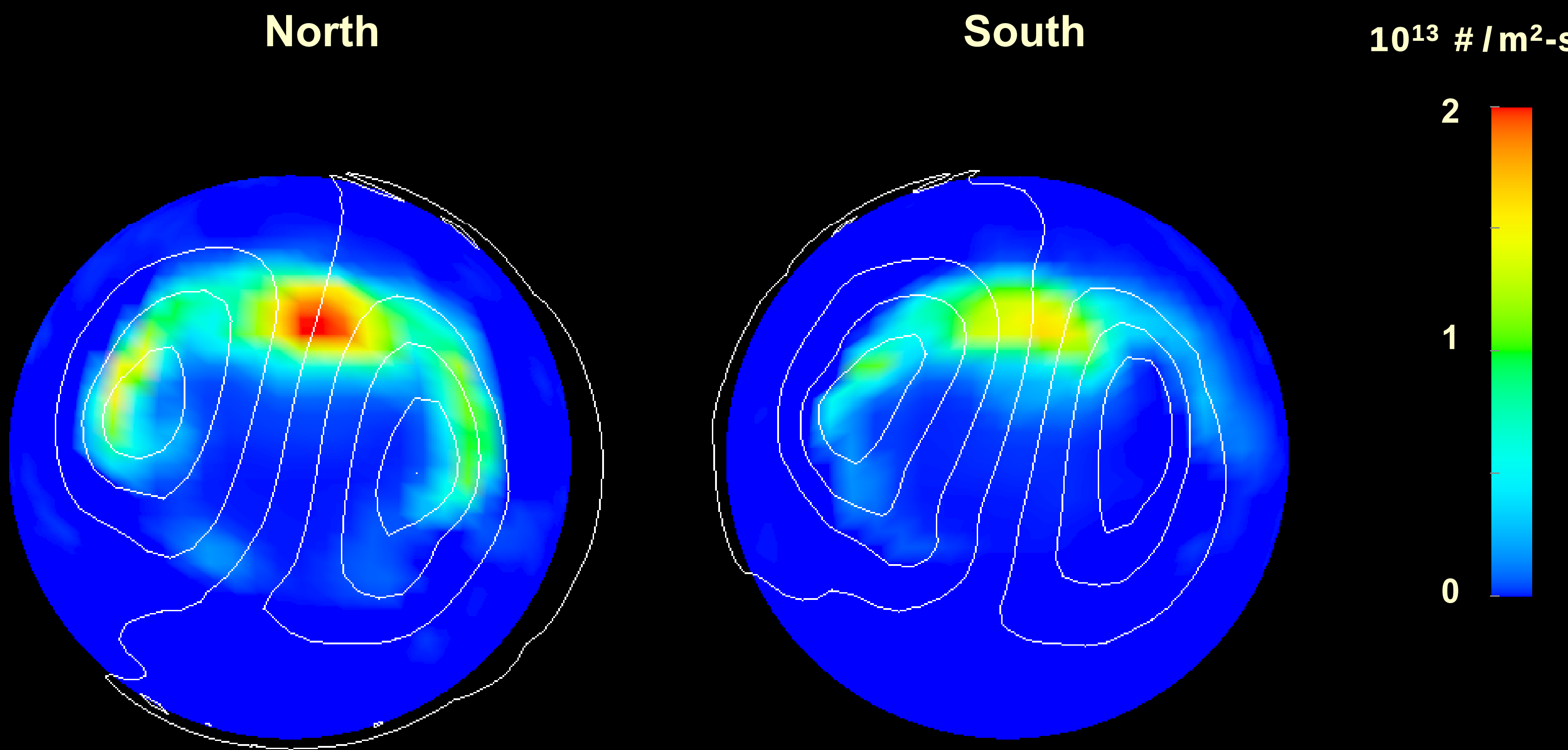
Strangeway et al. 05; *Zheng et al.* 05

Storm-Driven Outflow

Storm Simulation



O^+ Outflow Number Flux

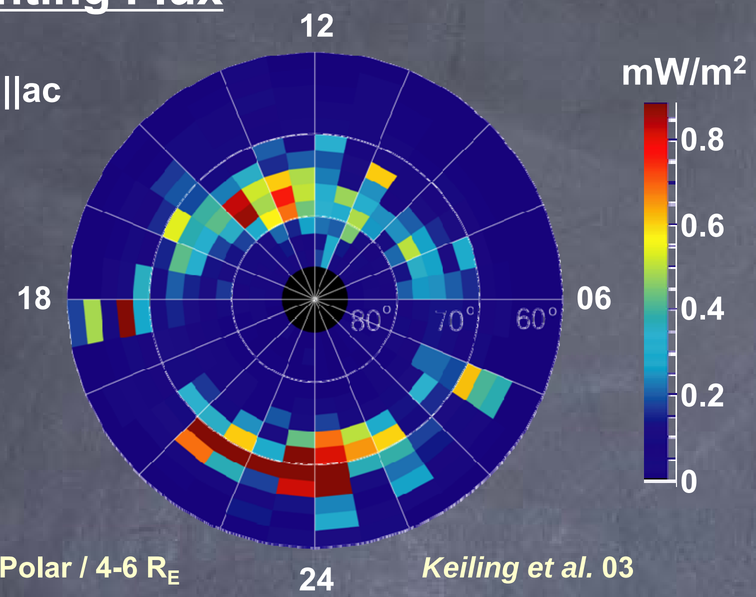


1.06×10^{26} # / s   Fluence 6.41×10^{25} # / s

15:50 UT, 31 Aug 2005

AC Poynting Flux

$S_{||ac}$



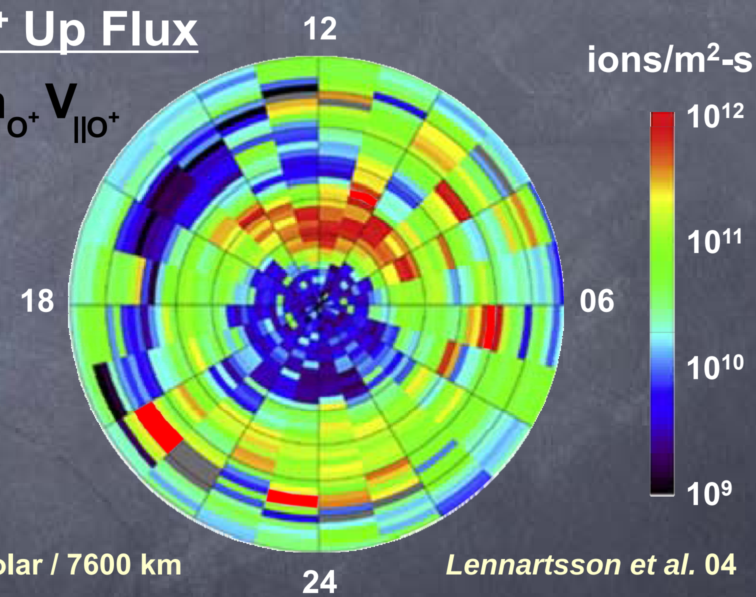
Polar / 4-6 R_E *Keiling et al. 03*

EM Power In

O^+ Flux Out

O^+ Up Flux

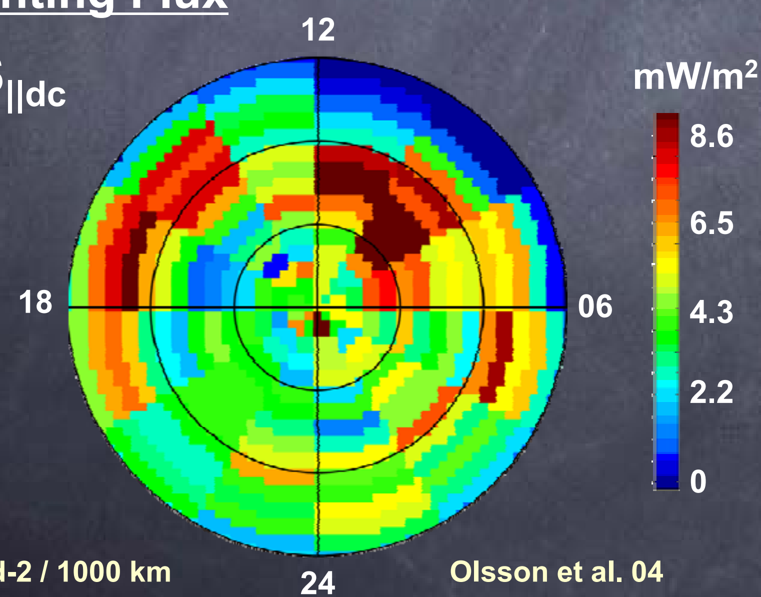
$n_{O^+} V_{||O^+}$



Polar / 7600 km *Lennartsson et al. 04*

DC Poynting Flux

$S_{||dc}$



Astrid-2 / 1000 km Olsson et al. 04

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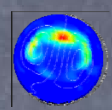

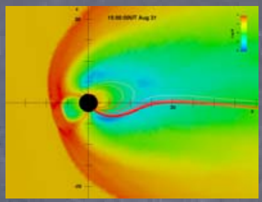

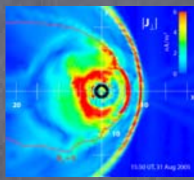

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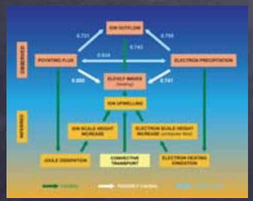
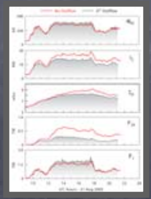
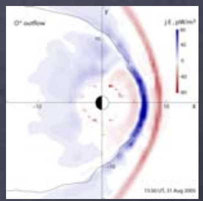


IONOSPHERE



MAGNETOPAUSE



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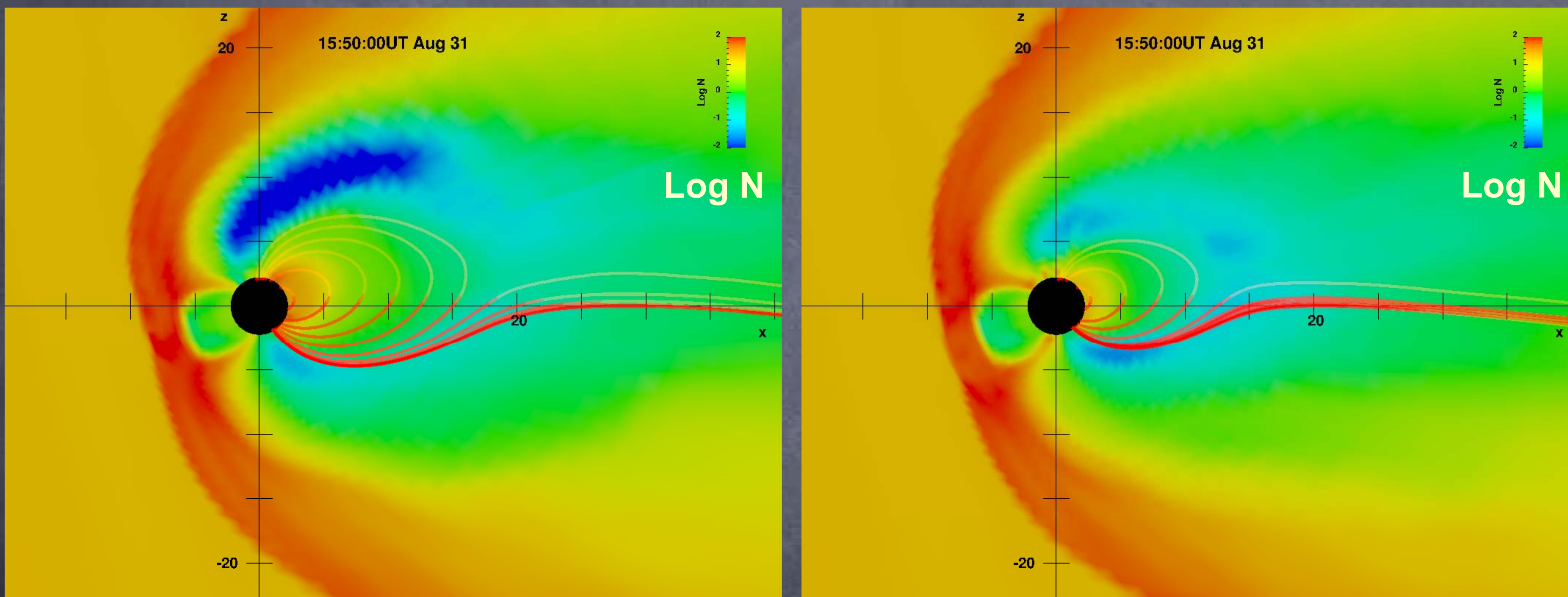
Storm-Driven Outflow

No outflow

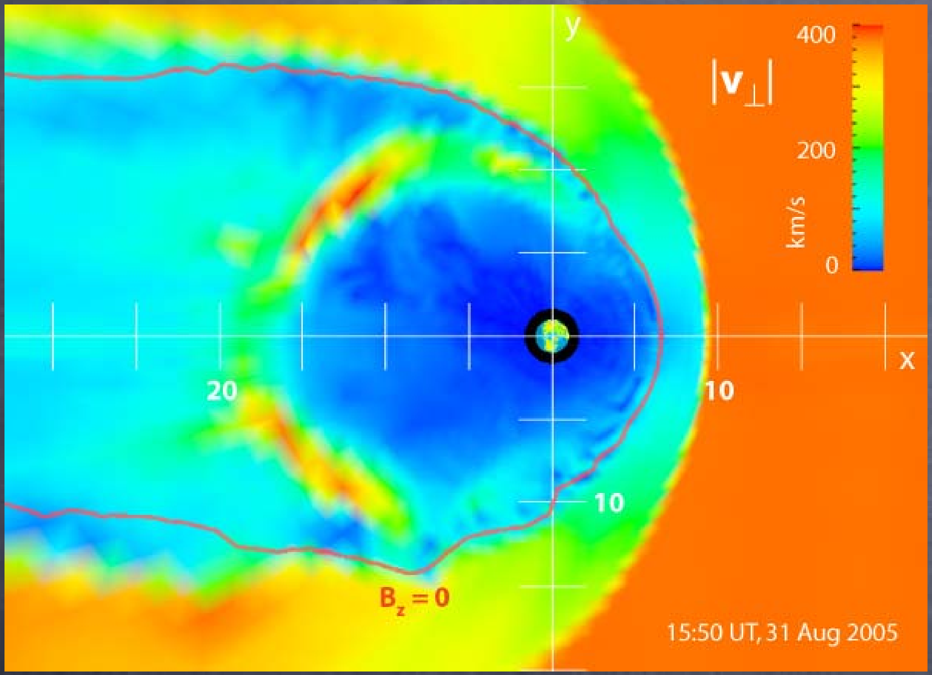
O$^+$ outflow



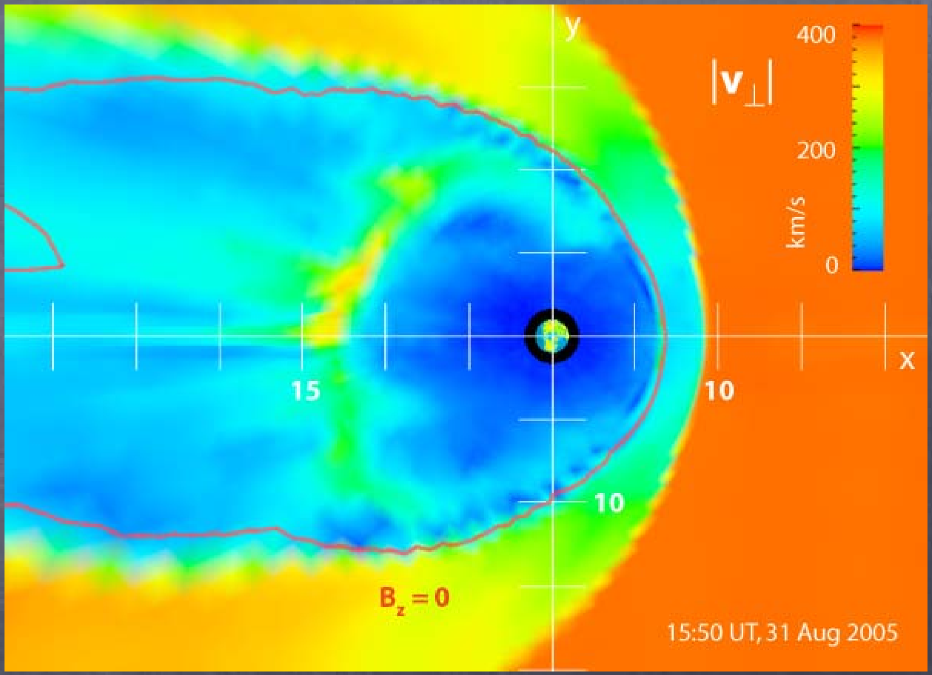
XZ plane, GSE coordinates

Convection

No outflow

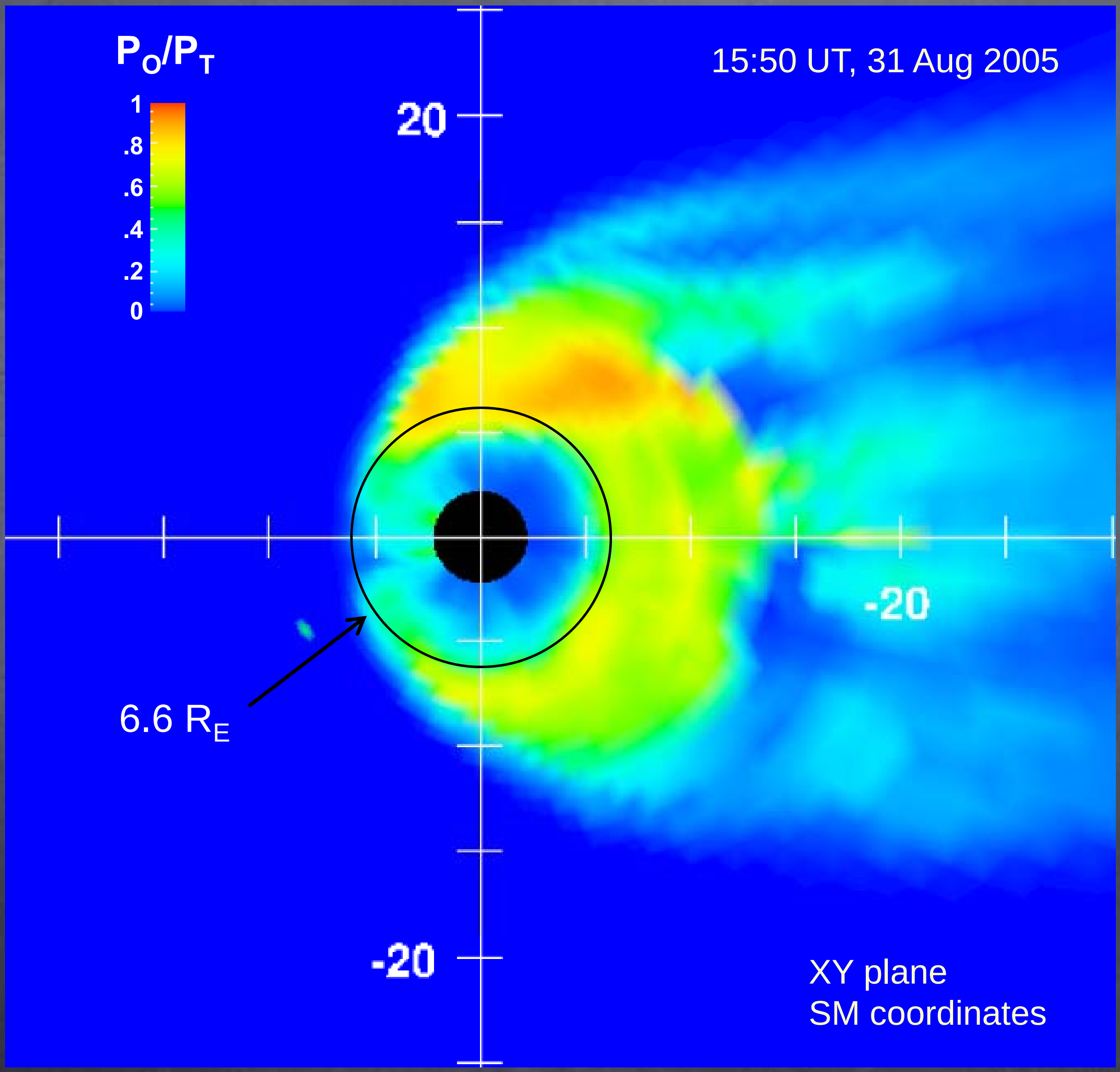


O+ outflow



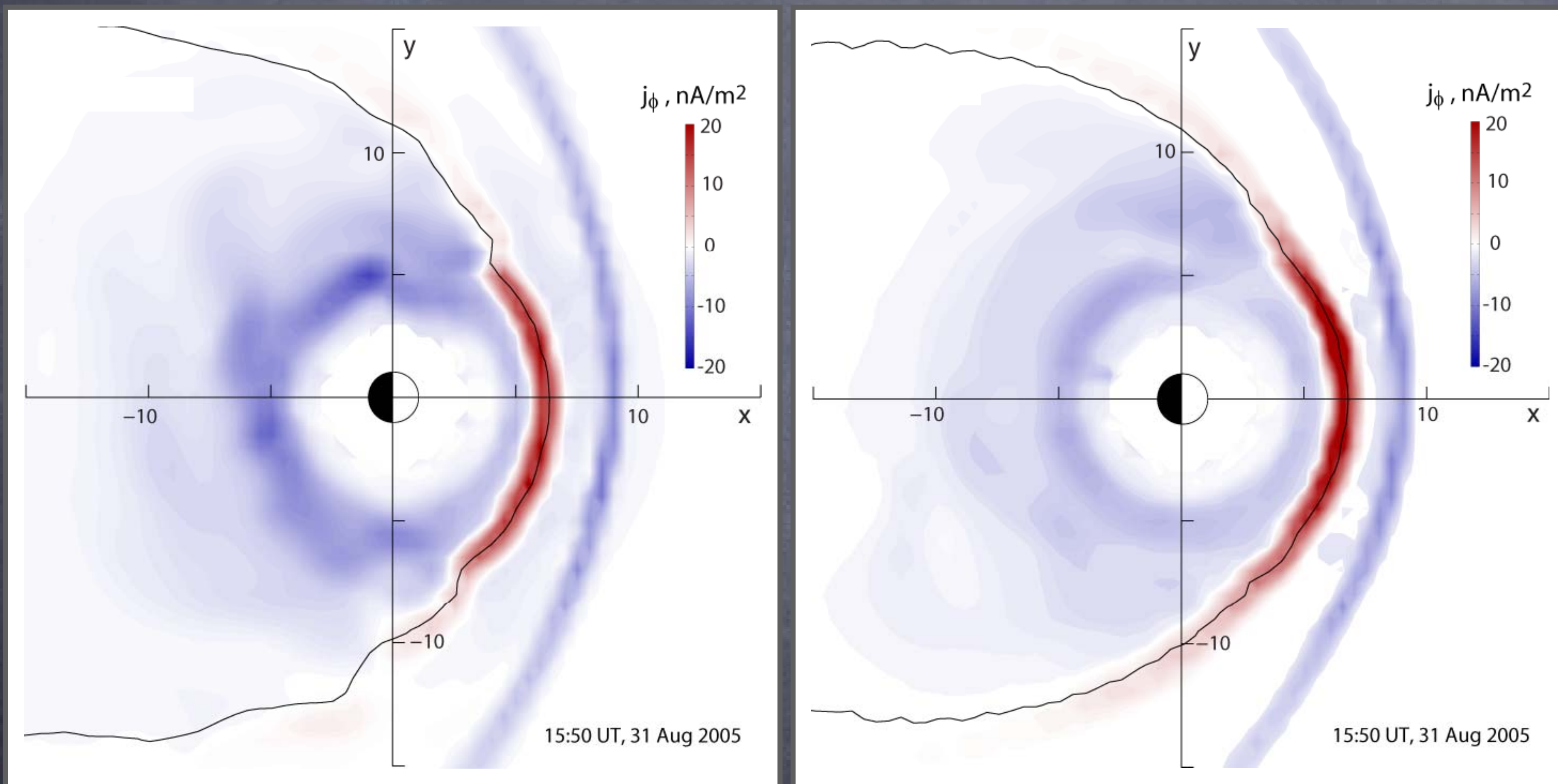
equatorial plane, SM coordinates

Fractional O^+ Pressure



Ring Current

No outflow **O^+ outflow**



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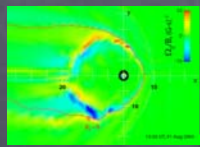

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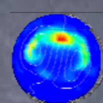

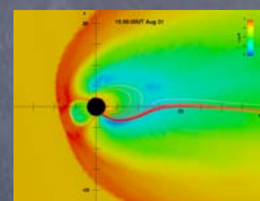

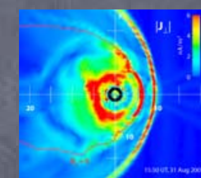

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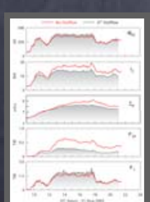
IONOSPHERE

MAGNETOPAUSE



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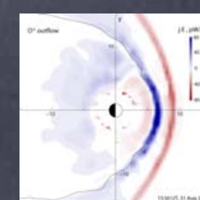
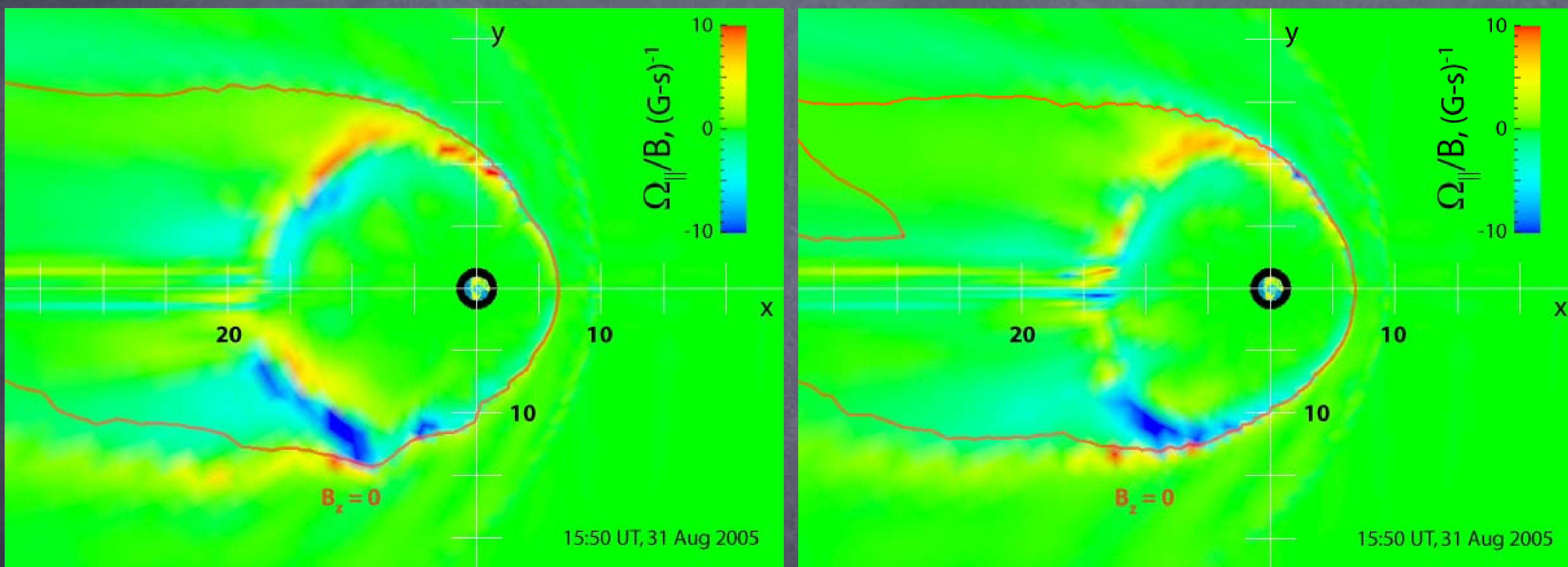


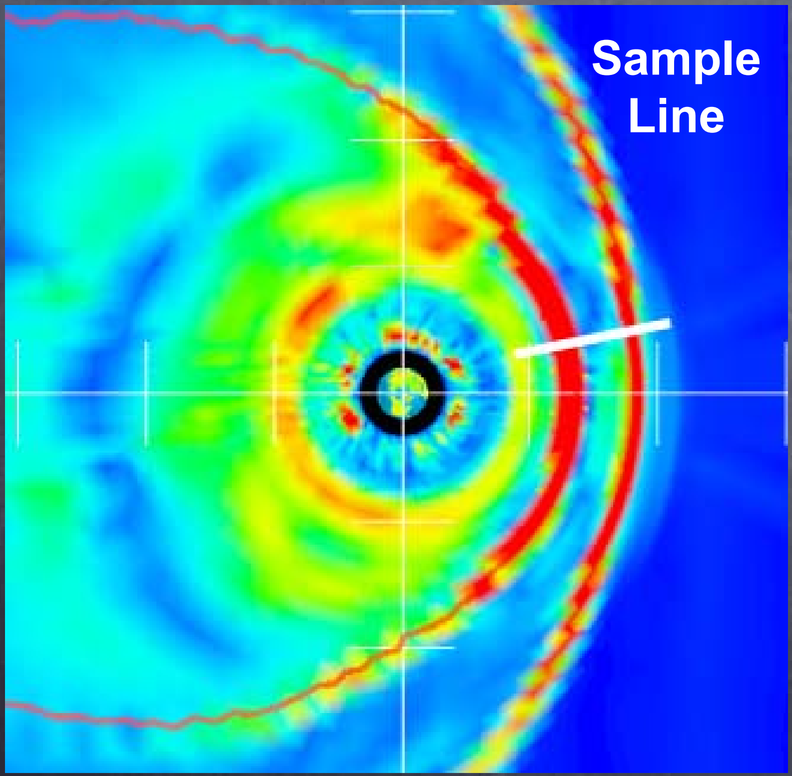
Vorticity ($\Omega_{||}/B$)

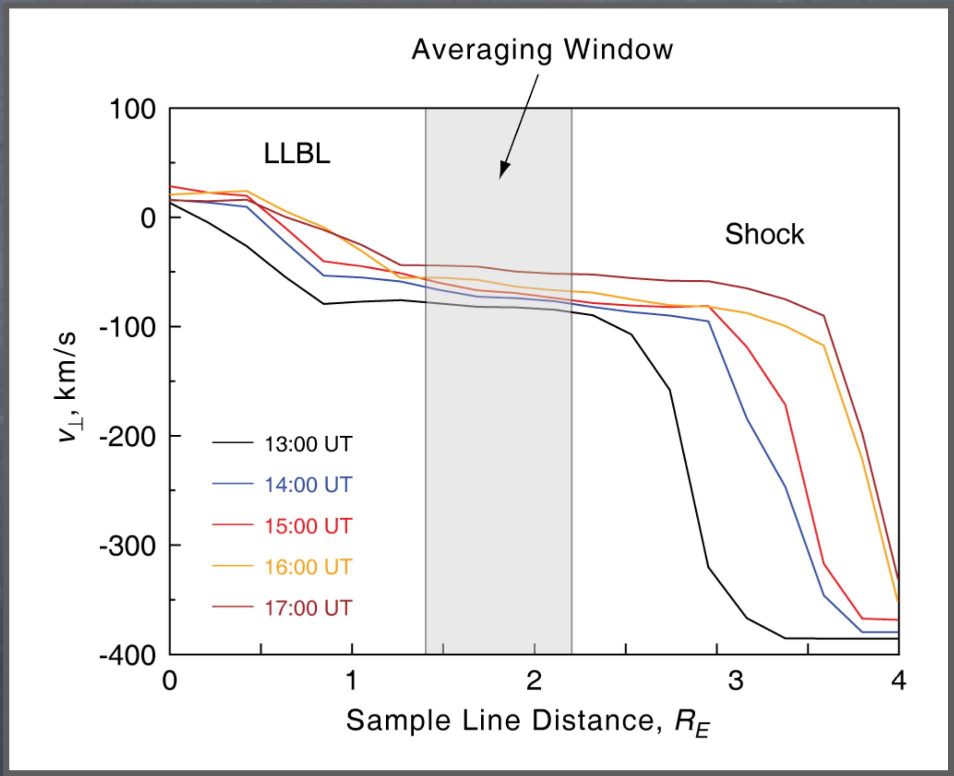
No outflow $\qquad$ O^+ outflow



equatorial plane, SM coordinates

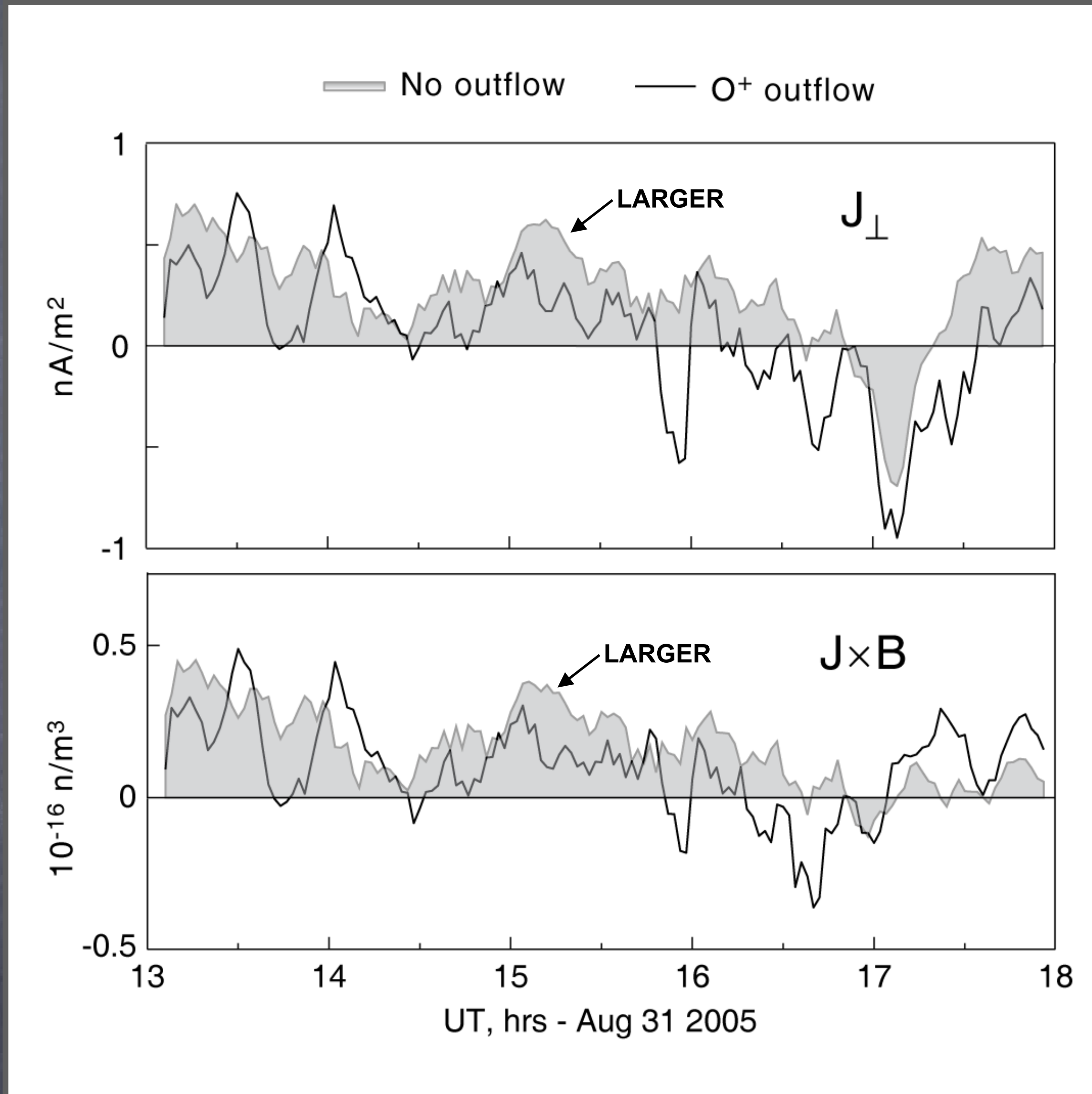
How do $J_\perp$ and $J \times B$ in the magnetosheath change when outflow is added?

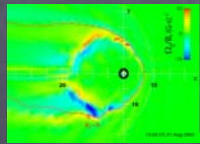




Magnetosheath $J_\perp$, $J \times B$ *decrease* with outflow

- flow diversion away from stagnation region is diminished
- more magnetic flux is reconnected
- reconn. potential, CPCP are larger





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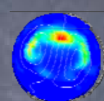

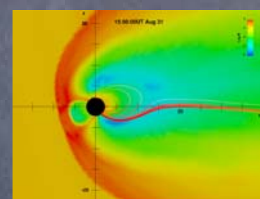

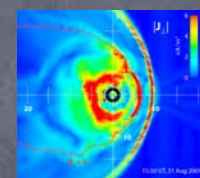

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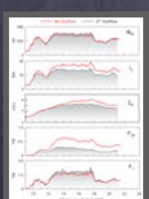
IONOSPHERE

MAGNETOPAUSE



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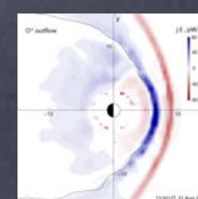
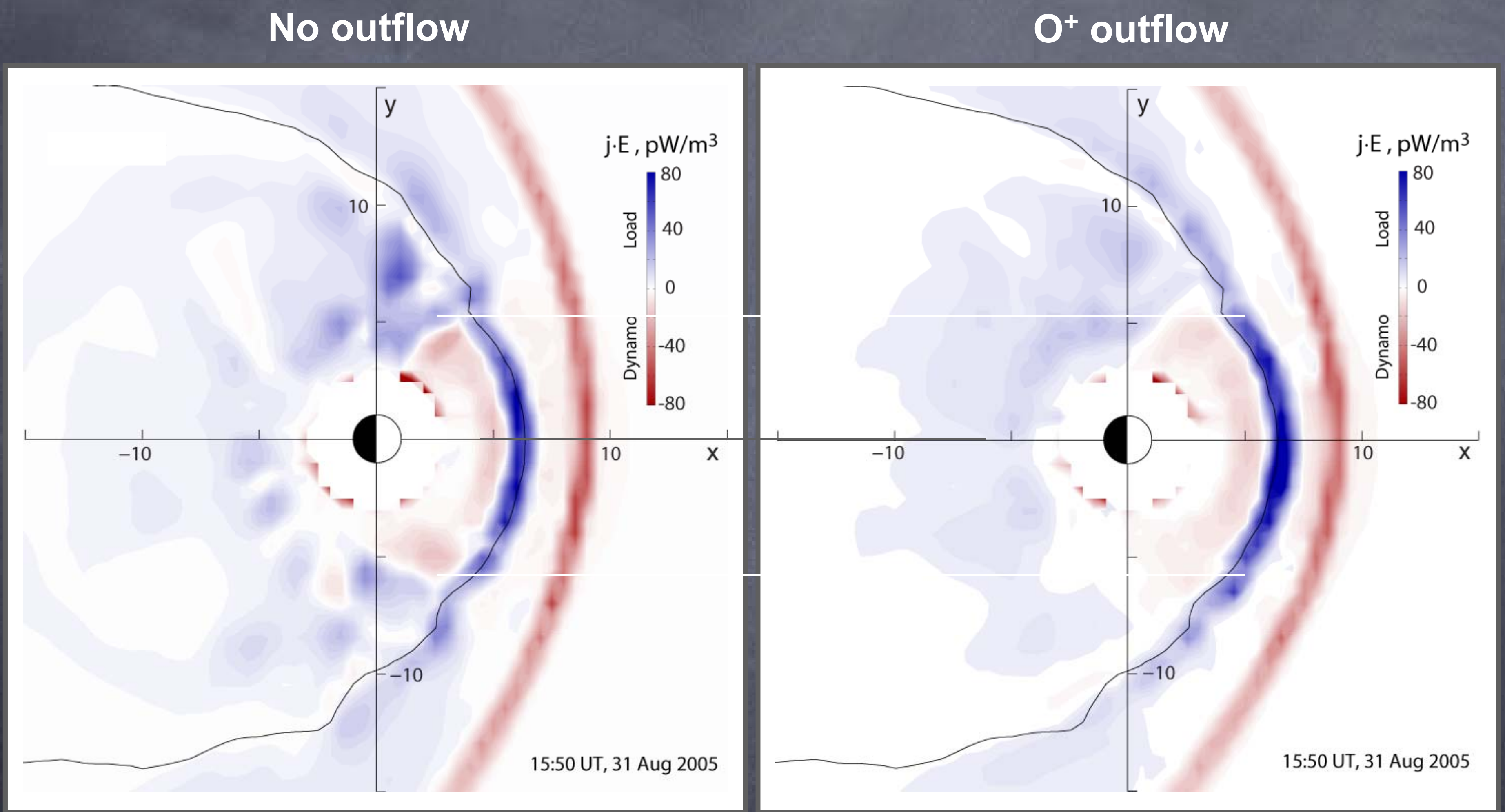


J·E



equatorial plane, SM coordinates

Dayside Reconnection Line

<u>LFM simulation</u>

V = 400 km/s

n = 5 cm^{-3}

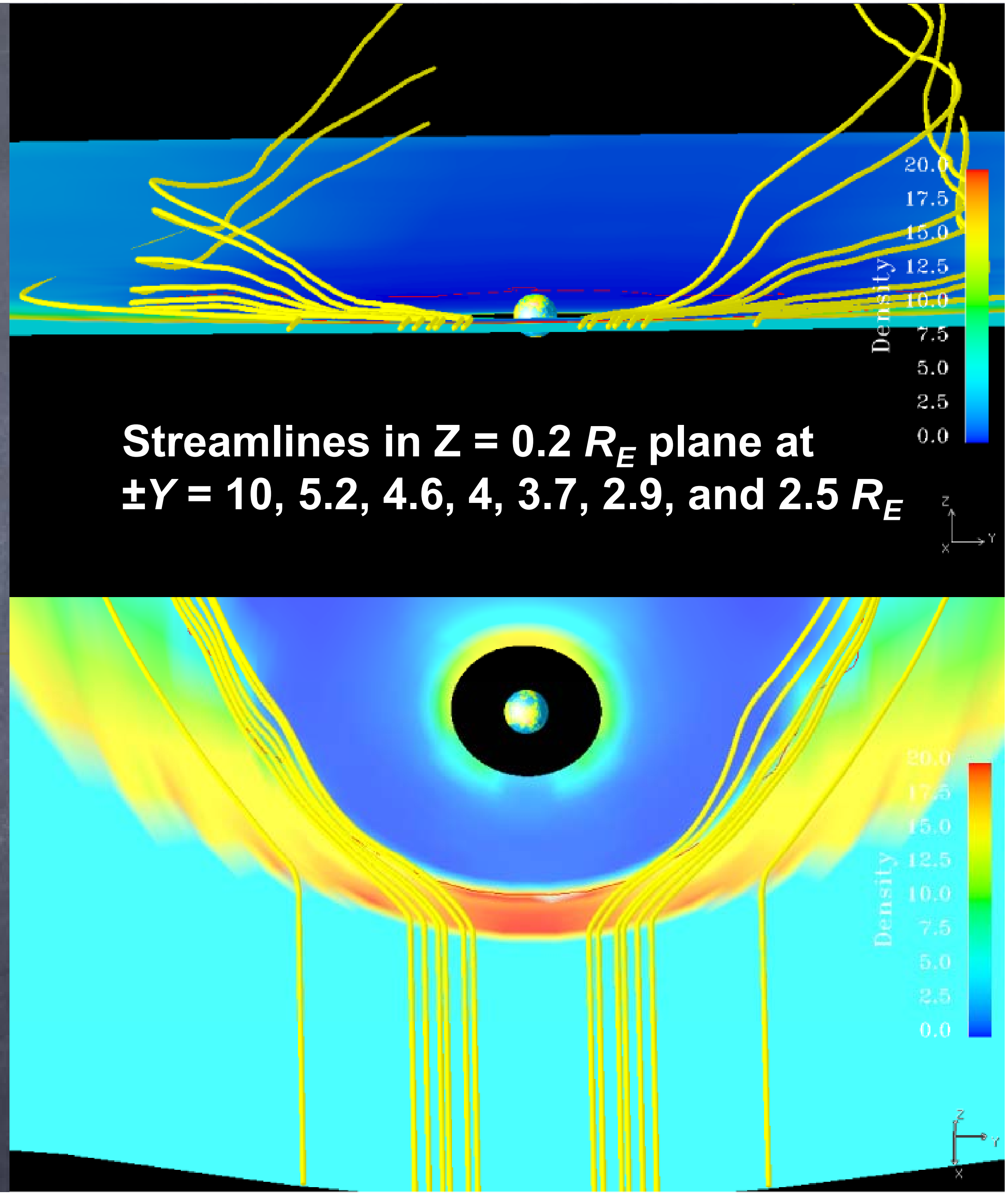
C_s = 40 km/s

B_z = -5 nT

Σ_p = 5 mhos

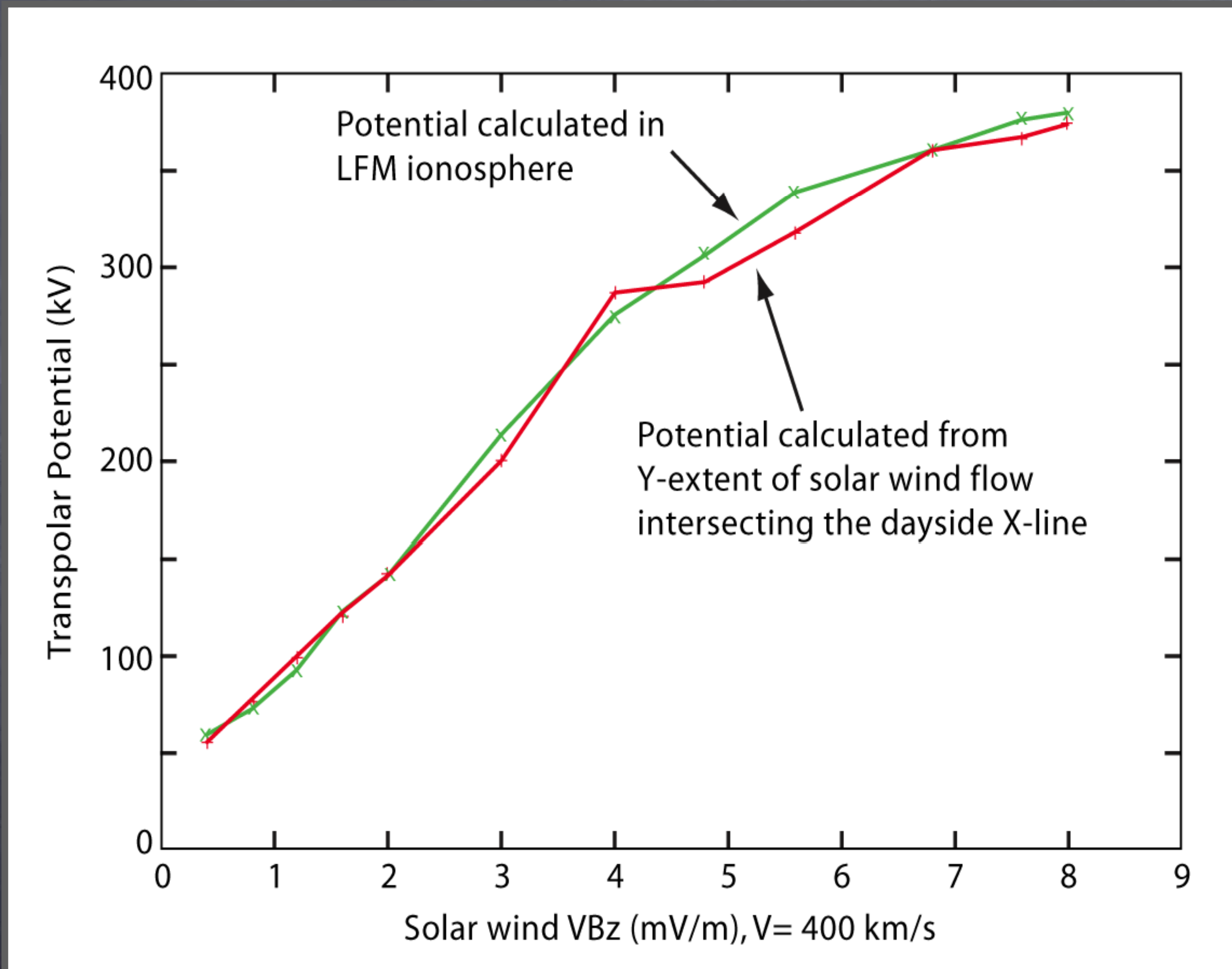
Color-coded density with streamlines

Lopez et al. 2009



Streamlines in Z = 0.2 R_E plane at $\pm Y$ = 10, 5.2, 4.6, 4, 3.7, 2.9, and 2.5 R_E

Comparison of Φ_{rec} with Φ_{PC}



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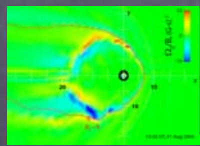

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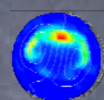
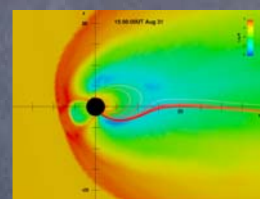
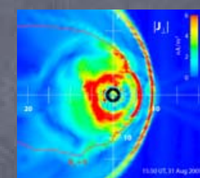
$$j_{\parallel} = -\nabla \cdot \vec{\mathbf{J}}_{\mathrm{P}}$$







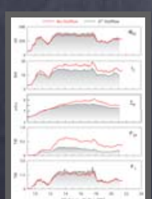
MAGNETOSHEATH

$$\vec{\mathbf{J}}_{\mathrm{P}} = \nabla \cdot \overleftrightarrow{\mathbf{\Sigma}} \cdot \vec{\mathbf{E}}_{\mathrm{PC}}$$

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

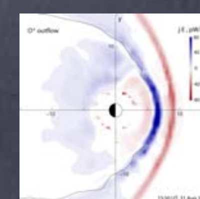
IONOSPHERE

MAGNETOPAUSE



$$\vec{\mathbf{E}}_{\mathrm{PC}} \rightarrow \Phi_{\mathrm{PC}}$$

$$\vec{\mathbf{E}}_{\mathrm{Rec}} \rightarrow \Phi_{\mathrm{Rec}}$$



MI Interaction

With O⁺ Outflow

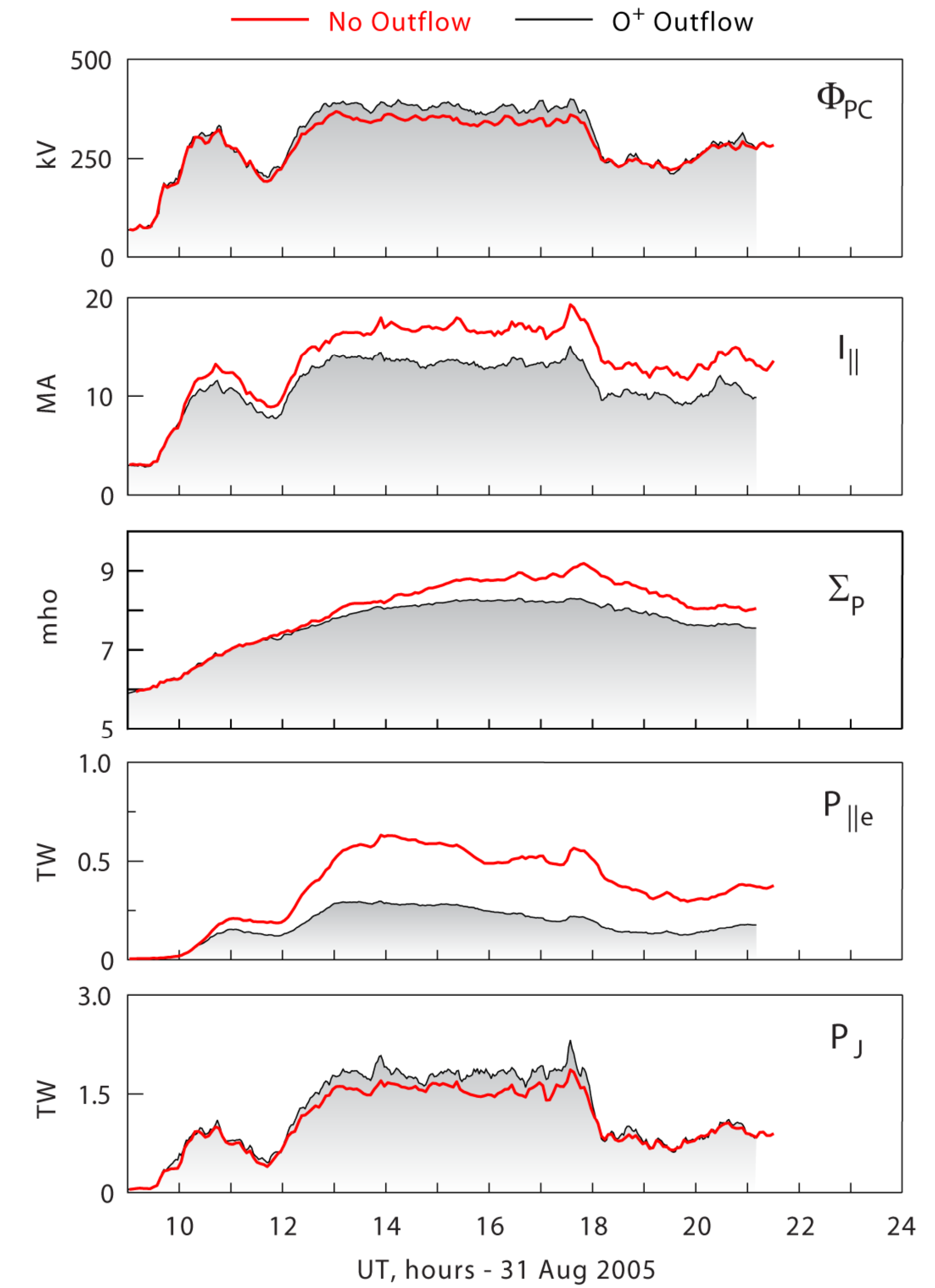
– CPCP ↑

– Hemispheric FAC ↓

– Dayside mean conductance ↓

– Precipitating electron power ↓

– Ionospheric Joule diss. ↓



Key Points

- Geospace exercises (some) self control
- Thermosphere-ionosphere actively responds to magnetosphere
- Ionospheric outflows modify
  - magnetotail state
  - upstream state
  - inner magnetosphere
- Understanding this behavior requires system thinking

Geospace System Focus Group?

<u>Icebreaker</u> **10:30-12:00 AM today, Erickson Room**

- **“Penetration” electric fields** *John Foster*
- **Magnetospheric-ionospheric plasma circulation** *Frank Toffoletto*
- **Reconnection and transpolar potentials** *Slava Merkin*
- **Global oscillation, periodicity, sawtooth phenomena** *Joe Borovsky*