The Physics of Space Plasmas

Auroral and Polar Cap Phenomenology

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BOSTON COLLEGE
ISR
INSTITUTE FOR SCIENTIFIC RESEARCH

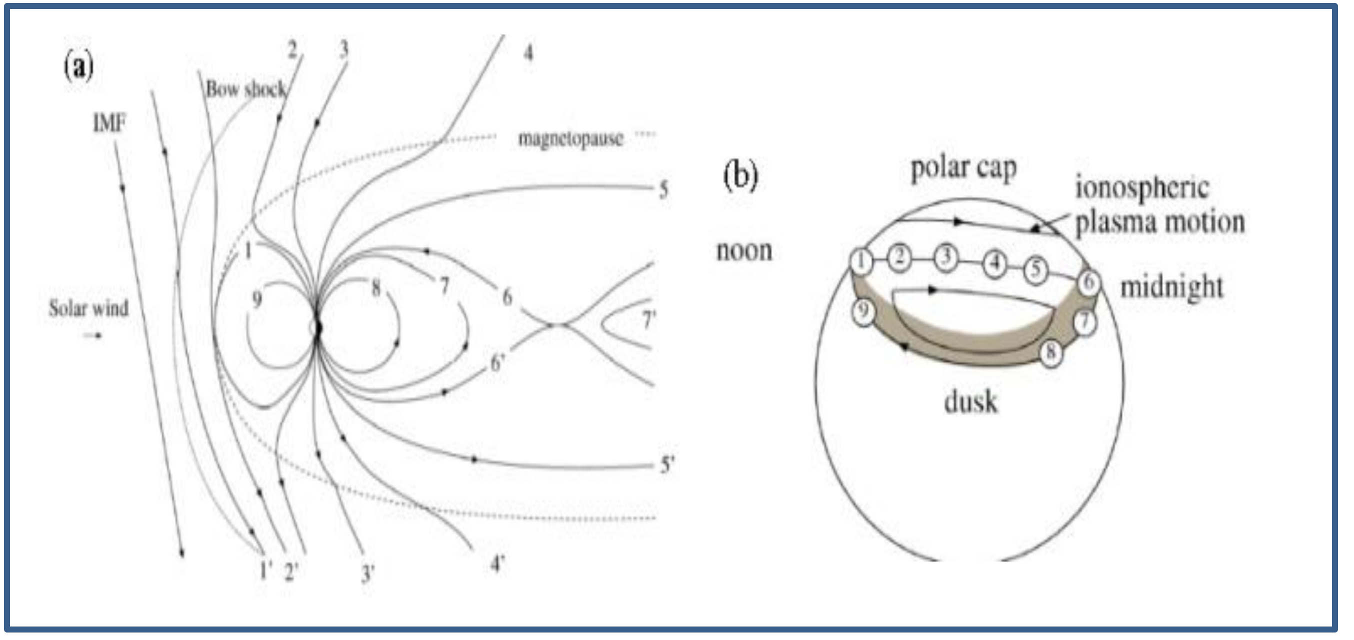
Lecture 3

- **This lecture deals primarily with electromagnetic coupling between the interplanetary medium and the high-latitude ionosphere.**
- **What do high-latitude convection / potential distributions look like?**
  - **How do they vary with the IMF's orientation?**
  - **What is the polar cap potential (Φ_{PC})?**
  - **How does Φ_{PC} depend on the IMF?**
  - **What happens when IMF B_Z turns northward?**
- **We have all seen schematics of the Region 1 – Region 2 system**
  - **How do they come about?**
  - **What are their relationships with particle precipitation electric field patterns?**
  - **What happens when IMF BZ turns northward?**
- **How do electromagnetic forces couple the ionosphere and magnetosphere?**

Boston College ISR

Aurorae and Polar Cap

Dungey, Phys. Rev. 1961

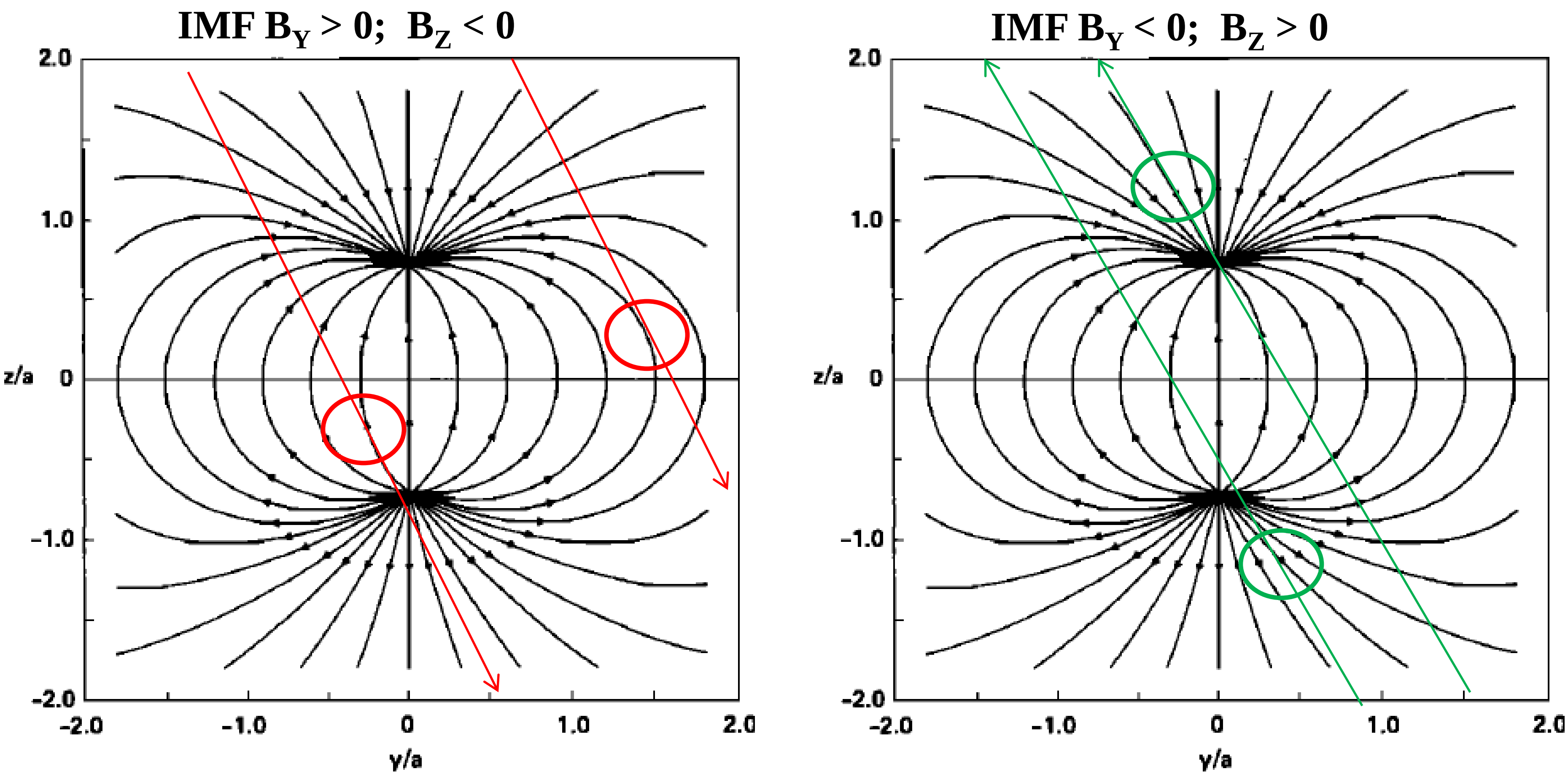


- **While this 2-D model has heuristic value for pointing out how the Dungey magnetosphere works, it seemed to contain seeds of its own rejection.**

- **Walter Heikkila often pointed out that along the sub-solar merging line the electric field and currents were in the same direction!**

  "How can a load drive the magnetosphere?"

Aurorae and Polar Cap

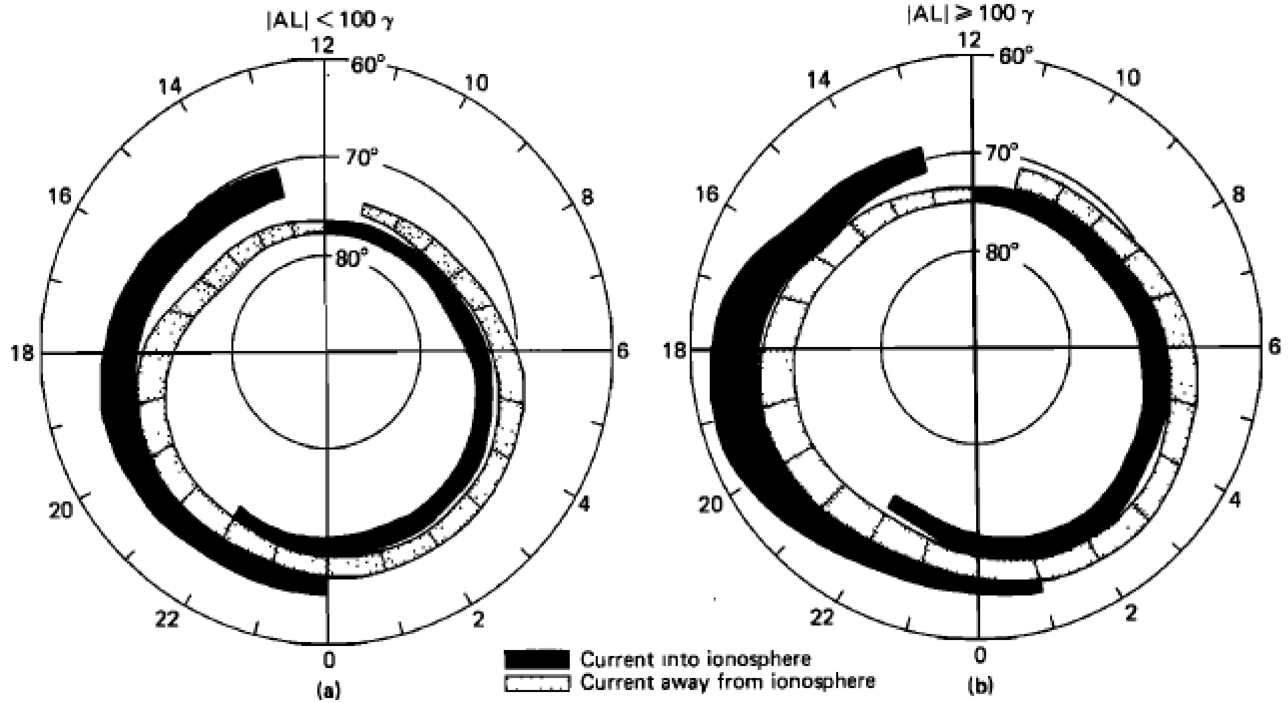


A second issue concerned the generalization of the *Dungey* model to 3D

- Component merging hypothesis (*Bengt Sonnerup*)
- Anti-parallel merging hypothesis (*Nancy Crooker*)

Aurorae and Polar Cap

Iijima and Potemra, JGR, 83, 599,1978

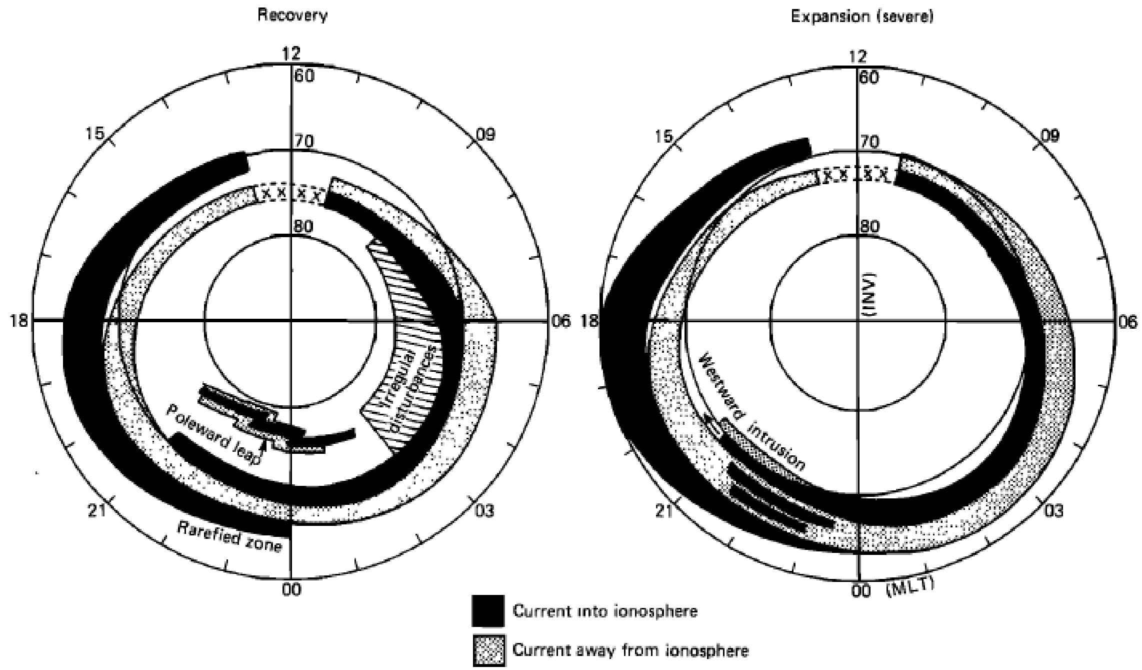


Large-scale system of FACs observed by TRIAD during relatively quiet (left) and disturbed (right) conditions

- **R1 and R2 expand colatitude ranges**
- **Cusp-related current system not yet identified**

Aurorae and Polar Cap

Iijima and Potemra, JGR, 83, 599,1978



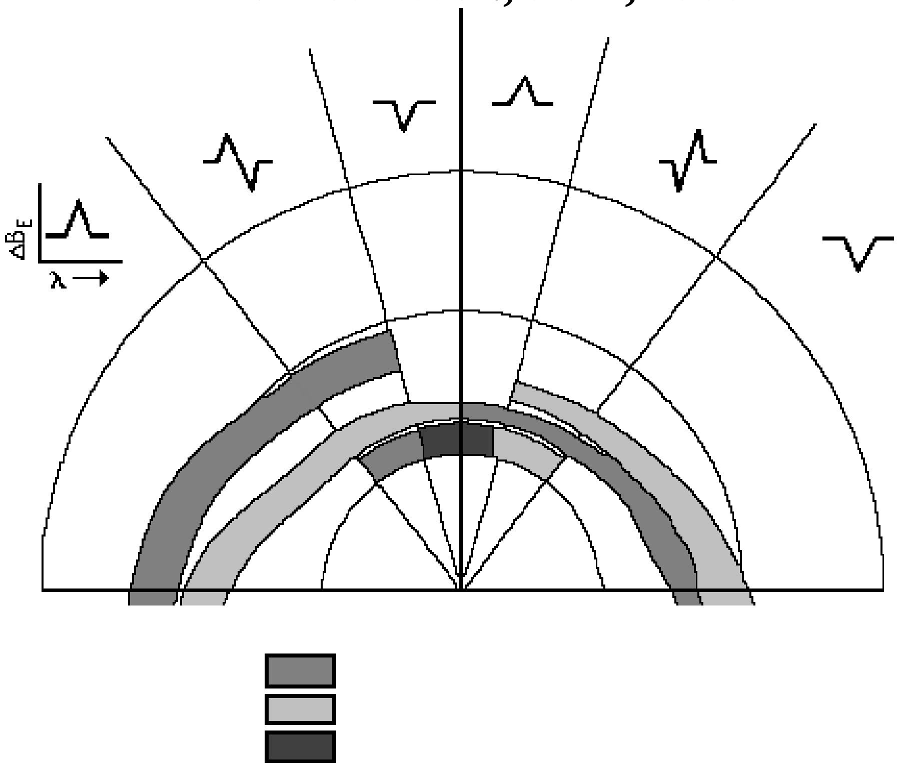
Large-scale system of FACs observed by TRIAD during the recovery (left) and expansion (right) phases of substorms

- **Small scale FACS associated with discrete auroral forms do not in this global-scale picture**
- **The infinite current sheet approximation**

Aurorae and Polar Cap

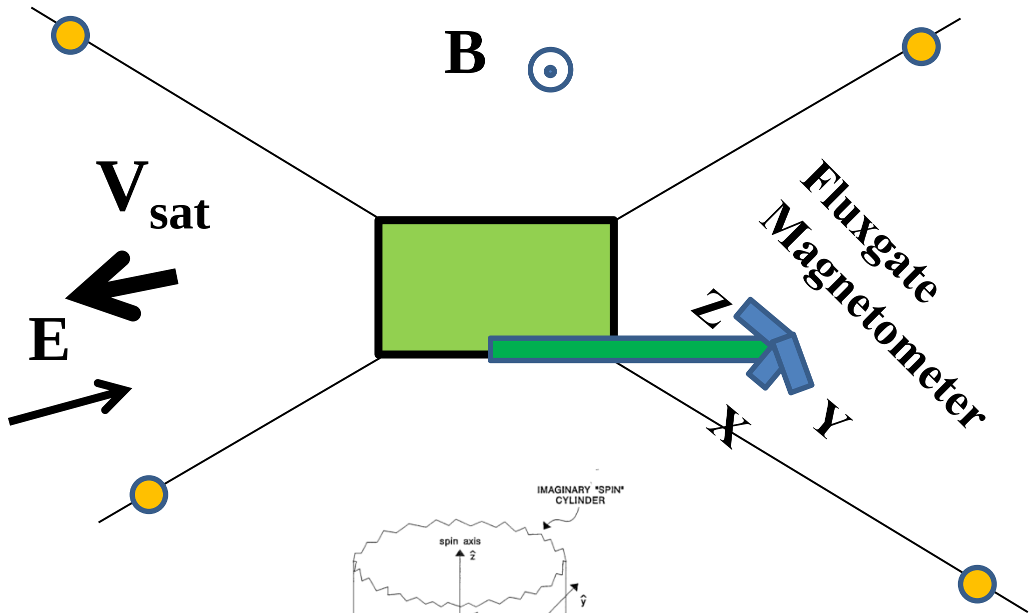
Dayside FAC System

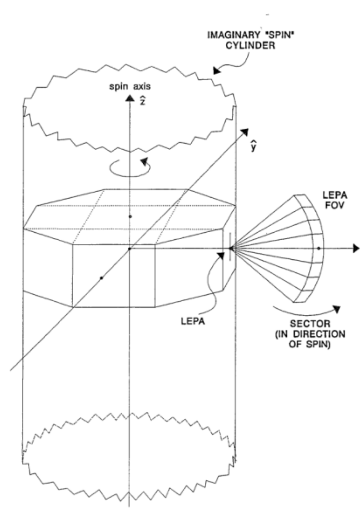
Erlandson et al., JGR, 1988

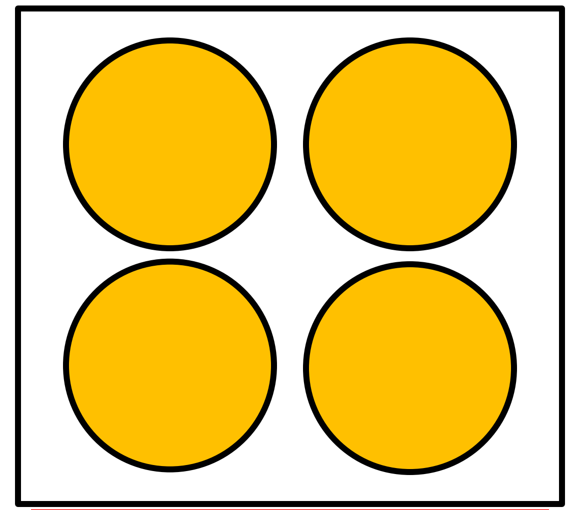


- From $\nabla \times B = \mu_0 j$ considerations, positive/ negative ΔB_E slopes indicate current into / out of ionosphere
- The existence / polarity of the cusp current system is IMF B_Y dependent
- *Erlandson* saw cusp currents as extensions of Region 1 past local noon.

Particle Electric / Magnetic Field Measurements



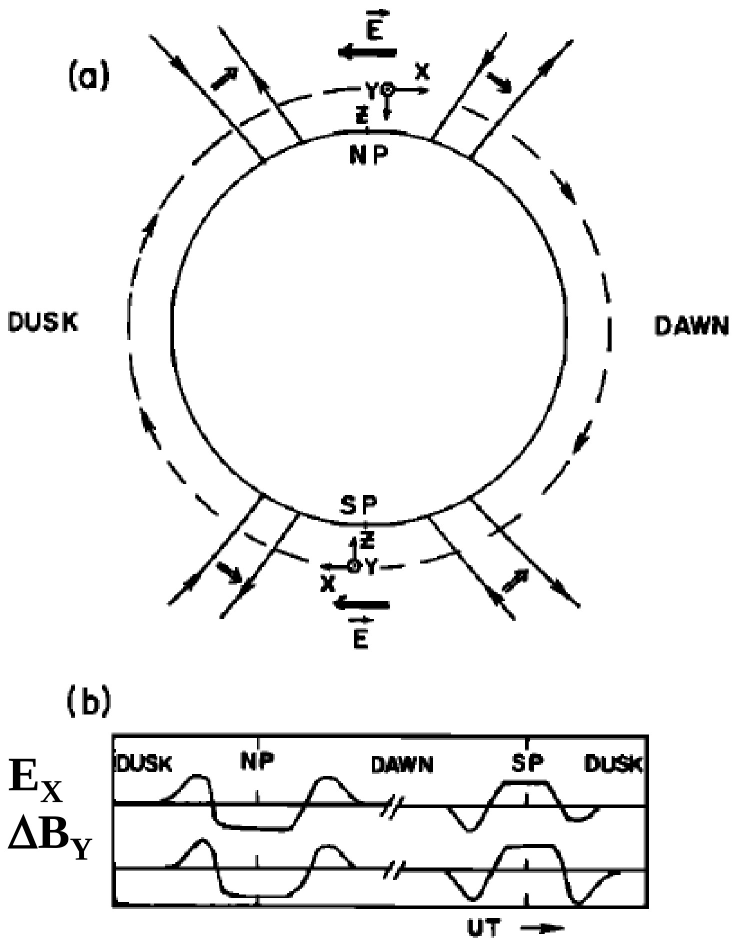




Ion Drift Meter
V_H, V_V

Electrostatic Analyzer

Aurorae and Polar Cap



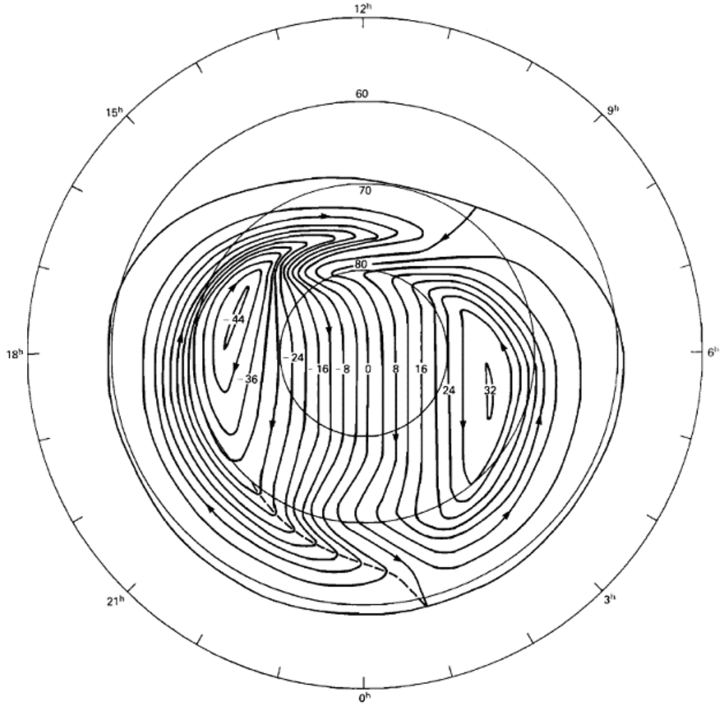
Earth cross section along the dawn-dusk meridian as viewed from the lunar surface

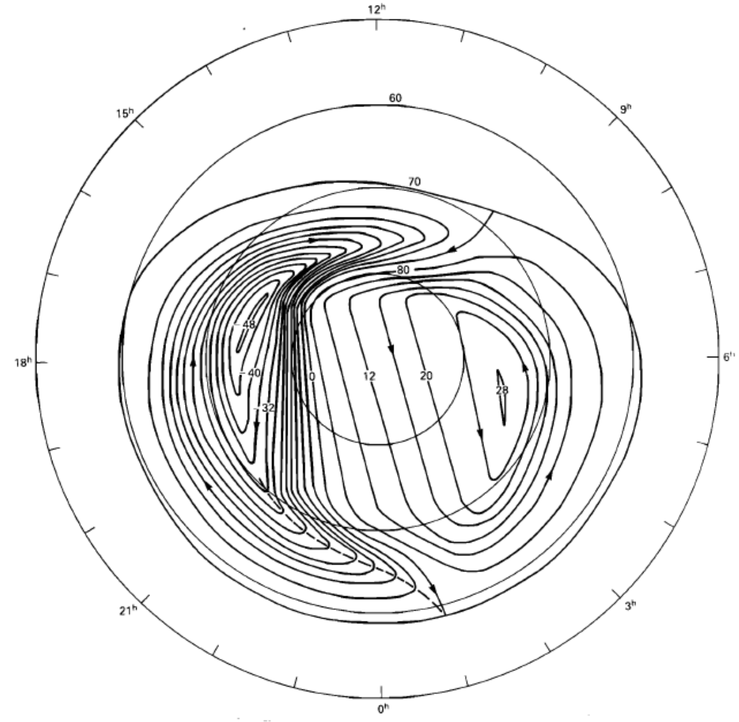
- **Before examining *E* and *B* data, as a guide it is useful to reflect on what to expect in measurements**
- **We consider a satellite in circular polar orbit that carries an electric field sensor and a magnetometer**
- **We assume that in the polar cap *E* is directed dawn to dusk**
- **In the specified satellite centered coordinate system**
  E_X => positive along s/c velocity
  ΔB_Y => positive in antisunward

Aurorae and Polar Cap

***Heppner-Maynard*, JGR, 1987**

Northern Hemisphere :
$B_Y < 0$, $B_Z < 0$





Model A

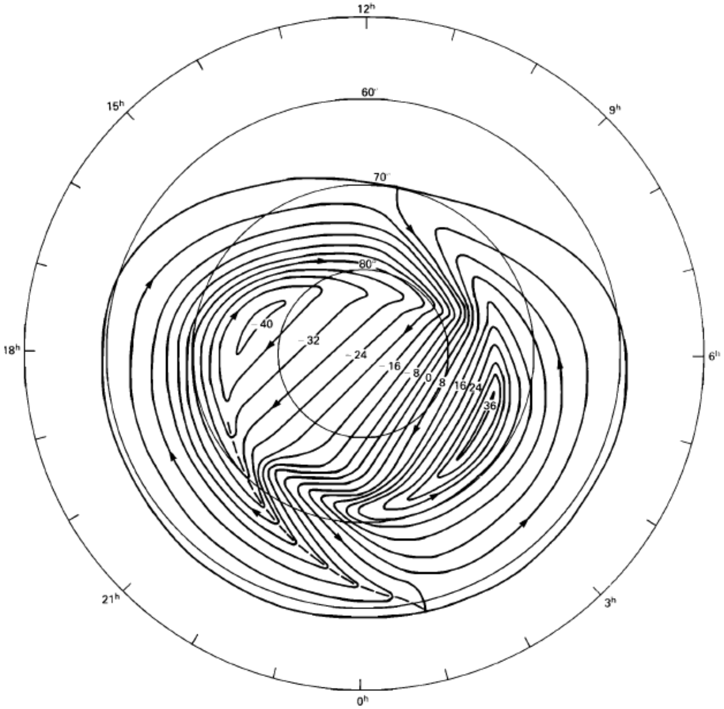
Southern Hemisphere :
$B_Y > 0$, $B_Z < 0$

Model DE

Space Plasma & Field Sensors

Heppner-Maynard, JGR, 1987

Northern Hemisphere:
$B_Y > 0$, $B_Z < 0$



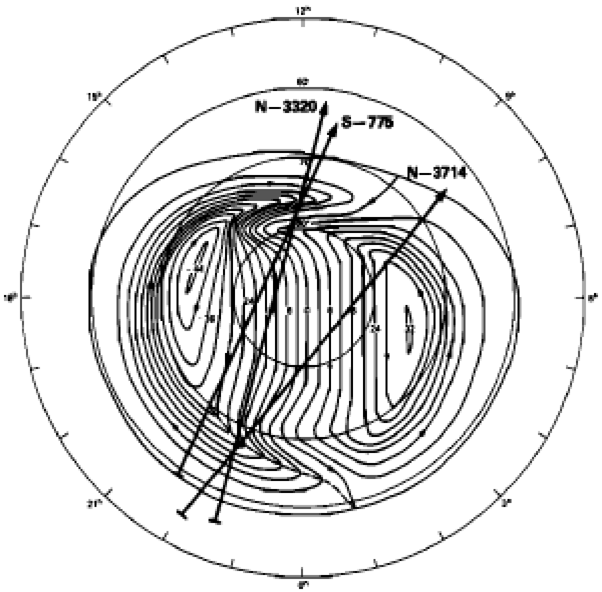
<u>Model BC</u>

Southern Hemisphere:
$B_Y < 0$, $B_Z < 0$

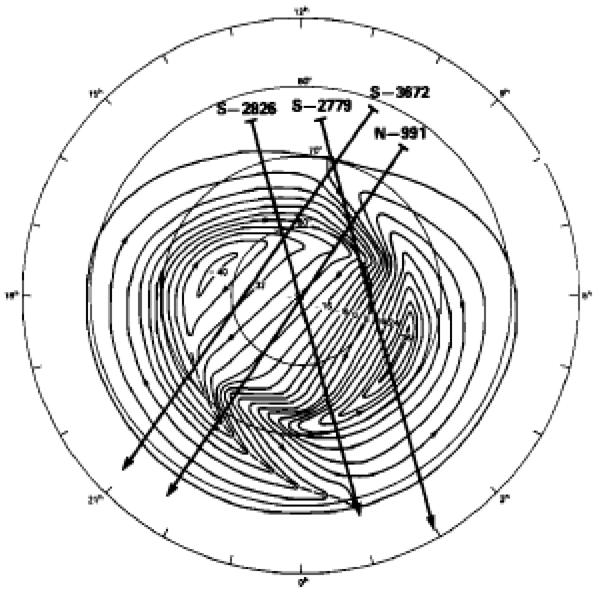
Space Plasma & Field Sensors

Methodology used by *Heppner and Maynard* (JGR , 4467, 1987) to construct Potential / convection patterns

H-M "pattern recognition" technique later quantified by *Weimer* (JGR, 23,639, 1995)

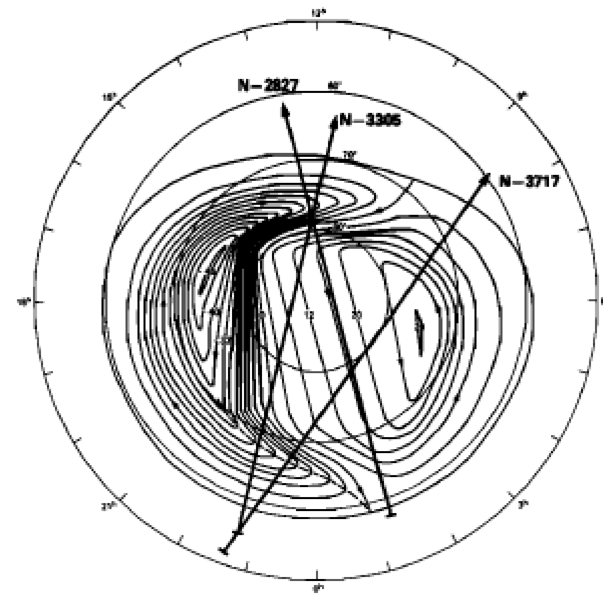


Model A



Model BC

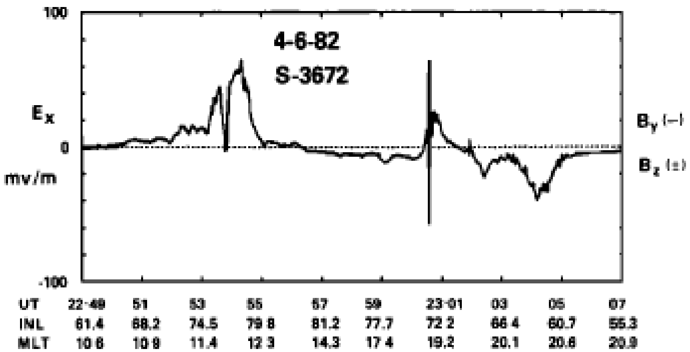
Appears in summer polar cap when IMF B_Y polarity would drive strong convection along dusk flank of polar cap

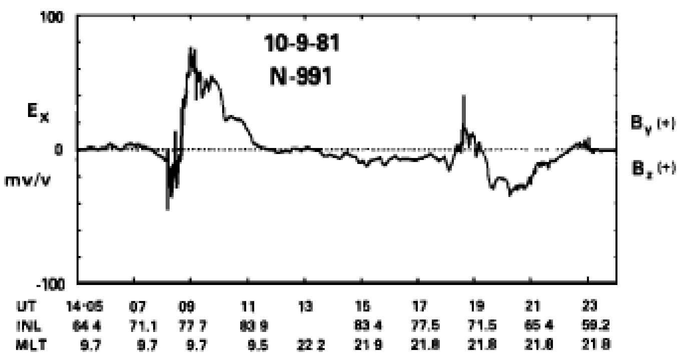


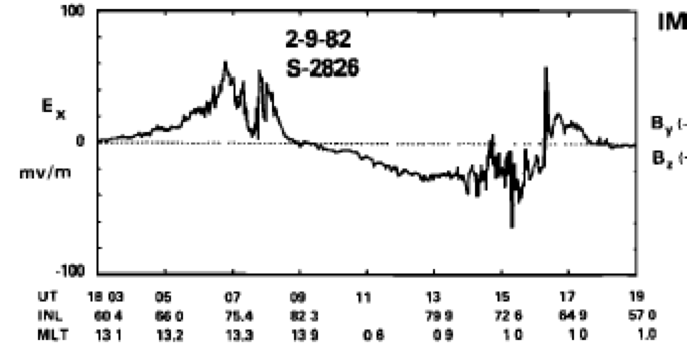
Model DE

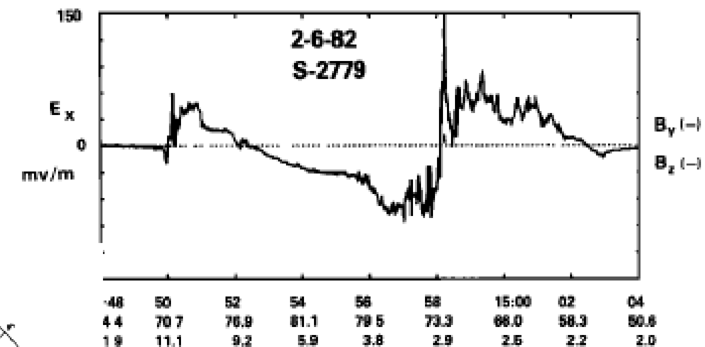
Aurorae and Polar Cap

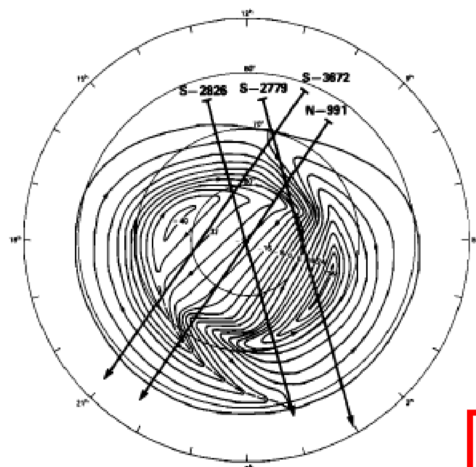
IMF $B_Z < 0$











Northern-hemisphere passes

IMF $B_Y > 0$

E_X is positive along direction of s/c motion

Model BC

Southern-hemisphere passes

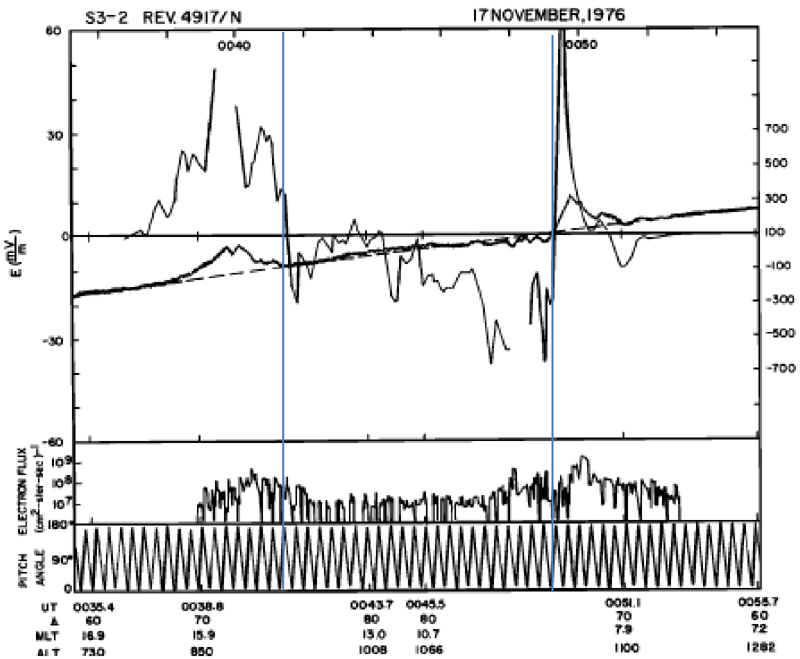
IMF $B_Y < 0$

Integrate E_X along trajectory, then connect equipotentials

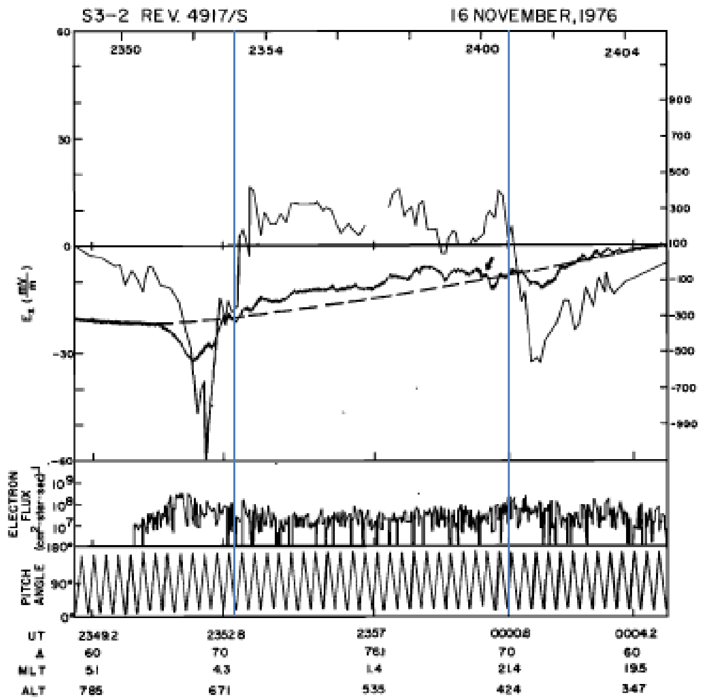
Aurorae and Polar Cap

***Smiddy et al*., JGR, 85, 6811 1980**

Winter Hemisphere



Summer Hemisphere

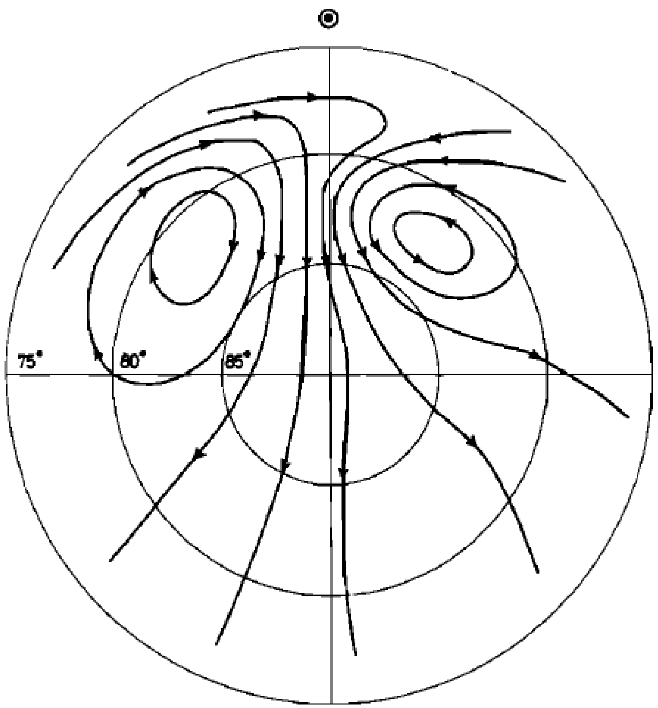


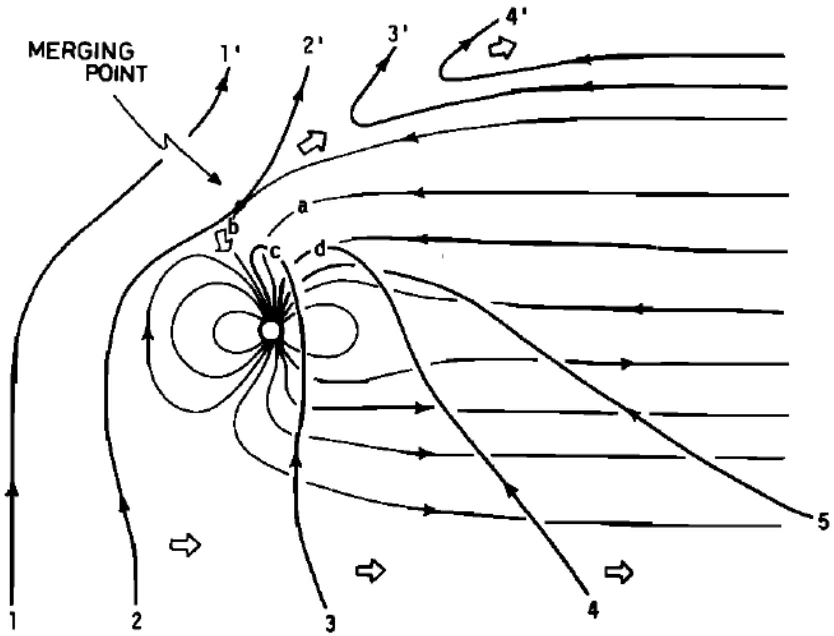
More current overcomes neutral drag on ion convection across summer polar cap

$$\vec{j} \times \vec{B} = \nu_{in}(\vec{V}_i - \vec{V}_n)$$

Aurorae and Polar Cap

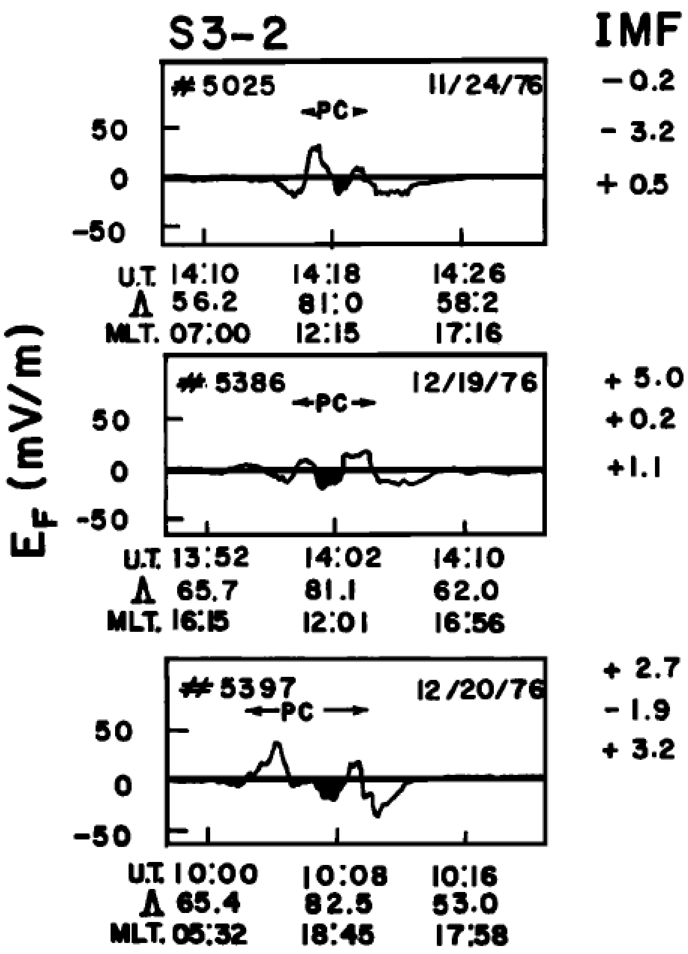
Equivalent current system and external driving with IMF $B_Z > 0$
***Maezawa*, JGR, 2289. 976**

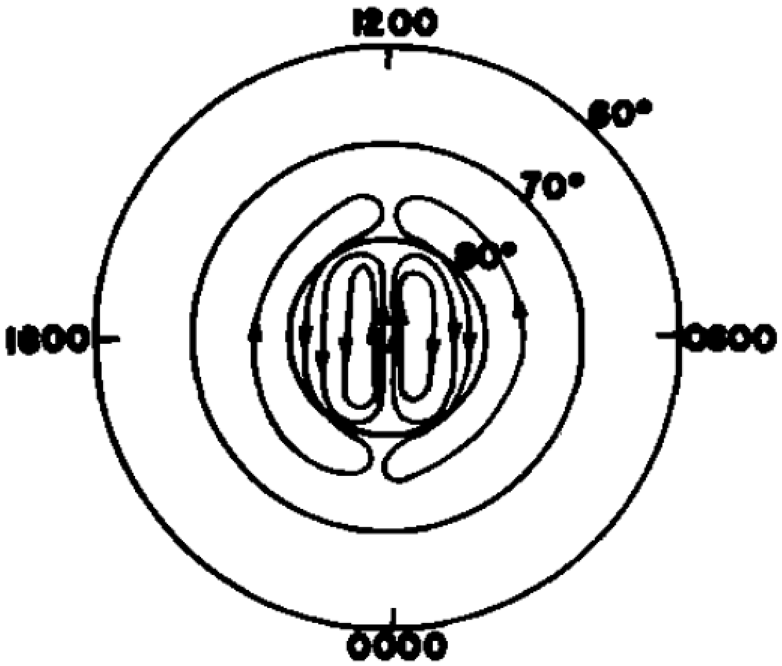




The NASA Explorer Series

***Burke et al.*, GRL, 21, 1979**

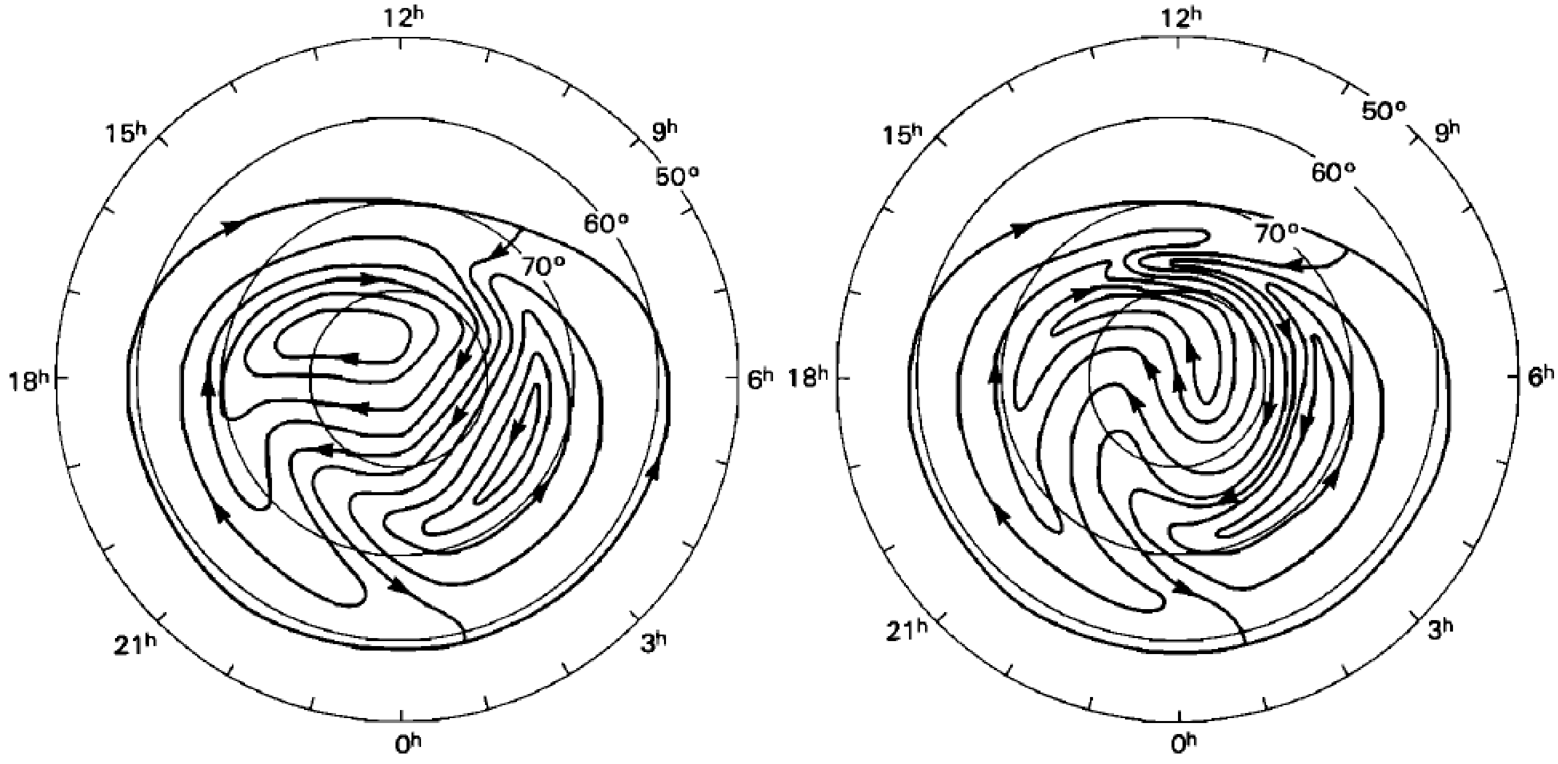




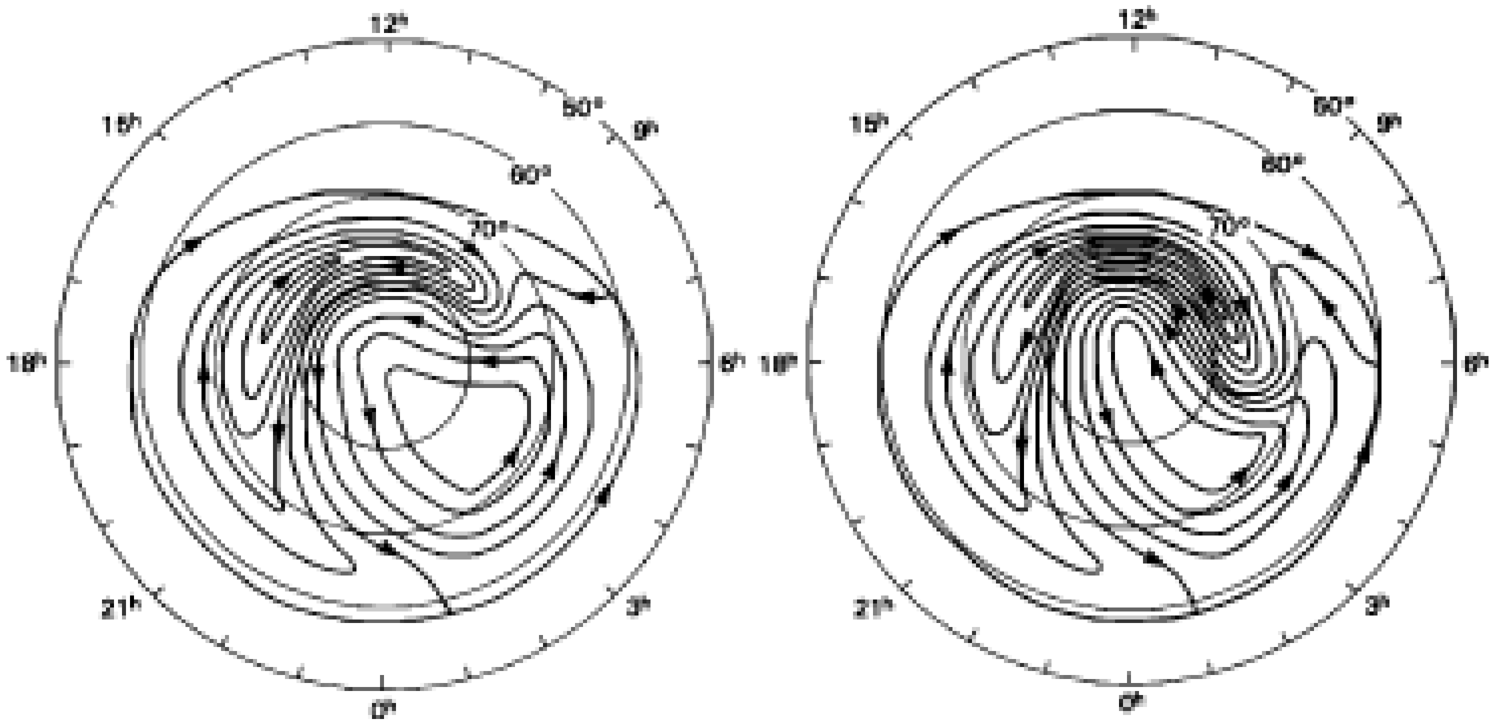
- **Outer cells due to LLBL viscous interaction**
- **Inner cells represent stirring of open flux**

Aurorae and Polar Cap

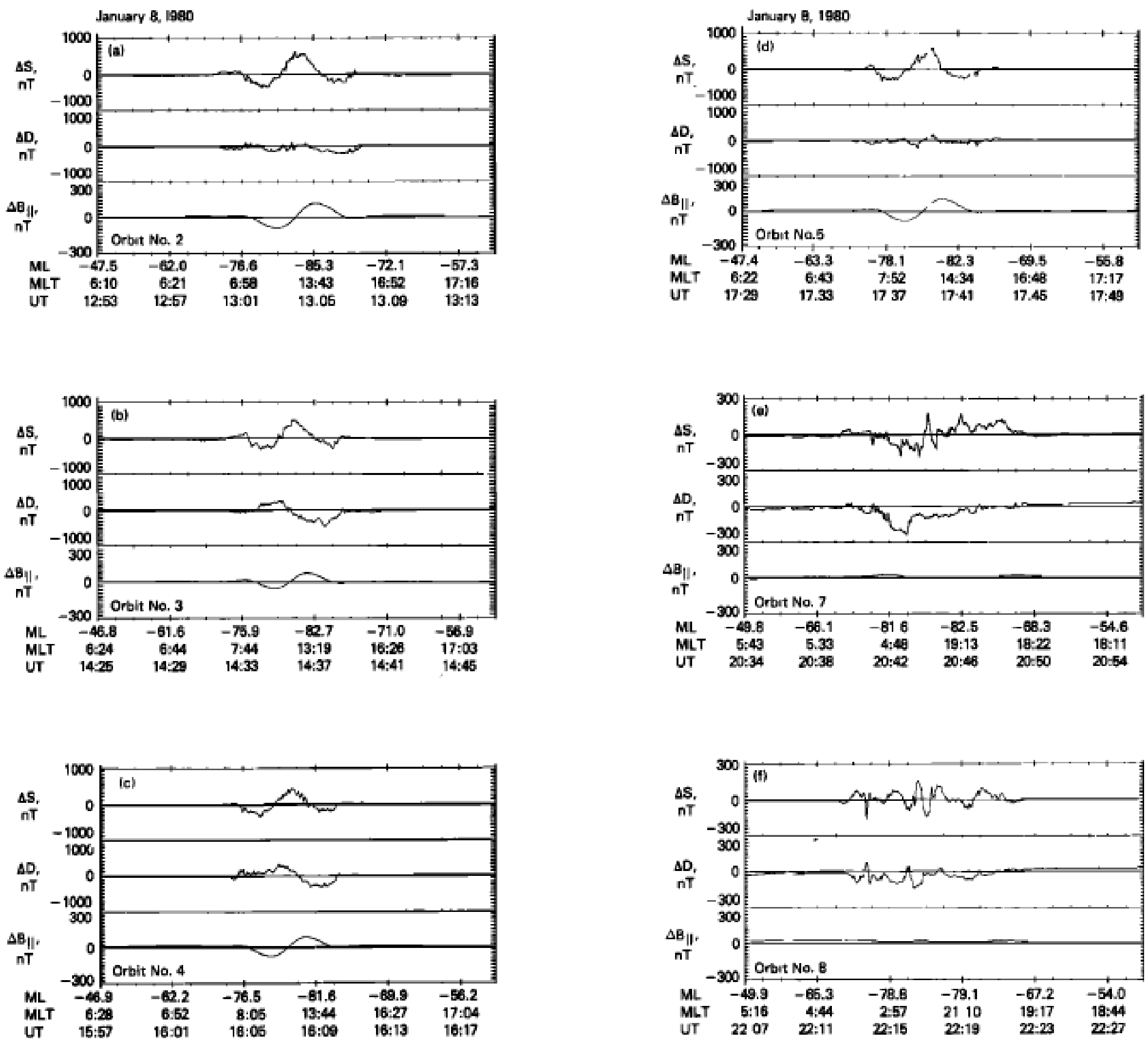
Distorted BC potential/convection patterns with IMF BZ "weakly" (left) and "strongly" (right) positive



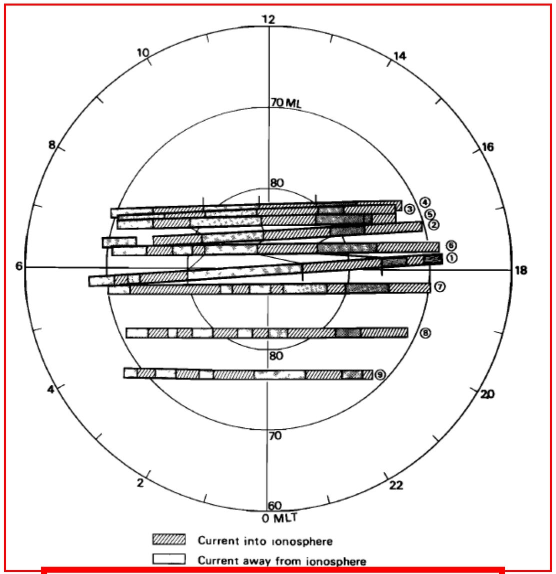
Distorted DE potential/convection patterns with IMF BZ “weakly” (left) and “strongly” (right) positive



Aurorae and Polar Cap

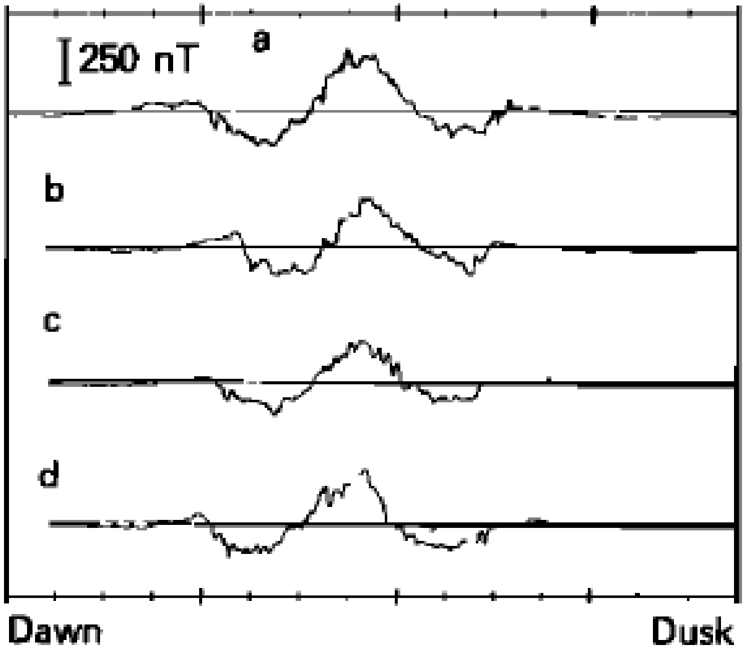


MAGSAT measurements acquired during six consecutive southern hemisphere passes on 8 January 1980 while IMF B_Z was strongly positive.
***Iijima et al.*, 7774, 1984**

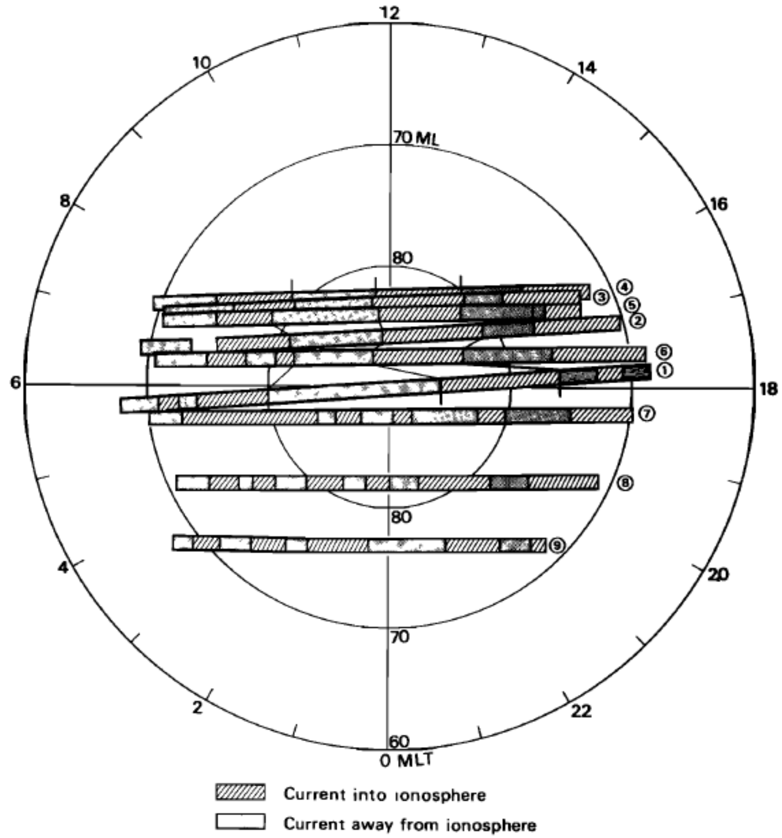


NBZ current system

Aurorae and Polar Cap



MAGSAT ΔS measurements from four southern high-latitude passes on 8 Jan. 1980

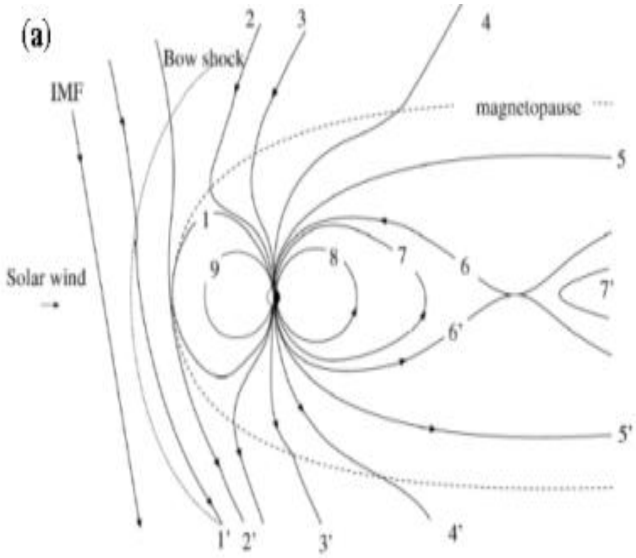


NBZ current system

Aurorae and Polar Cap

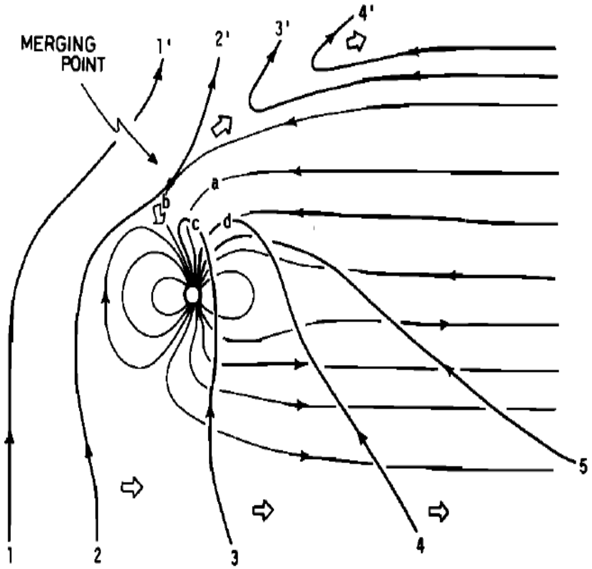
Ion Velocity Dispersion Effect

Dungey, 1961



IMF $B_Z < 0$

Maezawa, 1976

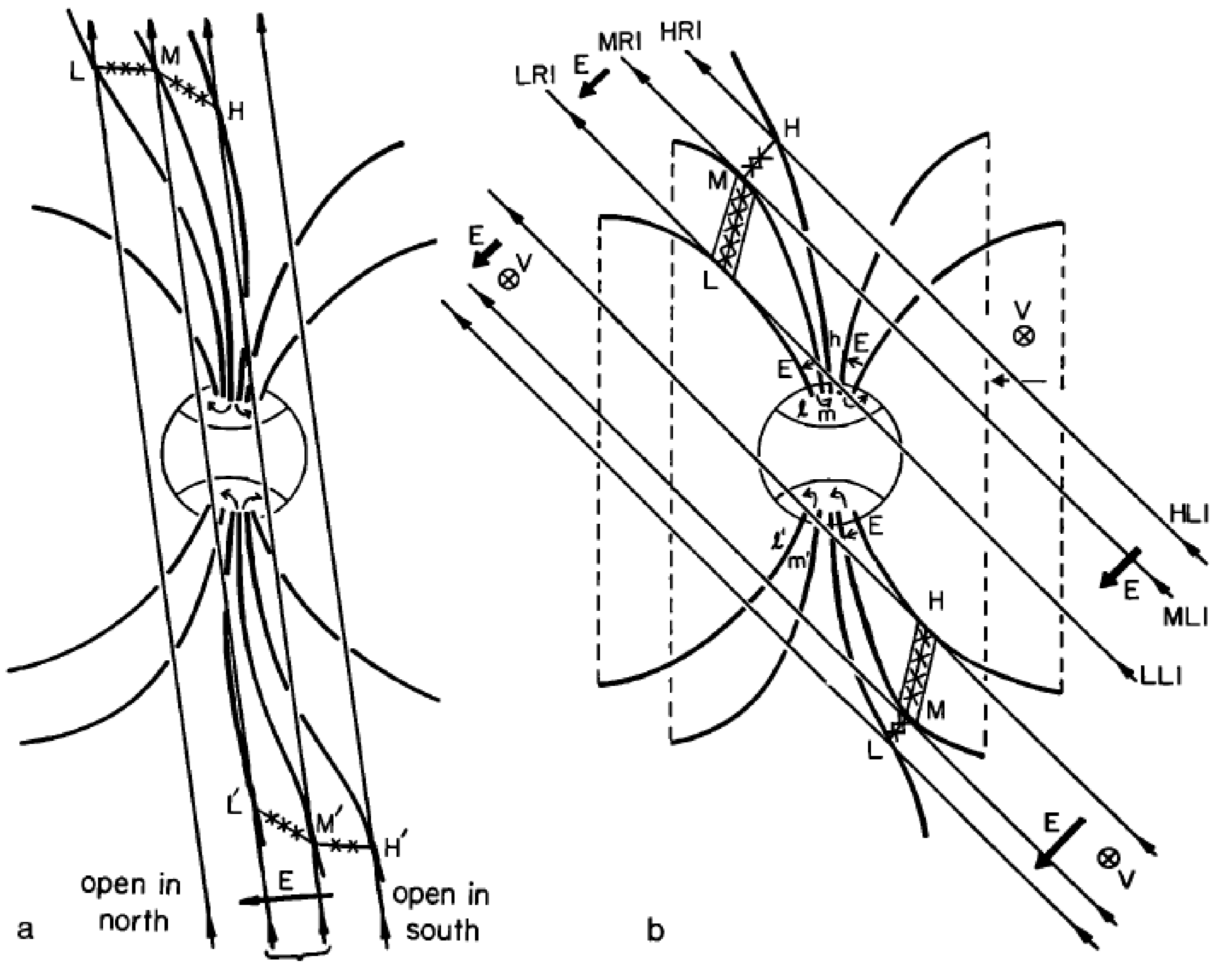


IMF $B_Z > 0$

Highest energy ions at equatorward boundary of the cusp

Highest energy ions at poleward boundary of the cusp

Aurorae and Polar Cap

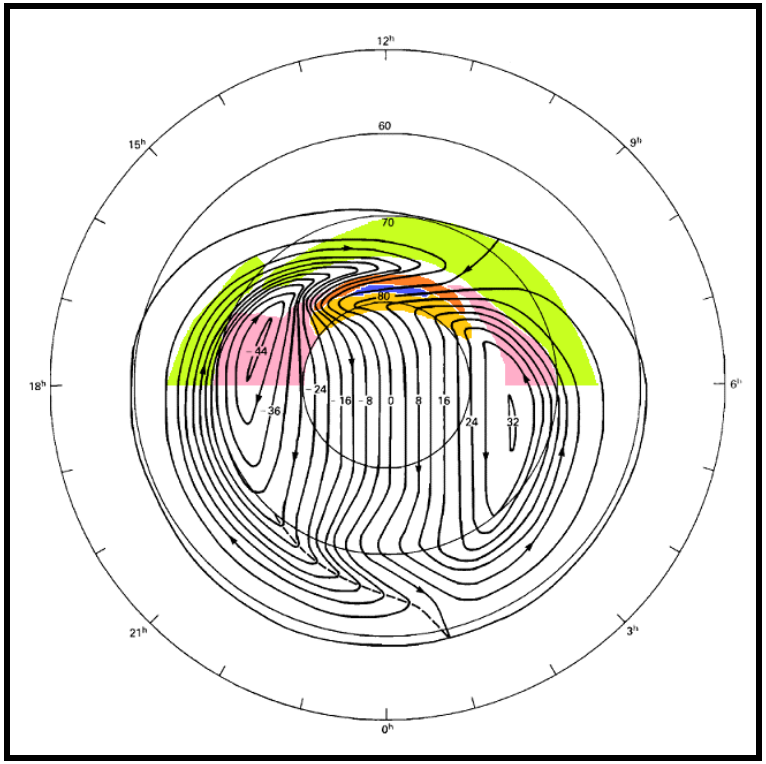


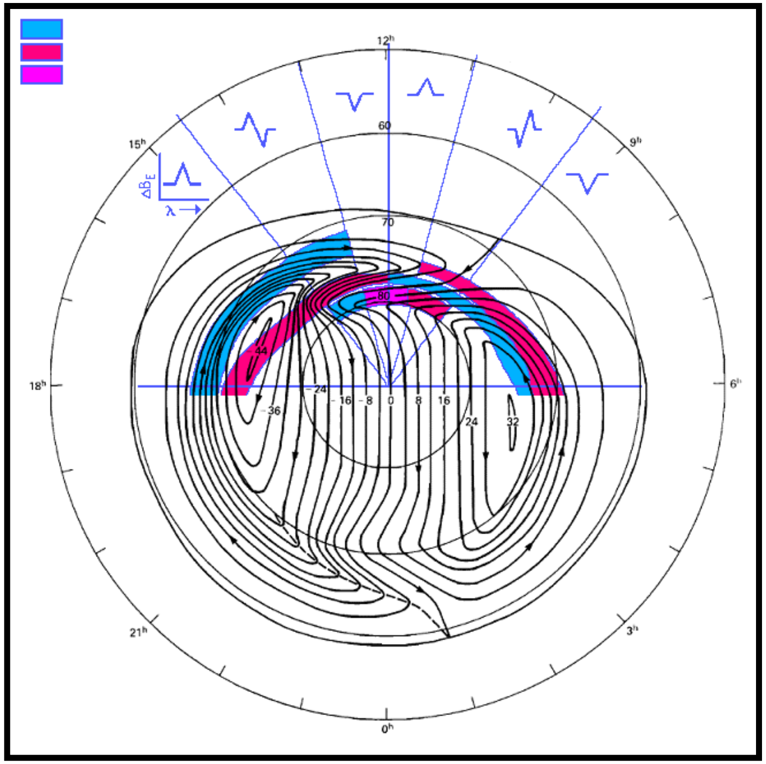
***Reiff and Burch*, JGR 1595, 1985**

Aurorae and Polar Cap

Dayside Precipitation Pattern
***Newell and Meng*, GRL, 1992**

Dayside FAC System
***Erlandson et al.*, JGR, 1988**

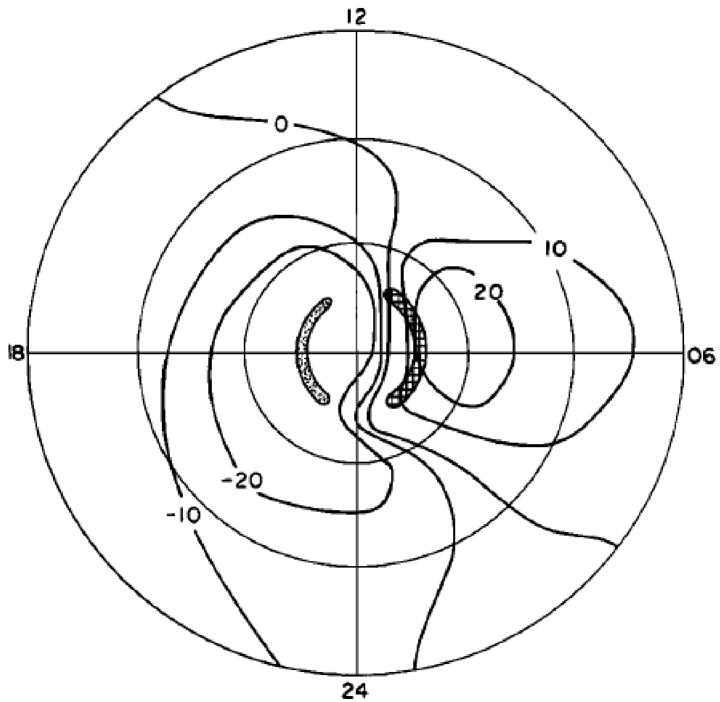




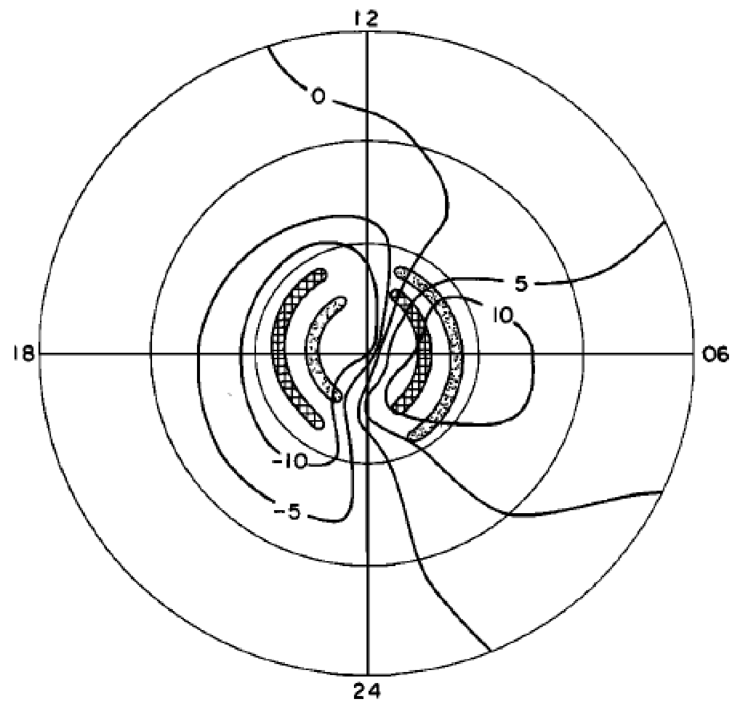
Heppner - Maynard Convection Patterns (JGR, 1987)

Aurorae and Polar Cap

Nopper and Carovillano, GRL 699, 1978



Region 1 = 10^6 A
Region 2 = 0 A



Region 1 = 10^6 A
Region 2 = $3 \cdot 10^5$ A

***Wolf, R. A.*, Effects of Ionospheric Conductivity on Convective Flow of Plasma in the Magnetosphere, JGR, 75, 4677, 1970.**

Aurorae and Polar Cap

Burke, Weimer and Maynard, JGR, 104, 9989, 1999.

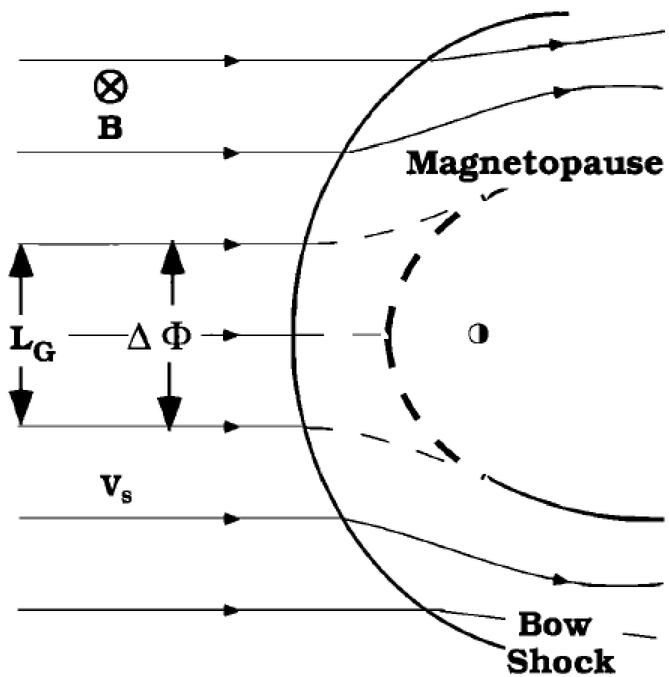
Independent studies using AE-C, S3.2 and DE-2 measurements of Φ_{PC} all showed that the highest correlation was obtained with

LLBL potential **IEF**

$$\Phi_{PC}(kV) = \Phi_0(kV) + \alpha V_{SW} B_T Sin^2(\theta/2)$$

$$B_T = \sqrt{B_Y^2 + B_Z^2}$$

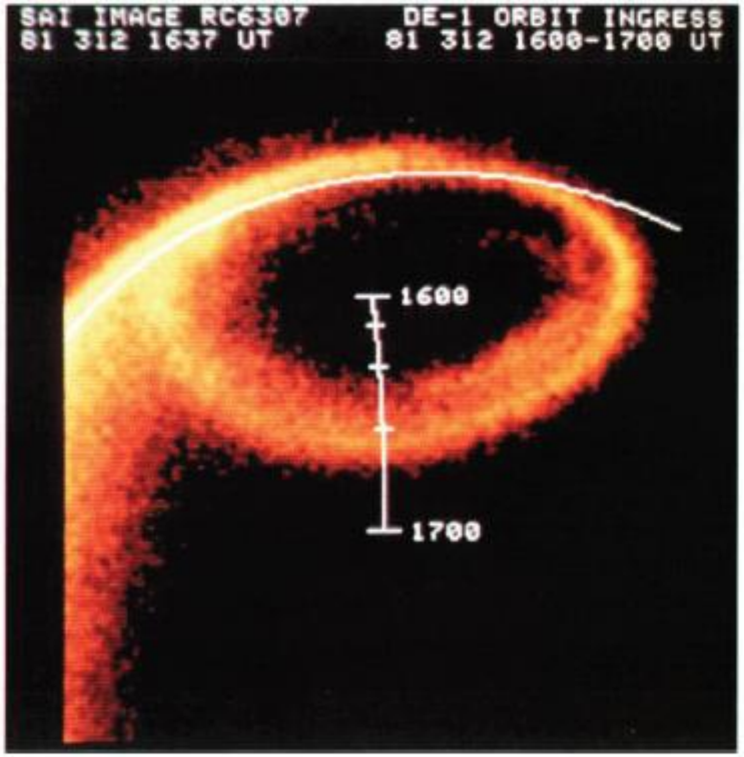
$$\theta = B_Z / B_T$$

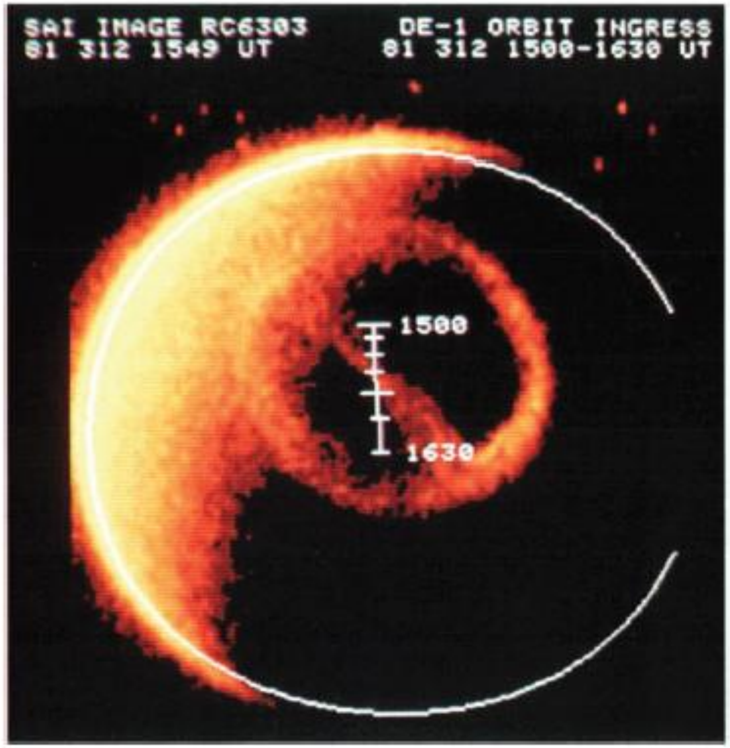


- **Interplanetary electric field (IEF) in mV/m. Since 1 mV/m $\approx$ 6.4 kV/ R_E**
- **L_G => width of the gate in solar wind (~ 3.5 R_E) through which geoeffective streamlines flow.**

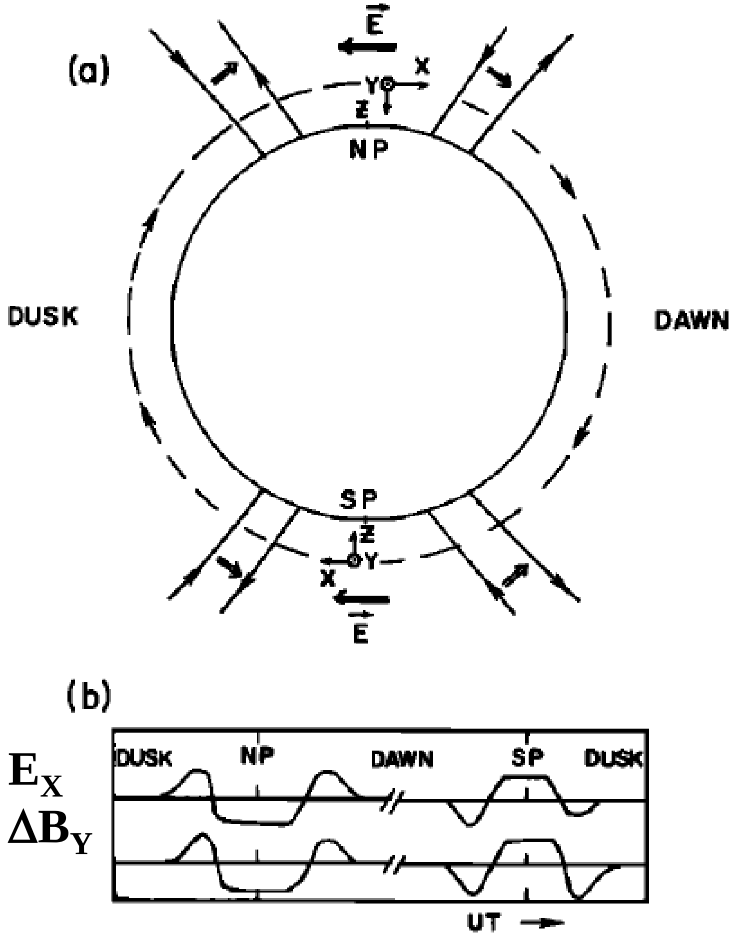
Aurorae and Polar Cap

Dynamics Explorer 1
135.6 nm image of
auroral oval and Theta aurora
***Frank et al.*, JGR, 1986**





Aurorae and Polar Cap



Earth viewed from lunar surface

- **Before examining *E* and *B* data**

It is useful as a guide to think a bit about what we might expect to see in the measurements

- **We consider a satellite in circular polar orbit**
- **That carries an electric field sensor and a magnetometer**

- **We assume that in the polar cap *E* is directed dawn to dusk**

- **In the specified satellite centered coordinate system**
  E_X => positive along s/c velocity
  ΔB_Y => positive in antisunward