CEDAR Grand Challenge Workshop:
The High-Latitude Geospace System
June 24, 2014

Challenges in high-latitude geospace science

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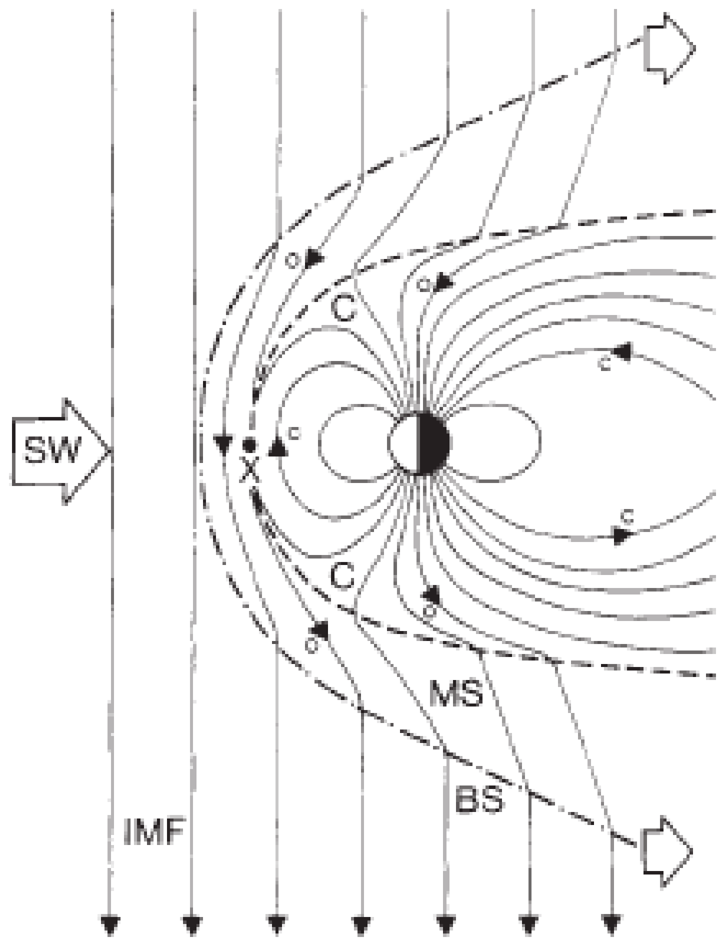
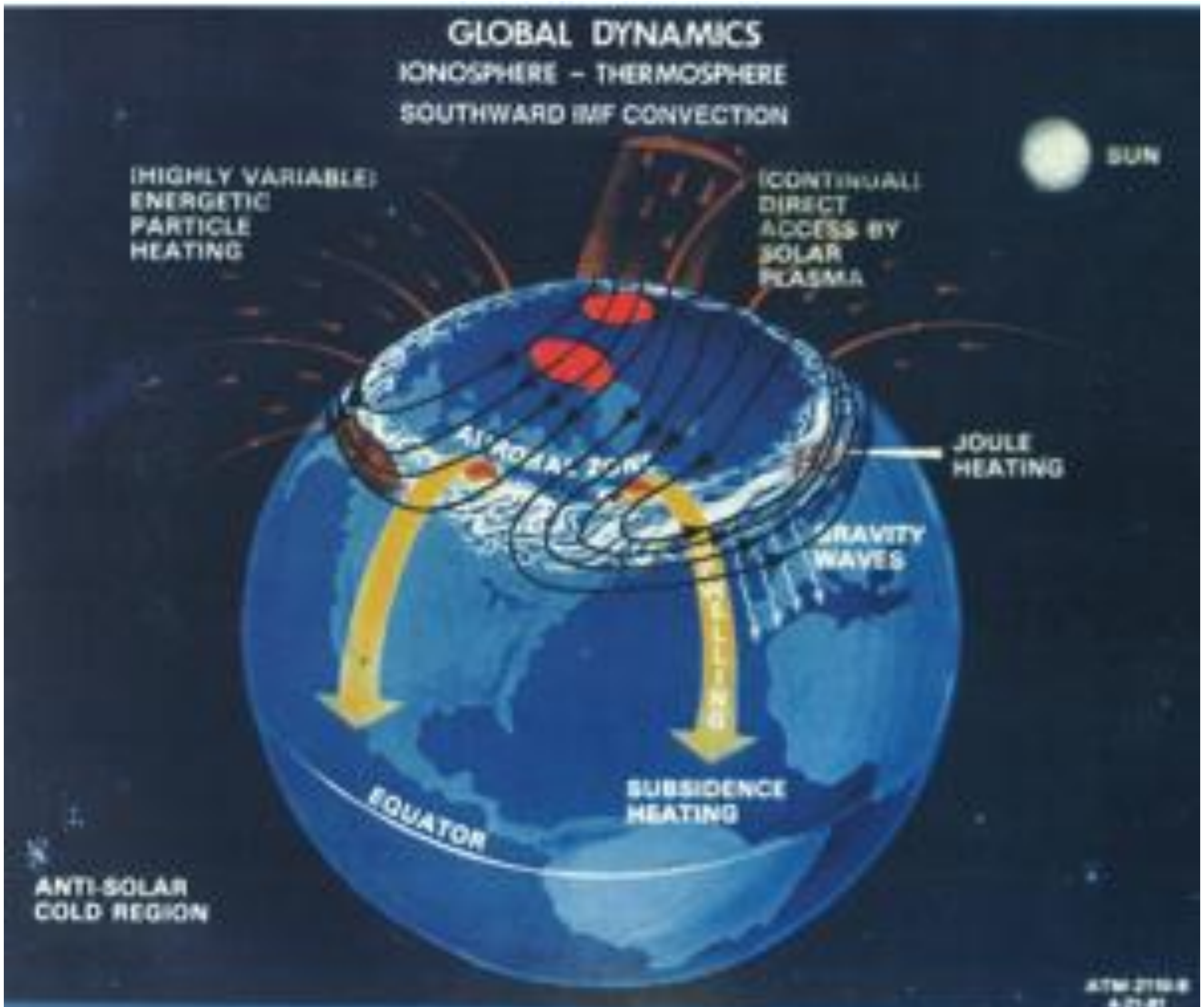
Utah State Univ.
Dept Physics/CASS

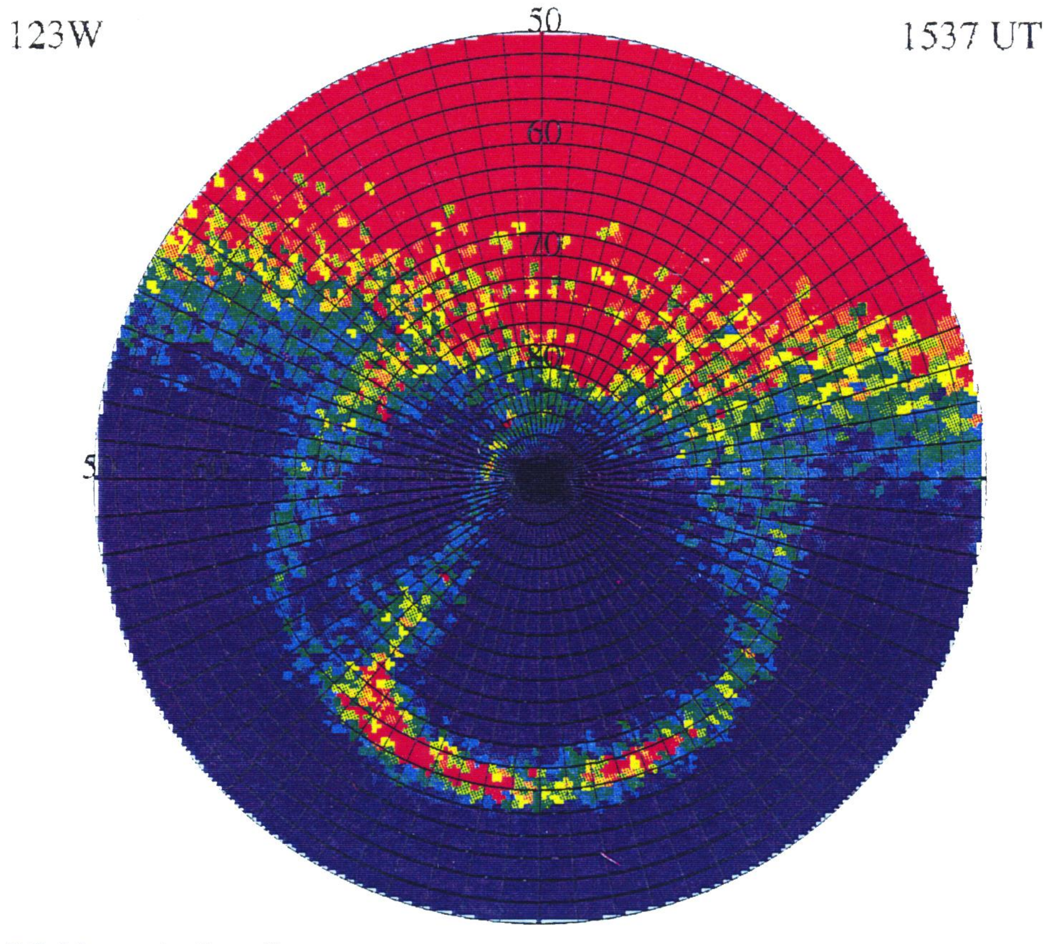
Solar Wind "Input" to SW-M-I-T Coupled System (IMF southward)



I-T "Response" to SW-M-I-T Coupled System (for IMF Southward)

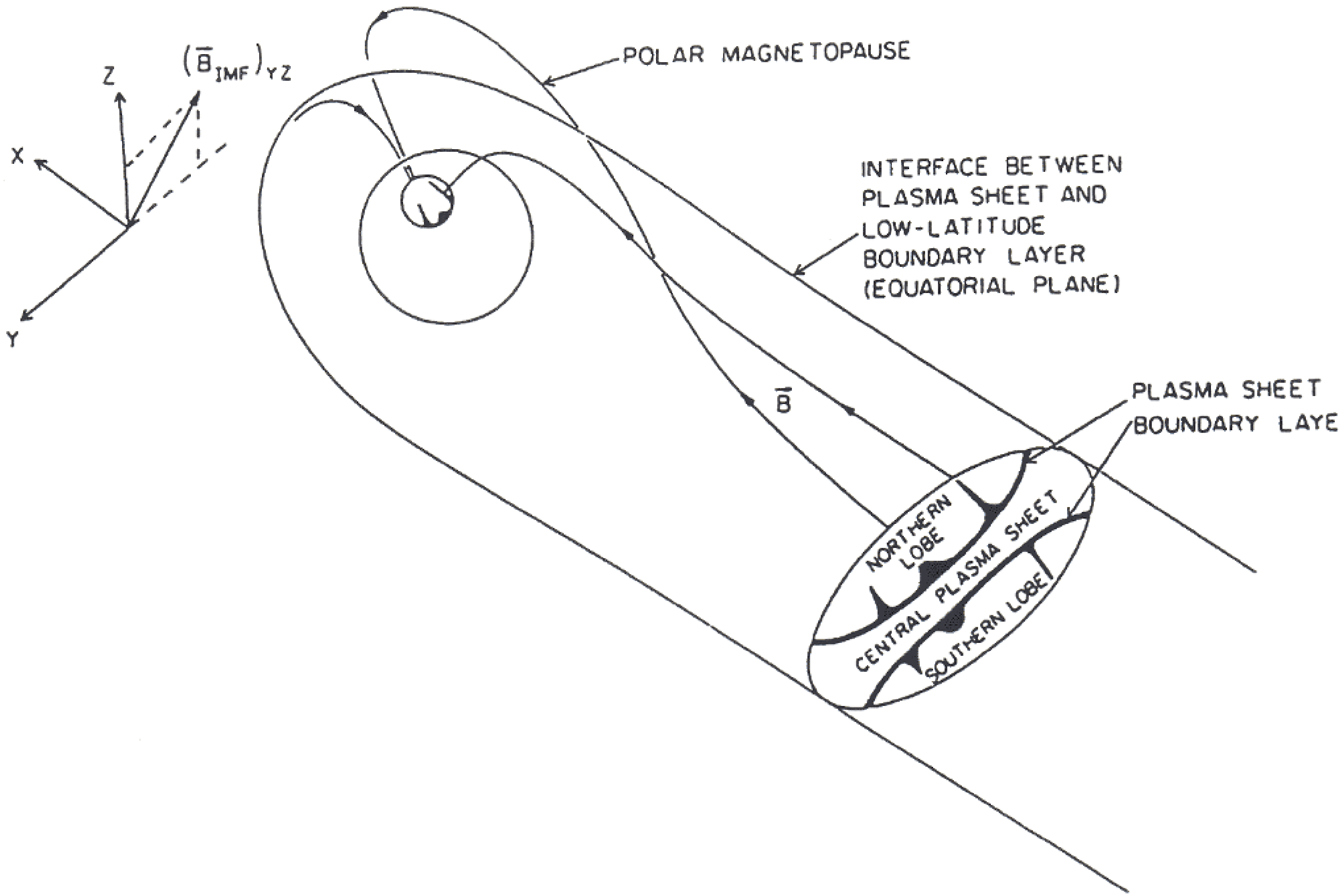


Northward IMF: SA Arcs,Theta Aurora Rare
Only after hours, Magnetosphere Reconfigures



(ISEE) Lobe connection to Theta Aurora?

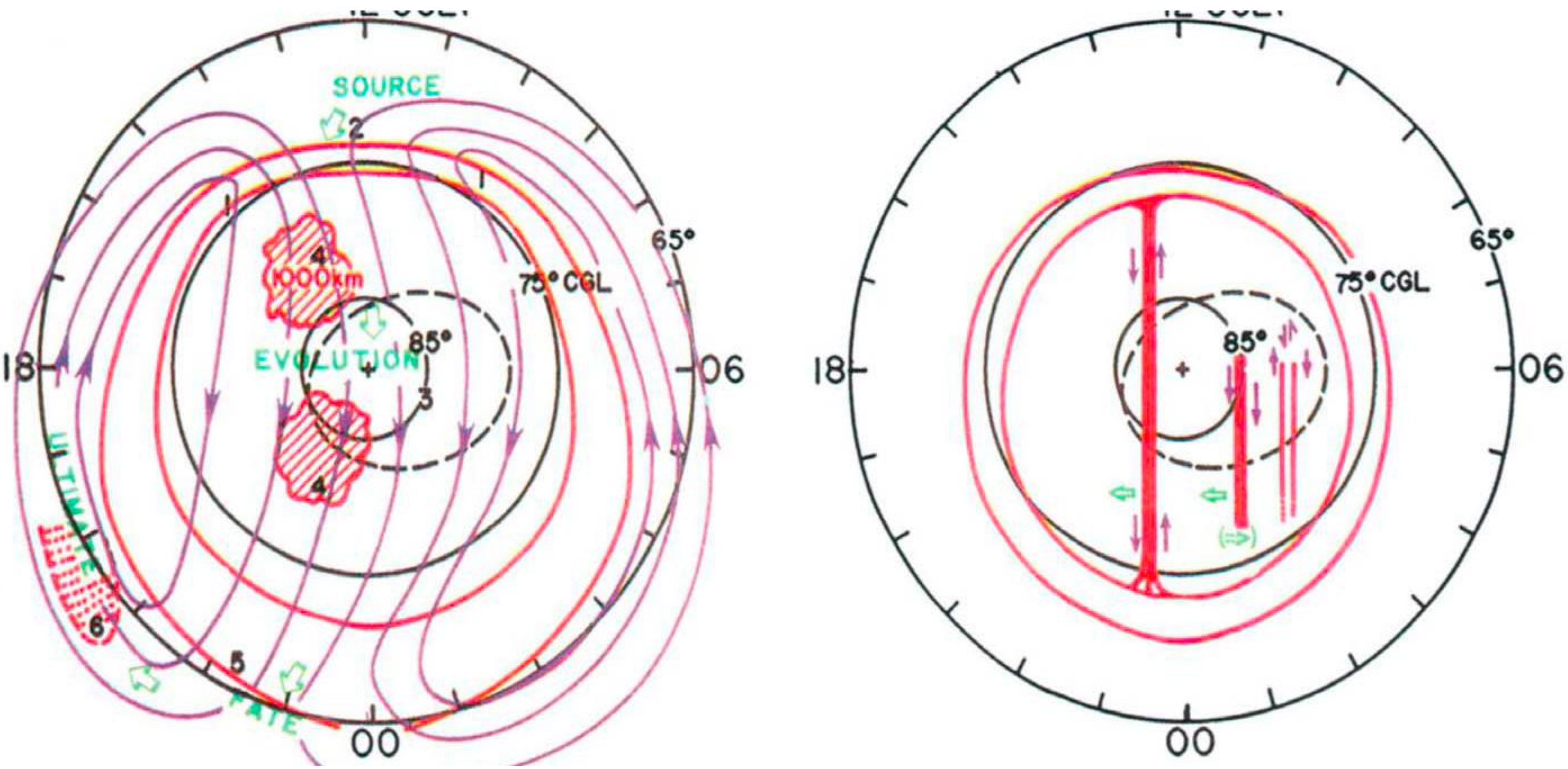
(Huang 1987)



Cartoon of Polar Cap: (left) Bz < 0, (right)> 0

Left: Hypothesized life-cycle of patches; Right PC arcs

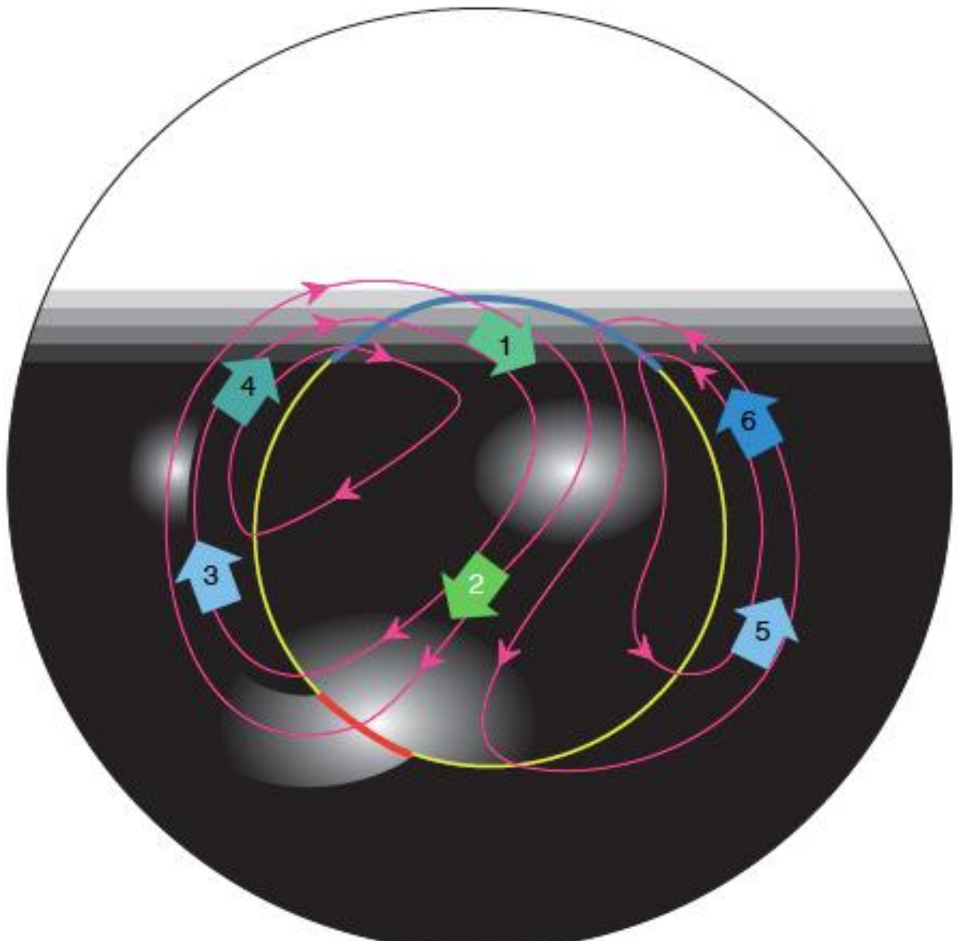
Carlson, 1994



However ,this is tracking actual data

Daylight/noon top, thru terminator, darkness bottom
Bright diffuse areas are PC “patches” from actual TEC receiver data

Zhang et al, 2013



Patch Lifecycle seen in actual TEC data

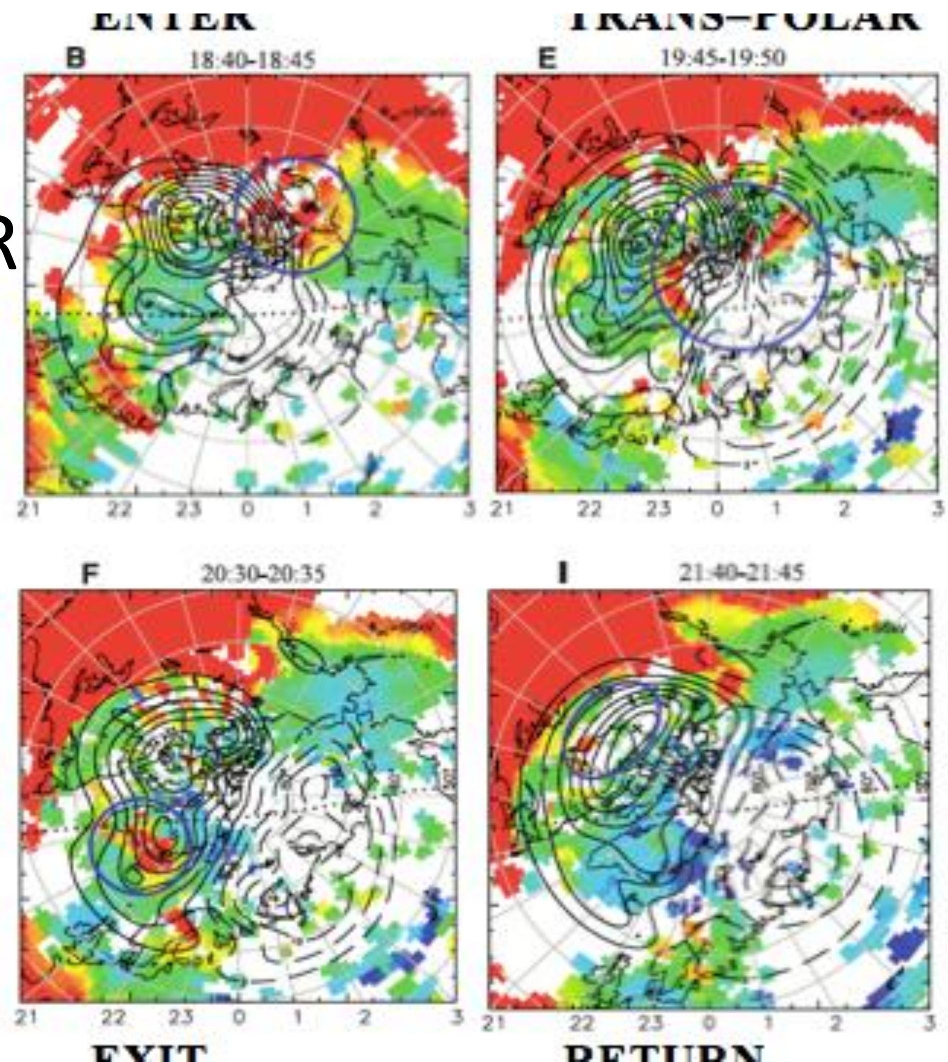
Daylight/noon top, (terminator middle) darkness bottom

Red = 17 TEC units; PC “patches” tracked by black circle

Zhang et al, 2013

ENTER

CROSS

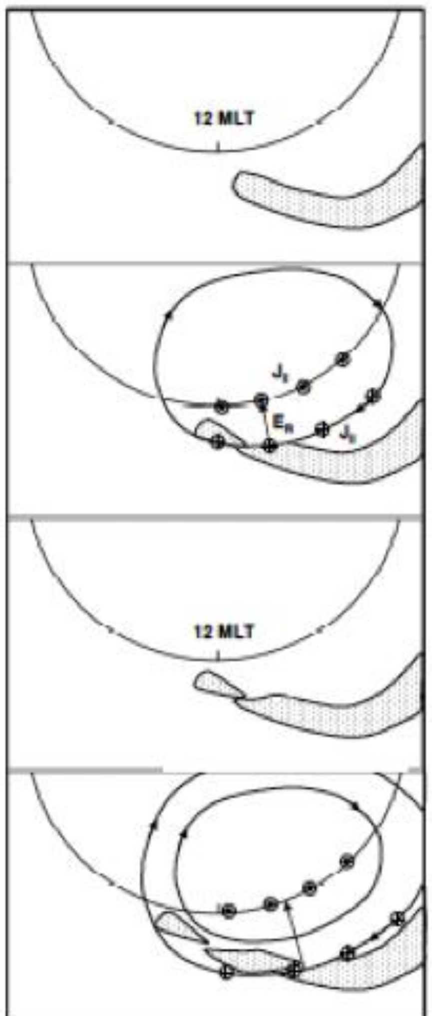


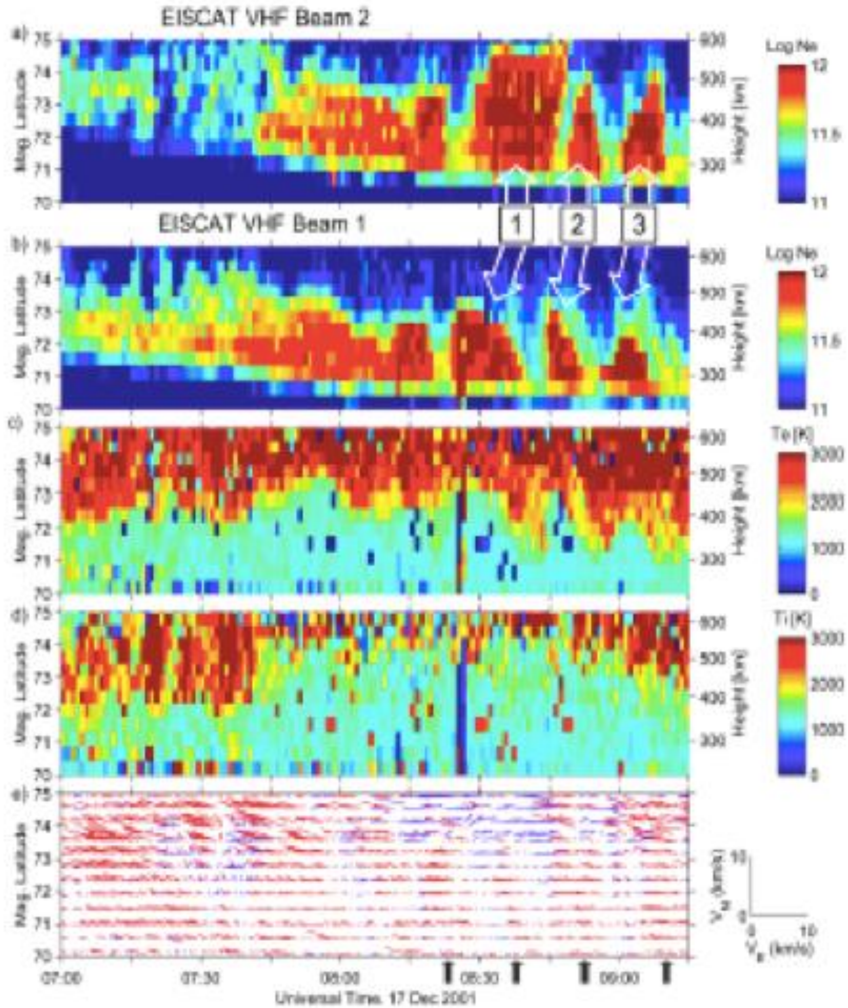
EXIT

RETURN

(Return) Blob "the second time around" Dual Beam Ne, Te, Ti, and Vi vectors!

(Moen et al, 2006)



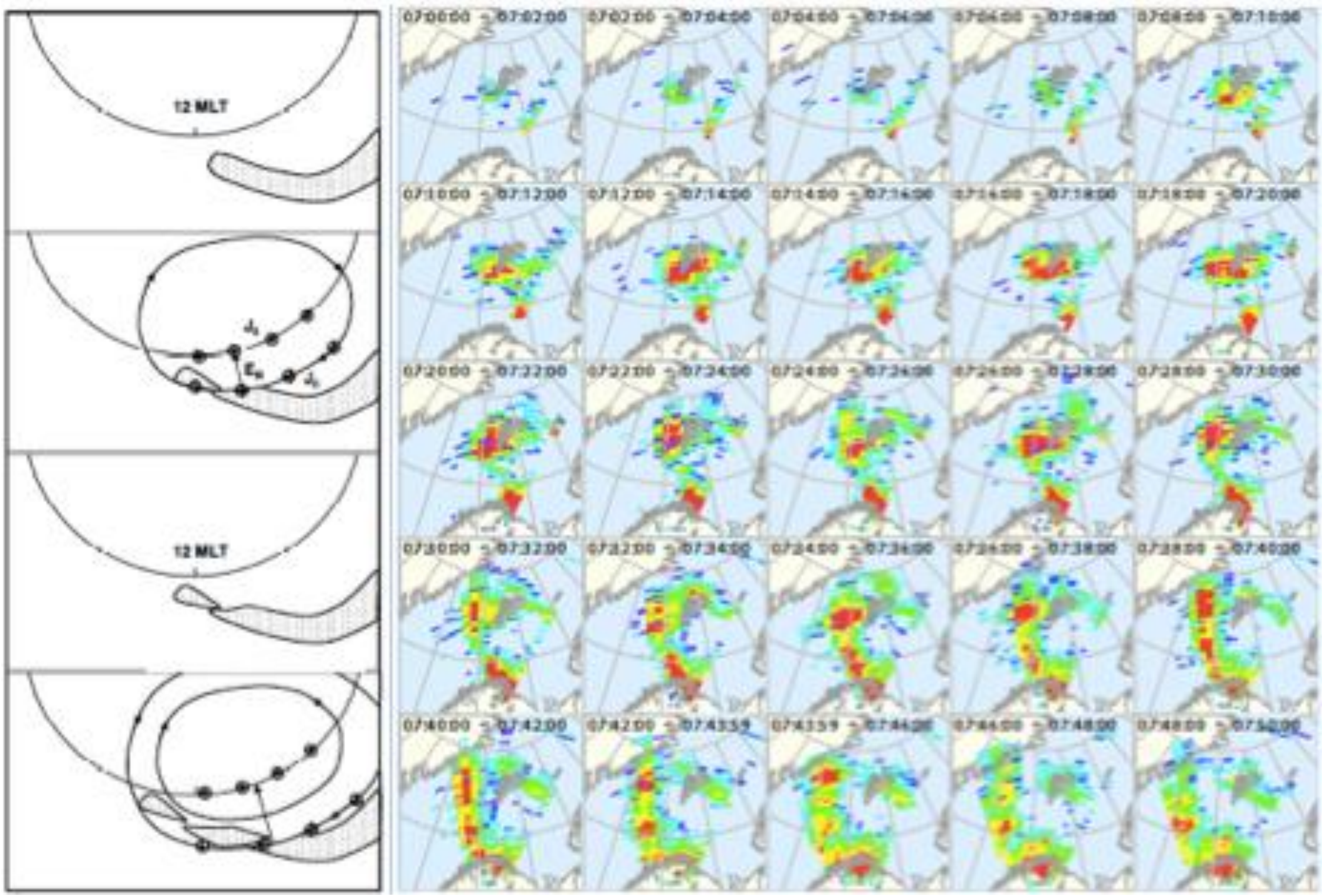


“Blob” returning to noon: segmented thru Cusp

CUTLASS HF backscatter-power IMAGE 07:00-07:45 UT

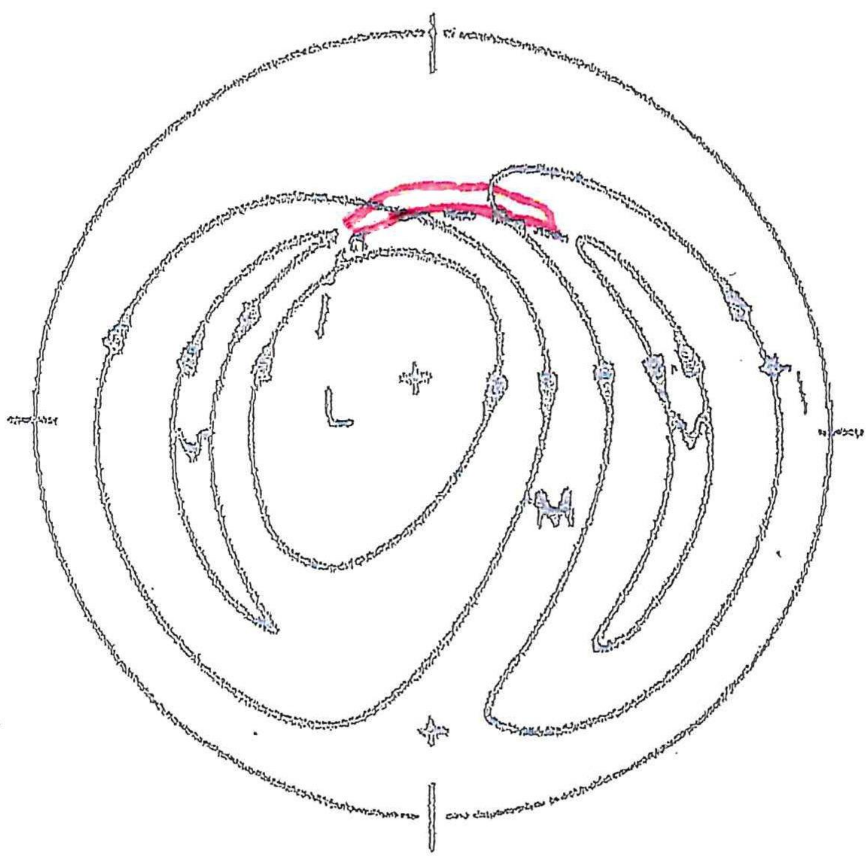
Matches dual beam EISCAT ISR electron density “islands”

Moen et al, 2006



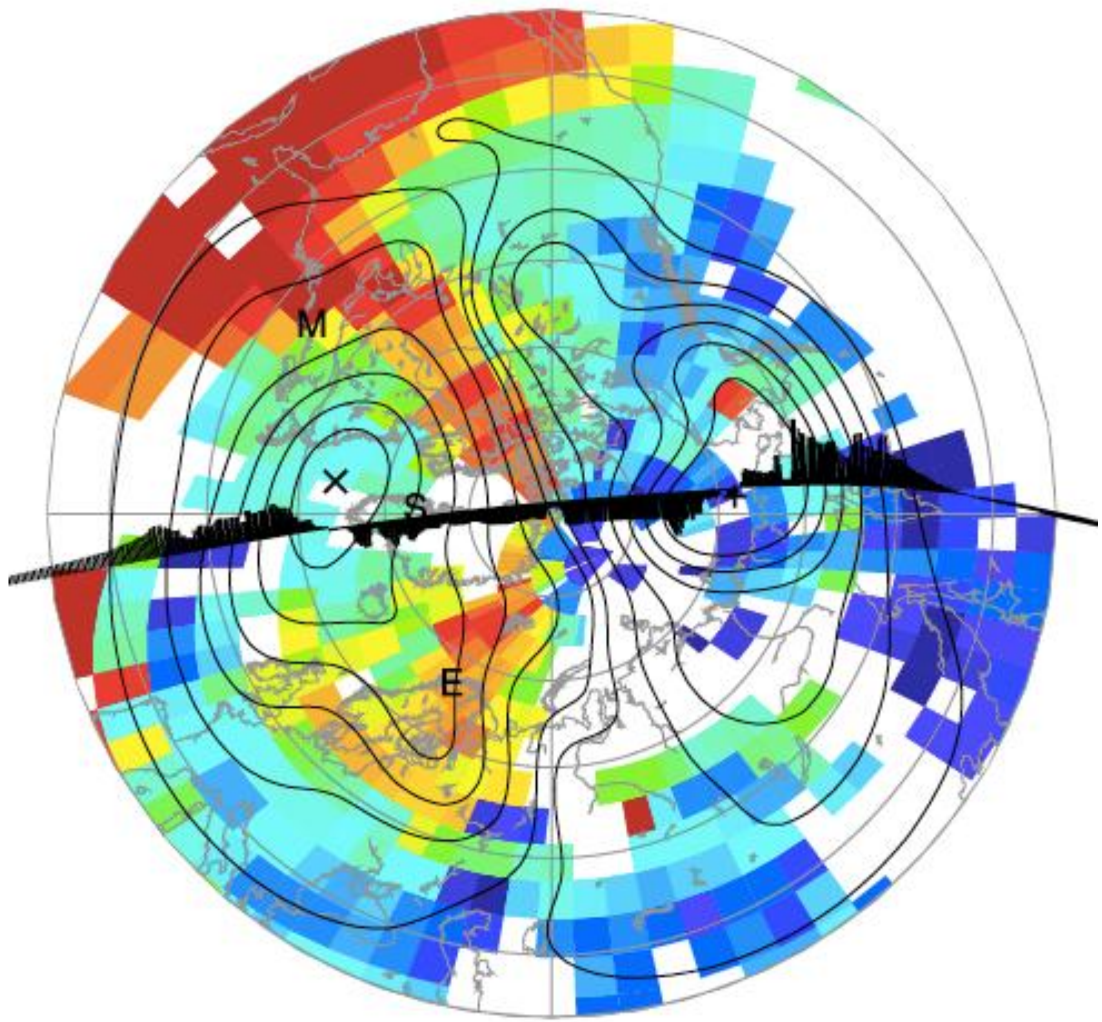
(Enter) IMF southward region Cusp [Flow Shear ~200 km x 1500+ km]

IMF $B_z < 0$, $B_y > 0$



Dramatic Tongue of ionization
(what is granularity within tongue envelope?)

(Foster et al, 2005)

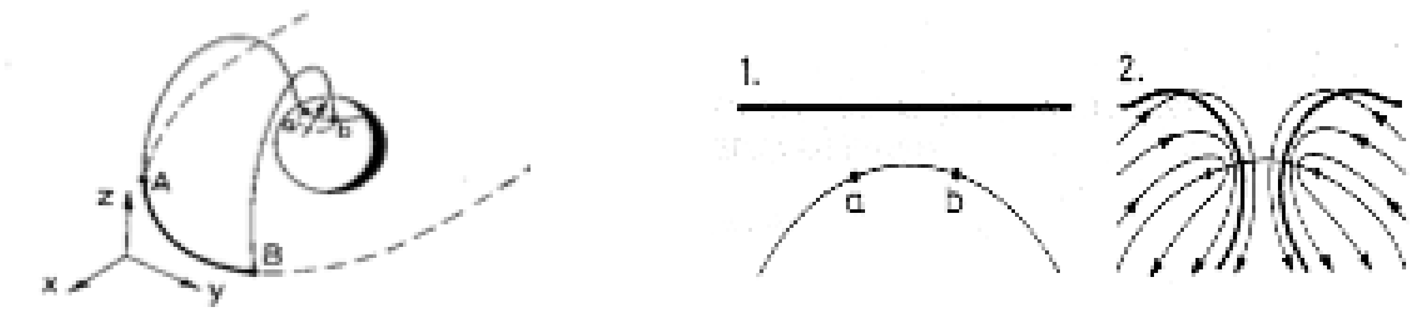


PULSED MAGNETIC RECONNECTION A-B

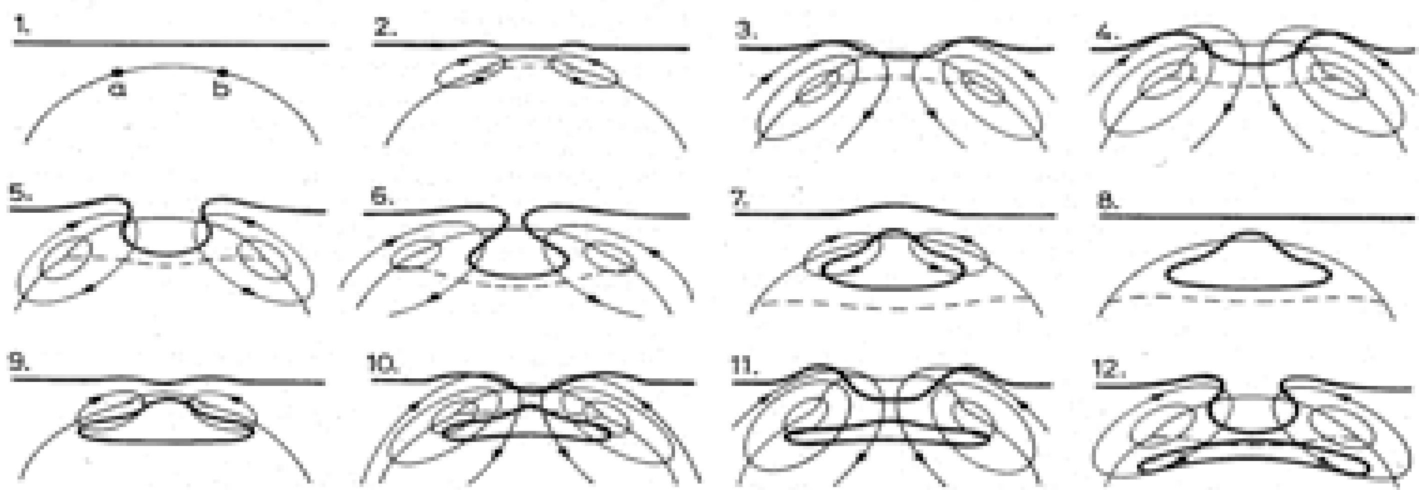
Merging gap a-b, noon top, --- Ne contour

(Lockwood and Carlson,1992)

STATIONARY MERGING GAP → TONGUE

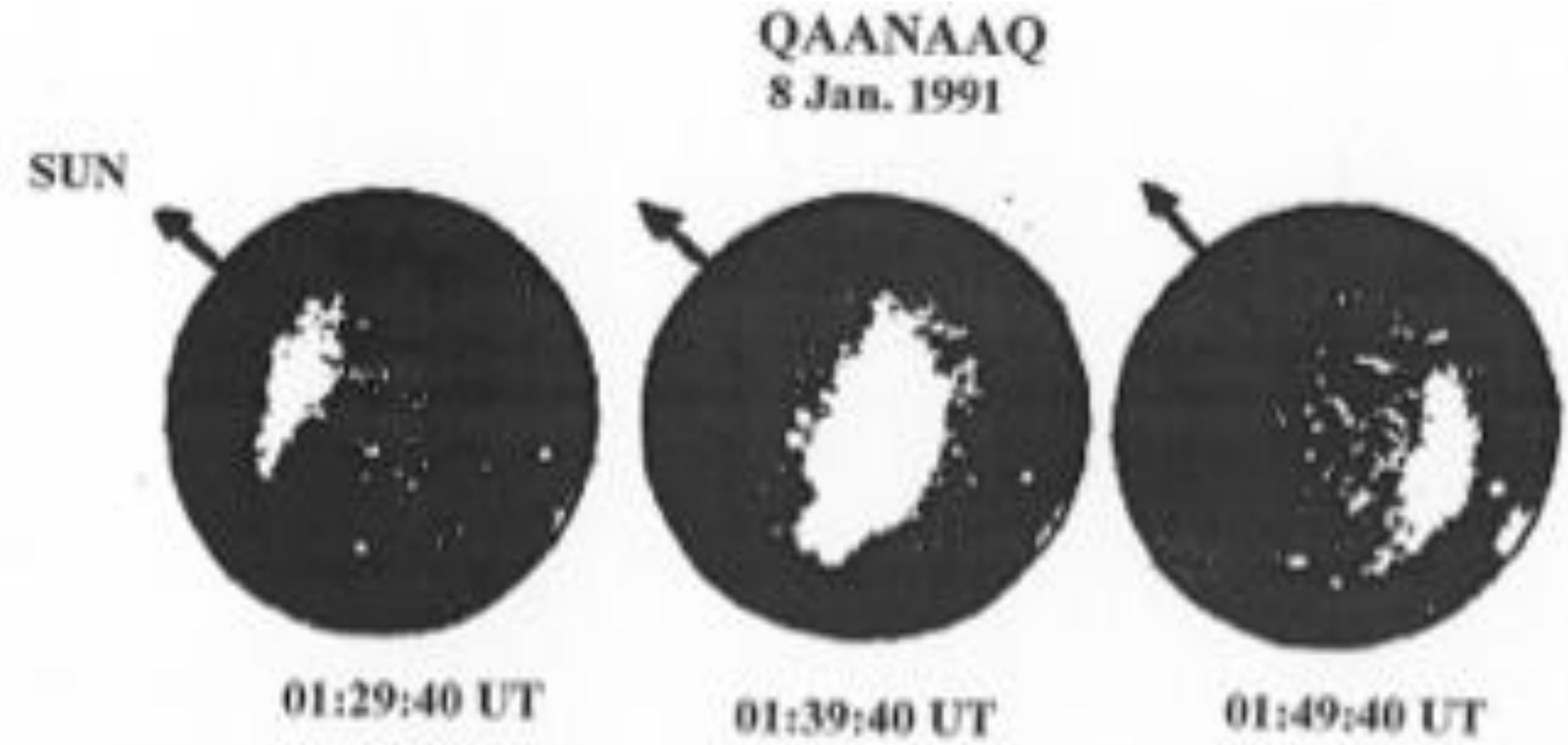


MIGRATING MERGING GAP → PATCHES



Typical Patch is Oval, antisunward
Most of time see flow jets and segments

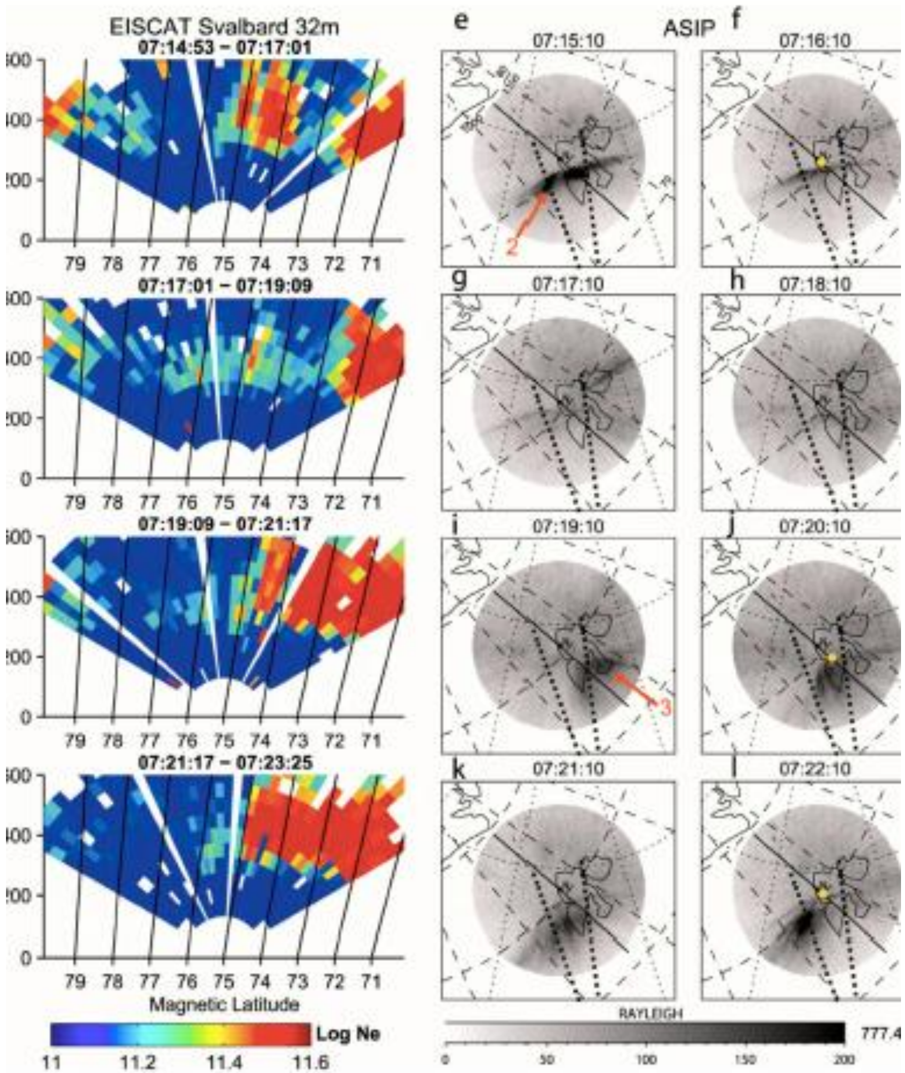
(Carlson, 1993)



': ASIP image of patch in central polar cap, showing typical oval shape c

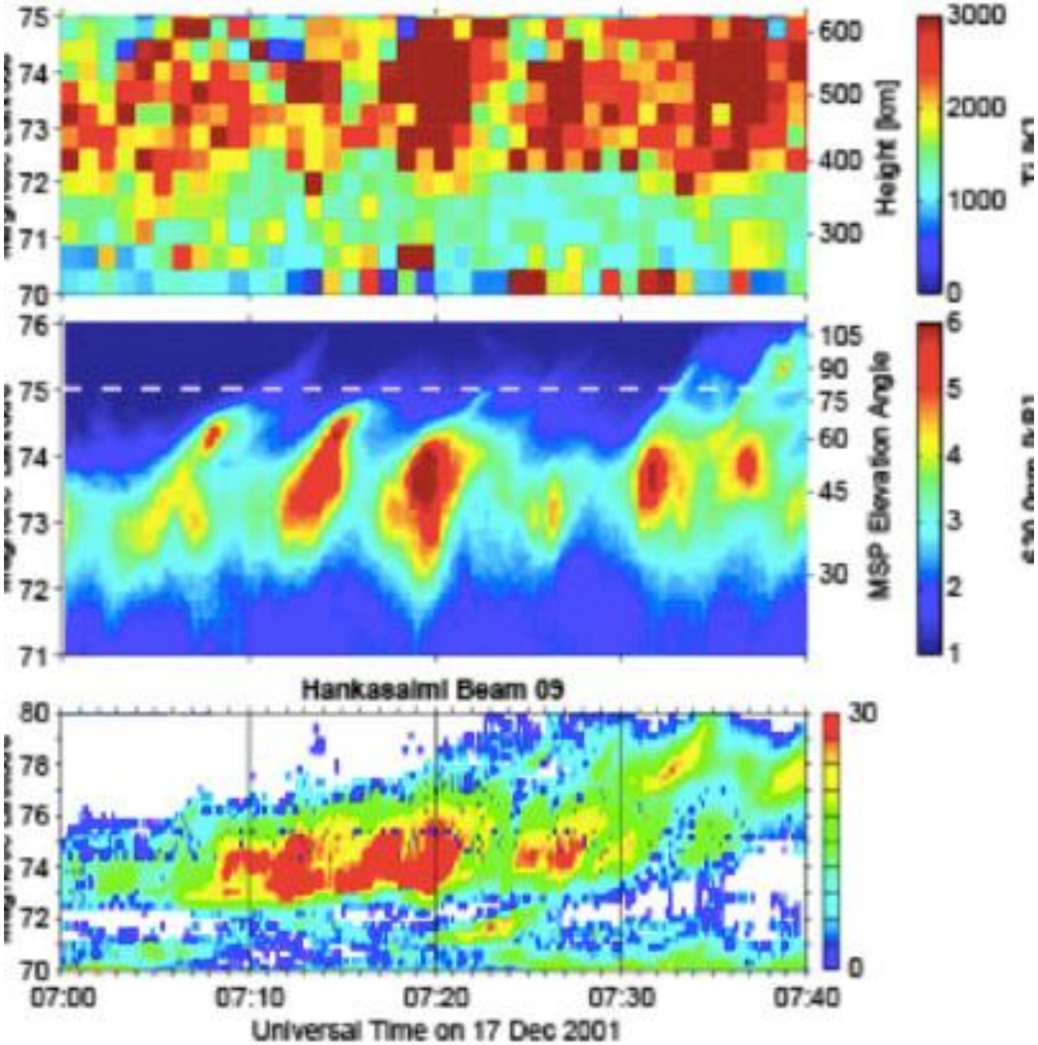
Left: Ne 71-80° latitude (red ~daytime Ne), 2 min frames: top fossil patches, mid birth of patch Right: ASIP 777.4 showing two PMAFs (grey),

Carlson et al. 2006=



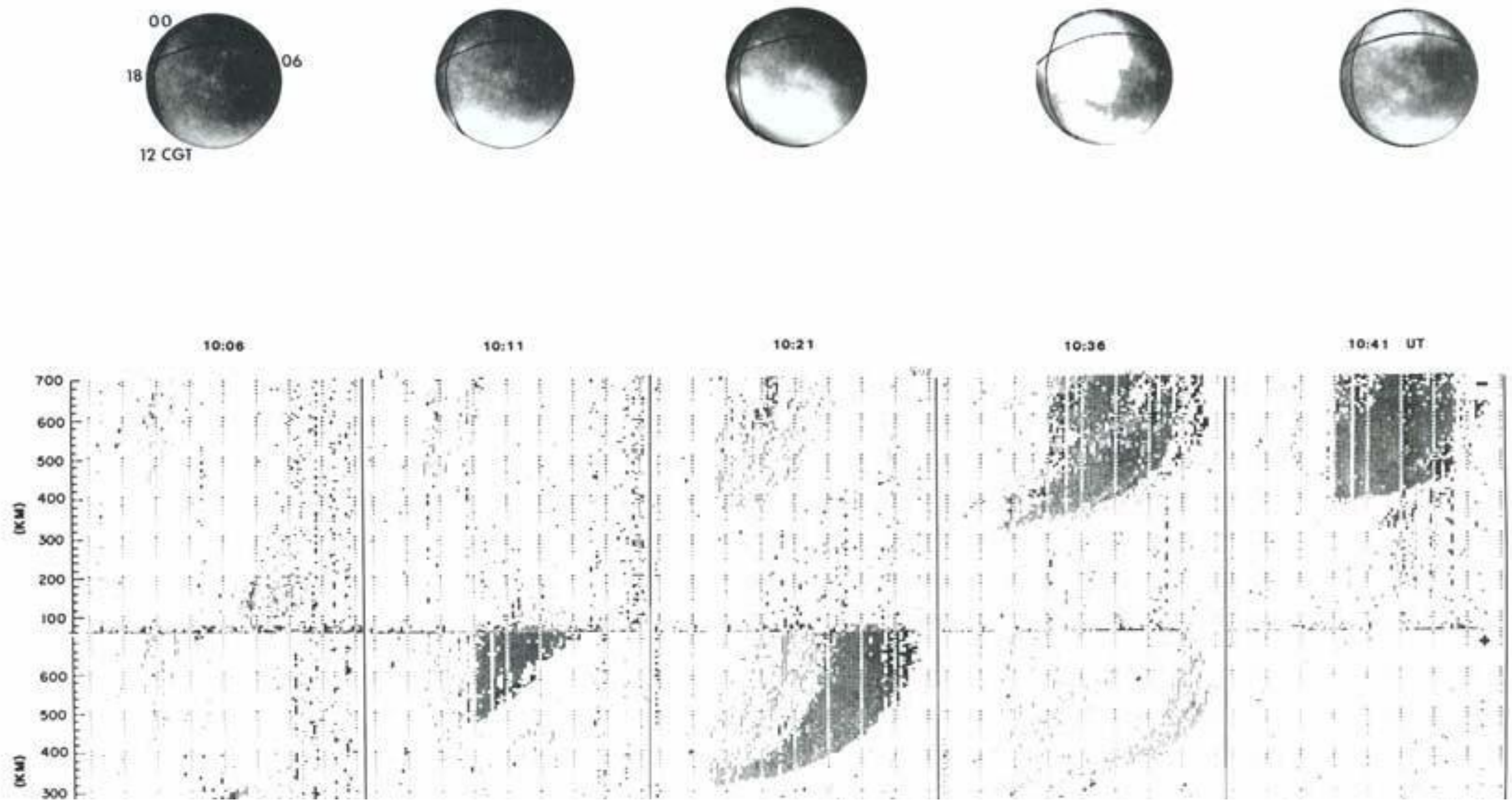
Coincides with Flow shear, PMF, structure

Carlson et al, 2008

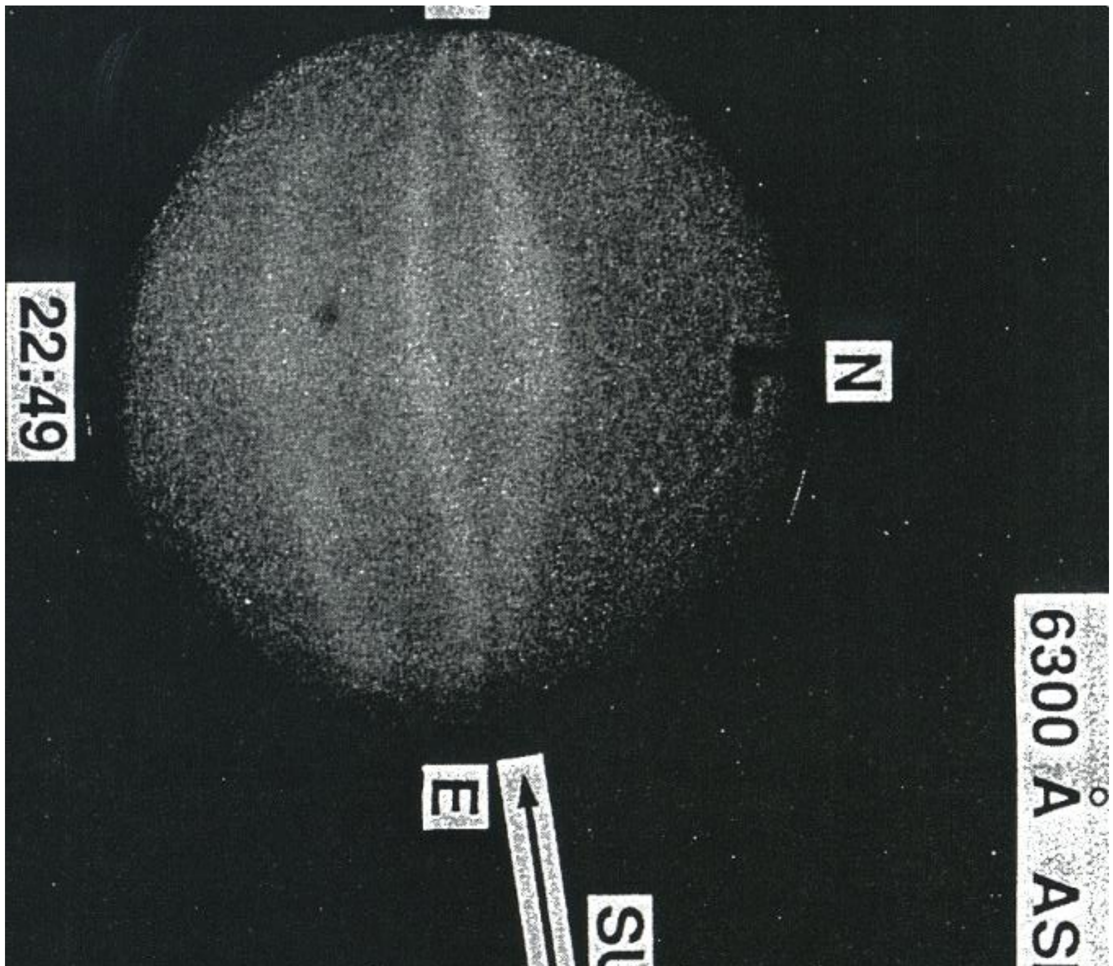


(Cross)Patches Characerize IMF southward
Why called PC "Patch" when discovered

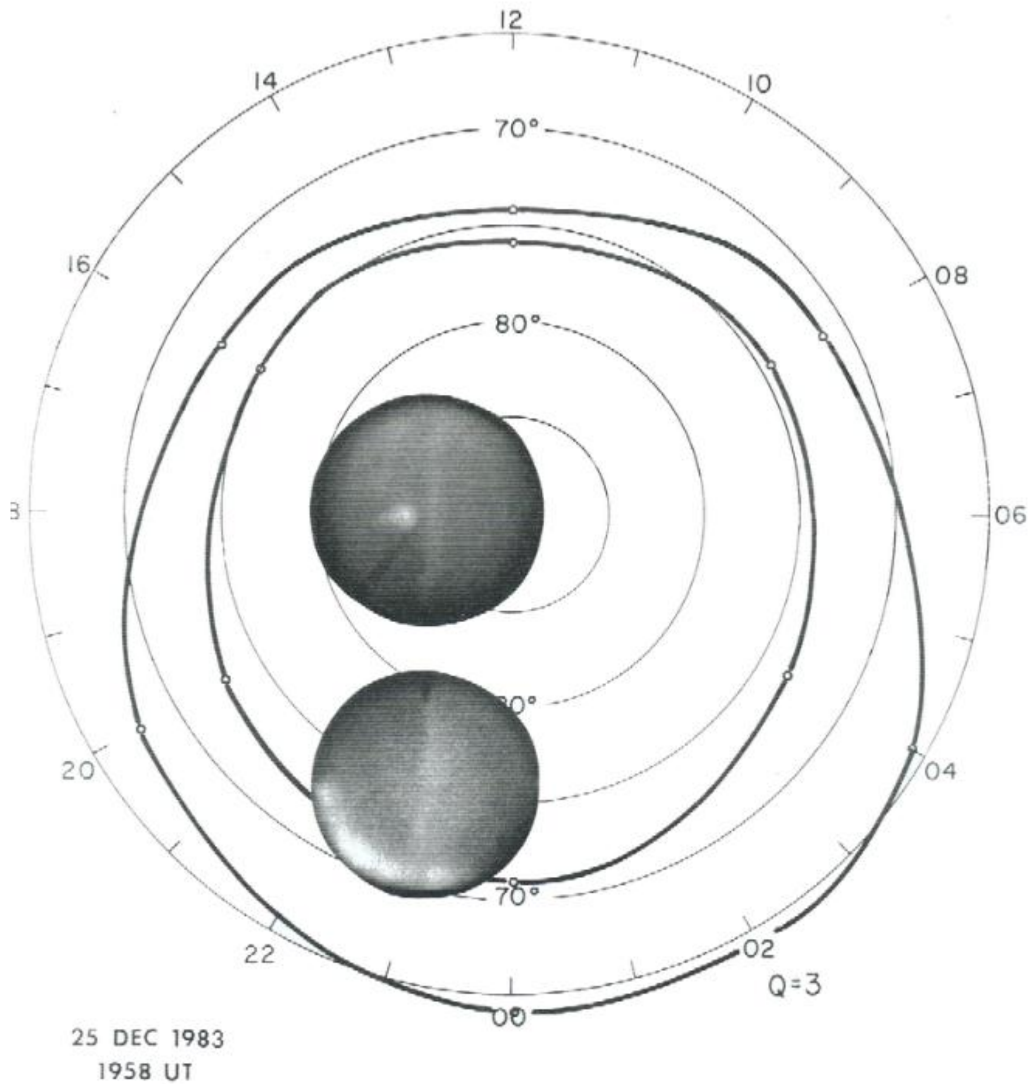
(Buchau and Weber, 1981)



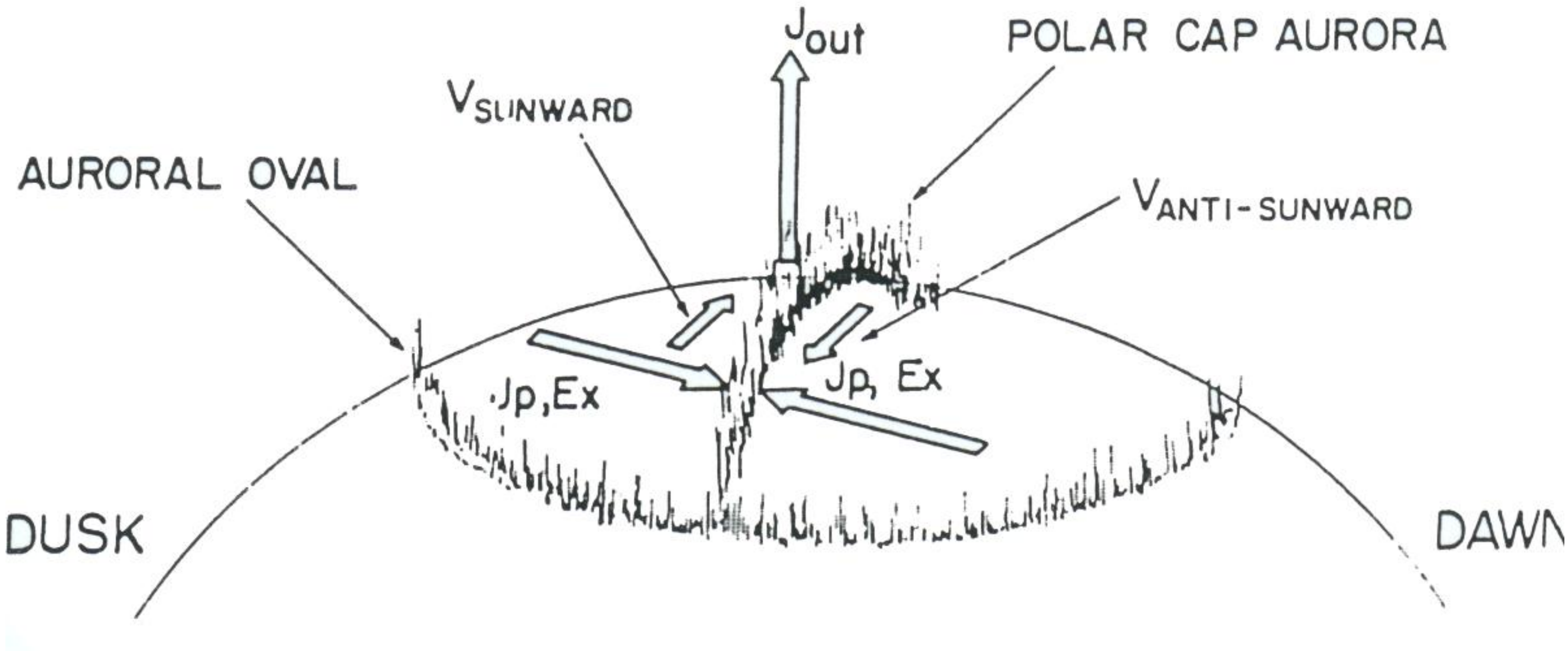
Sun Aligned Arcs Characterize Northward IMF (point towards thw sun)



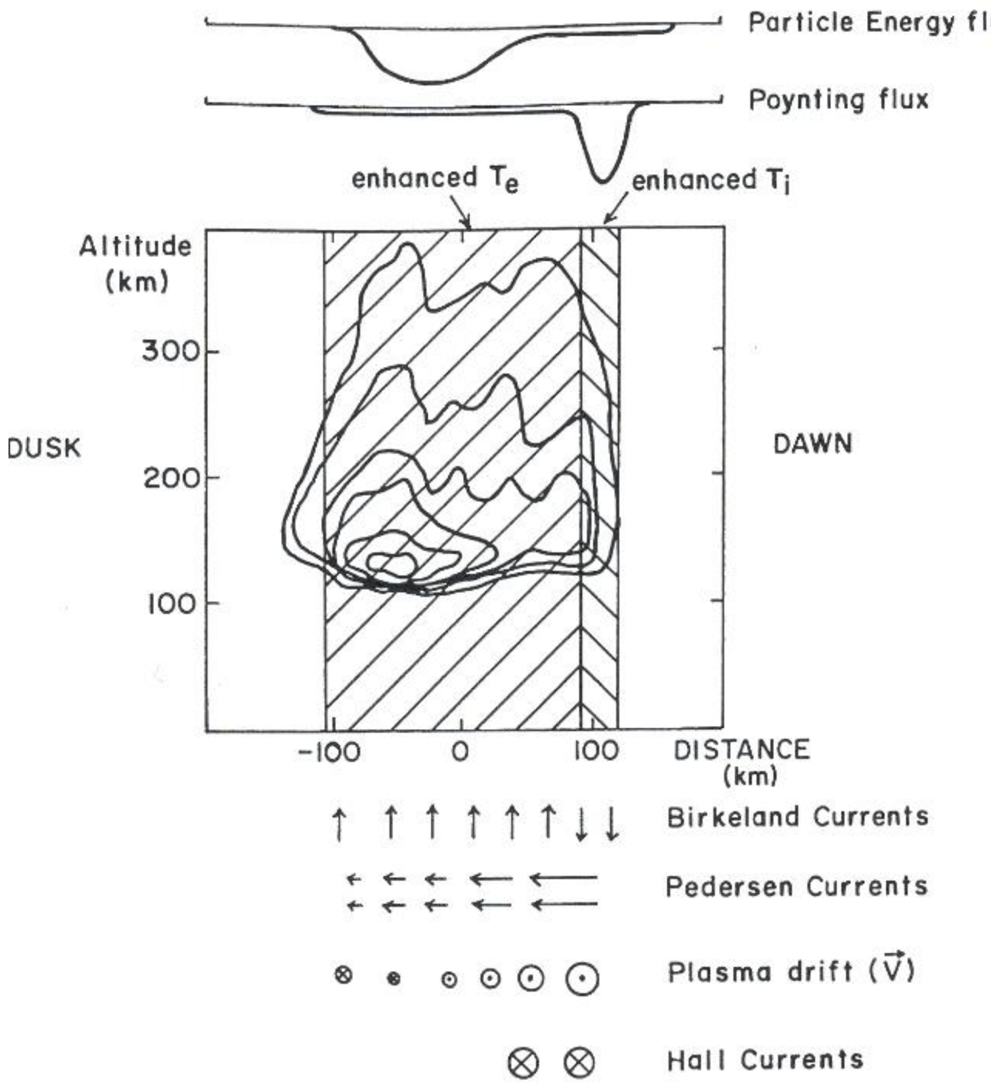
PS Arcs characterize IMF Northward
Within minutes, much weaker than Theta Aurora



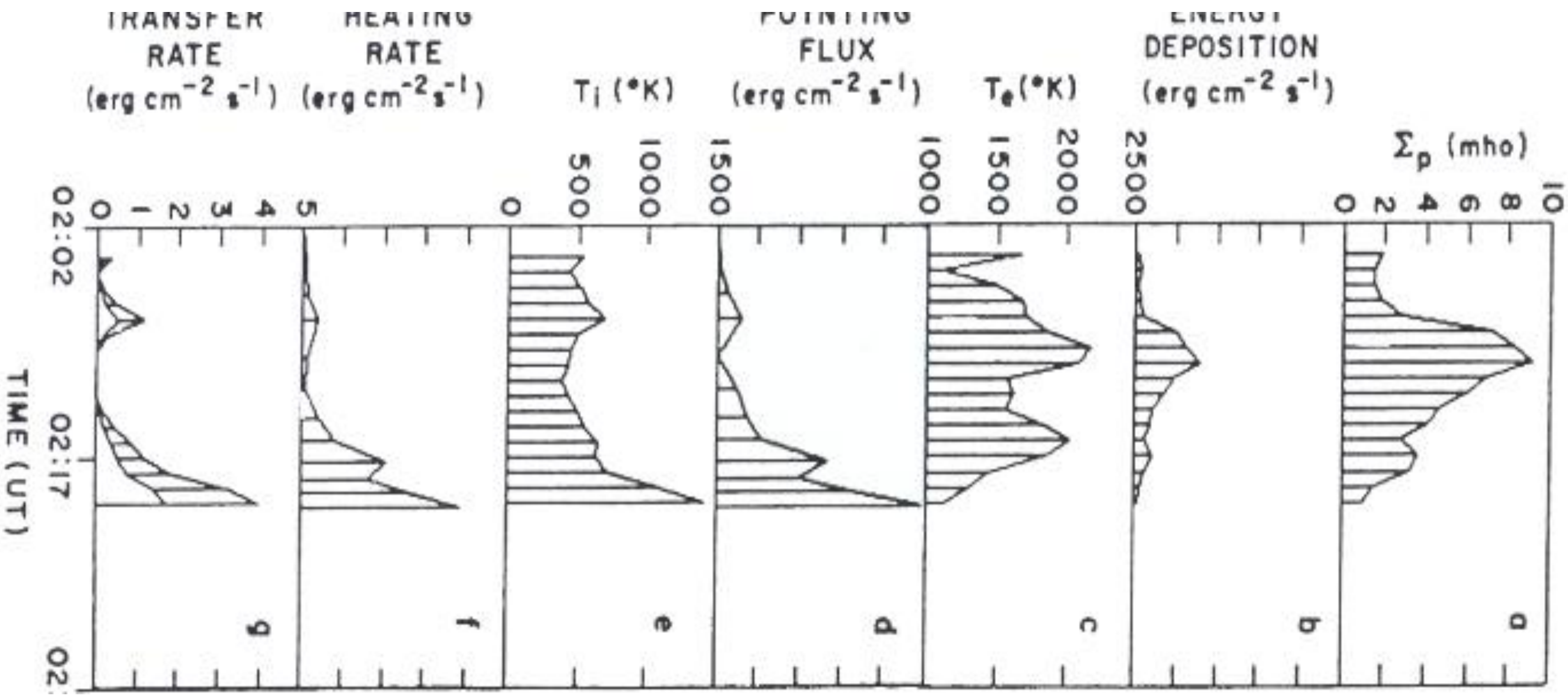
Currents are in rest frame of the Neutrals



Sun Aligned Arc
Thermal/energy/electro dynamics



Sondrestrom derivation of thermal and energy balance terms Poynting, Joule, Ti->Tn, Particle, Σ_p



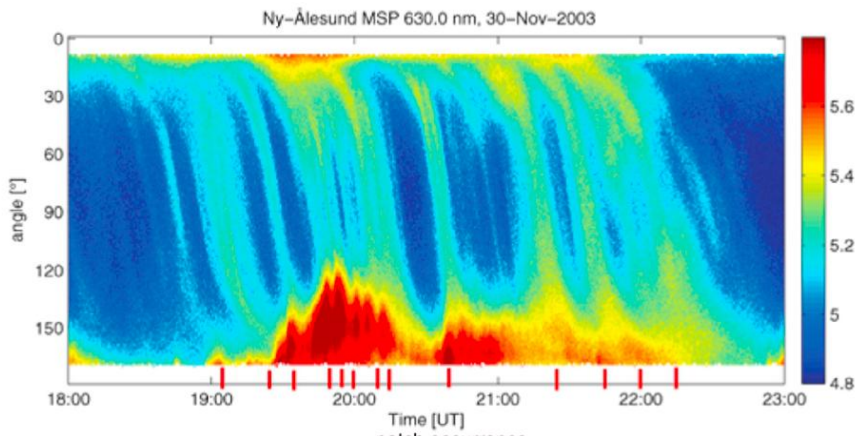
(Exit) Patches Exiting PC (recon?)

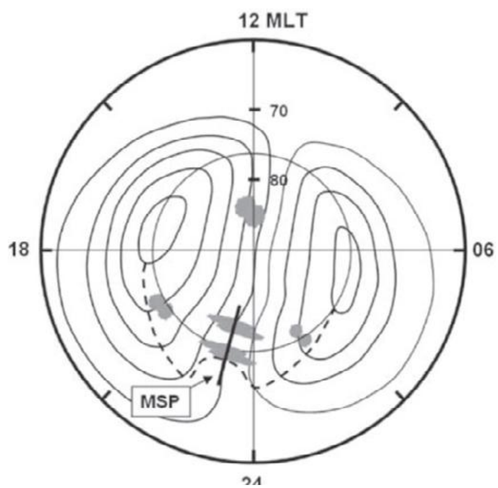
Trajectory, Morphology. Physics of patch exit

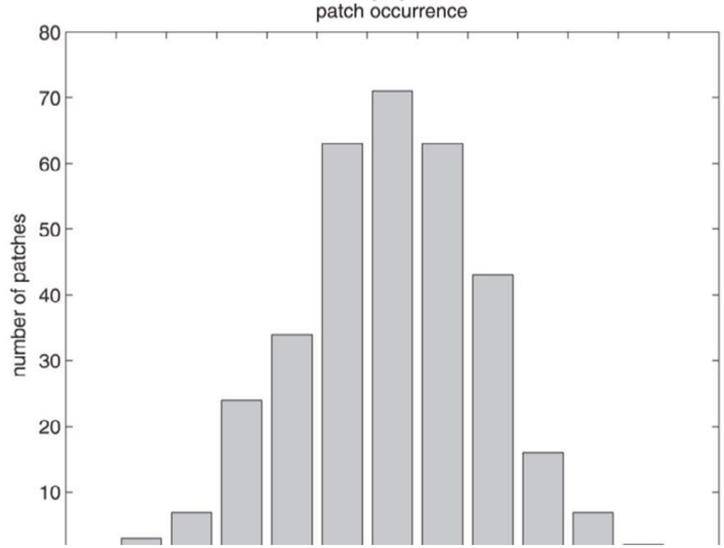
Moen et al, 2007

Occurrence rate of polar cap patches

- Eight winters (1997-2005) of MSP data from Ny-Ålesund have been analyzed
- 43 nights, 333 events
- About 60% of the patches exit the polar cap from 22-01 MLT, but patches was observed in the entire MLT range from 18:00-05:00.





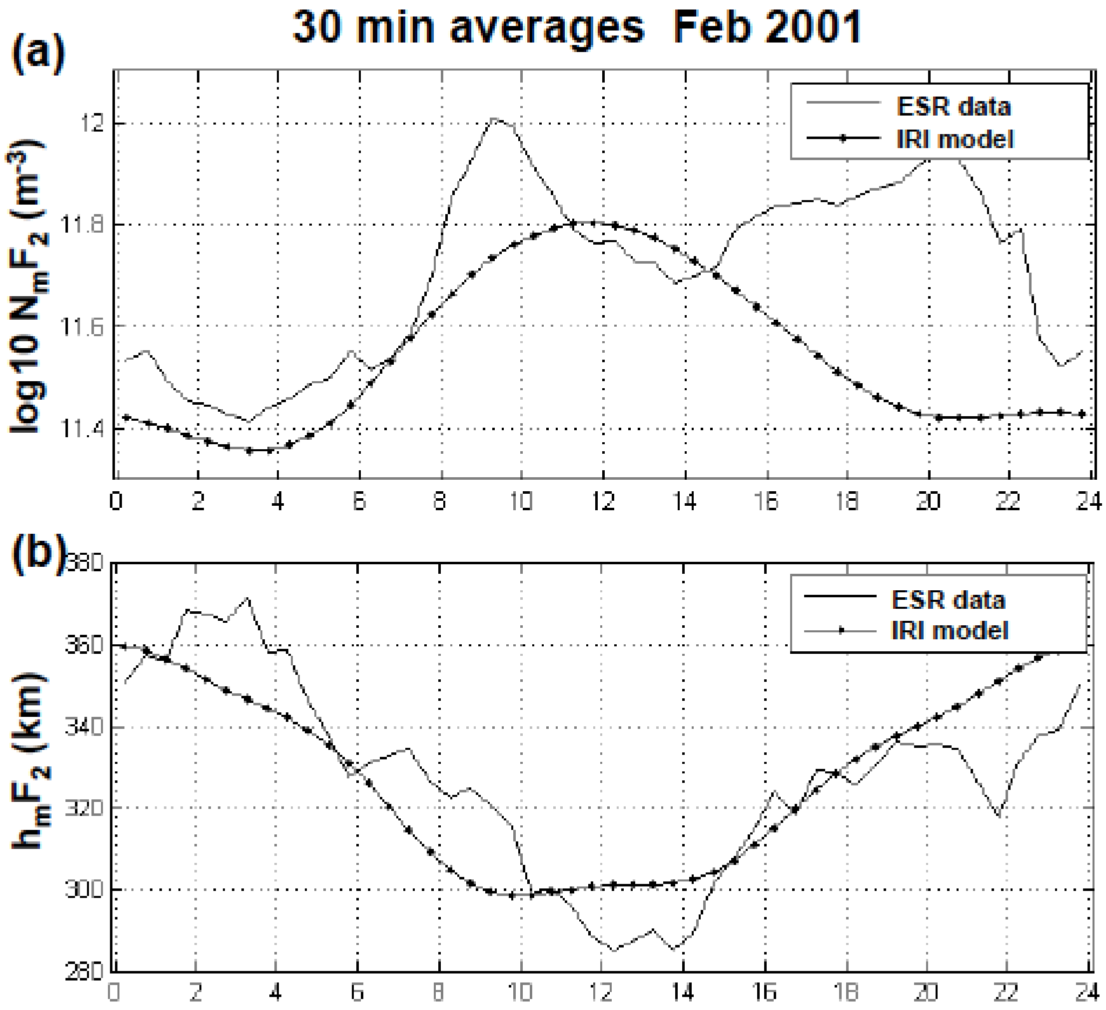


IRI can benefit greatly where data-starved

(Climate vs. Weather) Cusp N_mF_2 Peaks ~noon & midnight

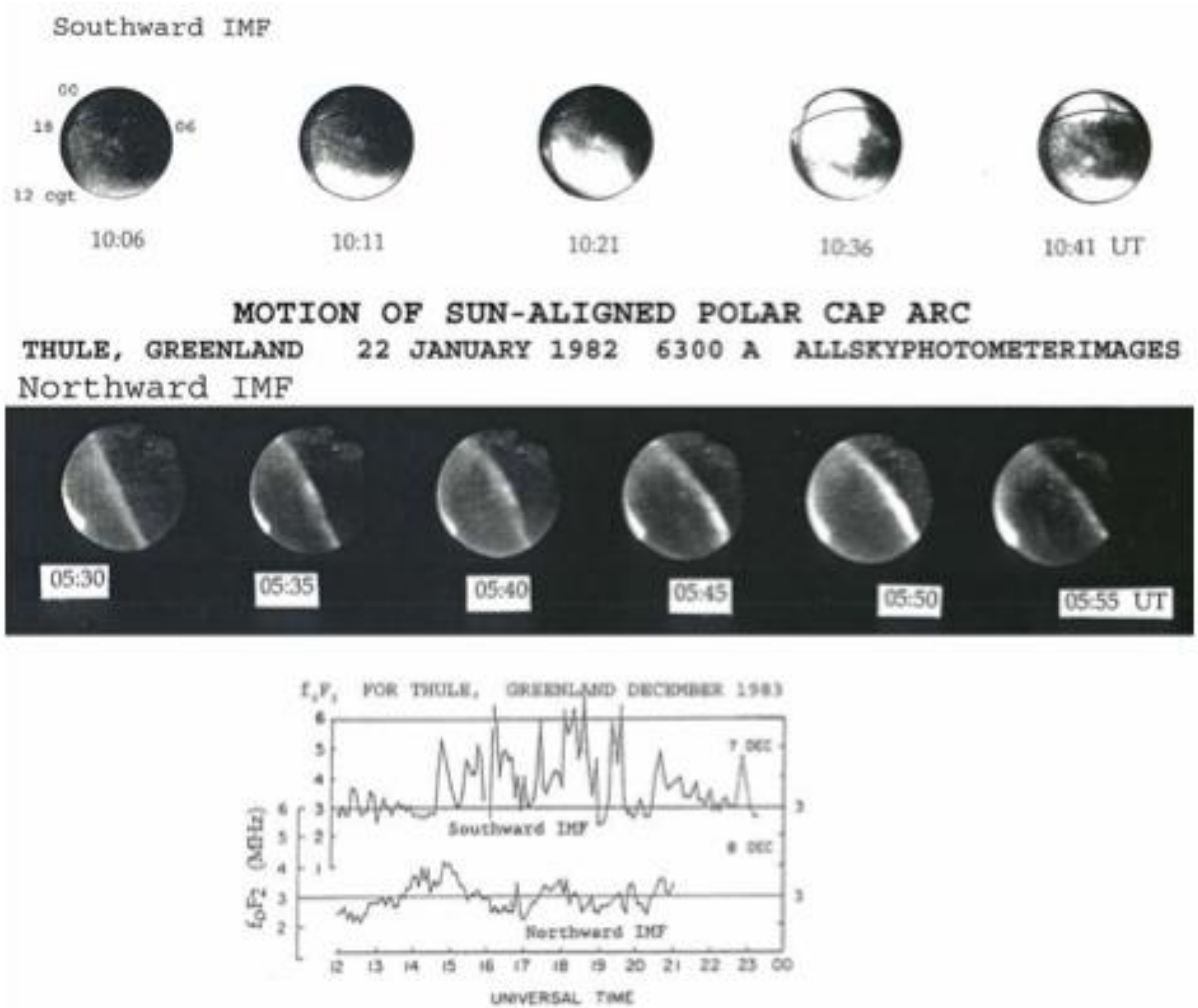
Several data starved parameters could benefit

Moen et al, 2008



<u>PC in "Two States"</u>: IMF South, North

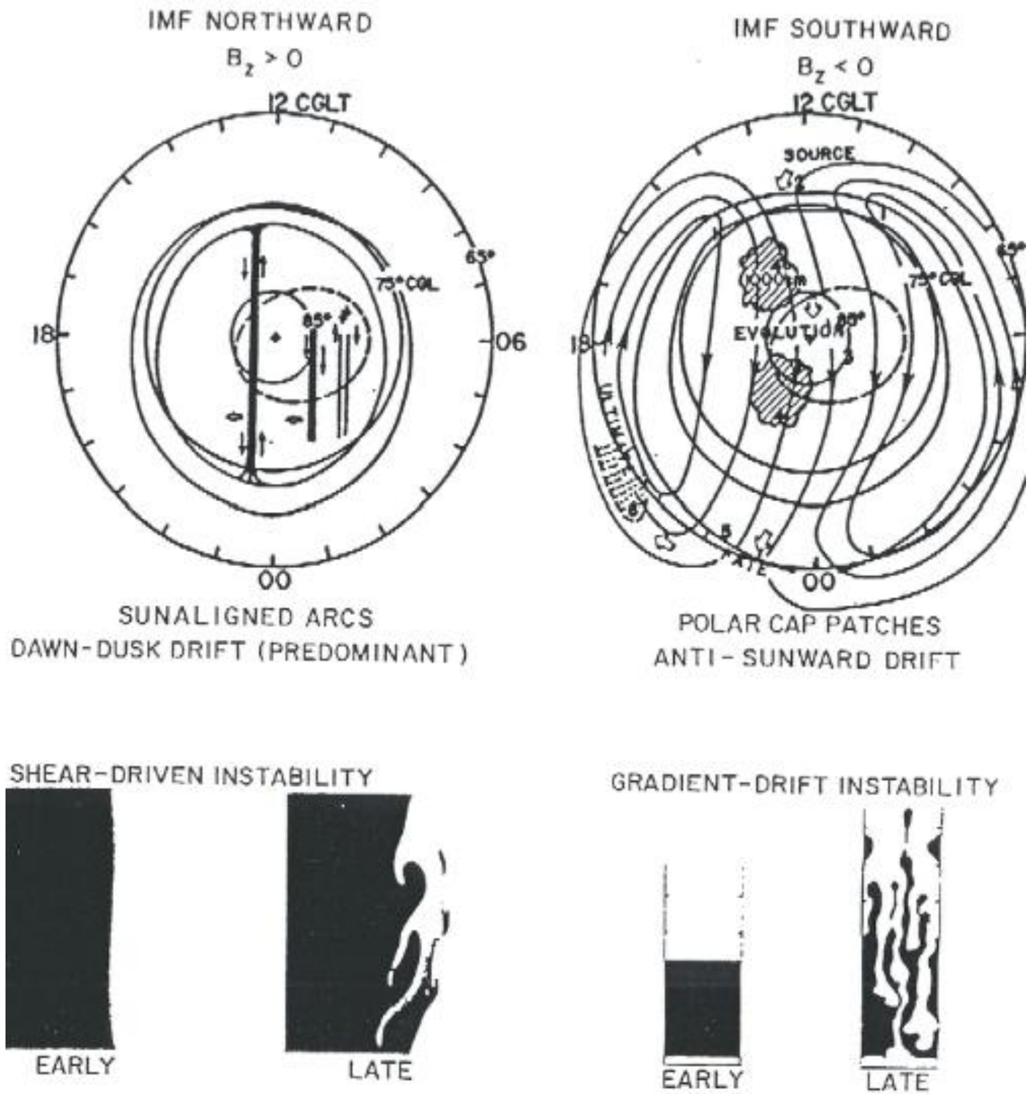
Detect in cusp in 2 min, flow channel in 5



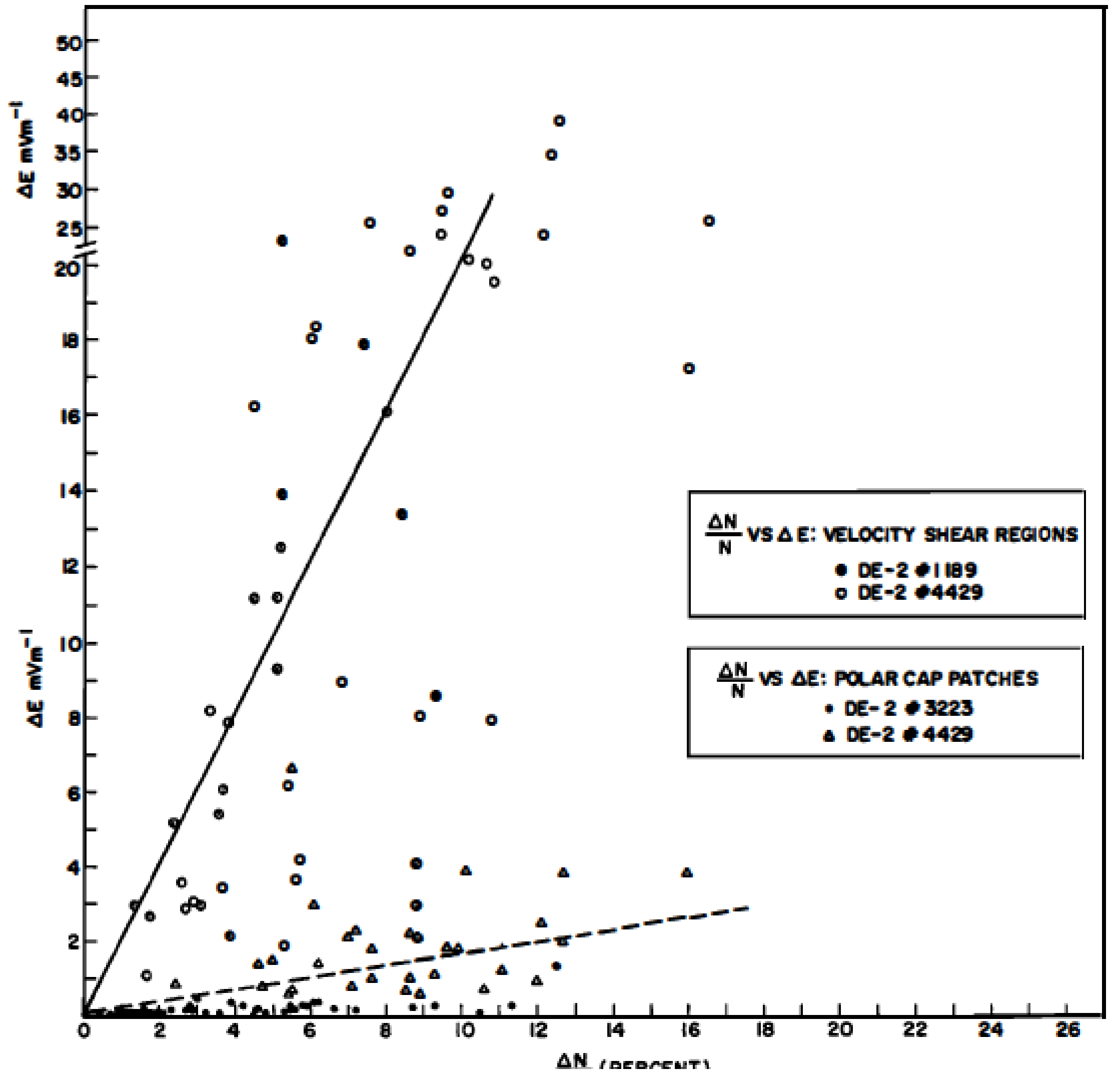
Polar Cap F-Region Structures: TWO states

Left: IMF Northward, velocity shear driven

Right: IMF Southward, late time Gradient drift

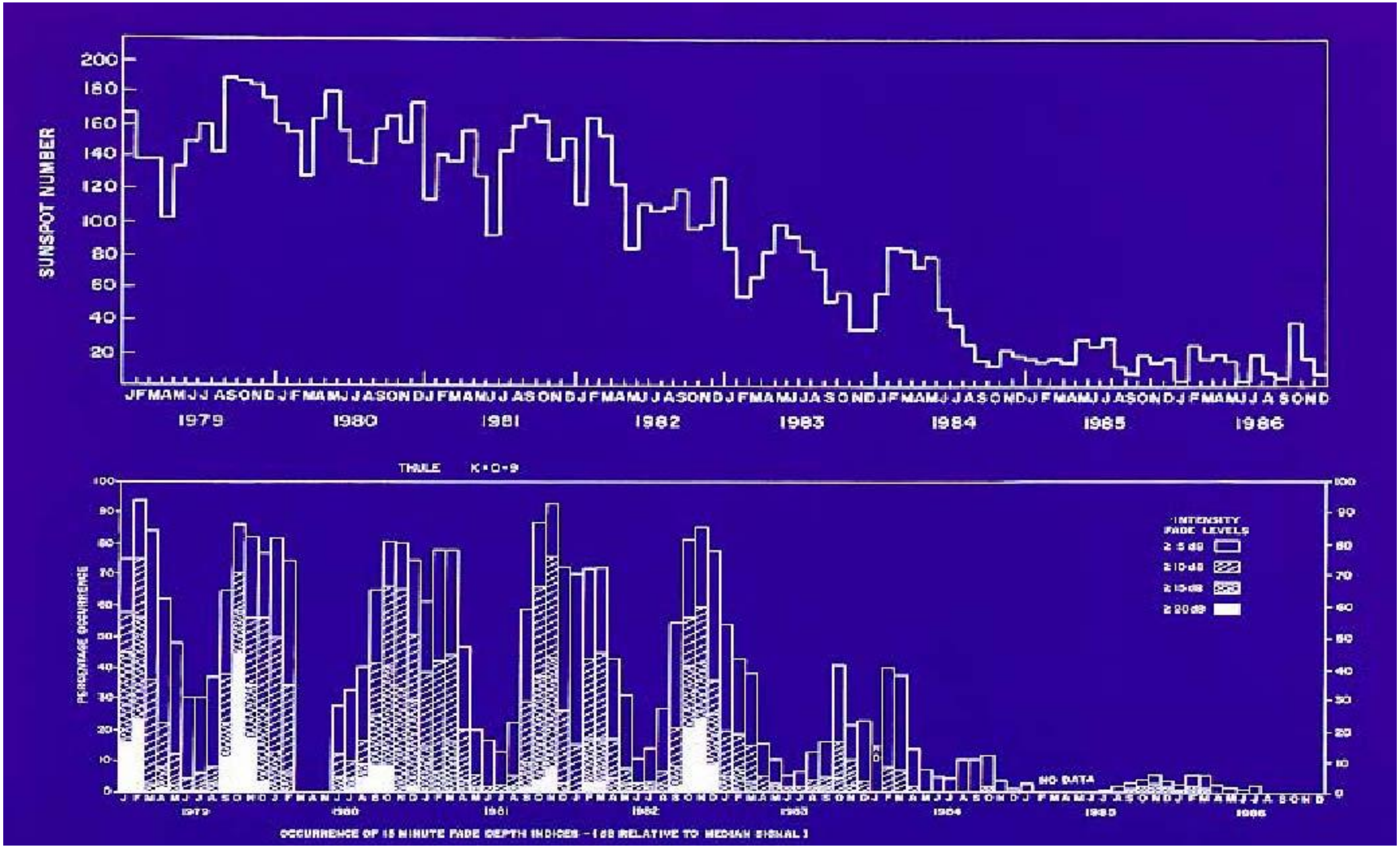


δE/(δNe/Ne): observed in Polar Cap Velocity shear 10x Gradient drift



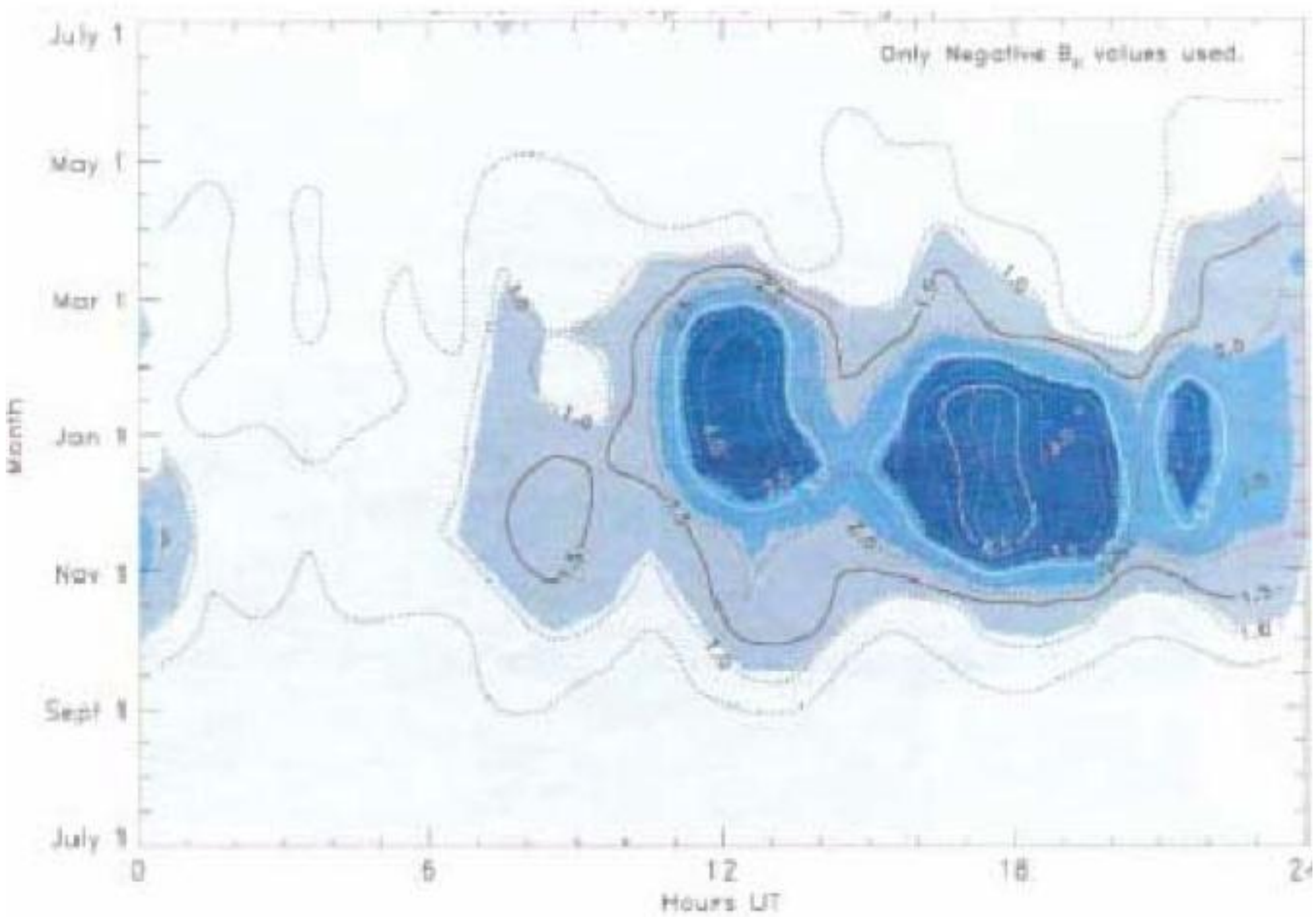
Solar cycle variation of PC scintillation
Can disrupts Communications and Navigation
Almost an on/off 6-year switch

(B(Basu et al1988)



DE Patch Frequency (IMF south) Strong UT winter dependence

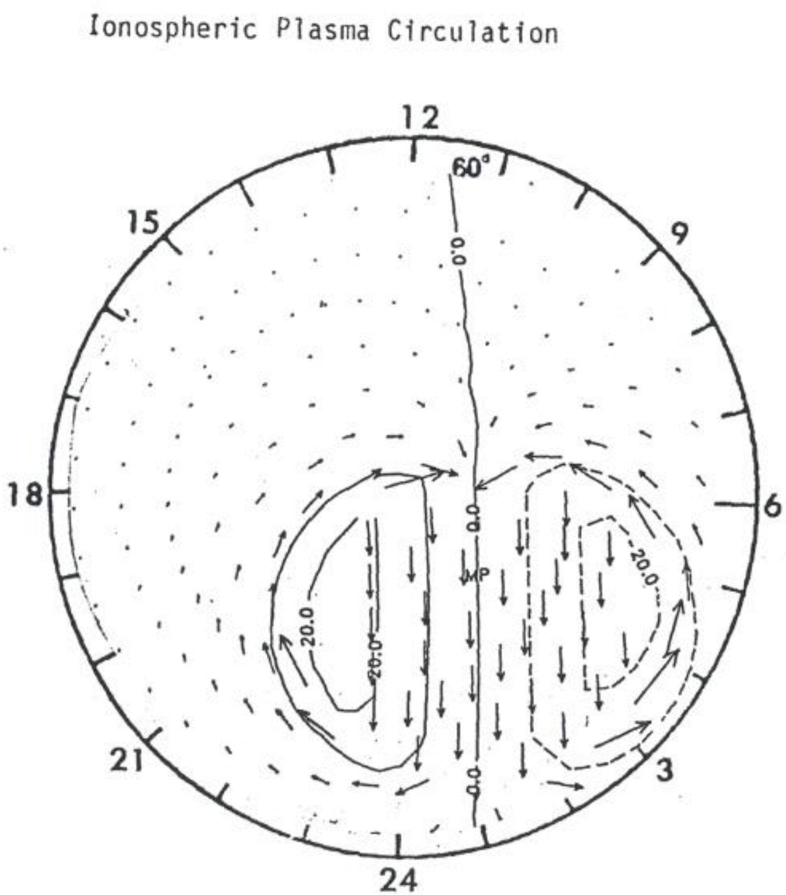
(Coley and Heelis 1998, Basu and Valladares 1999)

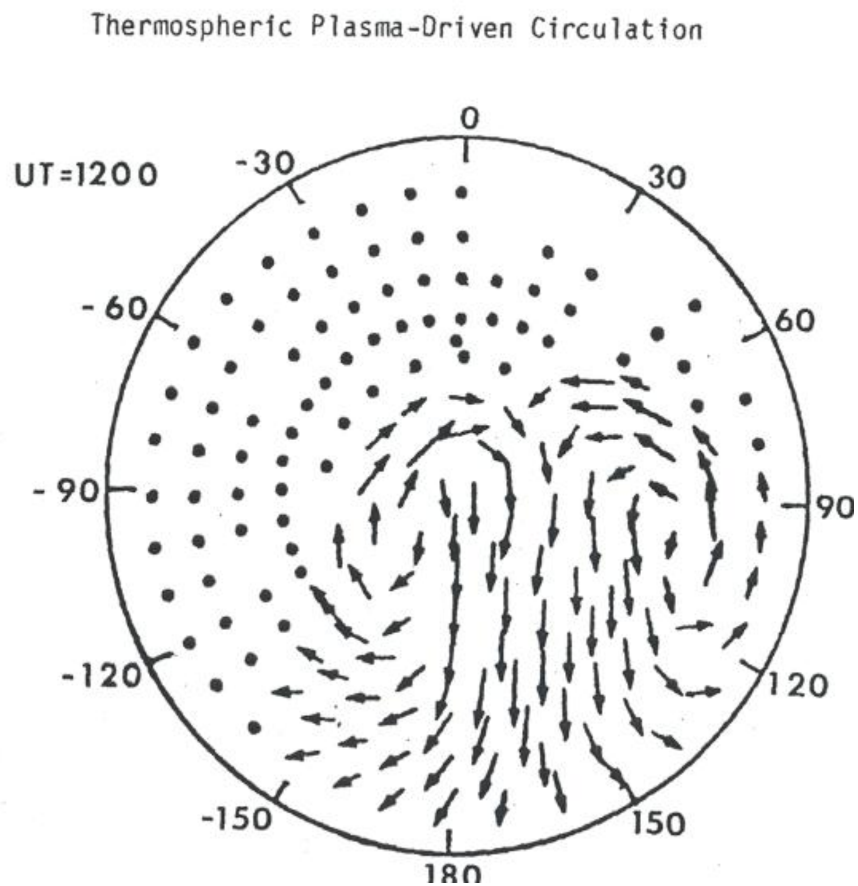


Neutral Gas i-n Momentum (no gradients)

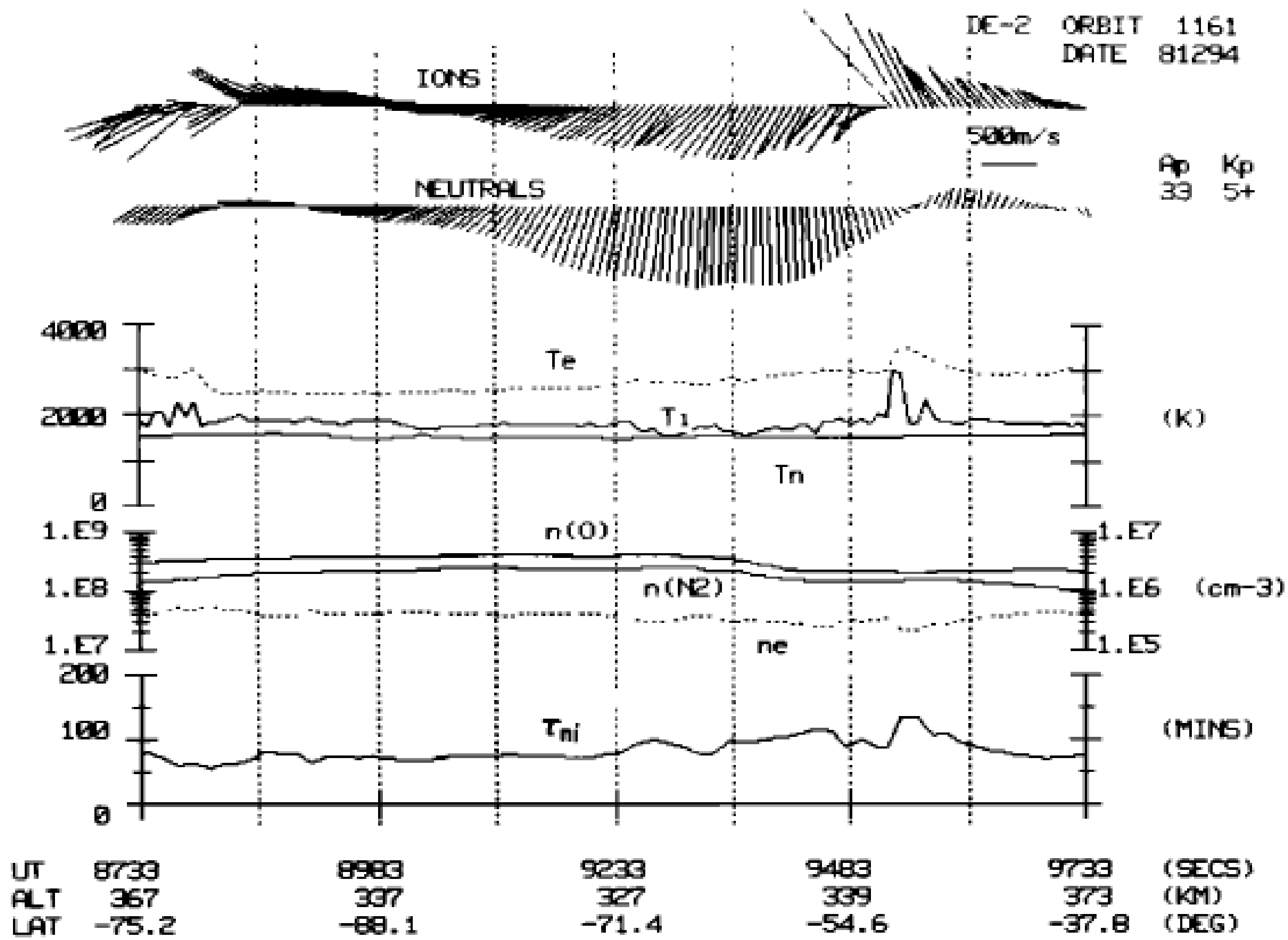
$$dV_n/dt = (\rho_i/\rho_n)\, \nu_{in}\, (V_i - V_n)$$

foF2: 9 MHz ~ 0.5 hr; 3 MHz ~ 5 hrs

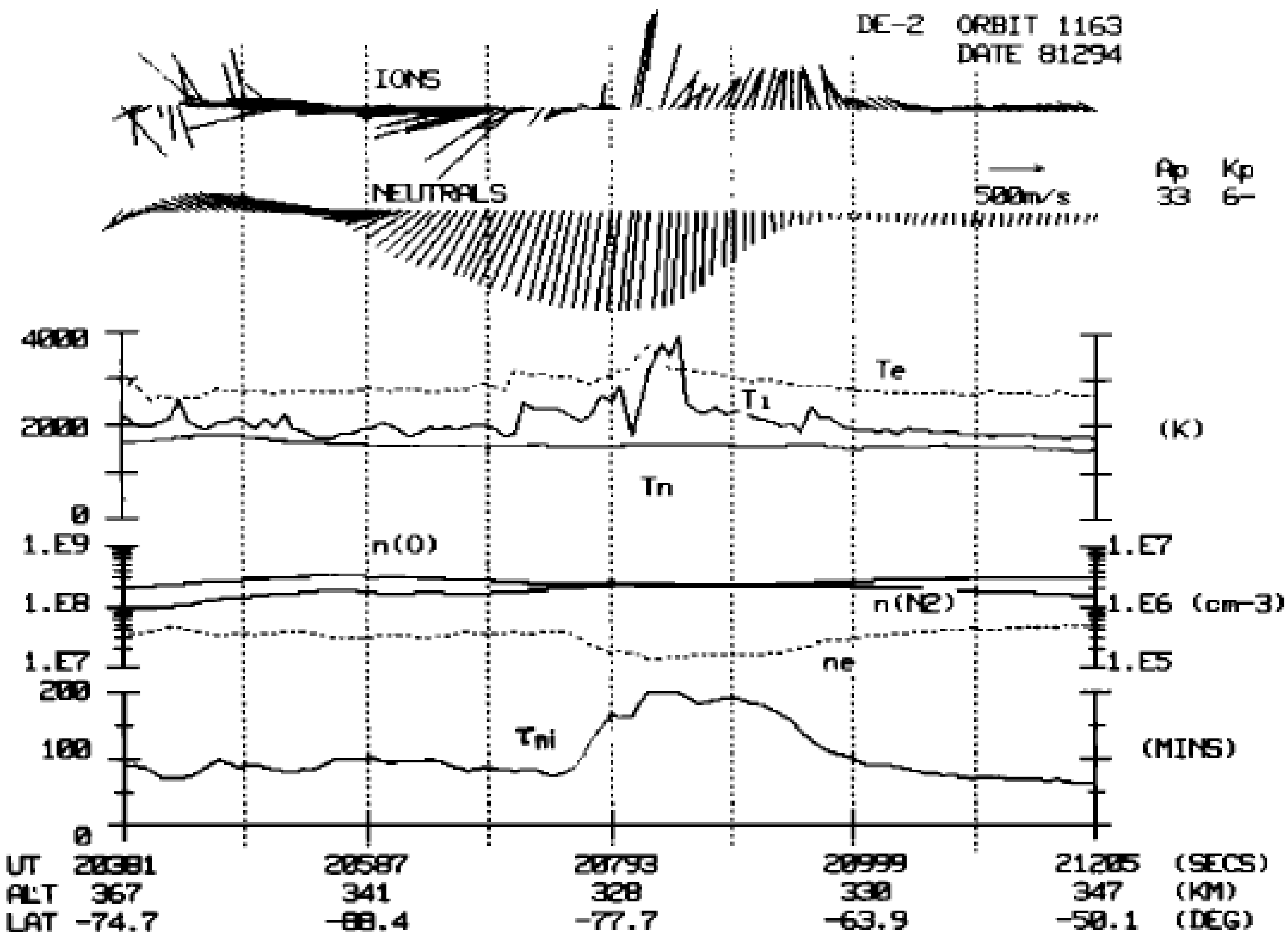




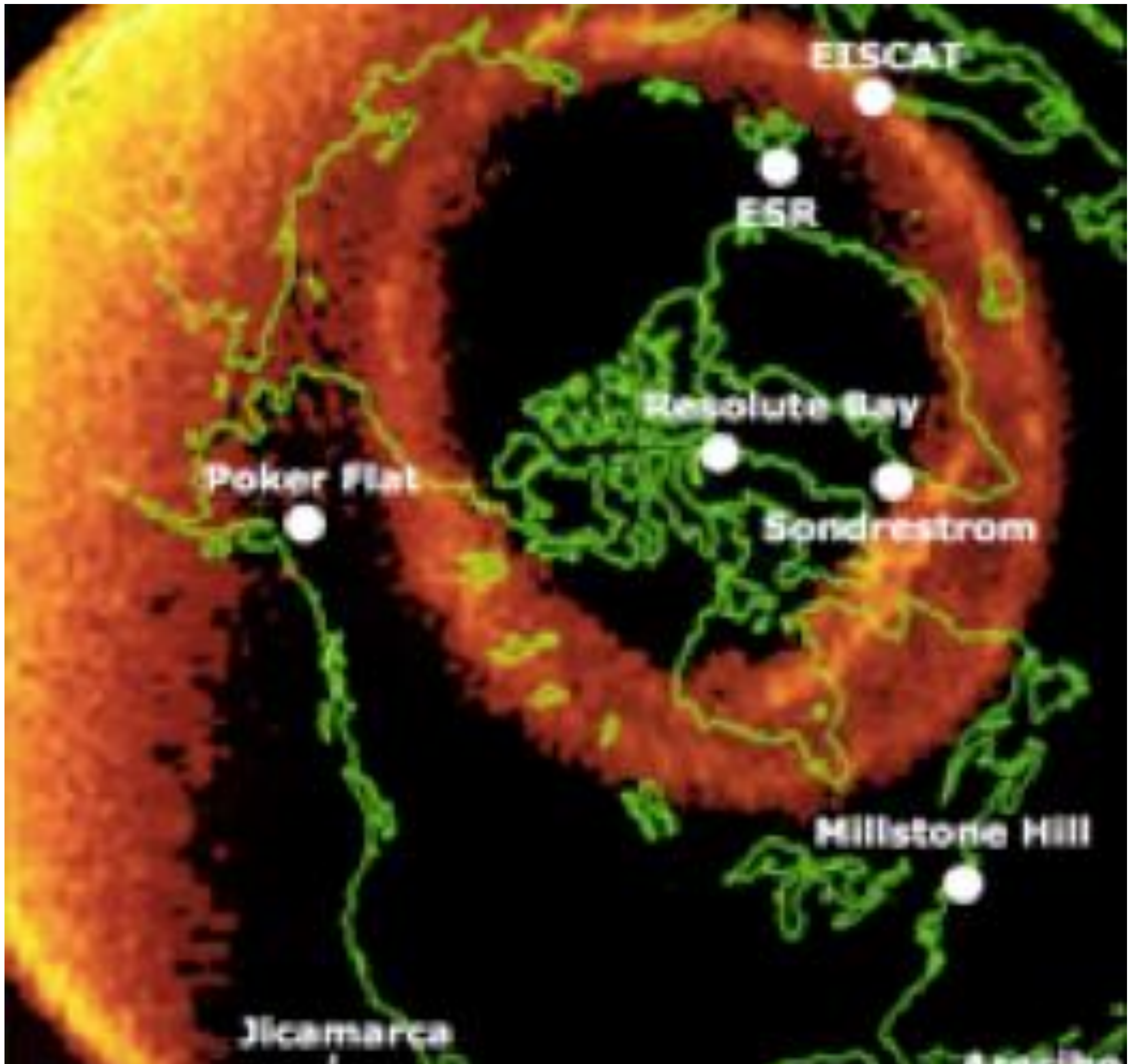
Vn up to speed with Vi (Climate)



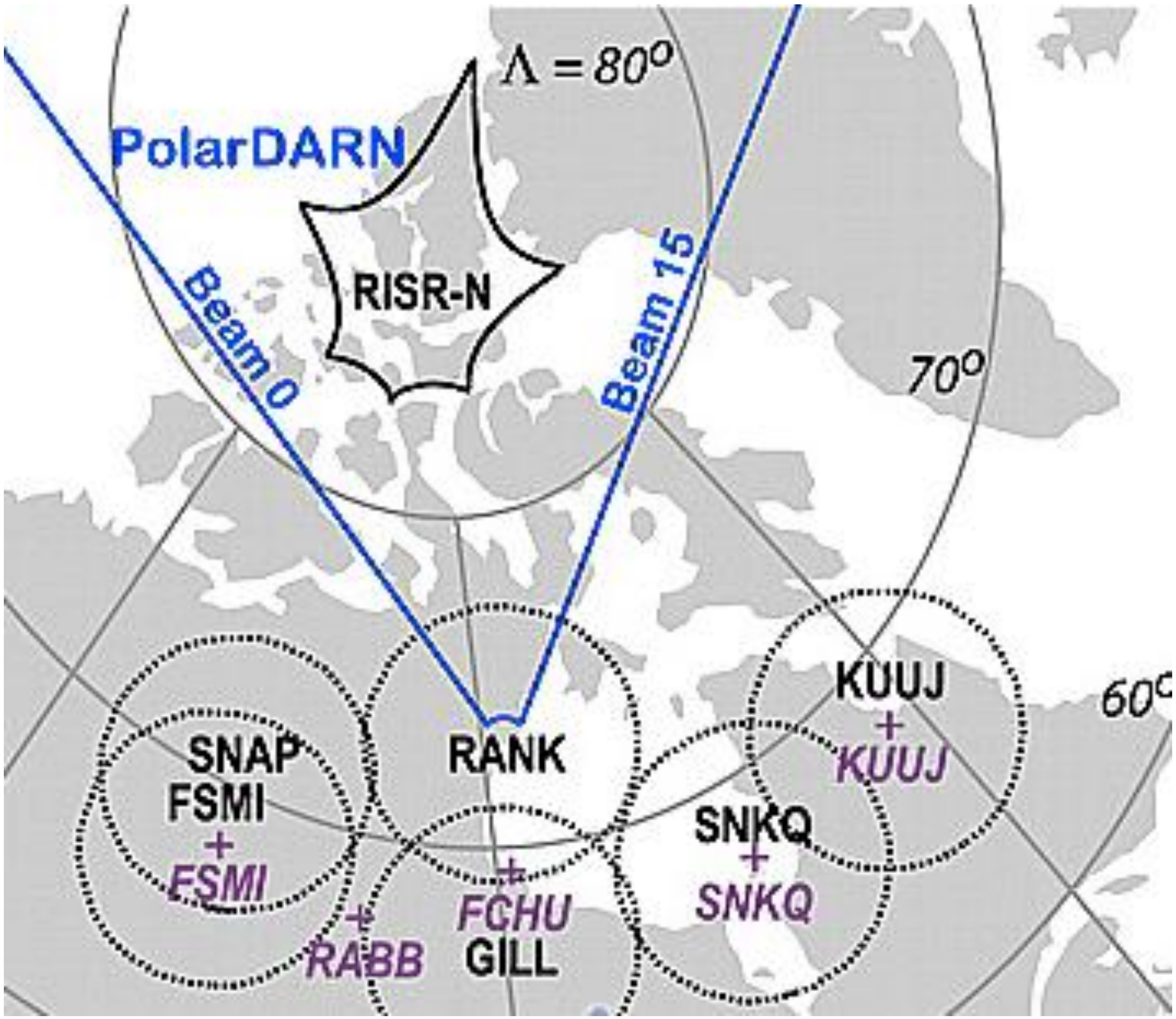
Vi changing too fast for Vn to keep up (Weather) Note strong frictional heating



Now What can we Measure: Global ISRs



RISR-N without RISR-S

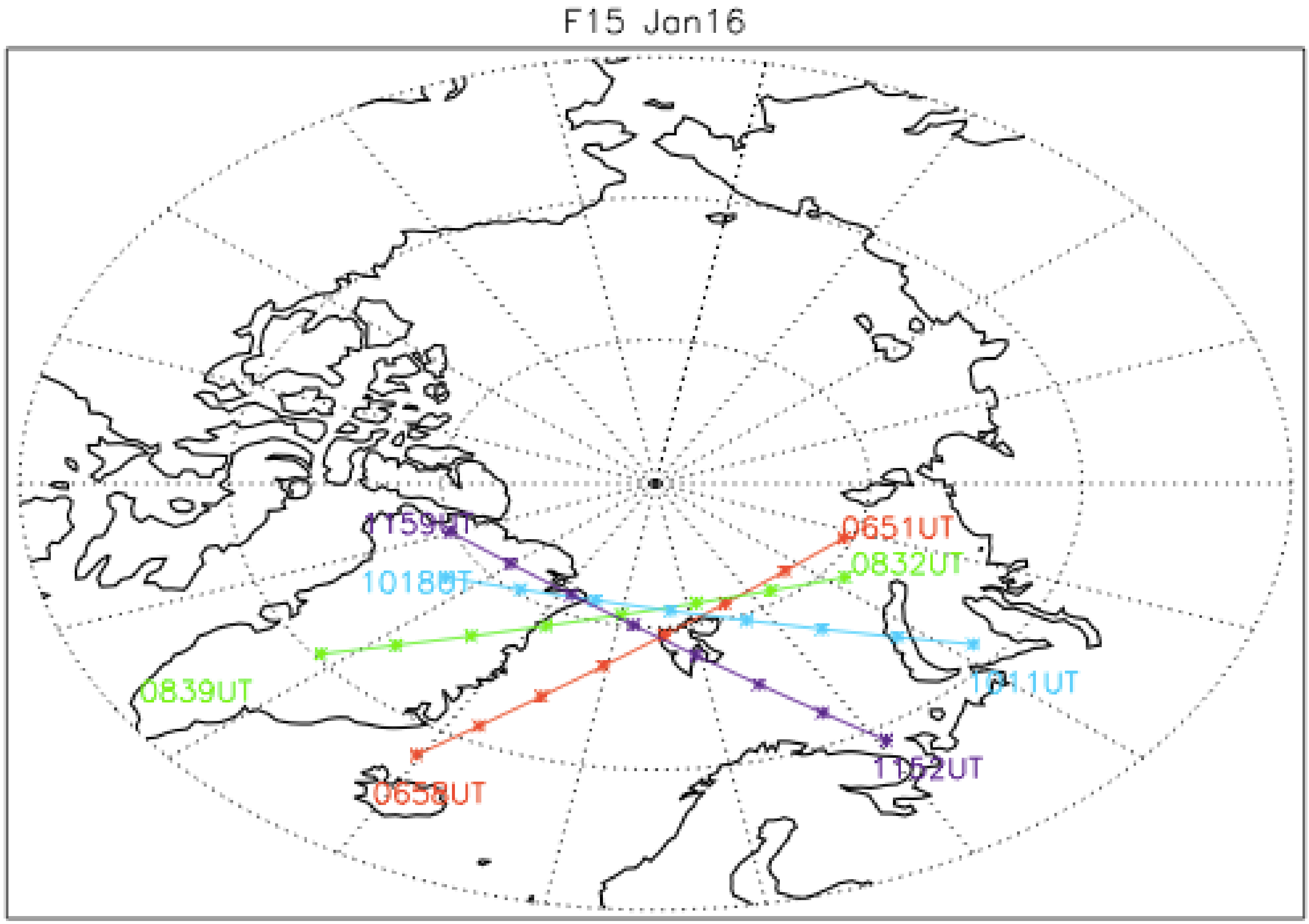


RISR-N+S Sub-Cusp Through Polar Cap Huge Advance!

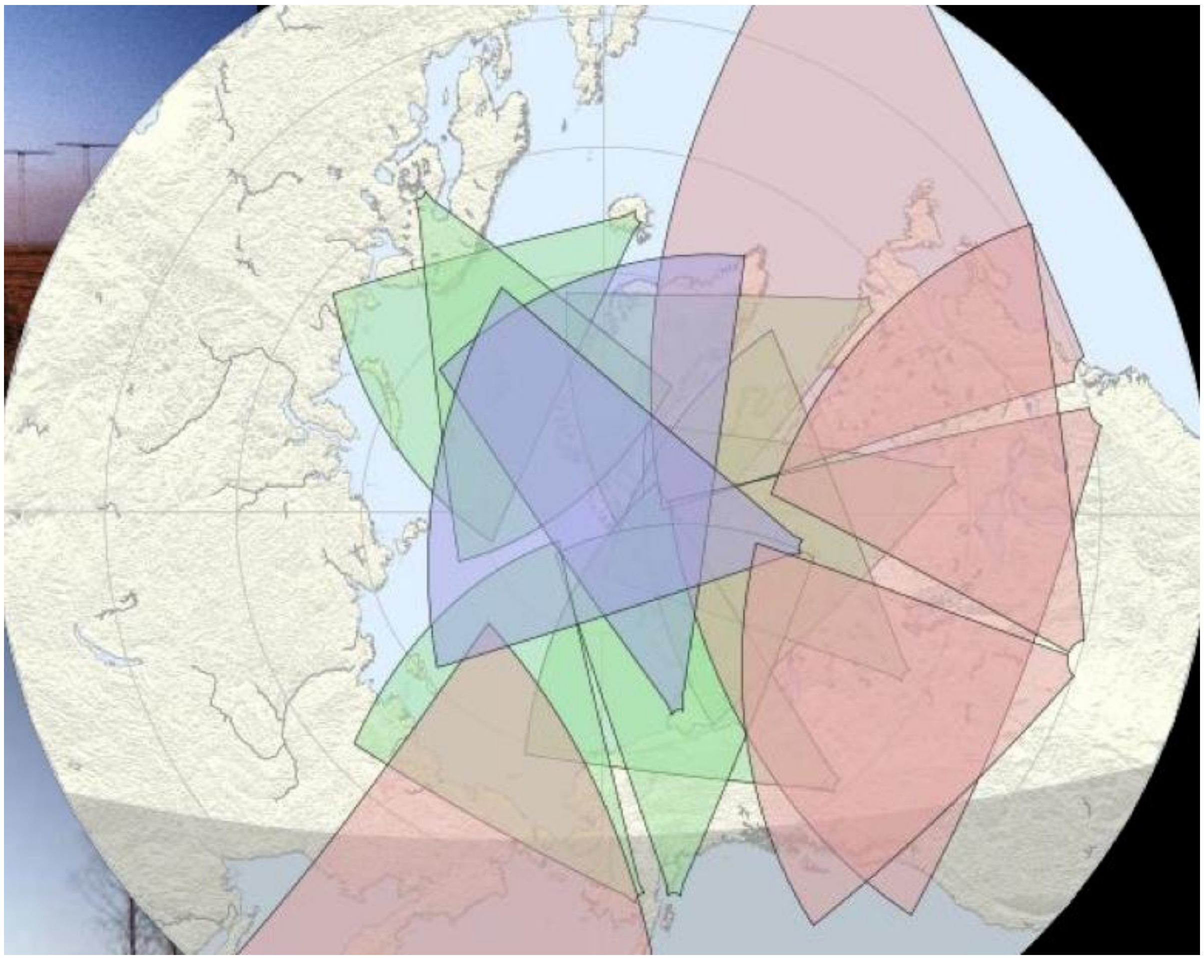
E-POP satellite

- **Orbit** 325 x 1500 km, 80.99° inclination
- **Orbital Period** 103 minutes (14 orbits per day)
- **Projected Lifetime** 2 years
- **Science Instruments** VHF/UHF transmitter (CER), VLF/HF receiver (RRI), auroral imagers (2) (FAI), GPS receivers (5) (GAP), ion detector (IRM), electron detector (SEI), neutral particle detector (NMS), magnetometers (2) (MGF)

DMSP 4 consecutive passes

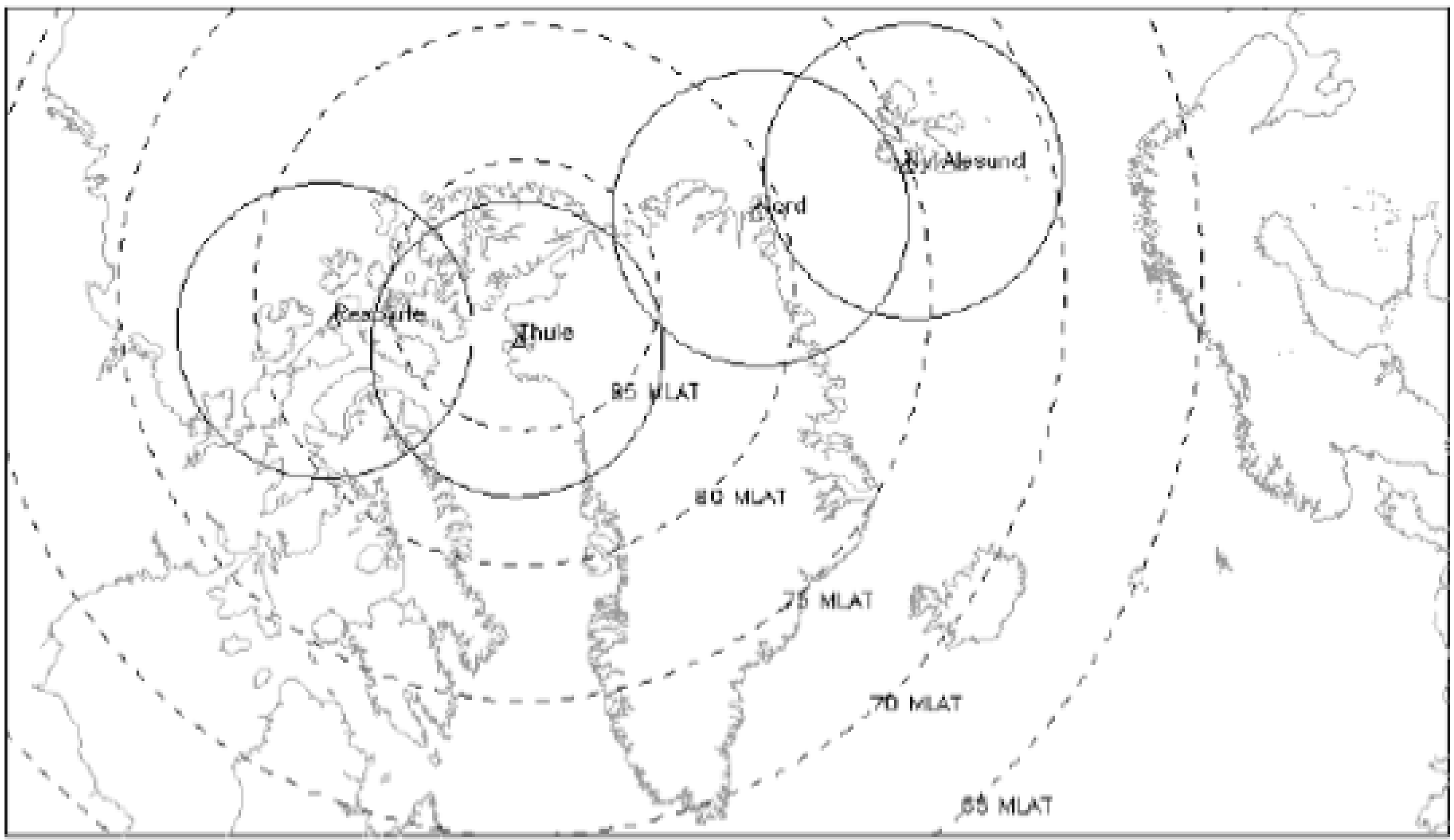


SuperDARN Northern Hemisphere



All Sky Imaging Photometers

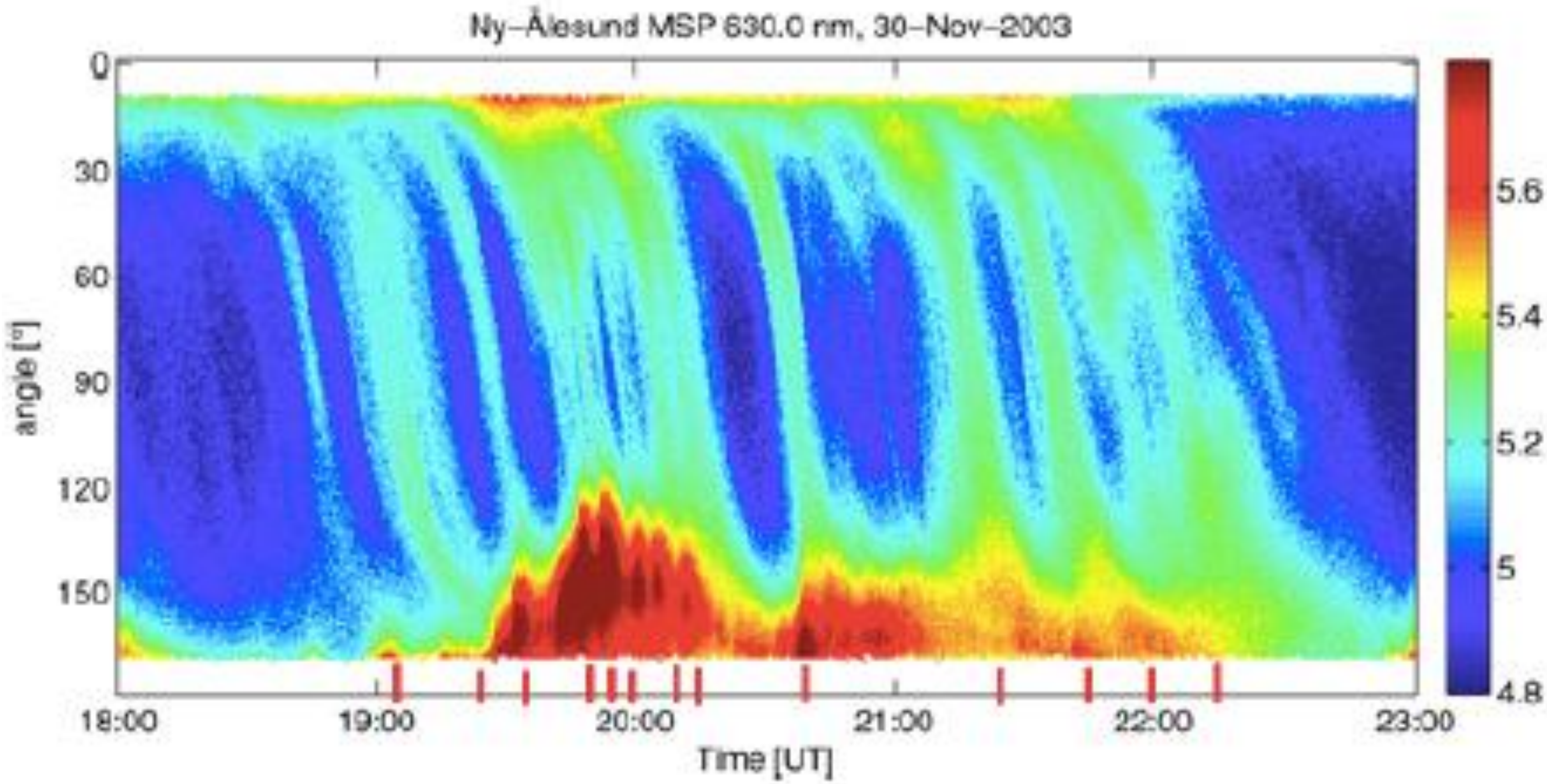
Fields of View at 250 km Altitude



630 nm MSP scan NYA Svalbard

As patches exit PC near midnight
(Magnetic Reconnection Signature?)

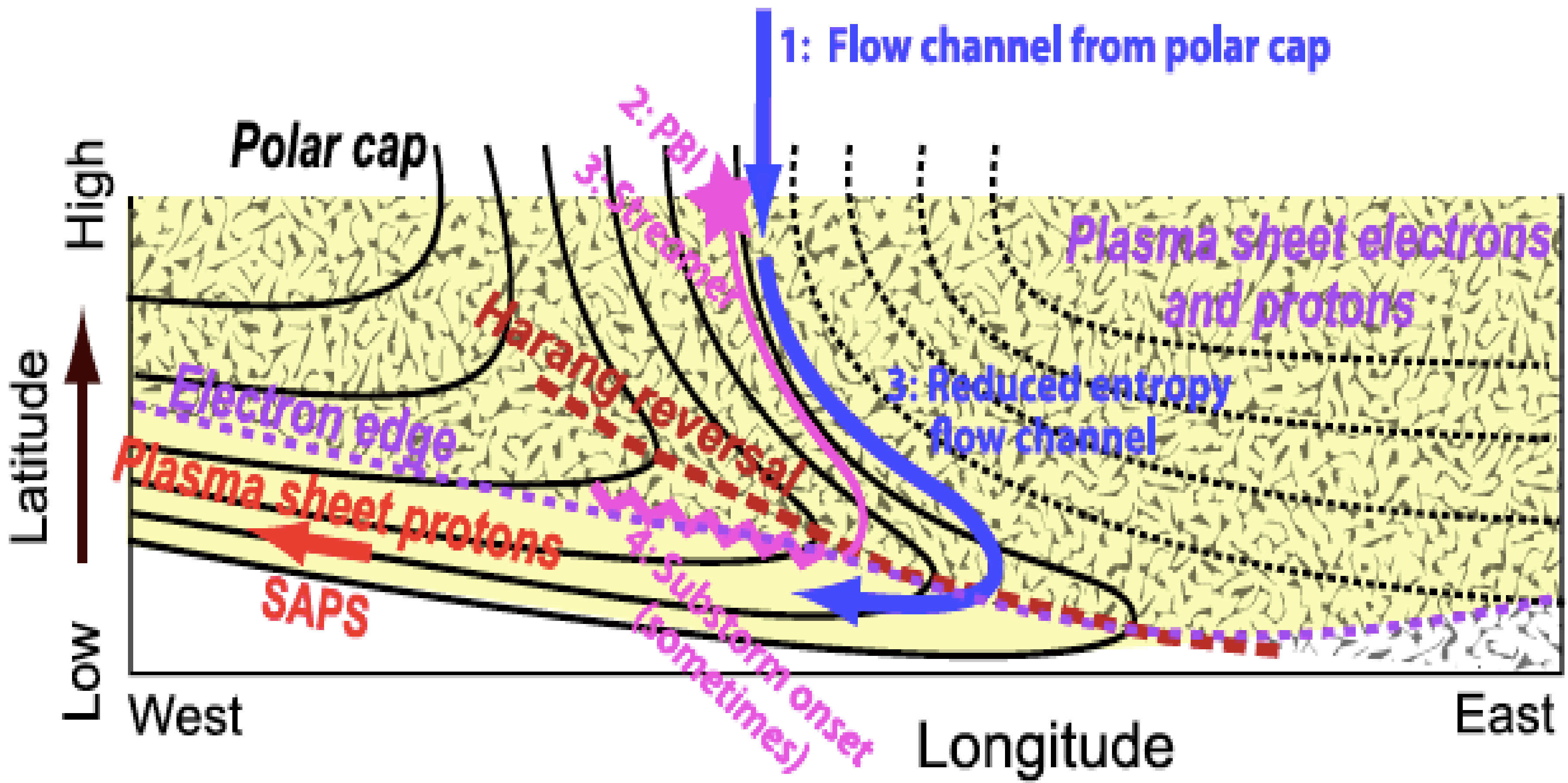
Moen ret al, 2007



Open- to Closed-B nightside flow jets, Poleward boundary Intensifications (PBI)

Earthward/equatorward mesoscale plasma flows

Lyons et al, 2011

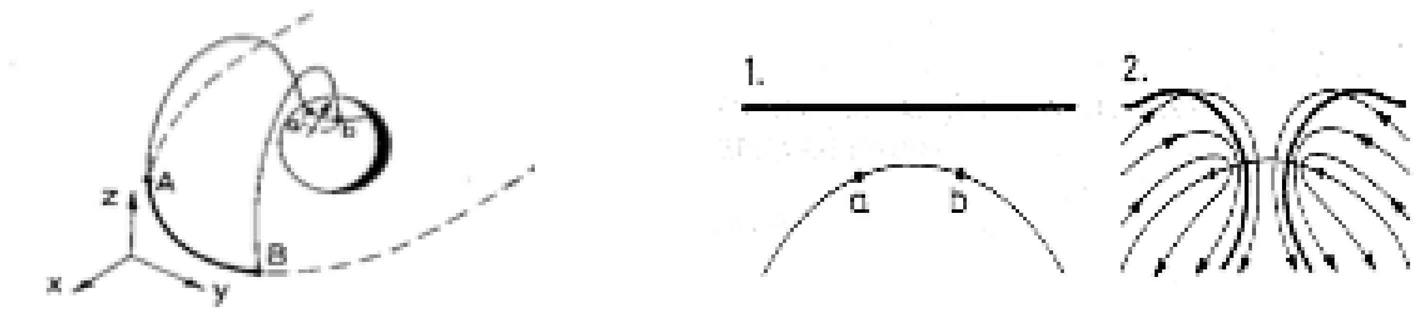


PULSED MAGNETIC RECONNECTION A-B

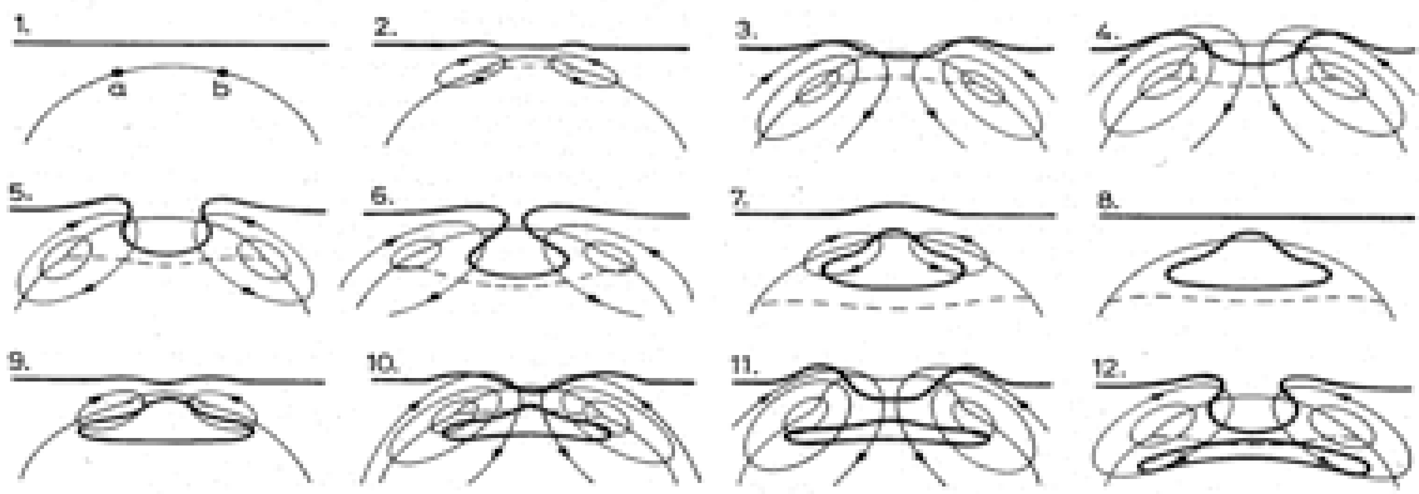
Merging gap a-b, noon top, --- Ne contour

(Lockwood and Carlson,1992)

STATIONARY MERGING GAP → TONGUE

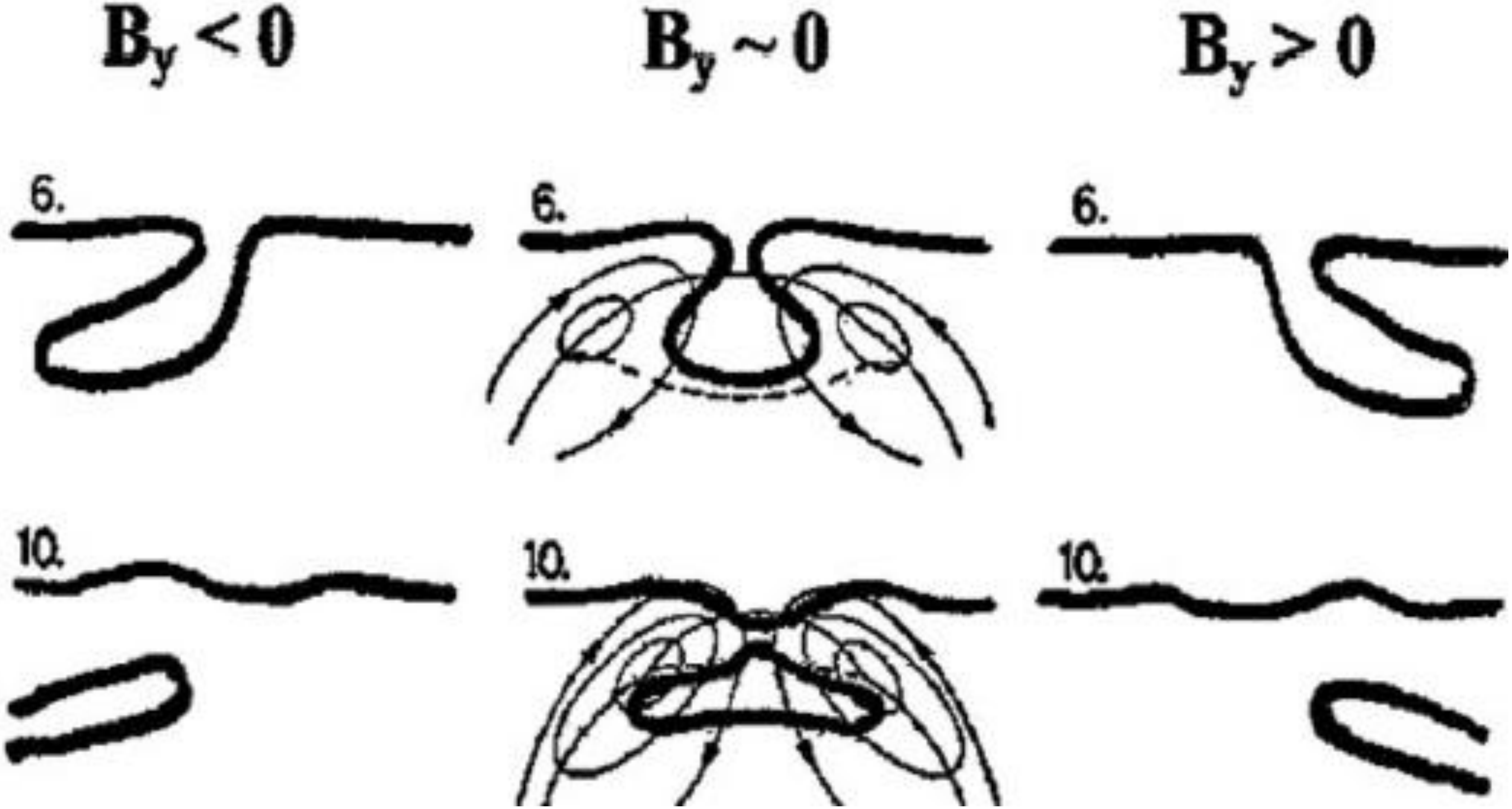


MIGRATING MERGING GAP → PATCHES



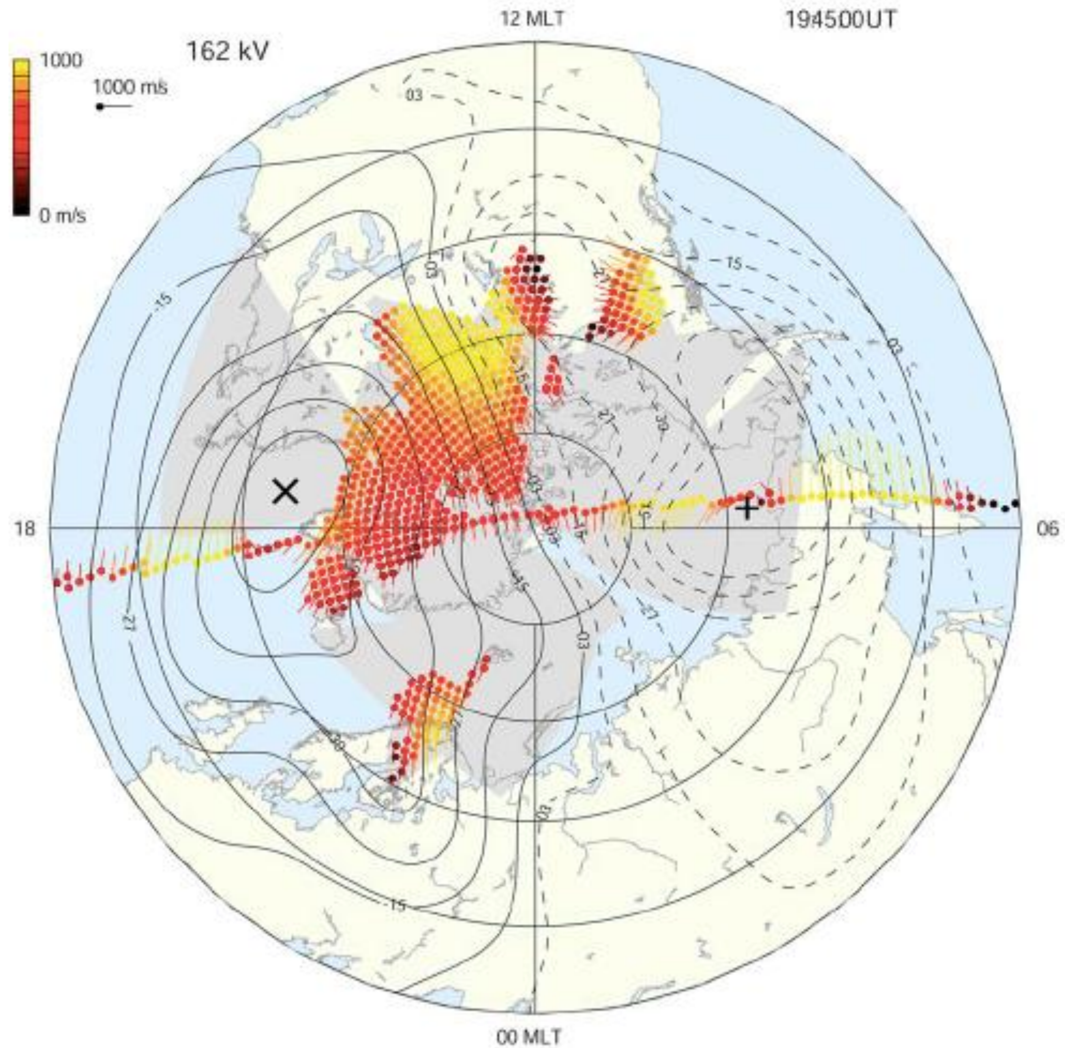
When magnitude of IMF B_y is large, get strongest flow in manetic tension direction

(Carlson 2003)

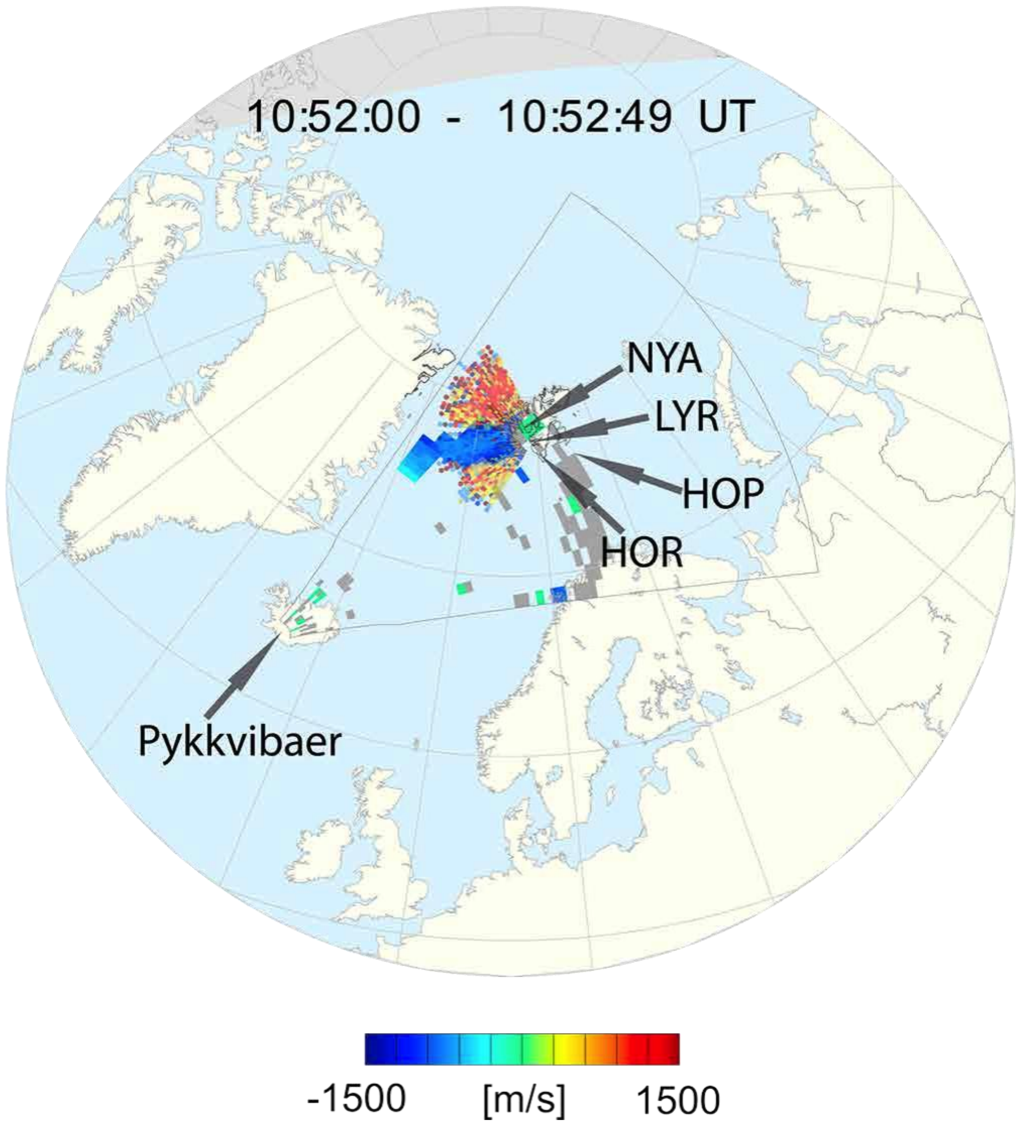


Must smooth SuperDARN for global picture (Climate) Vi ~ 1/km/s typical high

Foster et al, 2005)



Must not smooth for mesoscale Plasma (Weather) Flow Shear: SuperDARN



Does it matter?
It did to an 8 year old unsolved problem
Density/Drag Doubling over the Cusp

- Why Thermospheric Density/Drag Should Double Over the Cusp

Back to Basics (Equivalent by Math)

Altitude dependent Energy Deposition Rate ➔ δTn(h)/δt

Three Equivalent Formulas

Altitude Profile of Current/Joule Heating

$$j \cdot E¢\; s_p E¢^2 \quad mW/m^3$$

Altitude Profile of **Ion Frictional Drag** Heating

$$¶E_n / ¶t = S\ (n_i\ m_i\ n_{in})(V_i - V_n)^2$$

Ti Surrogate Altitude Profile of Ion Frictional Drag Heating

$$¶E_n / ¶t = 3k_B/m_n S\ (n_i\ m_i\ n_{in})(T_i - T_n)$$

Equivalence vs. Causality

- One can derive equivalence of thermospheric heating rate from: J•E, Vi-Vn, Ti-Tn [Theyer & Semeter, 2004]
- For causality, understanding the MIT coupled system most directly from mechanical frictional drag (E is a consequence of flow, not a cause) [Pakrer 1996, Vasyliiunas 2001, Strangeway 2012]
- For solar wind energy input [vs. thermosphere energy sink], currents relate best to causality

Joule dissipation and frictional heating in the collisional ionosphere
R J. Strangeway (JGR 2012)

- Investigate the role of frictional heating
- most of the **Joule dissipation in the neutral** frame, results in heating mainly by initially increasing the ion fluid temperature relative to the neutrals, while the neutral atmosphere temperature increases much more slowly.
- Energy input from the solar wind to the M-I-T system is inherently currents (vs. frictional I-T)

Back to Basic (By Causality)

Ion Frictional Drag Energy Deposition Rate

Altitude Profile of **<u>Ion Frictional Drag</u>** Heating

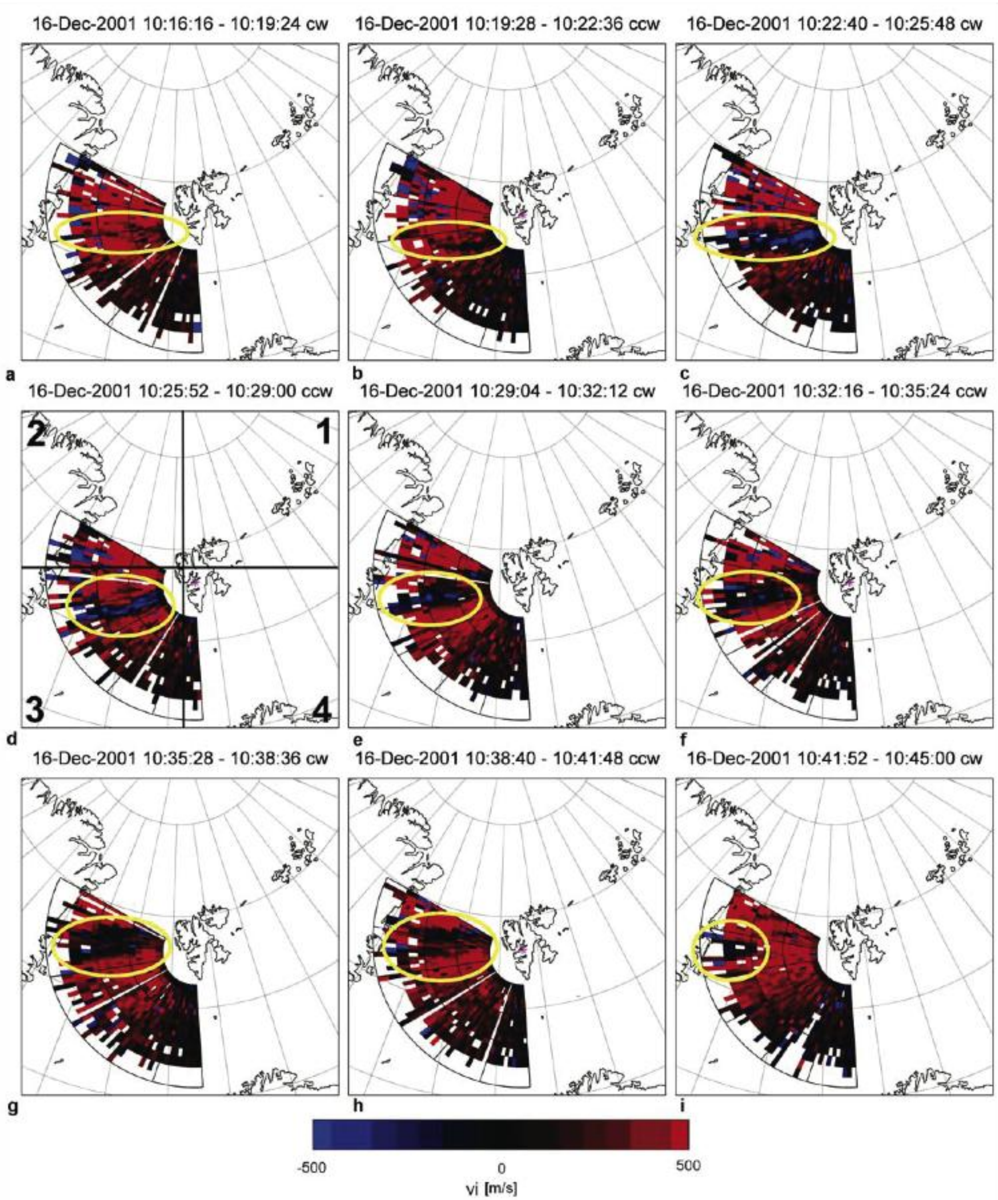
$$\P E_n / \P t = S \ (n_i \ m_i \ n_{in})(V_i - V_n)^2$$

Square Law Dependent on on ion velocity shear

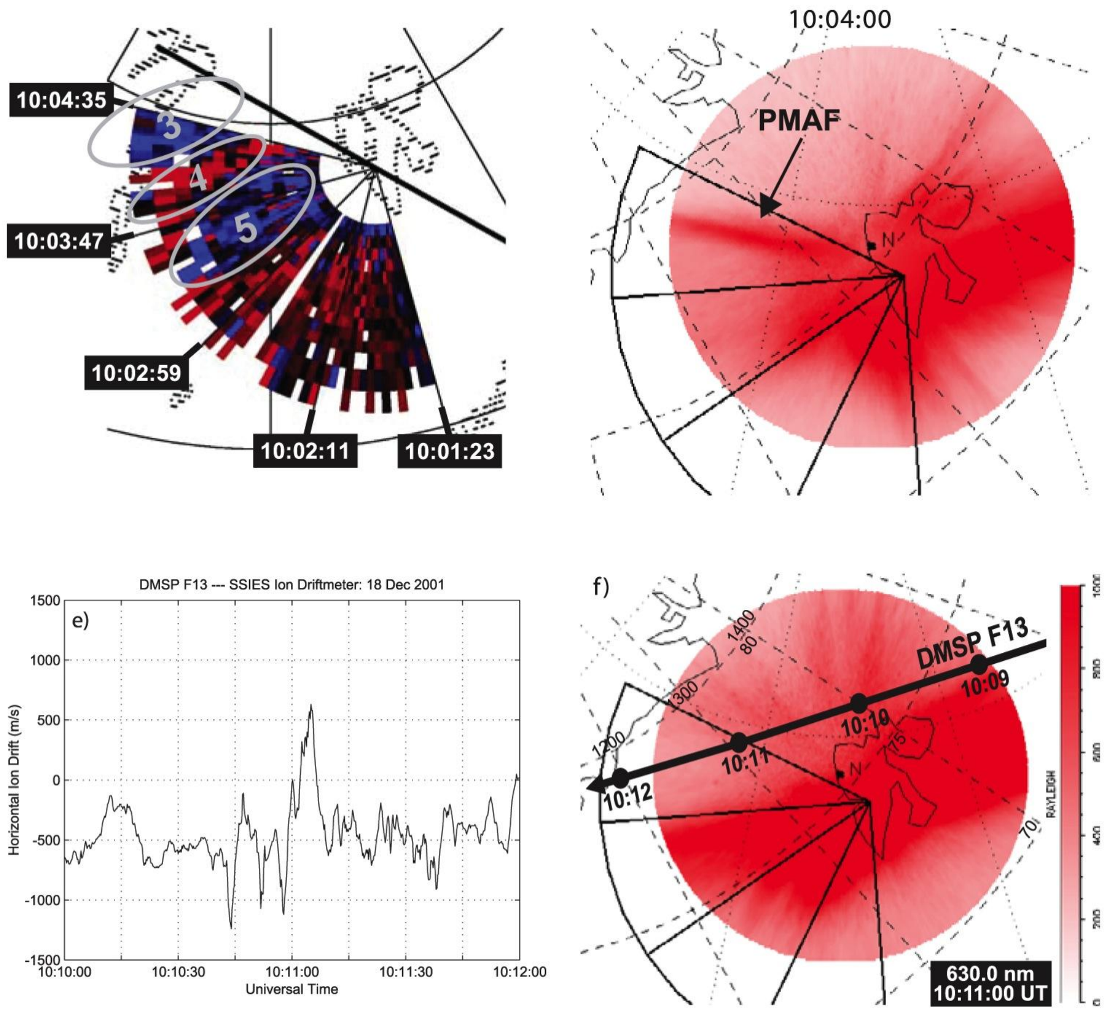
[i.e. Plasma Flow Jets]

Linearly Dependent on Electron Density Profile

Plasma Flow Shear: EISCAT Radar

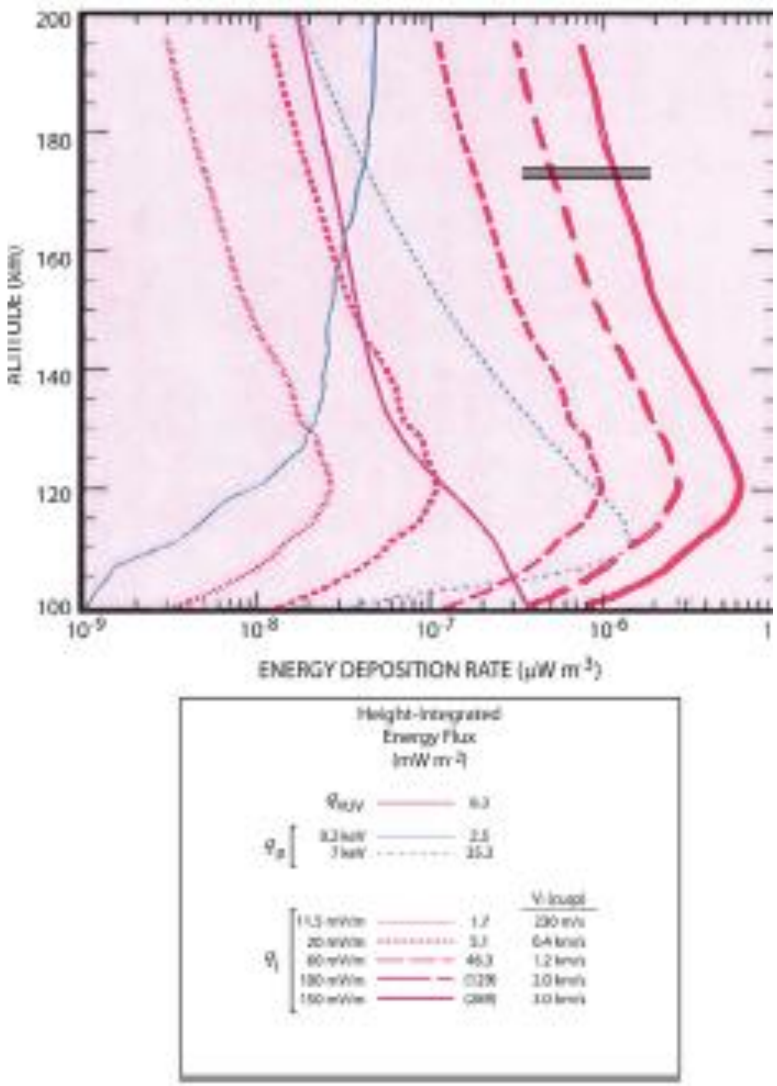


Plasma Flow Shear: DMSP (PMAF)



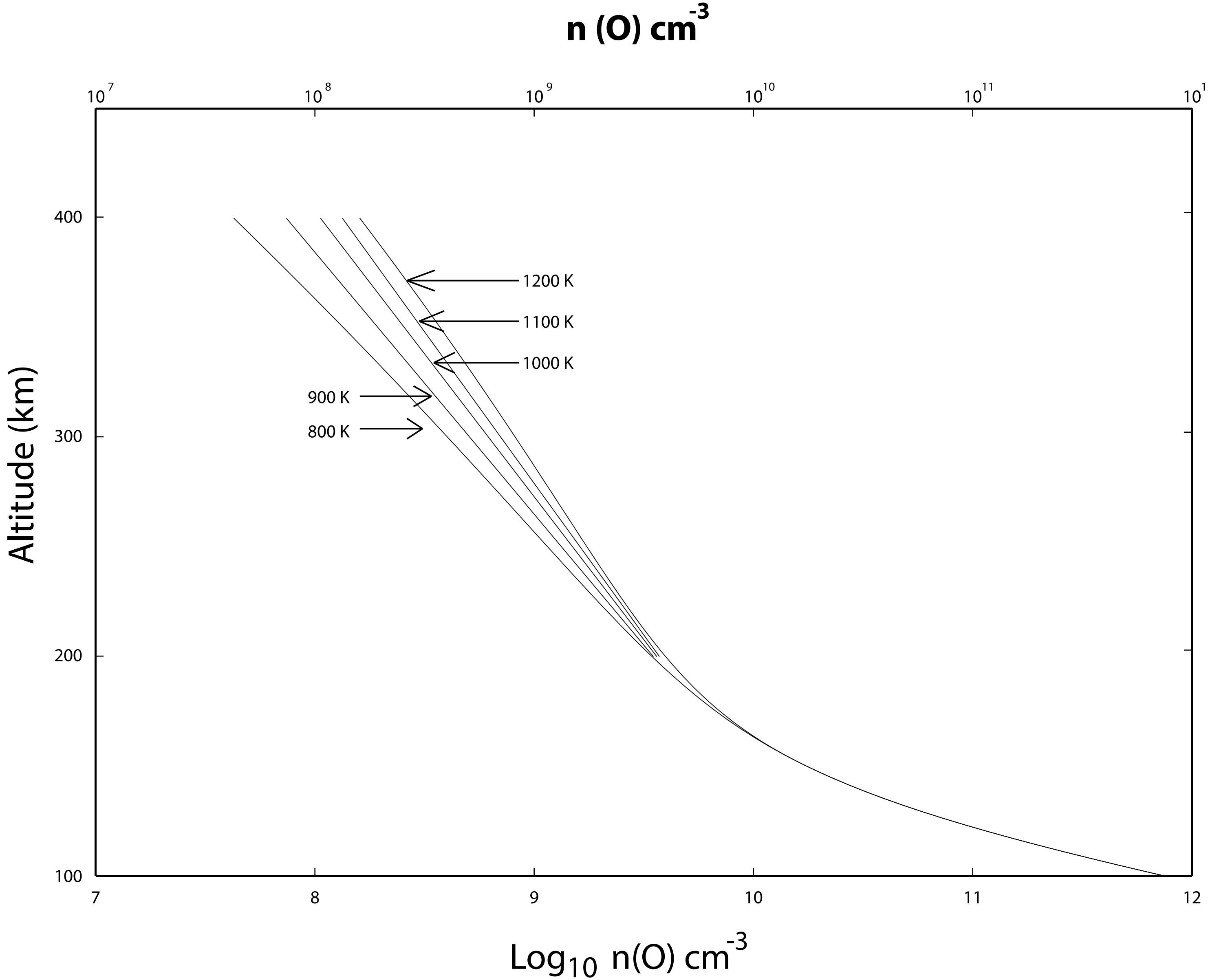
Climatological energy deposition rates compared to those from Space Weather

(Carlson, 2012 using Thayer and Semeter 2004)



Small Heat in at 200 km Compounds !

10 % at 200 km → 100% more drag at 400 km



Poynting's theorem: ionospheric application A. D. Richmond (JGR 2010)

- Poynting vector from spacecraft **δE x δB** cross product, used to estimate the field line**-**integrated EM energy dissipation in the ionosphere below:
- the downward perturbation Poynting vector can **underestimate** the EM energy dissipation in ionospheric regions of **high Pedersen** conductance,
- and can **significantly overestimate** the dissipation **in regions of low conductance**.

A NEED Polar F-layer model-observation comparisons: a neutral wind surprise

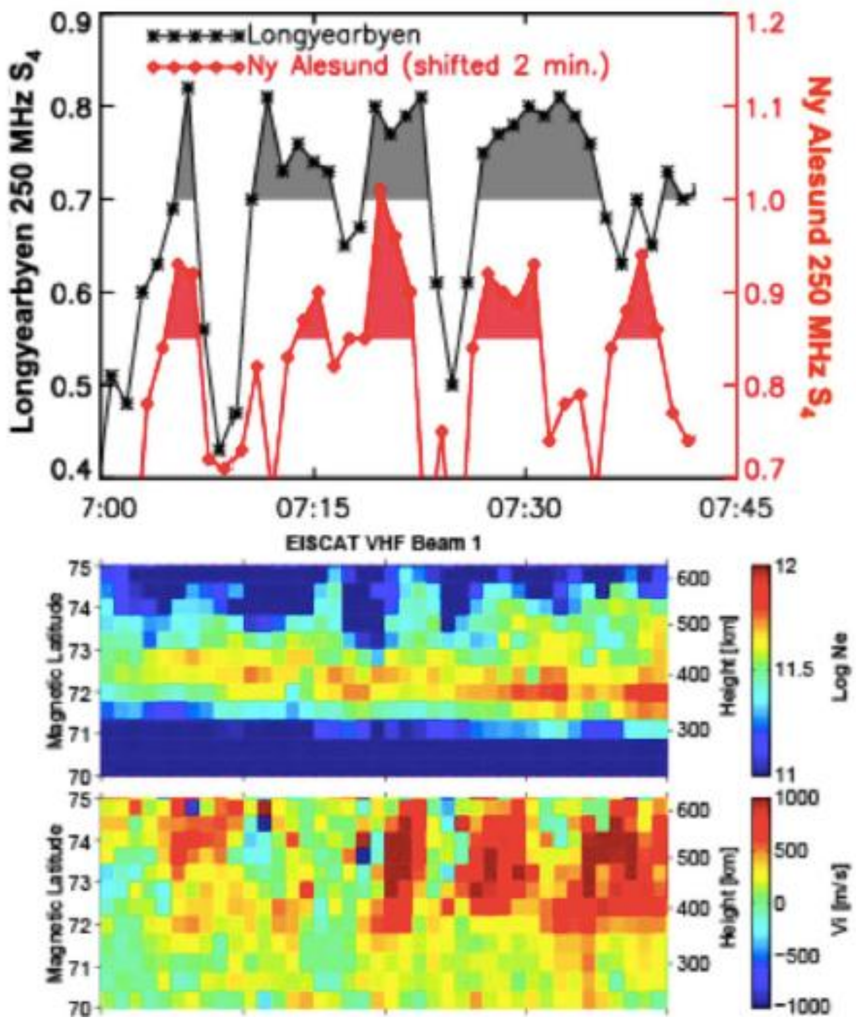
Sojka et al, 2005

- **Abstract.** Physics-based ionospheric models, are usually only compared with observations over 1-2 day events or climatological averages.
- Using month-long ESR observations, the daily weather, day-to-day variability, and month-long climatology can be simultaneously addressed to identify modeling shortcomings and successes.
- Since for this study the TDIM is **driven by climatological representations** of the magnetospheric convection, auroral oval, neutral atmosphere, and neutral winds, whose inputs are solar and geomagnetic indices, it is not surprising that the daily weather cannot be reproduced.
- Unexpectedly the horizontal neutral wind has come to the forefront as a decisive model input parameter in matching the diurnal morphology of density structuring seen in the observations.
- Zero Neutral wind beat any other neutral wind model input

Patch structure 1st by Shear, not Grad Drift

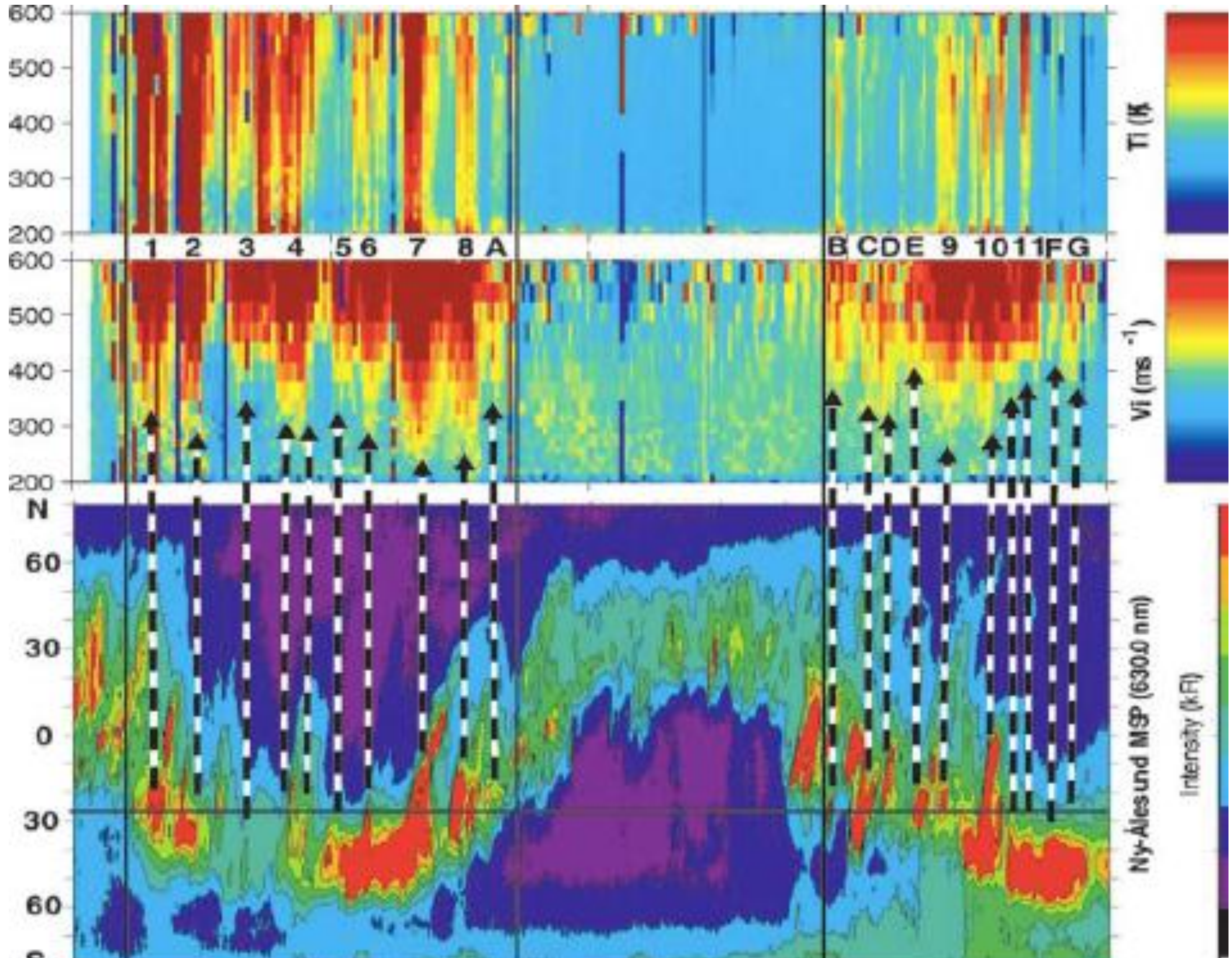
Gradient drift can't respond this fast, dominates in central PC

Carlson e al, 2008

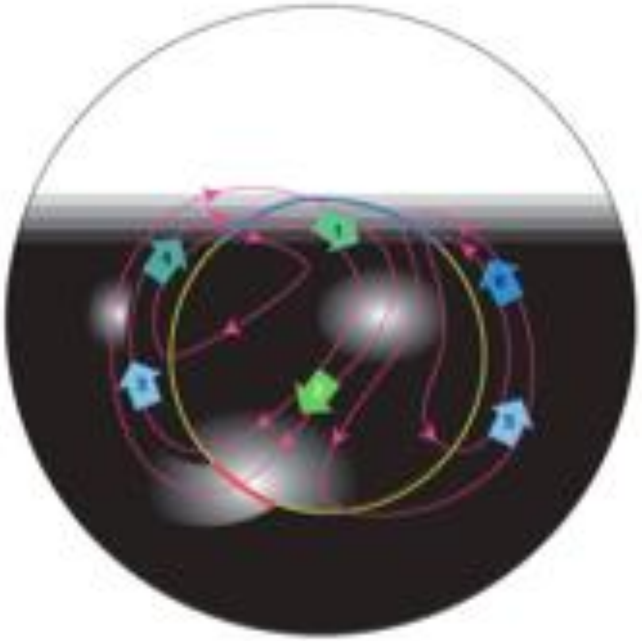


Ion Upflows MLT noon +/- 2 hours
Top Ti, Mid Vi, Bottom PMAFs (EISAT)

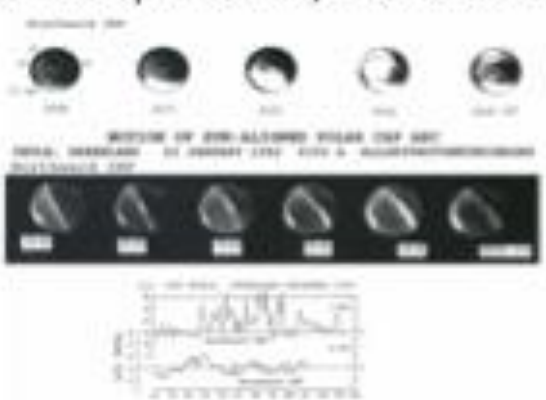
Moen et al,2004

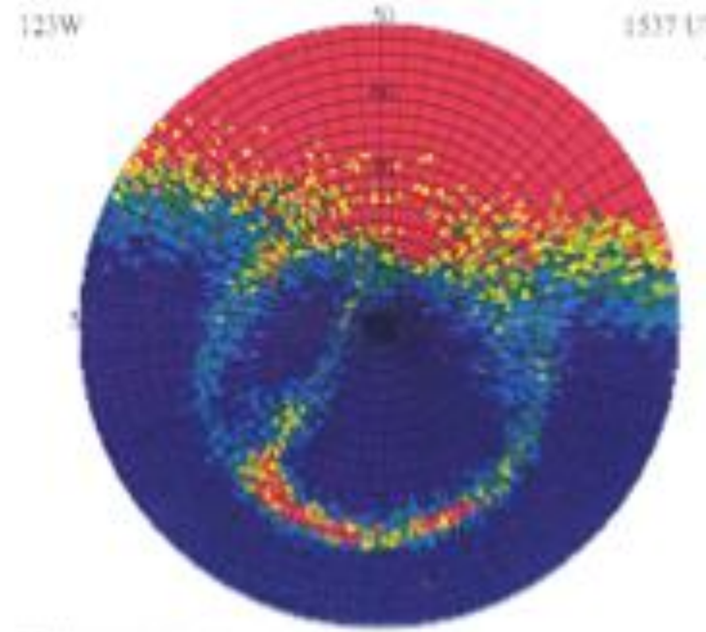


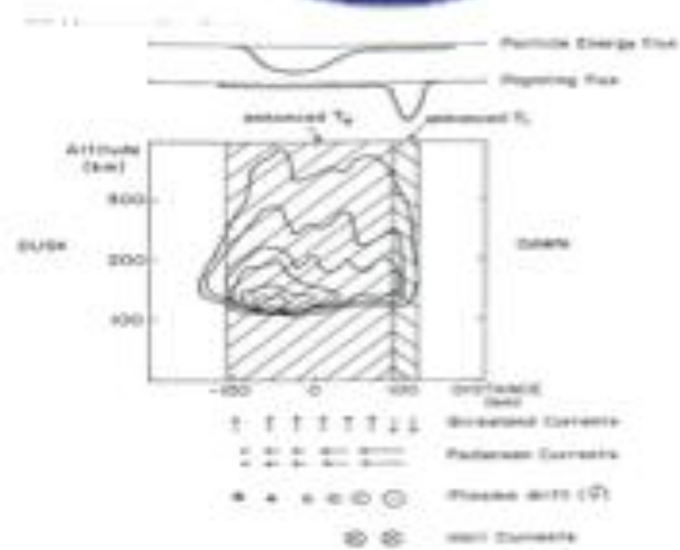
• How does solar wind-magnetotail-ionosphere coupling affect the structure and composition of the polar ionosphere?



PC in "Two States": IMF South, North
Detect in cusp in 2 min, flow channel in 5







• What are the effects on the neutral atmosphere, and what is the range of influence of these disturbances?

Back to Basics

Altitude dependent Energy Deposition Rate ➔ $\delta Tn(h)/\delta t$

Three Equivalent Formulas

Altitude Profile of Current/Joule Heating

$$j \bullet E';\ \sigma_p E'^2 \quad \mu W/m^3$$

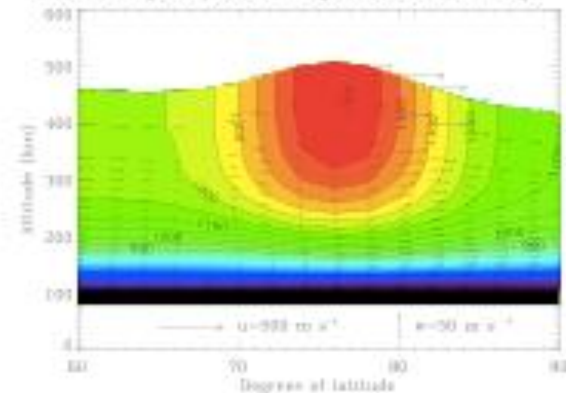
Altitude Profile of **Ion Frictional Drag** Heating

$$\partial E_n / \partial t = \Sigma \ (n_i\ m_i\ \nu_{in})(V_i - V_n)^2$$

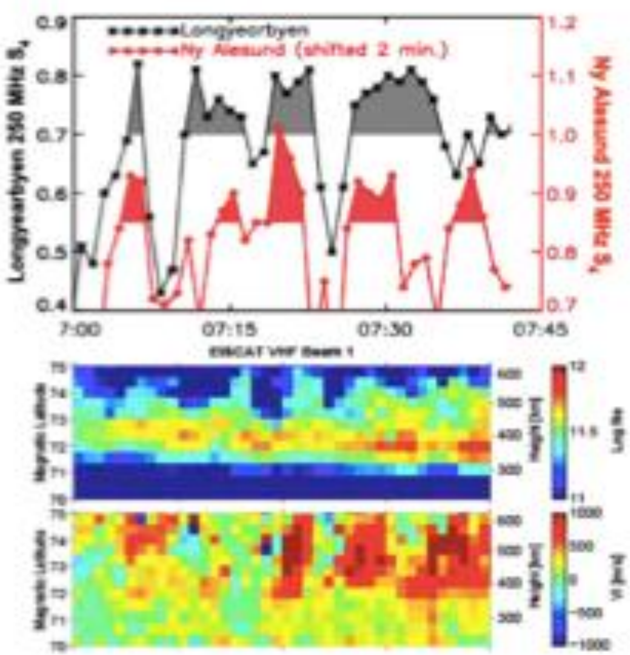
Ti Surrogate Altitude Profile of Ion Frictional Drag Heating

$$\partial E_n / \partial t = 3k_B/m_n \Sigma \ (n_i\ m_i\ \nu_{in})(T_i - T_n)$$

Heating/Upwelling/Out-welling

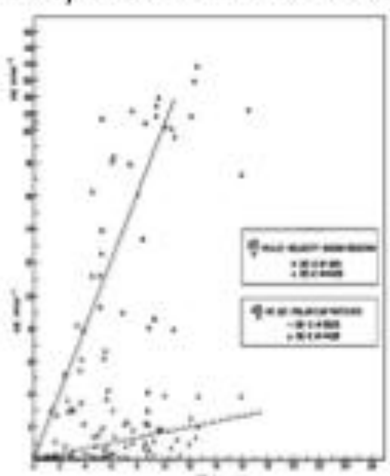


• What governs the internal structure and RF propagation characteristics of plasma patches?



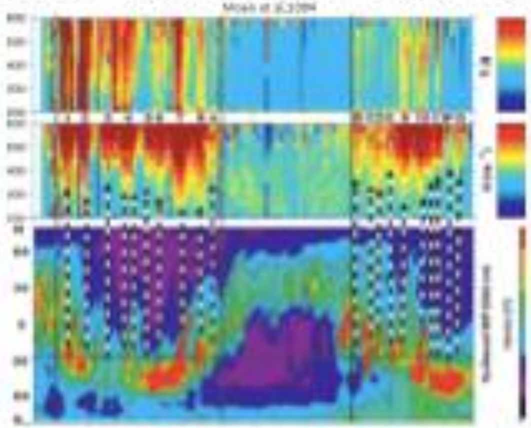
δE/(δNe/Ne): observed in Polar Cap

Velocity shear 10x Gradient drift



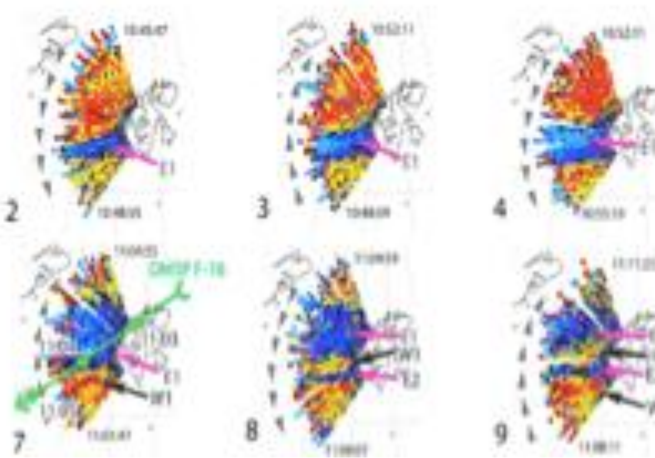
• How do these processes affect plasma outflow and its impact on magnetospheric configuration?

Ion Upflows MLT noon +/- 2 hours
Top Ti, Mid Vi, Bottom PMAFs (EISAT)

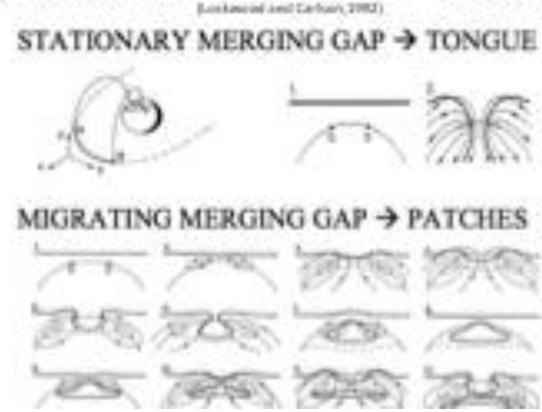


PHISR, RISR-N/S, Sondrestronfjord

When is the role of pulsed magnetic reconnection in unifying our base of understanding at the cross-roads of these and more?

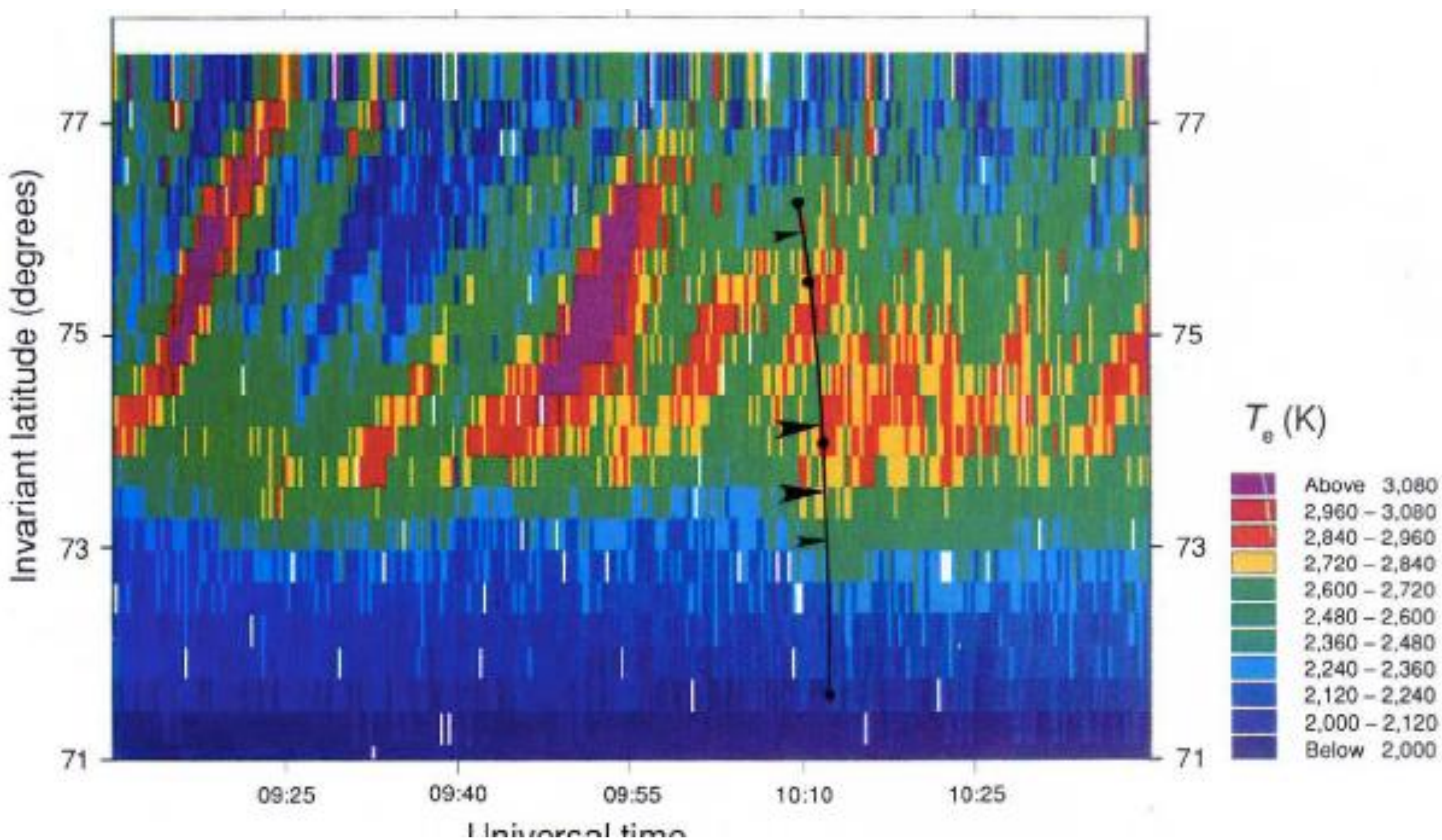


PULSED MAGNETIC RECONNECTION A-B
Merging gap a-b, noon top, --- Ne contour



Newly reconnected flux tube paths

(Lockwood et al, 1993)



Small scale Irreg onset time is minutes

Moen et al, 2000