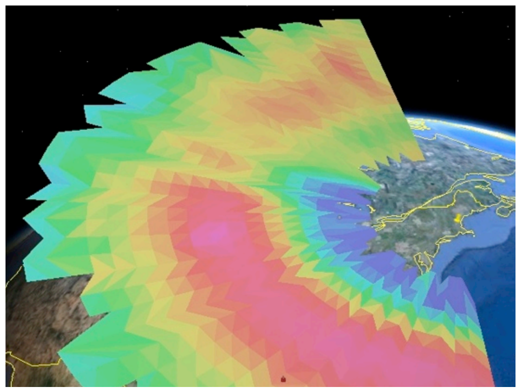
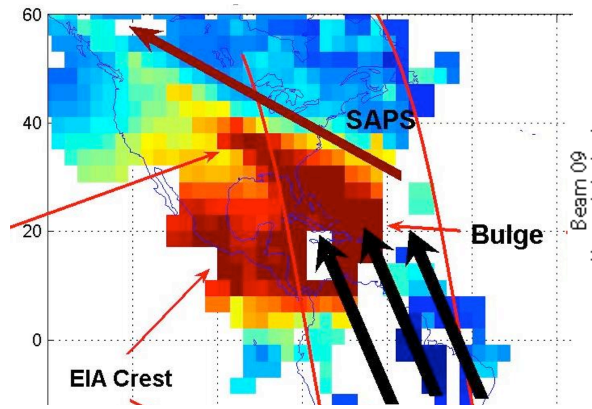
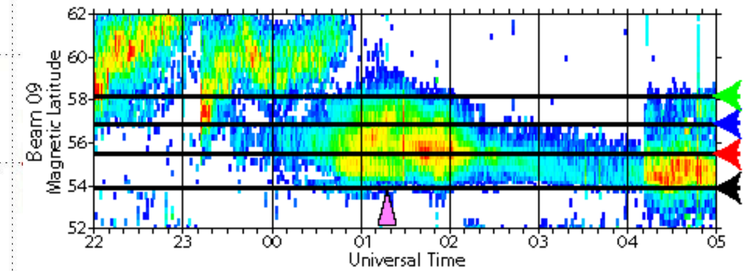
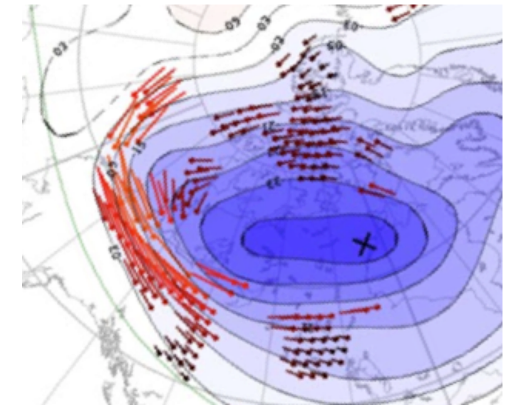
Midlatitude Ionospheric Features in the Plasmasphere Boundary Layer: The View From Millstone Hill









P. J. Erickson
Atmospheric Sciences Group
MIT Haystack Observatory

SuperDARN 2011 Workshop
June 2, 2011

Thanks to J. C. Foster, A. J. Coster, NSF, NASA,
MIT Haystack REU students, SD Collaborators, and the ASG

Massachusetts Institute of Technology

HAYSTACK OBSERVATORY

Outline

- The Plasmasphere Boundary Layer from Millstone Hill
- PBL Feature 1: SAPS Morphologies and Conductivity
- PBL Feature 2: Embedded Irregularities

Opportunities for SD-MHO Collaboration will be highlighted throughout..

The Plasmasphere Boundary Layer (PBL)

Annales Geophysicae (2004) 22: 4291–4298
SRef-ID: 1432-0576/ag/2004-22-4291

The Plasmasphere Boundary Layer

D. L. Carpenter[1] **and J. Lemaire**[2,3]

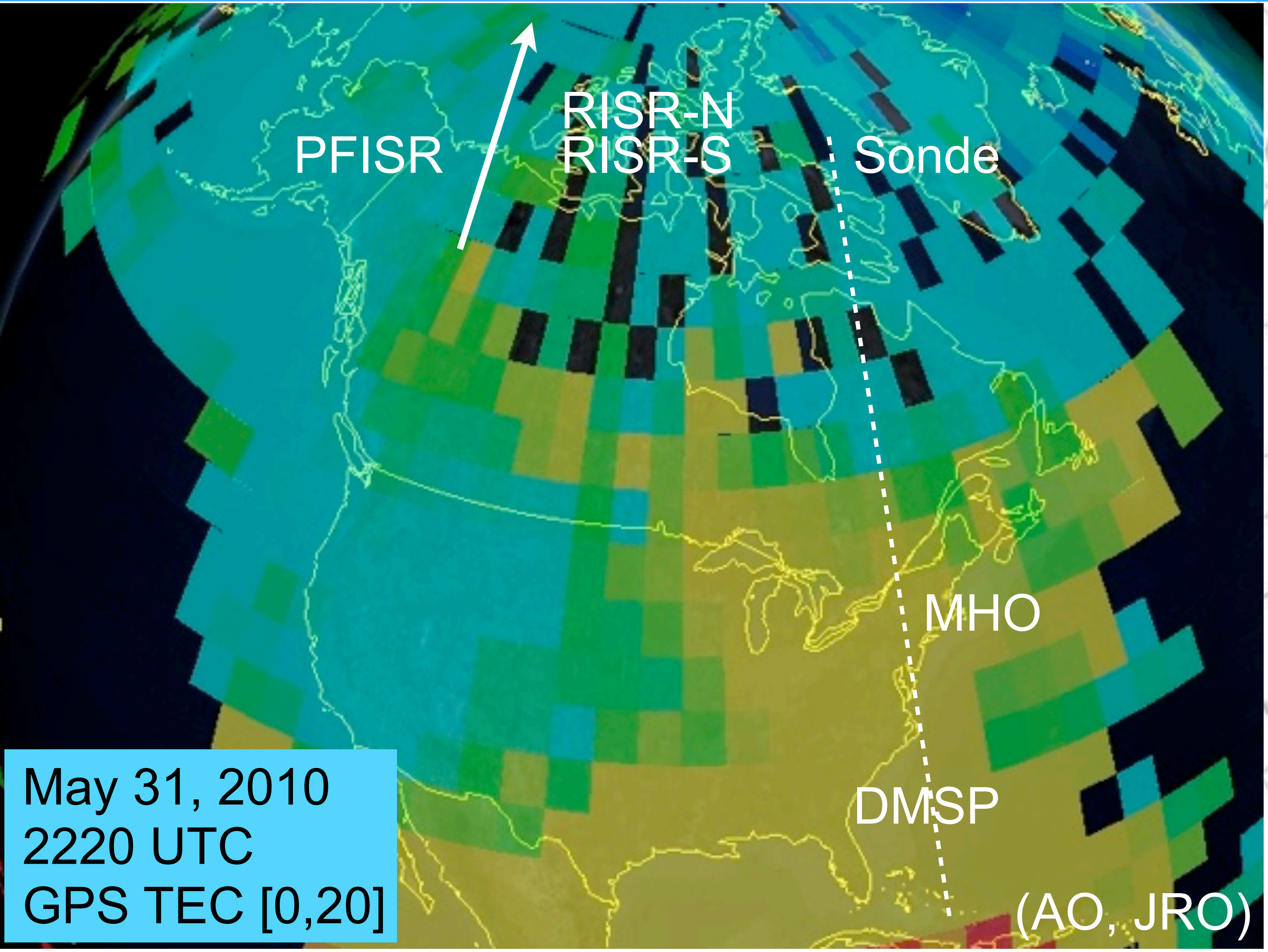
[1]STAR laboratory, Stanford University, Stanford, CA 94 305, USA
[2]CSR-UCL, Louvain, Belgium
[3]IASB, Brussels, Belgium

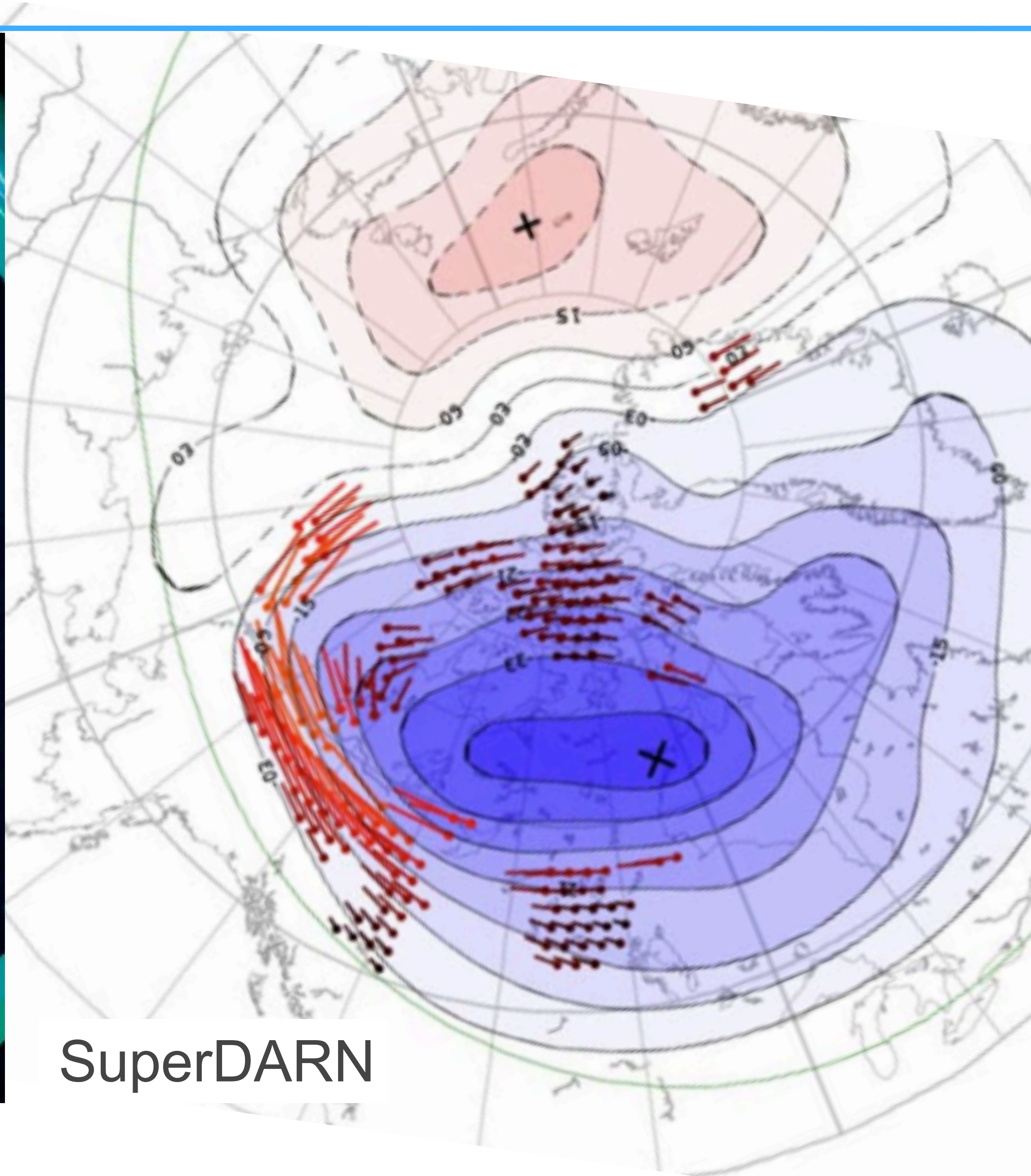
Received: 18 August 2004 – Revised: 29 September 2004 – Accepted: 3 October 2004 – Published: 22 December 2004

"... Curiously, the plasmapause region has not been described as a boundary layer, in spite of being observed at locations where the cool (≈1 eV) dense (≈400 el/cc) plasmasphere overlaps with, or is otherwise in close proximity to, the hot (≈100 eV–100 keV) tenuous (≈1 el/cc) plasmas of the plasmatrough or the plasmasheet and ring current ... "

SED, SAPS, Irregularities, Westward and Cusp-bound Flow, ...

The Plasmasphere Boundary Layer (PBL)





The PBL Is A Region of Dynamic, Meso/Microscale, System Level Response

System Level Responses Require System Level Observations and Science

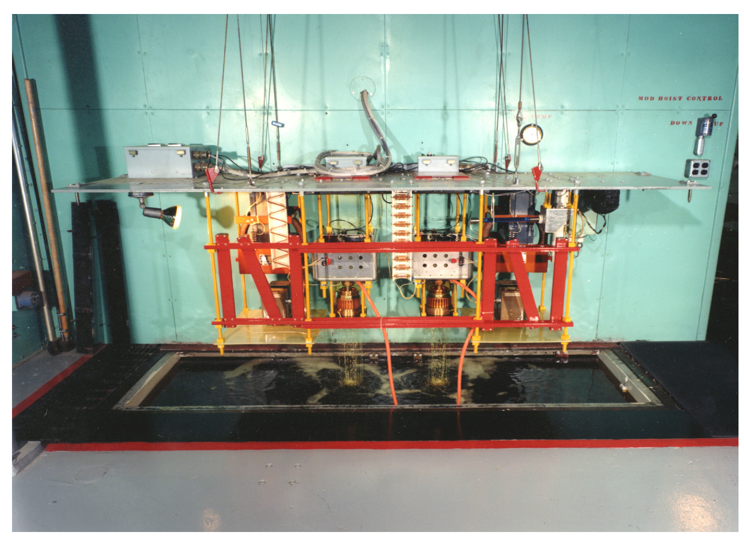
MIT Haystack Observatory Complex
Westford, Massachusetts
Established 1956
Haystack Observatory
Radio Astronomy
Atmospheric Science
Space Surveillance
Radio Science
Education and Public Outreach
Millstone Hill
Observatory
Millstone Hill Radar
Firepond Optical
Facility

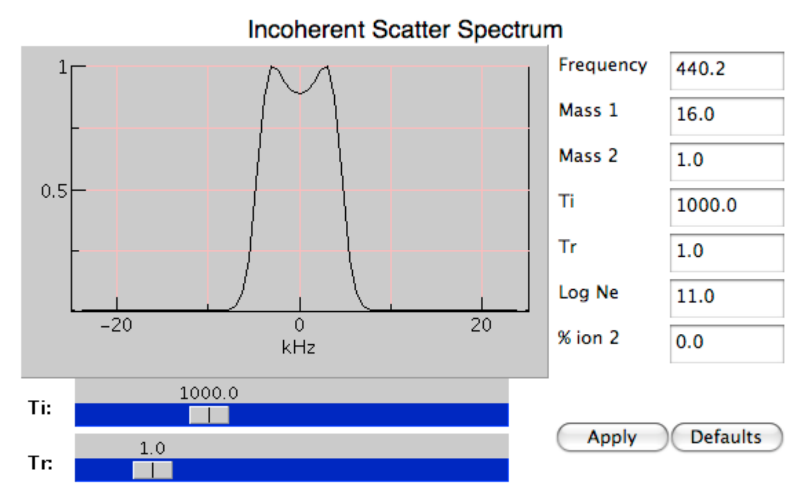
Millstone Hill UHF Incoherent Scatter Radar

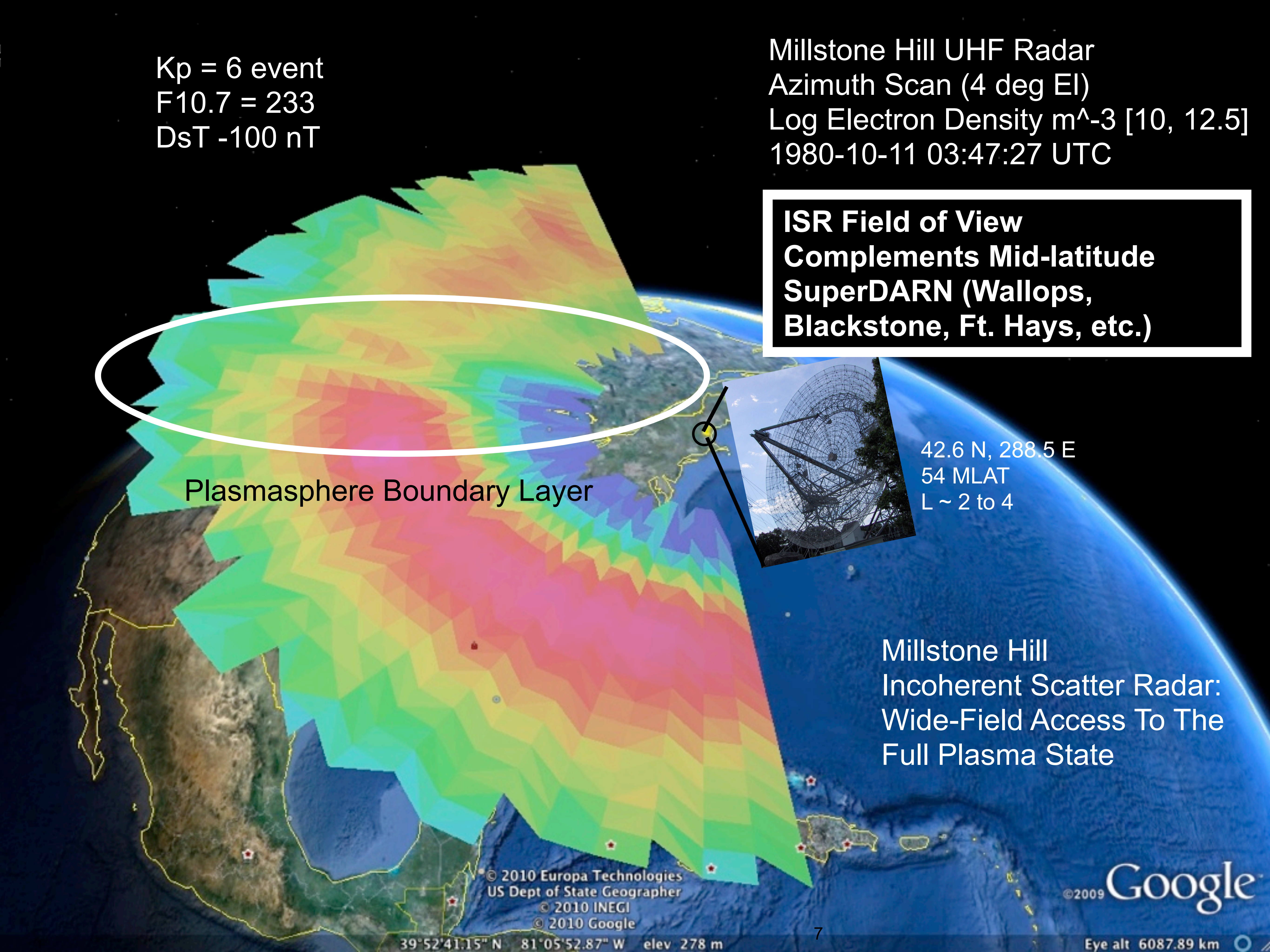
46 m steerable MISA
(68 m zenith not shown)

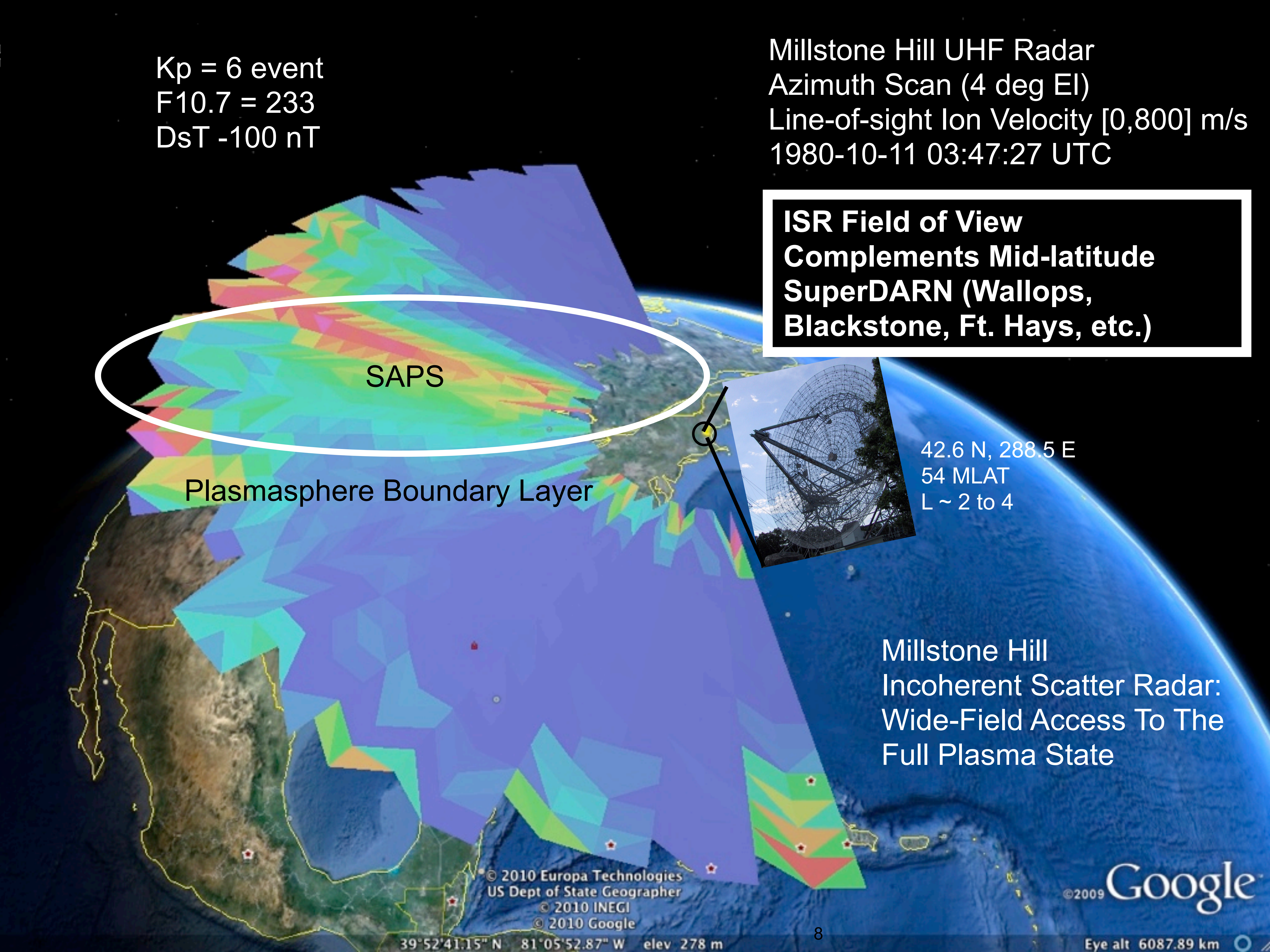
Zenith measurements since 1960
Fully wide-field since 1978

2.5 MW peak TX
440 MHz

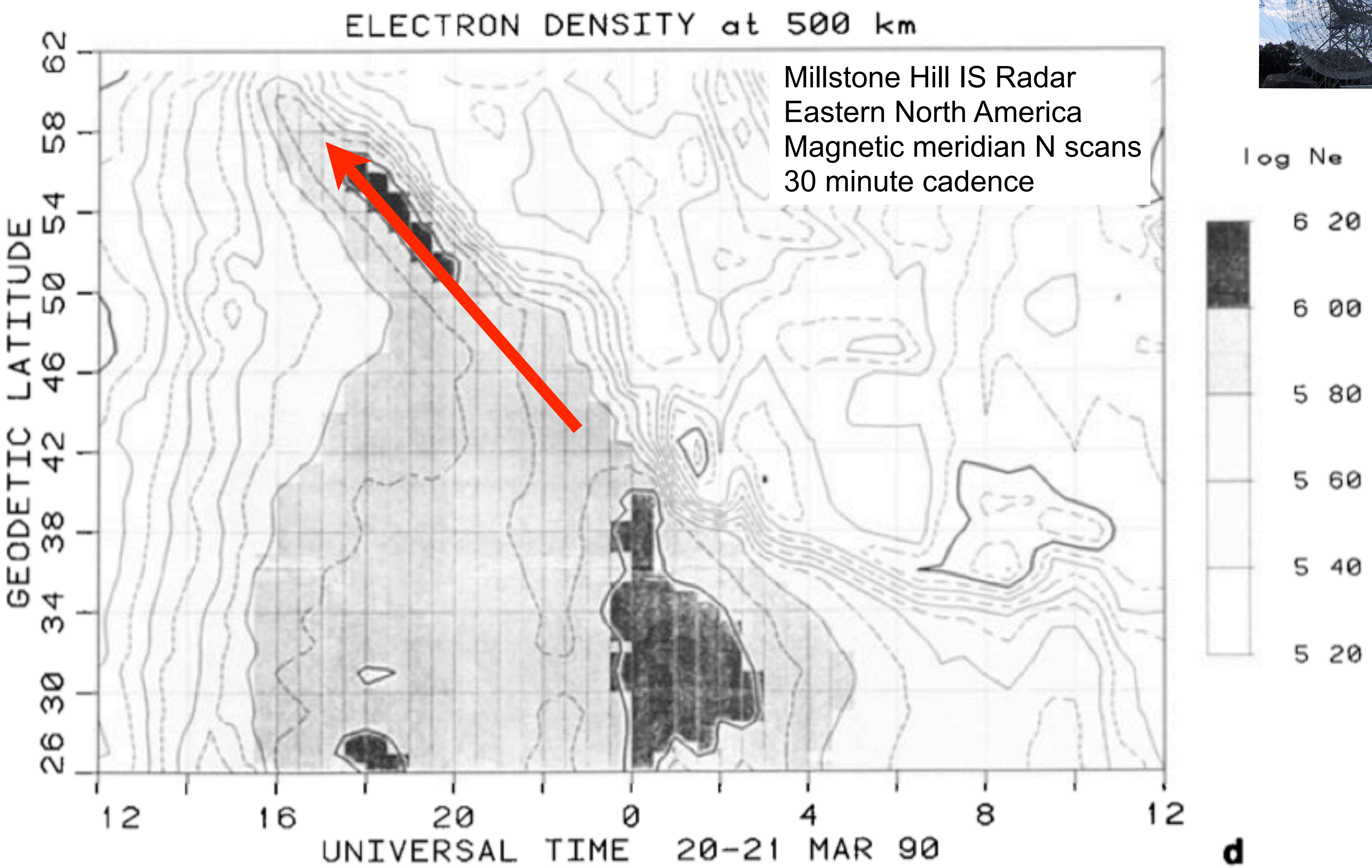





Kp = 6 event
F10.7 = 233
DsT -100 nT
Millstone Hill UHF Radar
Azimuth Scan (4 deg El)
Log Electron Density m^-3 [10, 12.5]
1980-10-11 03:47:27 UTC
ISR Field of View Complements Mid-latitude SuperDARN (Wallops, Blackstone, Ft. Hays, etc.)
Plasmasphere Boundary Layer
42.6 N, 288.5 E
54 MLAT
L ~ 2 to 4
Millstone Hill Incoherent Scatter Radar: Wide-Field Access To The Full Plasma State
© 2010 Europa Technologies
US Dept of State Geographer
© 2010 INEGI
© 2010 Google
©2009 Google
39°52'41.15" N 81°05'52.87" W elev 278 m
Eye alt 6087.89 km

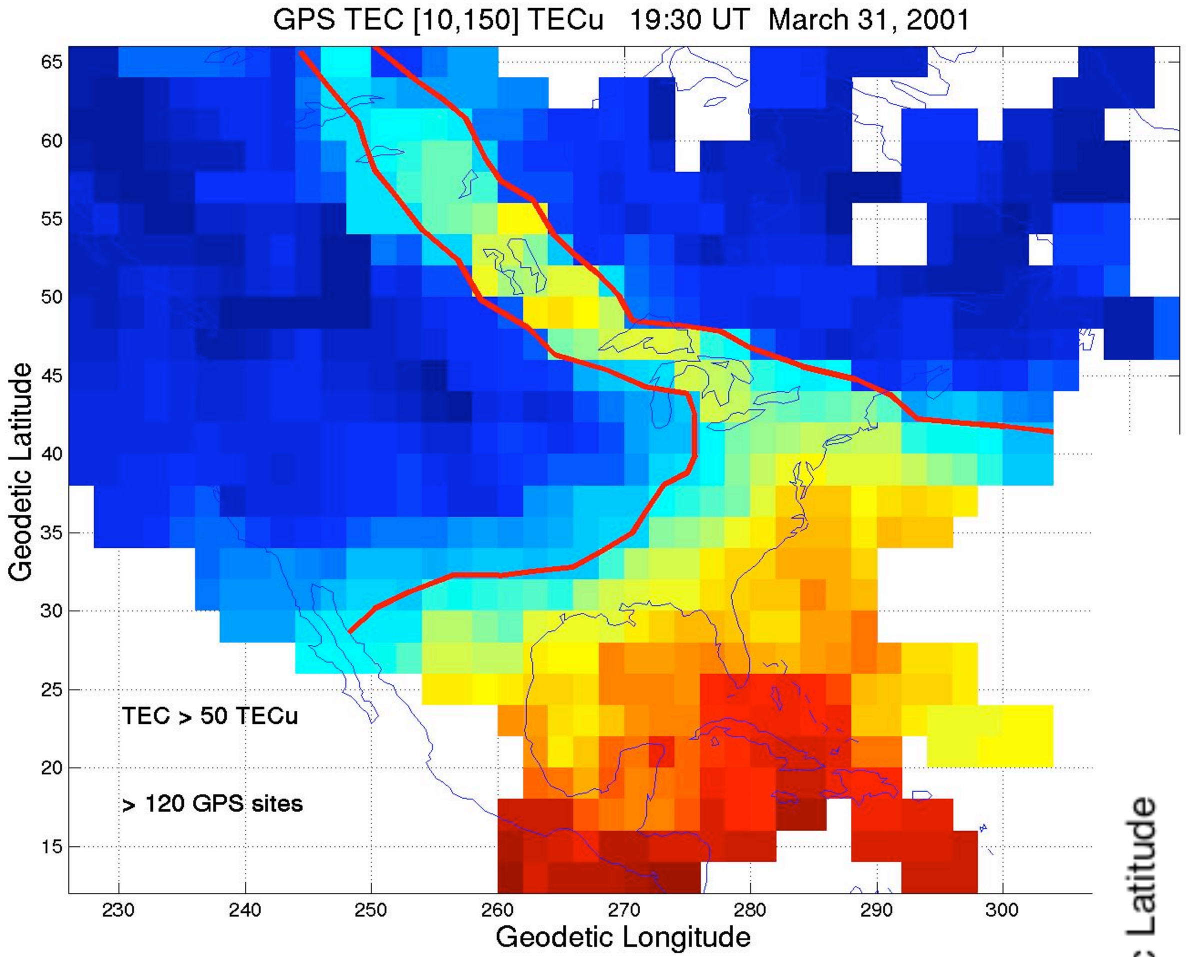

Kp = 6 event
F10.7 = 233
DsT -100 nT
Millstone Hill UHF Radar
Azimuth Scan (4 deg El)
Line-of-sight Ion Velocity [0,800] m/s
1980-10-11 03:47:27 UTC
ISR Field of View Complements Mid-latitude SuperDARN (Wallops, Blackstone, Ft. Hays, etc.)
SAPS
Plasmasphere Boundary Layer
42.6 N, 288.5 E
54 MLAT
L ~ 2 to 4
Millstone Hill Incoherent Scatter Radar: Wide-Field Access To The Full Plasma State
© 2010 Europa Technologies
US Dept of State Geographer
© 2010 INEGI
© 2010 Google
©2009 Google
39°52'41.15" N 81°05'52.87" W elev 278 m
Eye alt 6087.89 km

Storm Enhanced Density (SED): ISR Picture



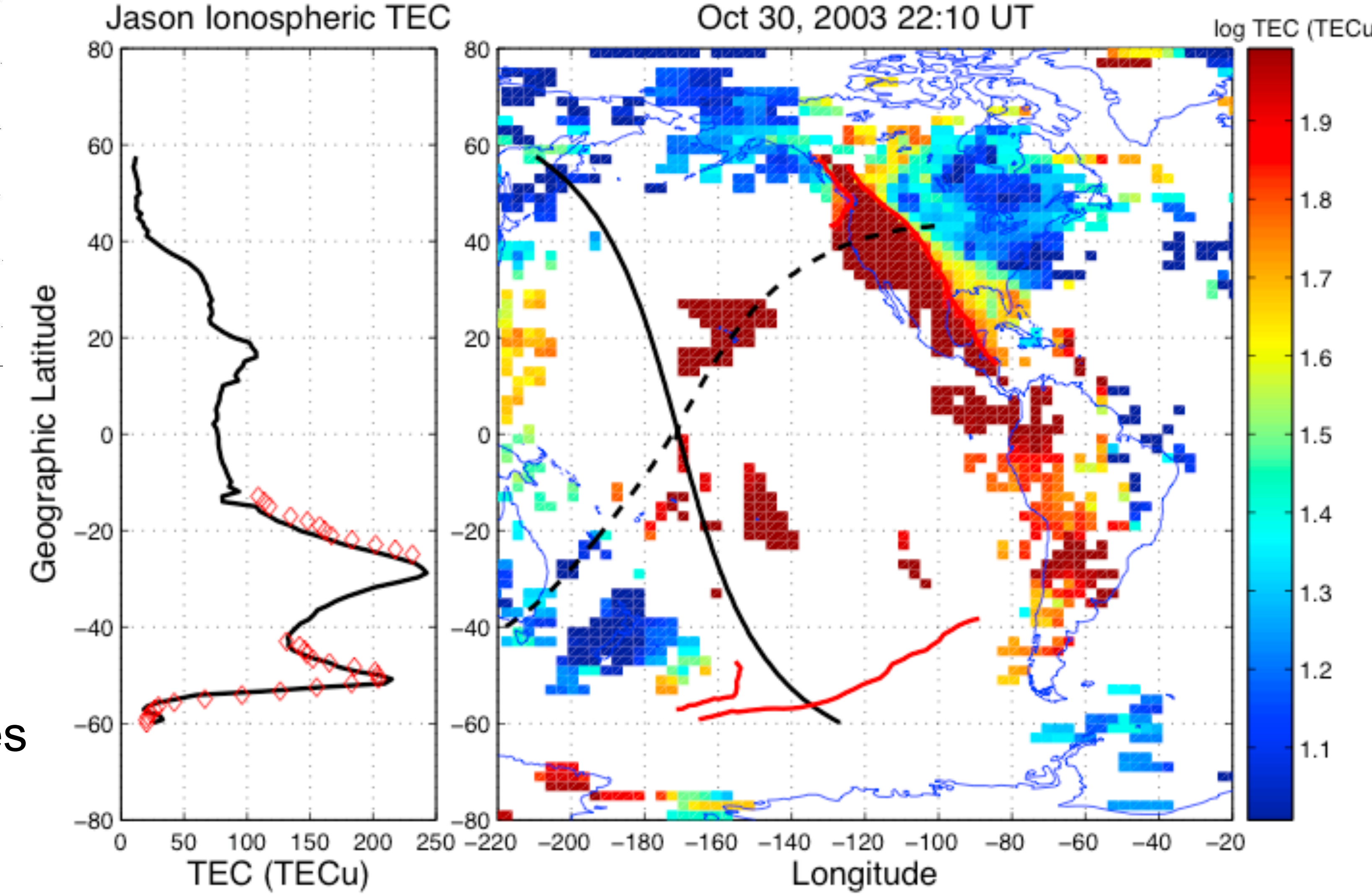
Foster, 1993

Storm Enhanced Density (SED): GPS Picture



Foster et al, 2002

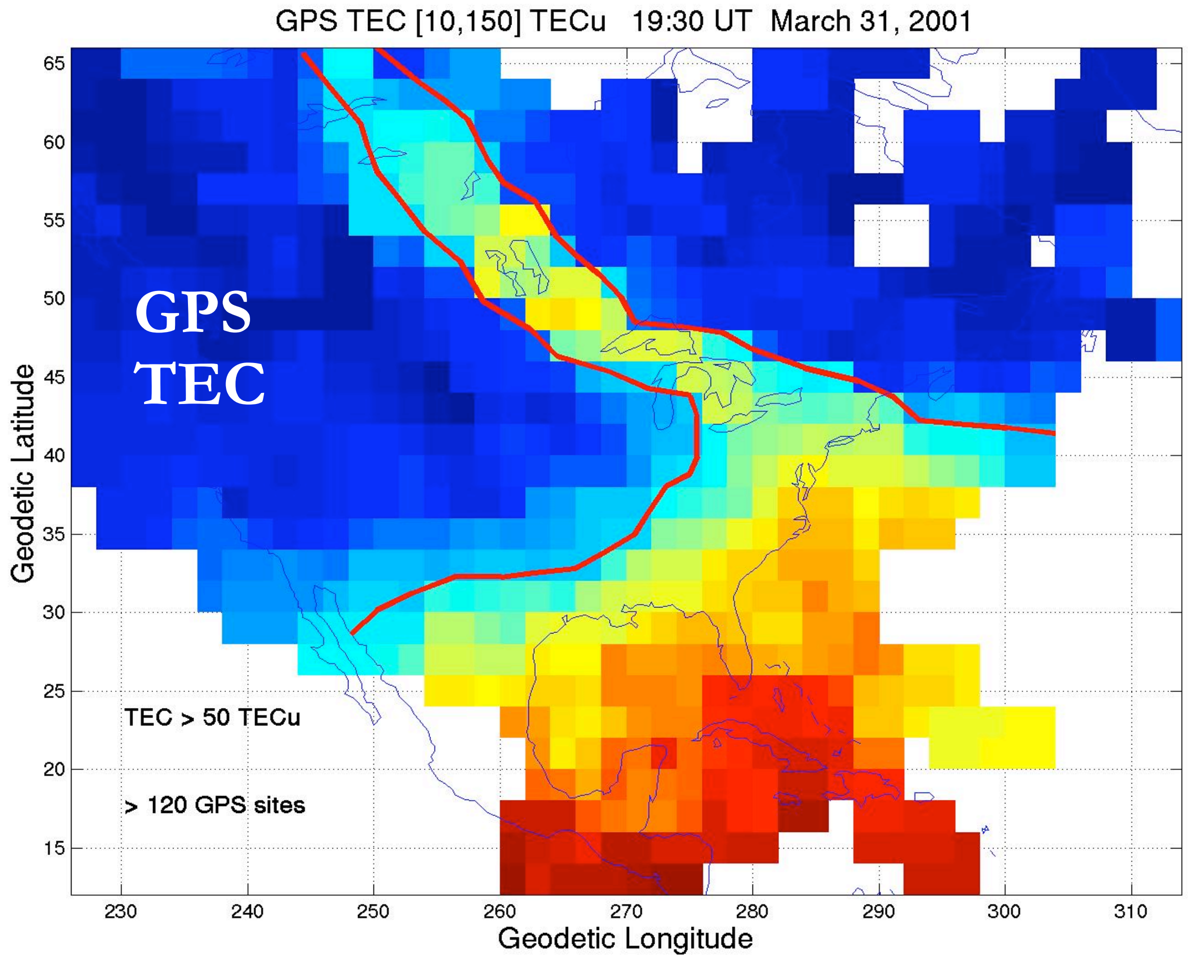
Foster and Rideout, 2007

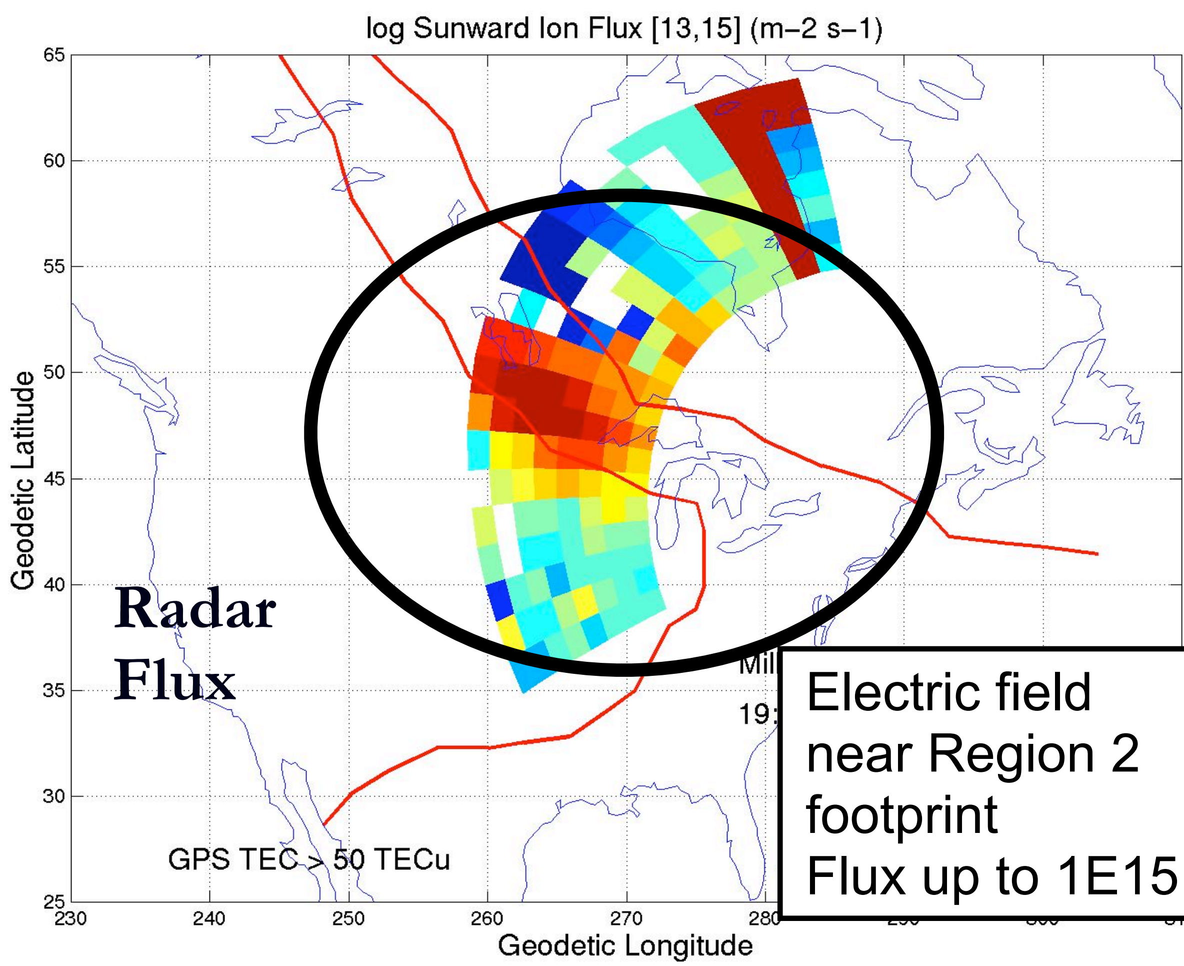


SED Plumes extend through mid-latitudes
Conjugate features are detected

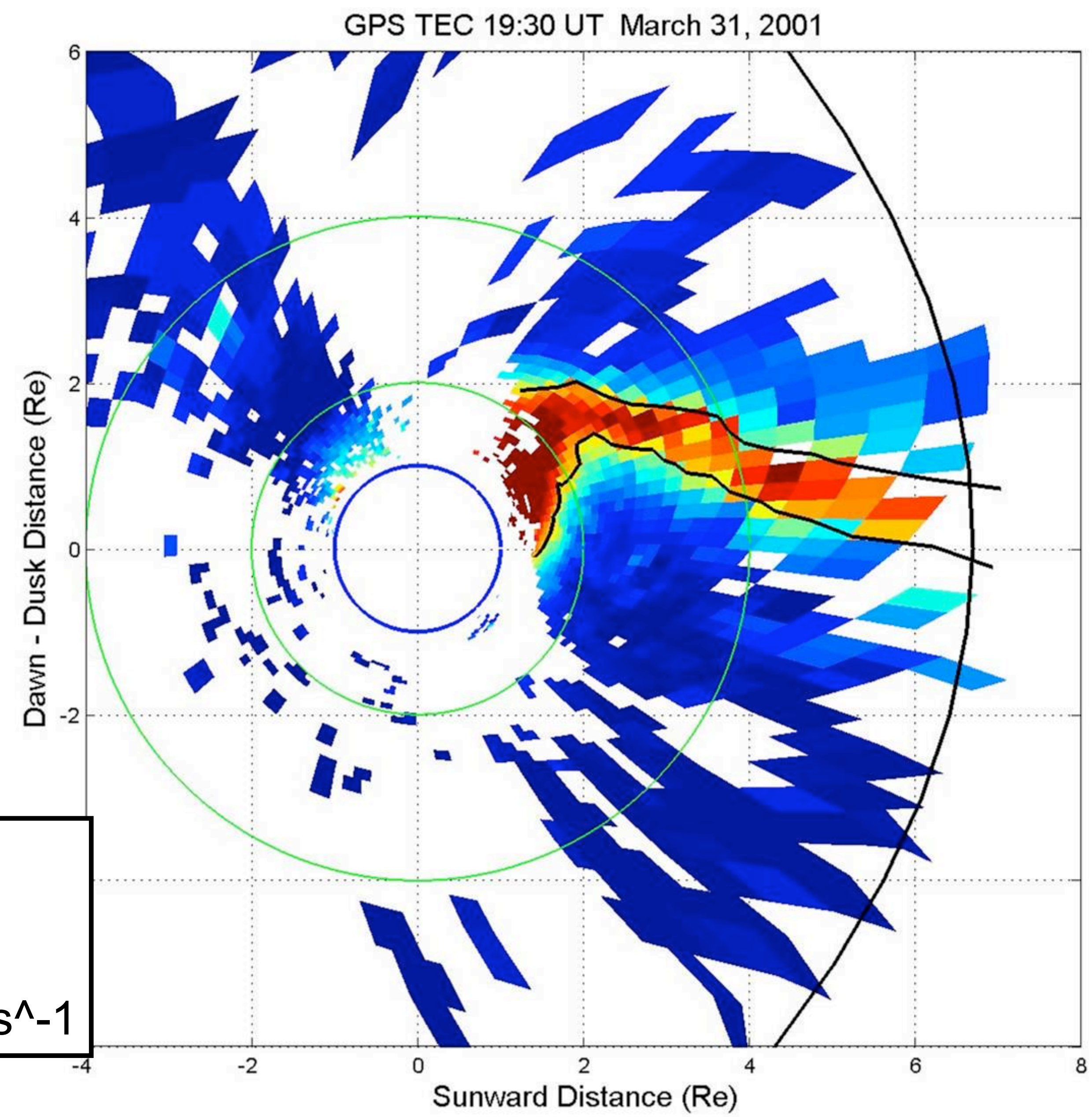
Plasma Redistribution TEC/ Plasmasphere Plume March 31, 2001

Magnetosphere-Ionosphere Coupling

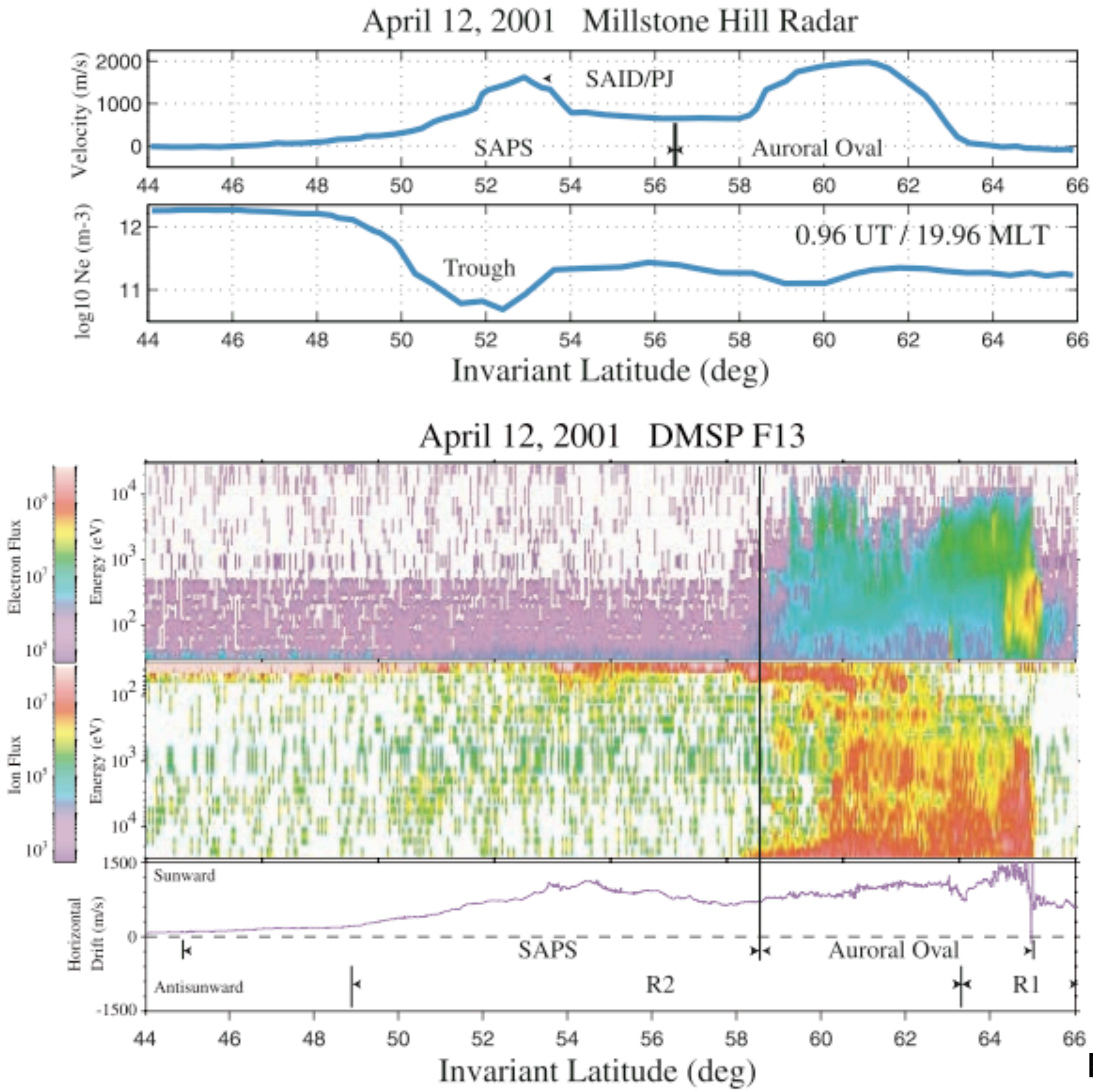




Electric field near Region 2 footprint
Flux up to 1E15 m^2 s^-1



Sub-Auroral Polarization Stream (SAPS)



Westward (sunward) subauroral velocity near footprint of region 2 / ring current

2-5 deg wide

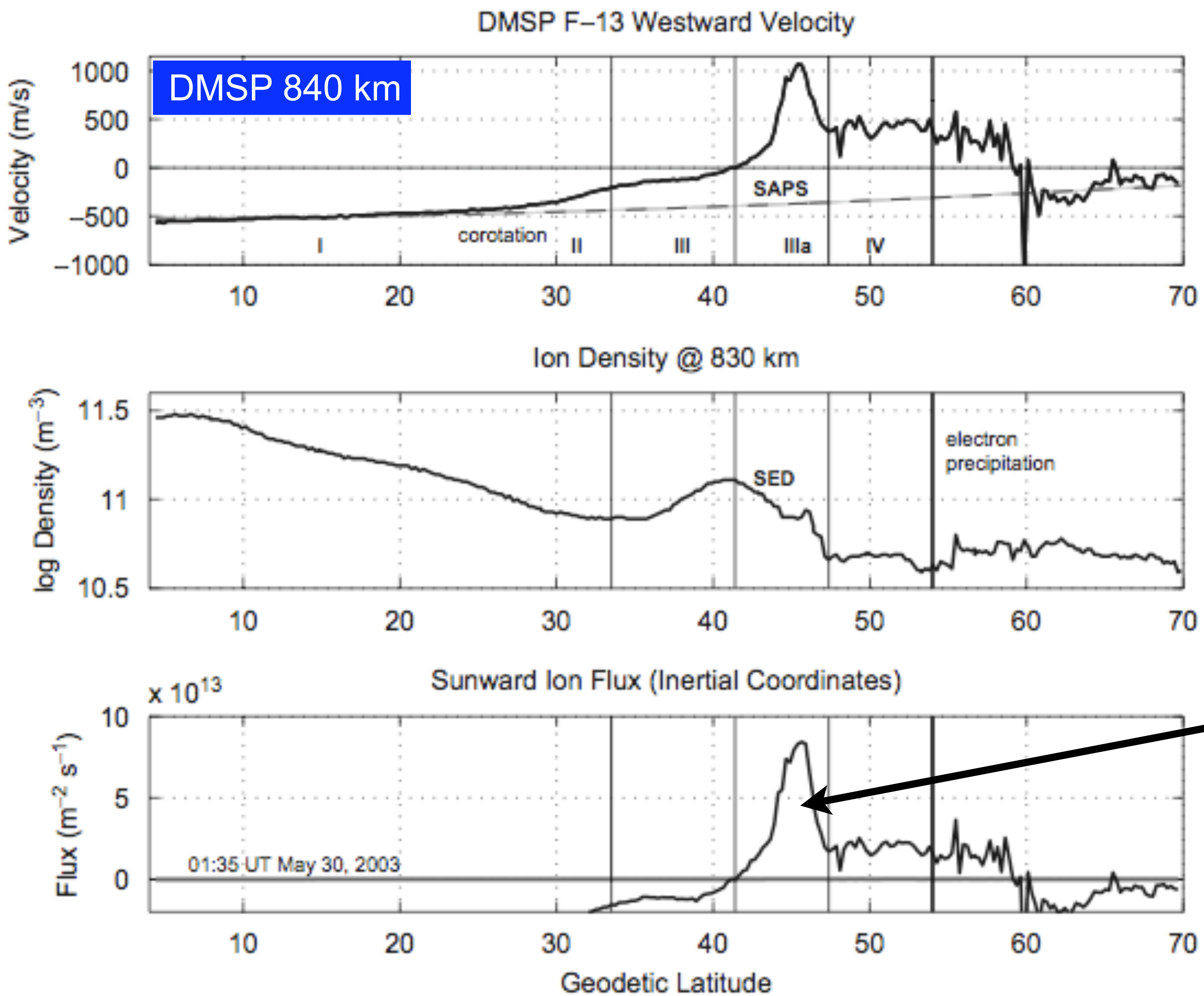
Embedded small and highly variable structures (SAID)

Overlaps edge of storm enhanced density (SED)

Dusk sector transport of material to noontime cusp

Foster and Vo, 2002

Sunward ion flux driven by SAPS

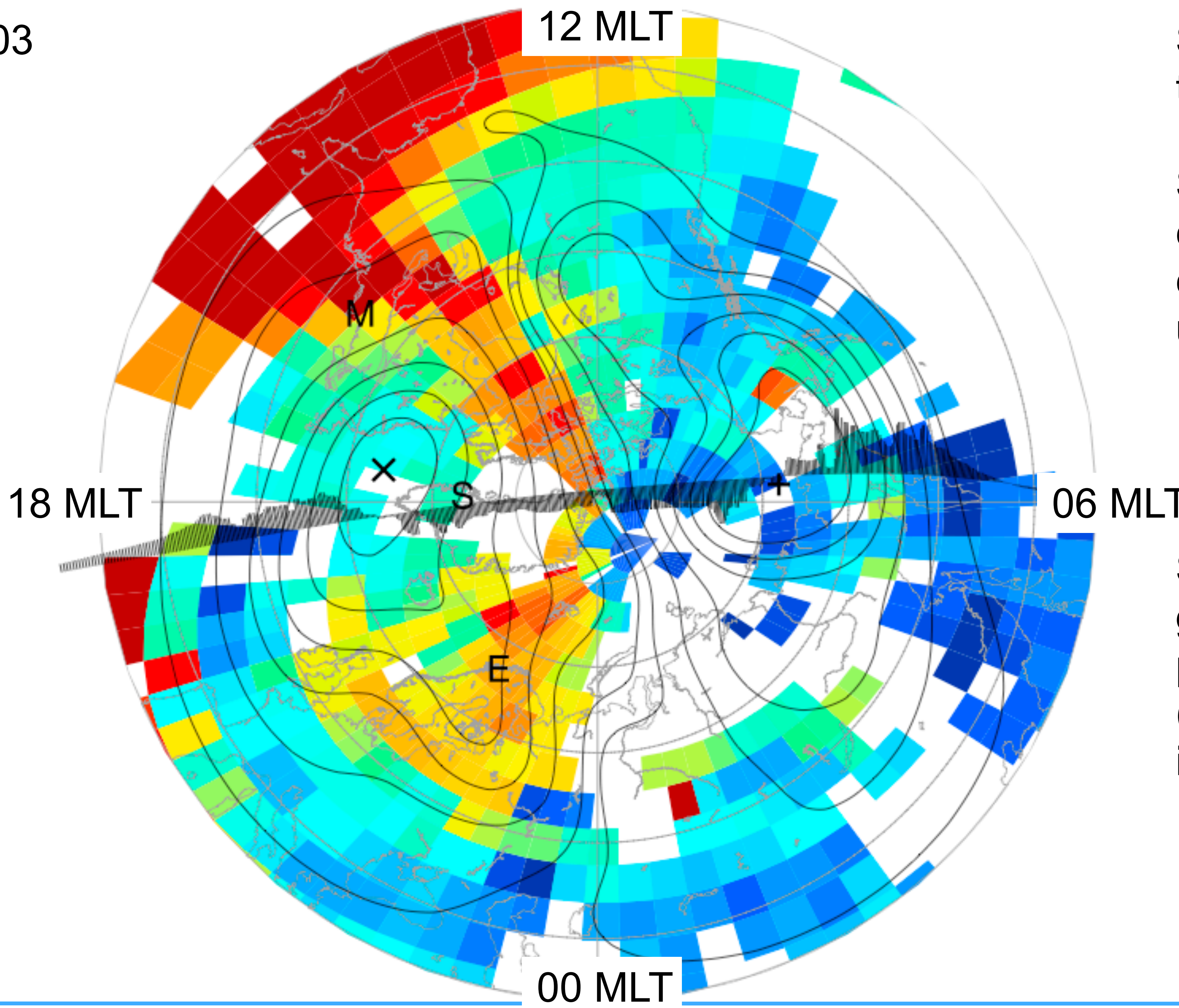


Sunward ion flux caused by SAPS/SED overlap

Foster et al, 2007

Connections to Polar Processes

20 Nov 2003
1820 UTC



SED connects through cusp

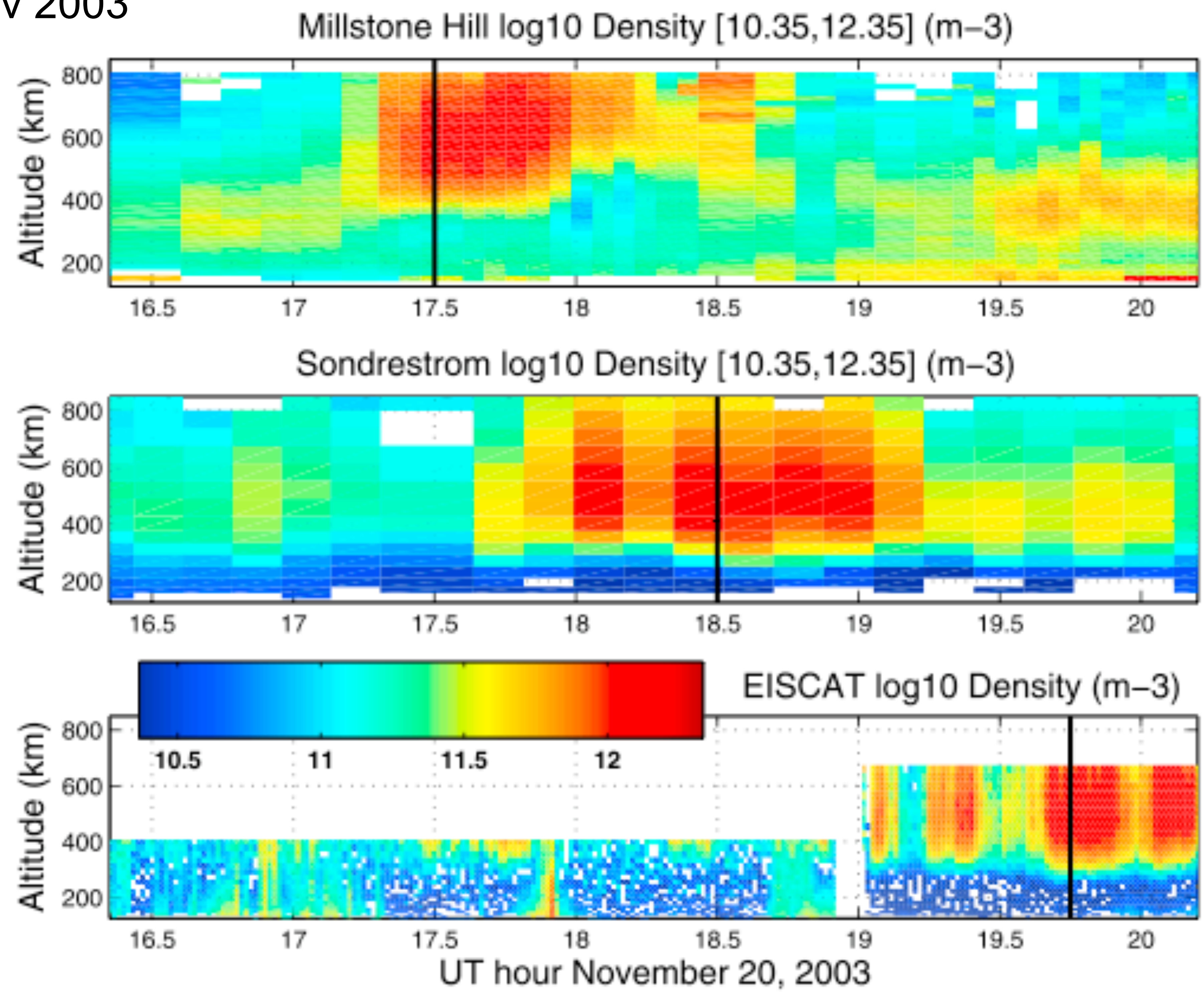
Some material contributes to cusp ion upwelling

Some material goes over polar cap (Tongue of ionization)

Foster et al, 2005

Connections to Polar Processes

20 Nov 2003



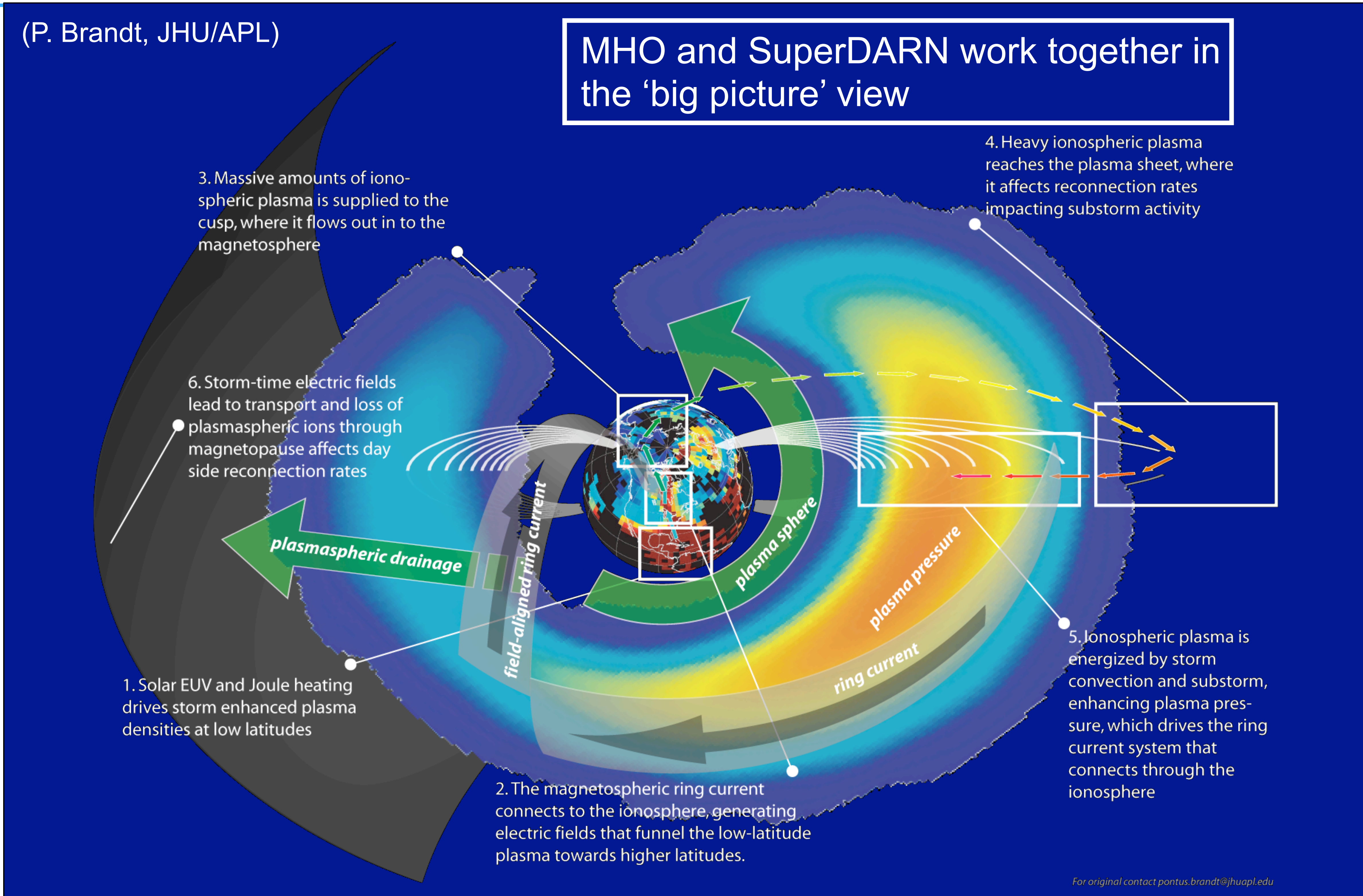
SED material is uplifted as it travels from mid to high latitudes

Participates in ion upwelling

Mass-loads plasma sheet with heavy, cold O+ ions

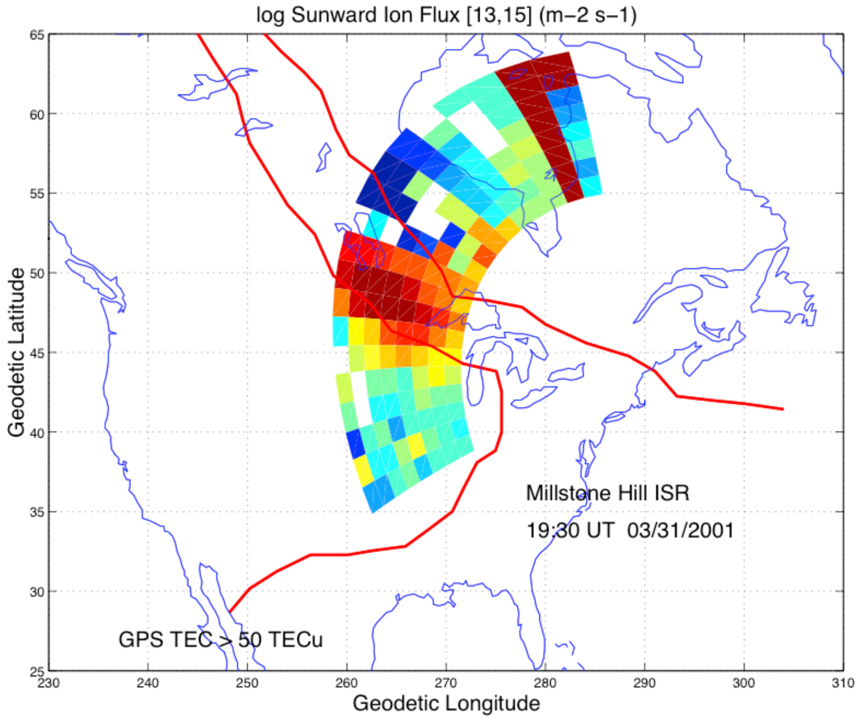
Foster et al, 2005

The Evolving Mesoscale Picture

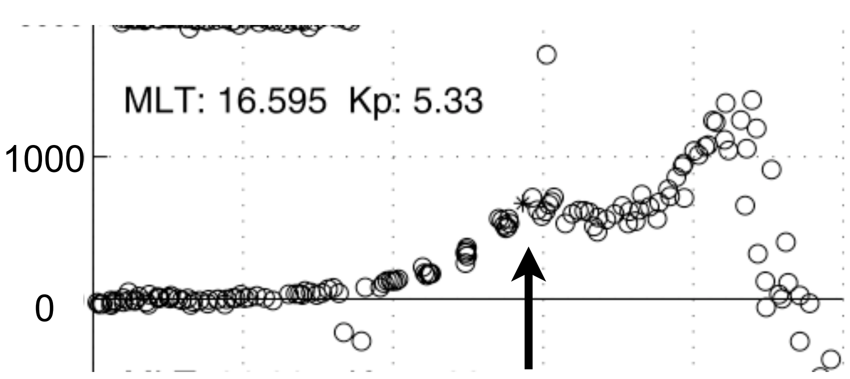


Mid-Latitude Flows: SAPS Statistical Study

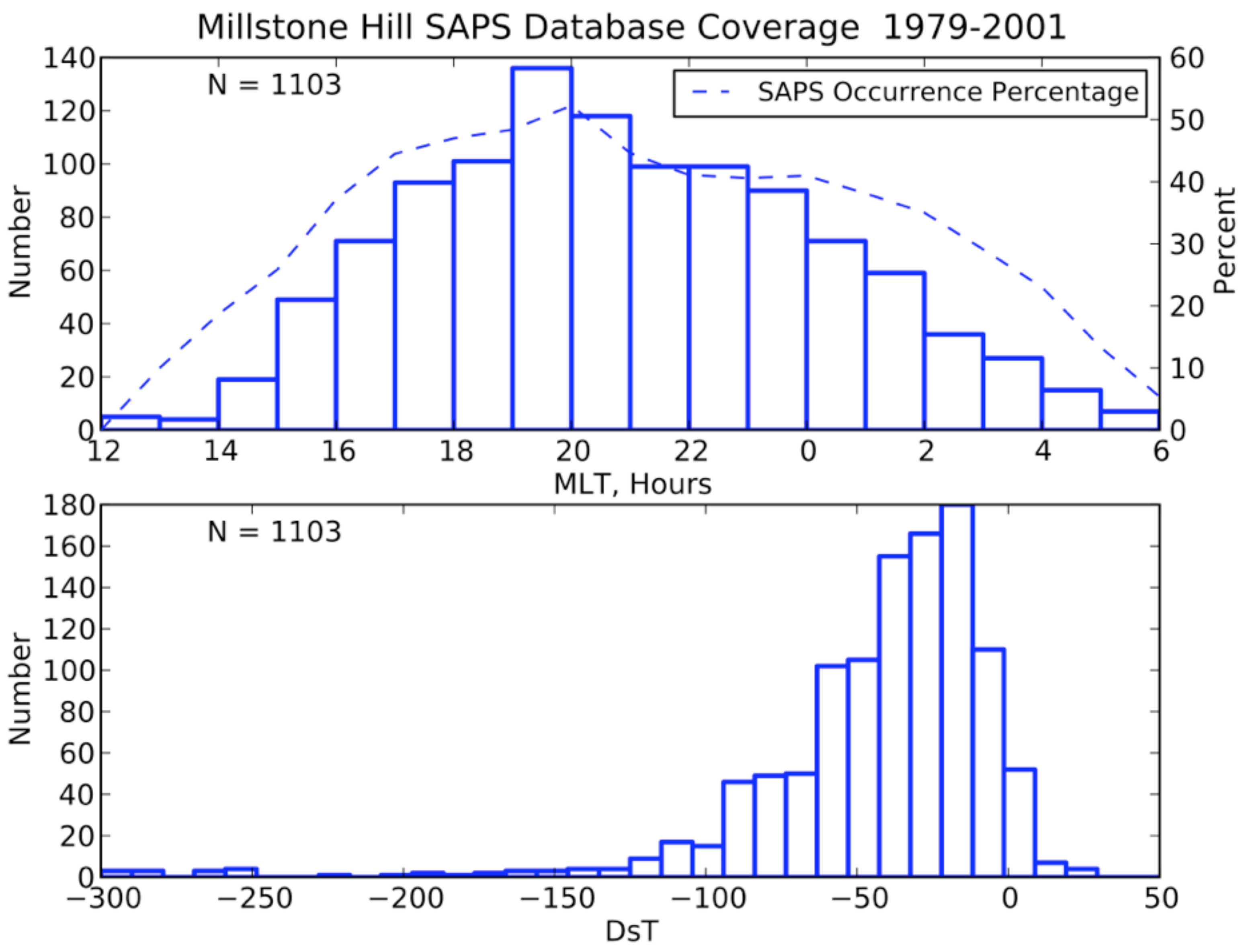
Individual events



Westward ion velocity, m/s

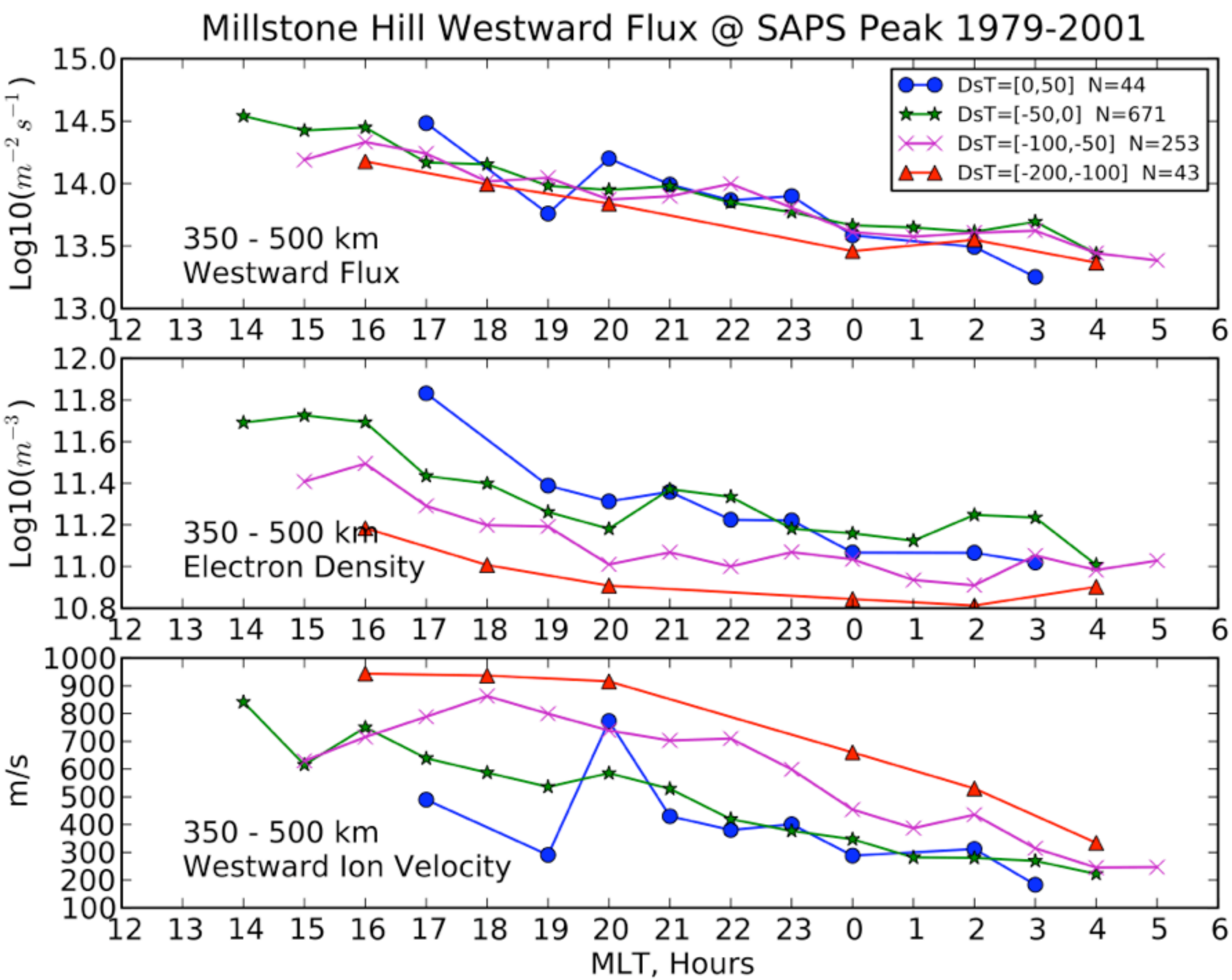


Latitude



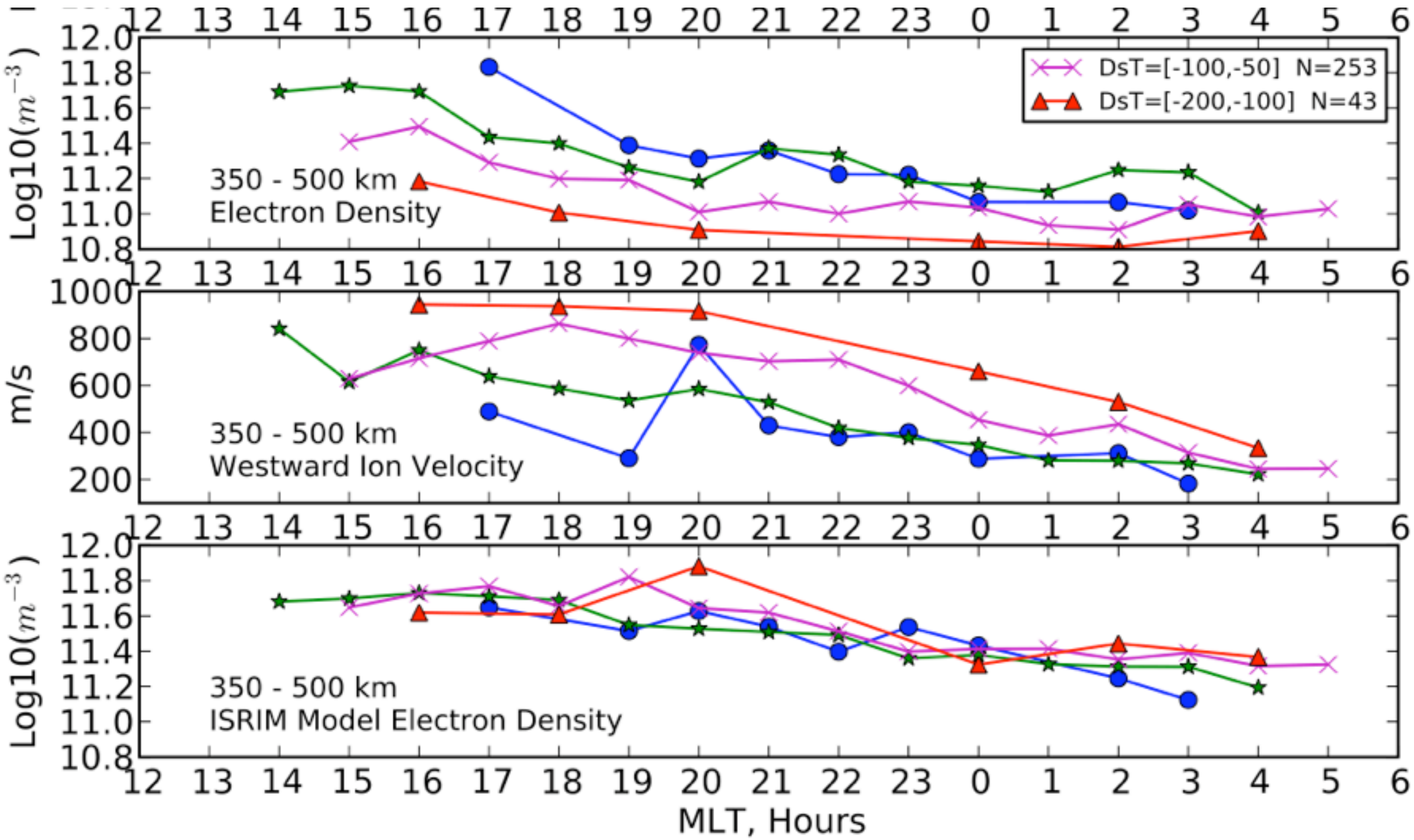
Kp = 2 and greater
10,000+ scan database

SAPS Flux: Inverse Density/Velocity Relation



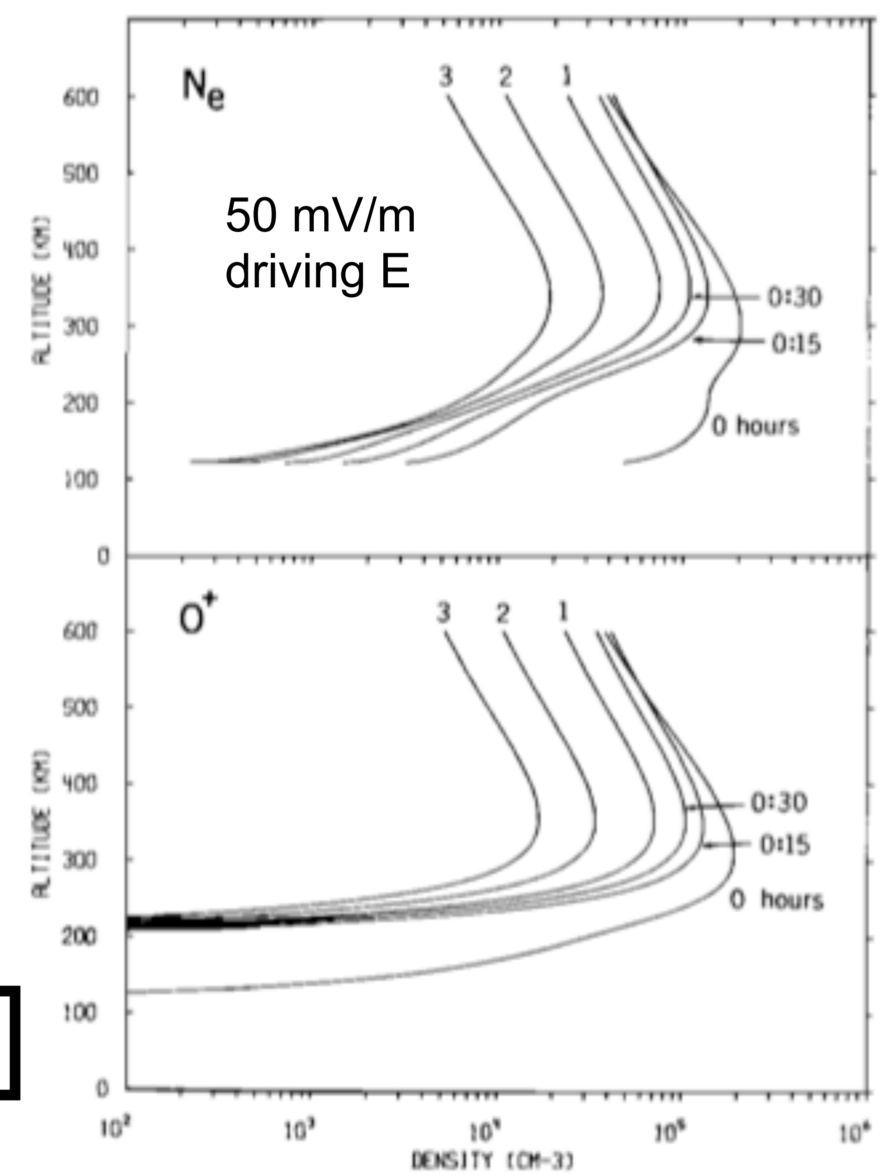
Erickson et al
JGR 2011

SAPS Flux: Inverse Density/Velocity Relation



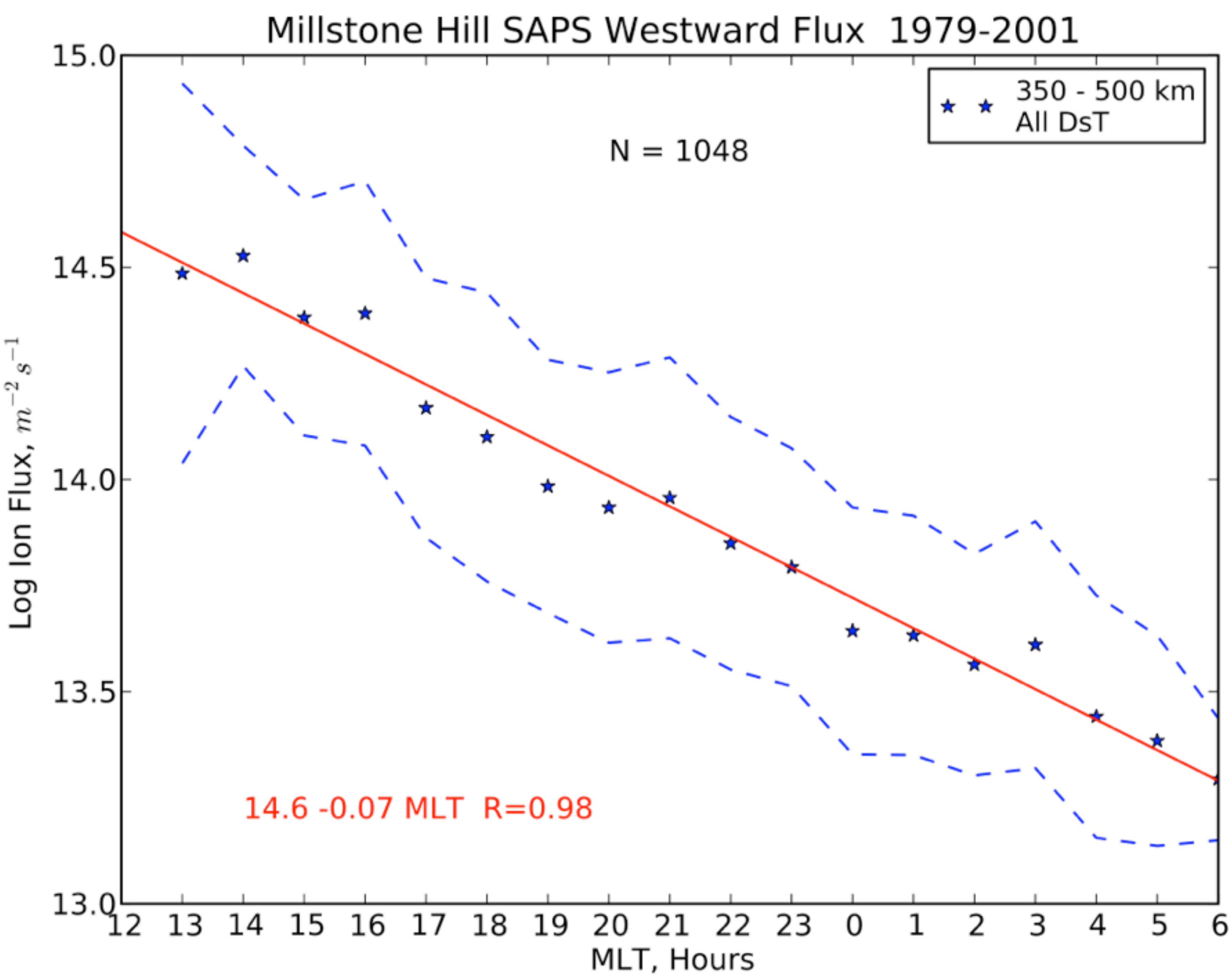
Erickson et al
JGR 2011

Schunk et al 1976



How do these features compare with SuperDARN statistics?

System Regulation: Westward Flux Invariance



Erickson et al
JGR 2011

MHO Measurements of SAPS Conductivity

What are characteristics of ionospheric conductivity in region 2 area and how do they regulate SAPS?

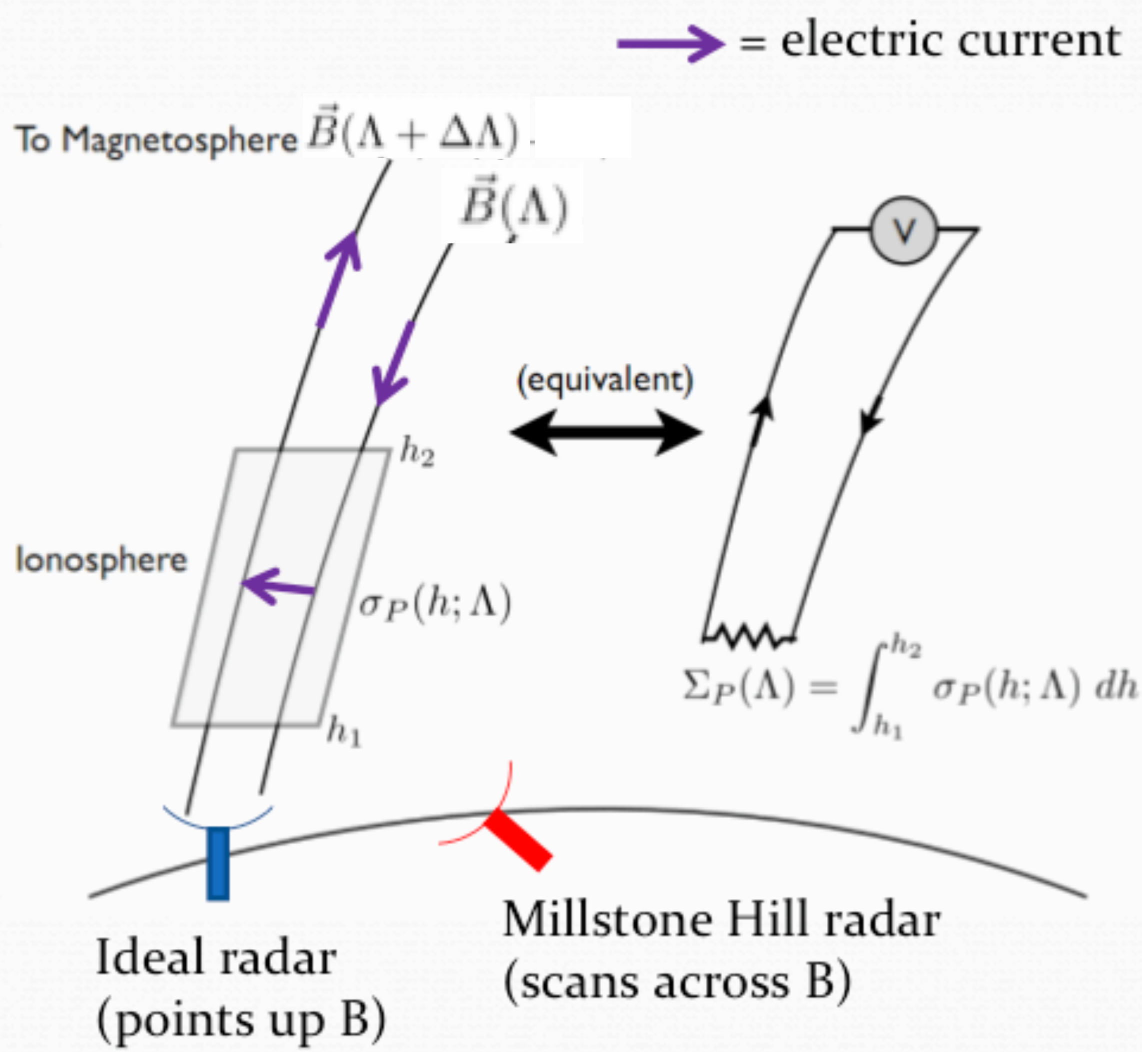
Pedersen Conductivity

$$\sigma_P = \frac{n_e q}{B}\left[\frac{\omega_{ci}\,\nu}{(\nu^2+\omega_{ci}^2)} - \frac{\omega_{ce}\,\nu}{(\nu^2+\omega_{ce}^2)}\right]$$

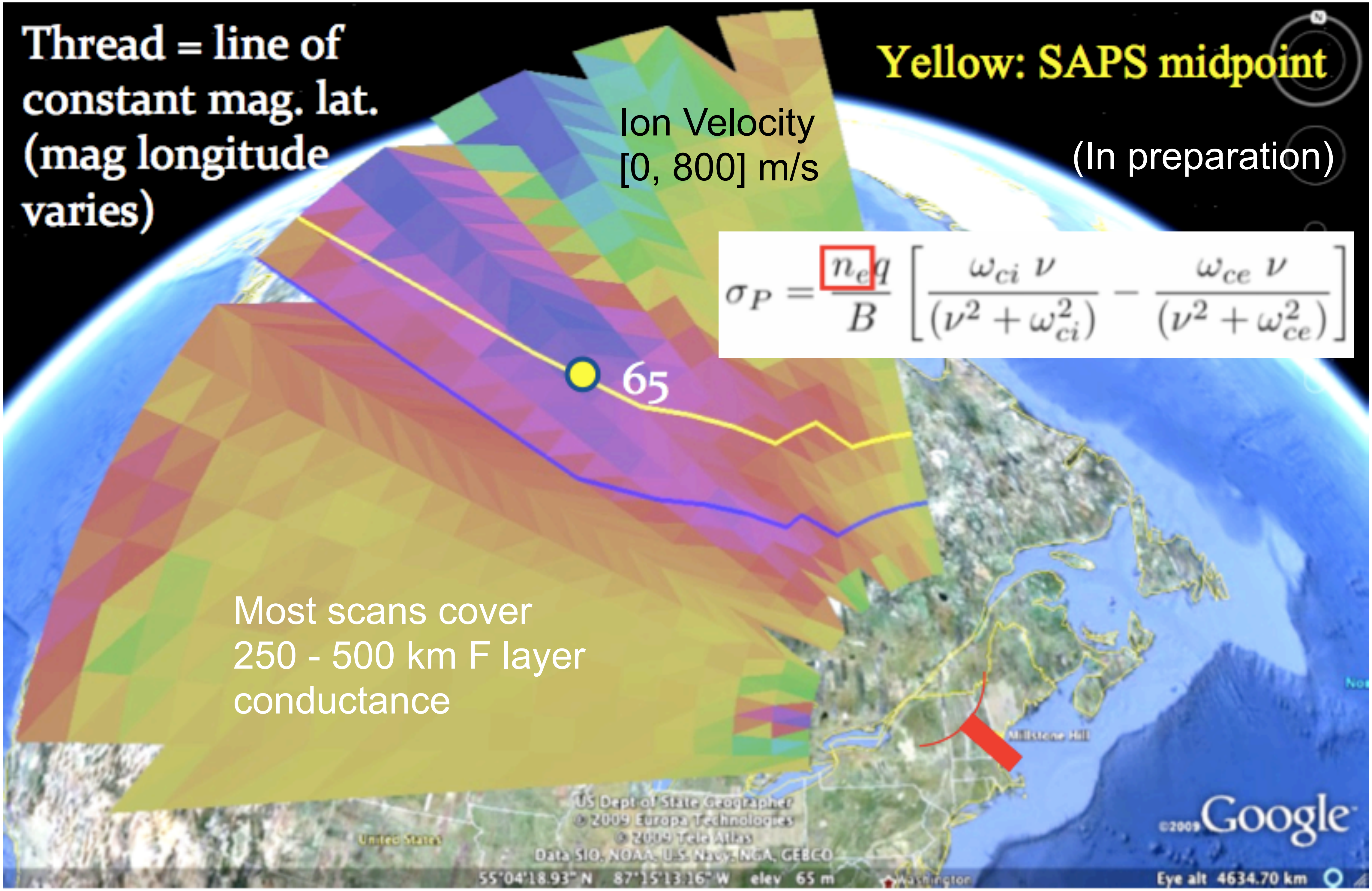
Depends on:

- ionospheric electron density
- neutral density
- ion-neutral collision frequency
- magnetic field strength

Red: measured by ISR
Green: modeled



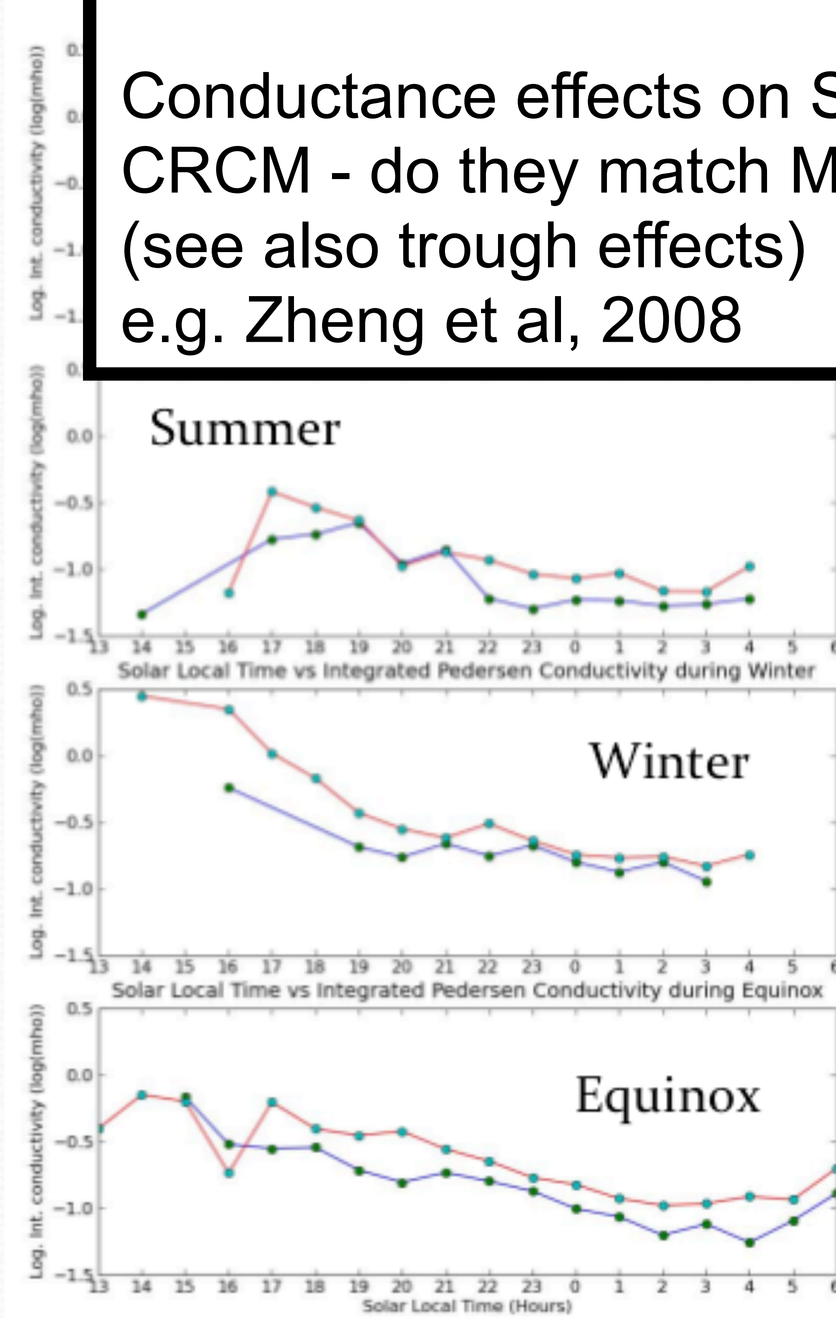
Field-Aligned Integrated Conductance



SAPS Integrated Conductivity Results

Integrated Pedersen Conductivity Inside and Outside SAPS

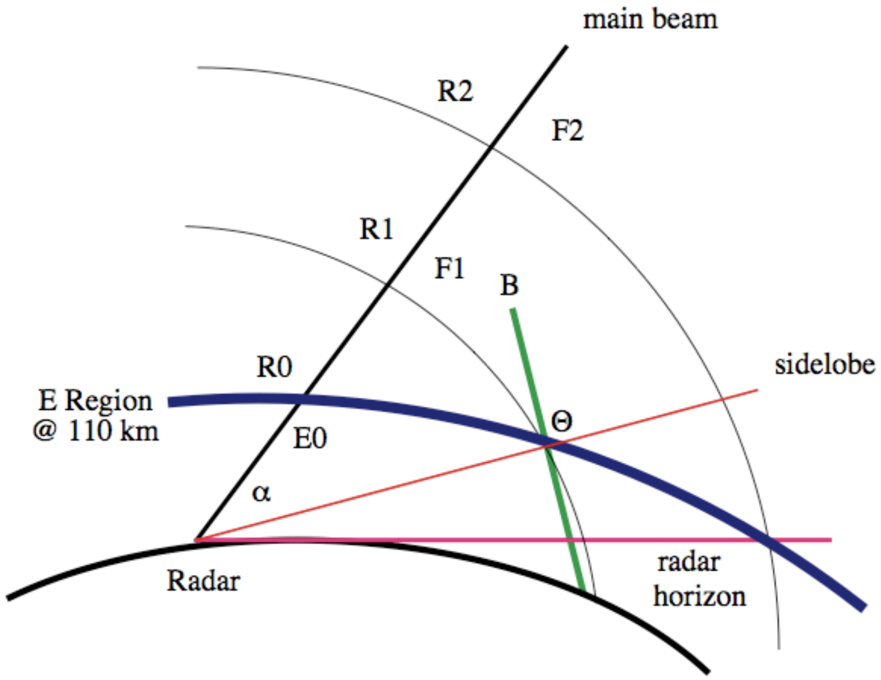
- Each graph shows the integrated Pedersen conductivity curves at the midpoint and three degrees equator-ward
- Integrated Pedersen conductivity at SAPS midpoint is 2x lower
- SAPS electron density peaks at higher altitudes: collisions with neutrals decrease, causing lower conductivity

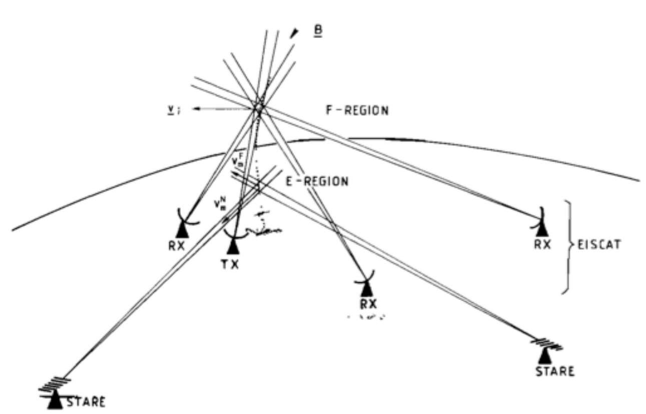


How do SuperDARN SAPS convection patterns compare in subauroral regions?

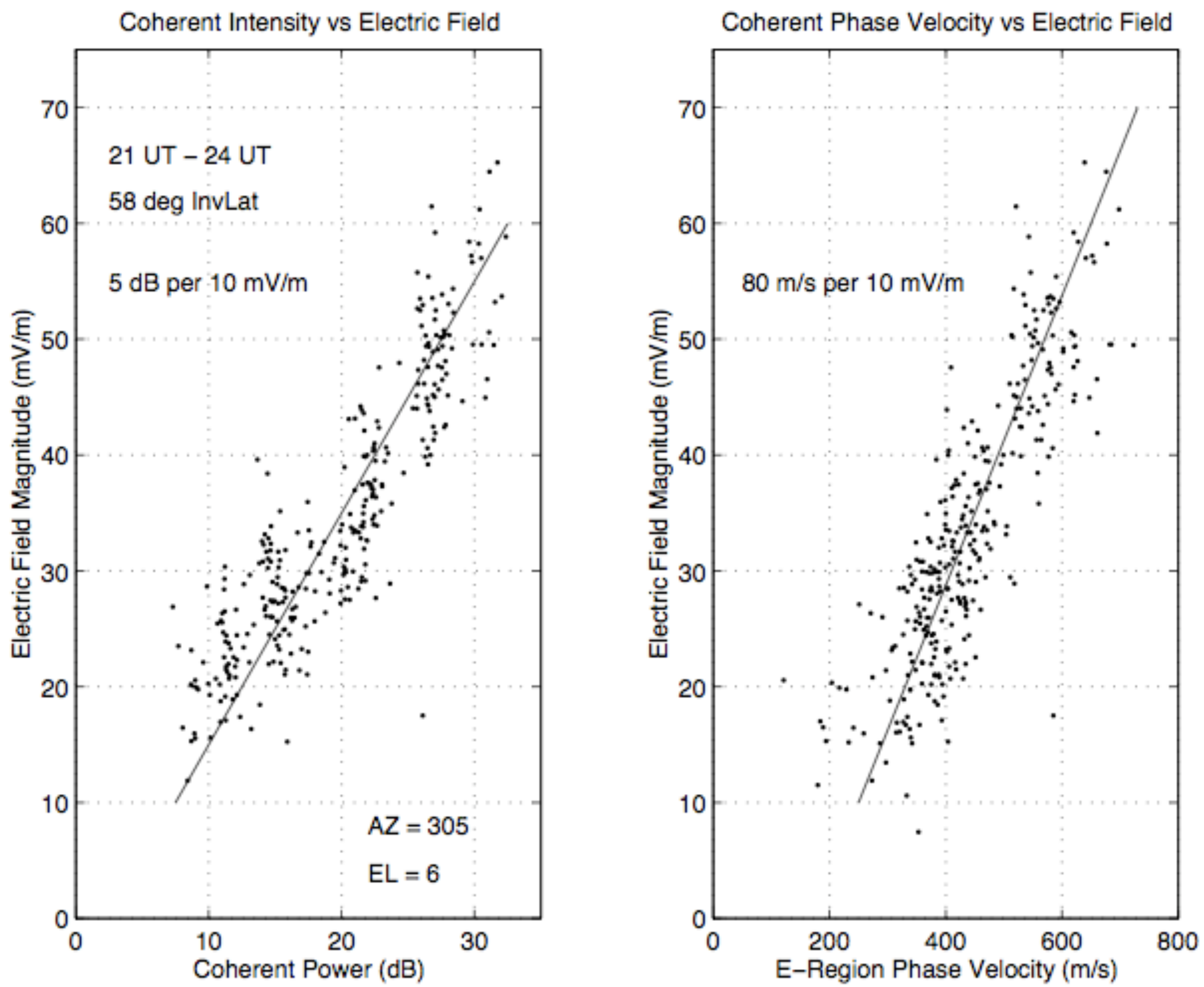
Conductance effects on SAPS features in CRCM - do they match MHO, SD data? (see also trough effects) e.g. Zheng et al, 2008

UHF Coherent Scatter as Electric Field Monitor





VHF; Nielsen and Schlegel, 1985



Foster and Erickson, 2000

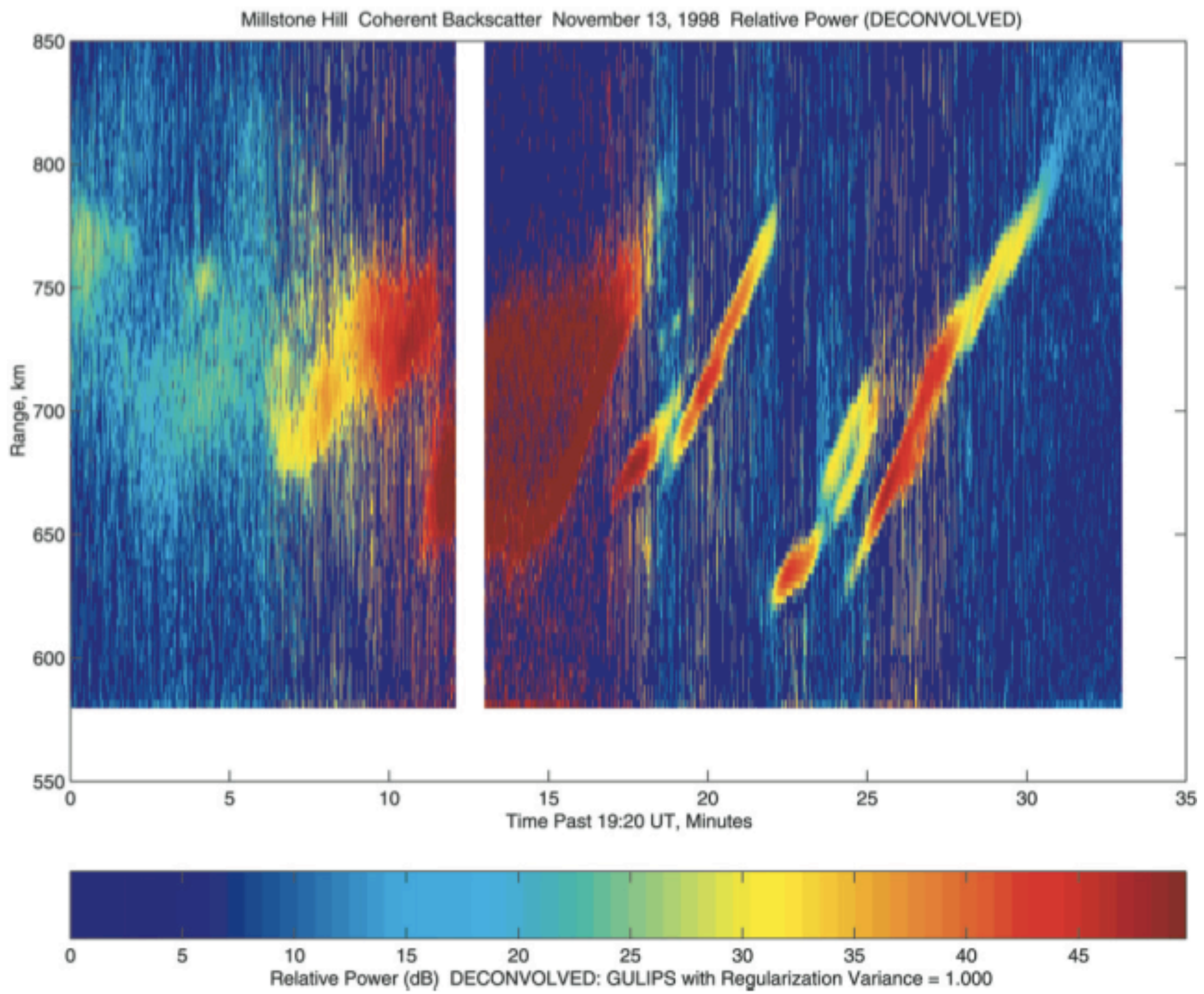
Subauroral Electric Field Dynamic Variations

Significant spatial, temporal structure within SAPS stream and specifically SAID size structures

Likely modulated by conductivity microscale variations

UHF megawatt class large aperture allows sub-second, km scale resolution

Relation to HF scattering irregularities? k-space, w-space studies..



Erickson et al, 2002

Temperature Gradient Instability (2006)

Persistent low velocity SD echoes

Very frequent (e.g. Feb 2006: 19 out of 27 observation days)

Long duration (7+ hours per night)

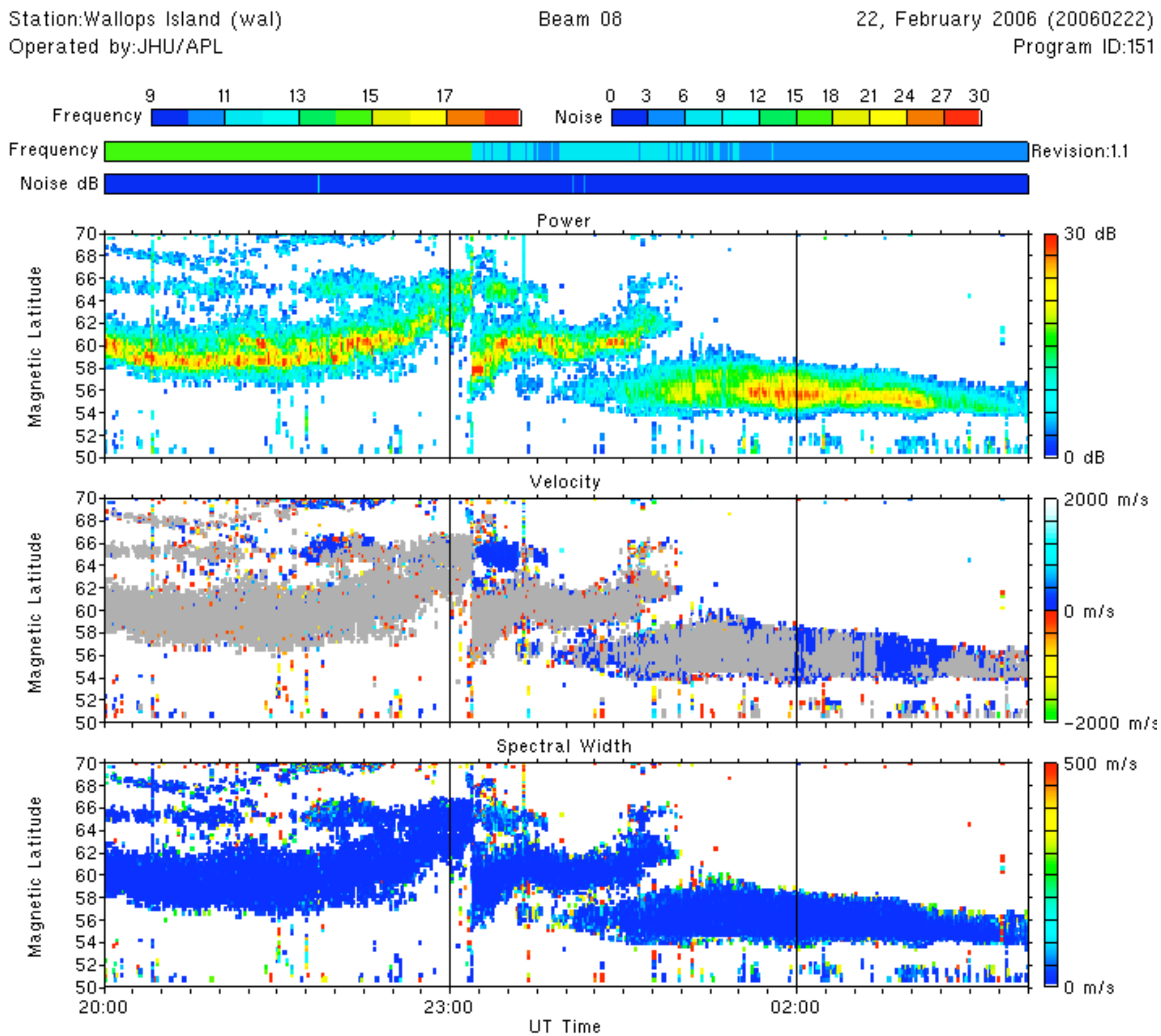
Low Doppler shift (30-90 m/s)

Very small spectral width

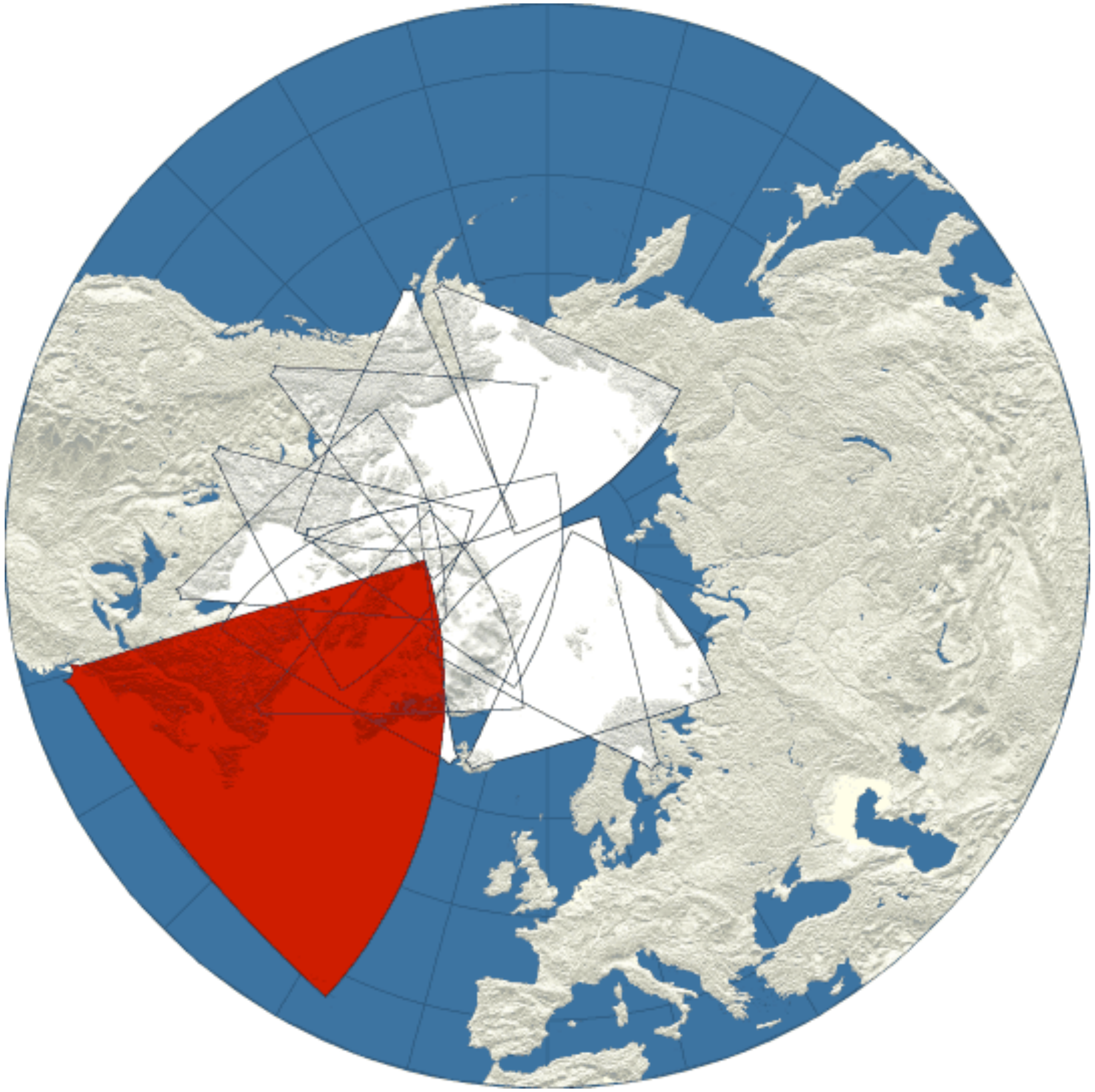
Low activity (Kp 0-2)

Sub-auroral region (54-60 inv lat)

Cause?

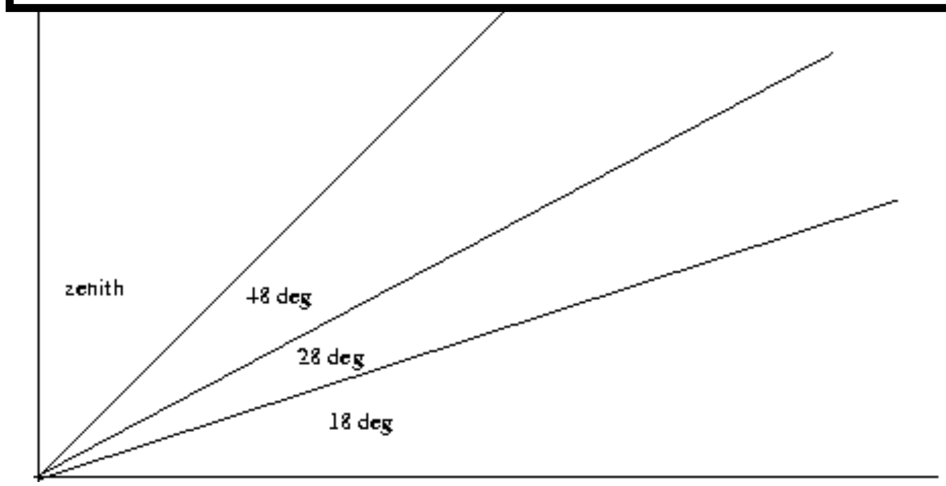


The Experiment: 22-23 Feb 2006 (SD + ISR)



Wallops SuperDARN: Individual Beam RTIs

MHO: 34 az, (18/28/48 el) + zenith
focused on 55-60 inv @ 300 km

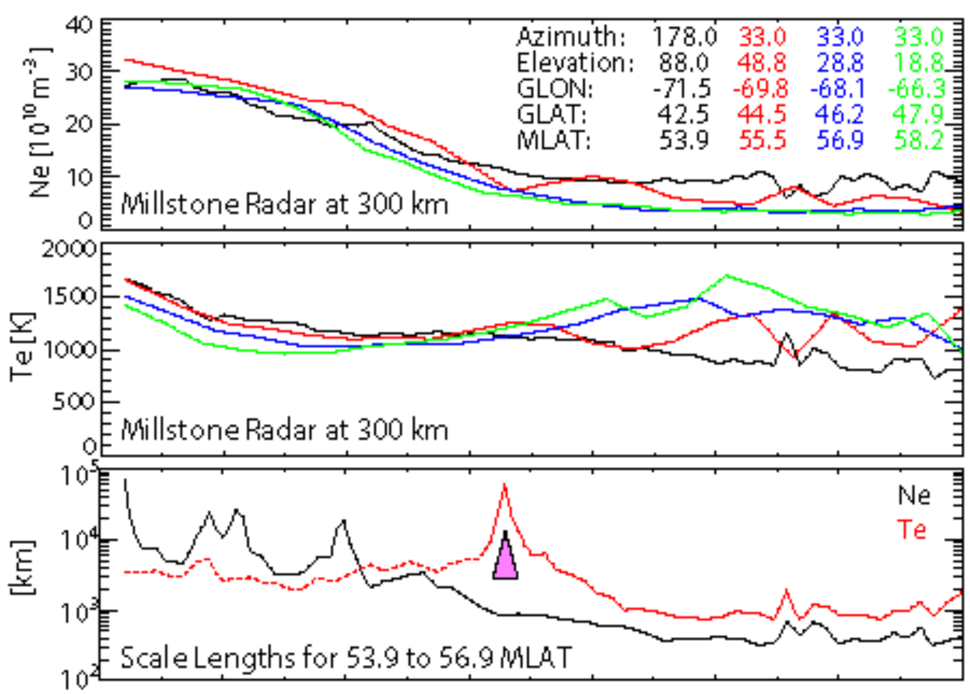


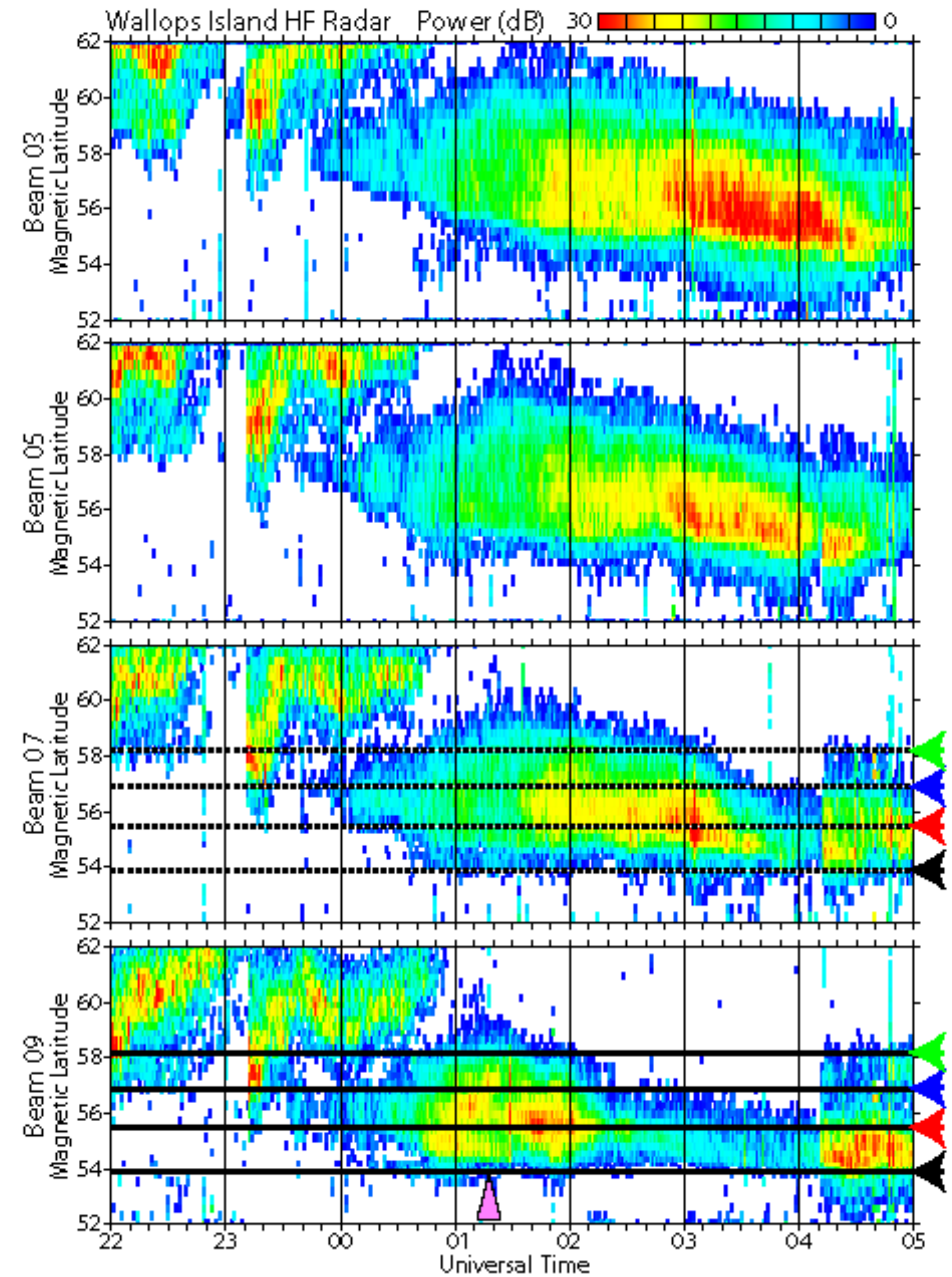
HF Backscatter + IS Temperature Gradients

SuperDARN Wallops HF Backscatter + MHO Gradients
2200 – 0500 UTC 2006-02-22

2200 – 2340: Ground refracted scatter
2340 – 0140: GDI or trough wall or zonal gradient (seen before). TGI not active yet.

<u>0140 onwards</u>: TGI conditions present as Te gradient changes sign. Scatter weakens at higher beams as density decreases. TX frequency adjusted at 0410 UT – enhances scatter (refraction change)



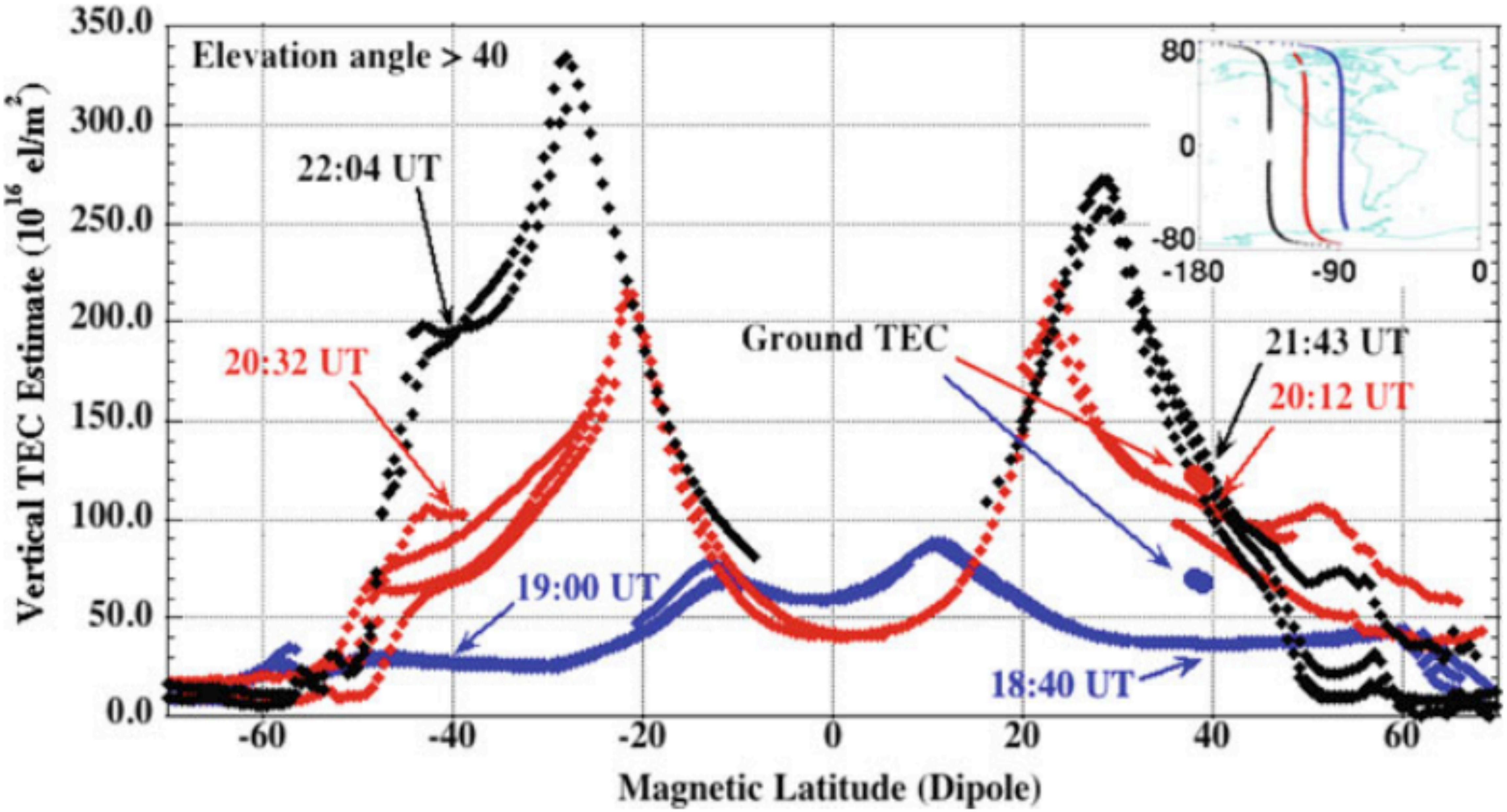


Summary

- PBL filled with interesting M-I coupling, subauroral physics
- Millstone Hill covers eastern North America plasma parameters
- Excellent opportunities for MHO-SuperDARN collaborations

Collaborations encouraged!
pje@haystack.mit.edu

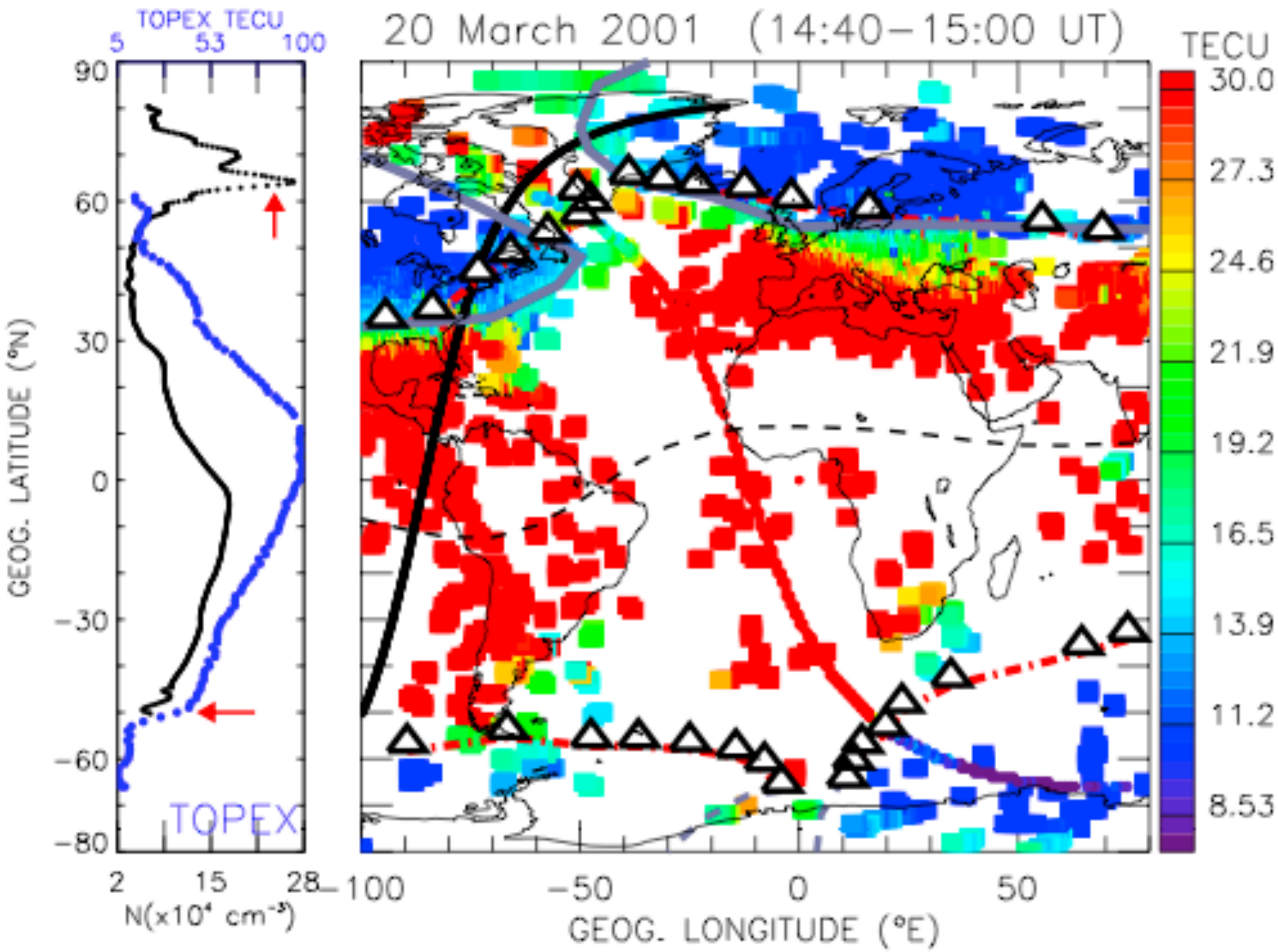
Dramatic, Longitude-Specific TEC Increases



(A. J. Mannucci Oct 2003 storm)

Storm Enhanced Density (SED): GPS Picture

Yizengaw et al, 2008



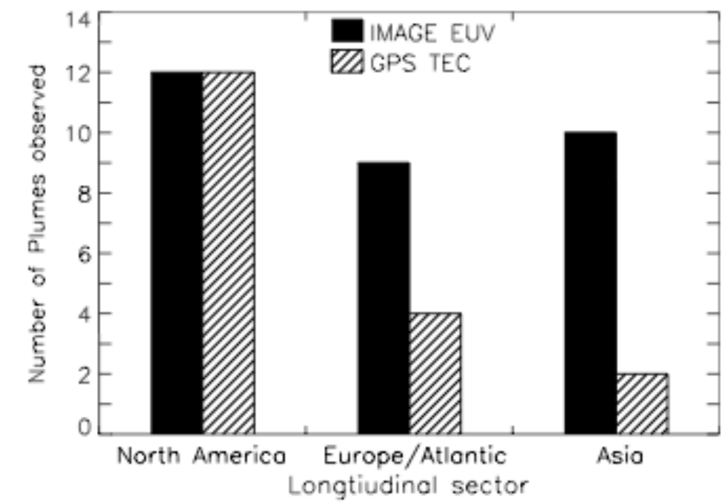
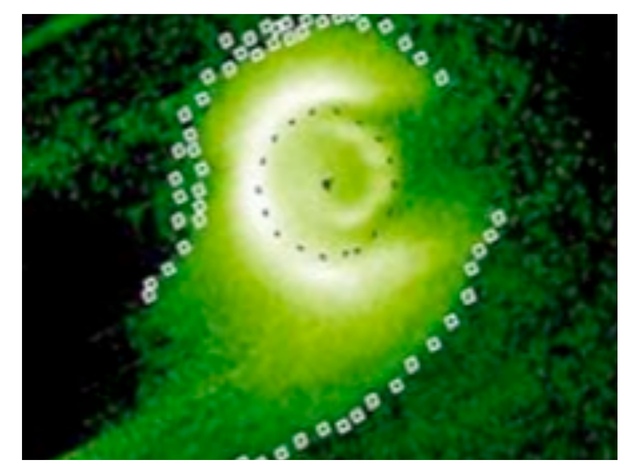


Figure 5. The histogram of plume observations from the ground (SED/TEC plume) and from space (IMAGE EUV) at various longitudinal sectors.



SED Plumes can be found in other longitudes (easier with IMAGE EUV help: plasmaspheric plumes)