Whole Atmosphere, Magnetosphere-Ionosphere-Thermosphere:

System Science at Mid and Sub-auroral Latitudes

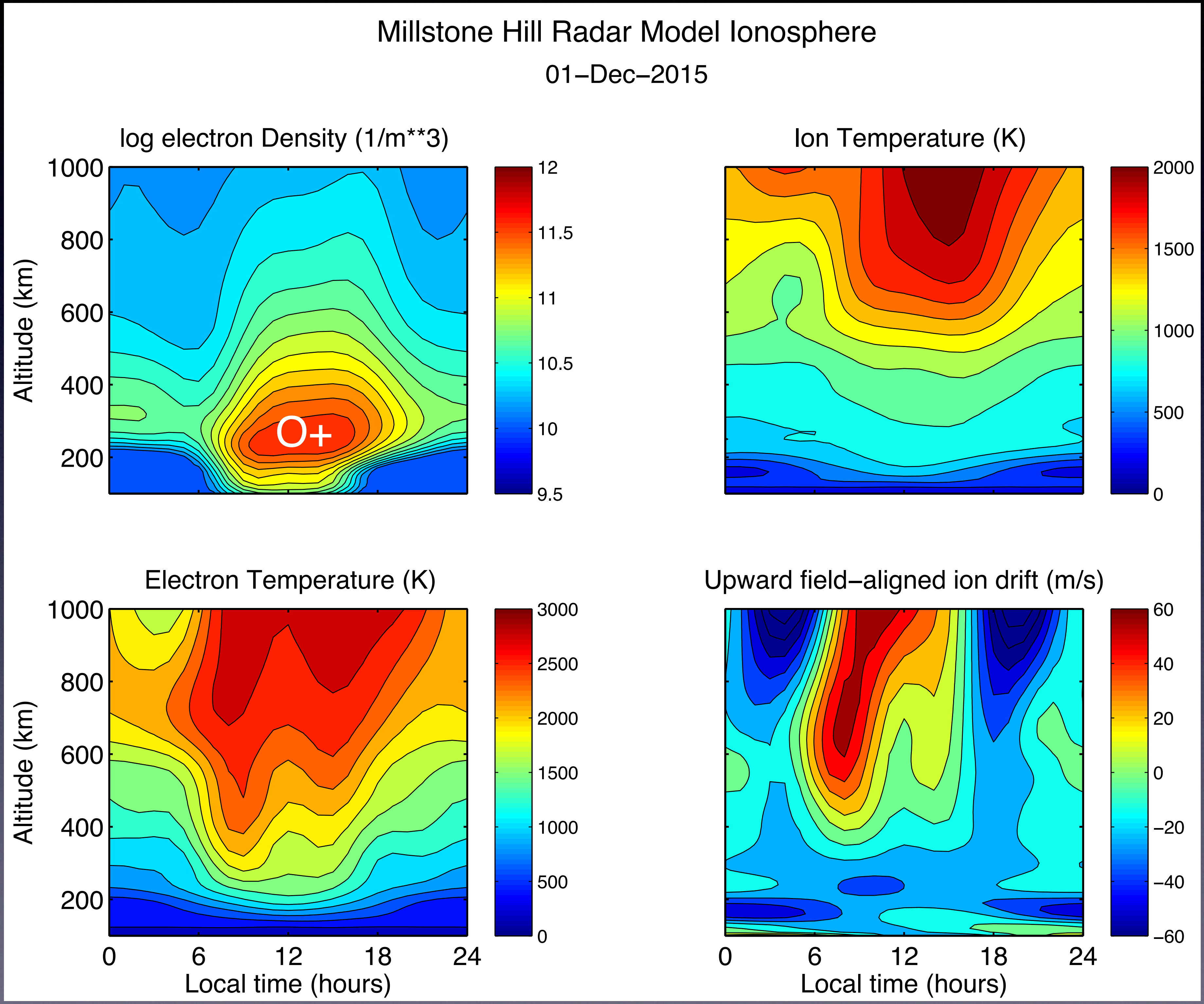
Phil Erickson and Shunrong Zhang
MIT Haystack

2018 ISR School

Topics in this talk:

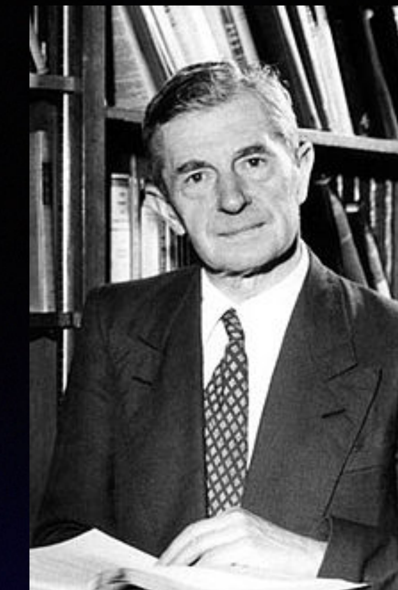
- M-I Coupling: SED, SAPS, Cold Plasma
- Whole Atmosphere Coupling
- TIDs

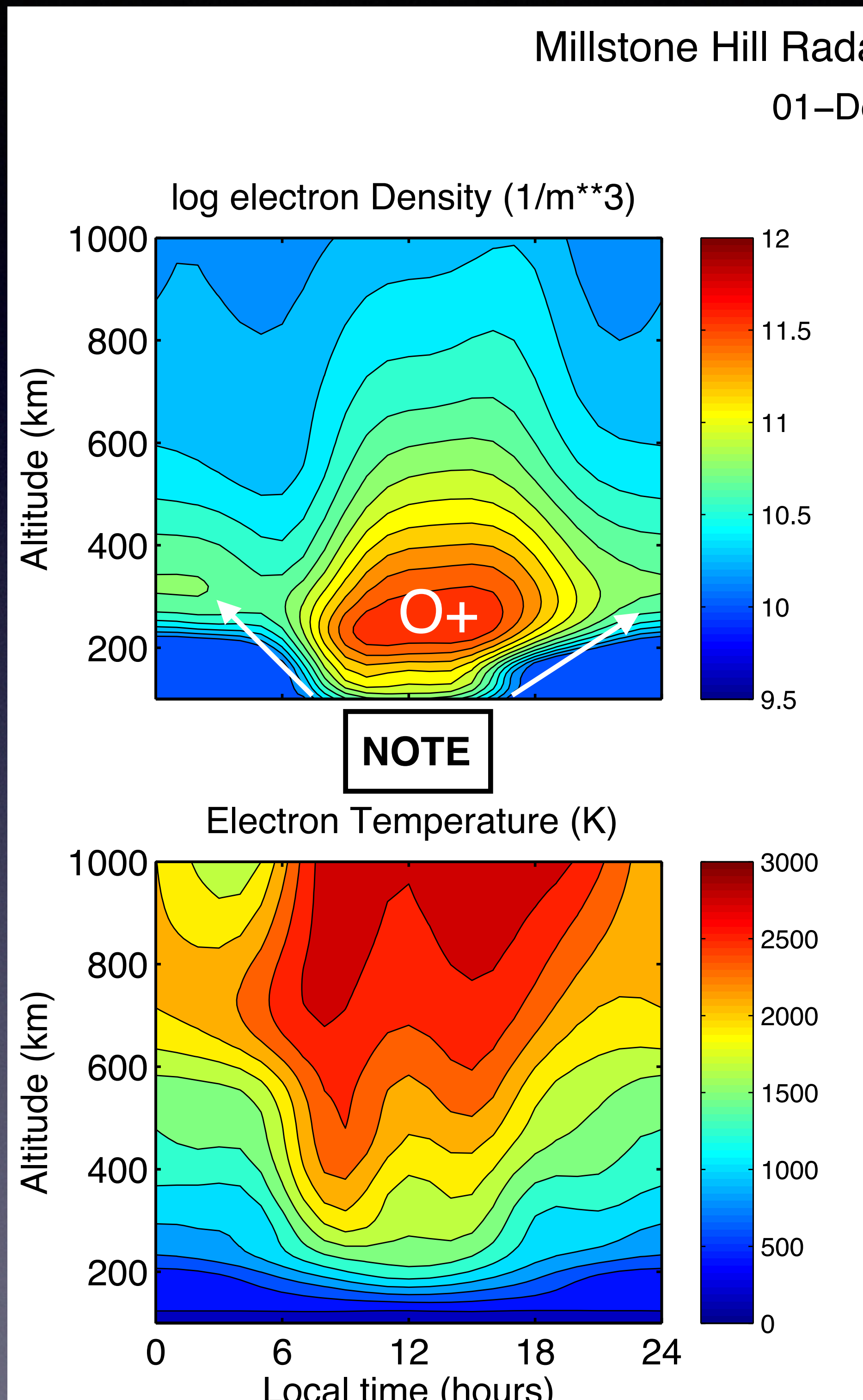
Cold Plasma Climatology: The Ionosphere



Zhang, Holt

Cold Plasma Climatology: The Ionosphere





Chapman Profile

$$n_e(\chi, z') = n_{em_0} \cdot e^{\frac{1}{2}\left(1 - z' - \sec(\chi) \cdot e^{-z'}\right)}$$

Marconi Says He Sent 10,000 Across the Atlantic

(CONTINUED FROM PAGE ONE)

his entire satisfaction with the operation of the system. Between five and ten thousand words were handled today.

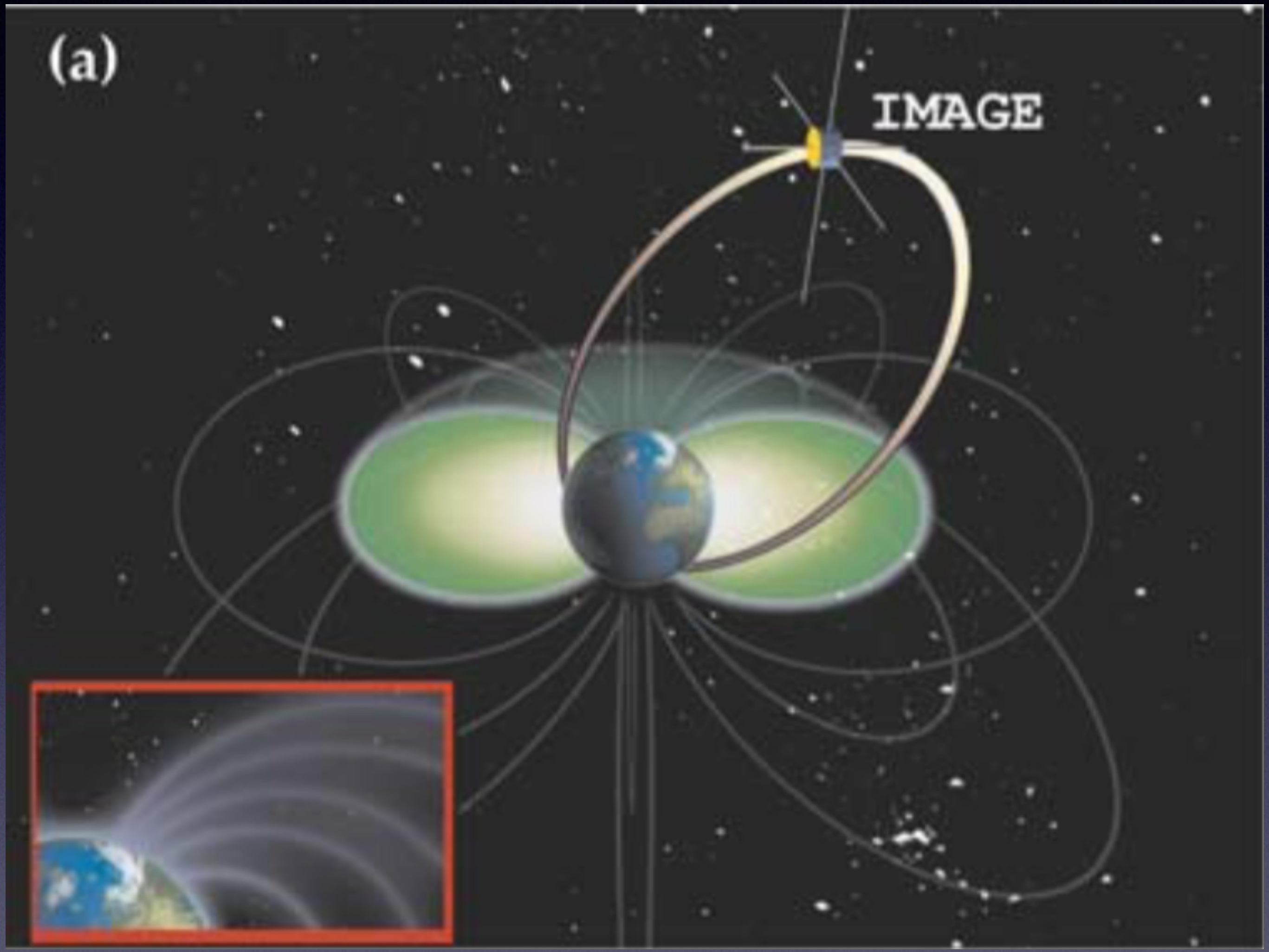
"I feel confident that the system will continue to work satisfactorily," Marconi said. "There has not been the slightest hitch today. We can handle about thirty words per minute at present and have Western Union and C. P. R. connections with the station. Messages are being handled without any delay."

Several messages were filed by press representatives but replies had not been received when the party left for town. Mr. Marconi said these messages could not be sent till tomorrow, owing to accumulation of work.

ACCEPTING BUSINESS IN BRITISH CAPITAL.

LONDON, October 17—Marconi's wireless opened for business here today, charging the ordinary 6½d per word, with a minimum of 5s. 6d. as against the cable rate of one shilling, without the minimum

The Plasmasphere



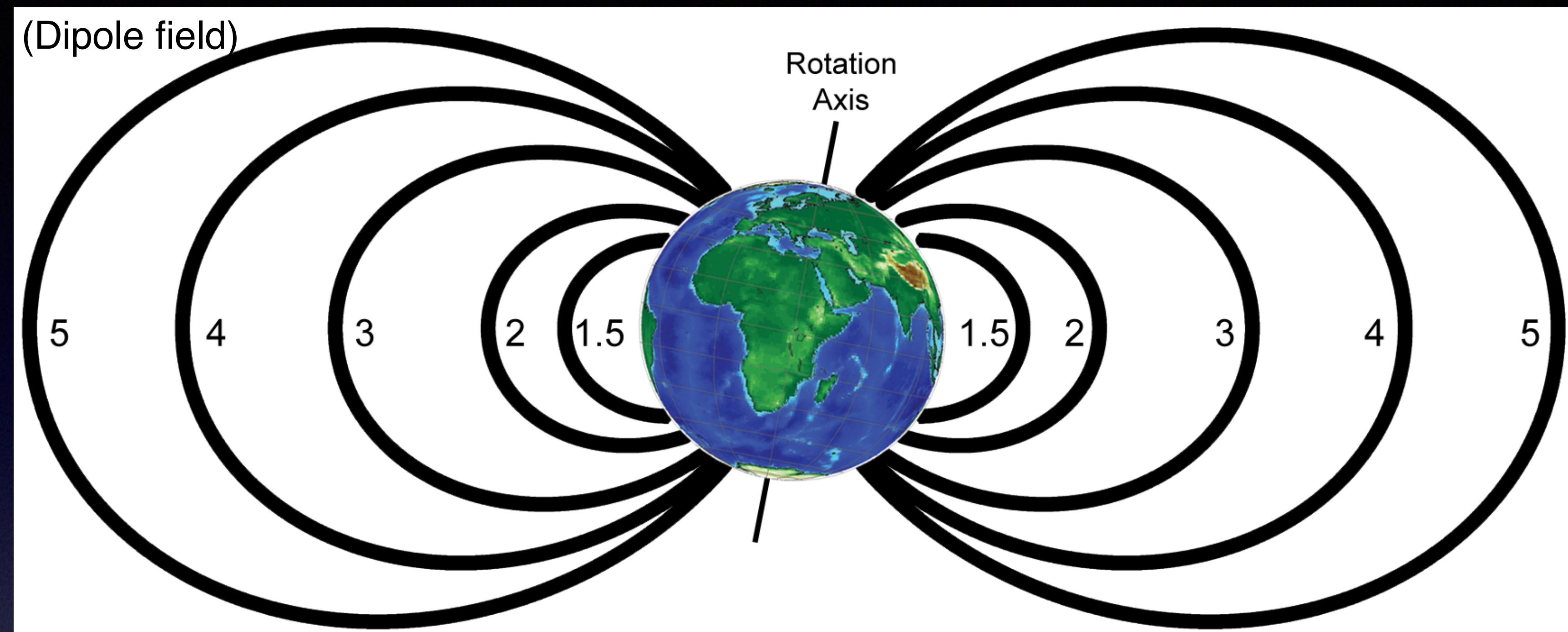
Cold plasma (~1 eV)
Dense (10 - 10,000 cm^{-3})
Governed by slow diffusion processes
Quiet times: Toroidal shape
$H+$ (80%)
$He+$ (10-20%)
$O+$ (1-10%)

??? not in the solar wind??

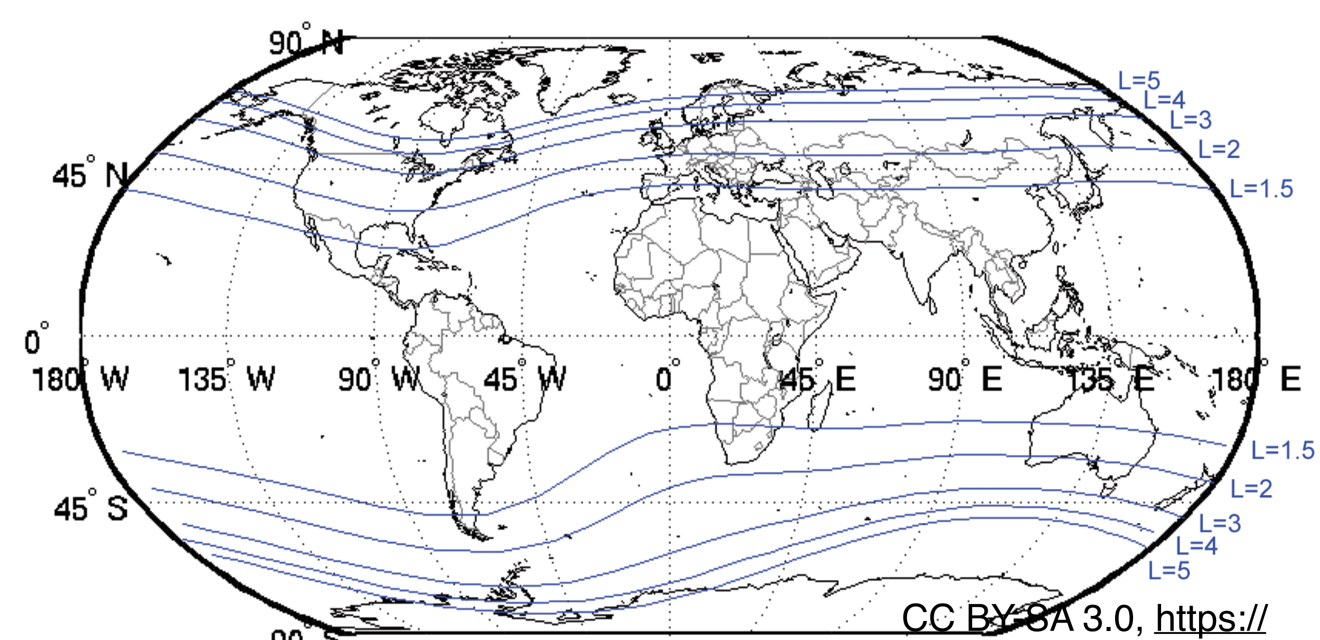
Goldstein, 2005
Lemaire and Gringauz, 1998

Plasmasphere Coordinates: L Shell

$$r = L \cos^2 \lambda$$

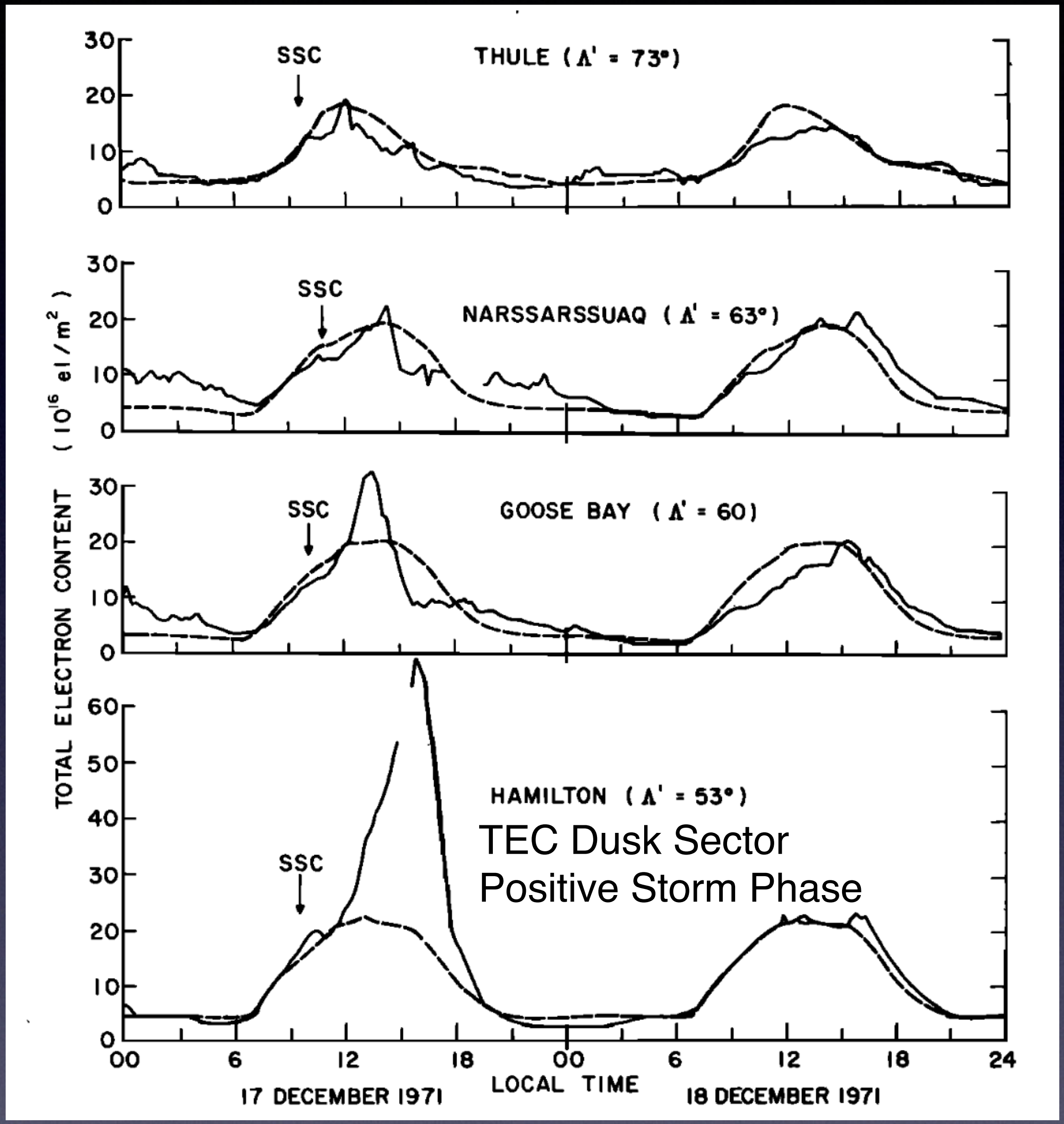


Carl McIlwain (1961)



(IGRF field)

Ionospheric Plasma Structure: Transport Consequences



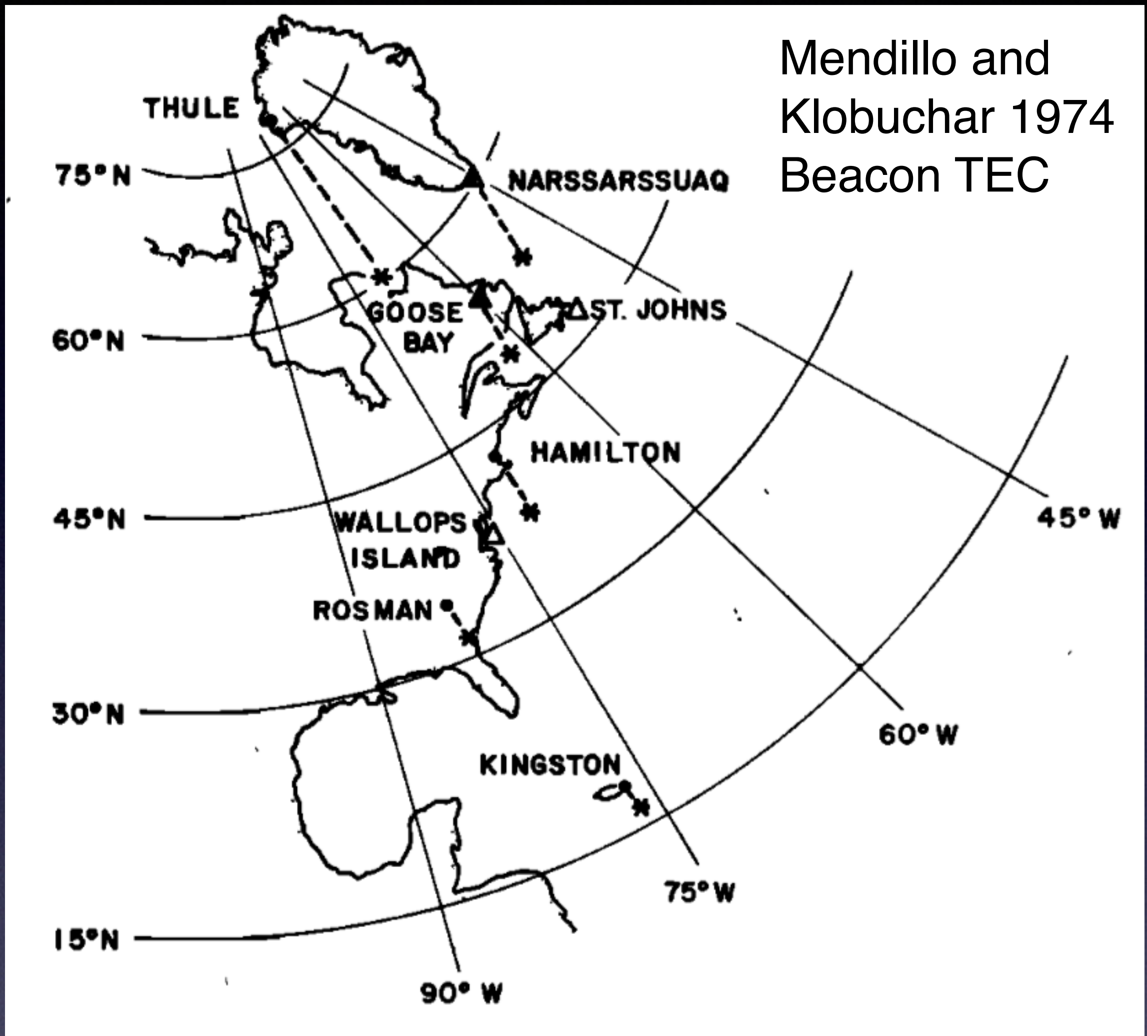
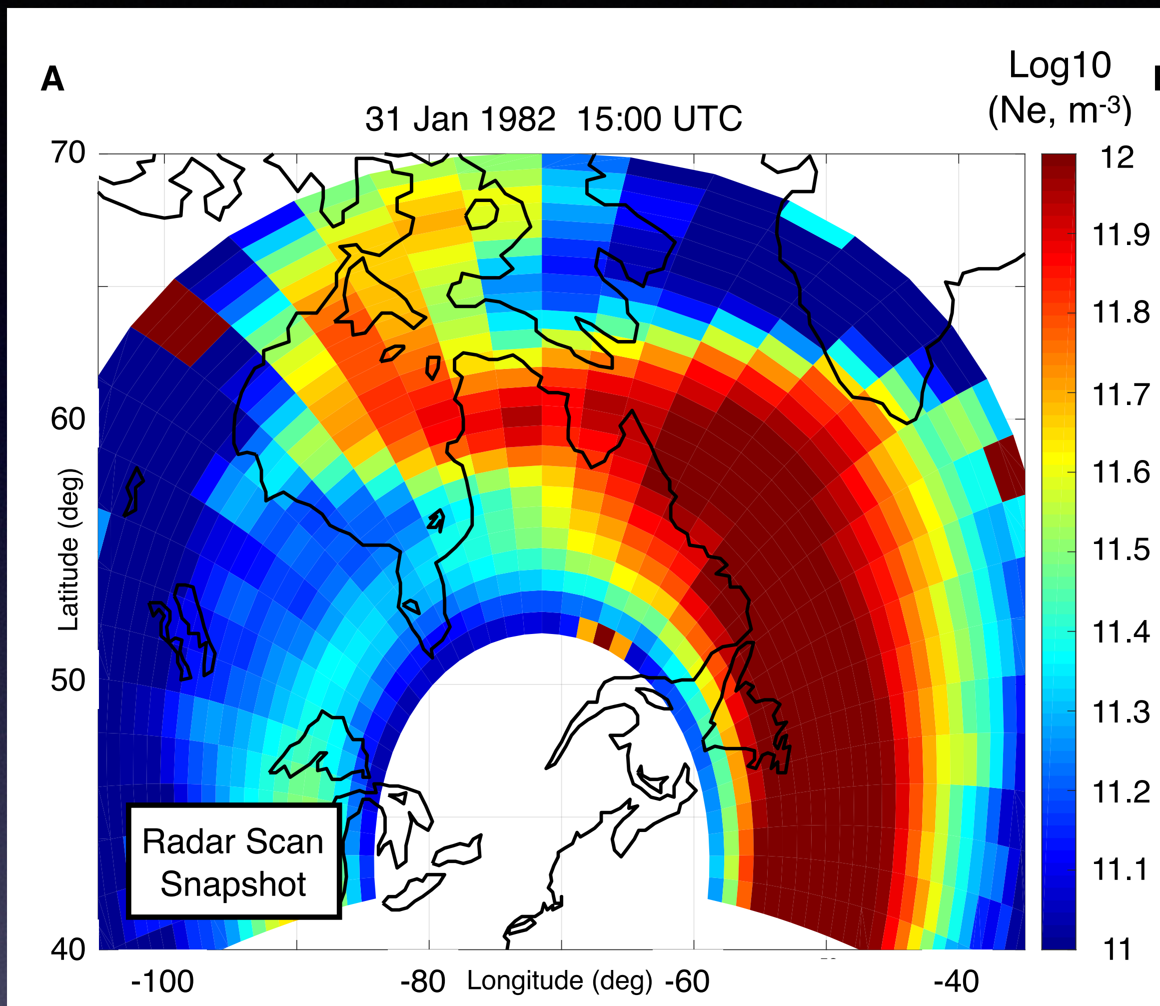


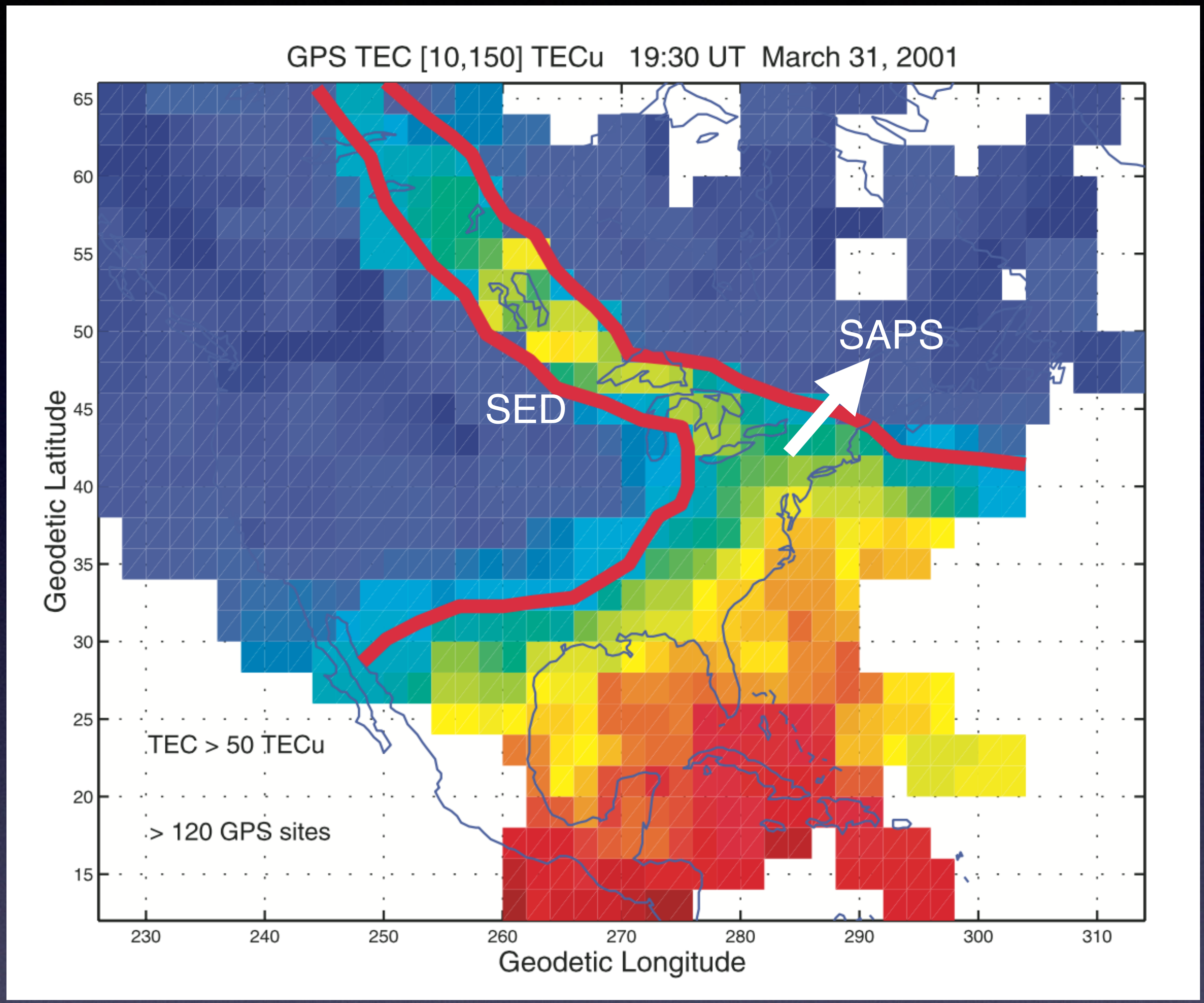
Fig. 1. Locations of TEC observing stations (solid dots), their 420-km subionospheric points (asterisks) for ATS 3 at 70°W, and the near-by ionosonde stations (open triangles).

- Unusually high, localized electron density columnar content
- Follows storm onset
- Latitude dependence

Ionospheric Plasma Structure: Transport Consequences



Millstone Hill Radar scans
Foster 1993

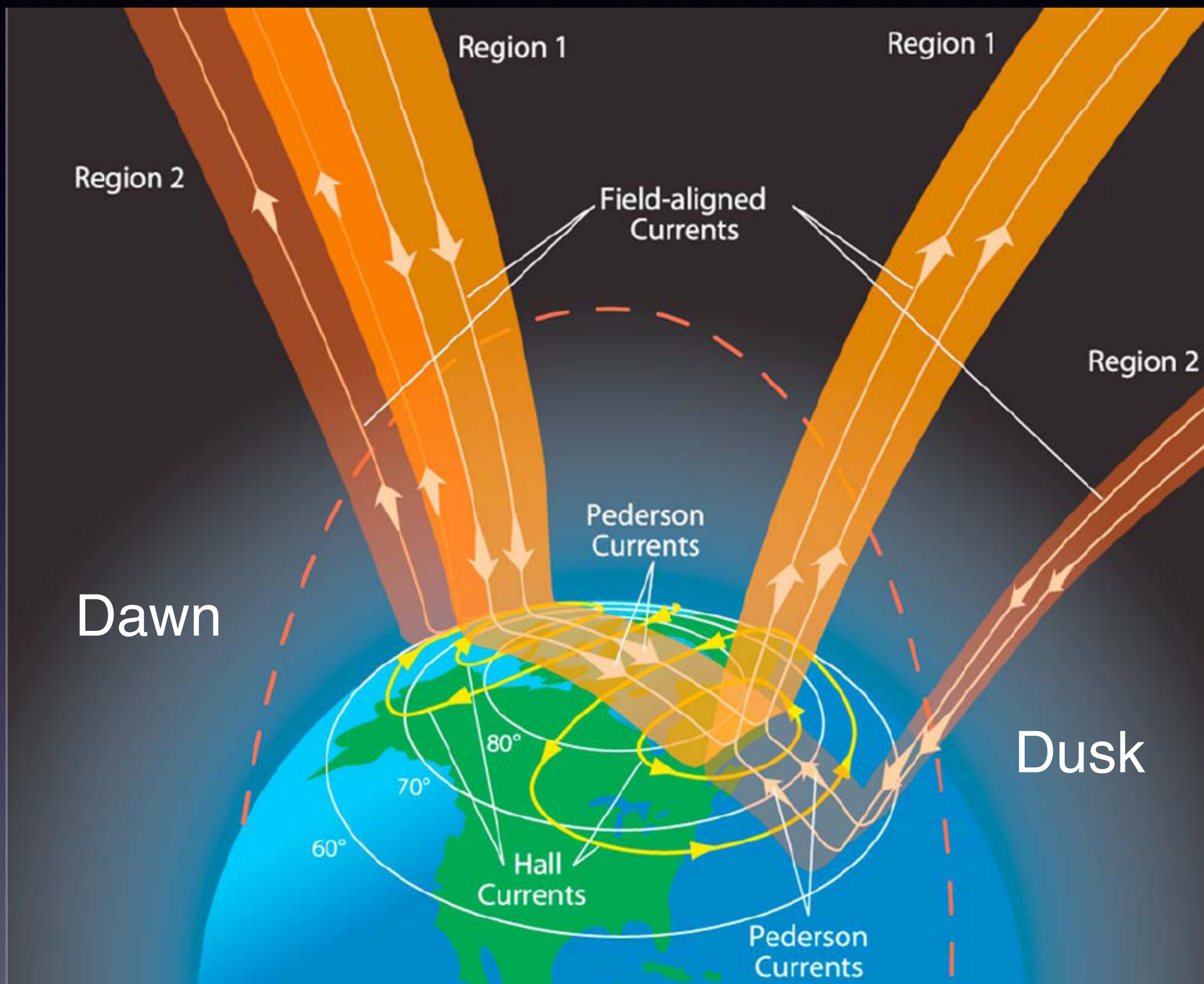


Foster et al 2002
GPS TEC

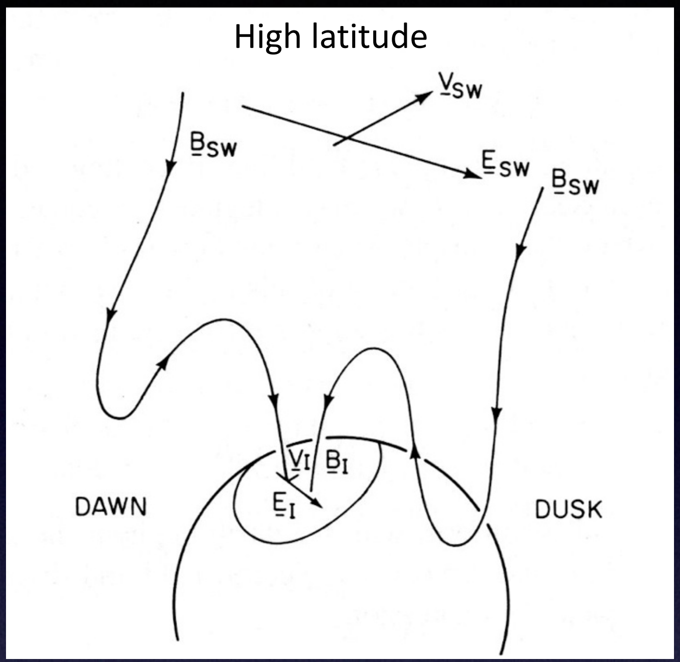
- Large density
- Predominantly O+
- Transport from lower latitudes towards noontime cusp
- Highly structured plasmasphere/plasmapause (local time dependence!)

What drives this structure?

Region 1 and Region 2 Birkeland currents



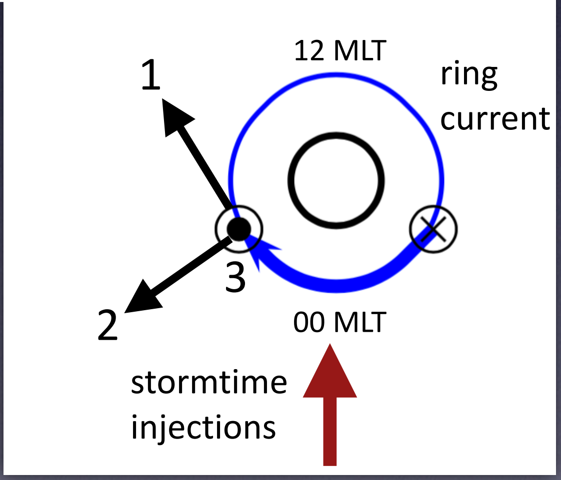
By Le, G., J. A. Slavin, and R. J. Strangeway - Space Technology 5 observations of the imbalance of regions 1 and 2 field-aligned currents and its implication to the cross-polar cap Pedersen currents, J. Geophys. Res., 115, A07202, doi:10.1029/2009JA014979



Kelley, 1989

$$j_{||} = \nabla p \times \nabla V$$

$$\nabla \cdot \mathbf{J} = 0$$



Sub Auroral Cold Plasma Structuring Agents: SAPS

Storm time FACs
Iijima and Potemra, 1978

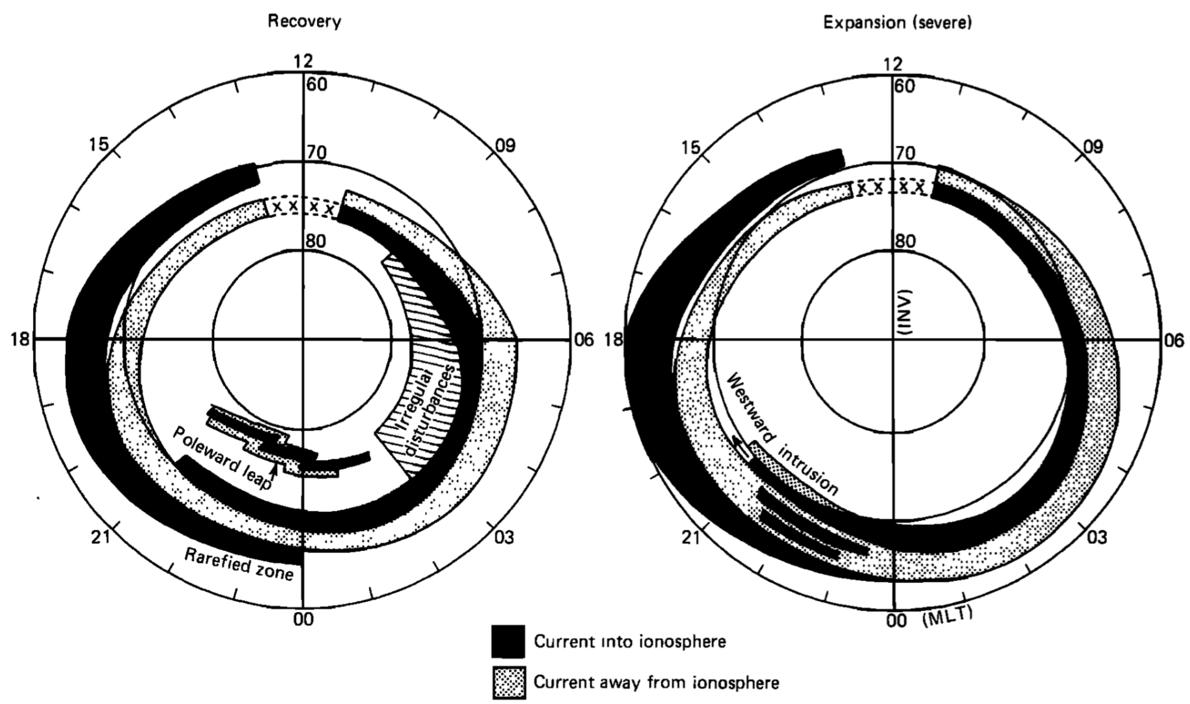
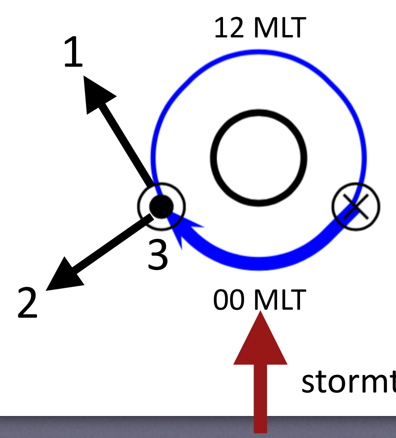


Fig. 15. Schematic diagram illustrating substorm-associated changes superimposed upon the basic distribution of field-aligned currents.

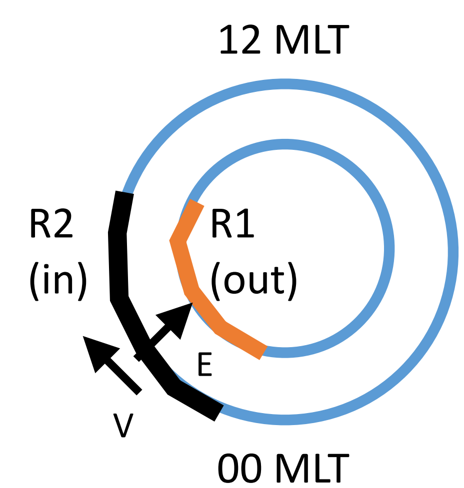
Region 2: $\nabla \cdot \mathbf{J} = 0$ $\quad j_{||} = \nabla p \times \nabla V$



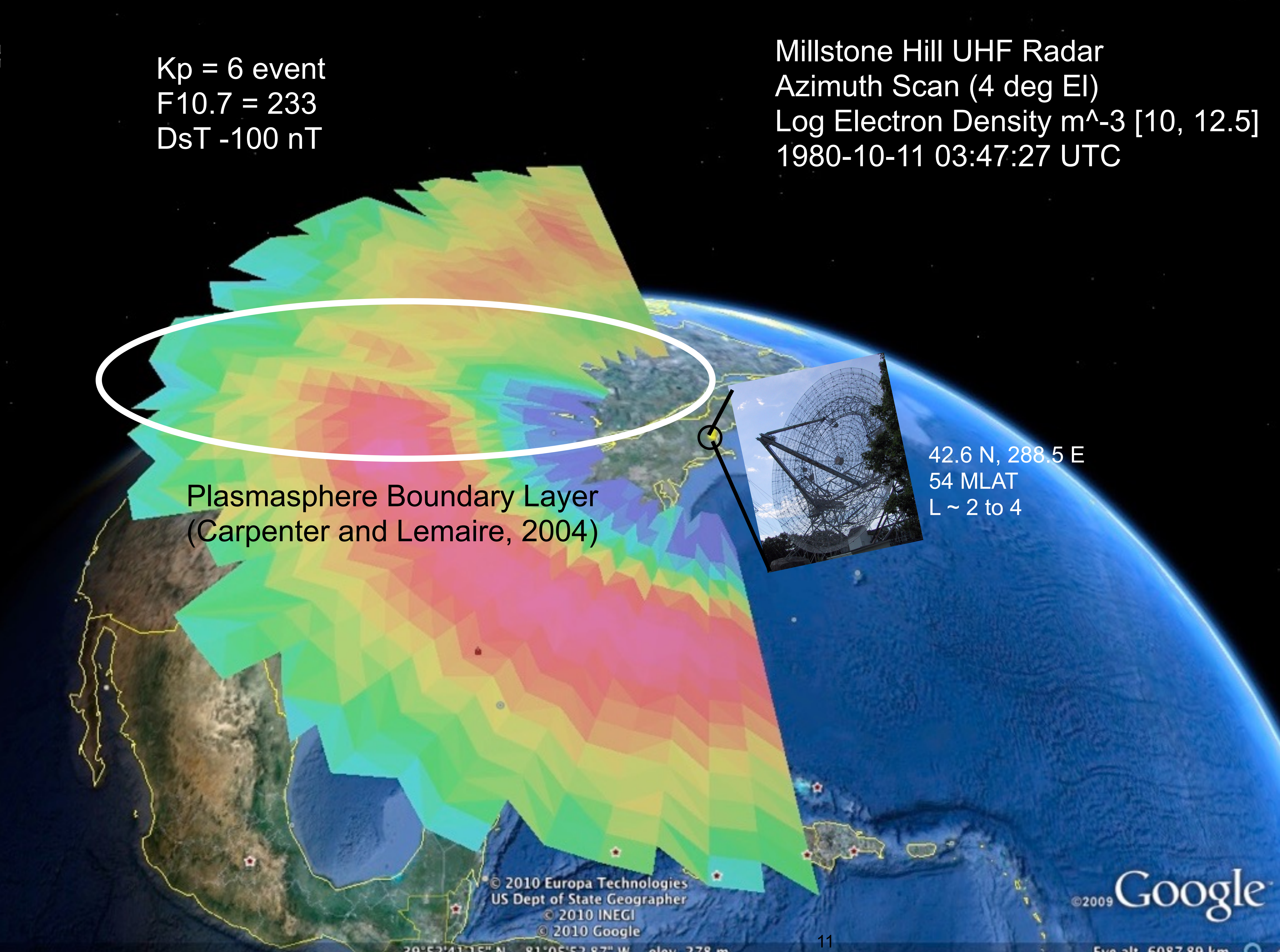
1: Azimuthal pressure gradient
2: Radial flux tube volume gradient
3: 1 x 2 = parallel current closure

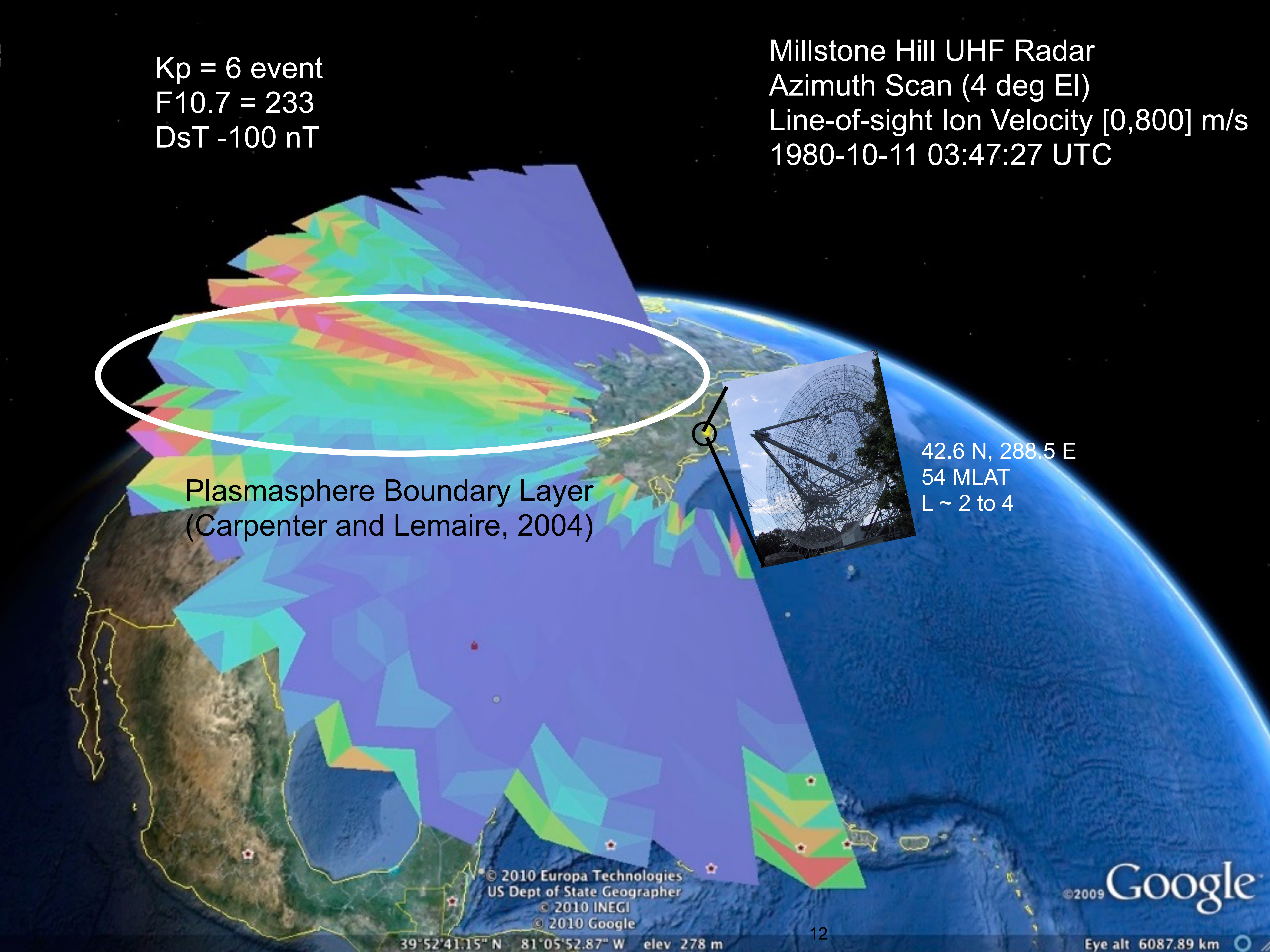
Vasyliunas, 1970; 2009

Electric fields in the ionosphere (Ohm's Law)



SAPS:
Current closure through low conductance ionosphere = potential created = poleward E field in dusk sector


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
Plasmasphere Boundary Layer
(Carpenter and Lemaire, 2004)
42.6 N, 288.5 E
54 MLAT
L ~ 2 to 4
© 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
Plasmasphere Boundary Layer
(Carpenter and Lemaire, 2004)
42.6 N, 288.5 E
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© 2010 Europa Technologies
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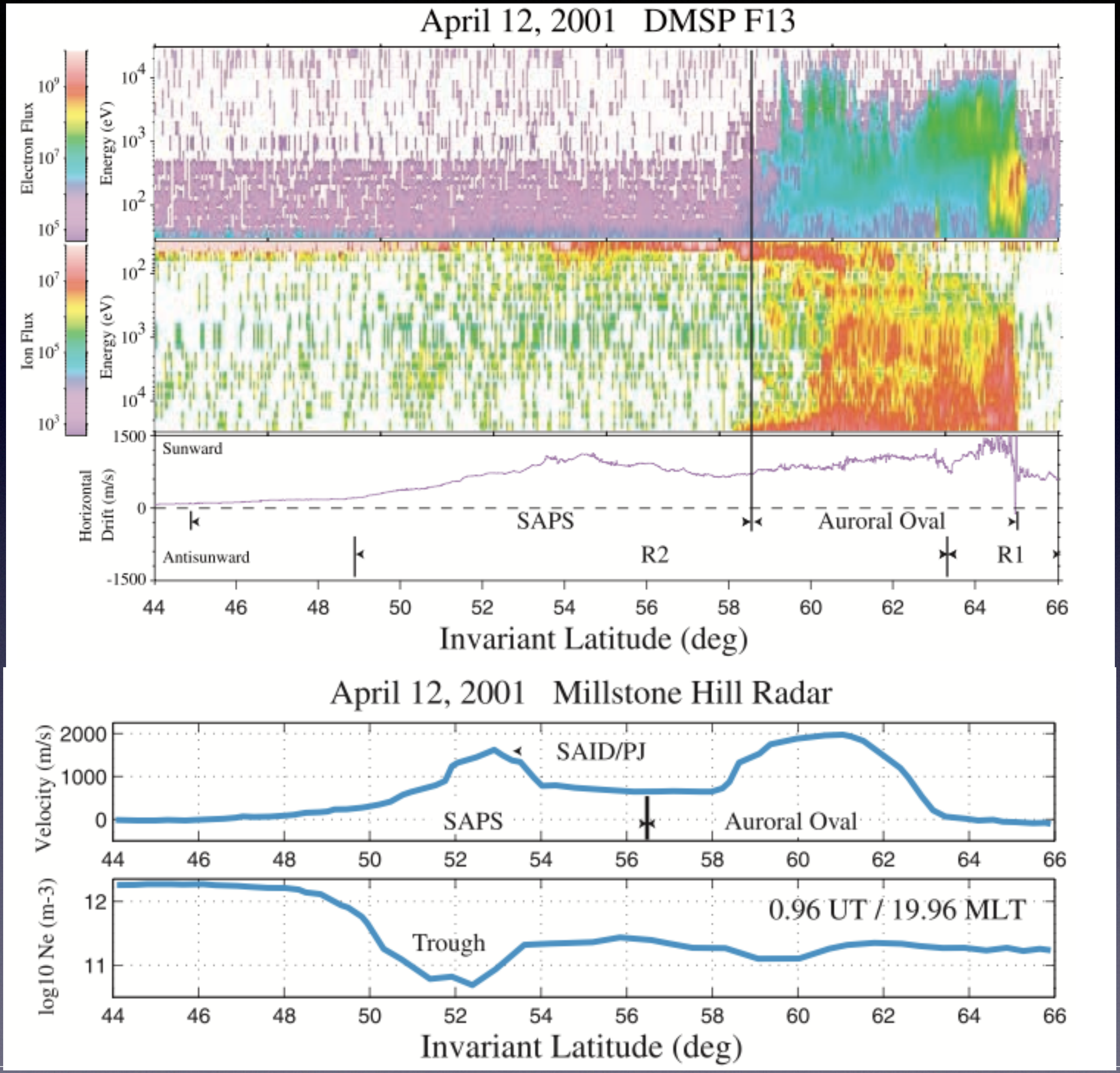
©2009 Google
39°52'41.15" N 81°05'52.87" W elev 278 m
Eye alt 6087.89 km

SAPS, SED Morphology



Voltage generator?
Current generator?

Answer:
Yes.
(and No.)

Foster and Vo, 2001

SAPS Structuring and Instabilities

ANDERSON ET AL.: MULTISATELLITE SAID OBSERVATIONS

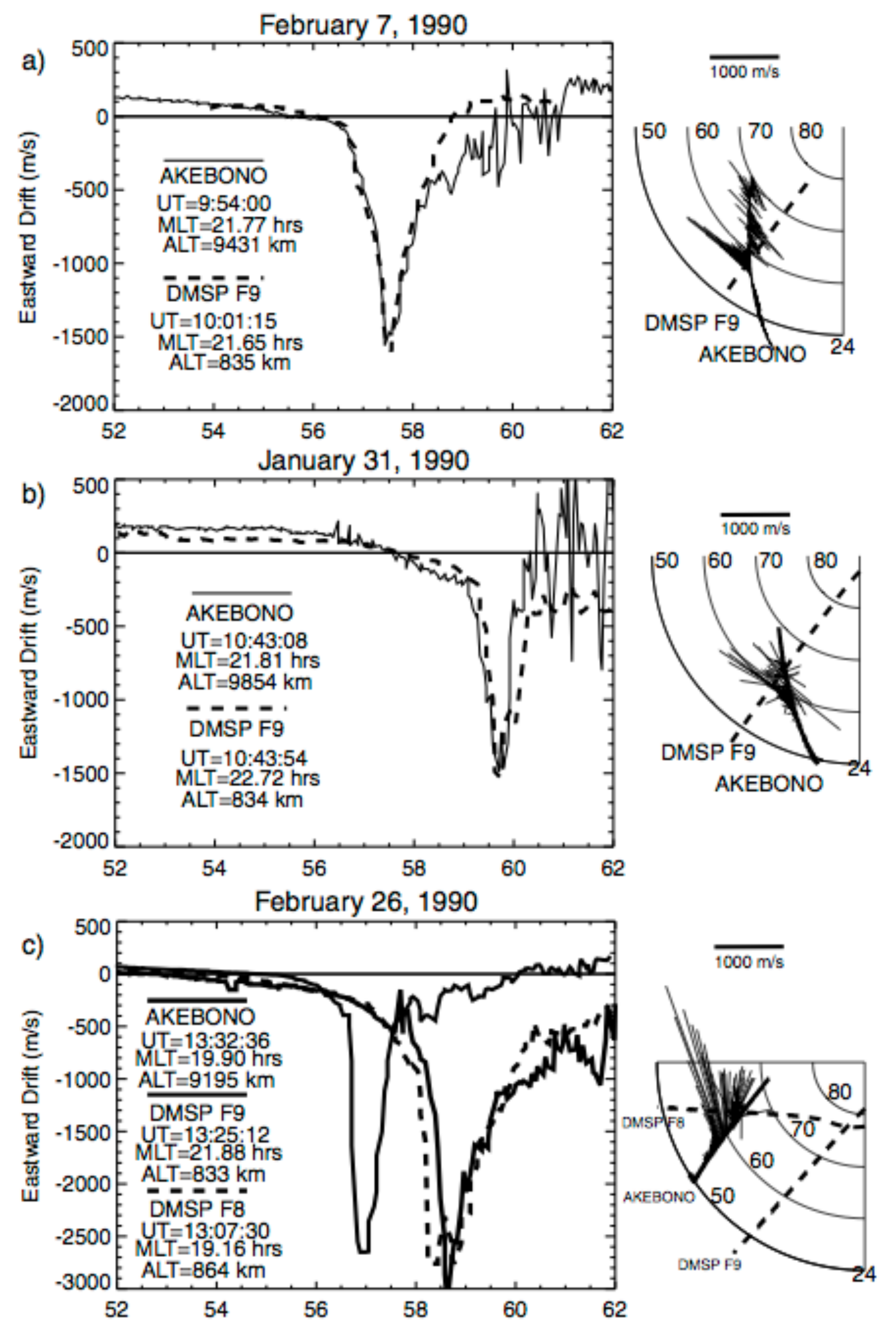
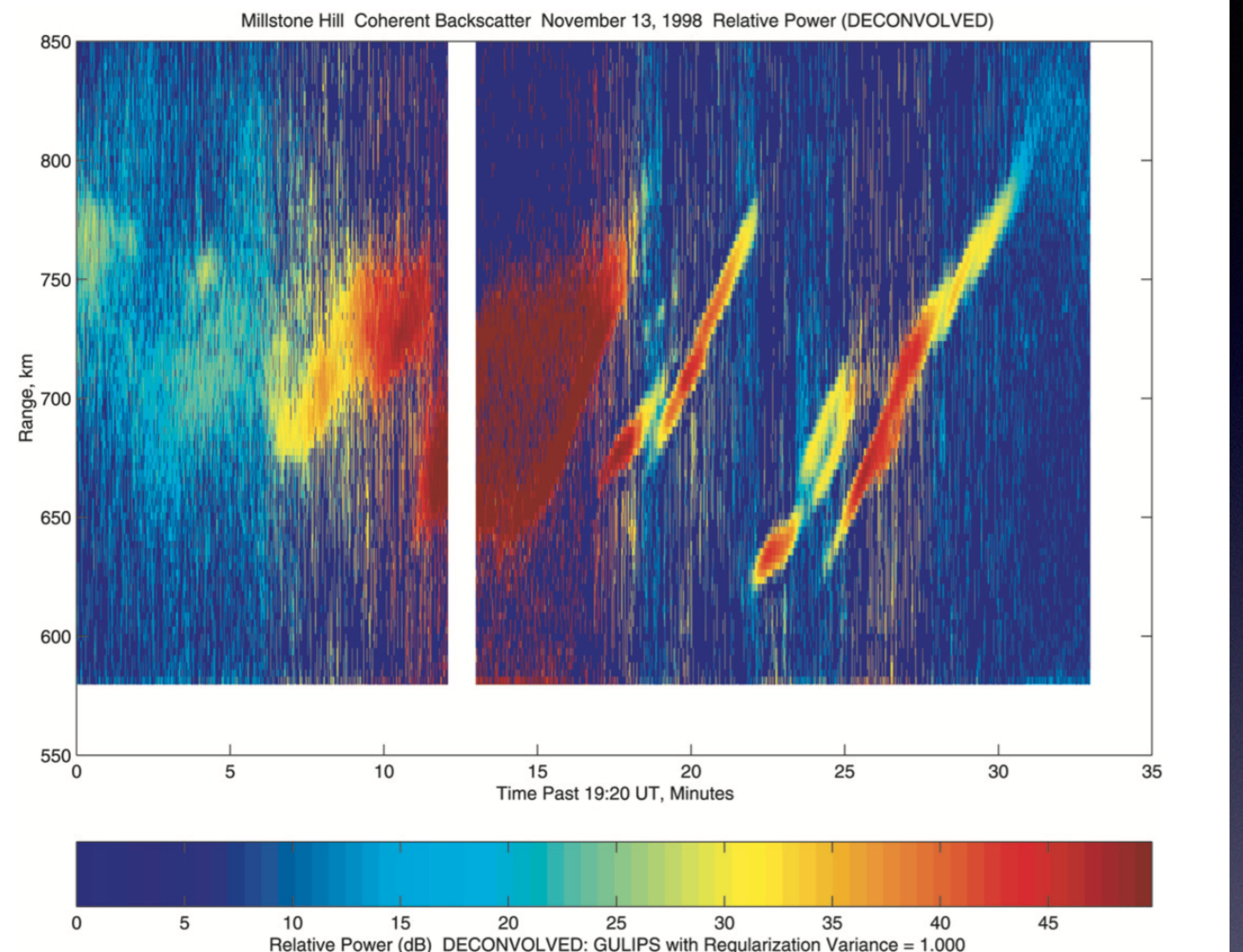


Figure 1. Three coincident DMSP and Akebono SAID measurements plotted versus magnetic latitude (MLAT). The satellite ephemerides are indicated in the plots, and the orbit tracks are plotted on polar dials on the right. The drift vectors inferred from the Akebono EFD data are plotted on the Akebono orbit tracks (shaded lines).

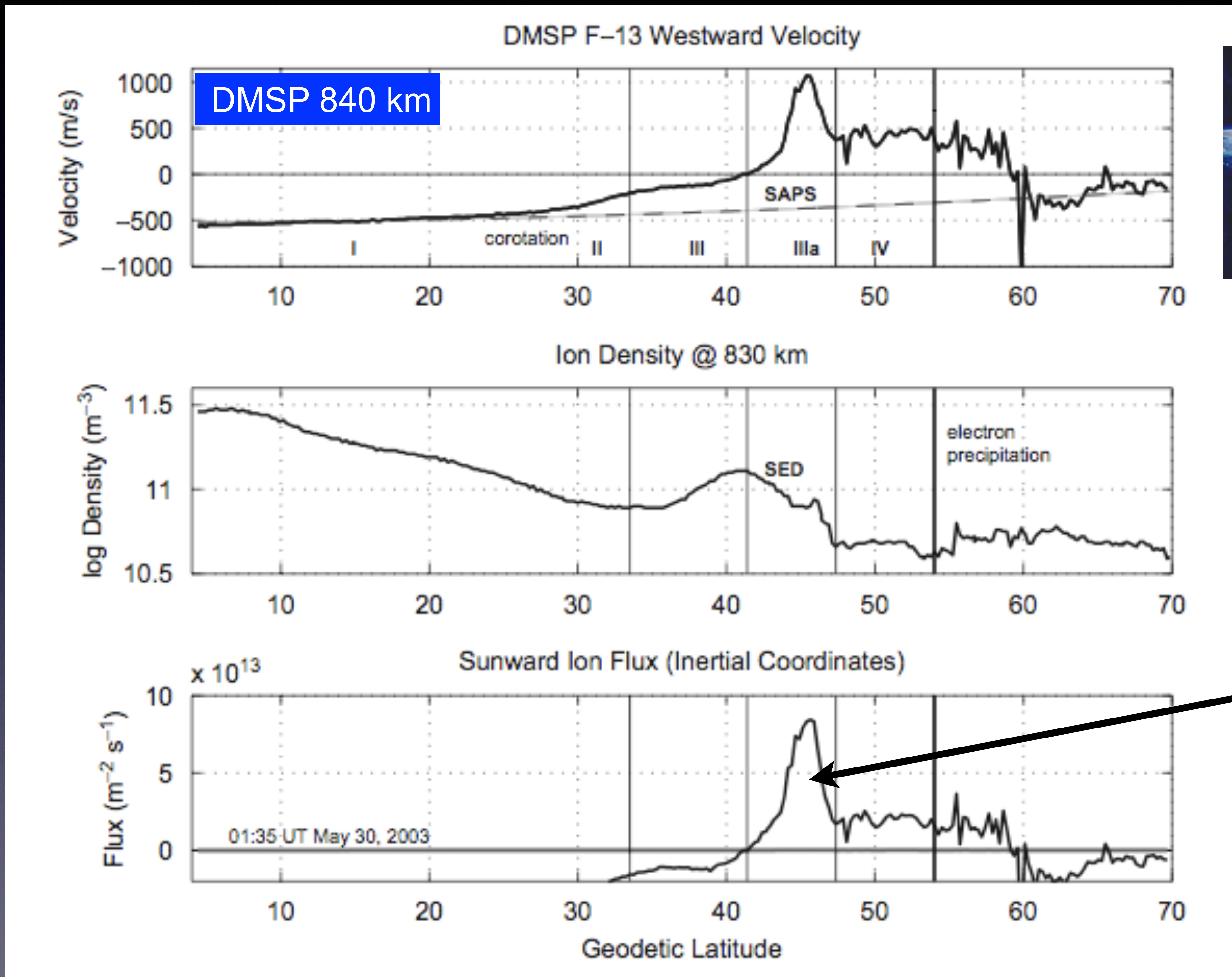
Anderson et al 2001



Erickson et al 2002

Currents close at E region heights

Sub Auroral Cold Plasma Structuring Agents: SAPS



Sunward ion flux caused by SAPS/SED overlap

Foster et al, 2007

Cold, Heavy Plasma Outflows

Important source for
ring current, plasma sheet
(it's not all solar wind plasma)

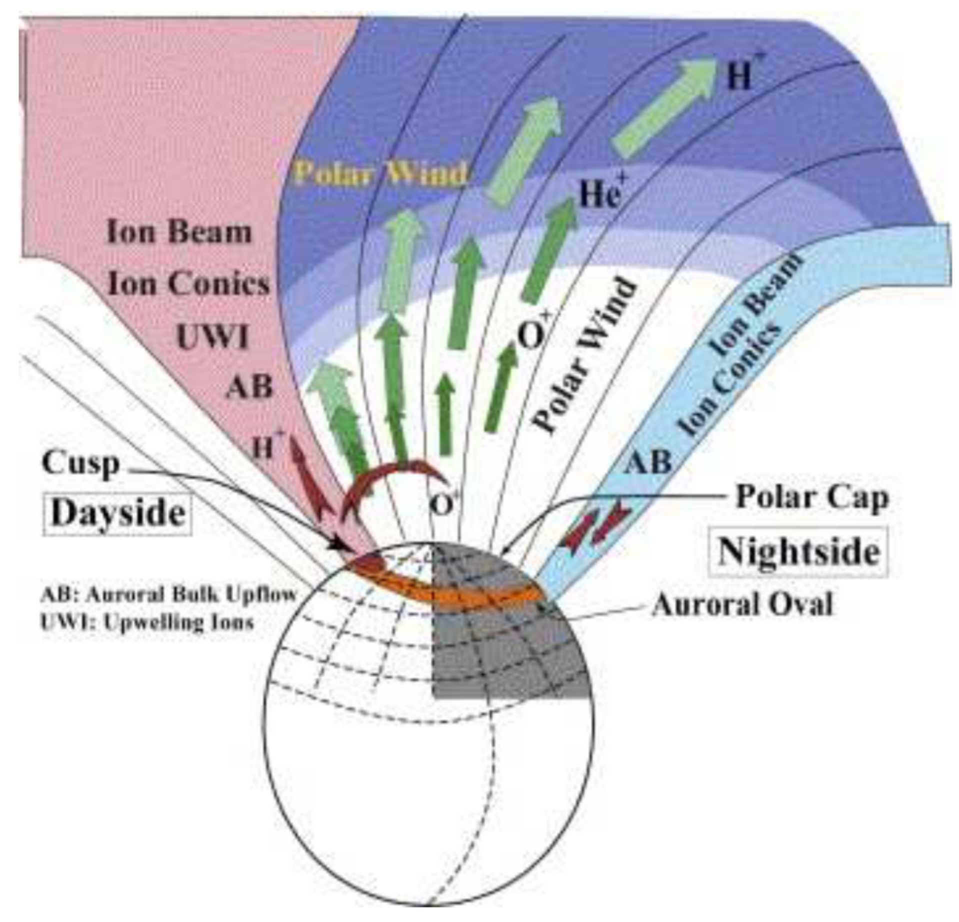
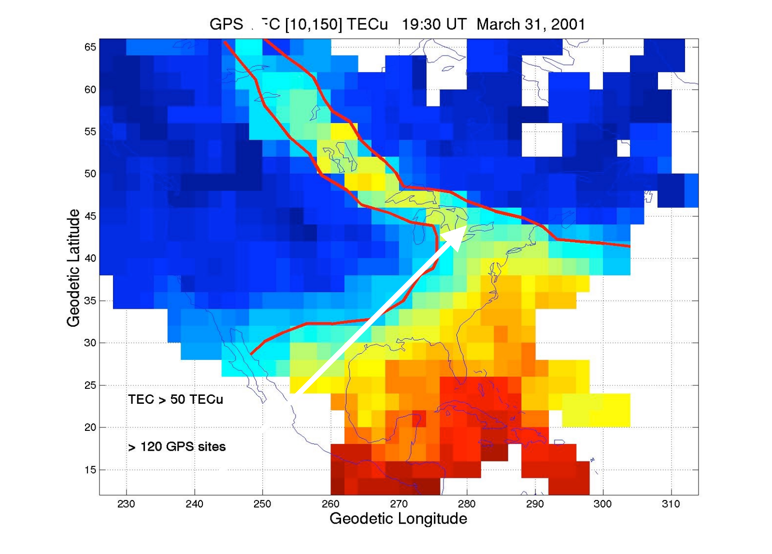
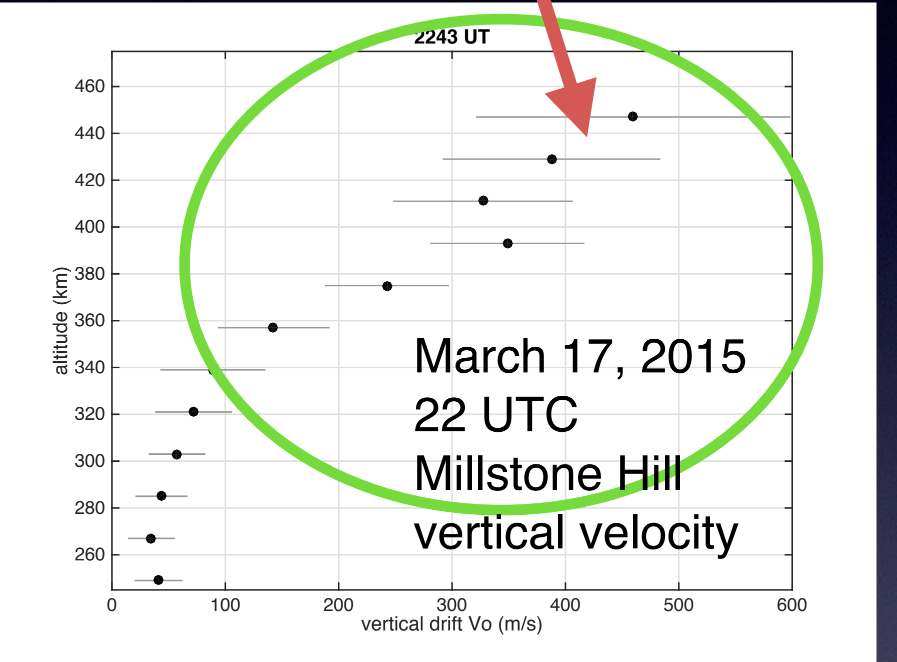


Image courtesy of the ePOP team

To high latitudes / cusp



400 m/s @ 400 km

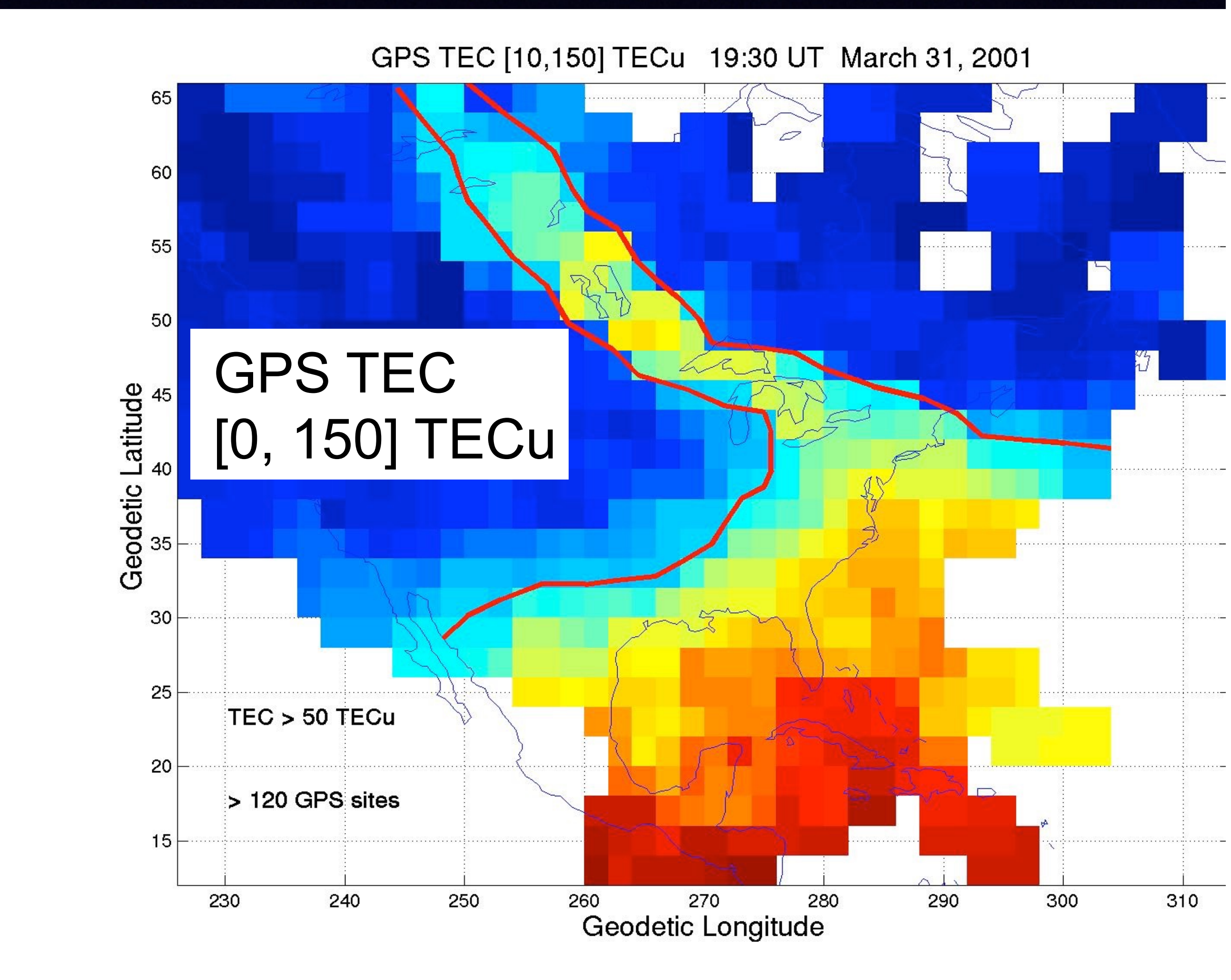


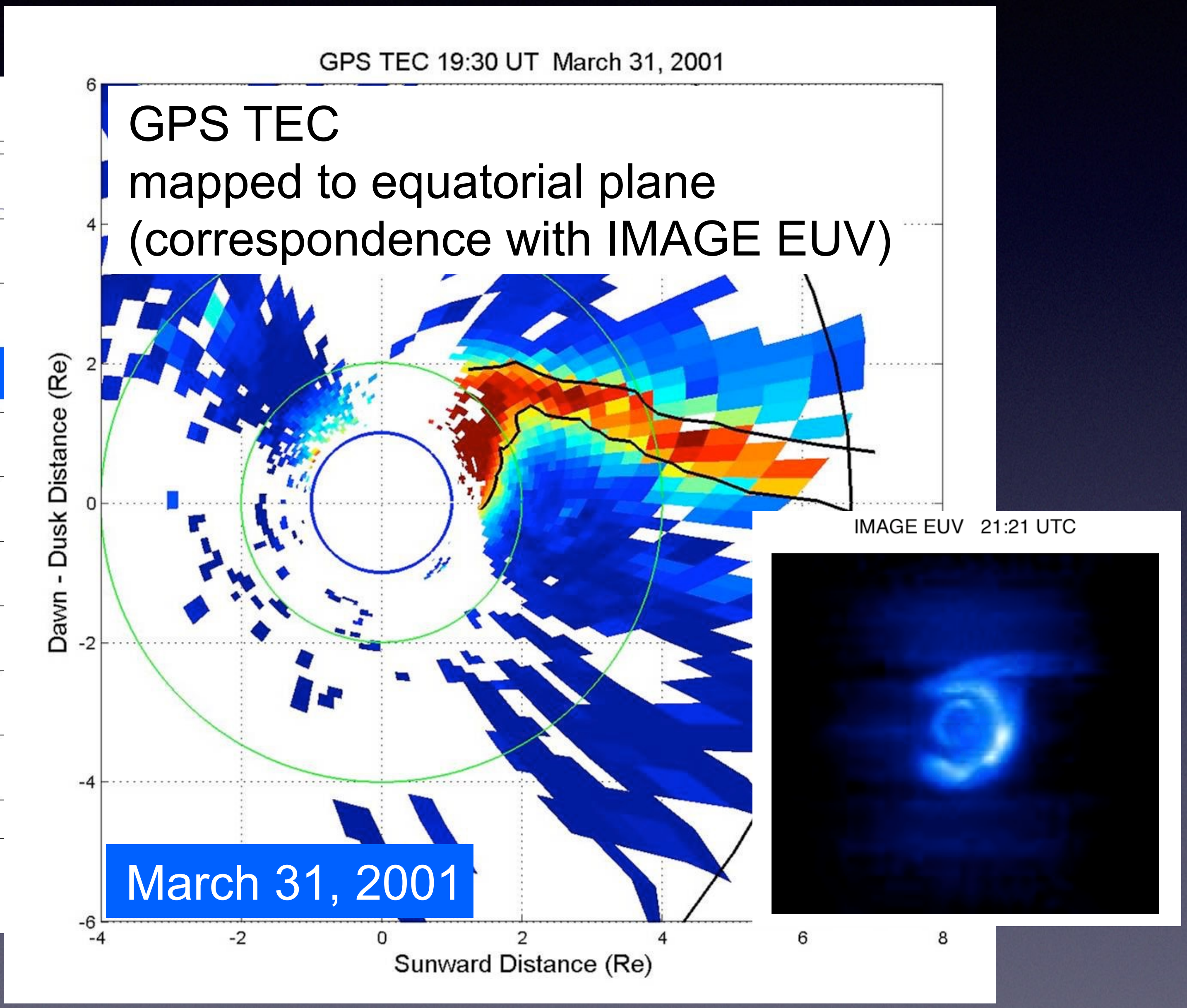
S.-R. Zhang, MIT Haystack

High latitude/cusp
Auroral bulk outflow, etc.
Heating, energization

Mid Latitude / SAPS
Associated vertical flow
Heating? Energization?

Electrodynamics Connections: Ionosphere, Plasmasphere





(e.g. Foster et al 2004)

Cold Plasma Effects on Geospace: It's Not A Boundary Value Problem

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Commentary

The Ionospheric Source of Magnetospheric Plasma is Not a Black-Box Input for Global Models†

D. T. Welling, M. W. Liemohn

Accepted manuscript online: 1 June 2016 Full publication history

DOI: 10.1002/2016JA022646 View/save citation

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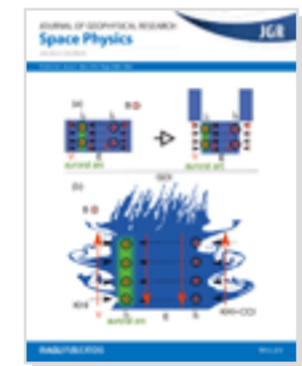

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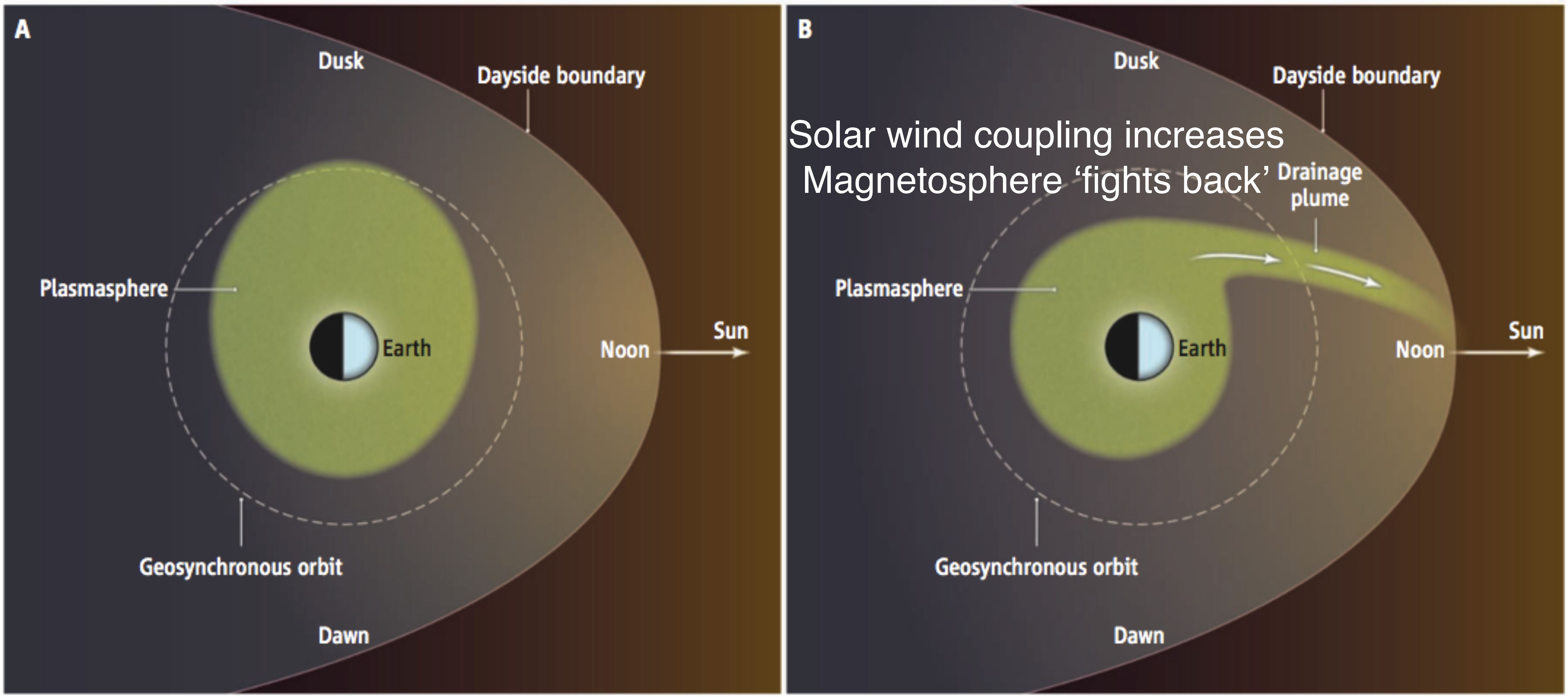
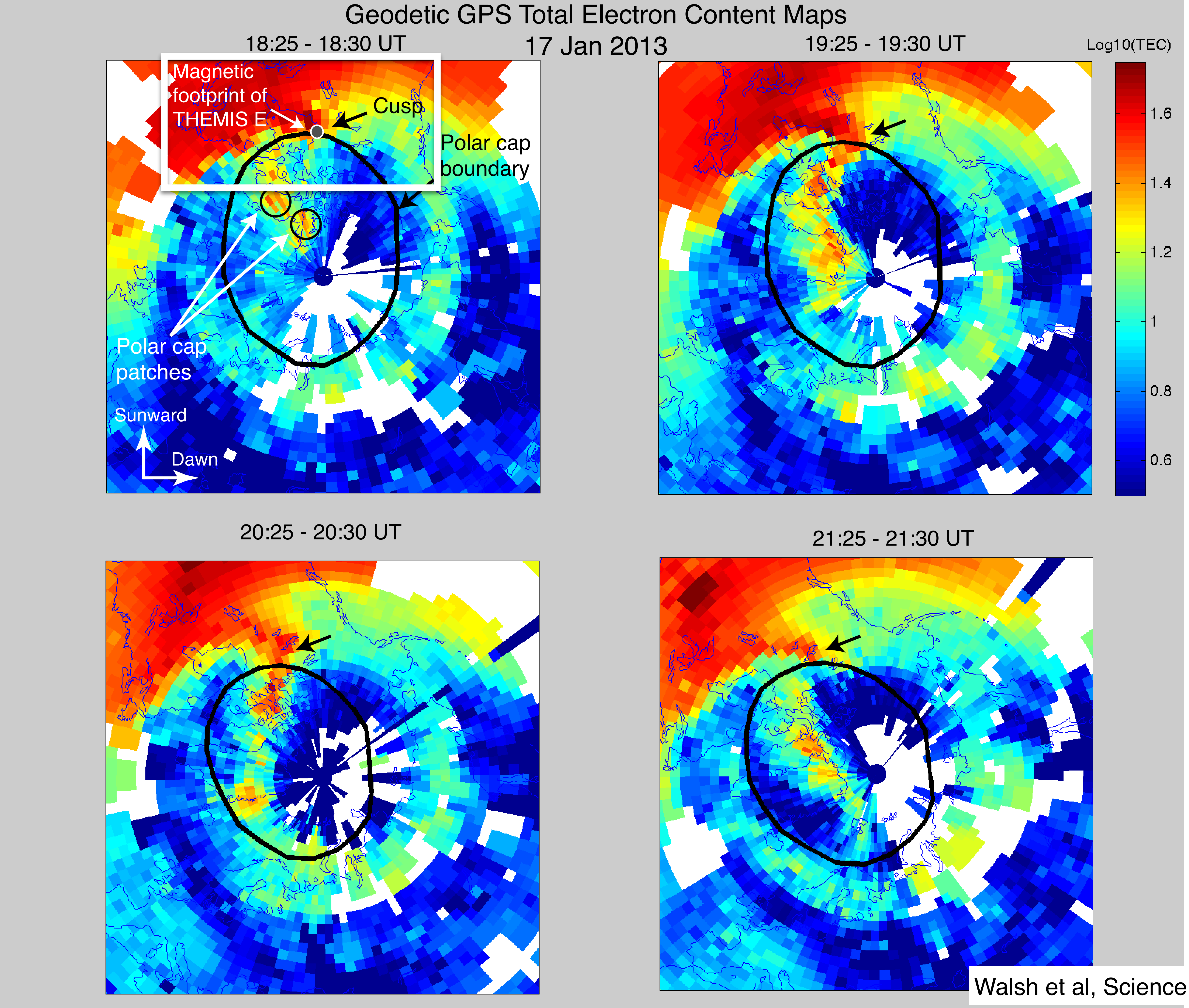
Plasmaspheric drainage plumes: Mass-loading the magnetopause



Pushing back. From a perspective high over the North Pole of Earth, the cold plasma in the equatorial plane of Earth's magnetosphere is sketched at two different times. (**A**) When solar-wind coupling is weak, the near-Earth reservoir (plasmasphere) is shown in green. (**B**) When coupling becomes stronger, the plume of sunward-convecting cold plasma eroding from the reservoir is seen. The cold plasma of the plume flows to the dayside boundary of the magnetosphere, where it interferes with the reconnection process. Space-based ultraviolet images of this cold-plasma movement can be seen in Goldstein (*7*).

Borovsky, Science, 2014



Walsh et al, Science, 2014

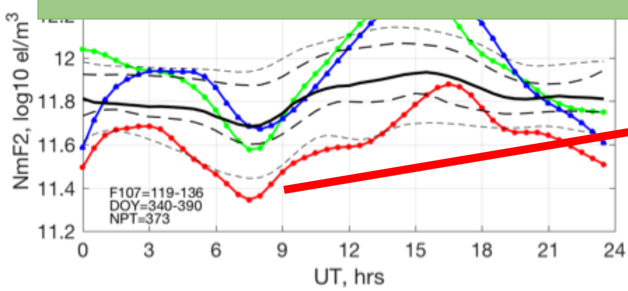
Topics in this talk:

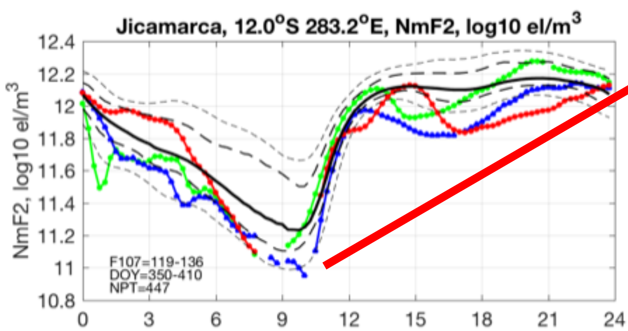
- M-I Coupling: SED, SAPS, Cold Plasma
- Whole Atmosphere Coupling
- TIDs

Nighttime effects of Sudden Stratospheric Warmings: deep depletion in electron density from ~50°S to 40°N

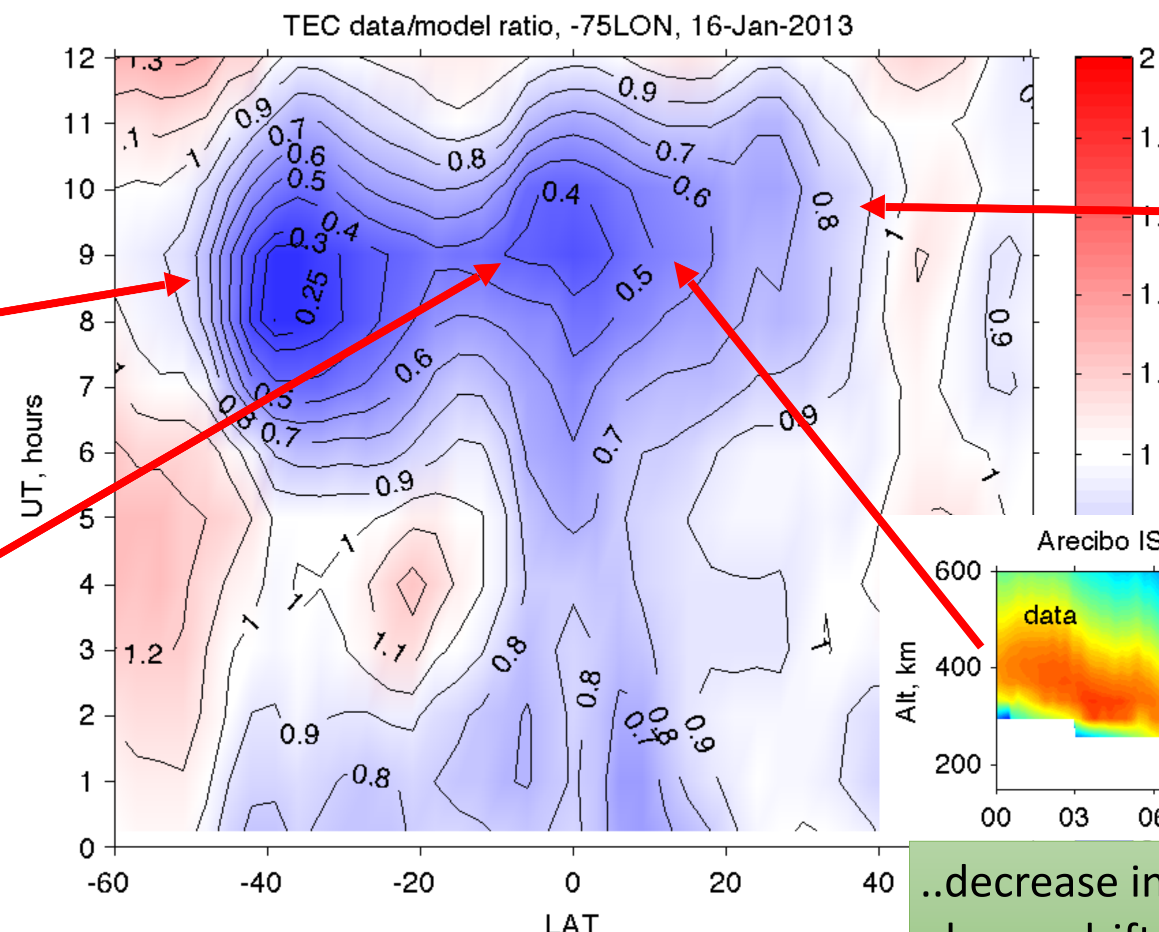
multi-diagnostics study: GNSS TEC + ISRs + ionosondes

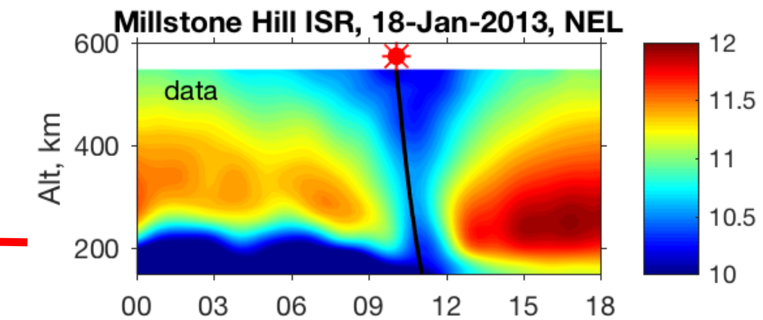
..decrease in NmF2 in the Southern Hemisphere middle latitude…



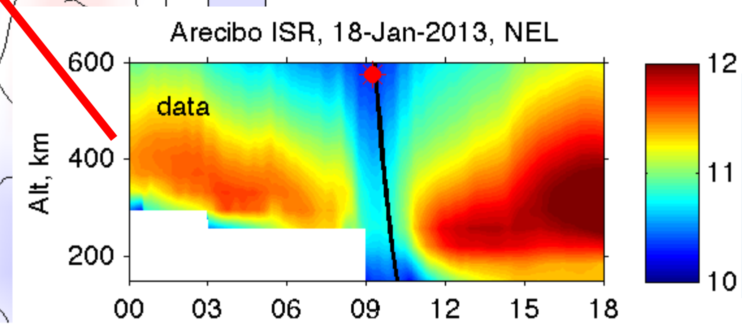


…spread-F development at the magnetic equator…





..decrease in Ne, cooling, and large downward plasma drift at NH middle latitude..



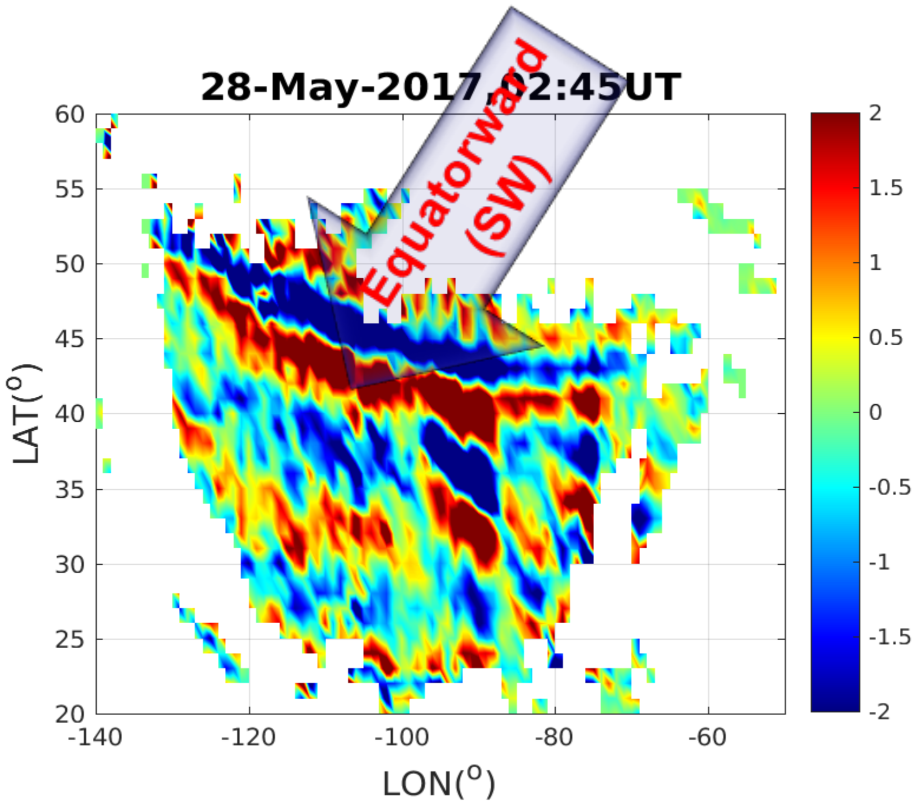
Goncharenko et al., 2018, JGR-Space physics, ***Journal highlight***

..decrease in Ne and large downward plasma drift at subtropical latitude..

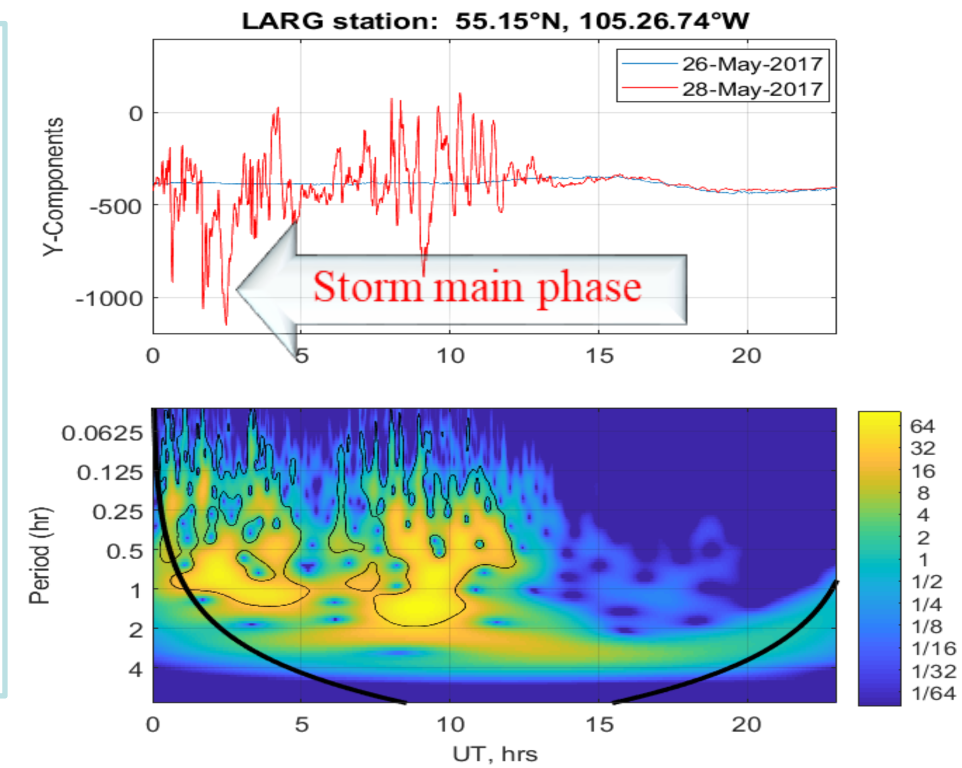
- SSWs affect the nighttime electron density, decreasing it by a factor of 2-5
- The hole in ionosphere covers half the globe – from 50°S to ~40°N
- These effects are likely to be related to changes in thermospheric zonal wind + lunar tide – not yet understood
- List of coauthors includes REU student and pre-college student

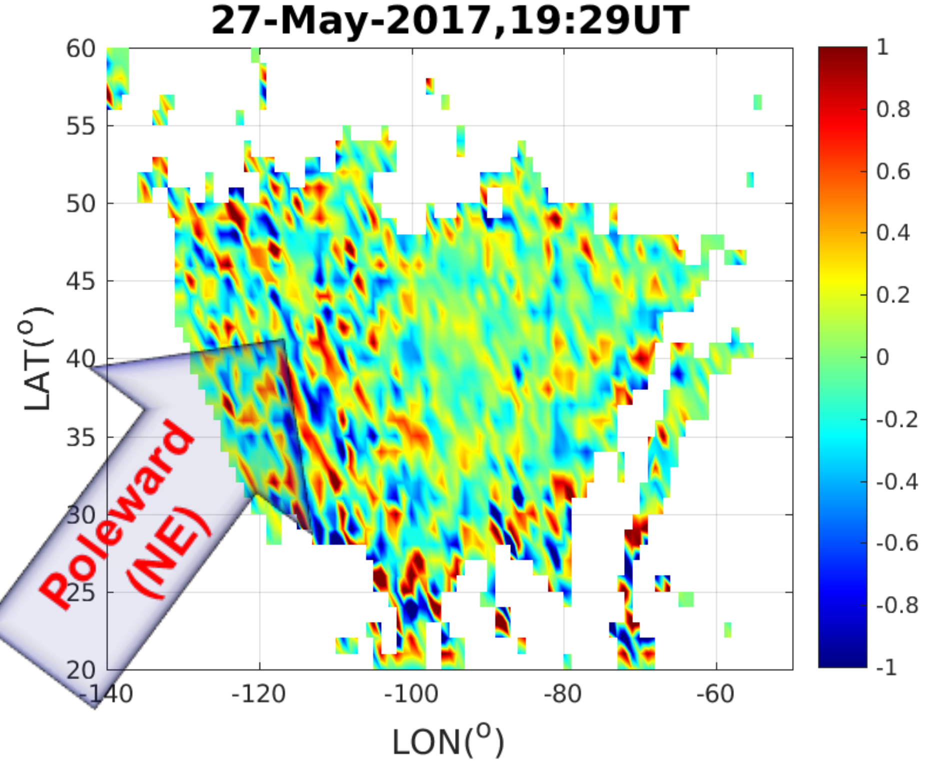
L. P. Goncharenko, MIT Haystack

EXAMPLES OF TRAVELING IONOSPHERIC DISTURBANCES (TIDS) AND SOURCE ANALYSIS OBSERVED DURING GEOMAGNETIC DISTURBED AND QUIET PERIODS

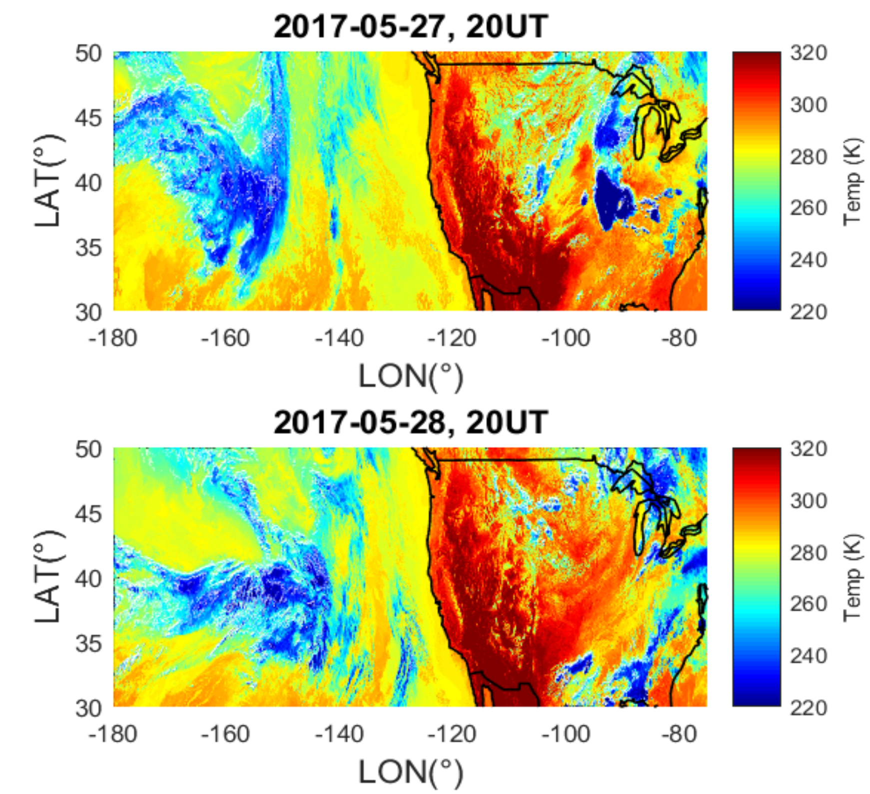


Large scale and equatorward propagating TIDs are generated from constant energy input from the auroral source as a result of the Memorial Day weekend storm.





Medium scale poleward propagating TIDs are probably be seeded by locally generated convective source (possibly gravity waves from convection activity at Pacific coast).



Olusegun J. et al, 2018