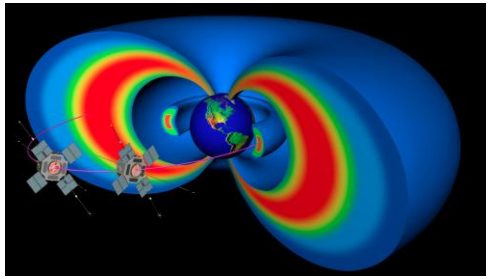
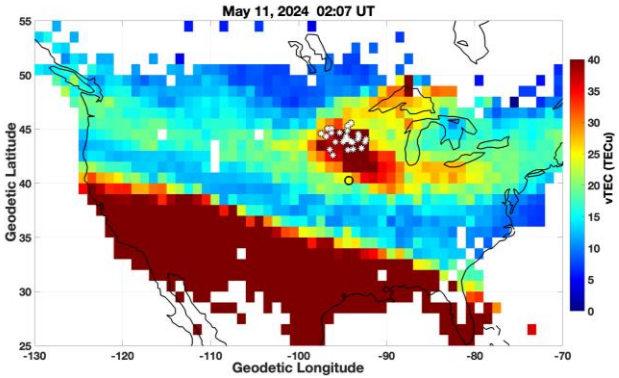
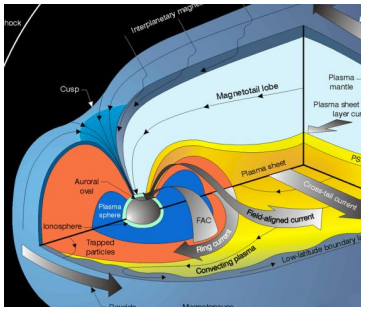
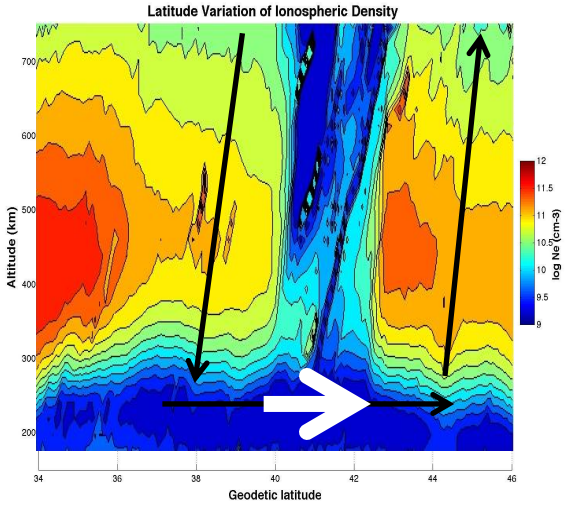






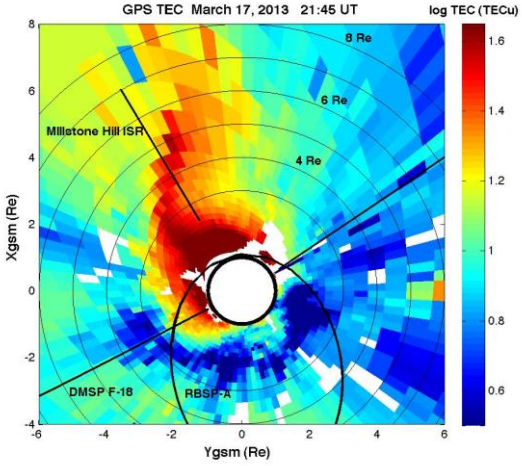
Multi-Instrument Observations of Stormtime Mid-Latitude Geospace Disturbances



John Foster

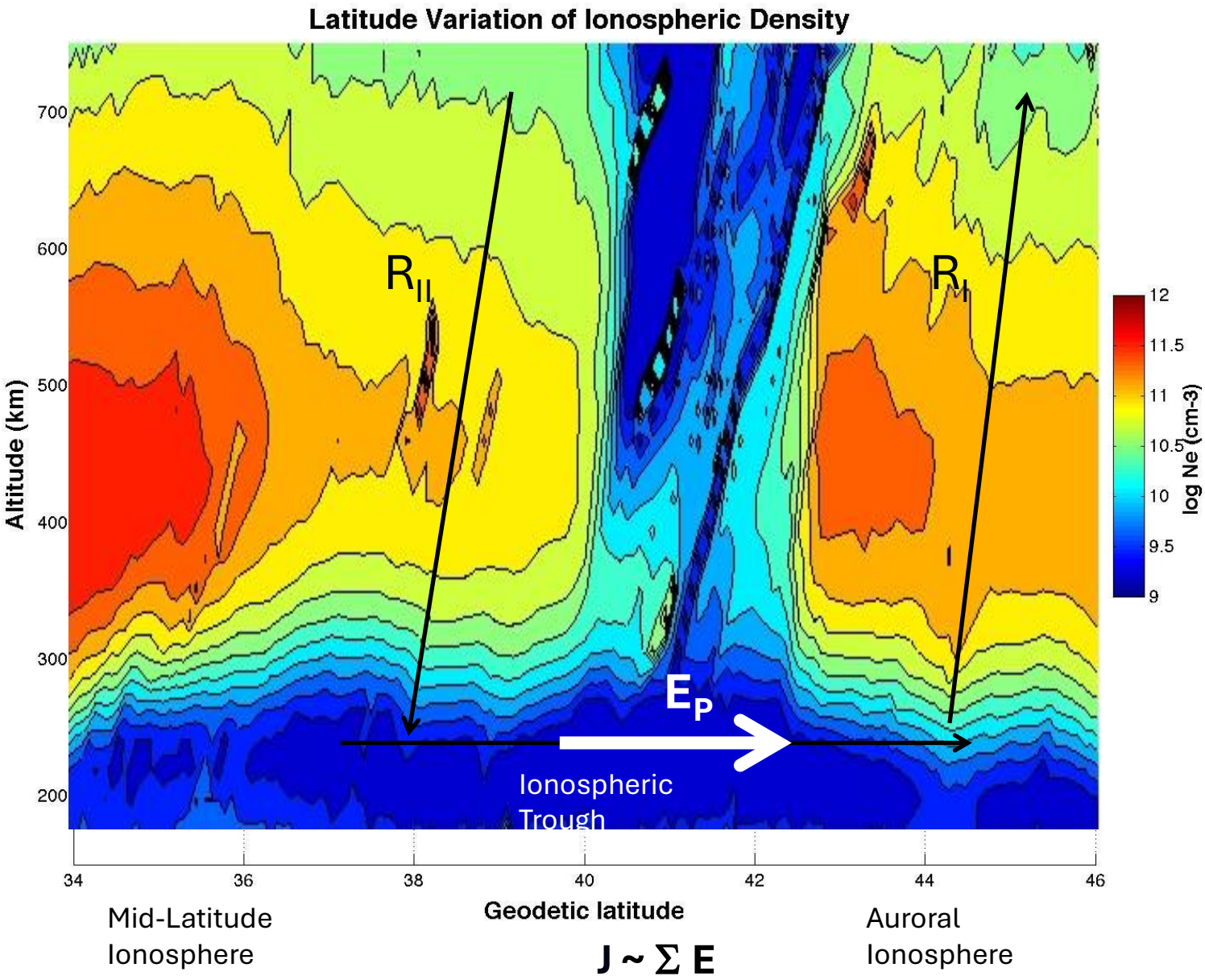
MIT Haystack Observatory (ret.)

with Input from
Many Lifetime Collaborators



Geospace is integrally coupled such that observations with different instruments at different altitudes tell parts of the same story from different points of view.

IS Radar: Current Closure across the Ionospheric Trough



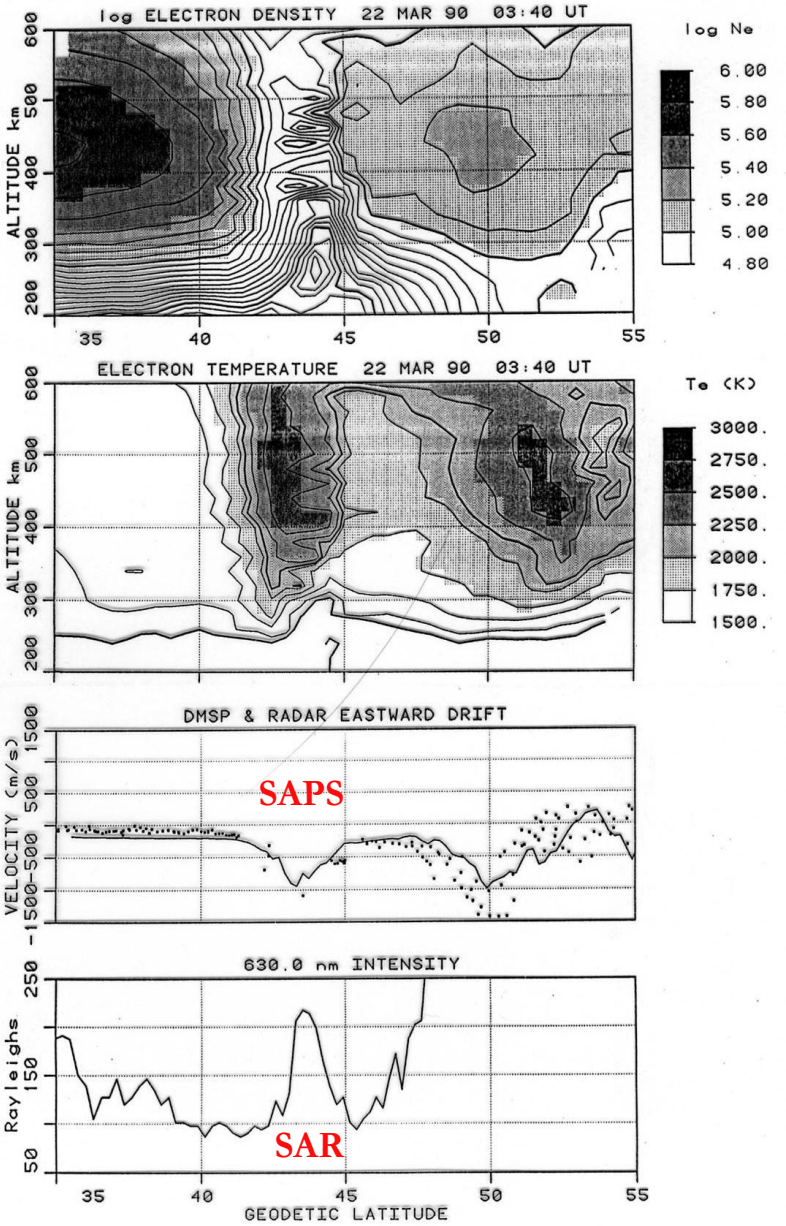
Plasmasphere Boundary Layer

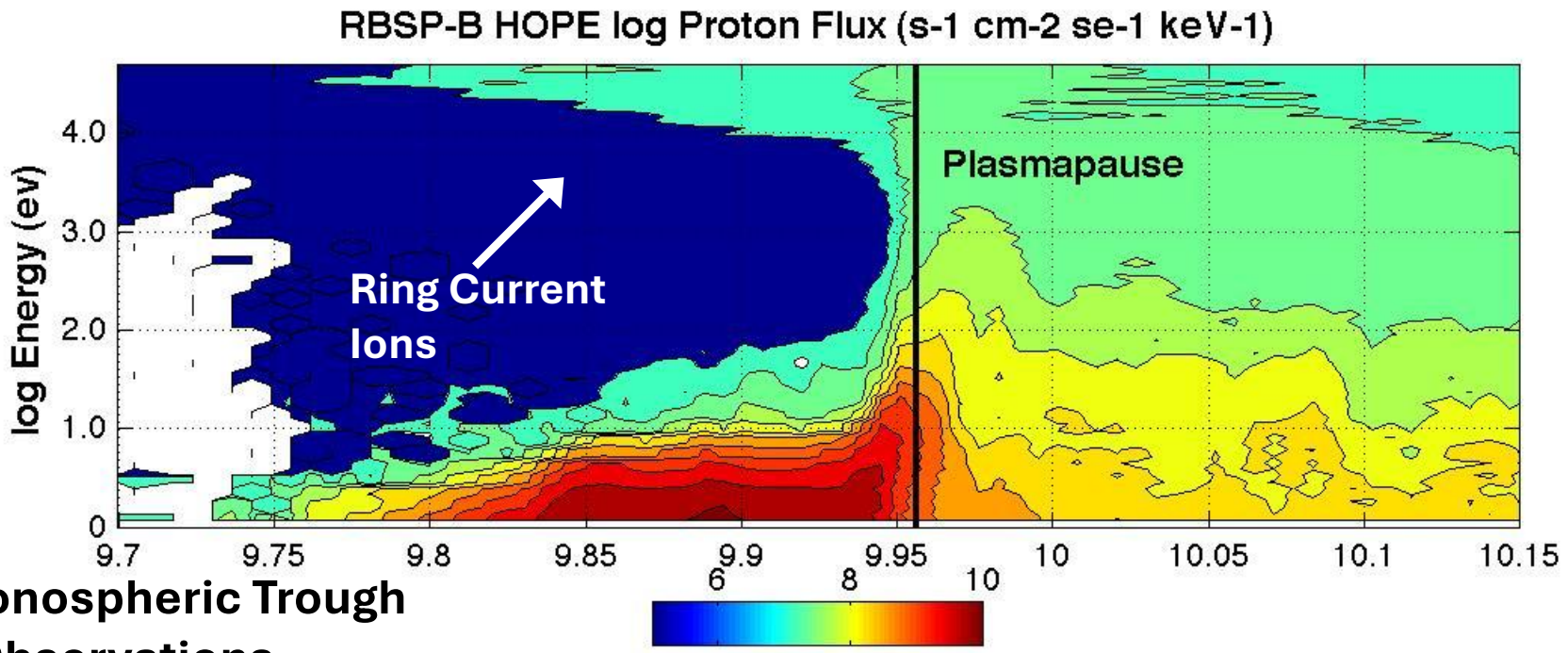
SAR (Stable Auroral Red) Arc

M-I Coupling in the Trough

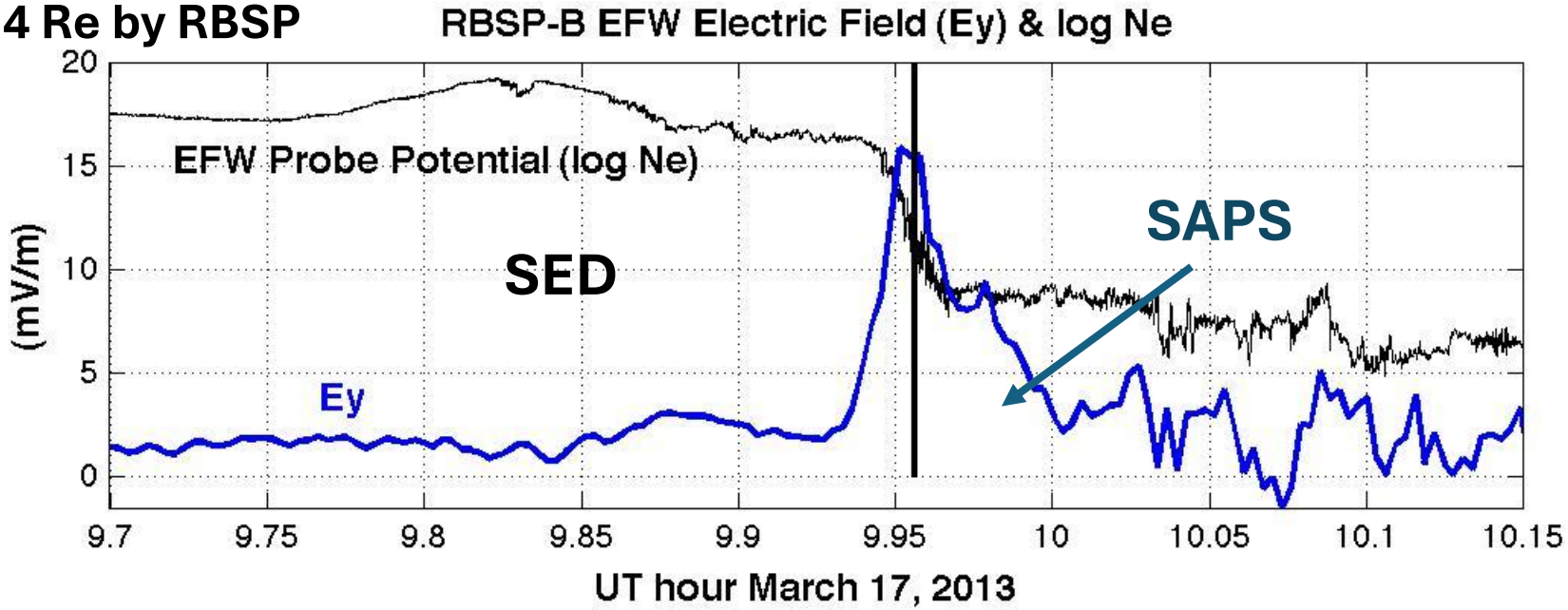
[Foster, Buonsanto, Mendillo, Nottingham, Rich, and Denig, 1994]

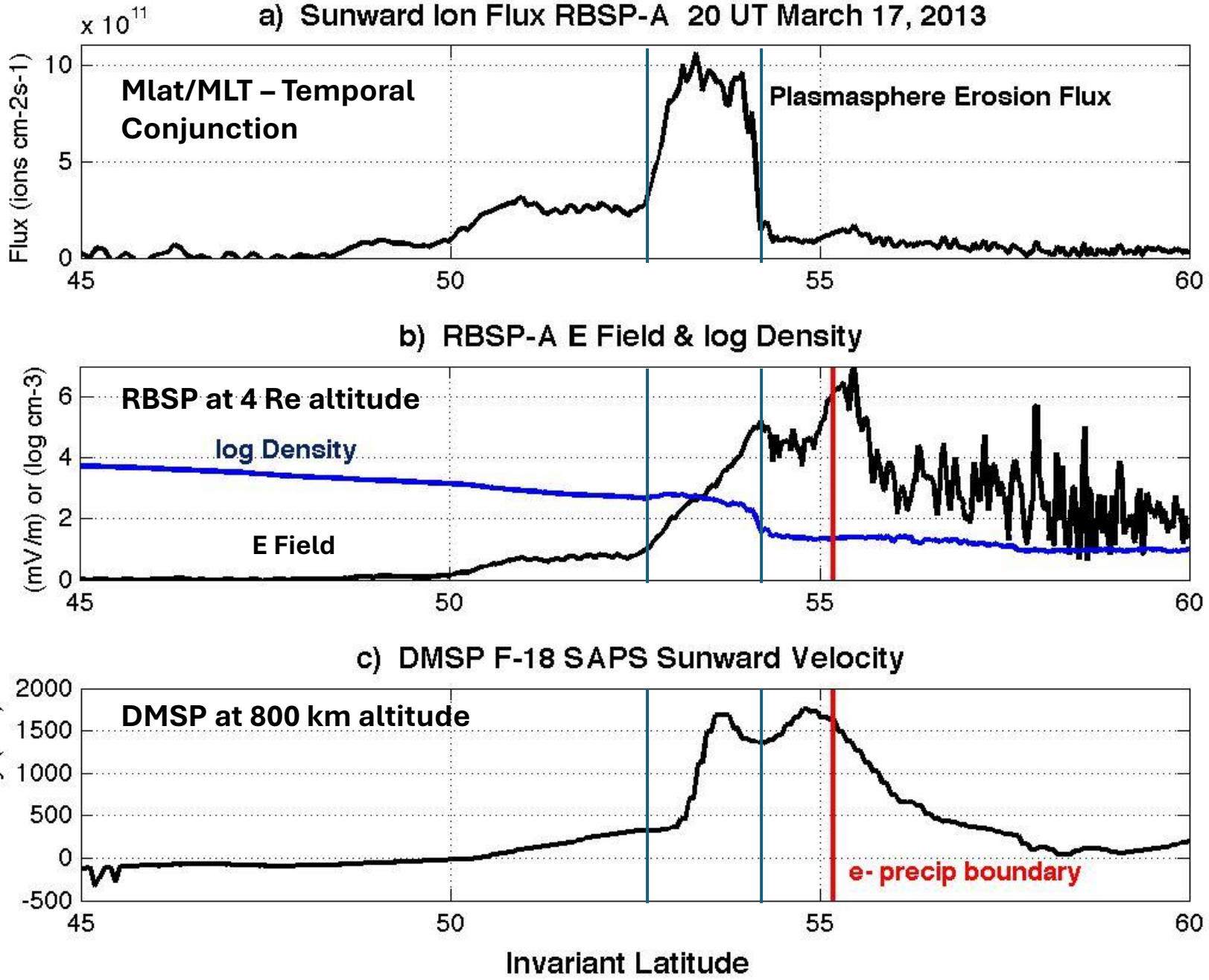
Millstone Hill Radar Observations



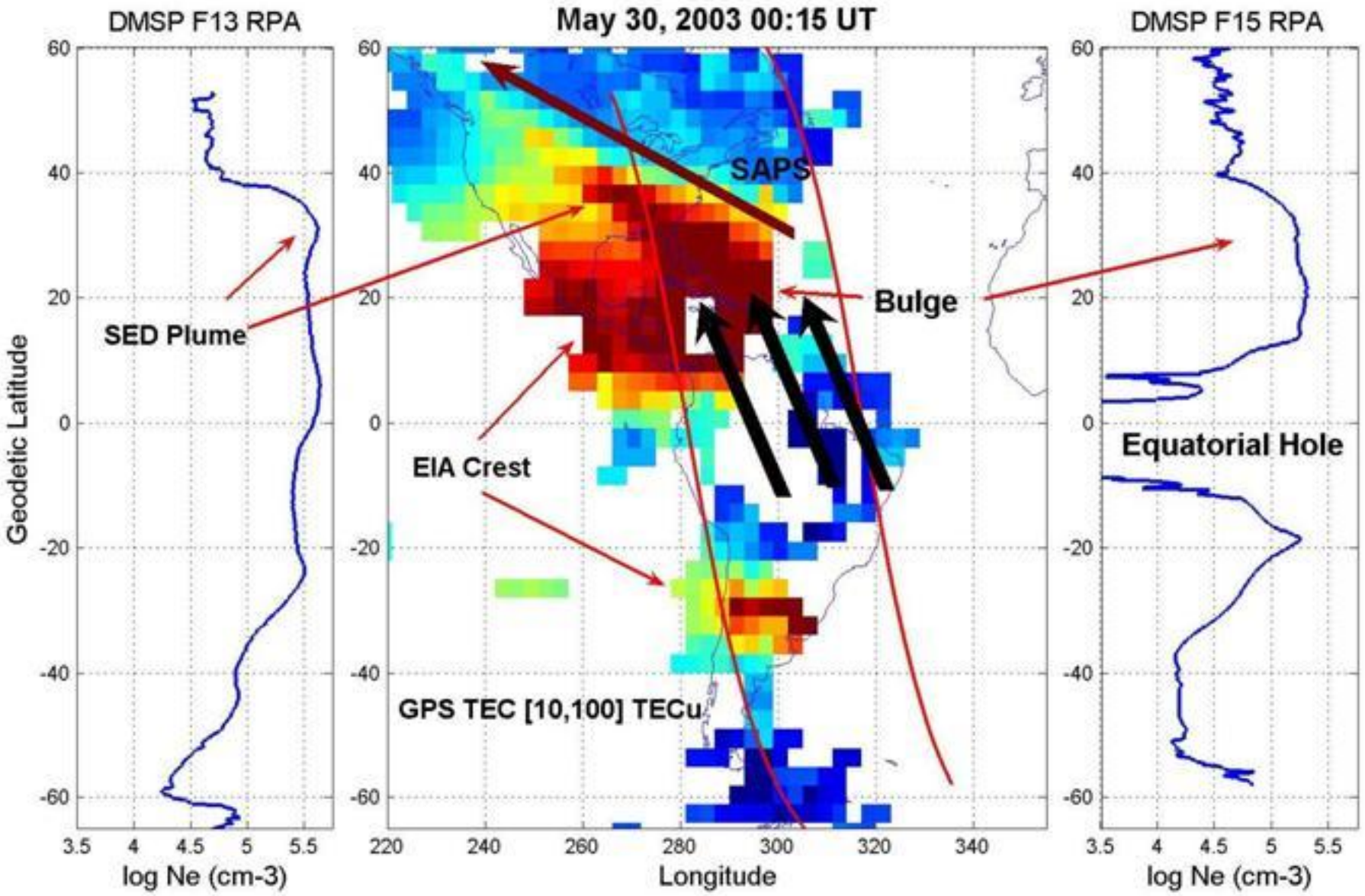


Ionospheric Trough Observations at 4 Re by RBSP

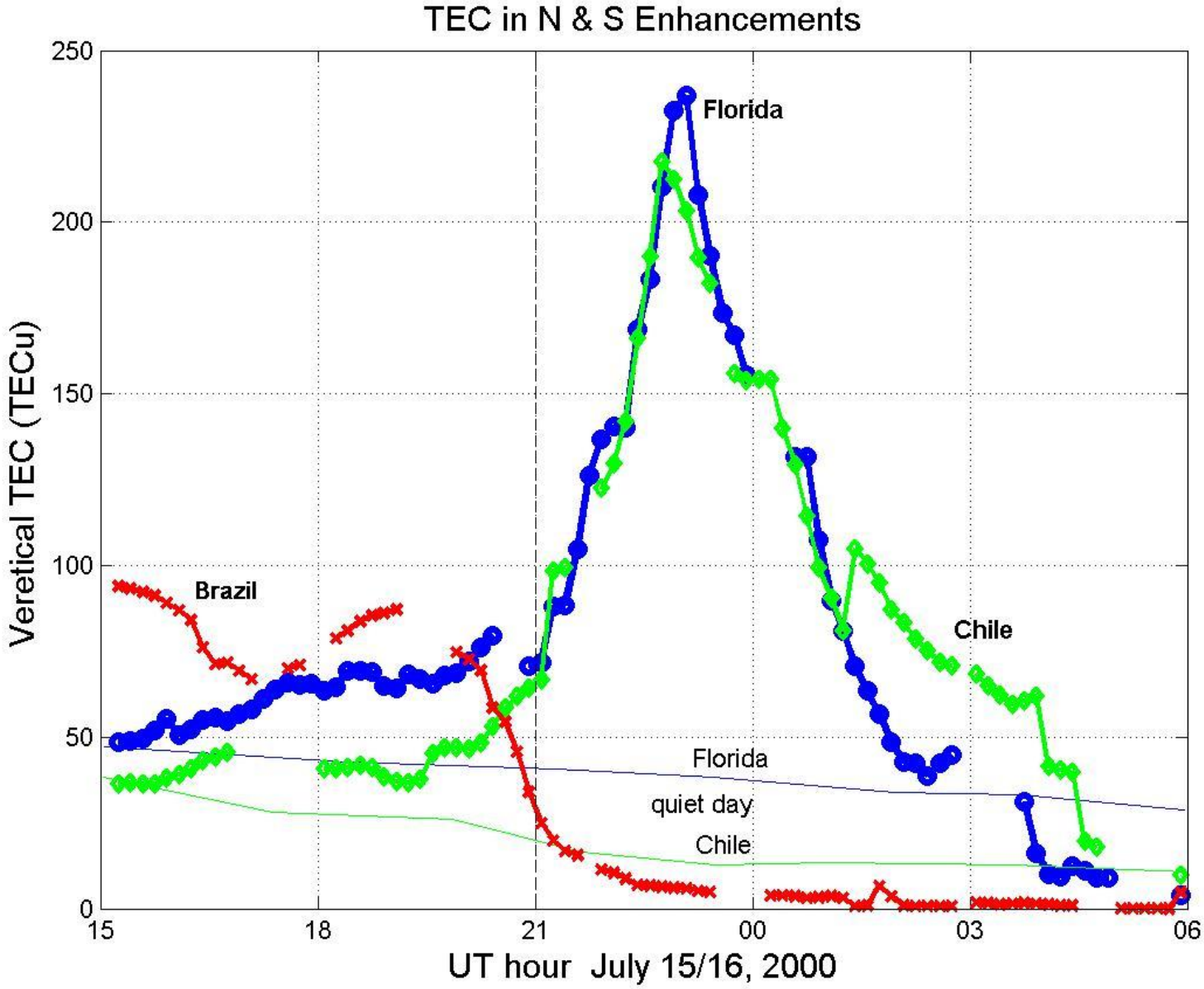



a) Sunward Ion Flux RBSP-A 20 UT March 17, 2013
x 10^11
Flux (ions cm-2s-1)
Mlat/MLT – Temporal Conjunction
Plasmasphere Erosion Flux
b) RBSP-A E Field & log Density
(mV/m) or (log cm-3)
RBSP at 4 Re altitude
log Density
E Field
c) DMSP F-18 SAPS Sunward Velocity
Ion Velocity (m/s)
DMSP at 800 km altitude
e- precip boundary
Invariant Latitude

Ionospheric Nomenclature

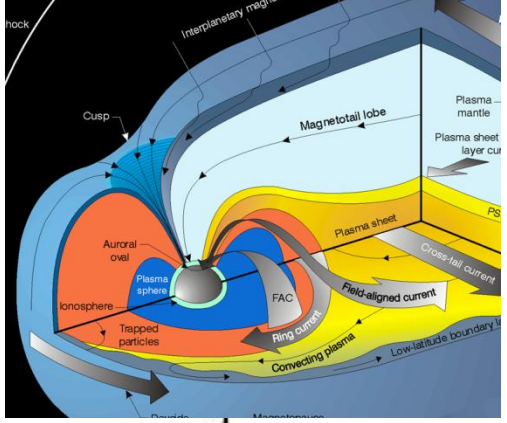


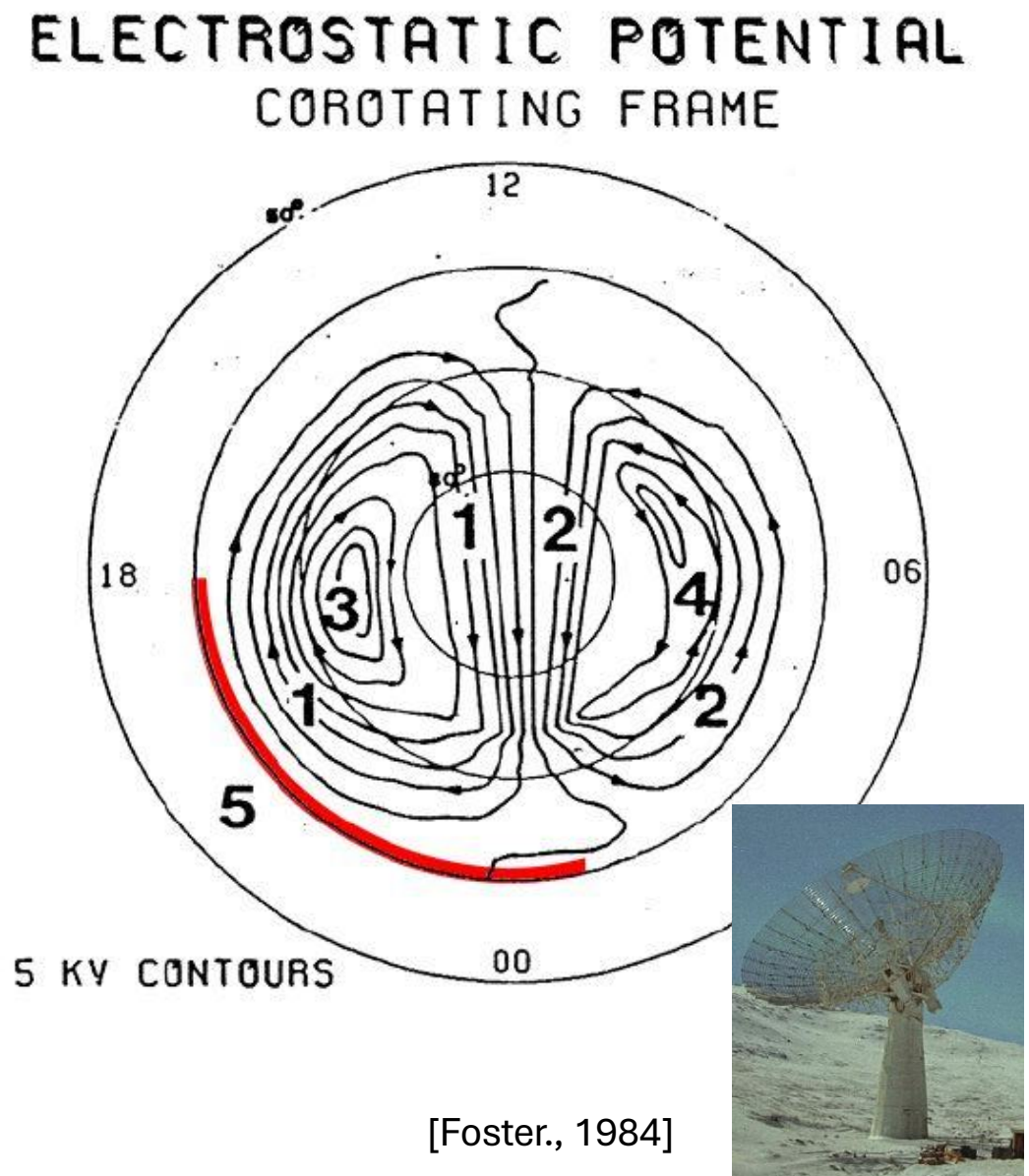
Magnetically Conjugate Effects



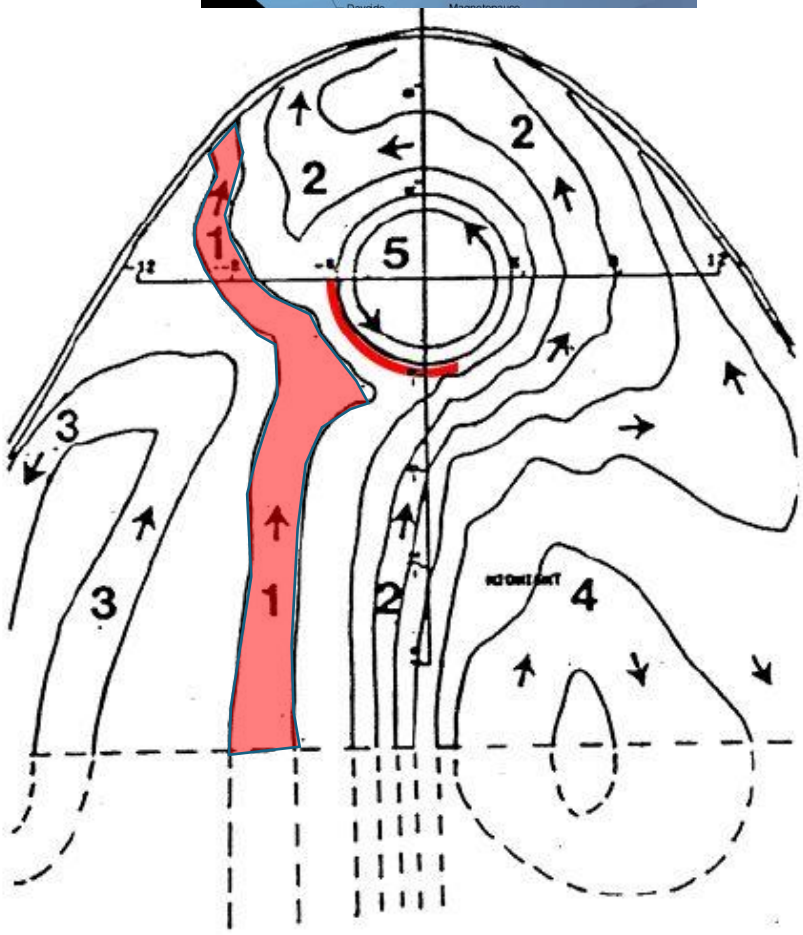
[Foster and Coster, JASTP, 2007]

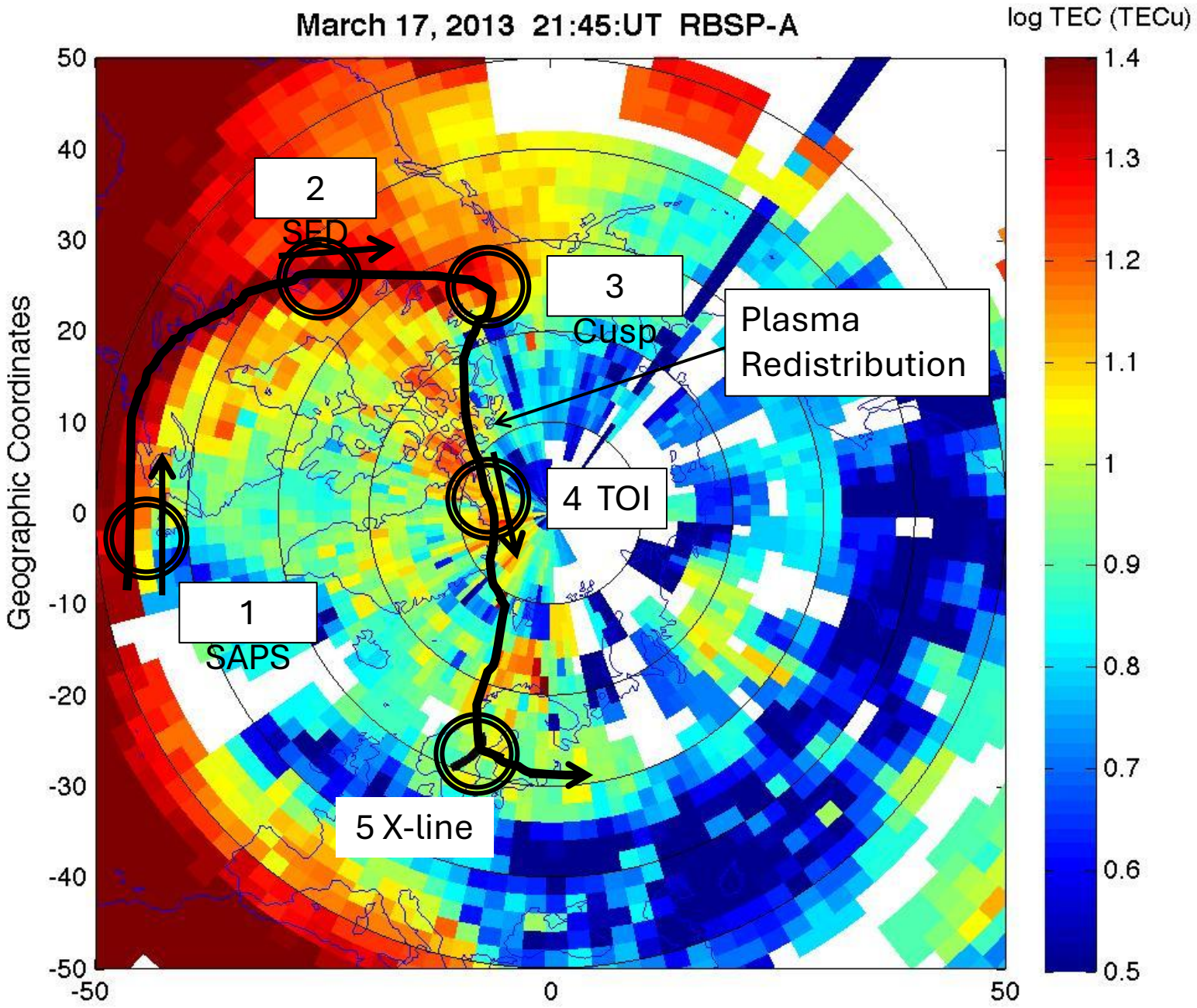
To first order, cold plasma redistribution proceeds such that plasma parcels at ionospheric heights and at the apex of a magnetic field line move together in the E x B direction maintaining their magnetic field alignment.





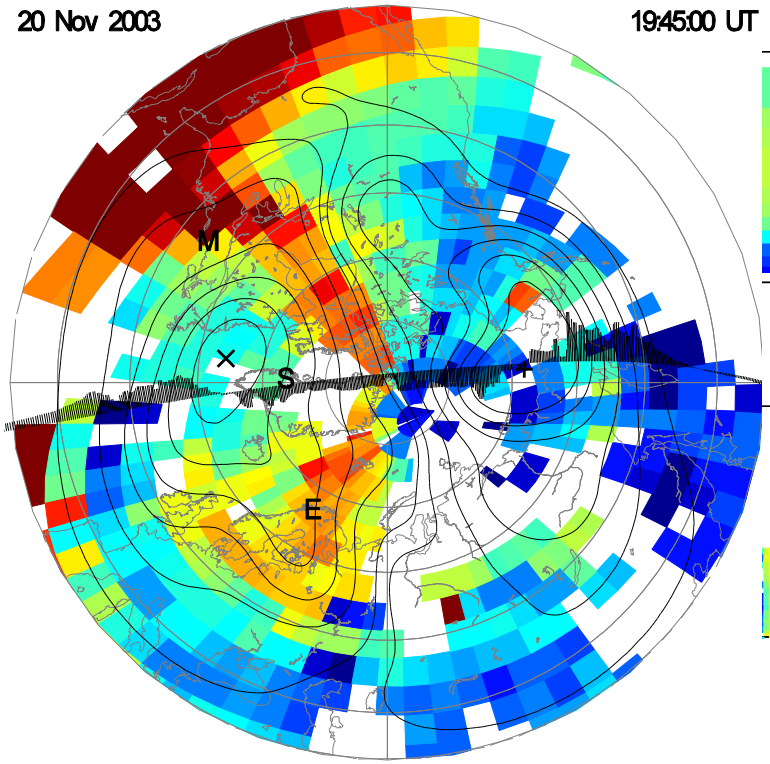
[Foster., 1984]

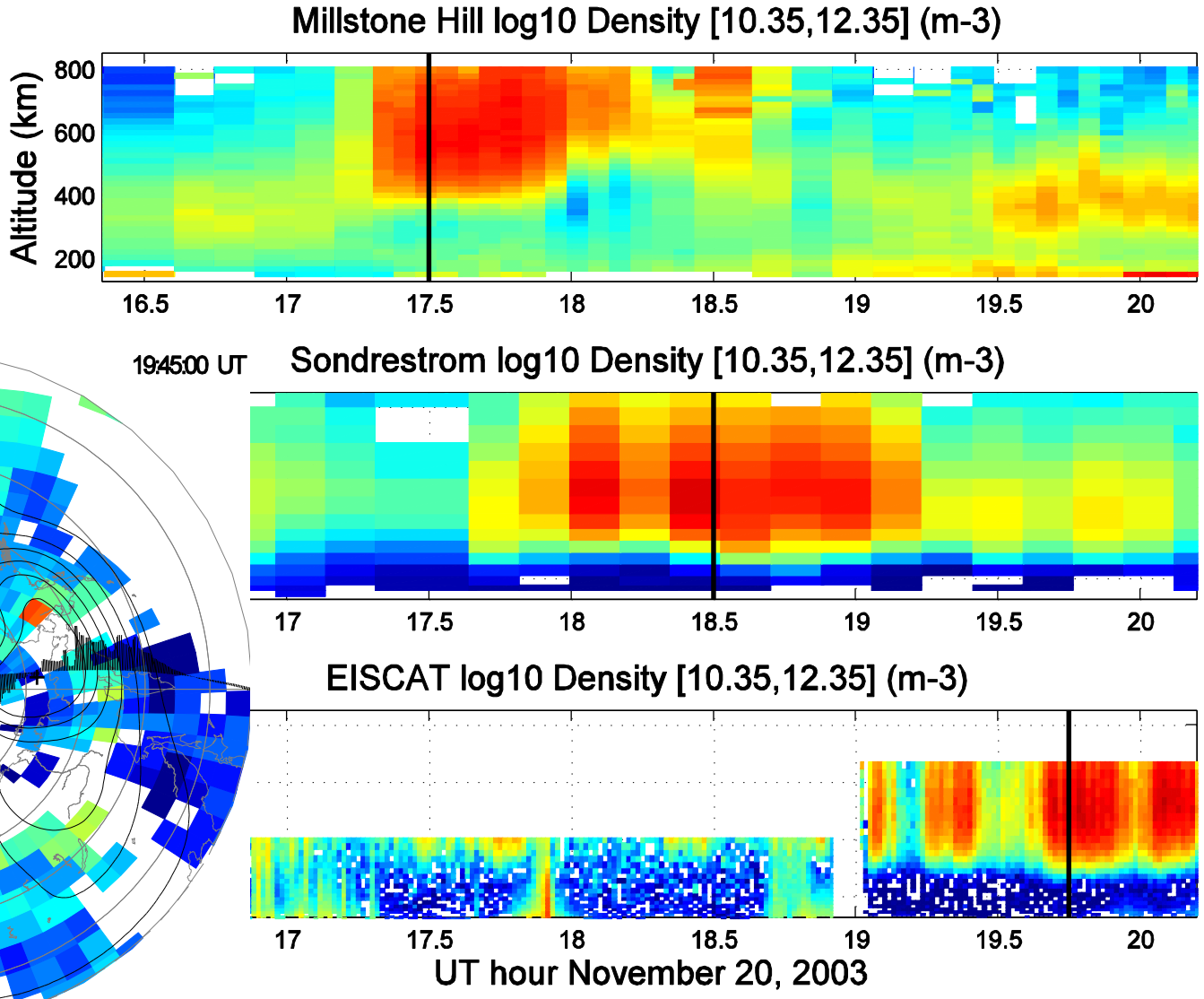




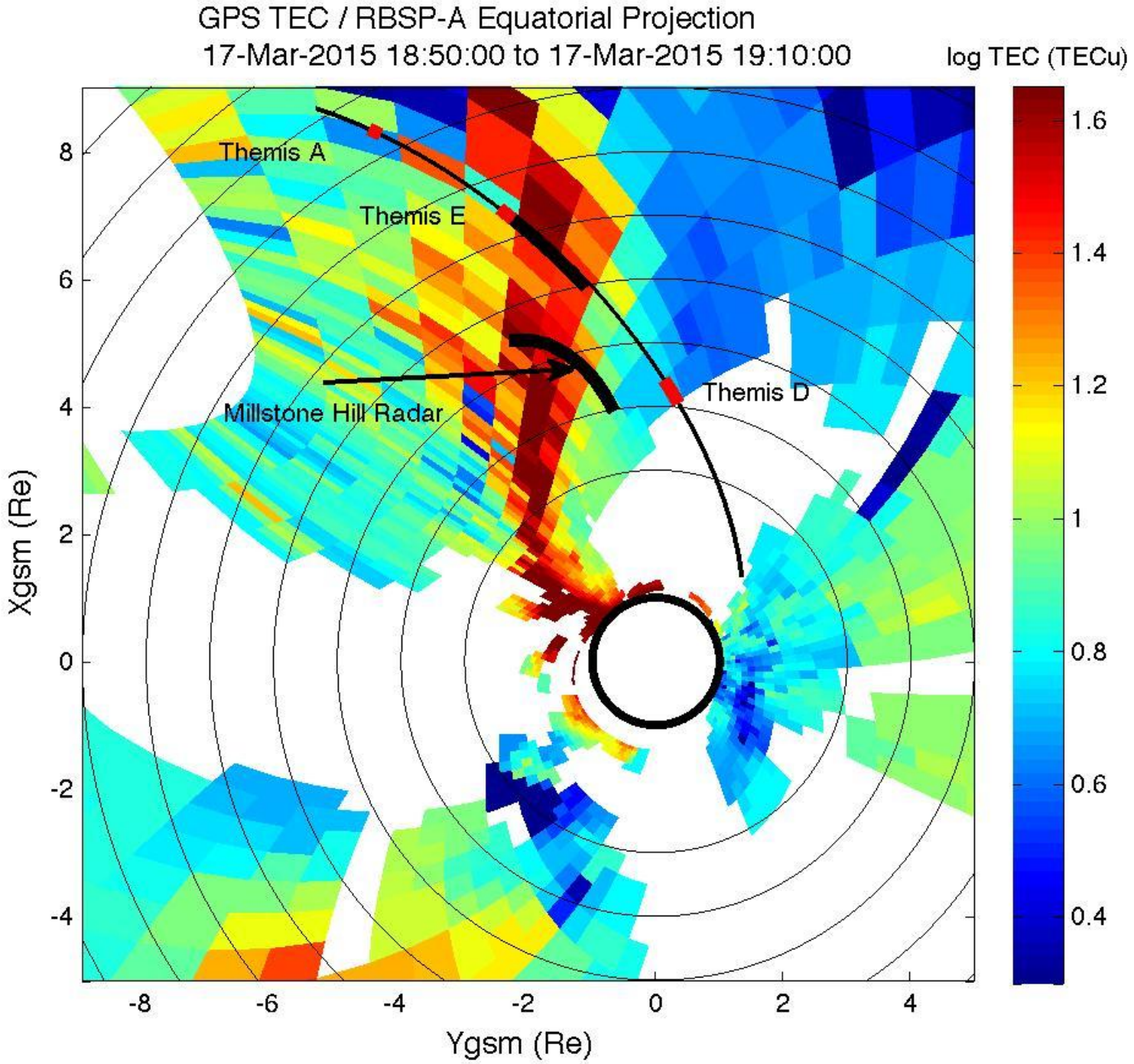
1) Plasmasphere Erosion 2) SED Plume 3) Cusp Rx 4) Polar TOI 5) Midnight Rx

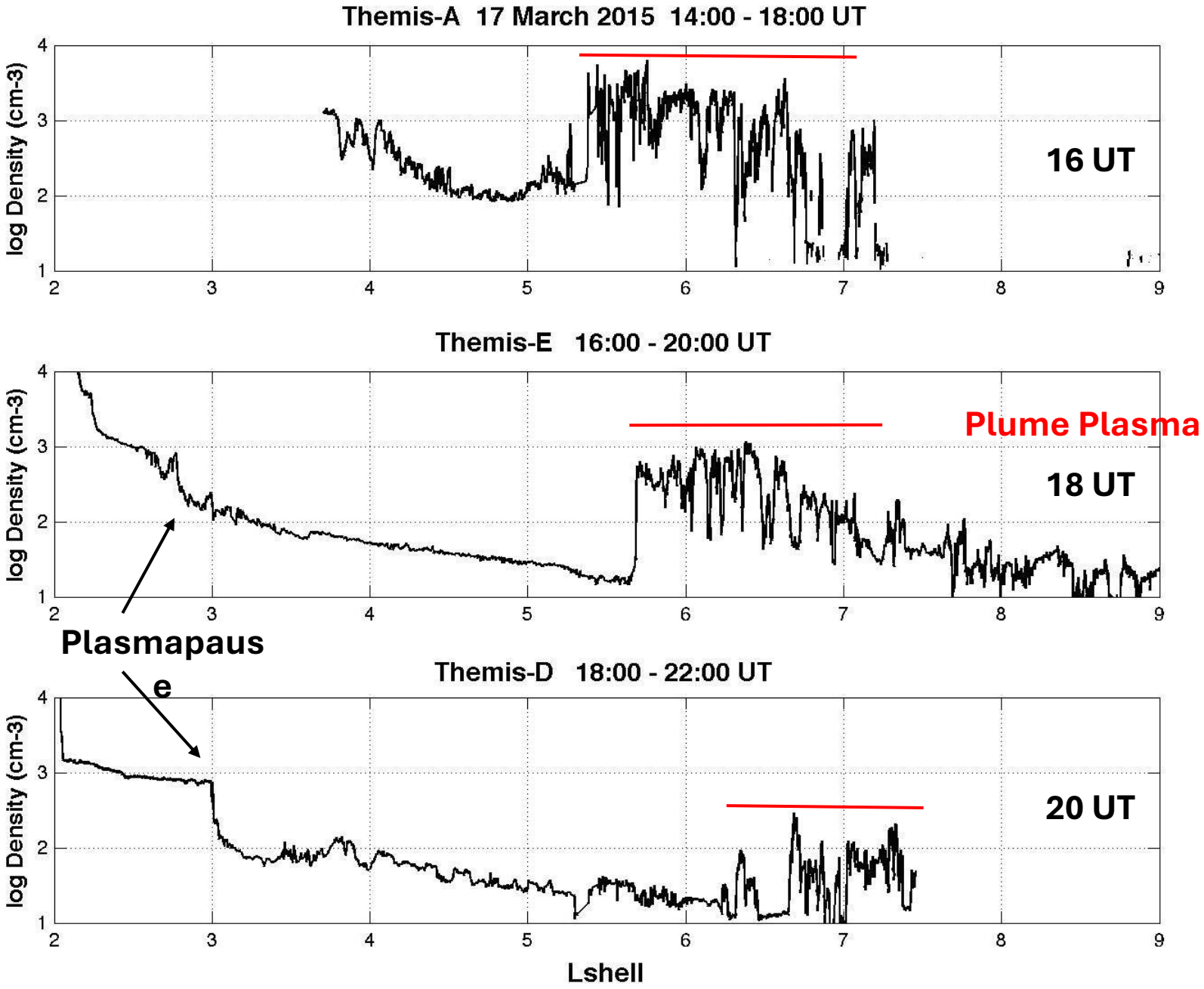
IS Radar Observations of SED/TOI at Cusp / Polar / Nightside Auroral Latitudes





[Foster et al., JGR 2004]

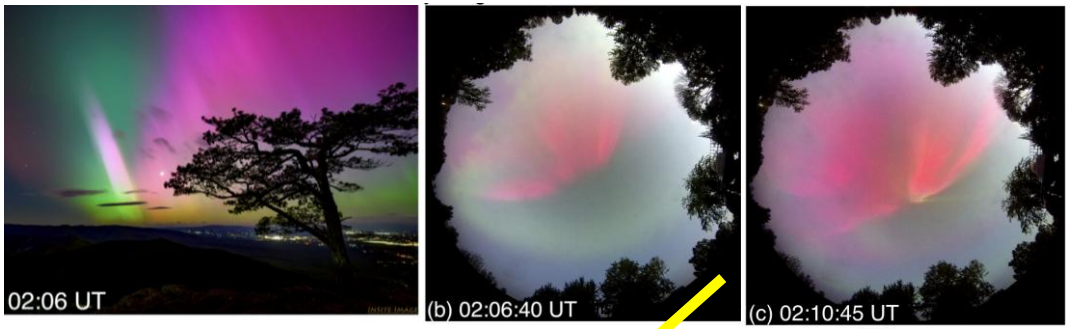

GPS TEC / RBSP-A Equatorial Projection
17-Mar-2015 18:50:00 to 17-Mar-2015 19:10:00
log TEC (TECu)
Themis A
Themis E
Themis D
Millstone Hill Radar
Xgsm (Re)
Ygsm (Re)
8
6
4
2
0
-2
-4
-8
-6
-4
-2
0
2
4
1.6
1.4
1.2
1
0.8
0.6
0.4

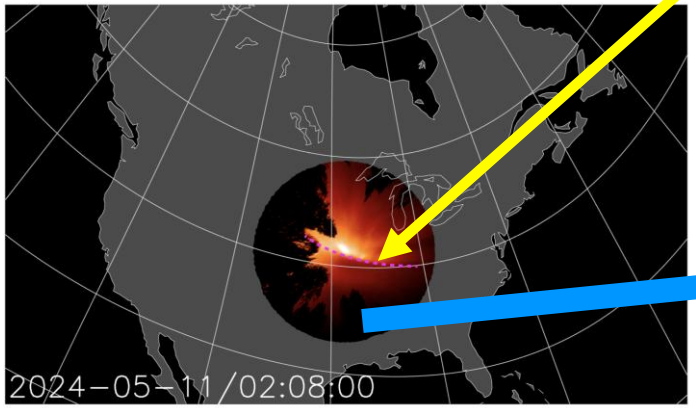

Themis-A 17 March 2015 14:00 - 18:00 UT
log Density (cm-3)
16 UT
Themis-E 16:00 - 20:00 UT
log Density (cm-3)
Plume Plasma
18 UT
Plasmapaus
e
Themis-D 18:00 - 22:00 UT
log Density (cm-3)
20 UT
Lshell

Imaging the May 2024 Extreme Aurora With Ionospheric Total Electron Content

Foster, J. C., Erickson, P. J., Nishimura, Y., Zhang, S. R., Bush, D. C., Coster, A. J., et al. (2024). Imaging the May 2024 Extreme Aurora With Ionospheric Total Electron Content. *Geophysical Research Letters*, *51*(20). https://doi.org/10.1029/2024gl111981

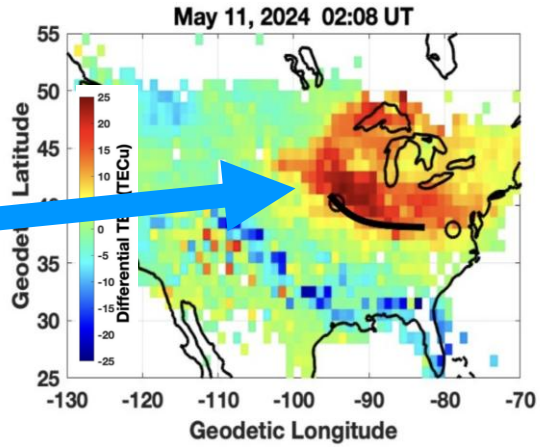
Auroral Images taken by citizen scientists

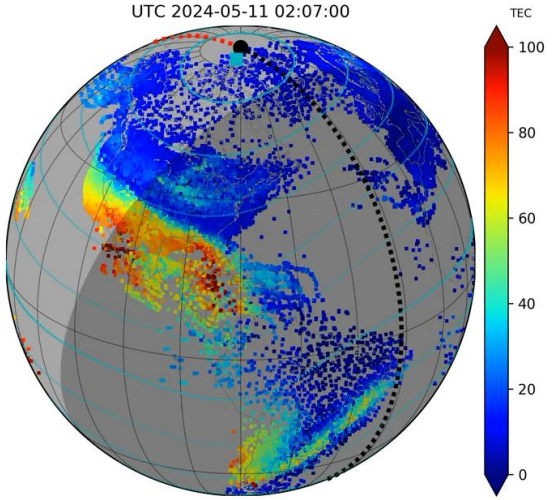




Red-channel Missouri all-sky imager data at 02:08:00 UT projected onto the map using a 230 km emission height. The dashed line indicating the advancing auroral boundary corresponds to the black curve on the differential vTEC map at 02:08 UT in Figure on the right.

TEC Enhancements during auroral breakup

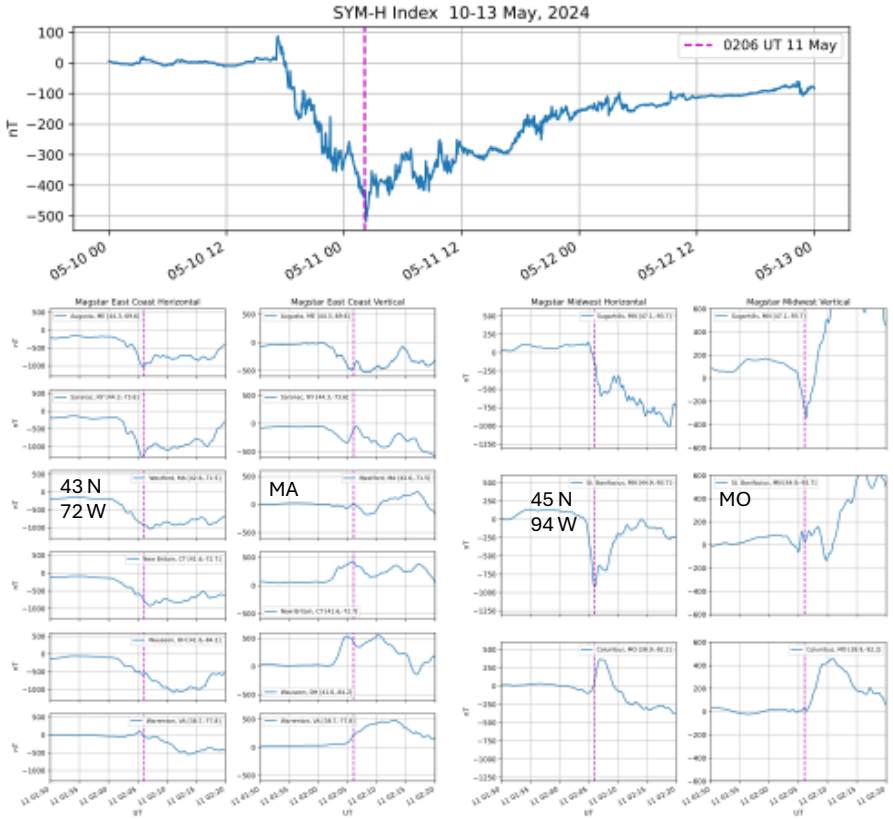




Over a 20-min interval, vertical TEC (vTEC) increased at unusually low latitude (~45°) and rapidly expanded azimuthally across the continent. Individual receiver/ satellite data sets indicate sharp bursts of greatly elevated of vTEC (~50 TECu). Intense red aurora was co-located with the leading edge of the equatorward and westward TEC enhancements, indicating that the large TEC enhancement was created by extremely intense low-energy precipitation during the rapid substorm breakup.

Substorm Breakup at Peak of 10-11 May 2024 Superstorm

Minimum Sym-H (-500 nT) 11 May 02:06 UT
Electrojet Centered @ ~ 44 N Latitude
(H ~ -1000 nT; Z ~ 0 nT)

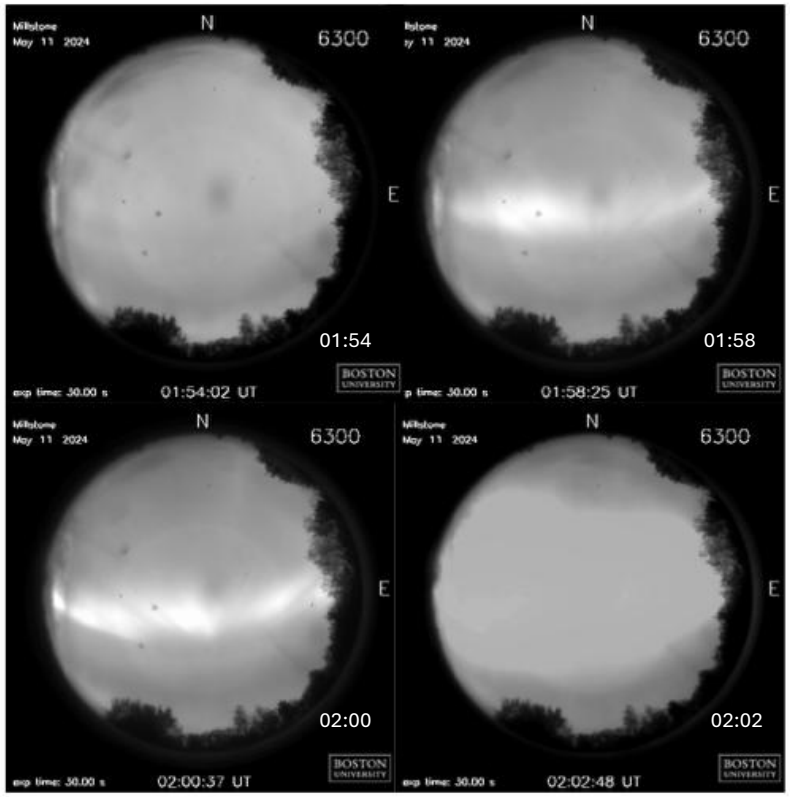


H Z H Z

East Chain West Chain

Magstar Magnetometers

Substorm Onset (T=0) at 02:00 UT
Boston University Redline Imager
at Millstone Hill Site (43 N, 72 W)



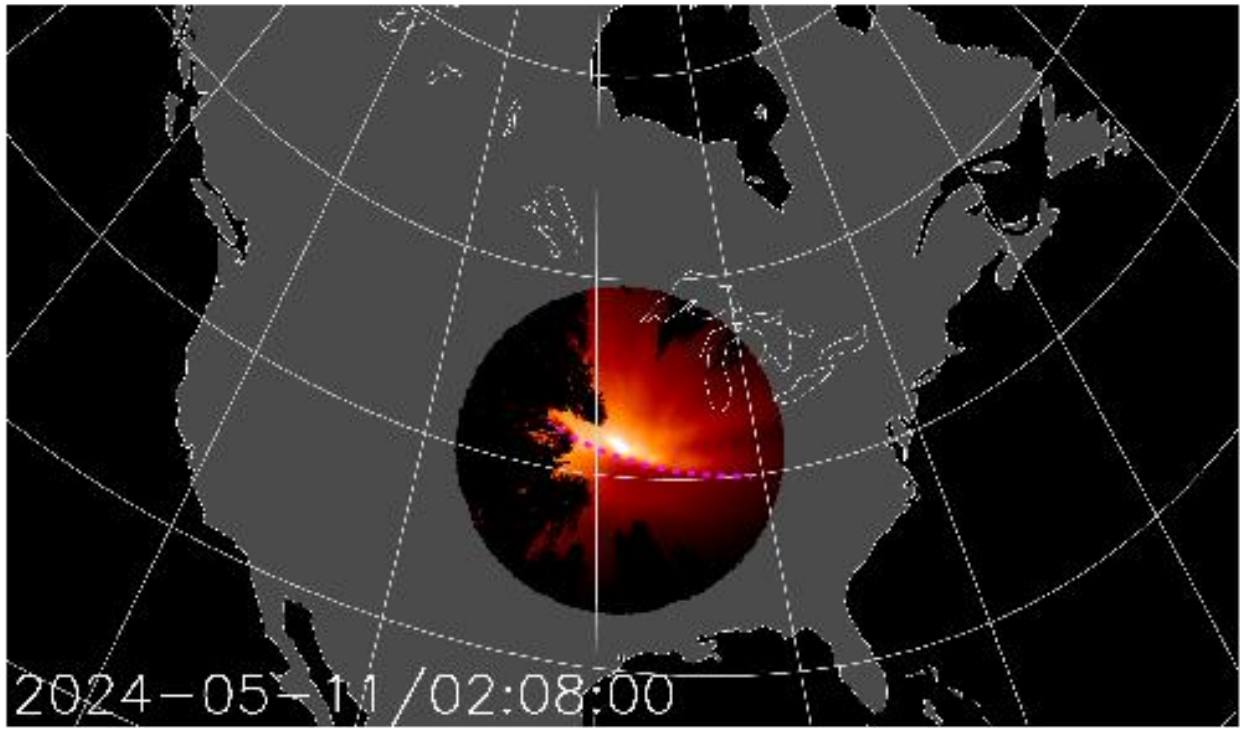
Citizen Scientist Auroral Imagery (Missouri, 41N, 94W)

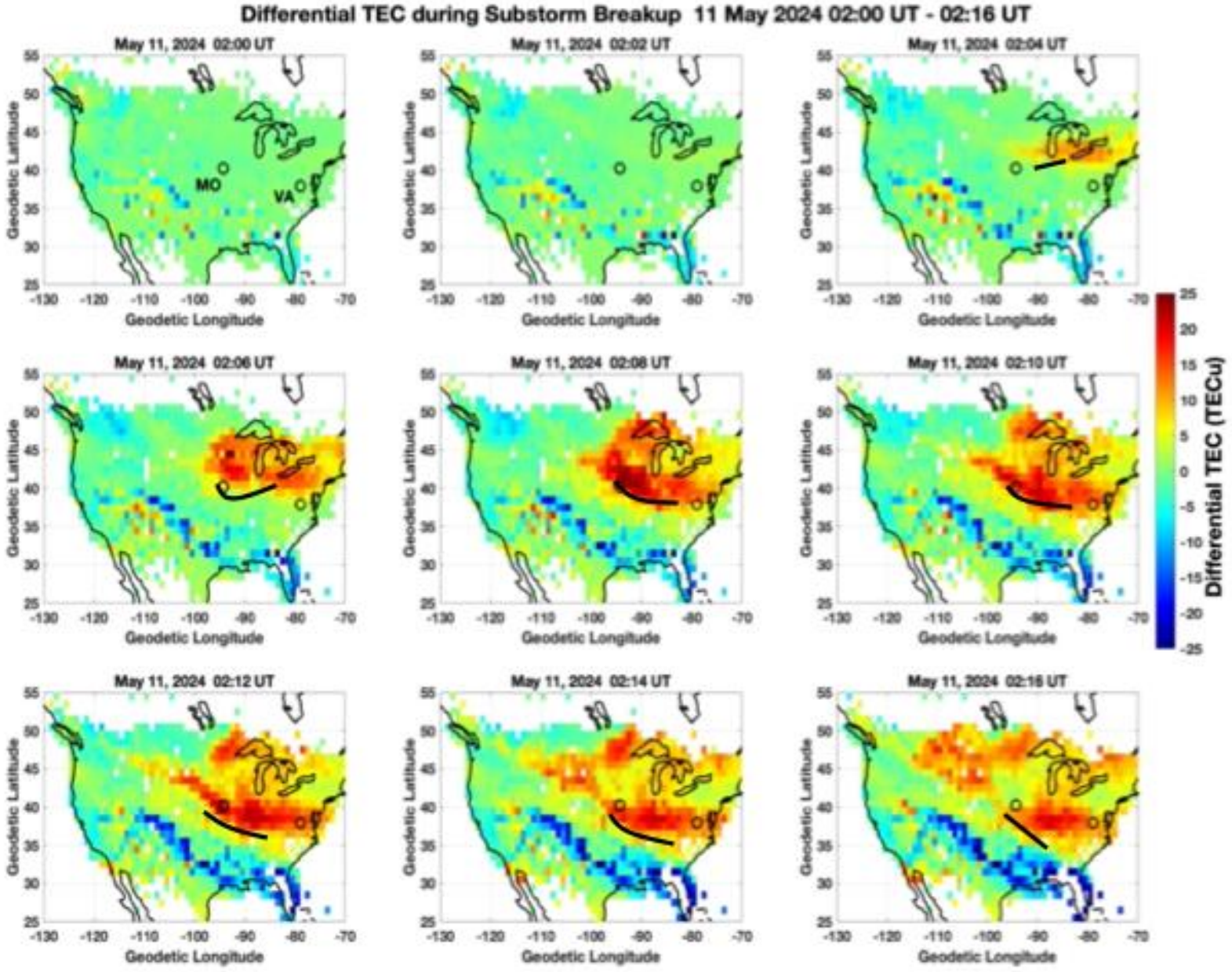
All-sky images at Missouri Skies Observatory

Missouri ASC 1-sec frame rate RAW RGB

All sky camera images were mapped into geodetic coordinates at 230 km altitude.

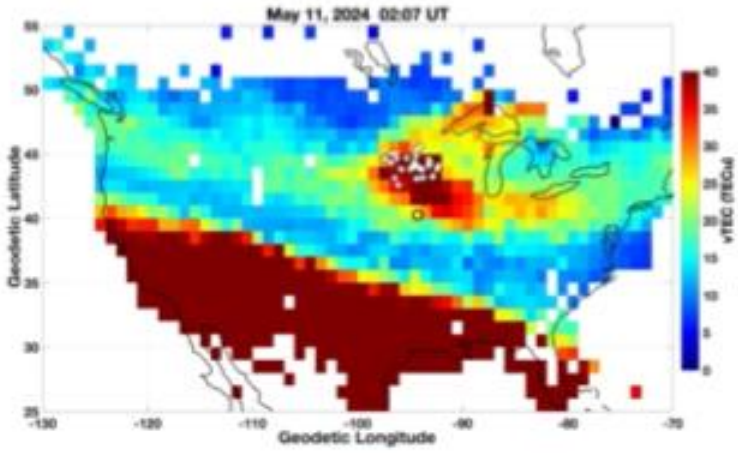
The equatorward boundary of strong red aurora was determined.

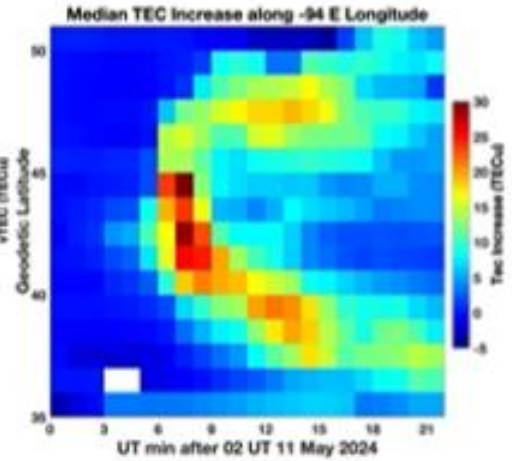


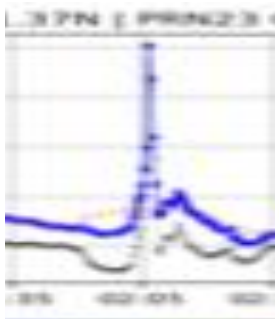


1-min median LOS vTEC, 1 deg lat-long bins, elevation angle >55 deg

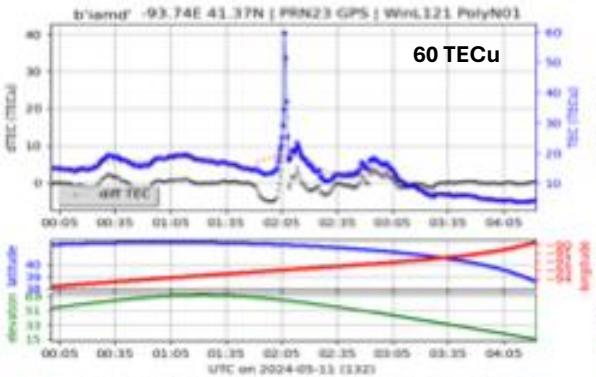
Coincident with auroral breakup, individual receiver/satellite data sets show sharp bursts of greatly elevated TEC

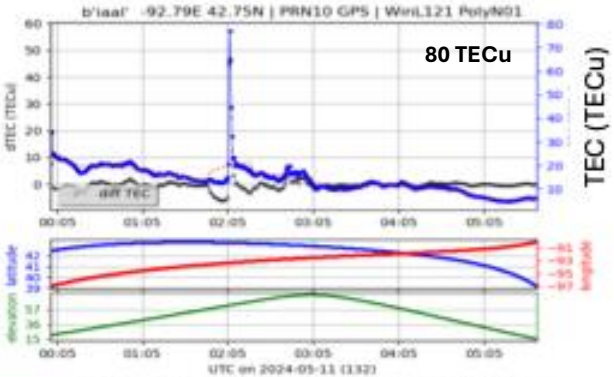


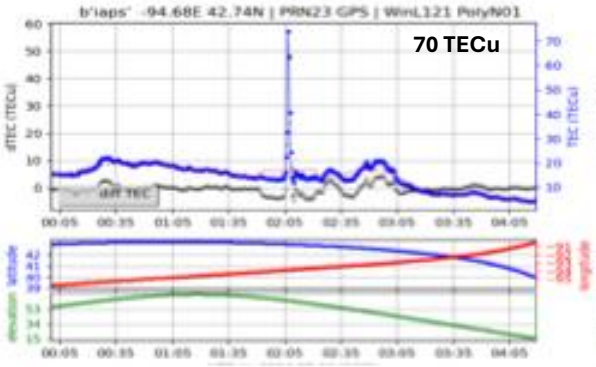




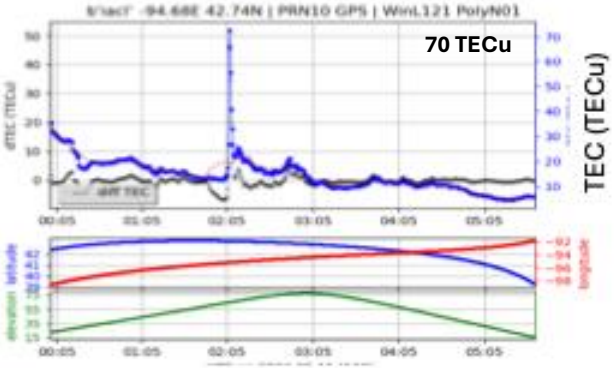
Gradual Onset





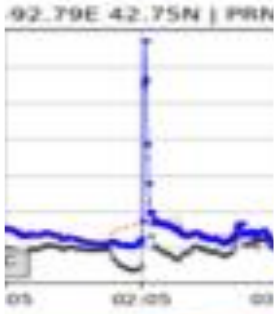


UTC 2024-05-11



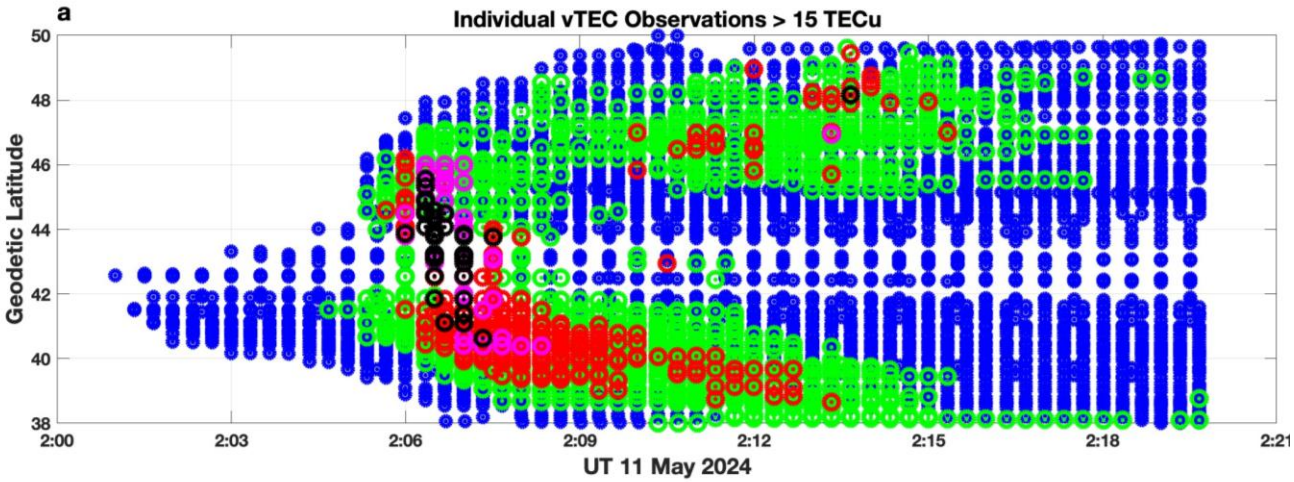
UTC 2024-05-11

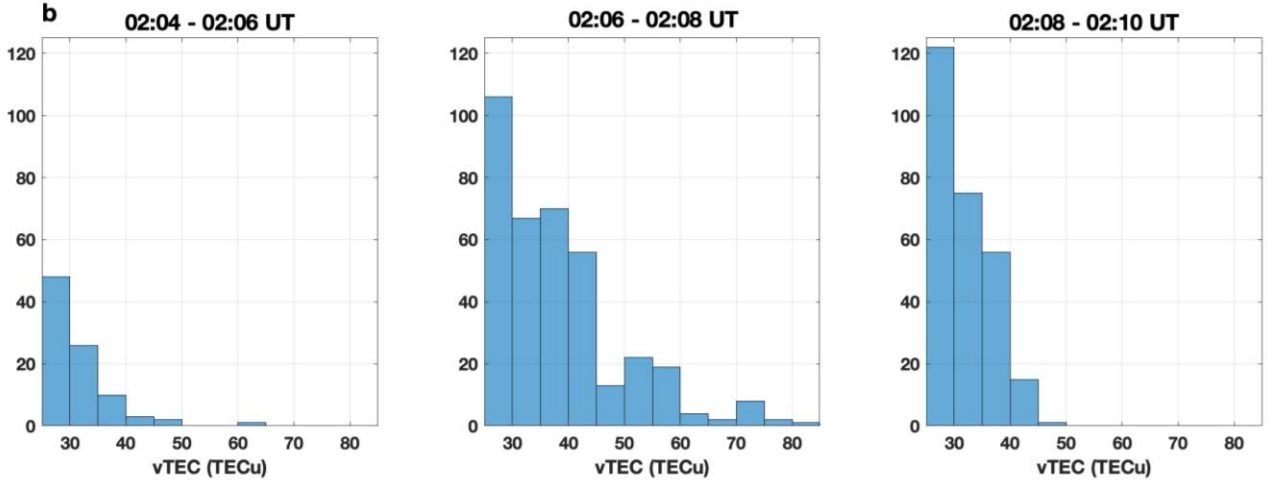
TEC (TECu)



Sharp Onset

Individual LOS vTEC samples with elevation angle > 15 deg for 92.5 - 94.5 W longitude





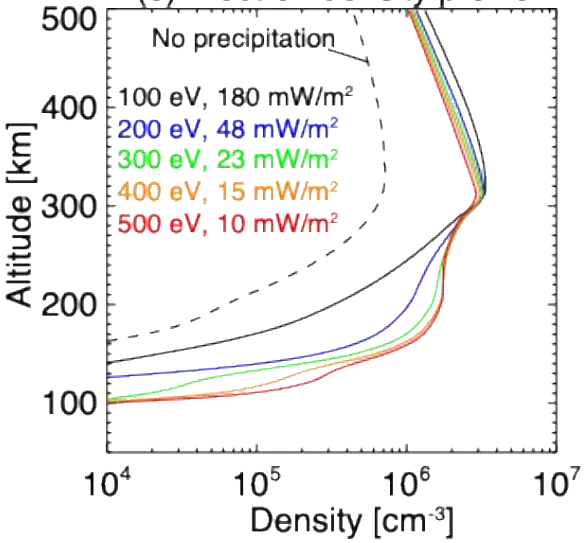
Sample Color	vTEC Range	# Samples
Black	>55 TECu	38
Magenta	45 - 55 TECu	39
Red	35 - 45 TECu	263
Green	25 - 35 TECu	1075
Blue	15 - 25 TECu	3282
Not Shown	< 15 TECu	2330

A total of 7027 samples were recorded between 02:00 UT and 02:20 UT

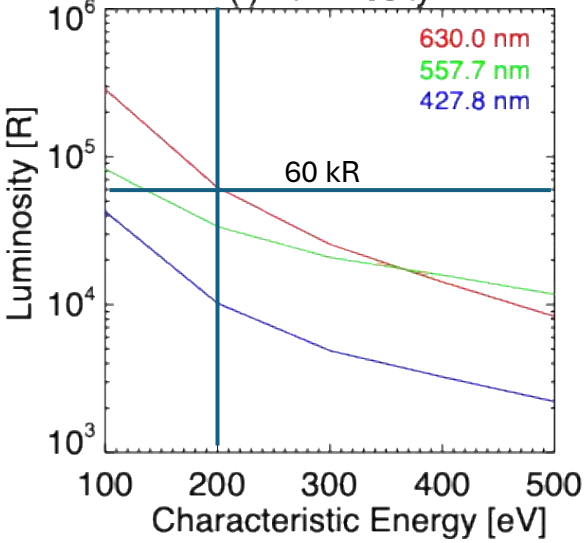
Electron Precipitation Associated with Extreme Red Aurora

(d) Photograph at Staunton, VA

(e) Electron density profile



(f) Luminosity



- Electron precipitation with a Maxwellian distribution with characteristic energies between 100 and 500 eV using the Fang et al. (2010) model.
- Energy fluxes for each characteristic energy are chosen to create a 50 TECu increase above the background.
- Auroral luminosities at 630.0, 557.7 and 427.8 nm wavelengths are calculated using the GLOW Model. Precipitation below ~300 eV creates auroral emission that is dominated by the red color.
- Considering the mixture of the red and green emission, it is likely that the characteristic energy is around 200-300 eV.
- The 23-48 mW/m^2 energy fluxes are intense and very unusual at mid-latitudes.
- Soft electron precipitation creates electron density enhancements above ~120 km altitude with a peak at ~300 km, indicating that the precipitation has a large impact in the F-region ionosphere.