Stormtime O+ Redistribution: a Connection to Storm Strength?

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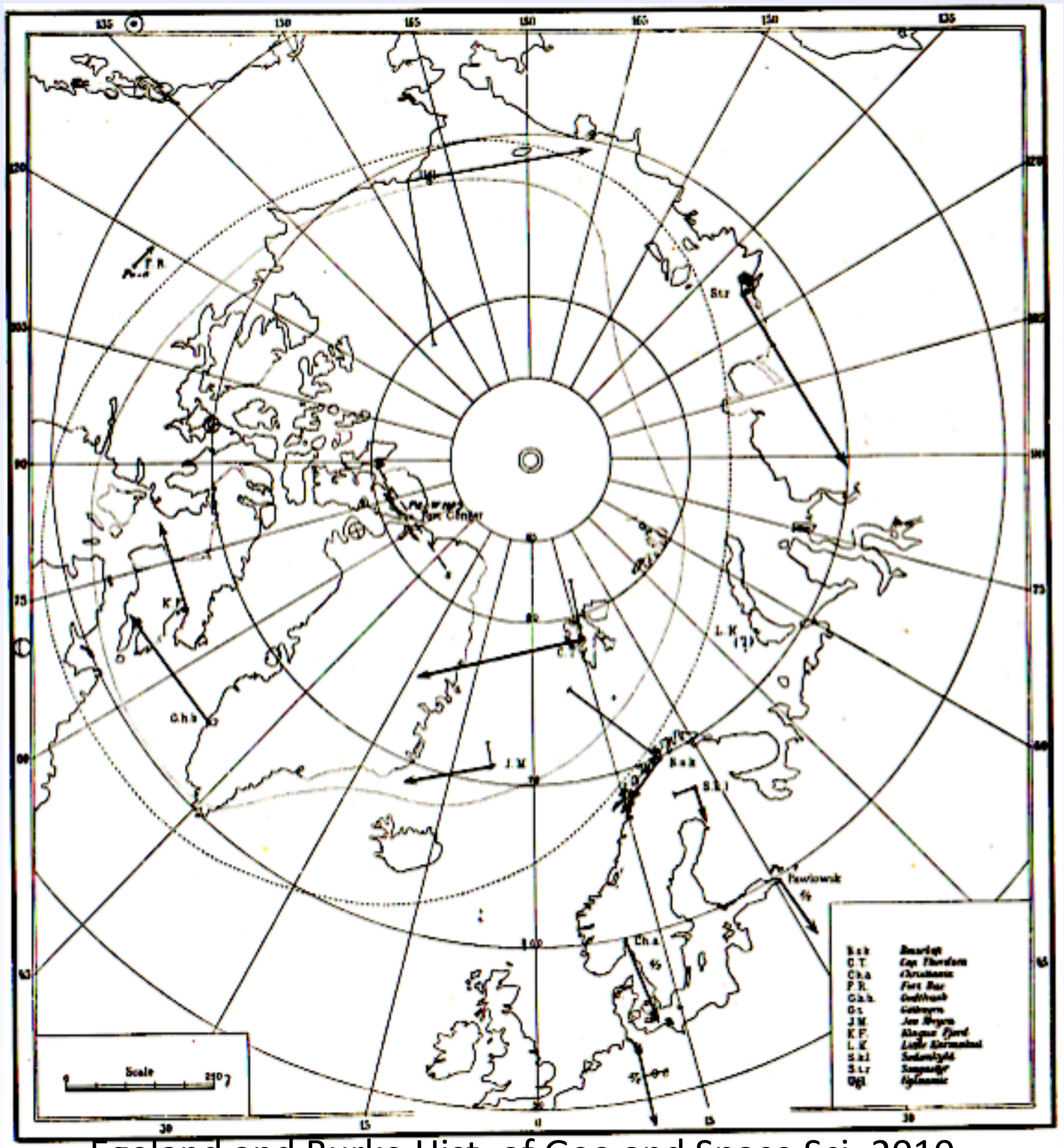
A Brief History of Space Physics

- A remarkable physical understanding of our space environment was developed solely with ground-based measurements.
- Disturbances in Earth's magnetic field were associated with auroral disturbances and also the appearance of sunspots (Halley 1716).
- Improvements in the magnetometer, deployed in expeditions, provided K. Birkeland, here in 1902, enough information to describe electrical currents associated with the aurora.

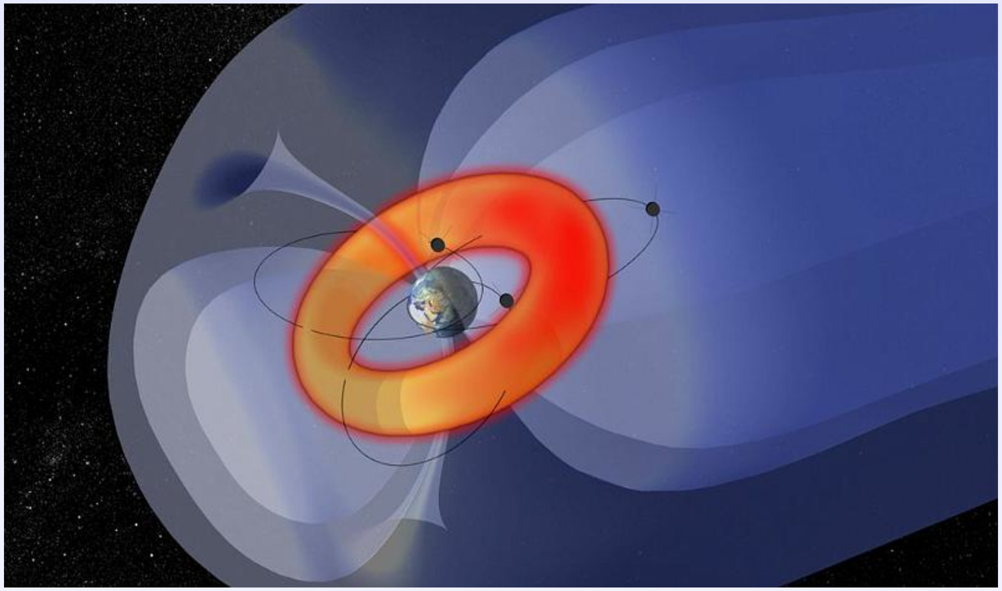
December 15, 1882, 21:05 UT

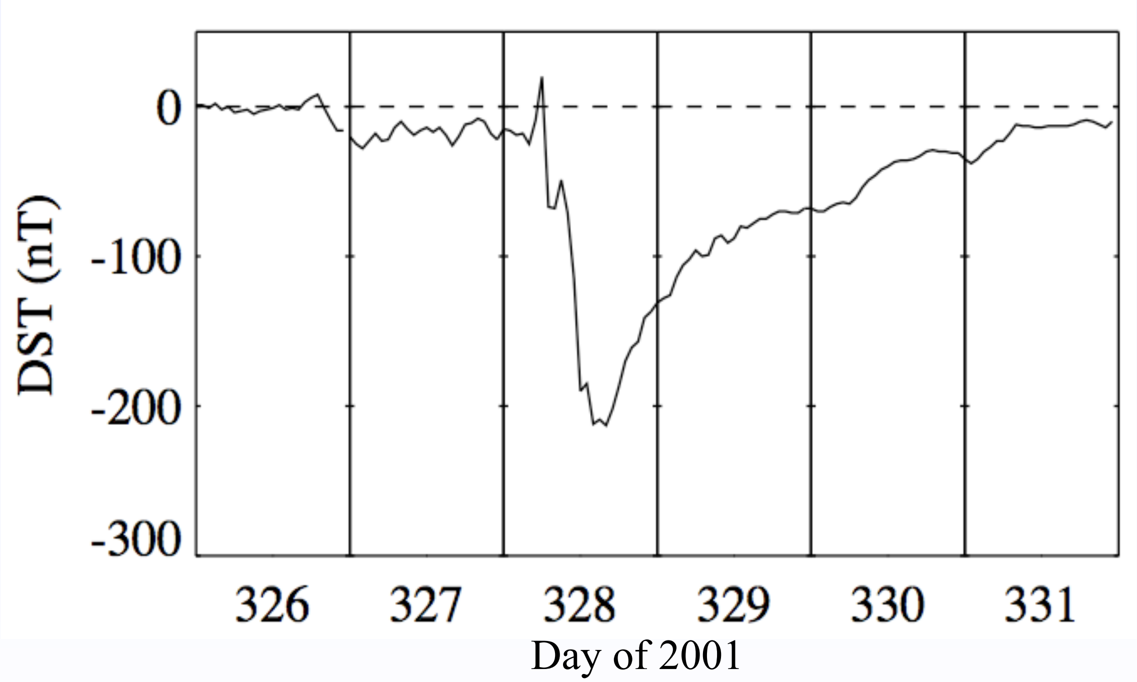


Egeland and Burke,Hist. of Geo and Space Sci.,2010.

A Brief History of Space Physics

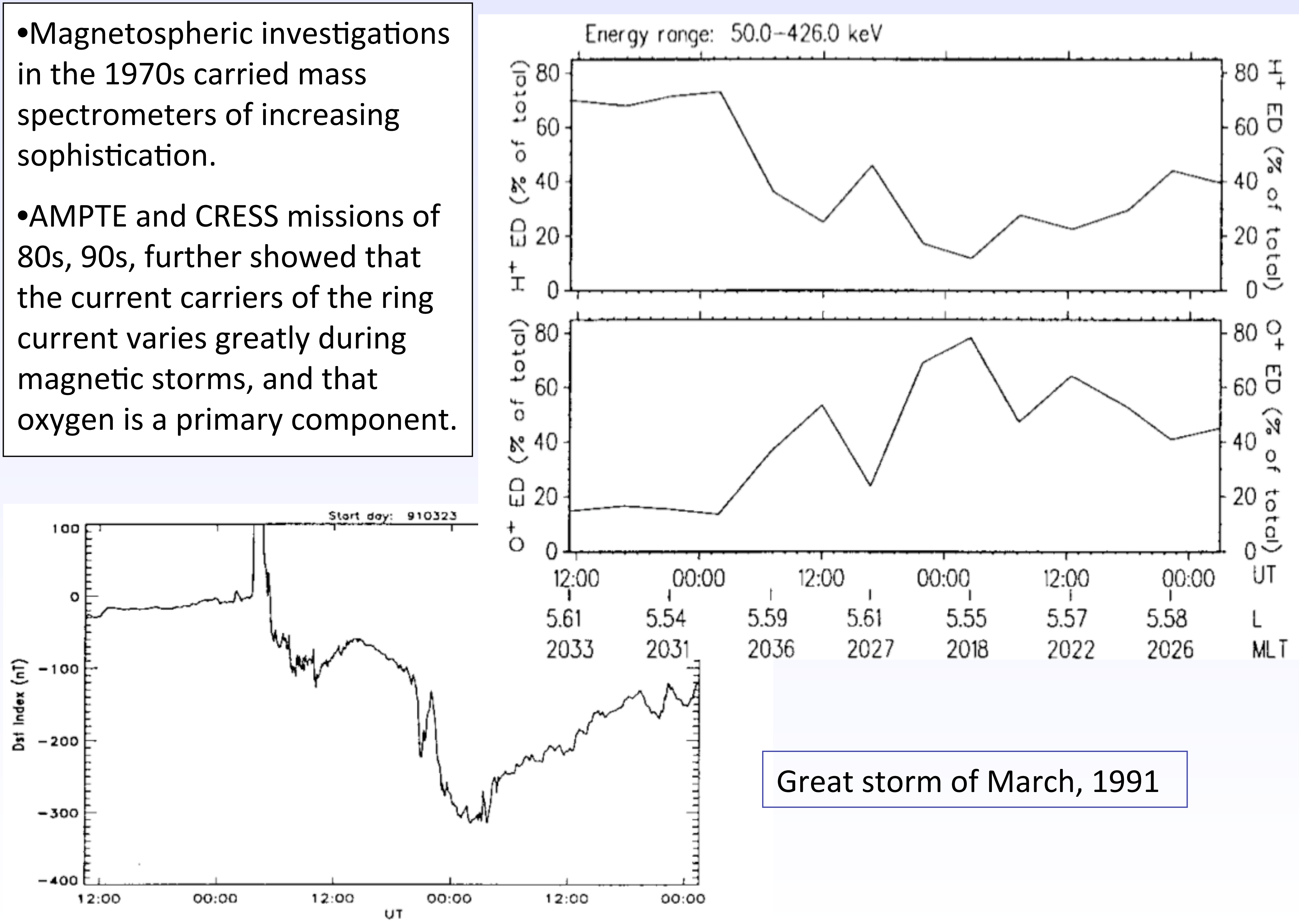
- The global scale of major magnetic disturbances at middle/low latitudes is due to the extraterrestrial disturbance current directed westward around the planet.
- Chapman and Ferraro described the ring current in 1941, supported by these observations, without knowing what its made of.
- Since the 1930s, magnetometer data have been collected with adequate calibration and longitudinal coverage to produce an hourly index of this current.





A Brief History of Space Physics

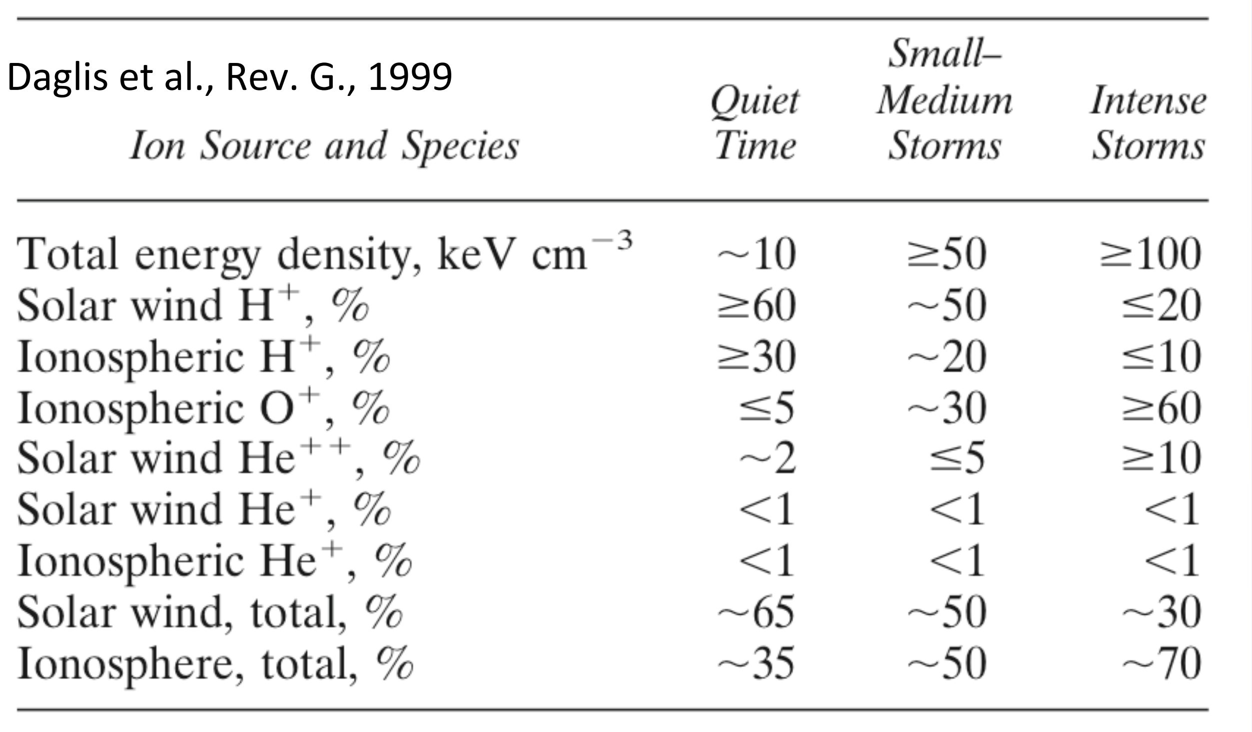
- Magnetospheric investigations in the 1970s carried mass spectrometers of increasing sophistication.
- AMPTE and CRESS missions of 80s, 90s, further showed that the current carriers of the ring current varies greatly during magnetic storms, and that oxygen is a primary component.



Great storm of March, 1991

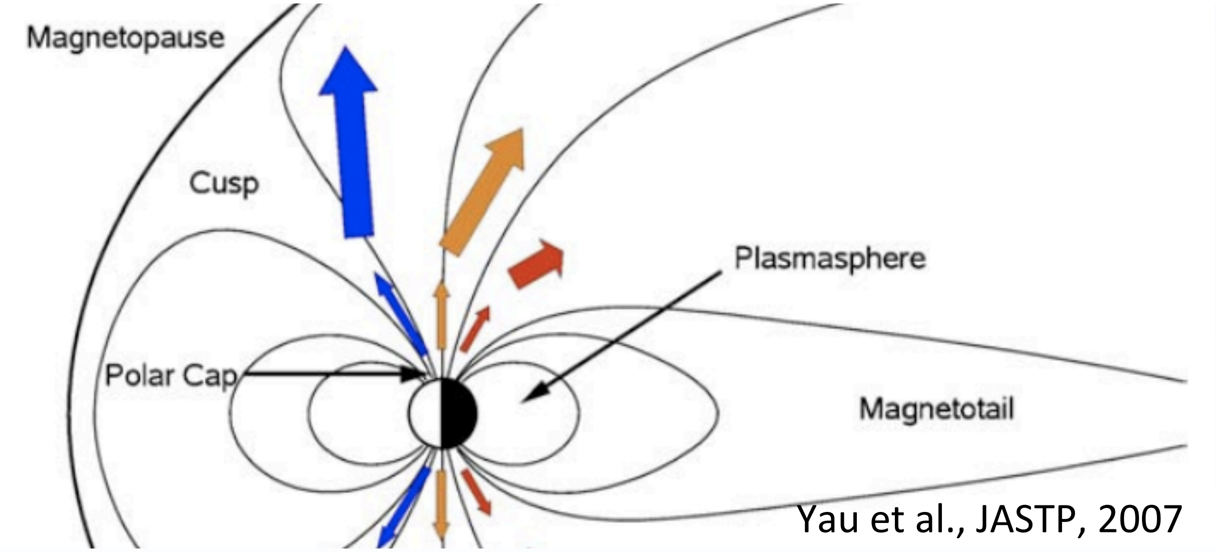
A Brief History of Space Physics

- Magnetospheric investigations in the 1970s carried mass spectrometers of increasing sophistication.
- AMPTE and CRESS missions of 80s, 90s, further showed that the current carriers of the ring current varies greatly during magnetic storms, and that oxygen is a primary component.
- All this oxygen has its origin in Earth's ionosphere, which is primarily O+. Origin is clearly from the auroral oval, about twice as much coming from dayside as nightside.



Daglis et al., Rev. G., 1999

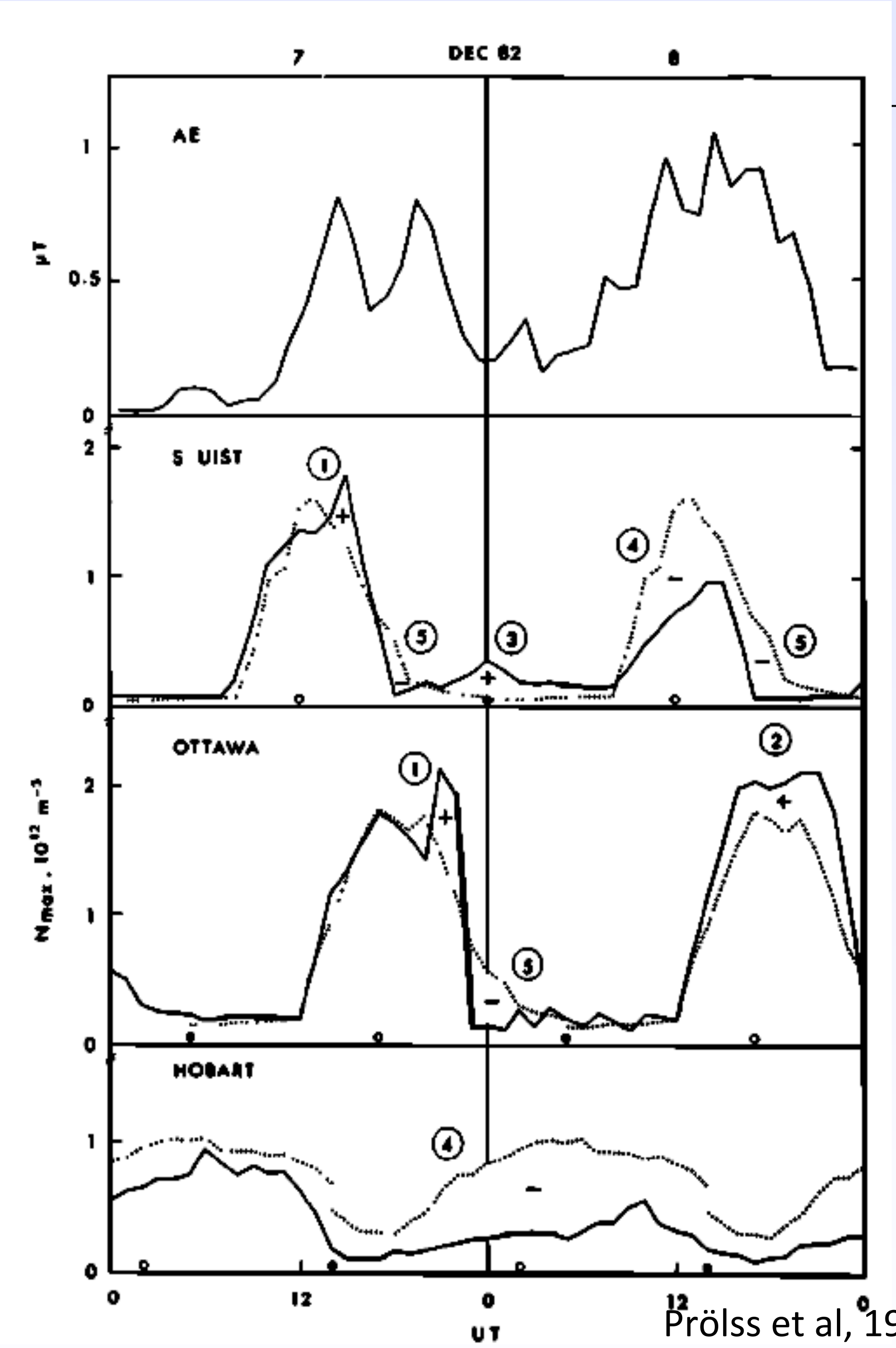
Ion Source and Species	*Quiet Time*	*Small–Medium Storms*	*Intense Storms*
Total energy density, keV cm^{-3}	~10	≥50	≥100
Solar wind H$^+$, %	≥60	~50	≤20
Ionospheric H$^+$, %	≥30	~20	≤10
Ionospheric O$^+$, %	≤5	~30	≥60
Solar wind He^{++}, %	~2	≤5	≥10
Solar wind He$^+$, %	<1	<1	<1
Ionospheric He$^+$, %	<1	<1	<1
Solar wind, total, %	~65	~50	~30
Ionosphere, total, %	~35	~50	~70



Yau et al., JASTP, 2007

A Brief History of Aeronomy

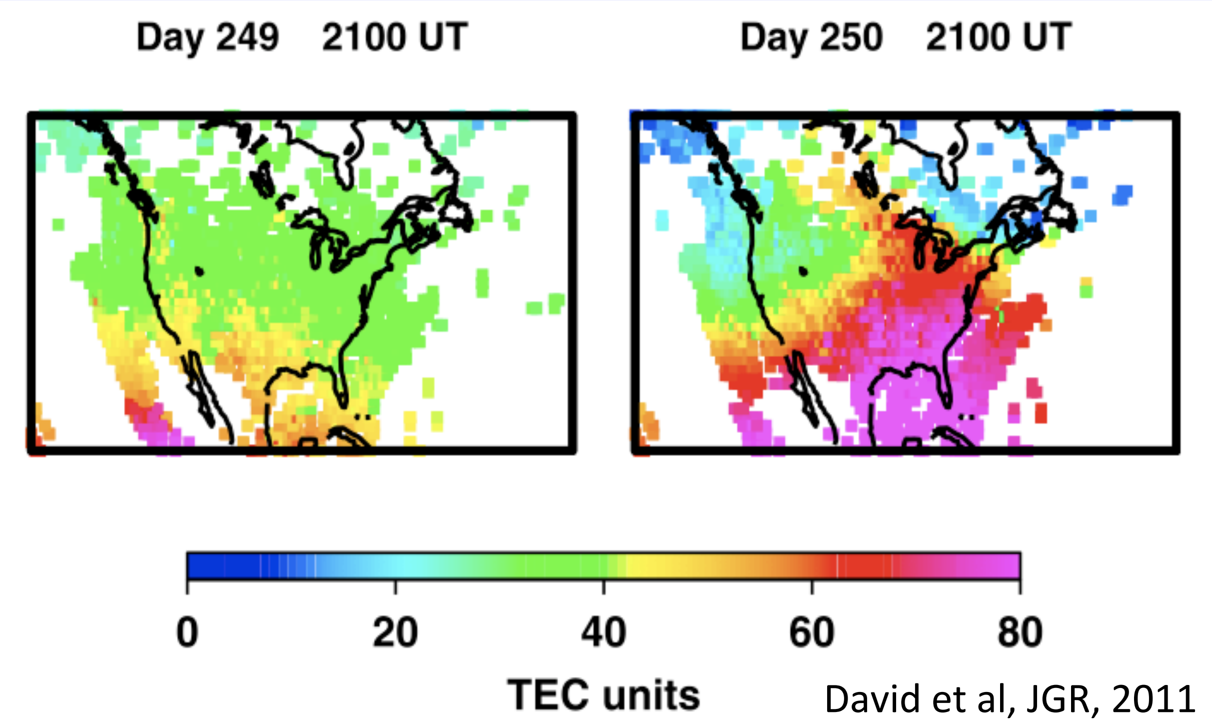
- Radio and radar gave scientists the first means of measuring the near-Earth plasma continuously.
- The theory of the ionosphere had been worked to the point that it was clear it was O+ well before anyone flew a rocket into it.
- Globally distributed ionosondes formed a picture of the dynamic storm-time ionosphere: initial positive phases followed by longer negative phases.



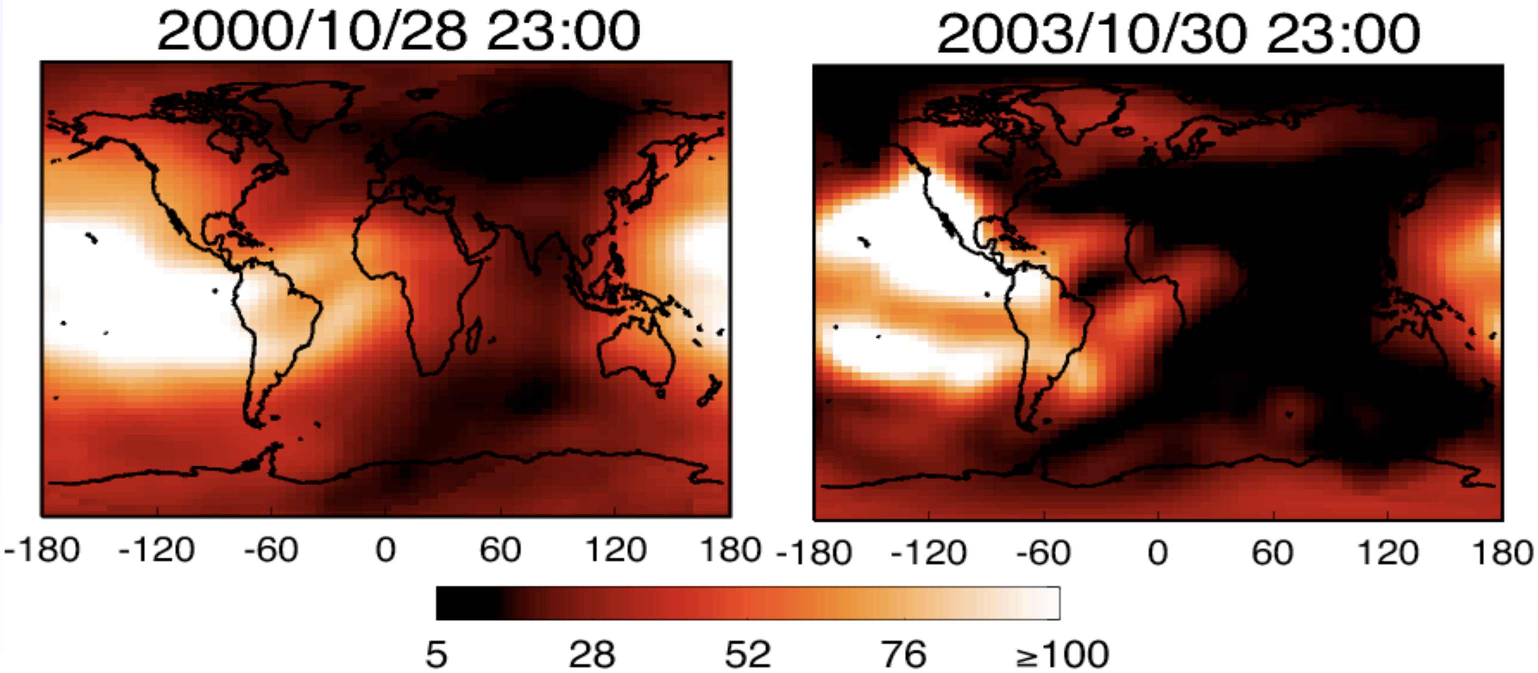
Prölss et al, 1991

A Brief History of Aeronomy

- The advent of radio occultation techniques allows for imaging of ionospheric total density in day and night.
- Positive phase now clearly seen to be highly structured.
- Global assimilative models provide GPS data on a regular grid, backed by empirical or physics models

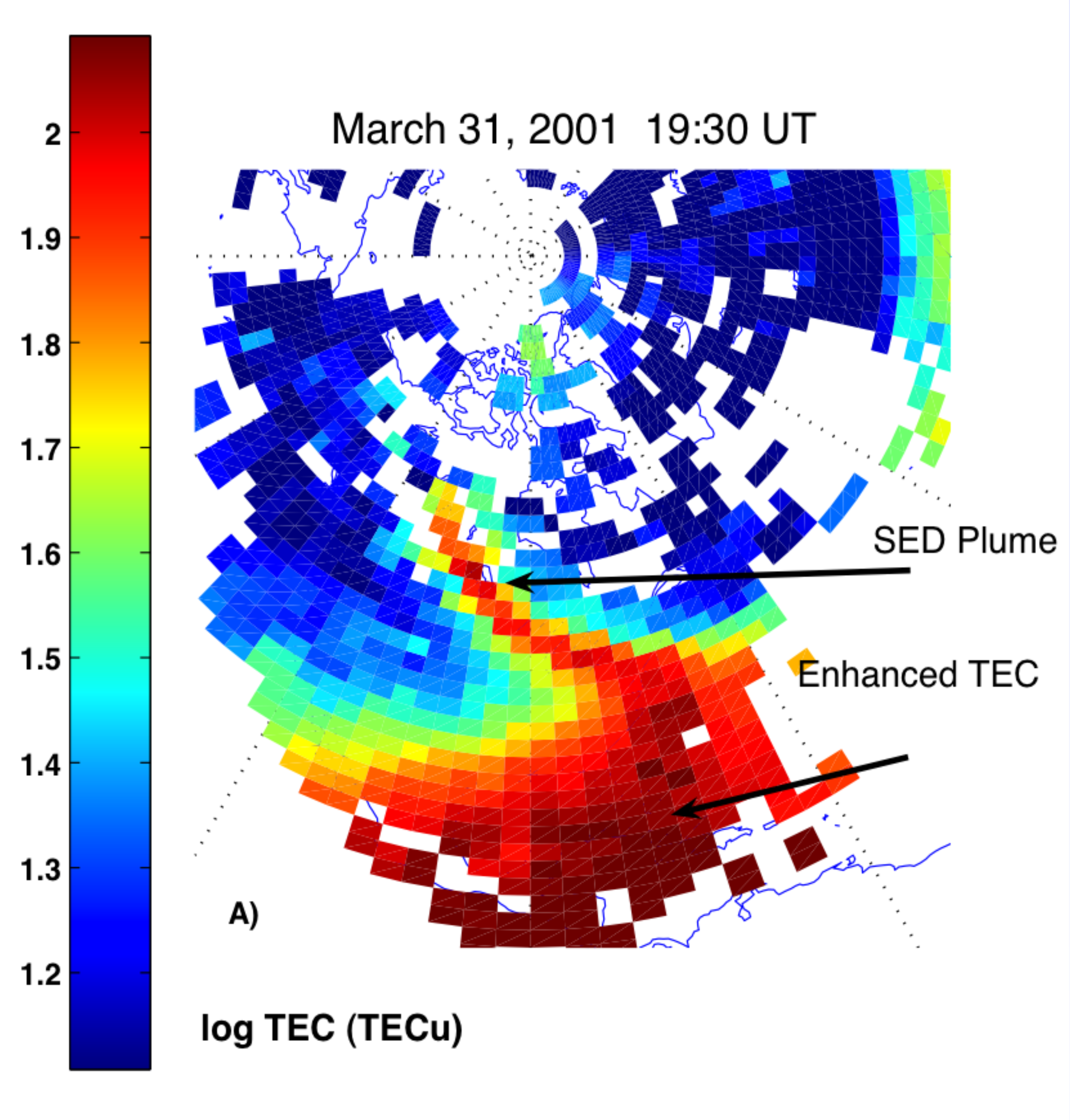


David et al, JGR, 2011



Aeronomy meets Space Physics

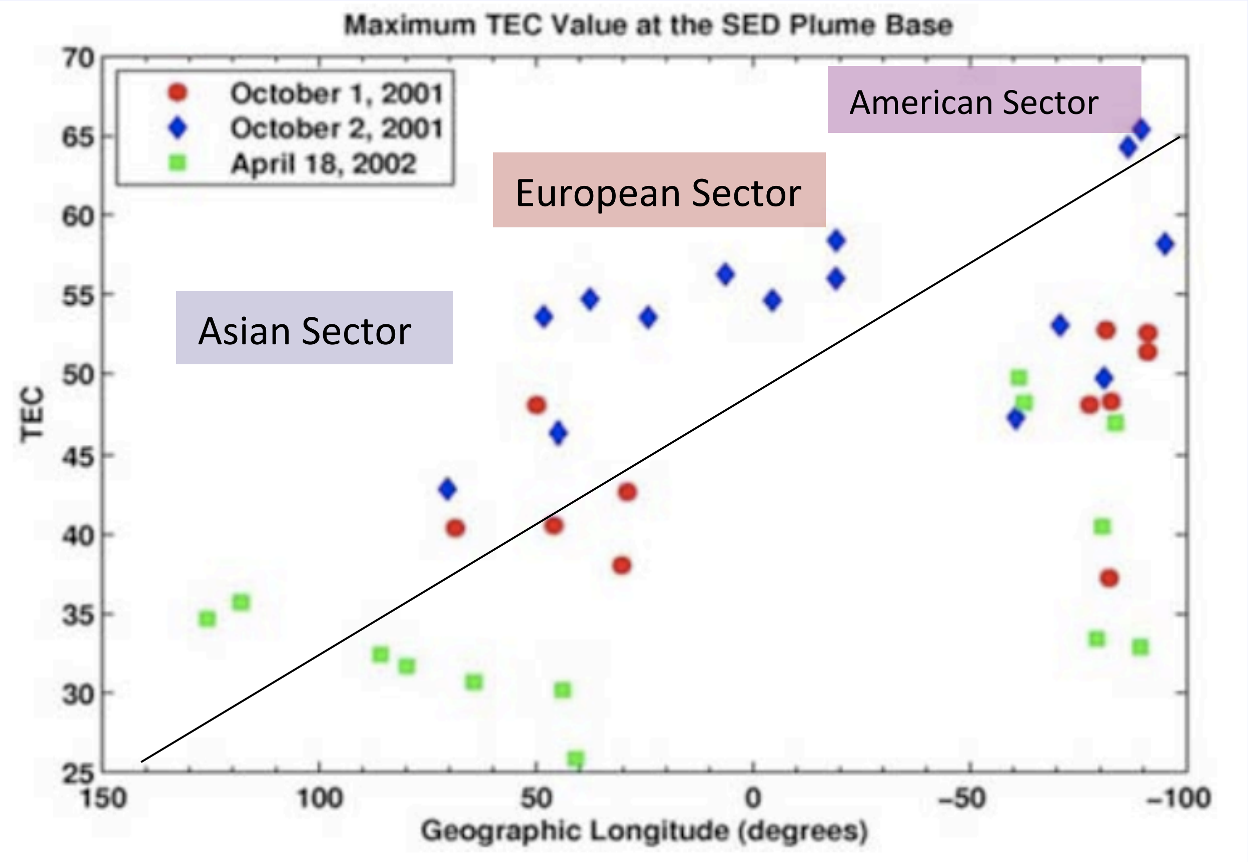
- Magnetospheric convection patterns expand during storms to put the ionosphere in motion.
- TEC "Plumes" extending to the auroral oval from middle latitudes transit the cusp.
- The cusp is the "hot spot" for O+ outflow
- The great local enhancement in O+ densities, boosted to higher altitudes & temperatures, is likely a very important factor in the O+ flux outbound.



From *Foster et al., Inner Magnetosphere Interactions : New Perspectives from Imaging, Geophysical Monograph Series, AGU, 2005*

Aeronomy meets Space Physics

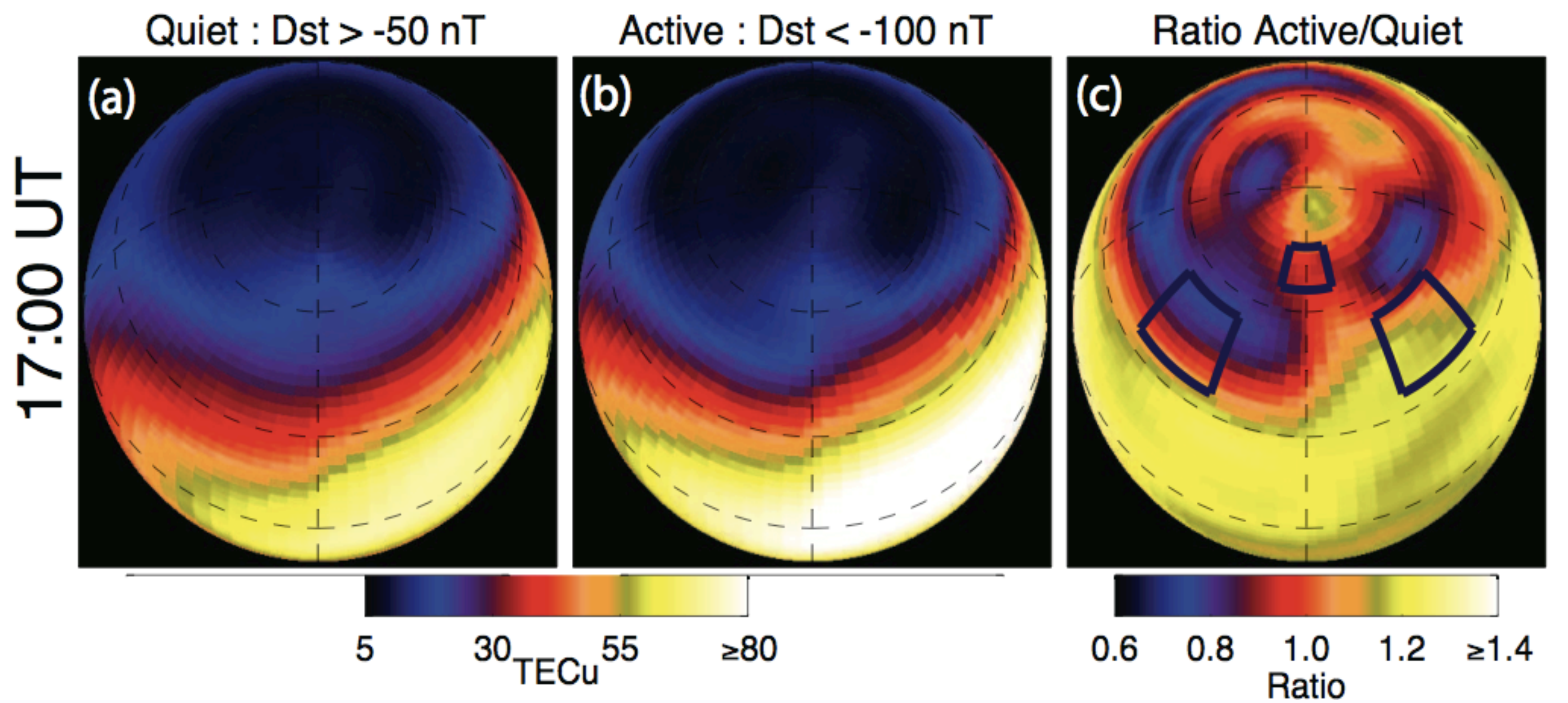
- Recent investigations describe a longitudinal dependence in the density and latitude of O+ plumes.
- If this affects the abundance of O+ in the cusp, then one might naturally expect longitudinal outflow dependence.
- Longitudinal dependence in outflow may have interesting consequences for Dst and magnetic storm strength.
- Let’s look.



Coster et al., GRL, 2007

Science Investigation Task 1: Quantify TEC Storm Effect

1) Sort all available JPL-TEC maps for the last solar maximum into quiet and active bins and determine the average TEC.
2) Determine the ratio of Active/Quiet for each UT (2 hour steps) in magnetic coordinates.
3) Track this ratio at middle latitudes (AM,PM) and in the cusp



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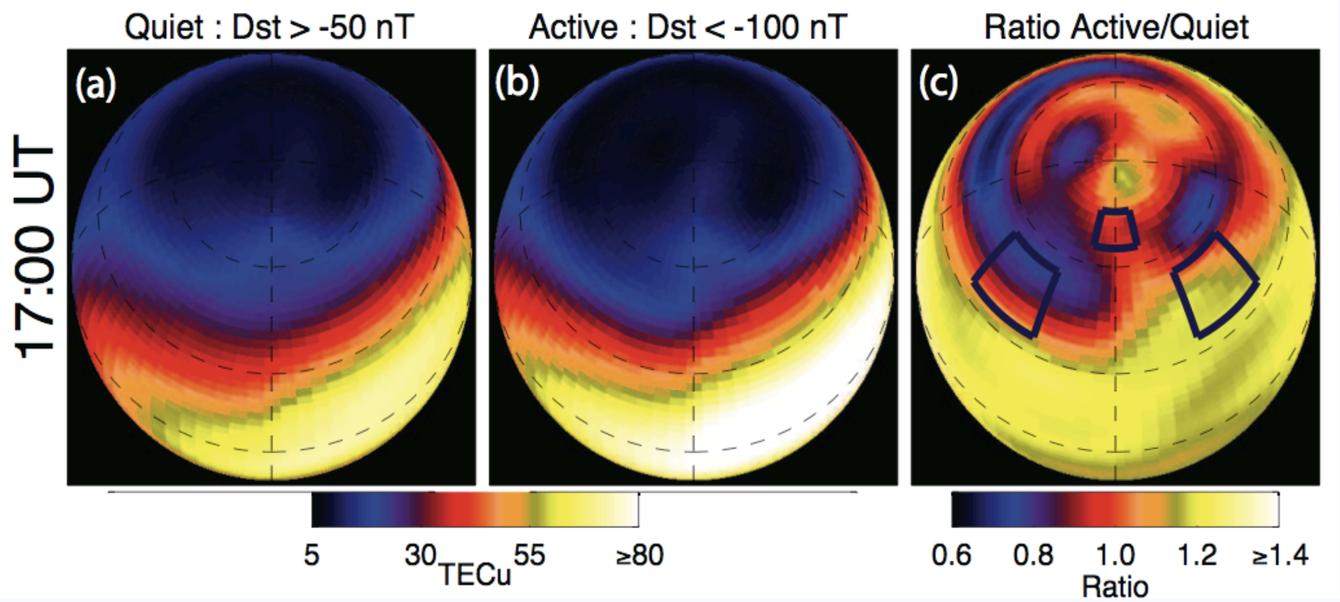
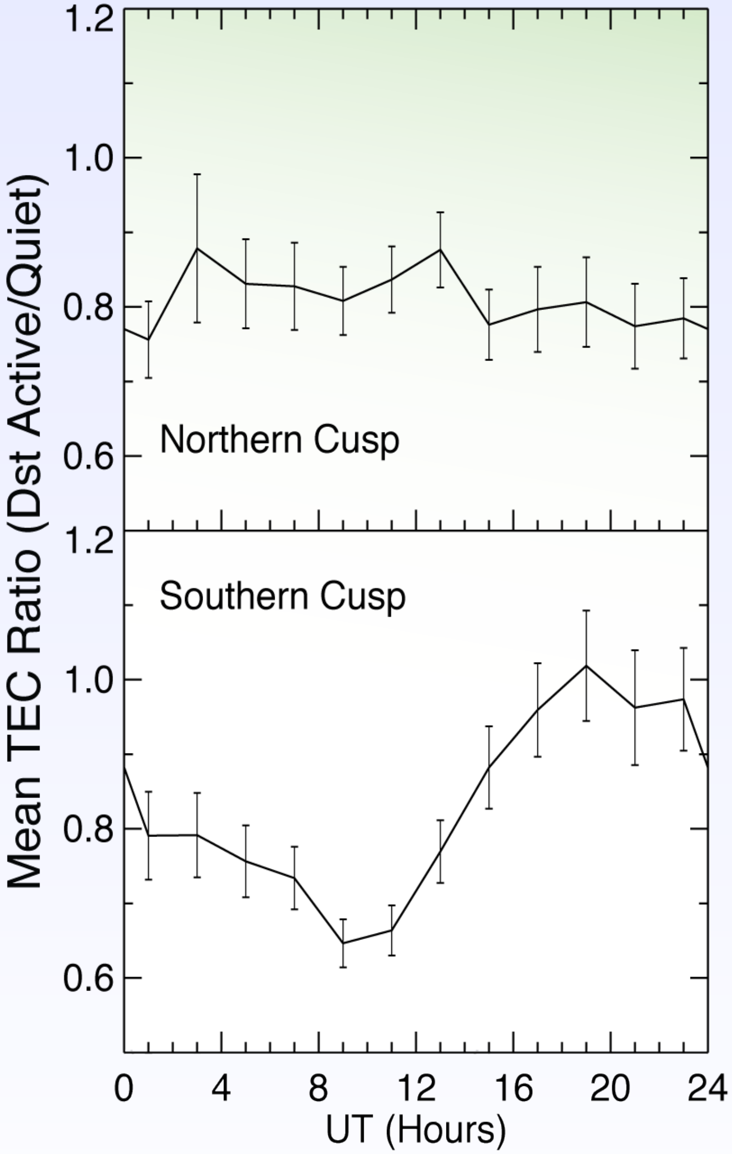
Science Investigation Task 1: Quantify TEC Storm Effect - Cusp

- Follow Active/Quiet TEC ratio in the cusp in northern, southern hemispheres.

Northern Hemisphere shows little variation.

Southern Hemisphere shows a remarkable 60% enhancement over lowest ratios.





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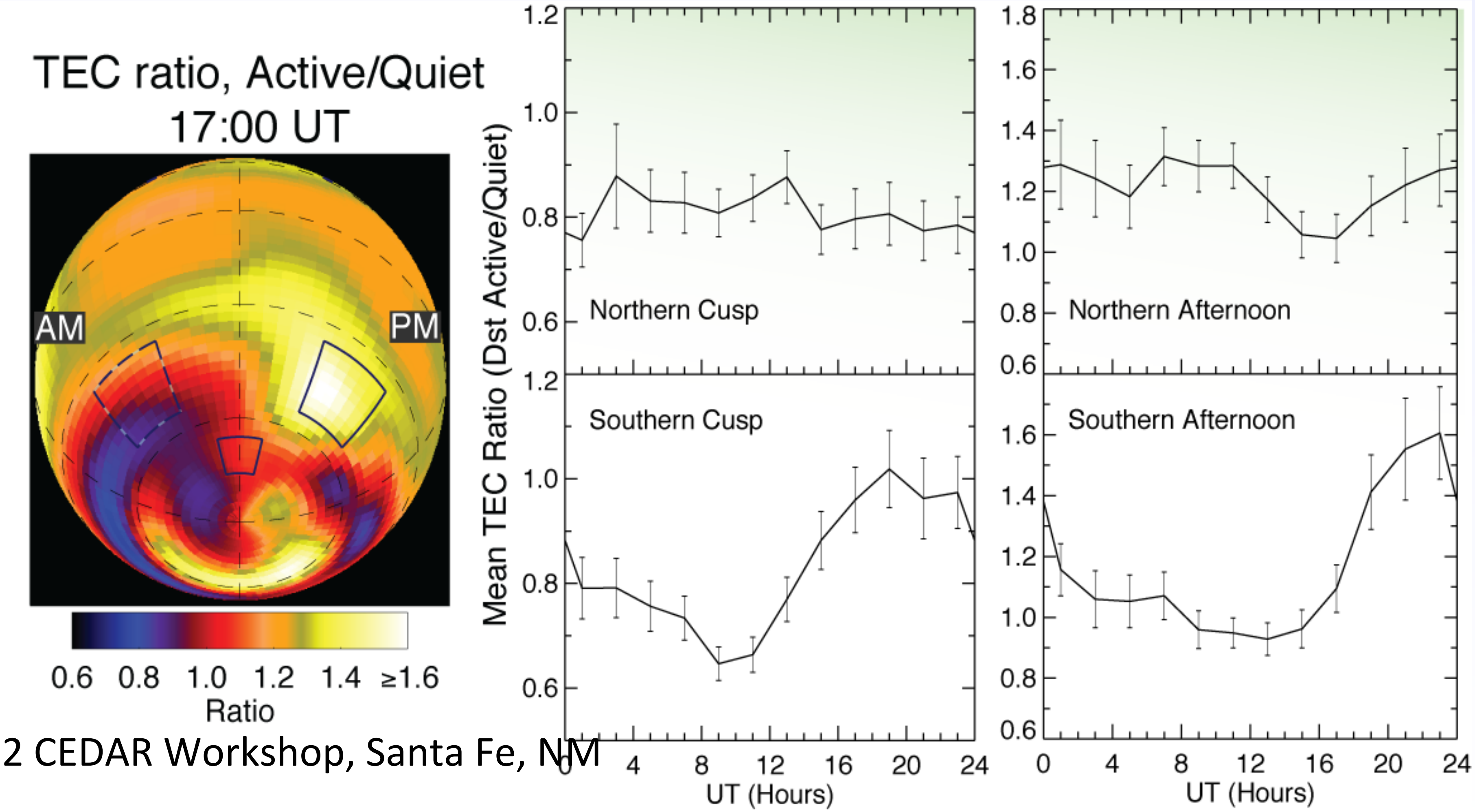
Science Investigation Task 1: Quantify TEC Storm Effect – Middle Lats

- Compare to middle latitudes, afternoon sector.

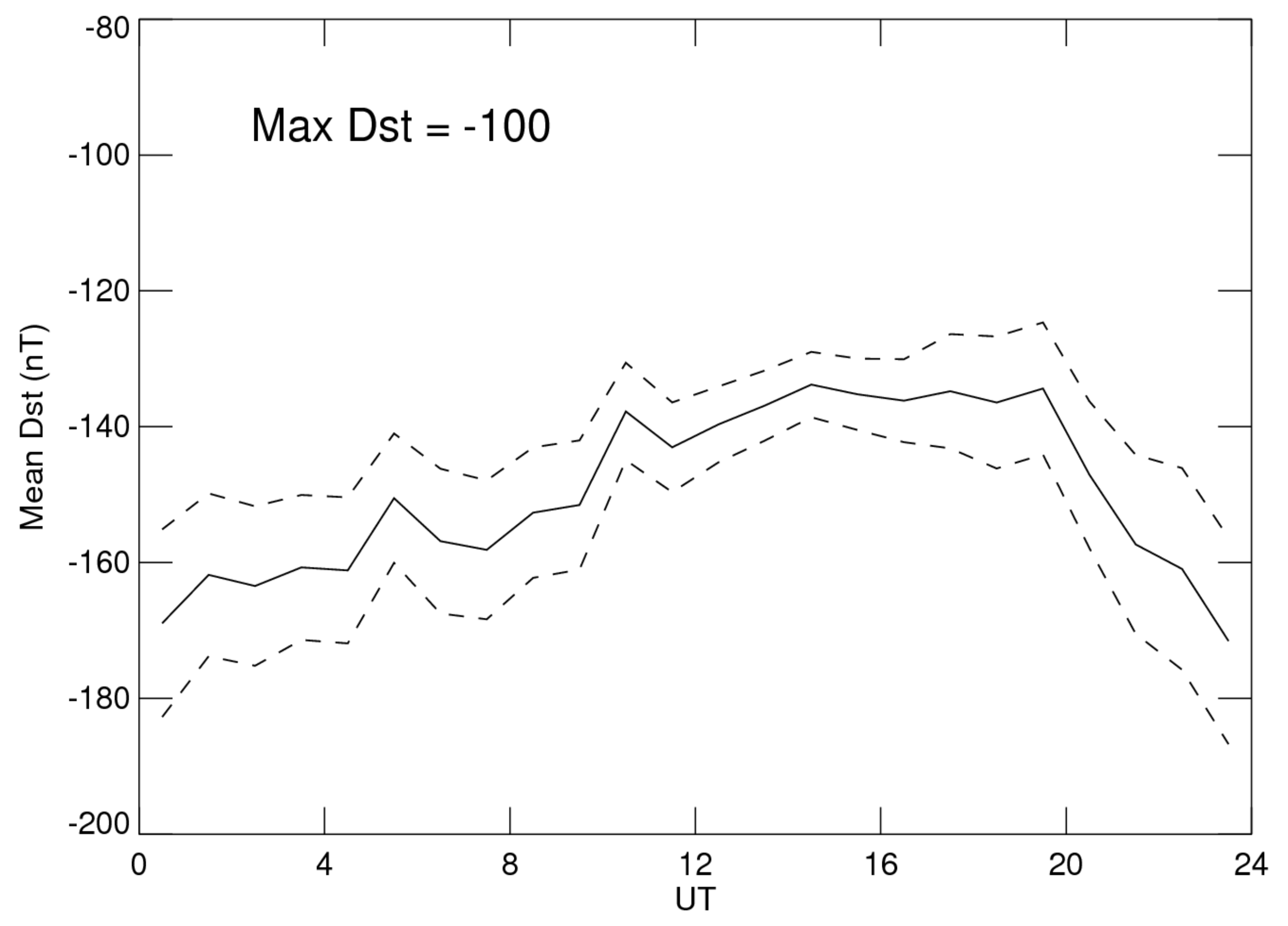
Northern Hemisphere shows more variation, about 30% enhancement between European and American sectors.

Southern Hemisphere again a remarkable 60% enhancement over lowest ratios.



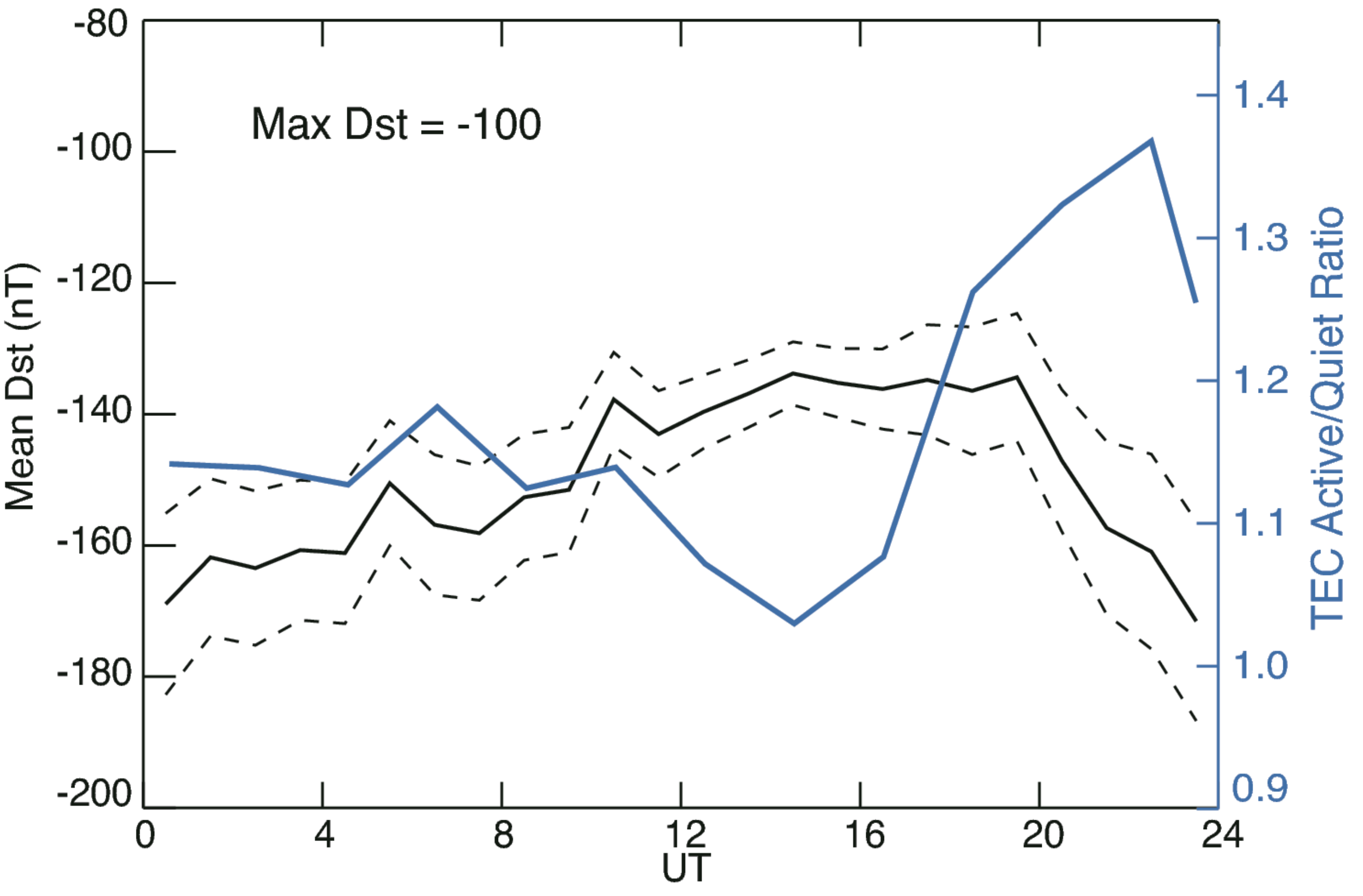
Science Investigation Task 2: Quantify Storm Dst Variability

- Collect all Dst data for active GPS times (Dst < -100 nT)
- Determine Mean Dst vs. UT : Find Minimum Dst (max Ring Current at 0 UT)



Science Investigation Task 3: Compare

- Anti-correlation of two data sets highest if Dst data are delayed 3 hours.
- A possible relationship between storm enhanced density and storm strength



Summary

- Characteristics, now “classic”, of SED and SAPS plumes are evident in average of stormtime (Dst < -100 nT) JPL TEC maps.
- Storm effects are most prominent in the 18-24 UT timeframe, and in the Southern Hemisphere.
- Question: Why not Northern Hemisphere? SAA connection?
- Another Question: Why the differences in the middle latitude and cusp signature timing?

Summary

- Mean Storm Dst during the same period shows a ~25 nT variation in anti-correlation with TEC variation.
- Delay in Dst minimum vs. TEC maximum is supportive of causative link.
- Observed longitudinal dependence in storm-enhanced density clearly a candidate to explain the storm variation

It gets more interesting for higher levels of Dst, here’s -125 nT

- If this were classic Russell-McPherron type effect, the effect in northern summer should be the weakest.
- Instead, it is the strongest.