Recent Studies of Multiscale Cold Plasma Dynamics and TIDs at Subauroral Latitudes

P. Erickson (1), L. Goncharenko (1), S. Derghazarian (1),
E. Aa (2), A. J. Coster (1), S.-R. Zhang (1)

(1) MIT Haystack Observatory
(2) National Space Sciences Center, Chinese Academy of Sciences

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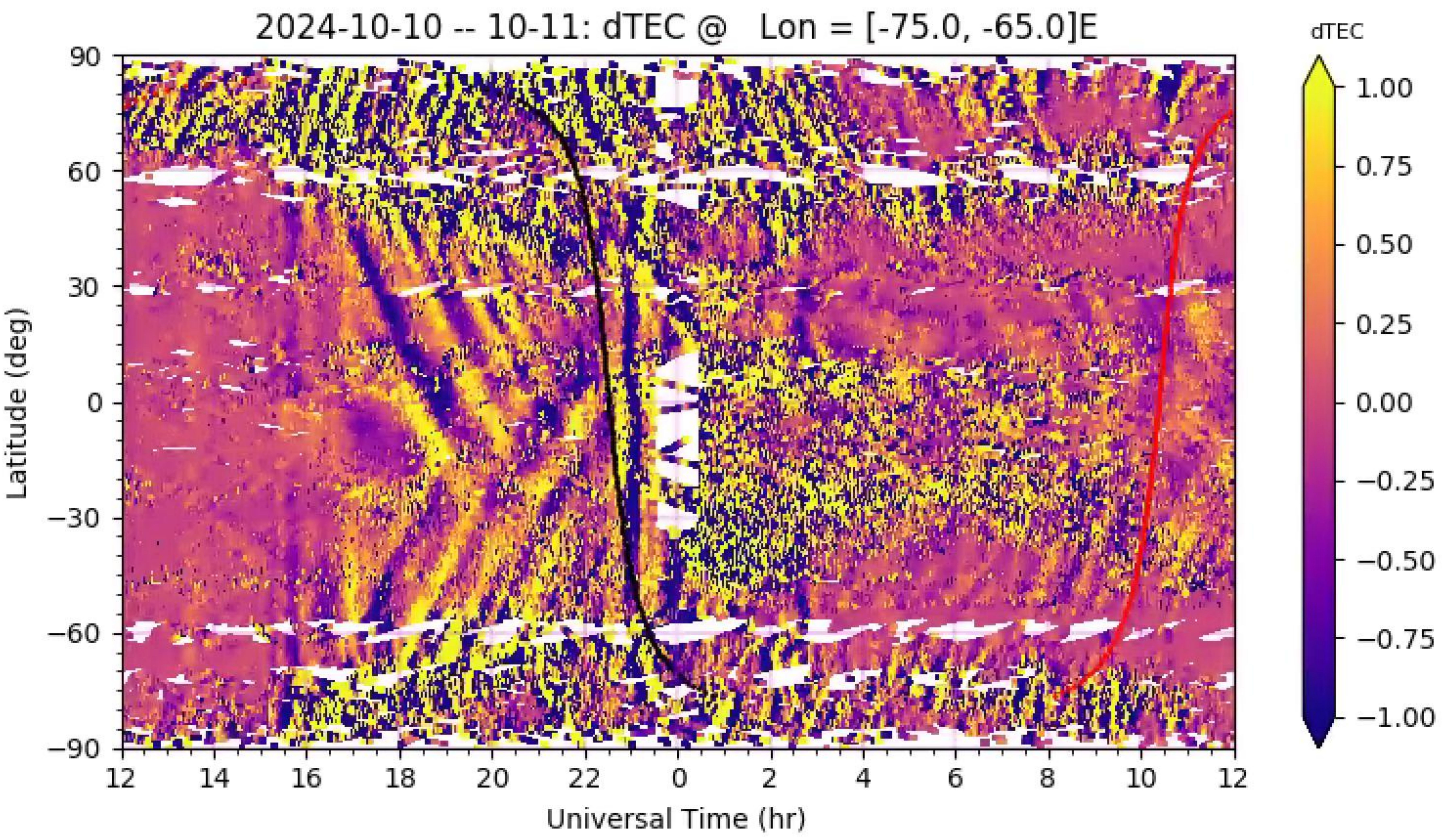
Common Diagnostic: Mid-latitude TIDs as viewed in Global TEC

MAPGPS product from NSF Millstone Hill Geospace Facility: 6000+ GNSS receivers, multi-constellation

Dense over e.g. CONUS

Subtract off background (typically with Savitzky-Golay filter)

TIDs are revealed



0.5 Million LOS TEC values in 5 minutes

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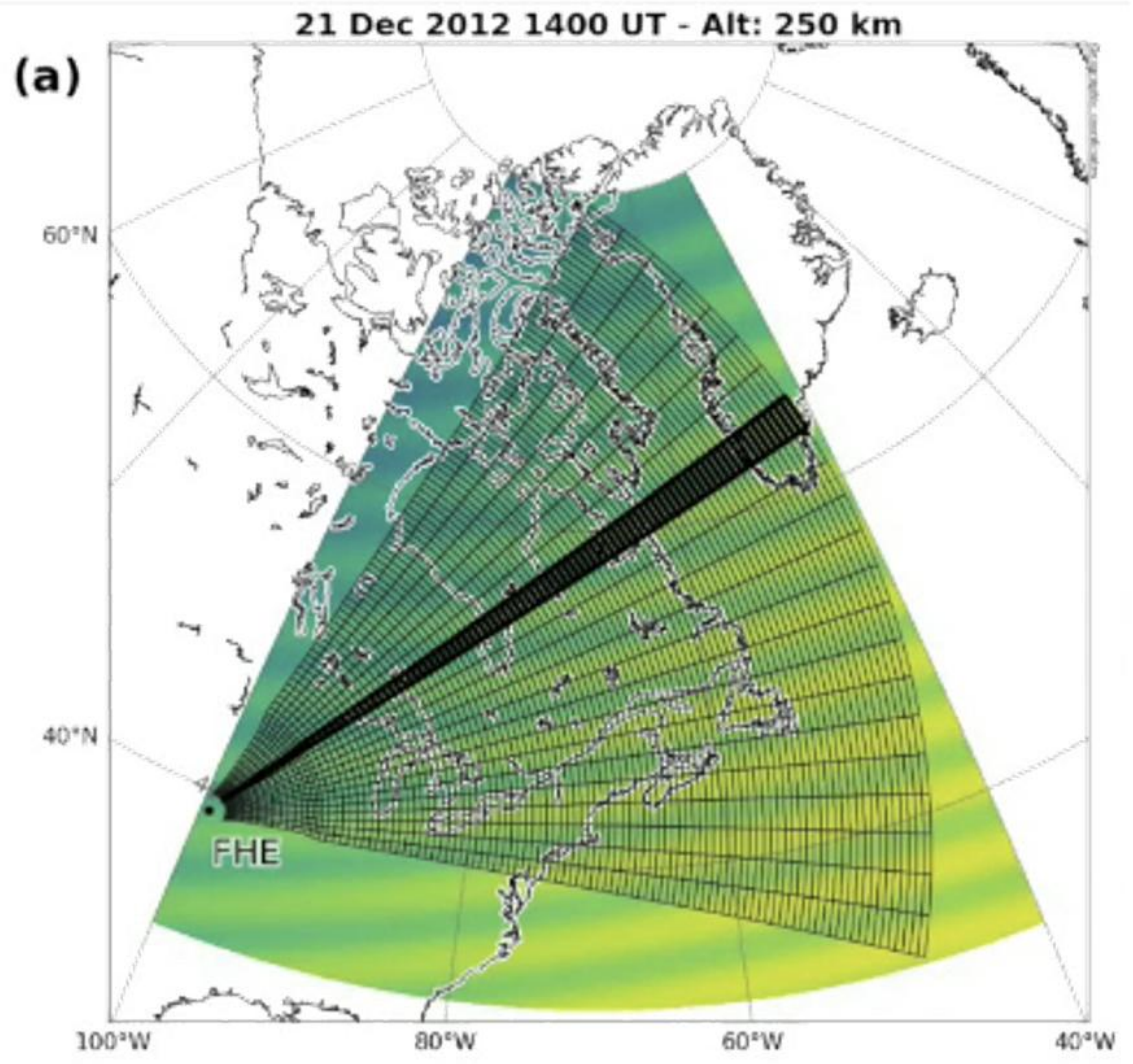
Traveling Ionospheric Disturbances

- **TIDs are Quasi-periodic Variations of F Region Electron Density**
- **Medium Scale (MSTID)**
  - $T \approx 15 - 60$ min
  - $v_H \approx 100 - 250$ m/s
  - $\lambda_H \approx$ Several Hundred km (< 1000 km)
  - May be associated with meteorological or auroral sources
- **Identifying the actual source can be difficult**
  - Originally attributed to auroral/geomagnetic activity
  - More evidence now suggesting neutral atmospheric origin/control

[Francis, 1975; Hunsucker 1982; Ogawa et al., 1967; Ding et al., 2012; Frissell et al., 2014; 2016]

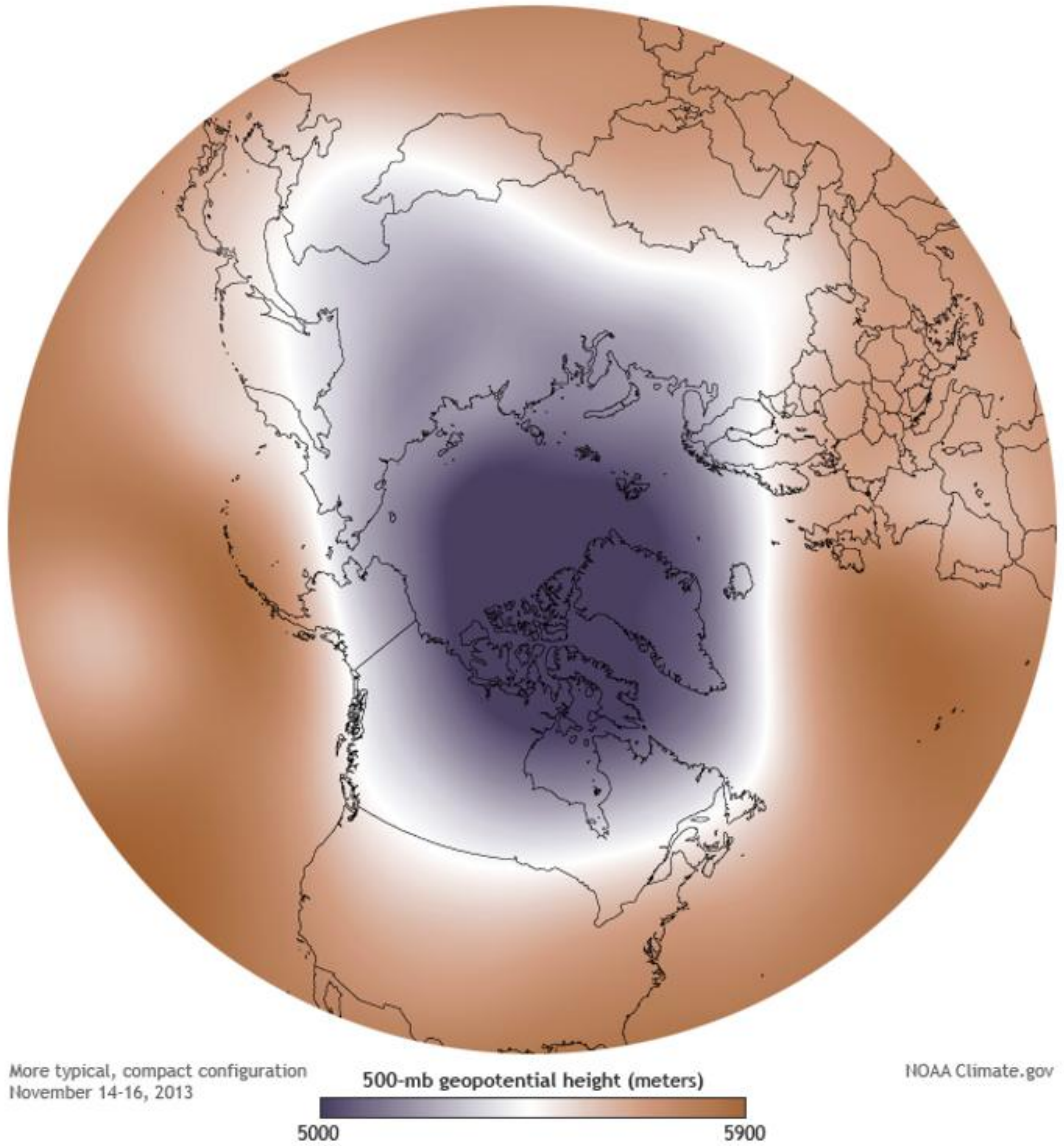


From *Frissell et al.* (2016).

THE UNIVERSITY OF SCRANTON A JESUIT UNIVERSITY
nathaniel.frissell@scranton.edu

Polar Vortex & Sudden Stratospheric Warmings

- Polar Vortex is a cyclonic winds system located on the polar regions in the stratosphere
- Driven by the increased temperature difference and is spun up by the Coriolis effect
- Occasionally SSWs break up the Polar Vortex
- This causes a reduction in Atmospheric Gravity waves



Polar Vortex Geopotential height mean
National Oceanic and Atmospheric Administration
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nathaniel.frissell@scranton.edu

S. Derghazarian[1], L. Goncharenko[1], V. L. Harvey[2] , A. Coster[1], S.-R. Zhang[1], C. E. Randall[2], G. Kwon[3]

Mid-Lat TIDs in Total Electron Content vs. Gravity Wave Activity

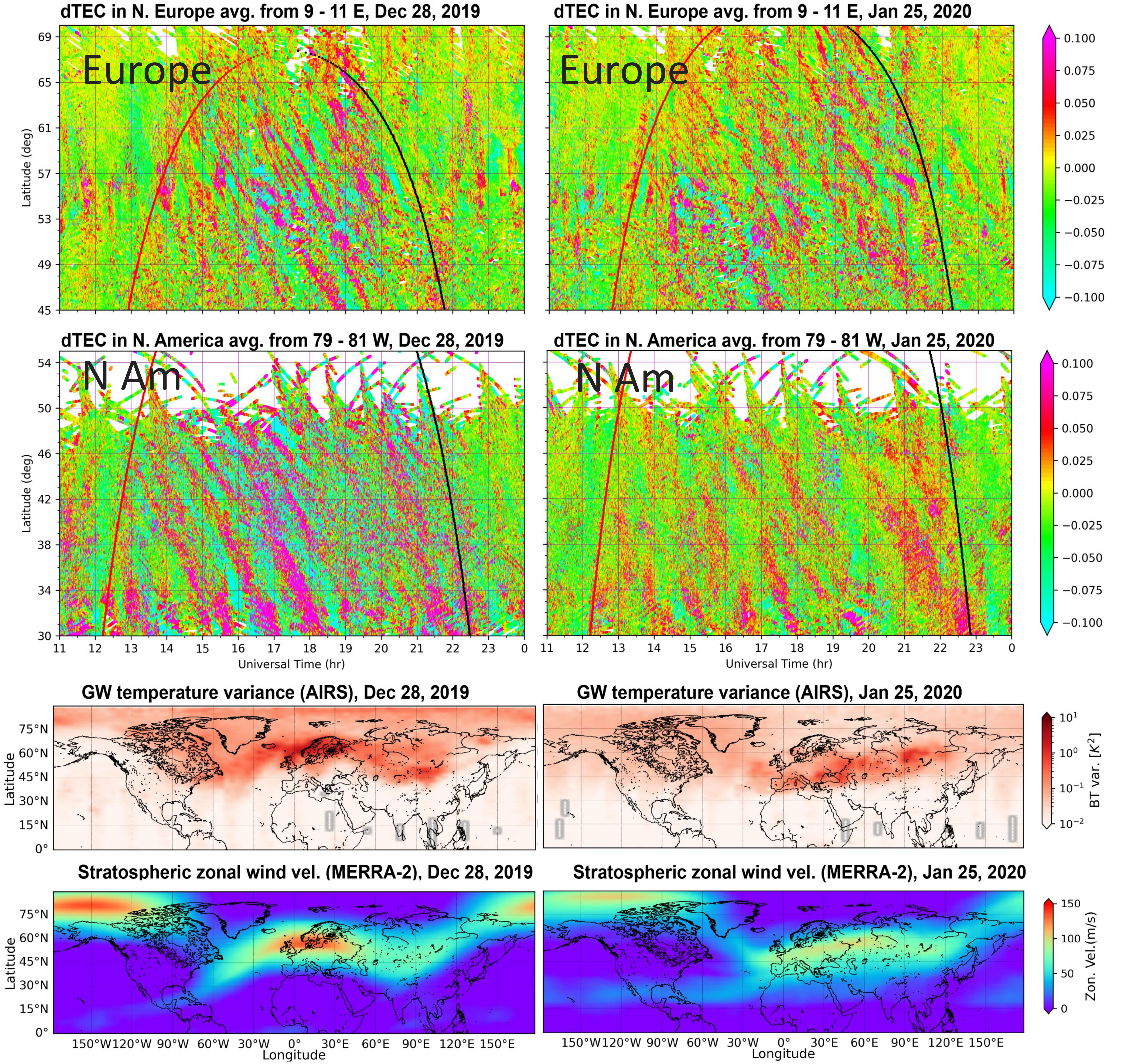
Relatively **weaker GW and wind velocities in northern Europe** on Jan 25, 2020 - compared to Dec 28, 2019 - correspond to **weaker daytime dTEC in midlatitude North America (but not Europe)**

Why?

GNSS: Differential TEC

AIRS: GW Temp.

MERRA-2: Stratospheric Wind



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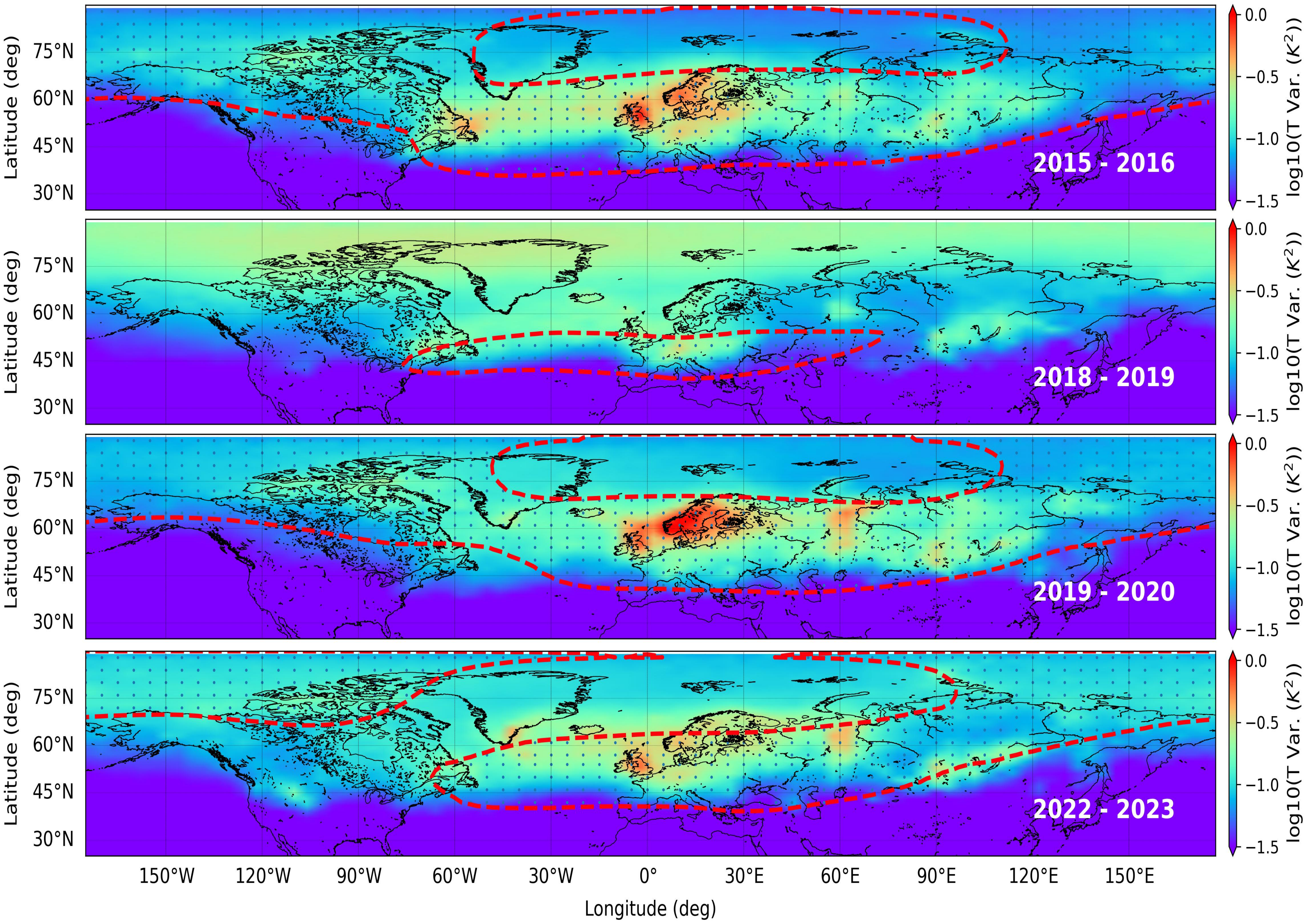
Averaged GW Activity

Wintertime: mean AIRS stratospheric GW variance poleward of 30 N

Dashed lines: wind velocities > 40 m/s at 35 km altitude

Consistent: GW is maximum in Europe - much lower amplitude over N America.

(cf previous slide)



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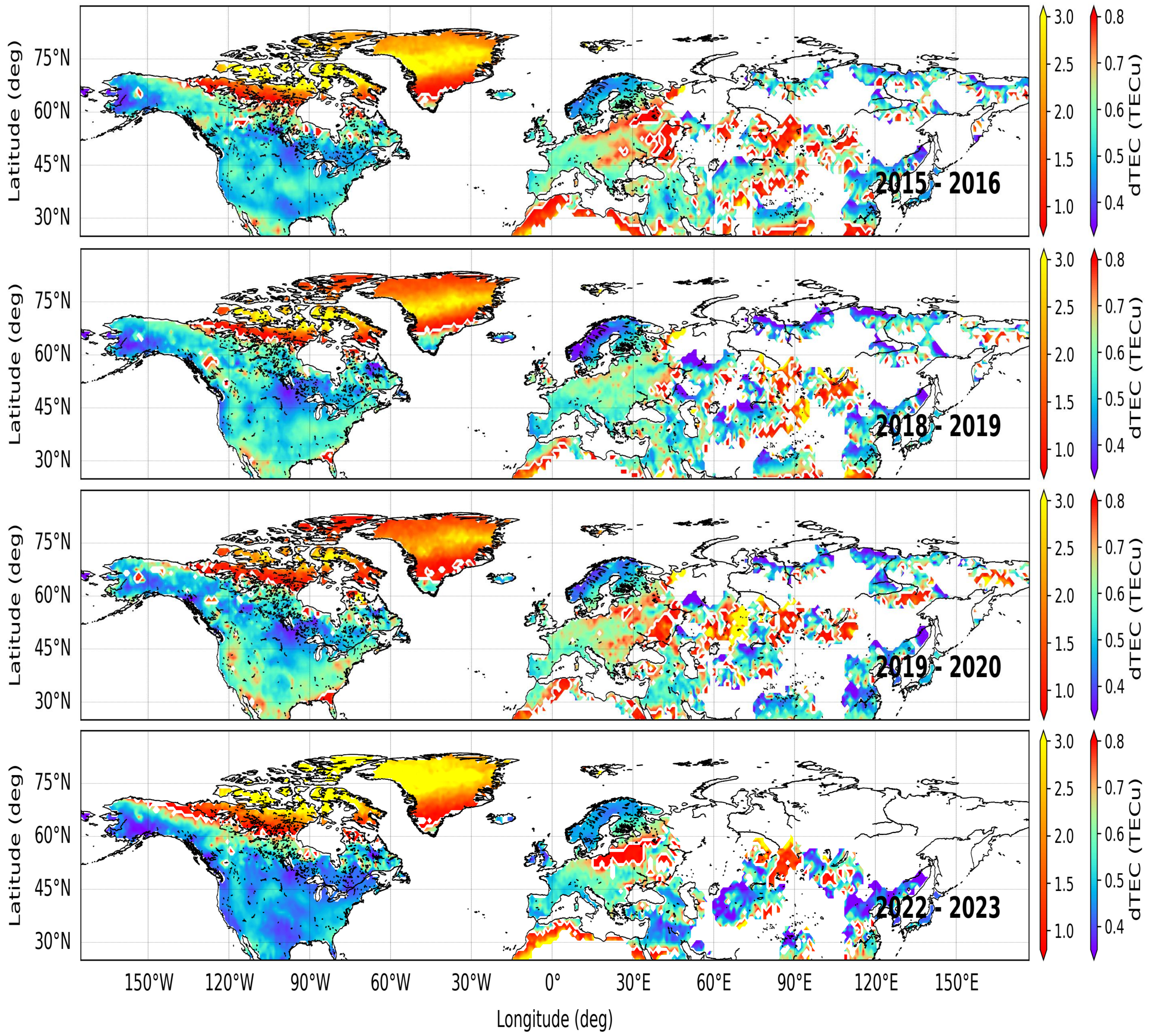

Averaged TID Amplitude from GNSS

(NB: High Latitudes have different color scales)

Blue separates High and Mid/Low lat

Winter averaged midlatitude dTEC does not show any obvious link with winter averaged GWs or winds..

<u>if</u> we compare at the same geographic position.

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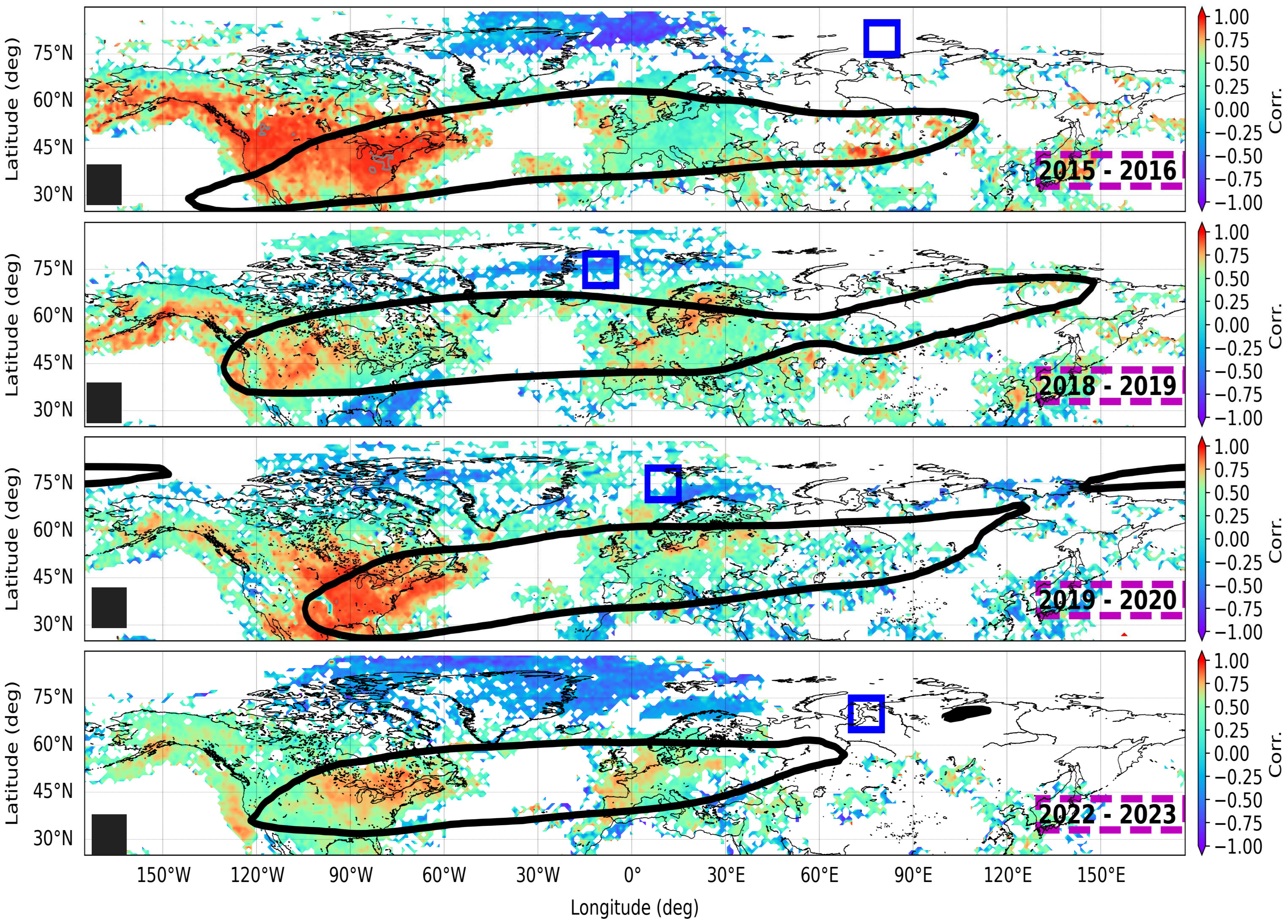
Non-local correlations between stratospheric GWs in eastern polar sector and MSTIDs



Now look for non-local correlations.

Select GW at blue squares (polar): Correlate with TIDs everywhere.

[1,-1] = [GW pos corr, neg corr]

Black contours = maximum polar night jet (PNJ) in mesosphere (not emphasized here)

Non-local correlation maximizes between polar GW and mid-latitude N American TIDs

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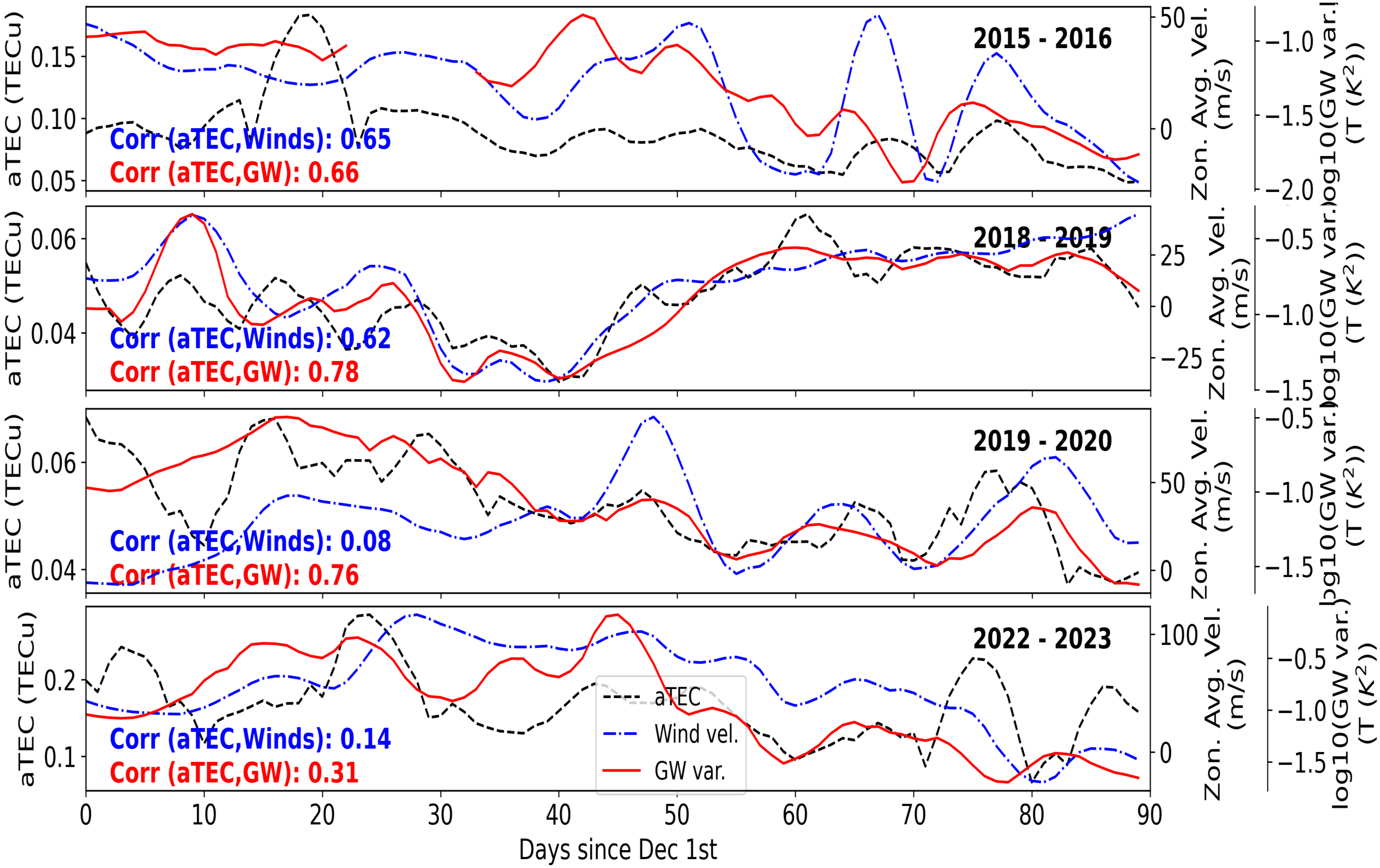
Strong <u>non-local</u> correlations between stratospheric GWs in <u>eastern polar sector</u> and MSTIDs in <u>N America</u>

Stratospheric GWs are strongly correlated with MSTIDs in North America from all regions poleward of the PNJ southwestward tilt (not described here)

Strong correlations with MSTIDs are most pronounced in North America which is encompassed by the mesospheric PNJ and southwestward of the GWs



Strong correlations between all time series [GW <-> TIDs] can be seen for periods longer than 10 days

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S. Derghazarian[1], L. Goncharenko[1], V. L. Harvey[2], A. Coster[1], S.-R. Zhang[1], C. E. Randall[2], G. Kwon[3]

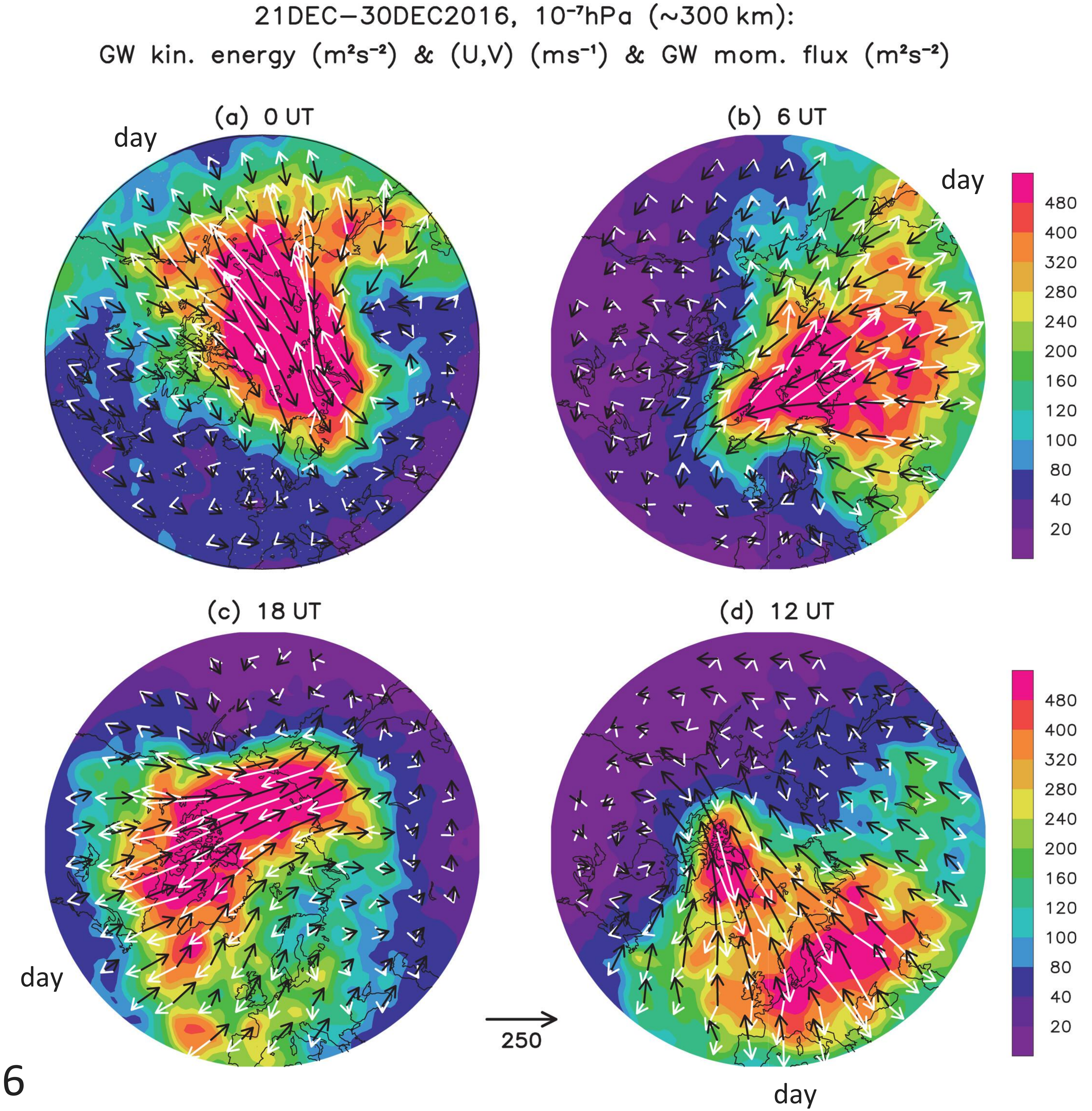
Theoretical mechanisms using HIAMCM

Daily cycle of GWs in the thermosphere during strong polar vortex is strongly affected by thermospheric wind

GW amplitude maximum extends northwestward to polar latitudes (morning hours LT)

Maximum GWs (and consequently, TIDs) are seen during local daytime:

- Tidal flow strongly poleward
- GW momentum flux ~equatorward



Becker et al (2002)
doi:10.1029/2022JA030866

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Summary: Cold Plasma and TID Dynamics at Mid-Latitudes

GW / TID correlations:

- TIDs have strong non-local response to GW / polar vortex configurations
- The correlation is persistent and points to substantial GW influence on TIDs

Oct 2024:

- Prompt ionospheric responses at mid- and low latitudes on both dayside and nightside to the arriving interplanetary shock and also during IMF Bz sudden changes in orientation
- Storm enhanced density (SED) at subauroral latitudes developed during the early stage of storm phases, and polar cap tongue of ionization (TOI) occurred at a later time. Their time relationship implies possible contributions from SED to TOI

Multi-technique / multi-messenger data is central to insight

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Session ST2.6 Multiscale Solar-Wind-Magnetosphere-ionosphere Interactions: Insights from Observations and Simulations

Mon, 28 Apr, 14:00–17:55 (CEST) Room 0.94/95

Global ionospheric disturbances during the 10-11 Oct 2024 superstorm

Shun-Rong Zhang,

Phil Erickson,

Anthea Coster

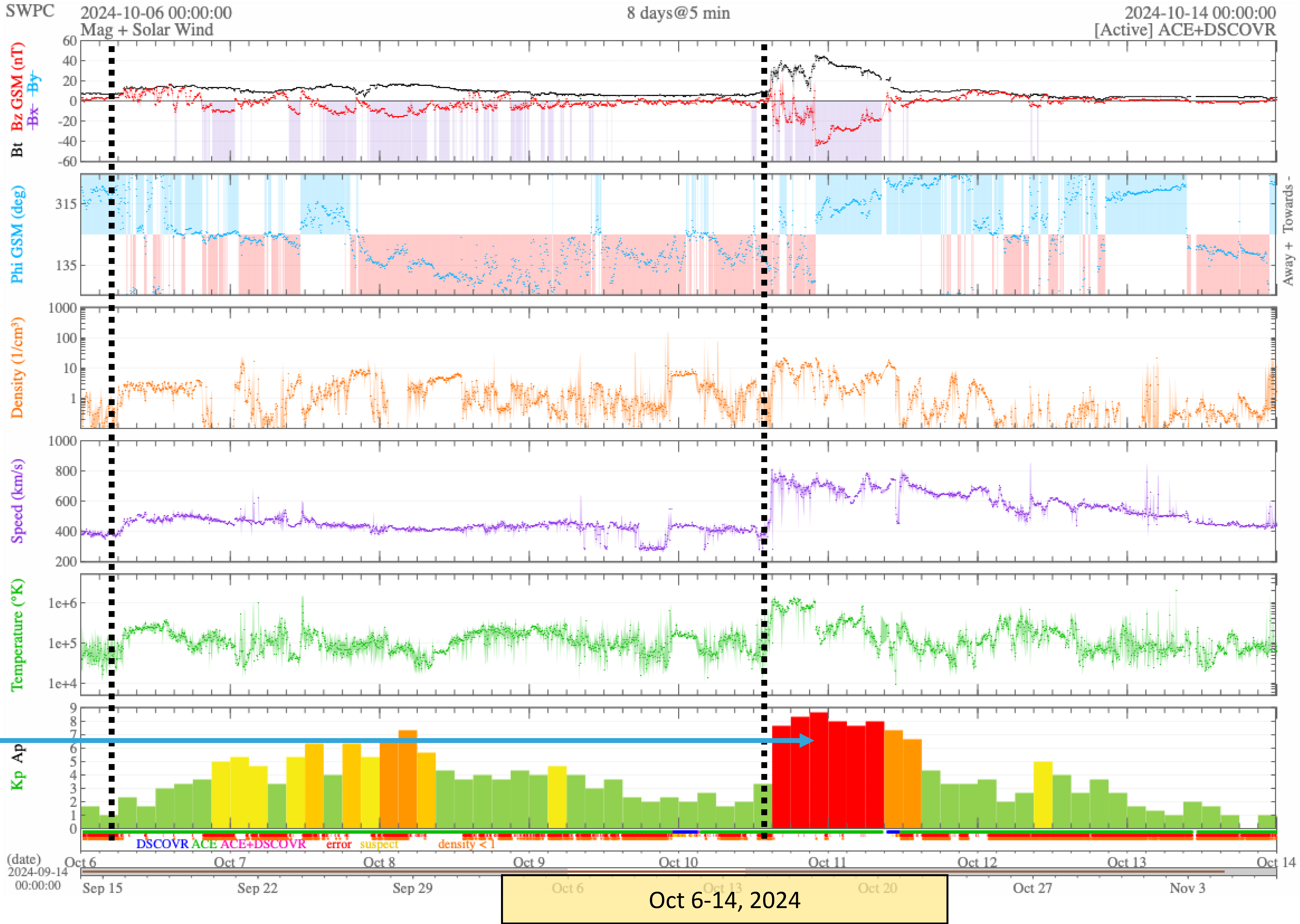
Larisa Goncharenko

MIT Haystack Observatory

Oct 6-14, 2024 International Observational Campaign

Solar Flares

- **X7 Oct 1**
- **X9 Oct 2**
  - **Slow CME**
- **CME on Oct 8**



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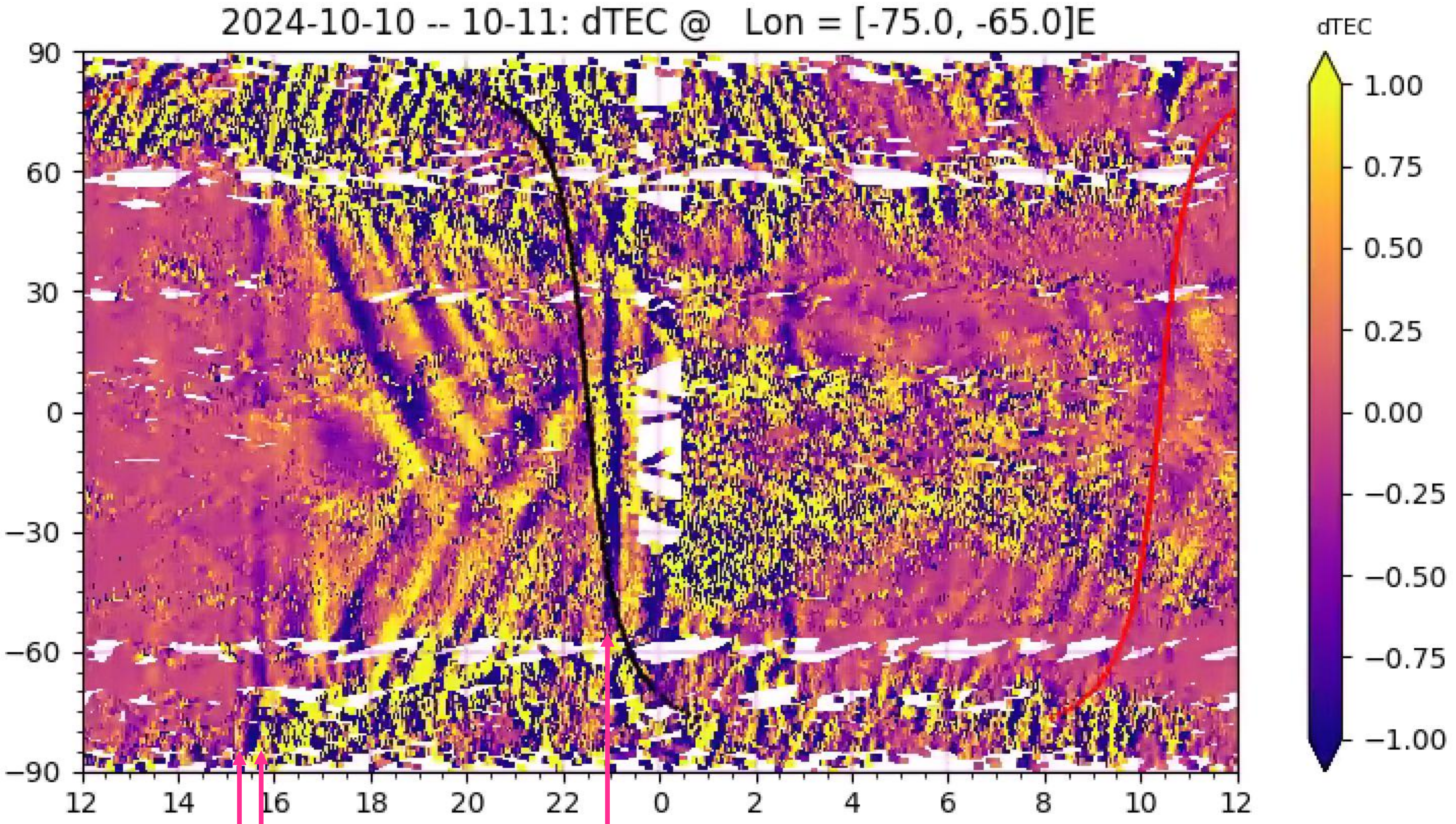
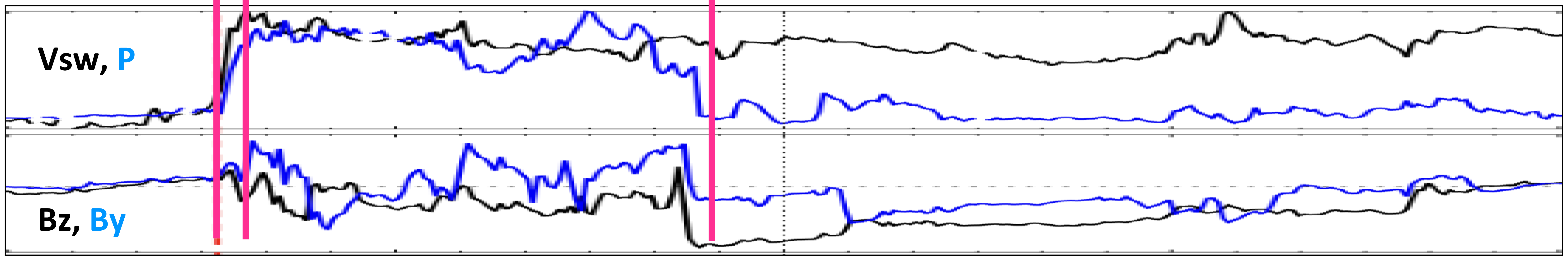
GNSS TEC (dTEC) responses in Eastern American longitudes



prompt penetration electric field impact on the ionospheric density



Solar wind figure courtesy of Ercha Aa

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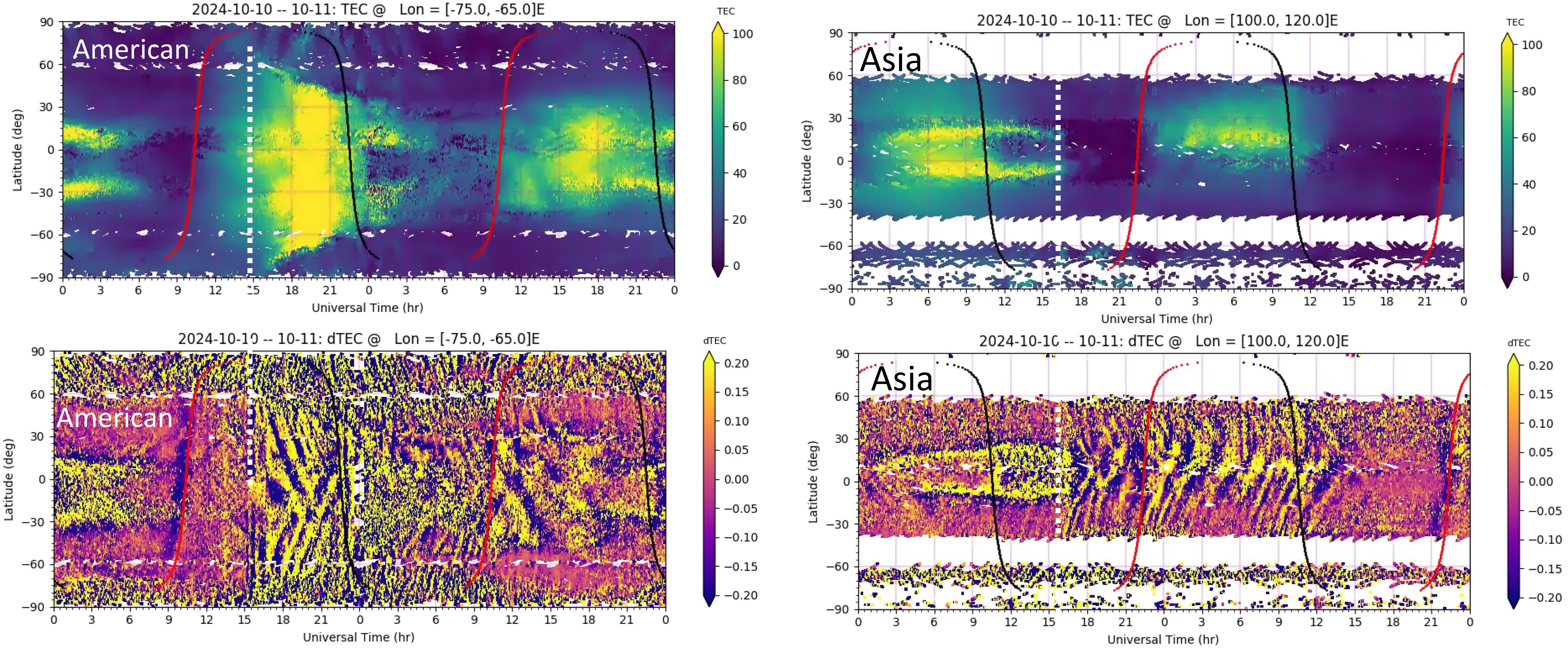
East-west Hemispheric comparisons: TEC & dTEC



- **Arriving shock caused simultaneous + and - changes**
- **Deep depletion in the eastern hemisphere during the negative/recovery phase of the storm**

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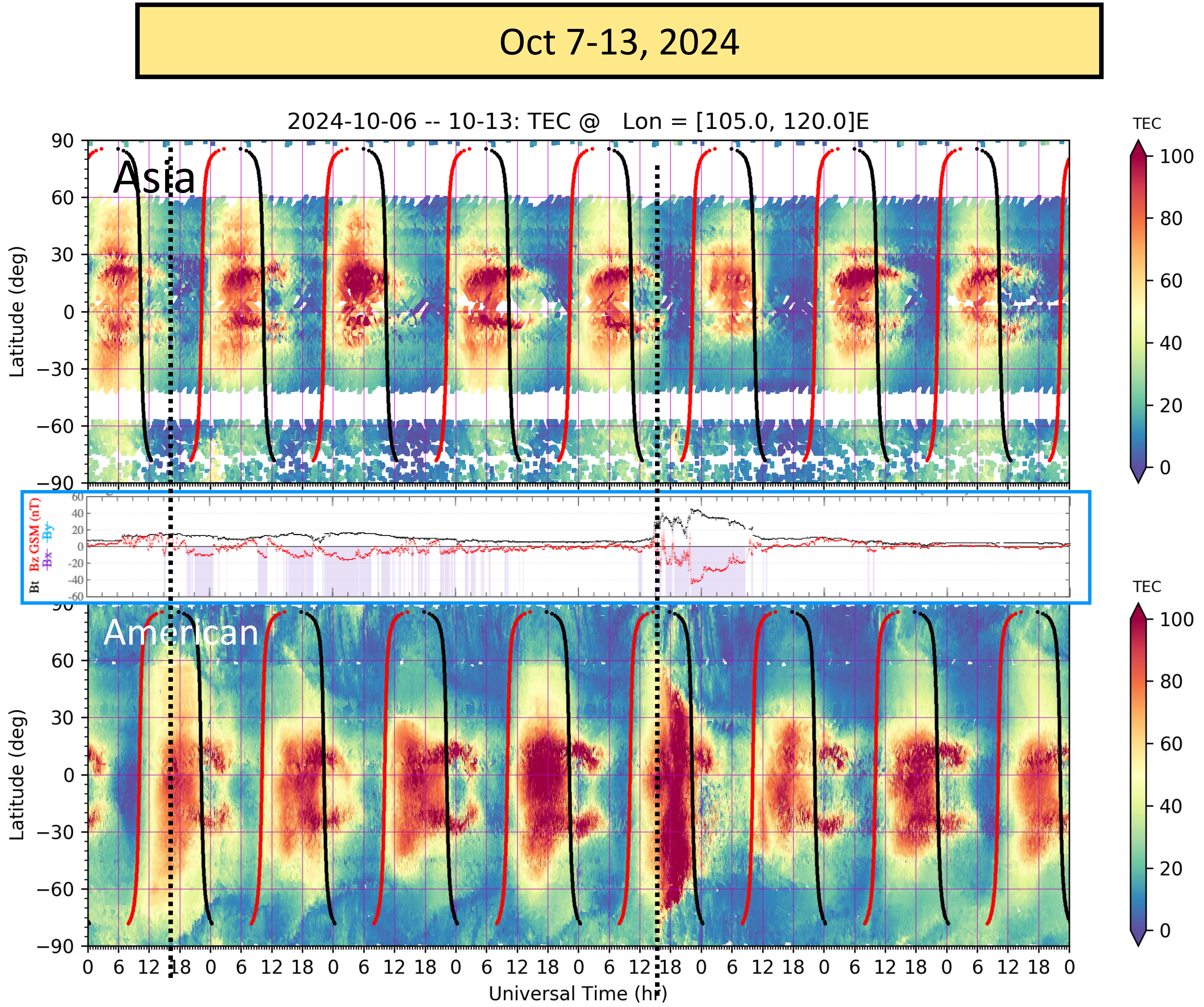
East-west Hemispheric comparisons: TEC

- **Changes in the American sectors seem more dramatic during the storm main phase**
- **Quiet-time variability in EIA is also substantial**



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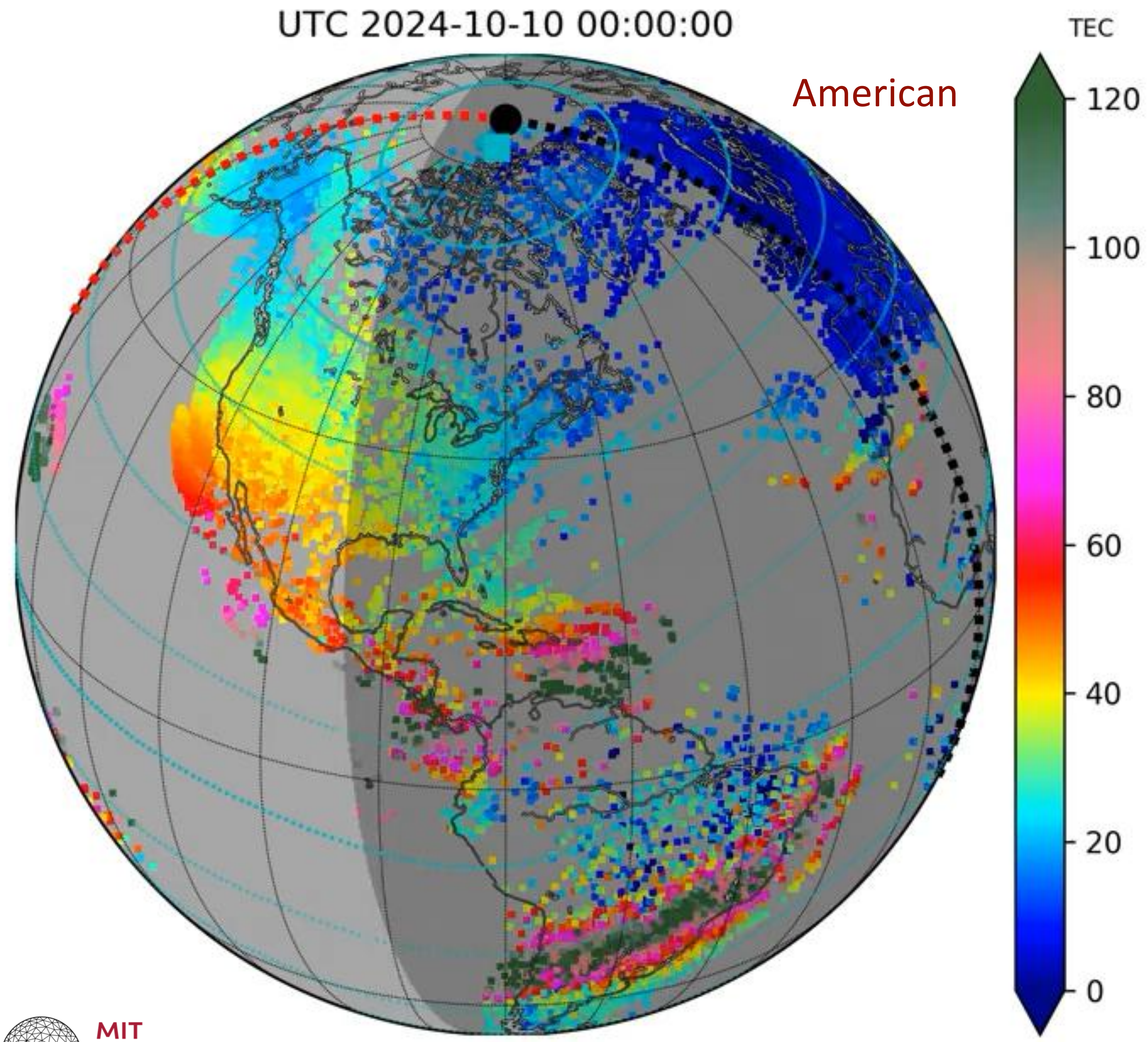
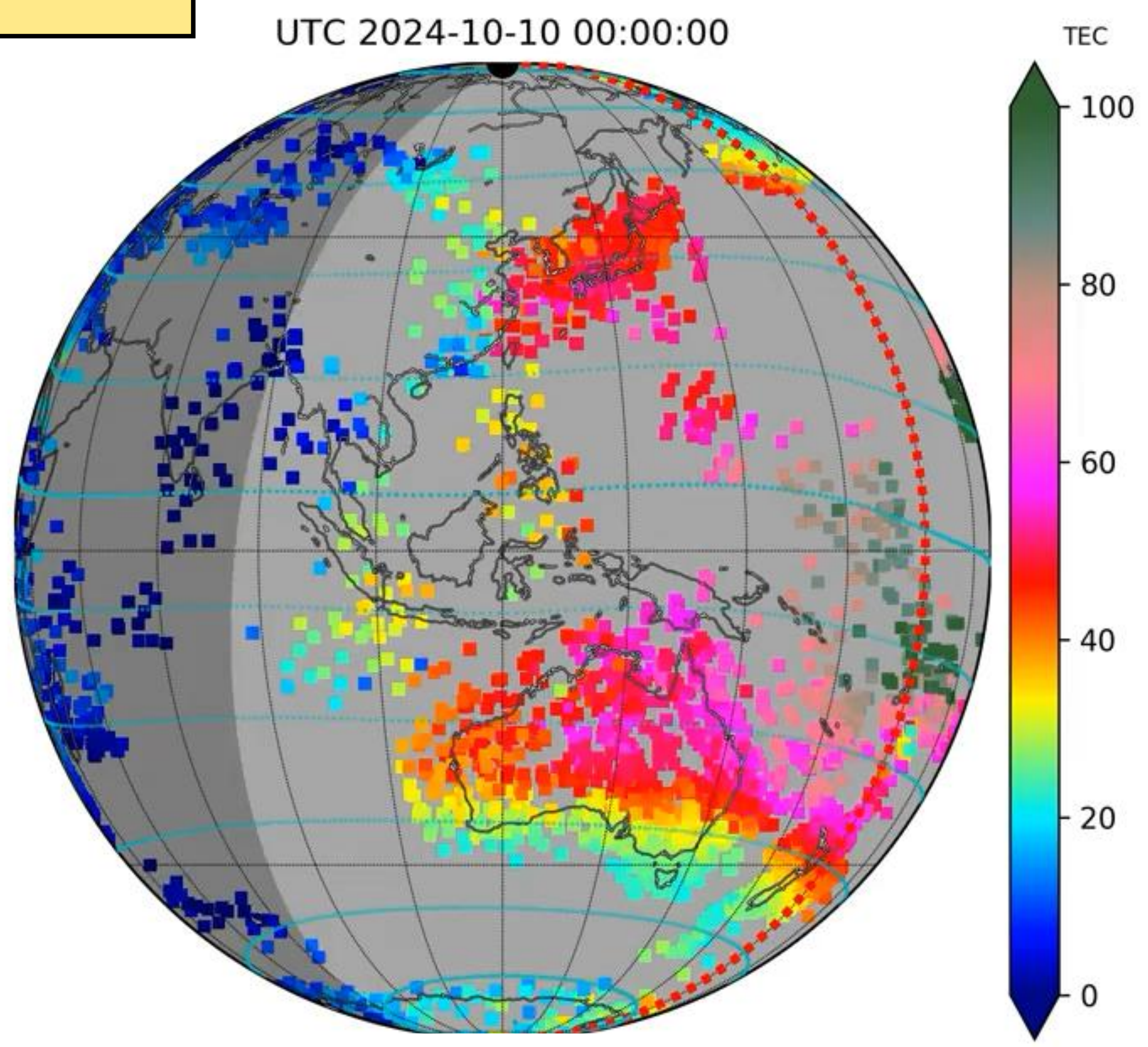
TEC Global Disturbances

Oct 10-12, 2024

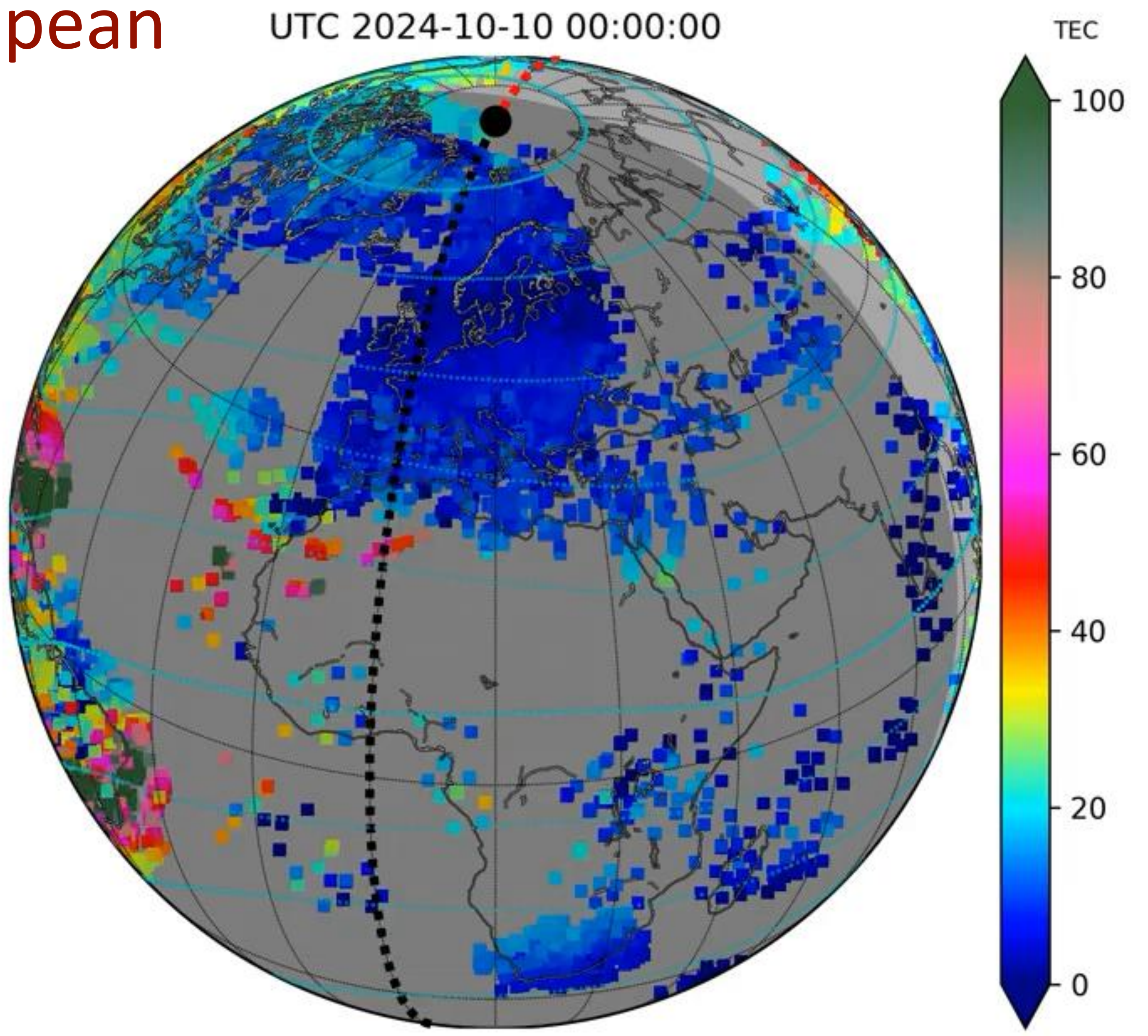
American



Asian



European



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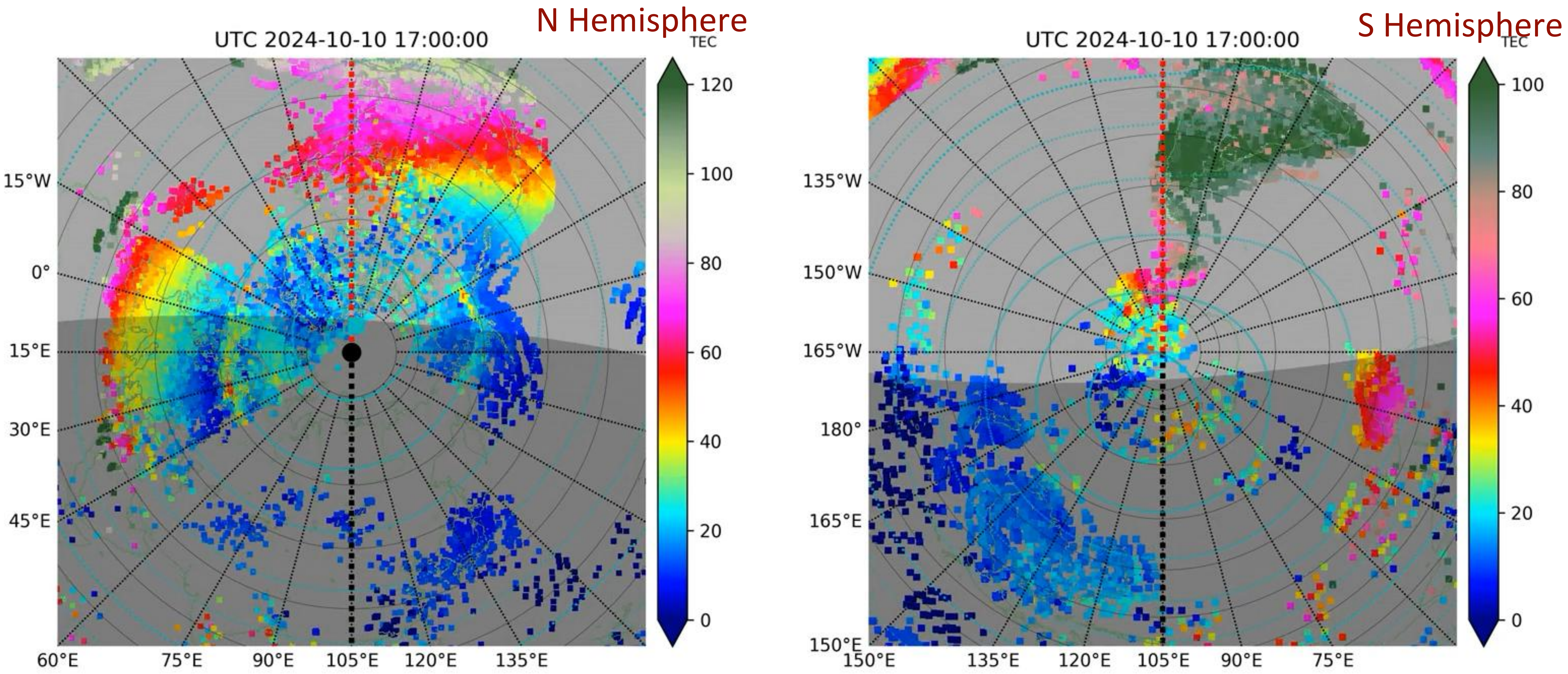
transpolar ionospheric conve

Oct 10-11, 2024



dayside —-> polar cap —-> nightside

Summary: Oct 2024 Mid-Latitude Storm Response

- **Prompt ionospheric responses (strong TIDs) at mid- and low latitudes on both dayside and nightside to the arriving interplanetary shock and also during IMF Bz sudden changes in orientation**
- **Dramatic density enhancements occur more often in American longitudes than in Asian and European sectors**
- **Storm enhanced density (SED) at subauroral latitudes developed during the early stage of storm phases, and polar cap tongue of ionization (TOI) occurred at a later time. Their time relationship implies possible contributions from SED to TOI.**

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