Monday 1000-1200 Science Highlight I: Pacific A&B

Traveling ionospheric disturbances (TIDs) and geospace-atmosphere multi-scale coupling processes

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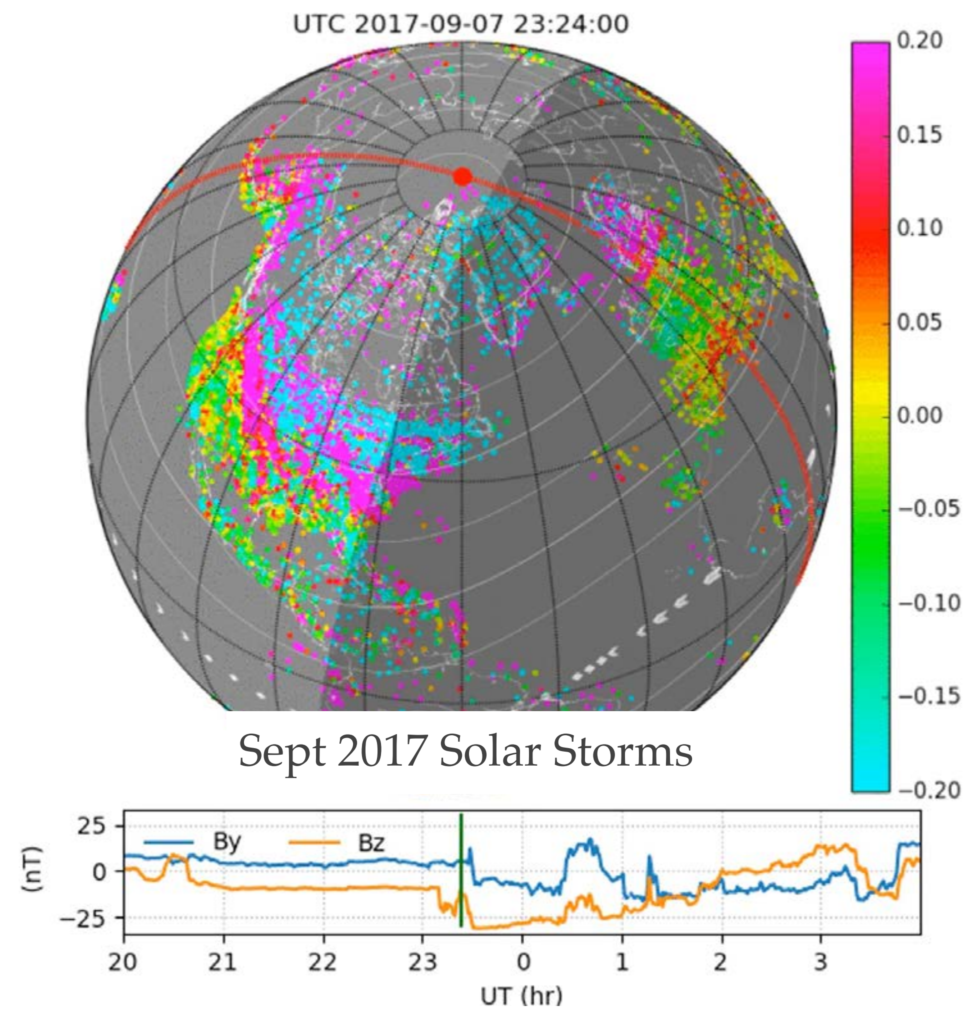
[5] Dartmouth College

Outline

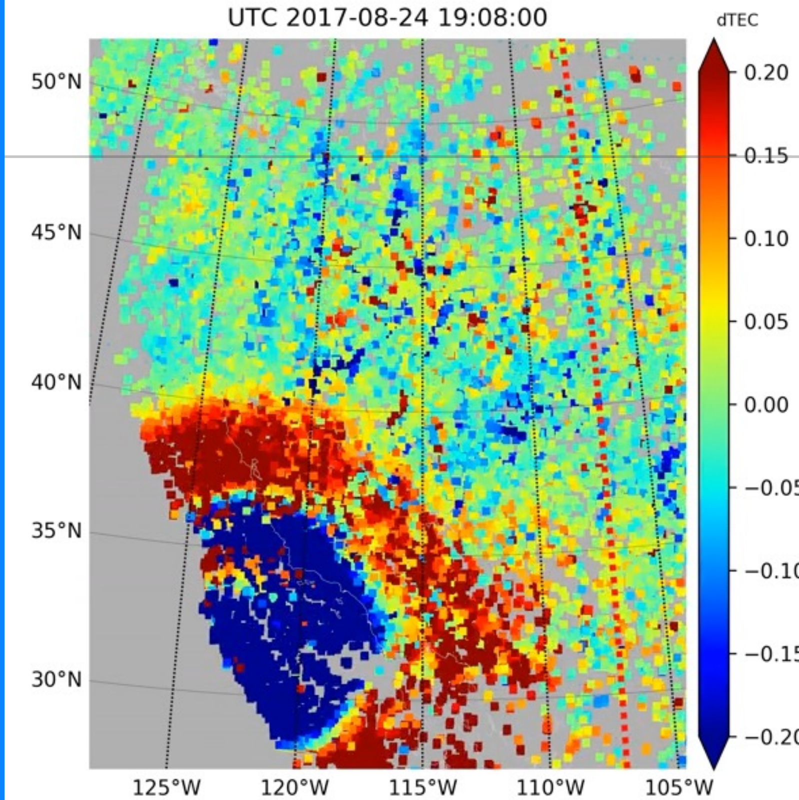
- **Introduction**
  - **All kinds of TIDs**
  - **Observation techniques**
- **Toward building a global picture of storm-time TIDs**
  - LSTIDs (equatorward)
  - **Trans-polar TIDs**
  - Trans-equatorial TIDs
  - **MSTIDs** at mid- and subauroral latitudes
- Understanding transient solar-terrestrial forcing
  - During Solar Eclipse
  - During Solar Flare
- Man-made space weather
- **Lower atmospheric forcing**
  - **Postsunrise**, electrified (MHISR)
  - **Tonga eruption**

TIDs

- Large scales **vs** Medium Scales
- Exciting source (Above **vs** Below)
- Gravity waves **vs** Electrodynamics
- Propagation, Dissipation, Impact
- Detection & Simulation

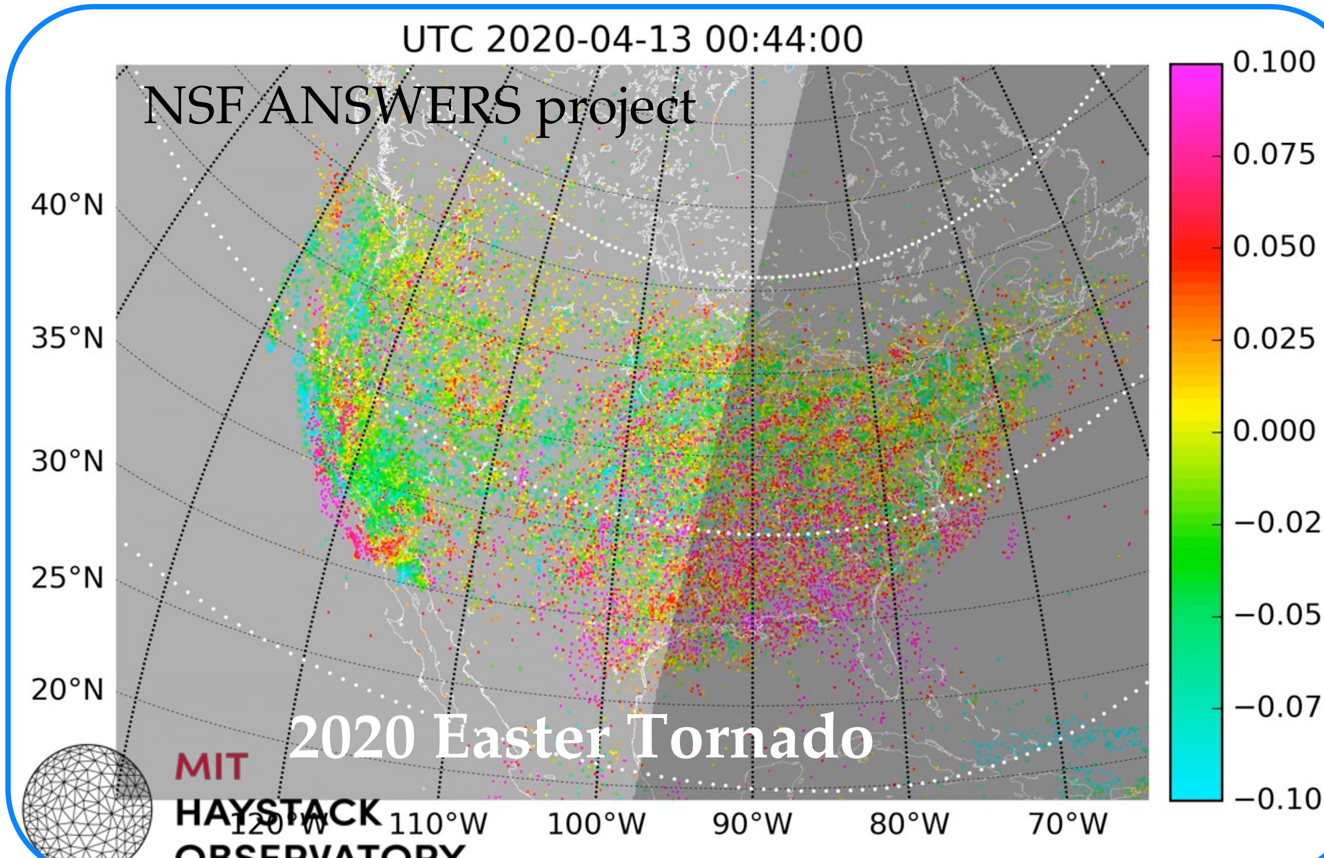


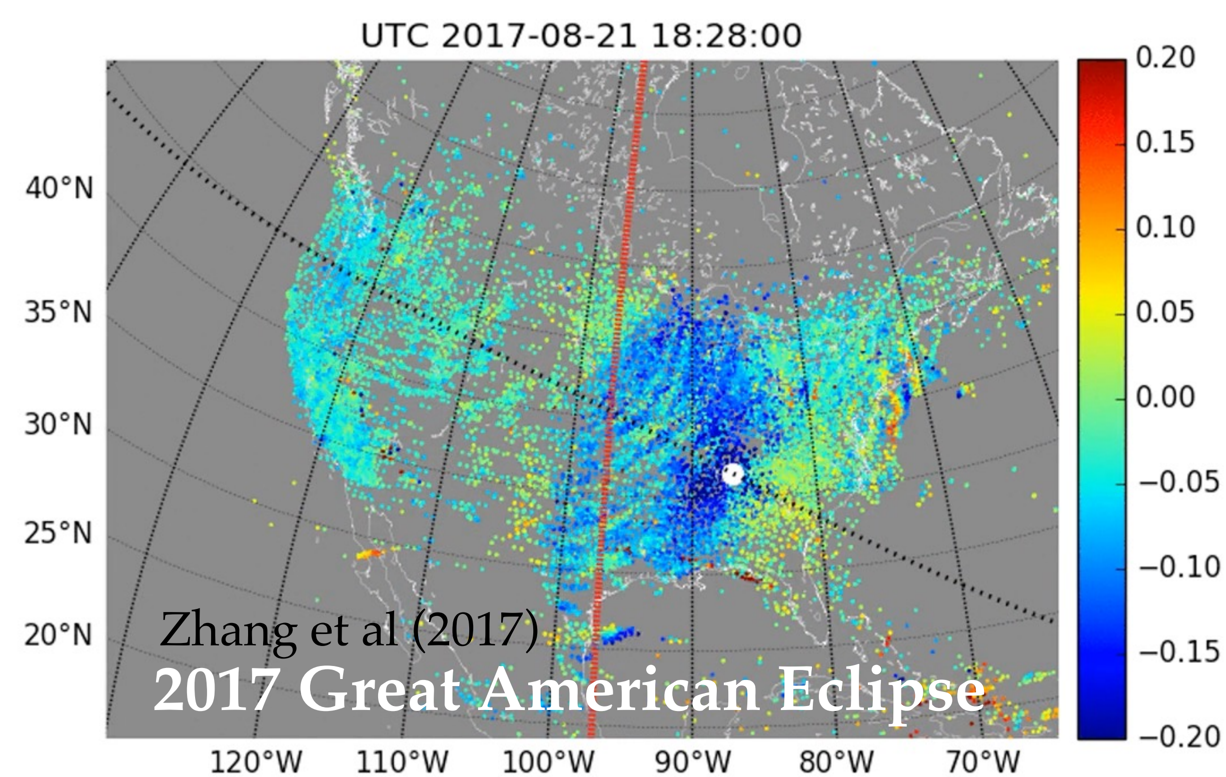
Zhang et al (2019, 2022)



SpaceX Falcon 9

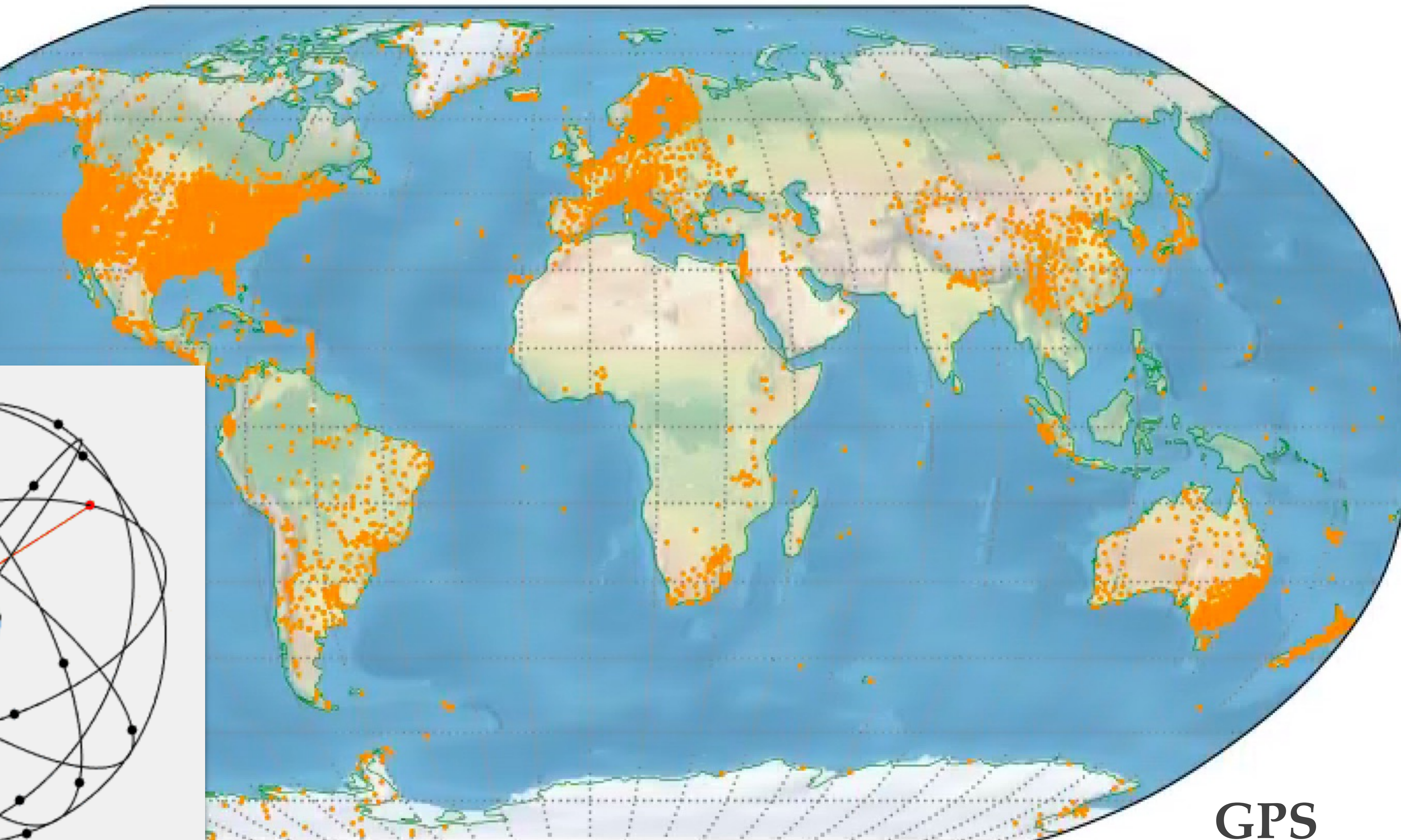
See also Chou et al (2018)

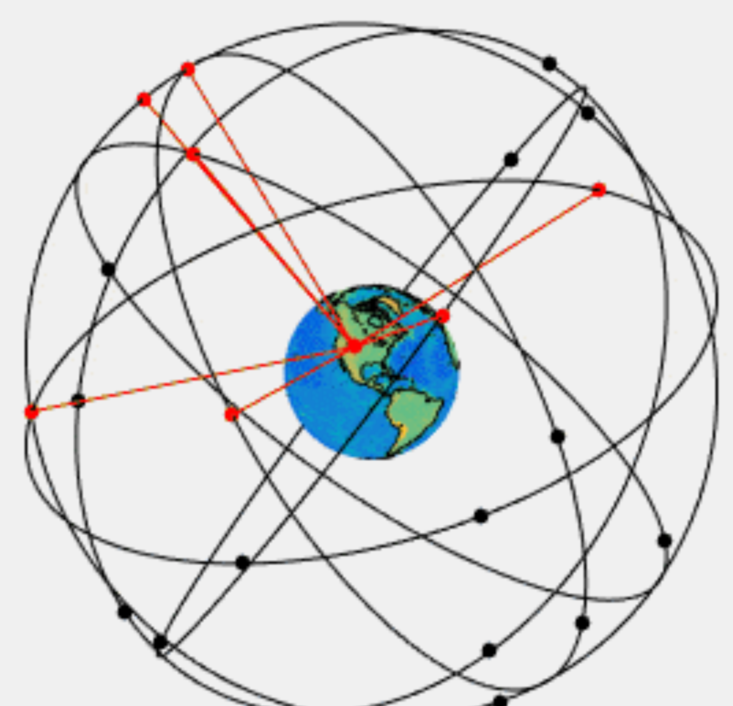




MIT GNSS TEC/dTEC from 6000+ Receivers

GNSS sites on 09 Sep 2017





Anthea Coster | Bill Rideout | Nestor Aponte

GPS
GLONASS
BeiDou

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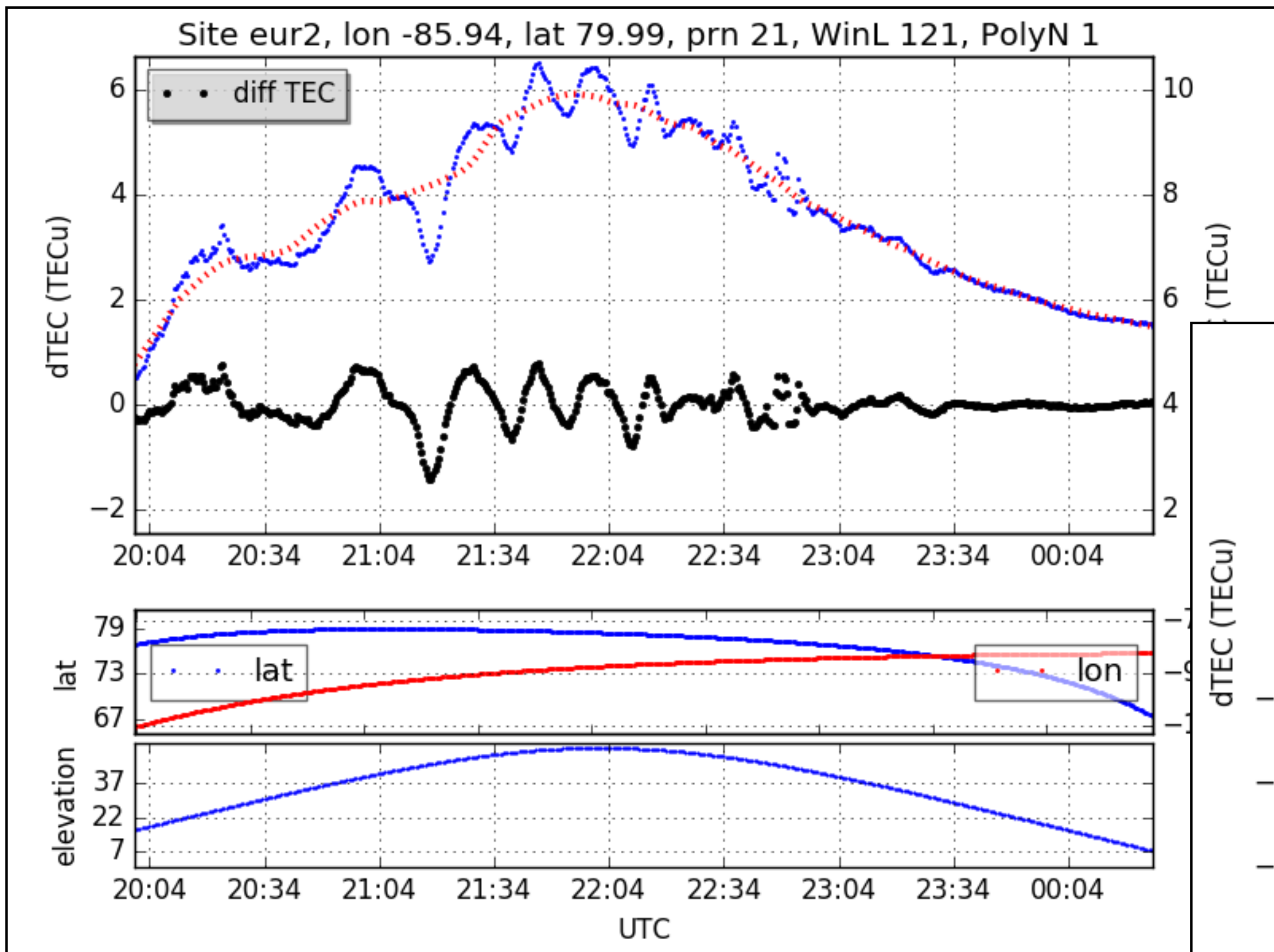
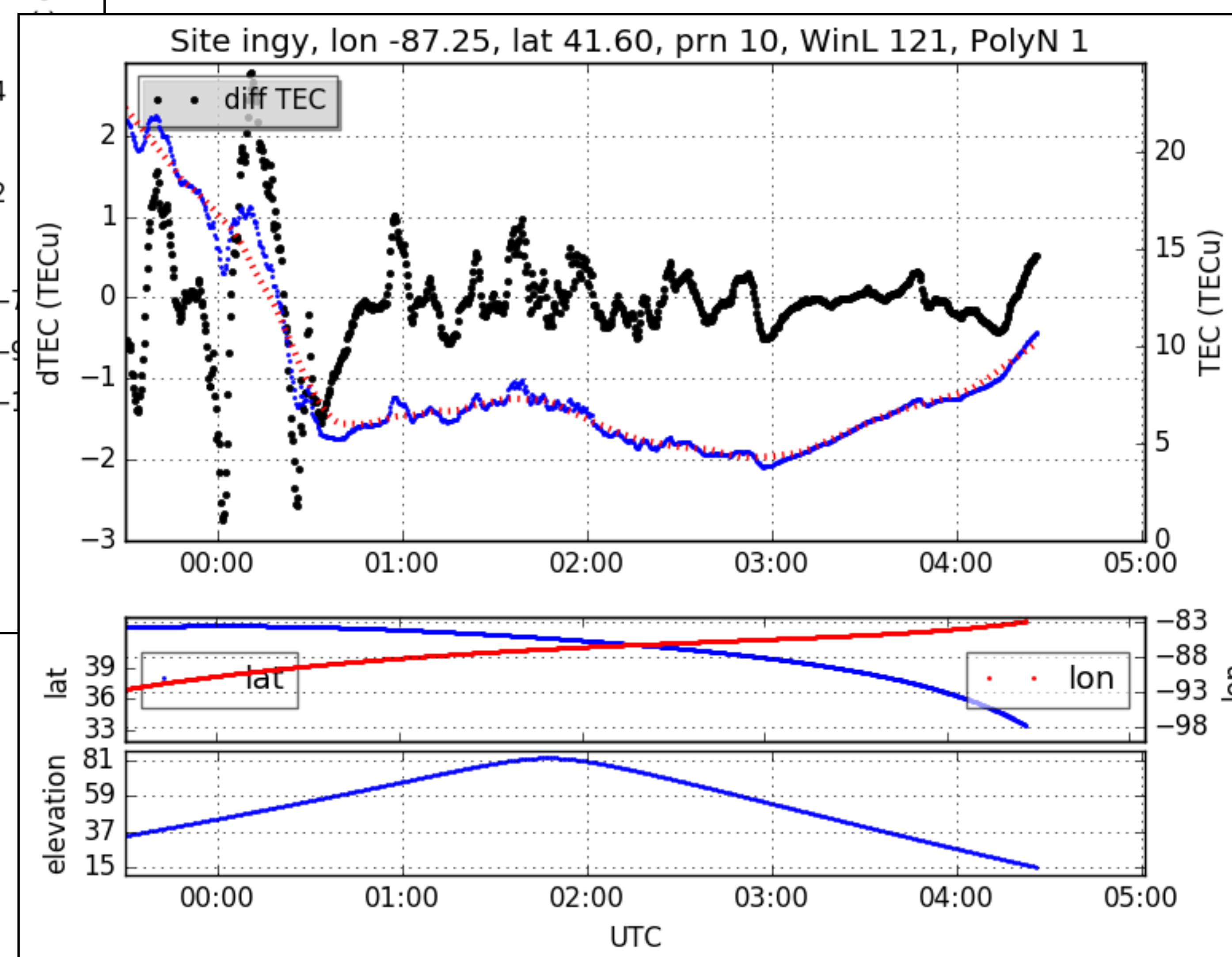
Detecting TIDs

Savitzky-Golay low-pass filter to provide background TEC variations that will be de-trended: similar to running averaging with sliding windows.

Polar region



Midlatitude main trough region



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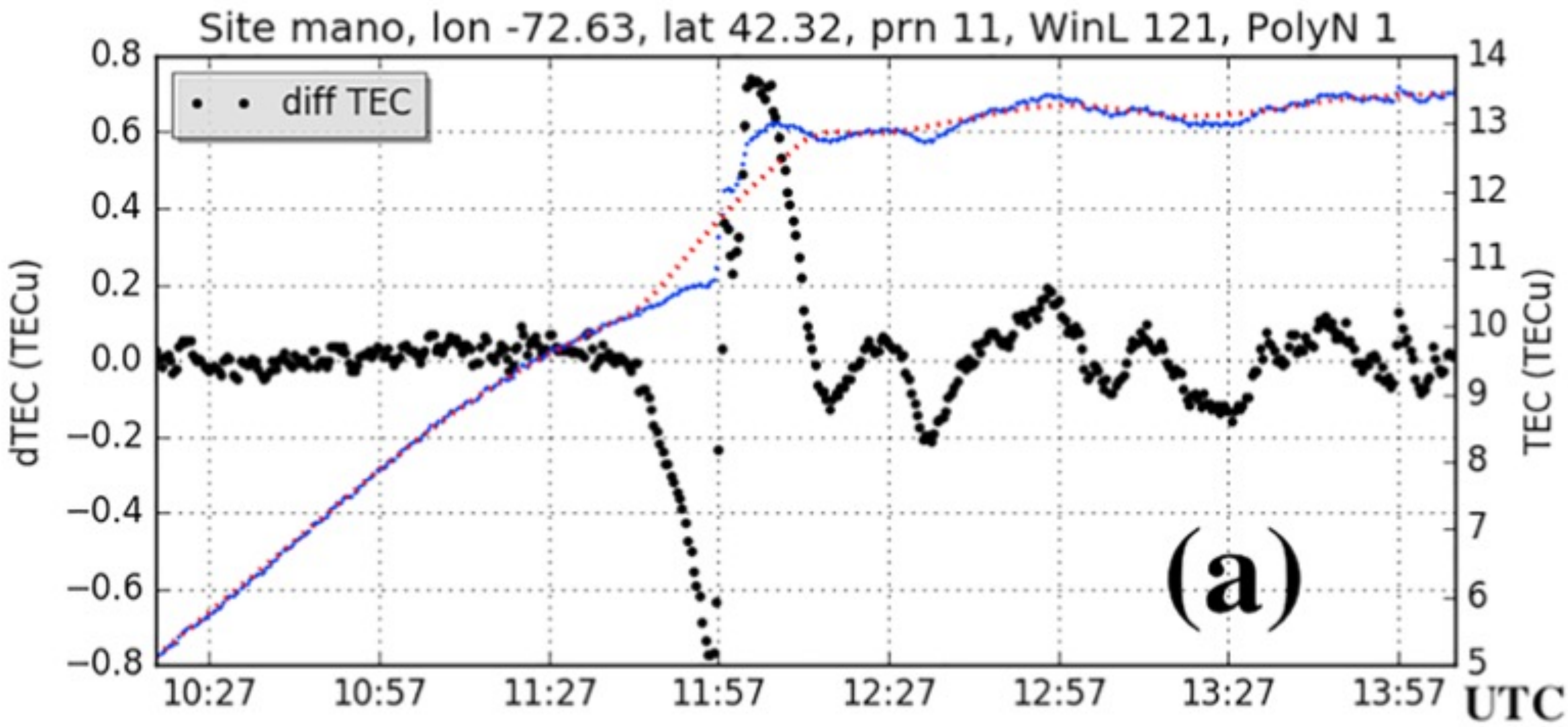
Detecting TIDs: Solar flare Impact

Sept 6, 2017: X9.3

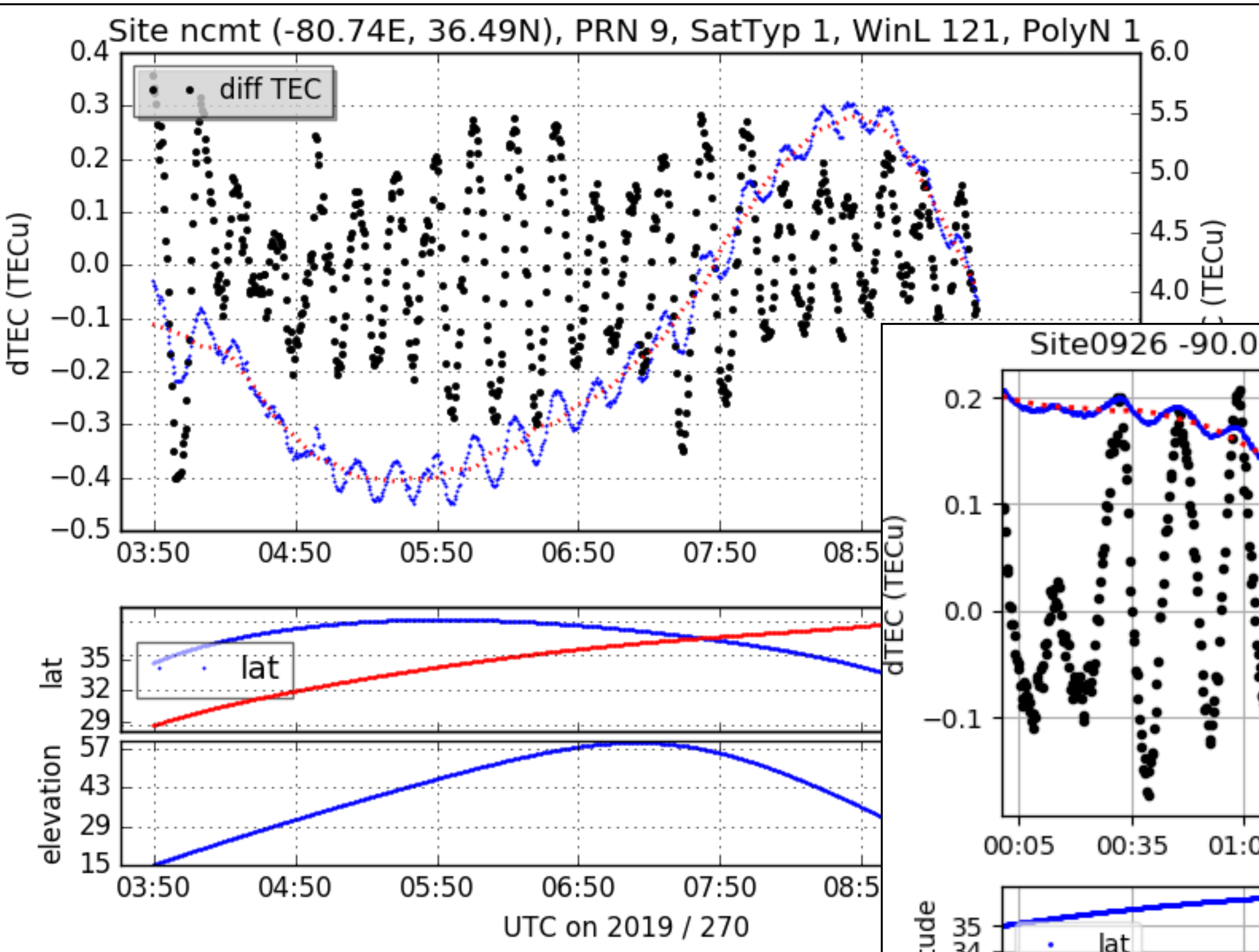


Zhang, S.-R., Coster, A. J., Erickson, P. J., Goncharenko, L. P., Rideout, W., & Vierinen, J. (2019). Traveling Ionospheric Disturbances and Ionospheric Perturbations Associated With Solar Flares in September 2017. Journal of Geophysical Research: Space Physics, 60(8), 895. http://doi.org/10.1029/2019JA026585

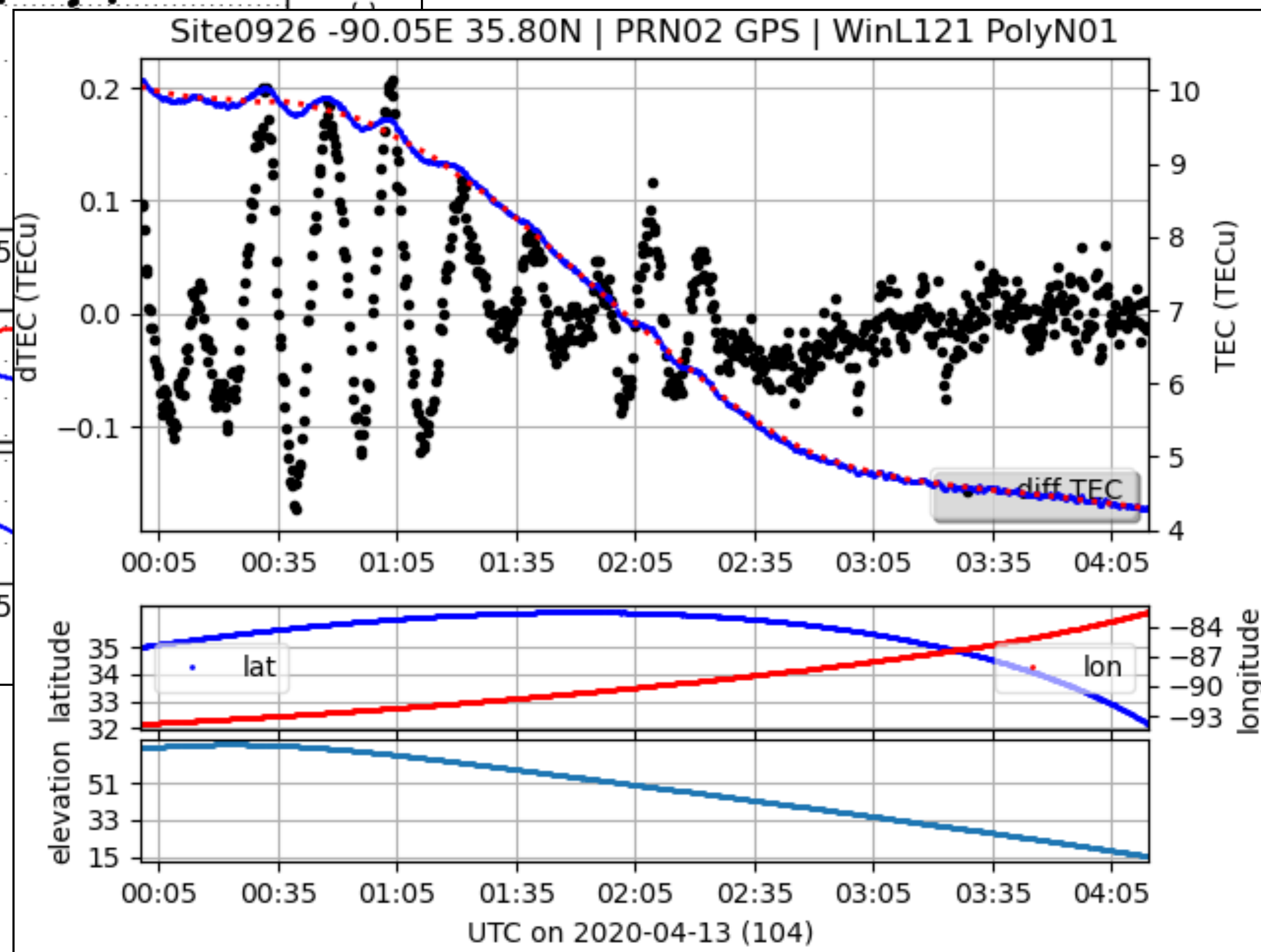
Detecting TIDs: terrestrial weather (hurricane)

Hurricane Lorenzo

Category 4 at 00 UTC 2019-09-27



2020 Easter Tornado



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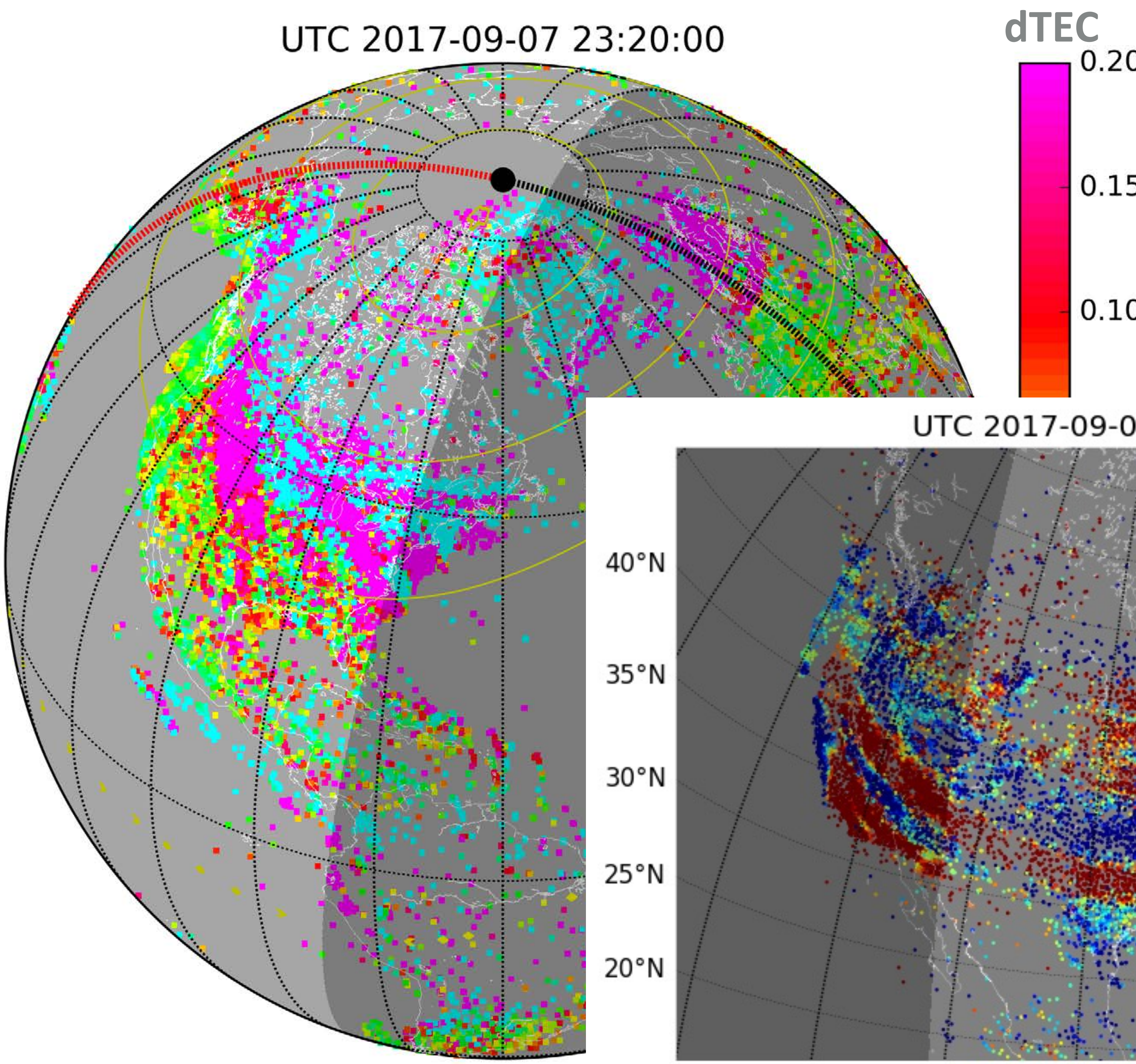
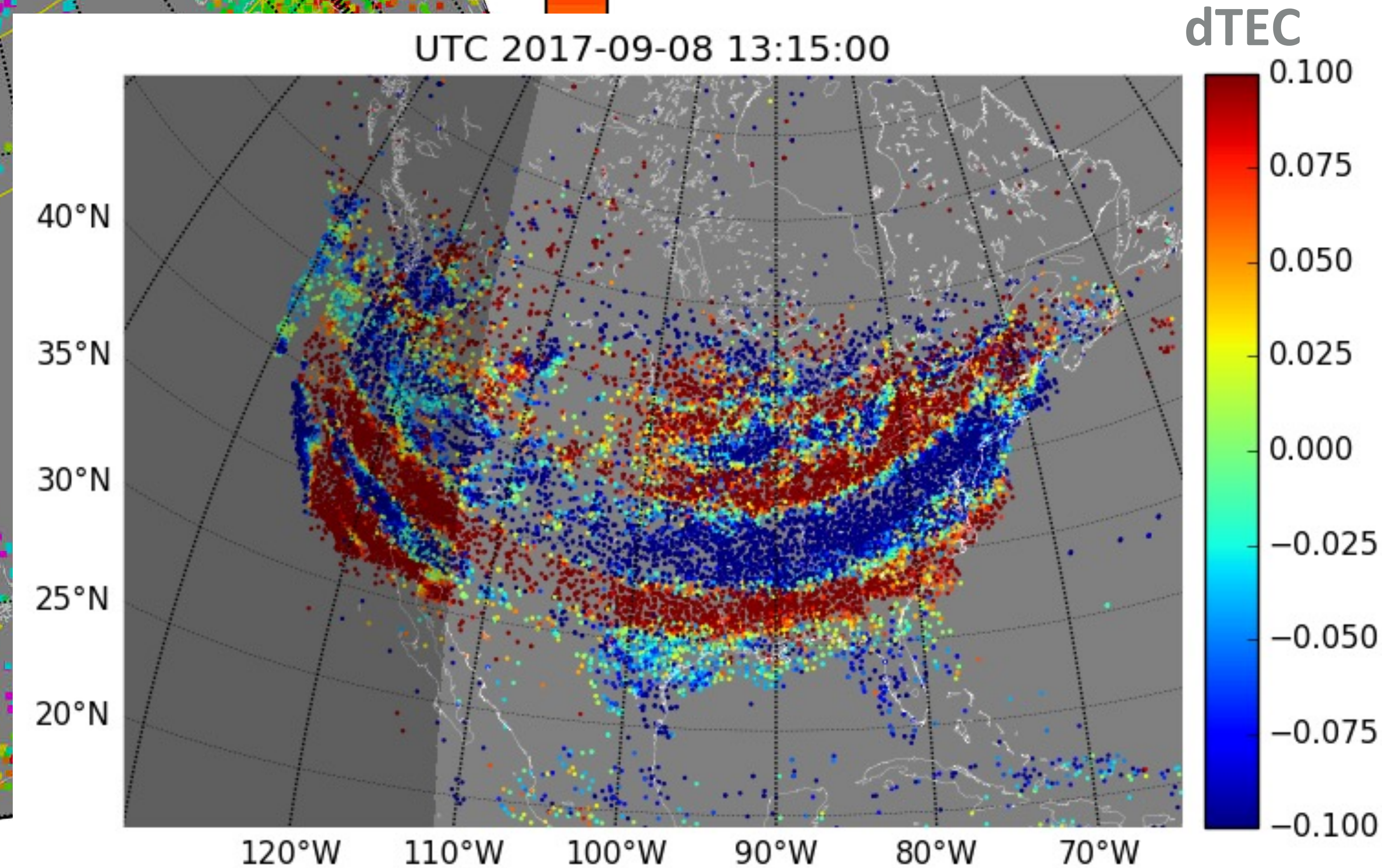
Toward building a global picture of storm-time TIDs



Subauroral TIDs: Concurrent LSTIDs & MSTIDs



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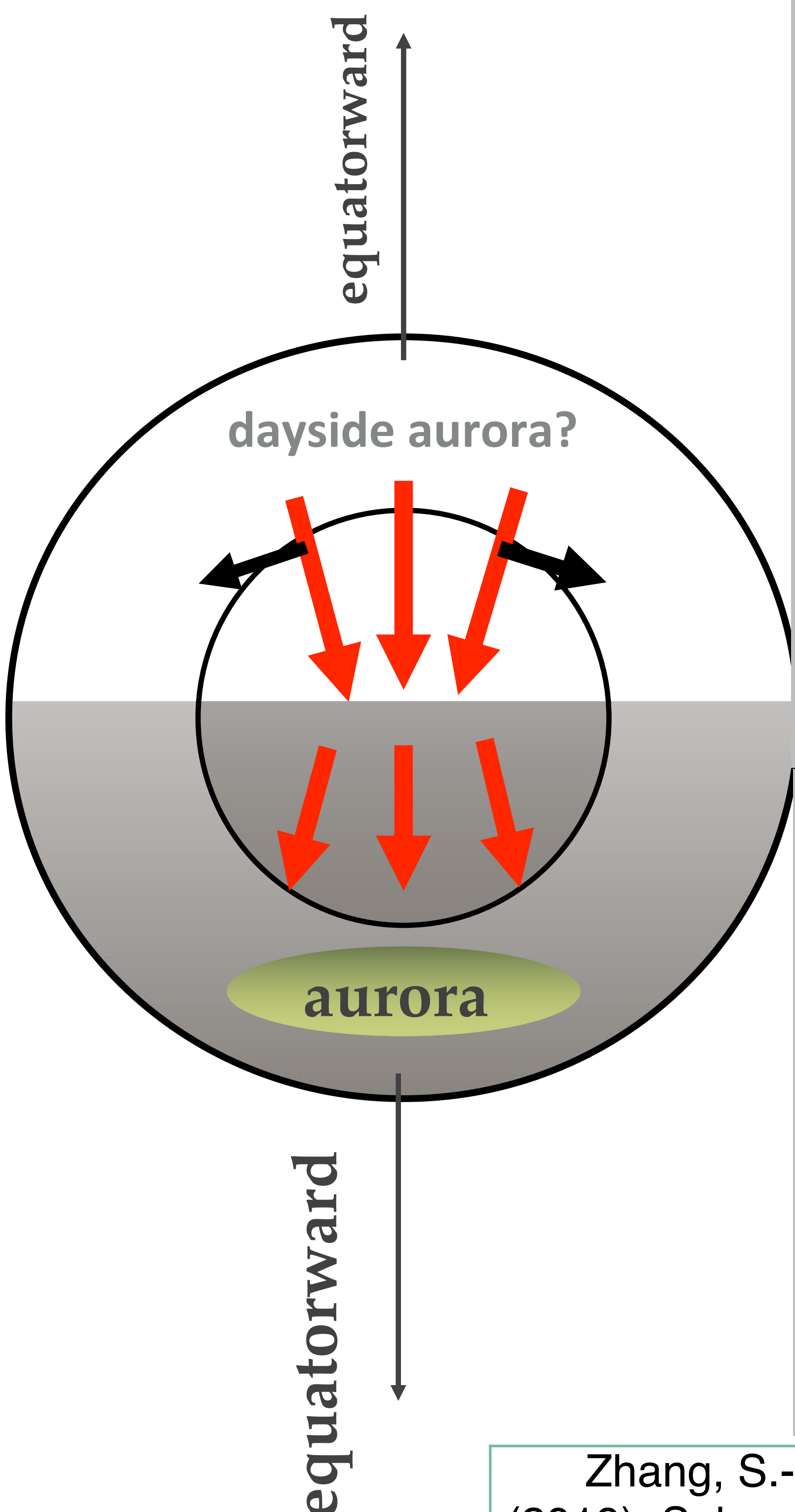
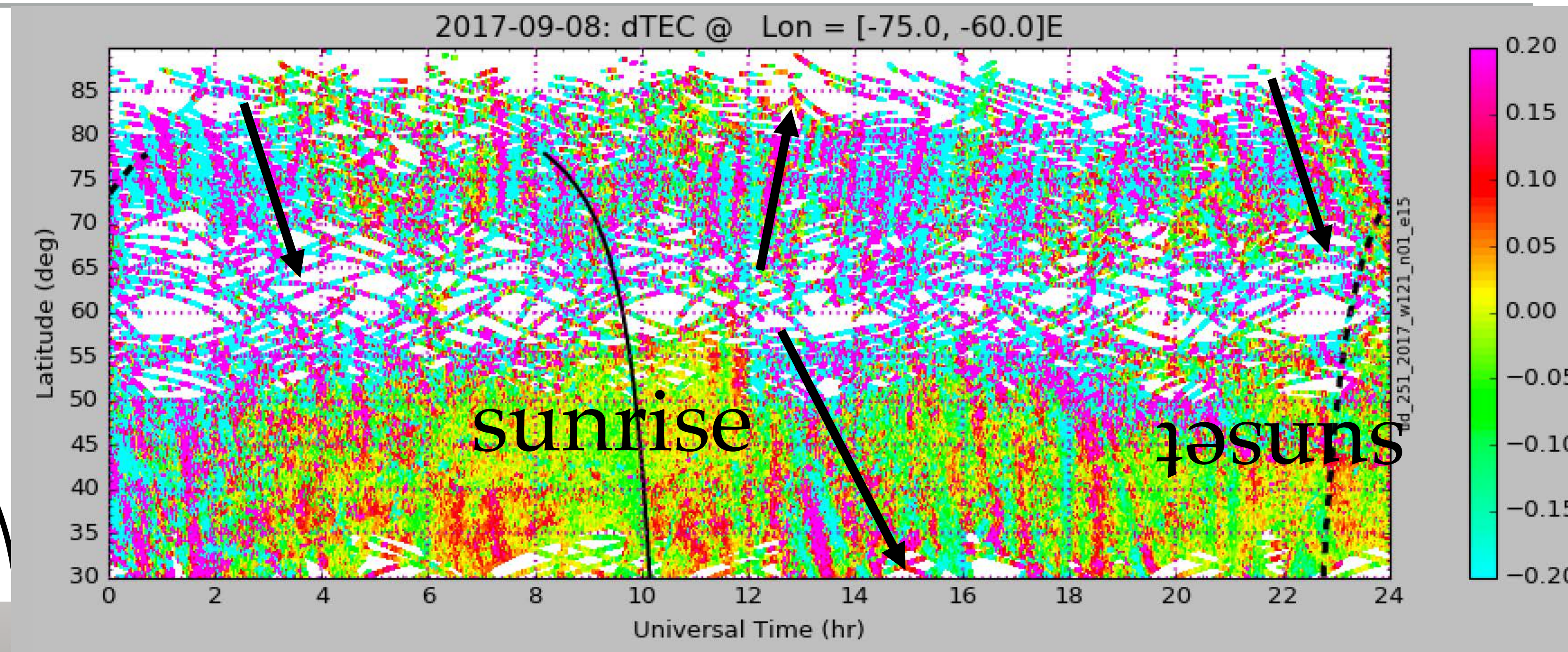
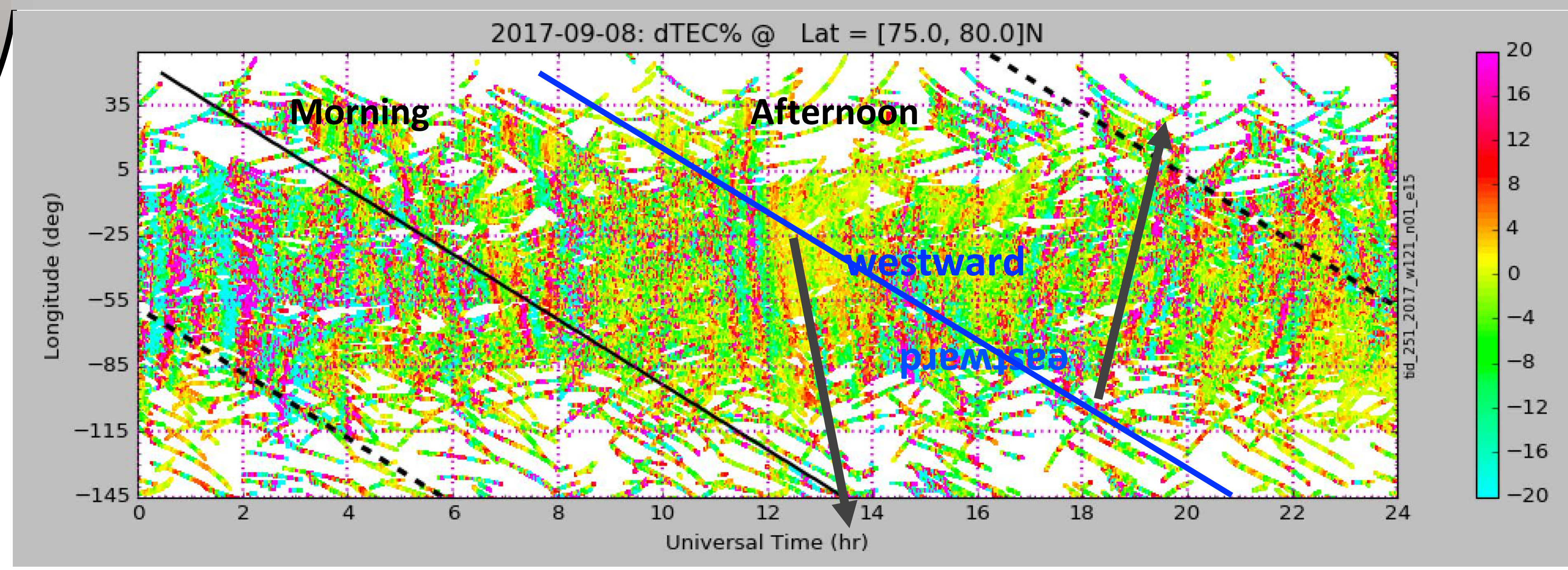
Zhang, S.-R., Erickson, P. J., Coster, A. J., Rideout, W., Vierinen, J., Jonah, O., & Goncharenko, L. P. (2019). Subauroral and Polar Traveling Ionospheric Disturbances During the 7-9 September 2017 Storms. Space Weather, 17(1), 1748–1764.

Storm-time trans-polar TIDs



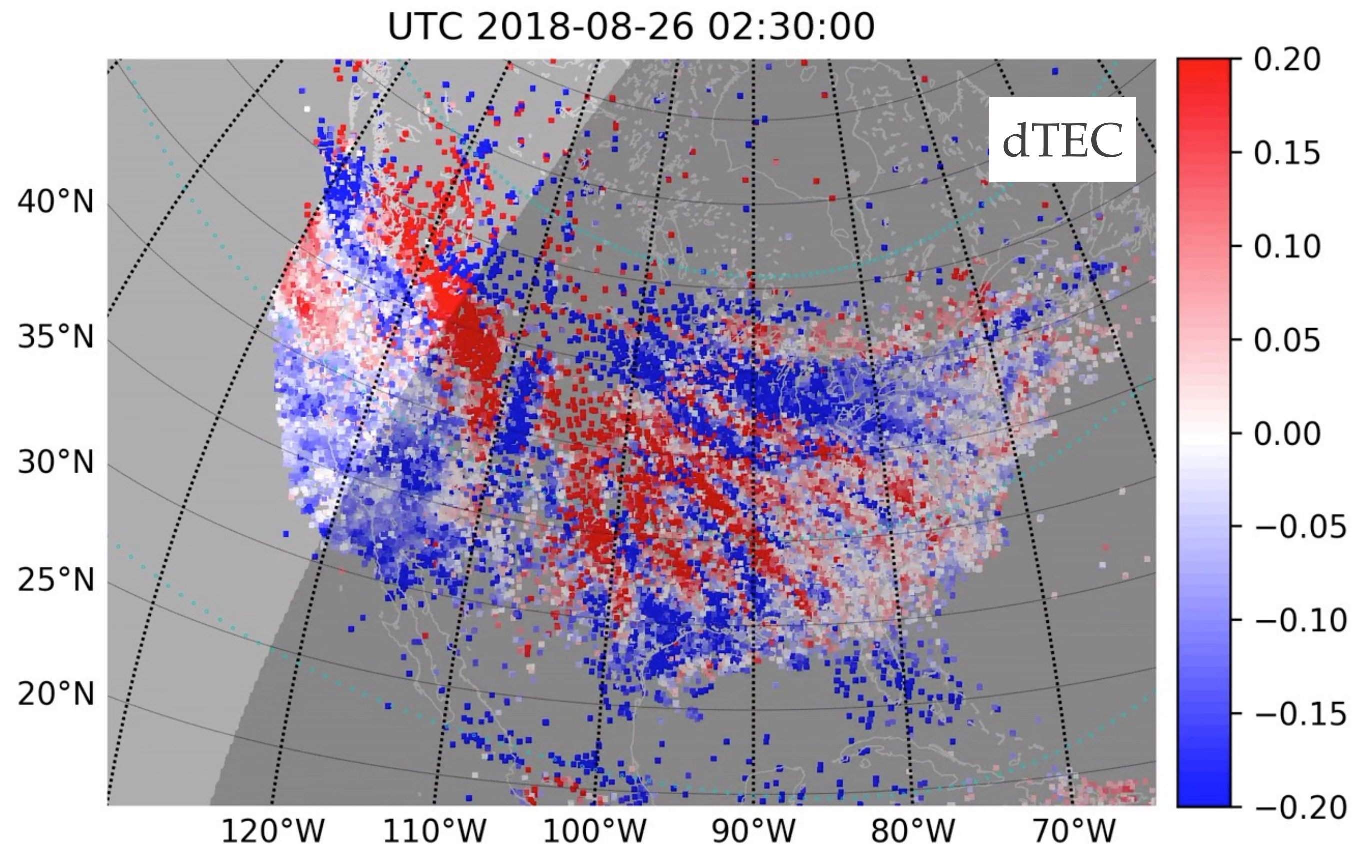


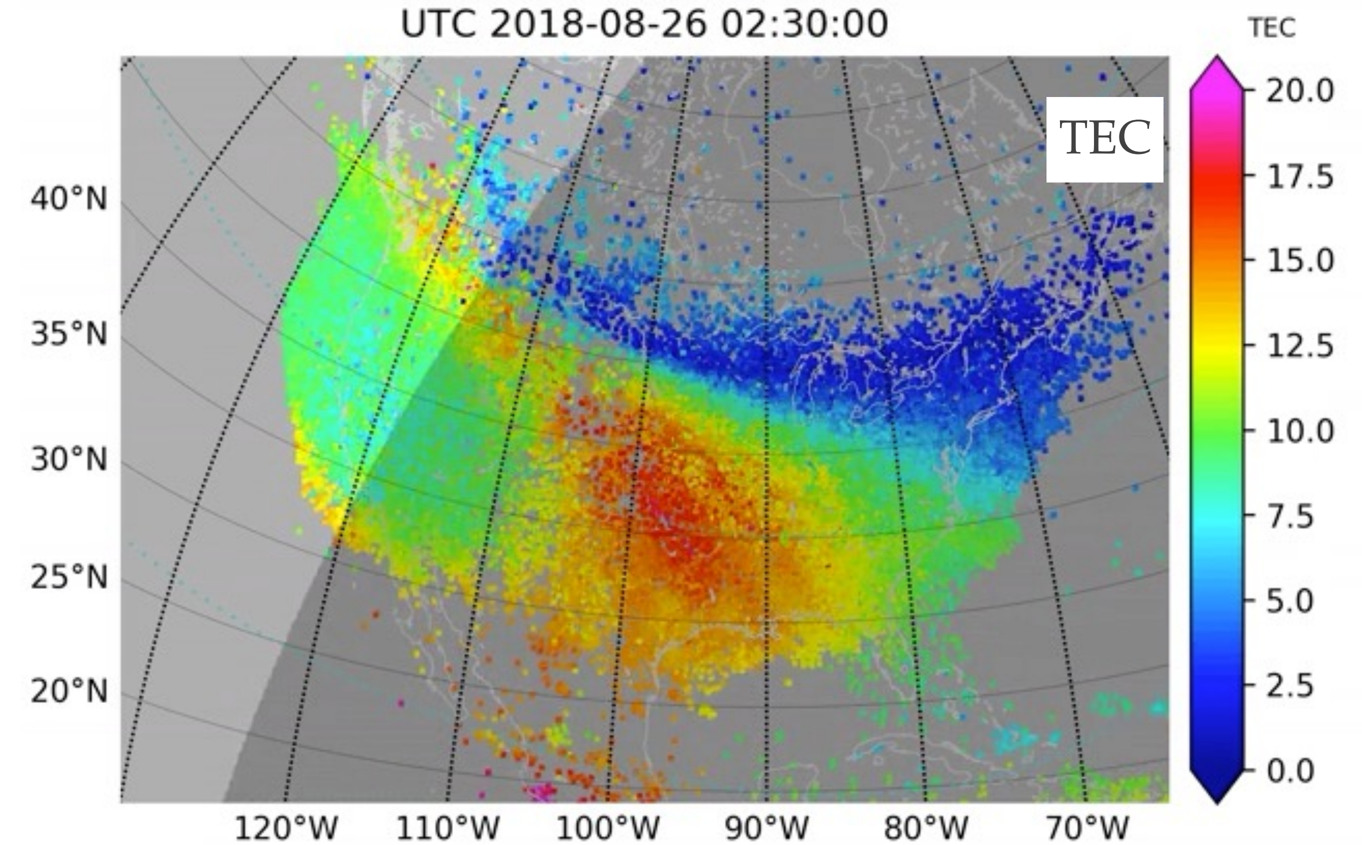


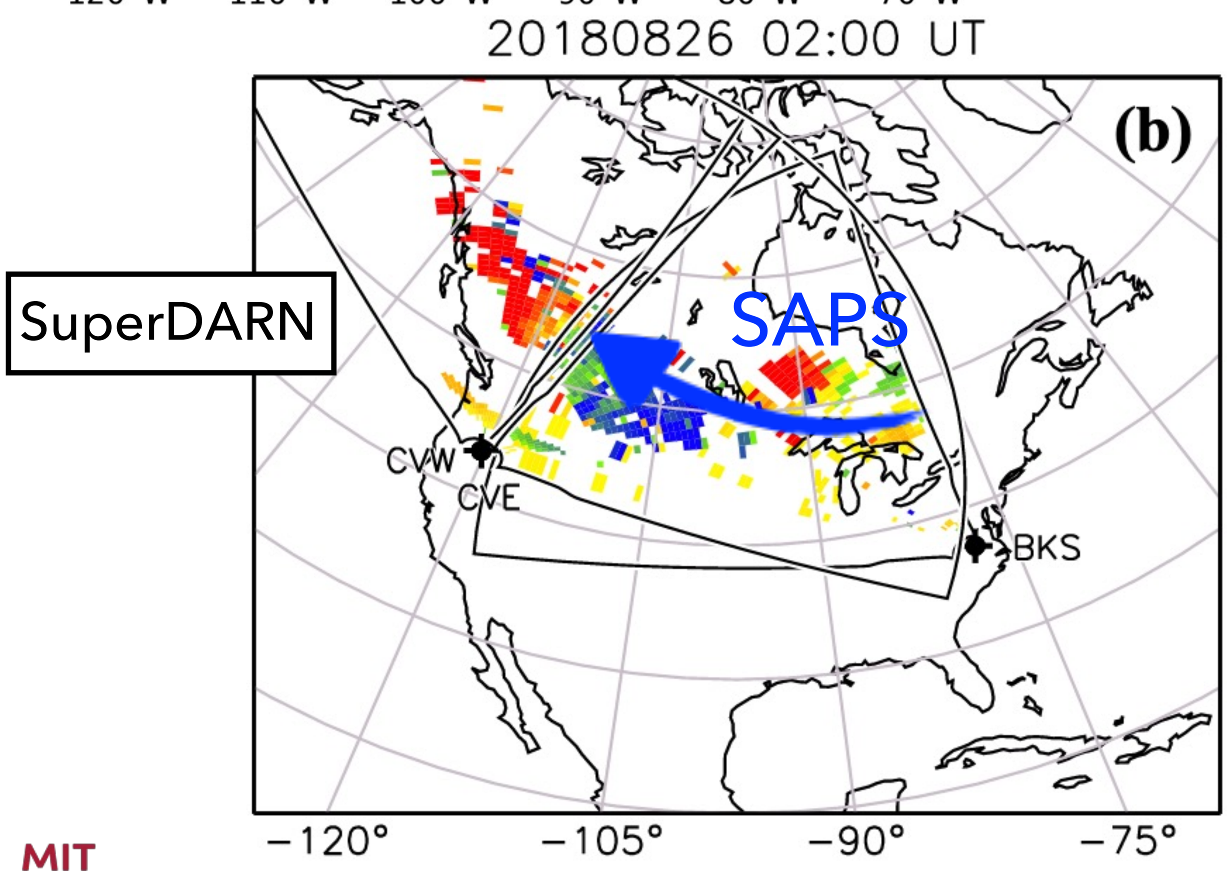
Zhang, S.-R., Erickson, P. J., Coster, A. J., Rideout, W., Vierinen, J., Jonah, O., & Goncharenko, L. P. (2019). Subauroral and polar traveling ionospheric disturbances during the 7-9 September 2017 storms. *Space Weather*, 2019SW002325. http://doi.org/10.1029/2019SW002325

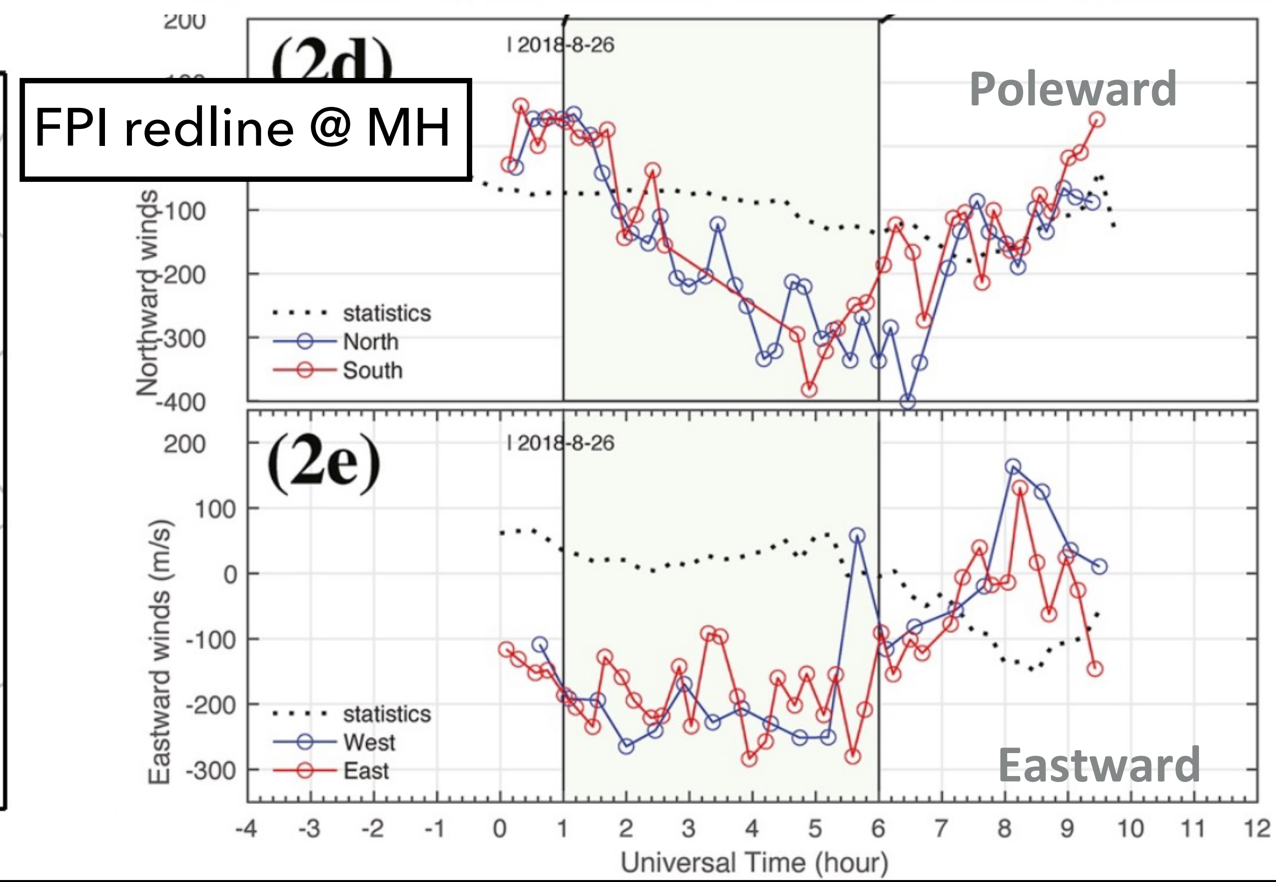
Nishimura, Y., Zhang, S.-R., Lyons, L. R., Deng, Y., Coster, A. J., Moen, J. I., Clausen, L. B., Bristow, W. A. & Nishitani, N. (2020). Source Region and Propagation of Dayside Large-Scale Traveling Ionospheric Disturbances. *Geophyical Research Letters*, *47*(19), 619. https://doi.org/10.1029/2020gl089451

(Finger-bone like) Storm-time MSTIDs at SED base









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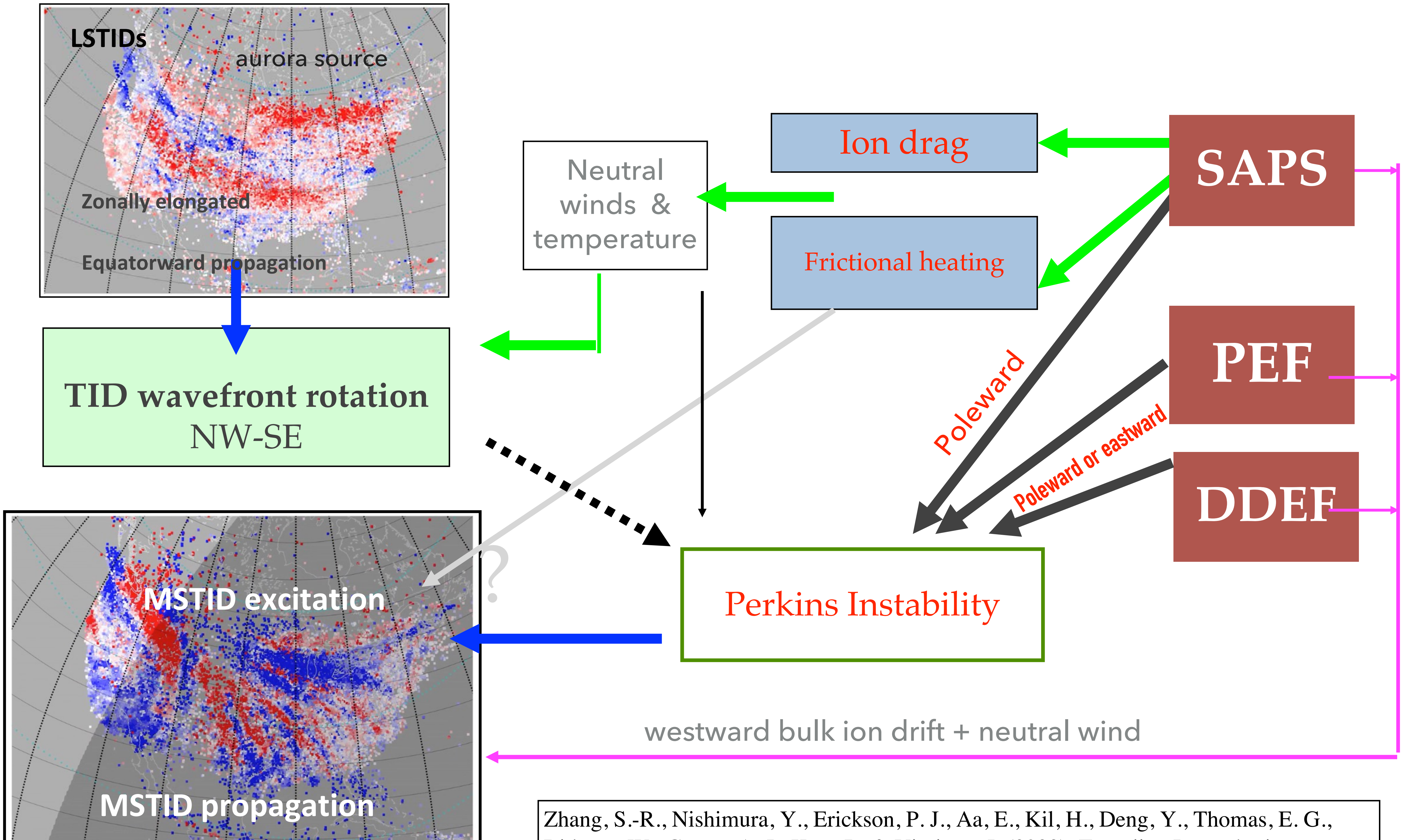
Zhang, S.-R., Nishimura, Y., Erickson, P. J., Aa, E., Kil, H., Deng, Y., Thomas, E. G., Rideout, W., Coster, A. J., Kerr, R. & Vierinen, J. (2022). Traveling Ionospheric Disturbances in the Vicinity of Storm-Enhanced Density at Midlatitudes. *Journal of Geophysical Research: Space Physics*, *127*(8), e2022JA030429.

How Stormtime electric Fields impact LSTIDs & MSTIDs



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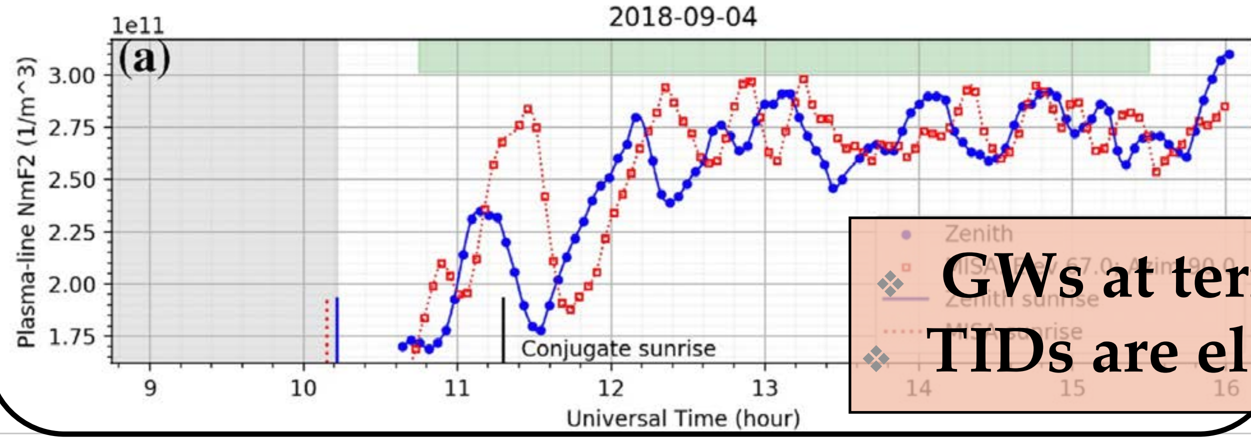
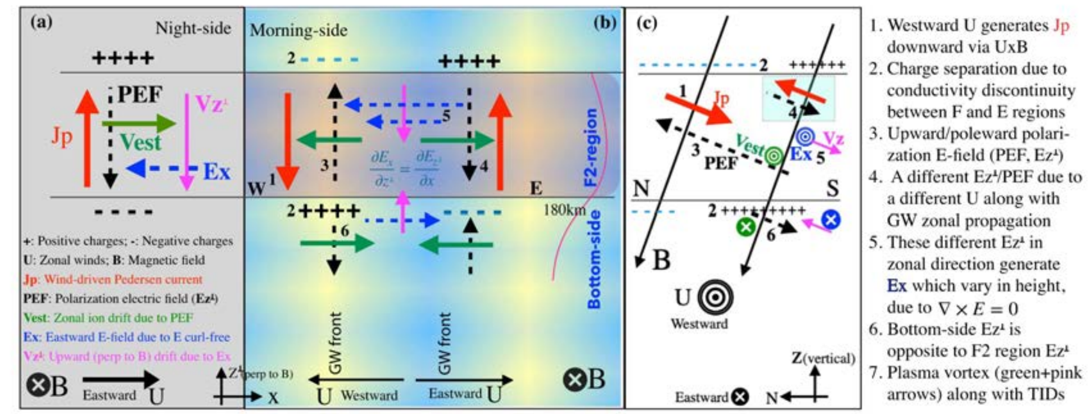
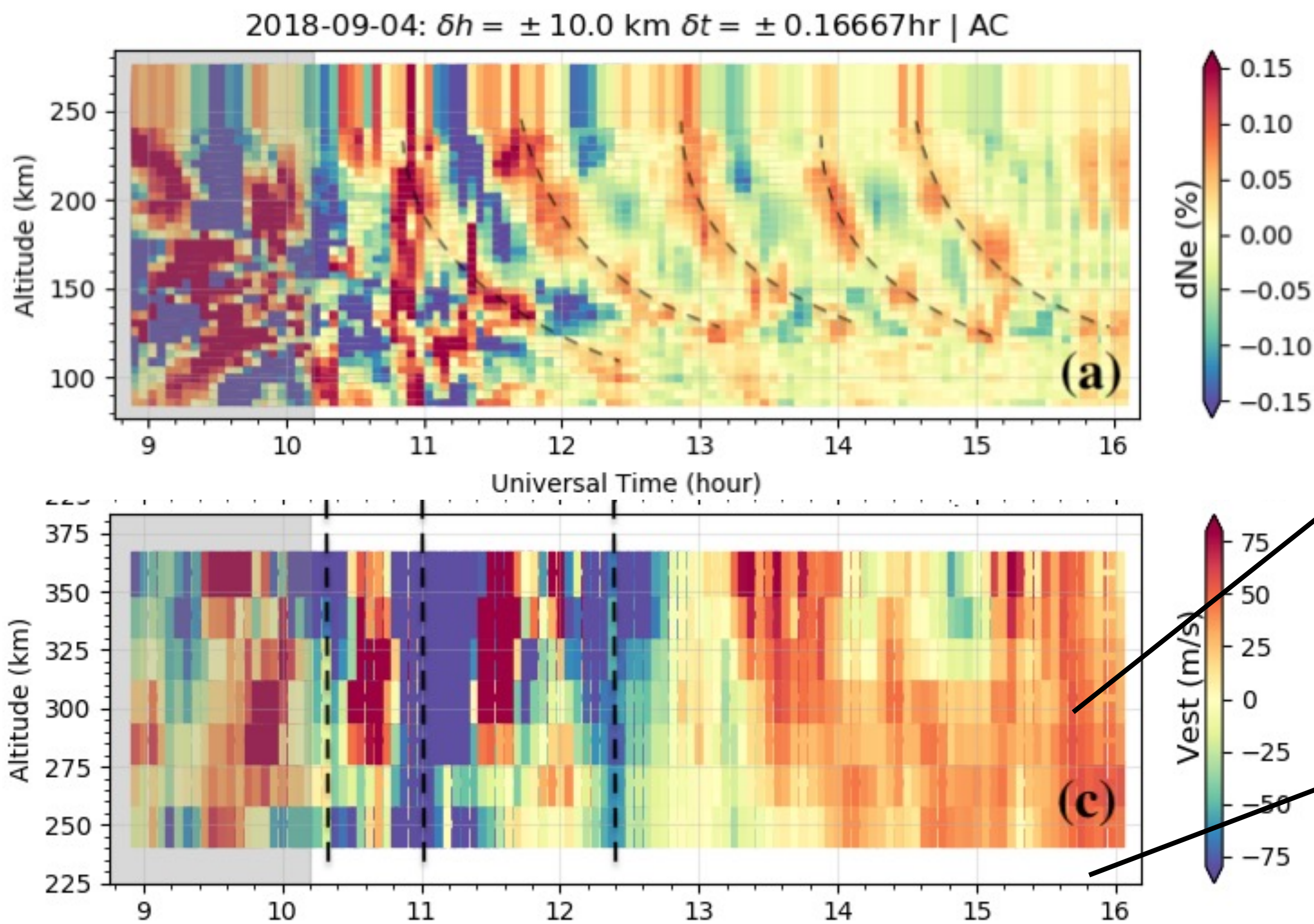
Post-sunrise TIDs at Millstone Hill

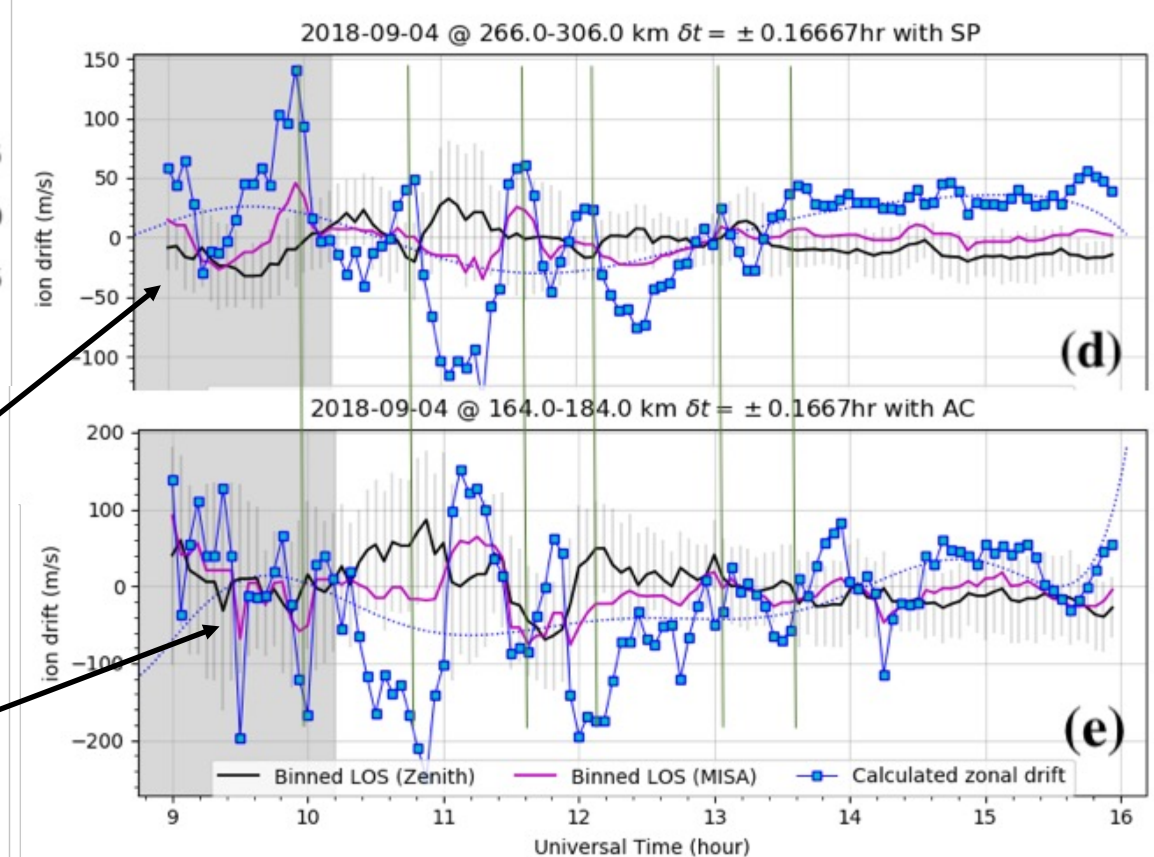
MHISR Plasma-line on two antennas



- **GWs at terminator**
- **TIDs are electrified**







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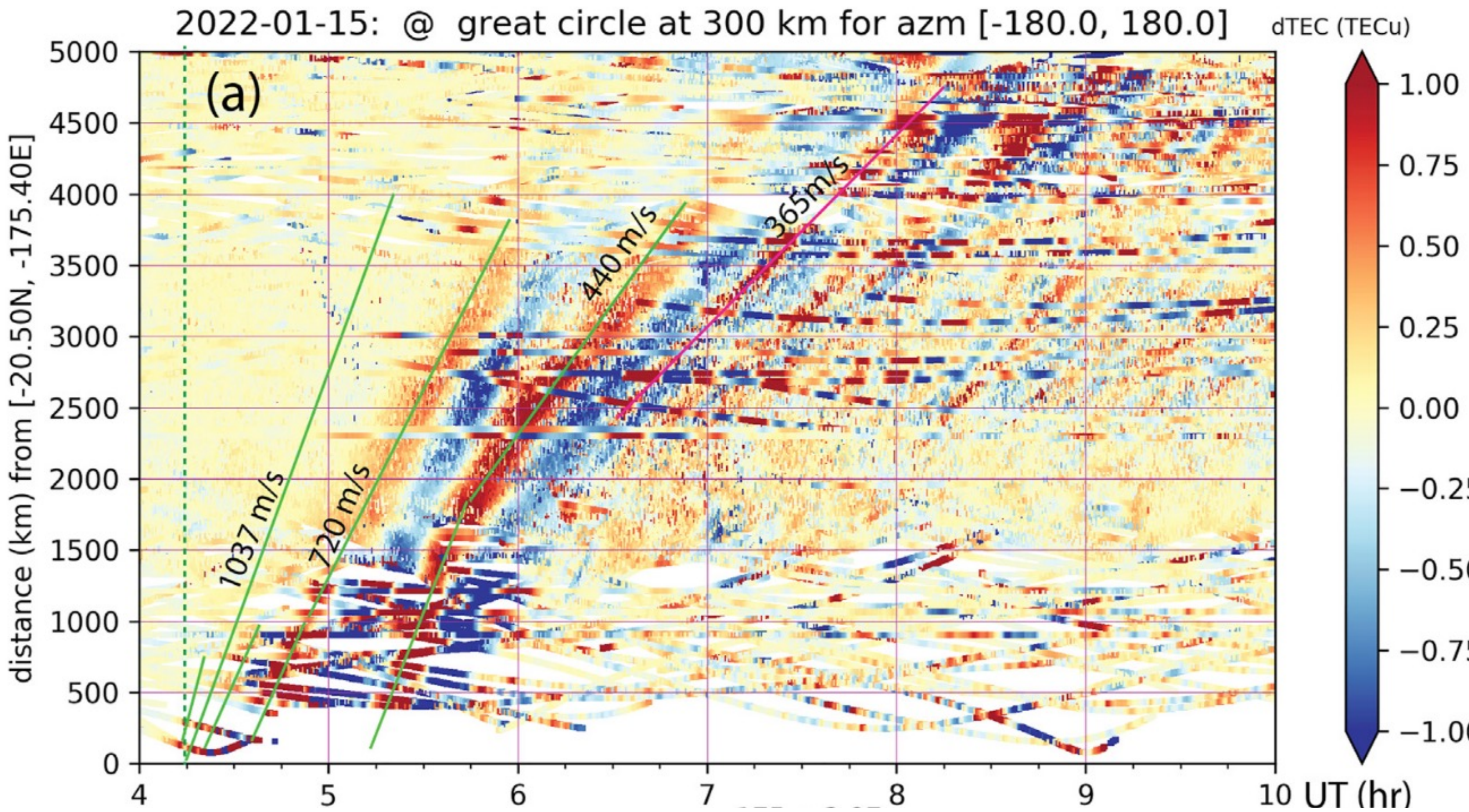
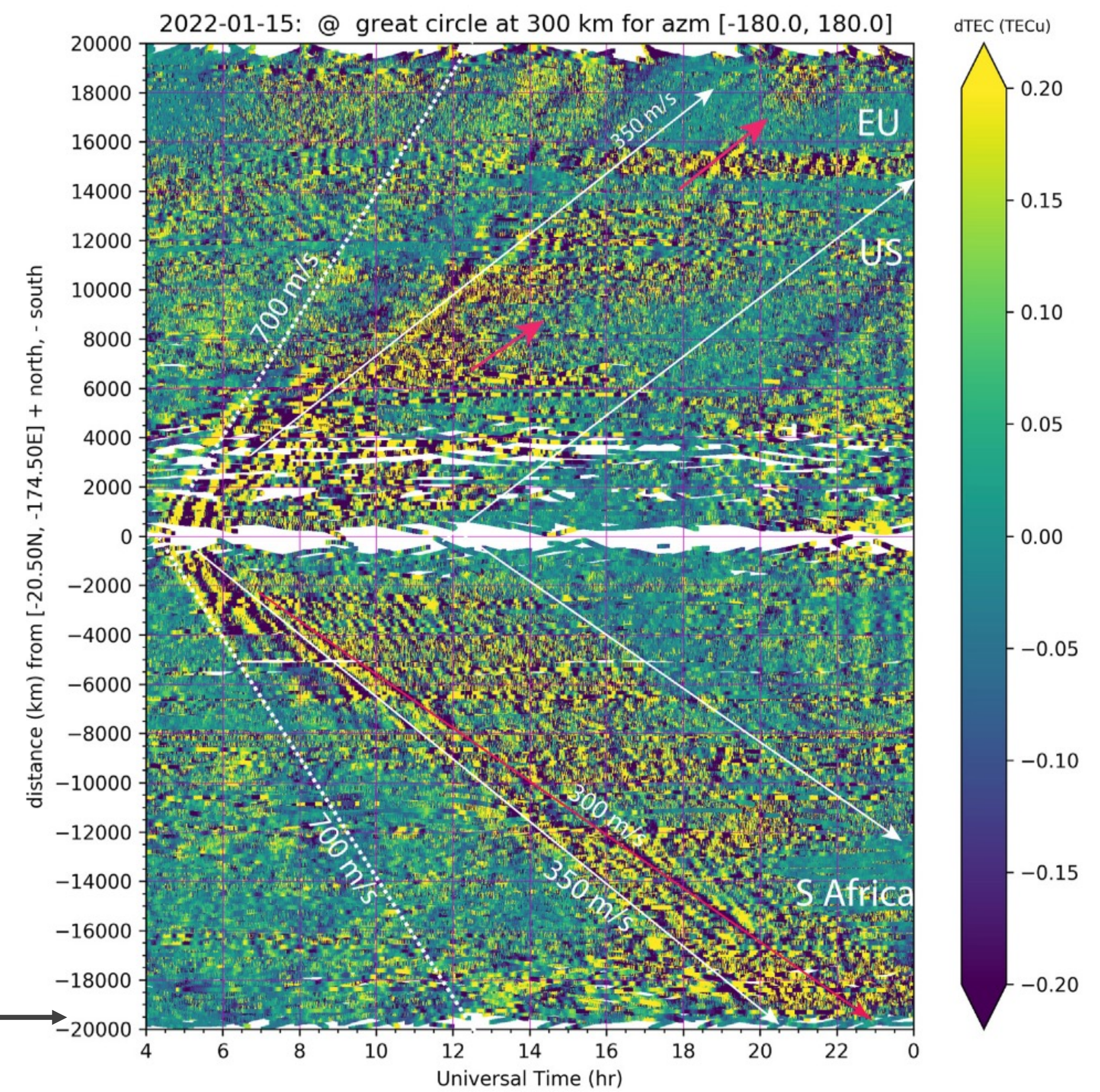
Zhang, S.-R, Erickson, P. J., Gasque, L. C., Aa, E., Rideout, W., Vierinen, J., Goncharenko, L. P. & Coster, A. J. (2021). Electrified Postsunrise Ionospheric Perturbations at Millstone Hill. *Geophysical Research Letters*, *48*(18), e2021GL095151. https://doi.org/10.1029/2021gl095151

Tonga eruption TIDs

Near-field diverse types of TIDs

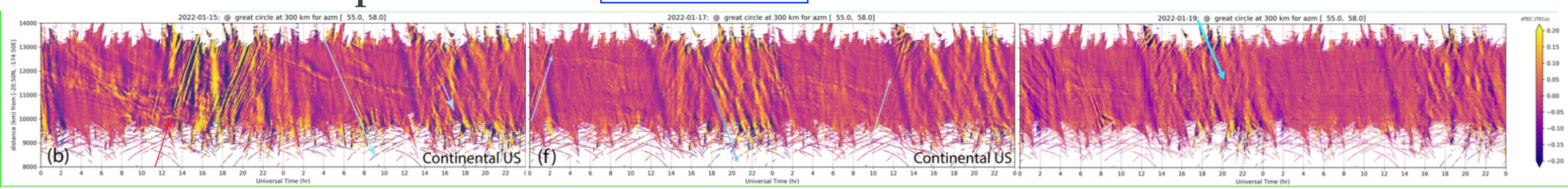




Certain TIDs propagated globally

300-350 m/s

Certain TIDs were persistent



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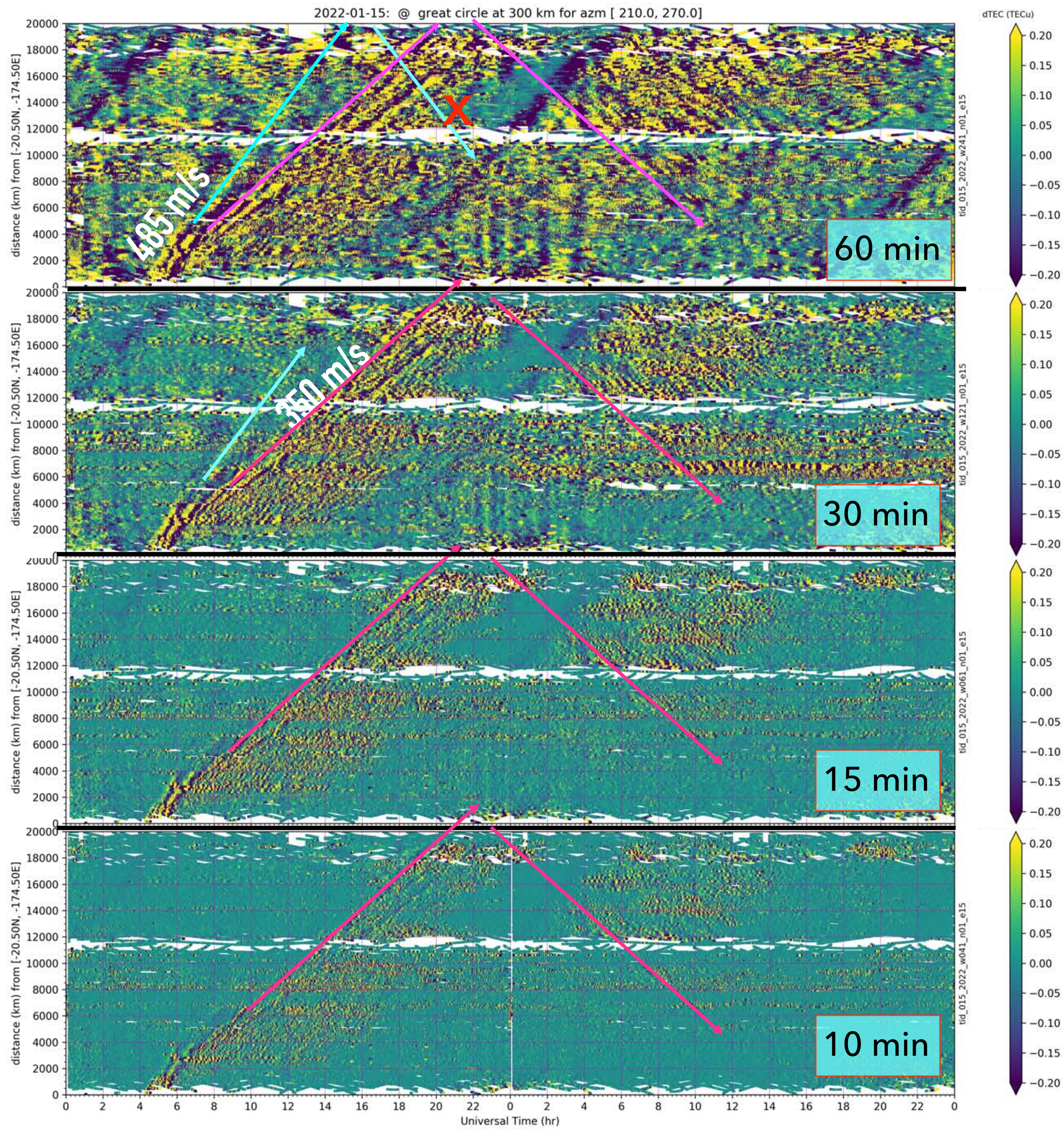
Zhang, S.-R., Vierinen, J., Aa, E., Goncharenko, L. P., Erickson, P. J., Rideout, W., Coster, A. J. & Spicher, A. (2022). 2022 Tonga Volcanic Eruption Induced Global Propagation of Ionospheric Disturbances via Lamb Waves. *Frontiers in Astronomy and Space Sciences*, *9*, 871275. https://doi.org/10.3389/fspas.2022.871275

Different categories of TIDs

- TIDs at 485 m/s, appear to have reached 20K distance (near antipode) but don't seem to continue propagating
  - A large impulsive wavefront, of > 30 min width.
  - They started at SW azimuth; **not visible everywhere**
- TIDs at ~350 m/s were persistent globally, with a range of periods from <10 min (acoustic waves) to longer time (gravity waves)



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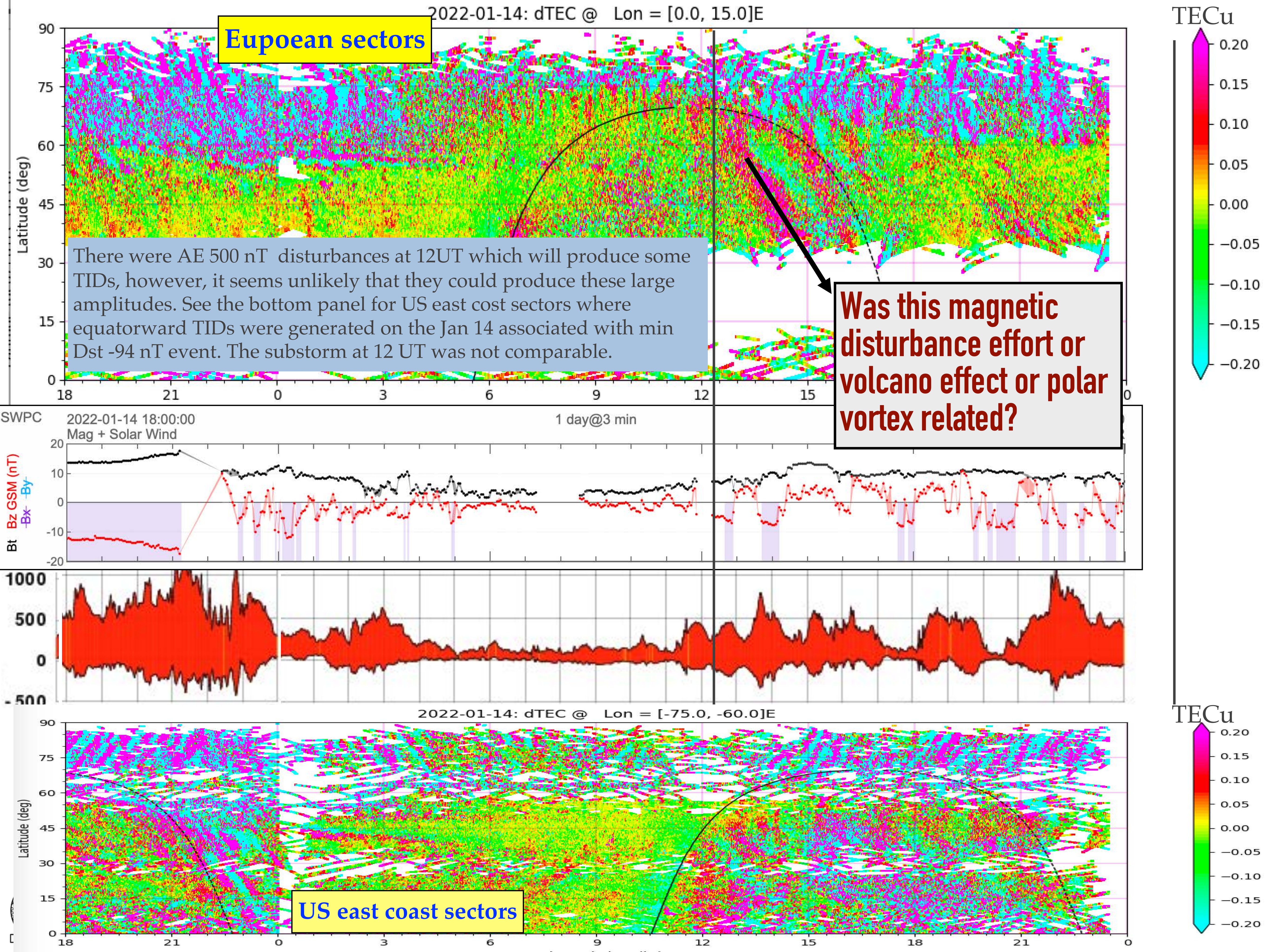
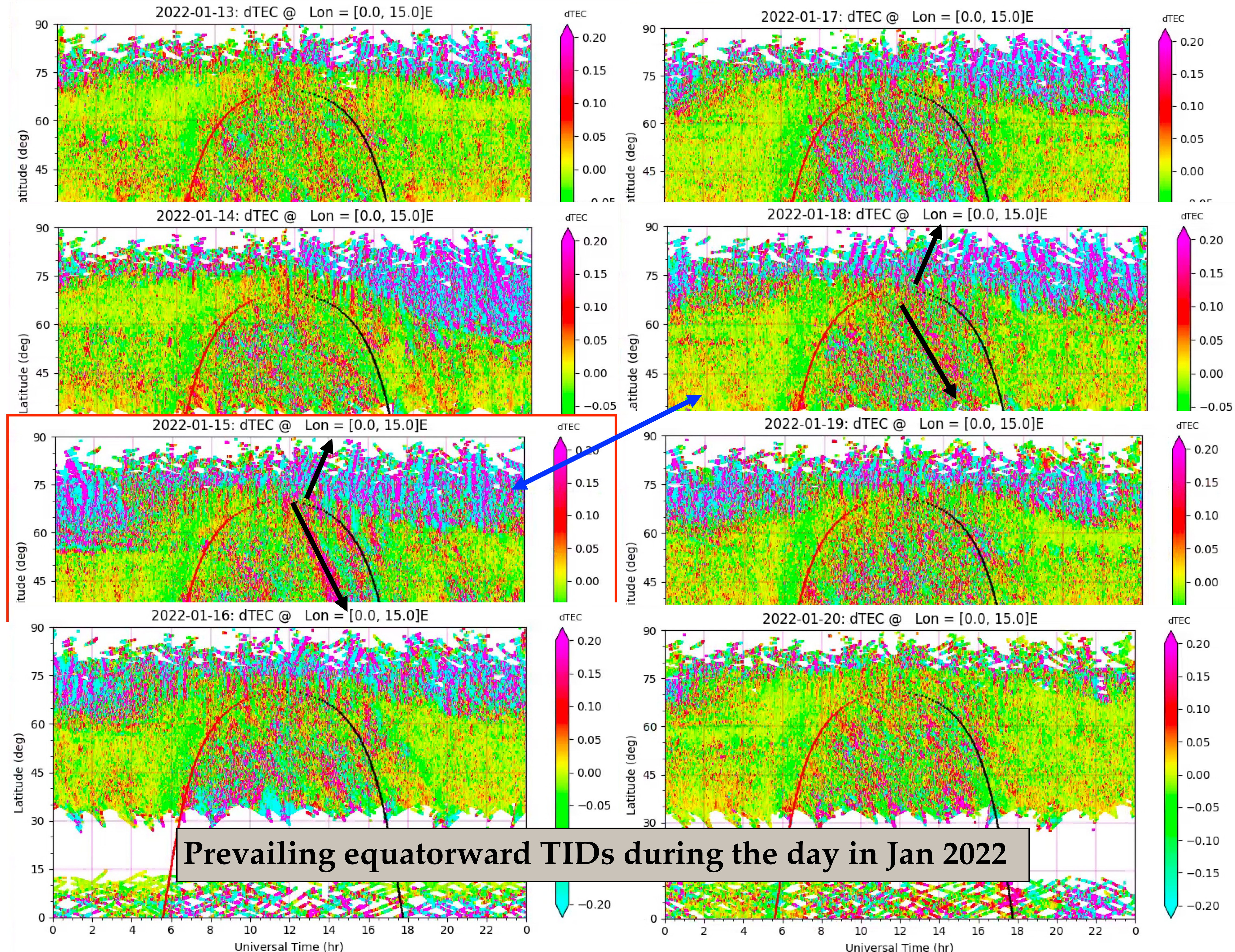


2022-01-14: dTEC @ Lon = [0.0, 15.0]E
Eupoean sectors
Latitude (deg)
TECu
There were AE 500 nT disturbances at 12UT which will produce some TIDs, however, it seems unlikely that they could produce these large amplitudes. See the bottom panel for US east cost sectors where equatorward TIDs were generated on the Jan 14 associated with min Dst -94 nT event. The substorm at 12 UT was not comparable.
Was this magnetic disturbance effort or volcano effect or polar vortex related?
SWPC
2022-01-14 18:00:00
Mag + Solar Wind
1 day@3 min
Bt Bz GSM (nT) Bx By
2022-01-14: dTEC @ Lon = [-75.0, -60.0]E
US east coast sectors



Prevailing equatorward TIDs during the day in Jan 2022

Conclusions

- TIDs are vital manifestation of fundamental geospace-atmosphere coupling processes, tracking their effects on the ionosphere.
- **Dense (high spatial-temporal res) ionospheric observations** with wide coverage can facilitate new findings of TIDs, advancing our understanding of geospace-atmosphere coupling.
- Understanding some of those TID observations remains a significant challenge: their excitation, propagation, and dispersion processes are still poorly known.

Thank you to the global GNSS communities who have made these studies possible

GPS TEC data products and access through the Madrigal distributed data system are provided to the community by the Massachusetts Institute of Technology under support from US National Science Foundation grant AGS-1952737. Data for the TEC processing is provided from the following organizations: **UNAVCO**, Scripps Orbit and Permanent Array Center, Institut Geographique National, France, **International GNSS Service**, The Crustal Dynamics Data Information System (**CDDIS**), National Geodetic Survey, Instituto Brasileiro de Geografia e Estatística, RAMSAC CORS of Instituto Geográfico Nacional de la República Argentina, Arecibo Observatory, Low-Latitude Ionospheric Sensor Network (**LISN**), **Canadian High Arctic Ionospheric Network,** Institute of Geology and Geophysics, Chinese Academy of Sciences, China Meteorology Administration, Centro di Ricerche Sismologiche, Système d'Observation du Niveau des Eaux Littorales (SONEL), RENAG: REseau NAtional GNSS permanent - https: //doi. org/10. 15778/resif. rg, GeoNet - the official source of geological hazard information for New Zealand, Finnish Meteorological Institute, SWEPOS - Sweden, Hartebeesthoek Radio Astronomy Observatory, TrigNet Web Application, South Africa, Australian Space Weather Services, RETE INTEGRATA NAZIONALE GPS, Estonian Land Board, TU Delft, Western Canada Deformation Array, EUREF Permanent GNSS Network, GeoDAF: Geodetic Data Archiving Facility, African Geodetic Reference Frame (AFREF), Kartverket - Norwegian Mapping Authority, Geoscience Australia, IGS Data Center of Wuhan University, Pacific Northwest Geodetic Array, Nevada Geodetic Laboratory, Earth Observatory of Singapore, National Time and Frequency Standard Laboratory - Taiwan, and Korea Astronomy and Space Science nstitute.

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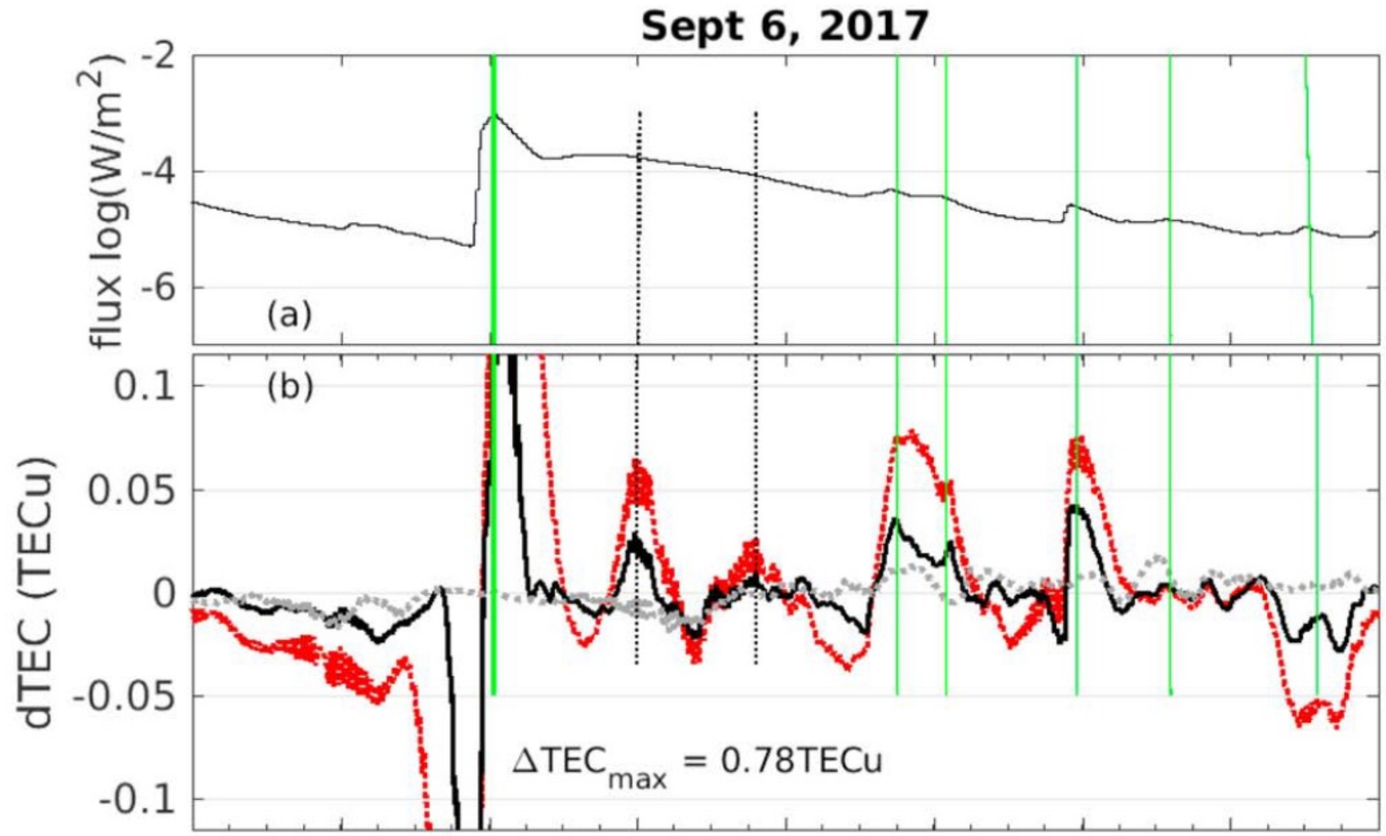

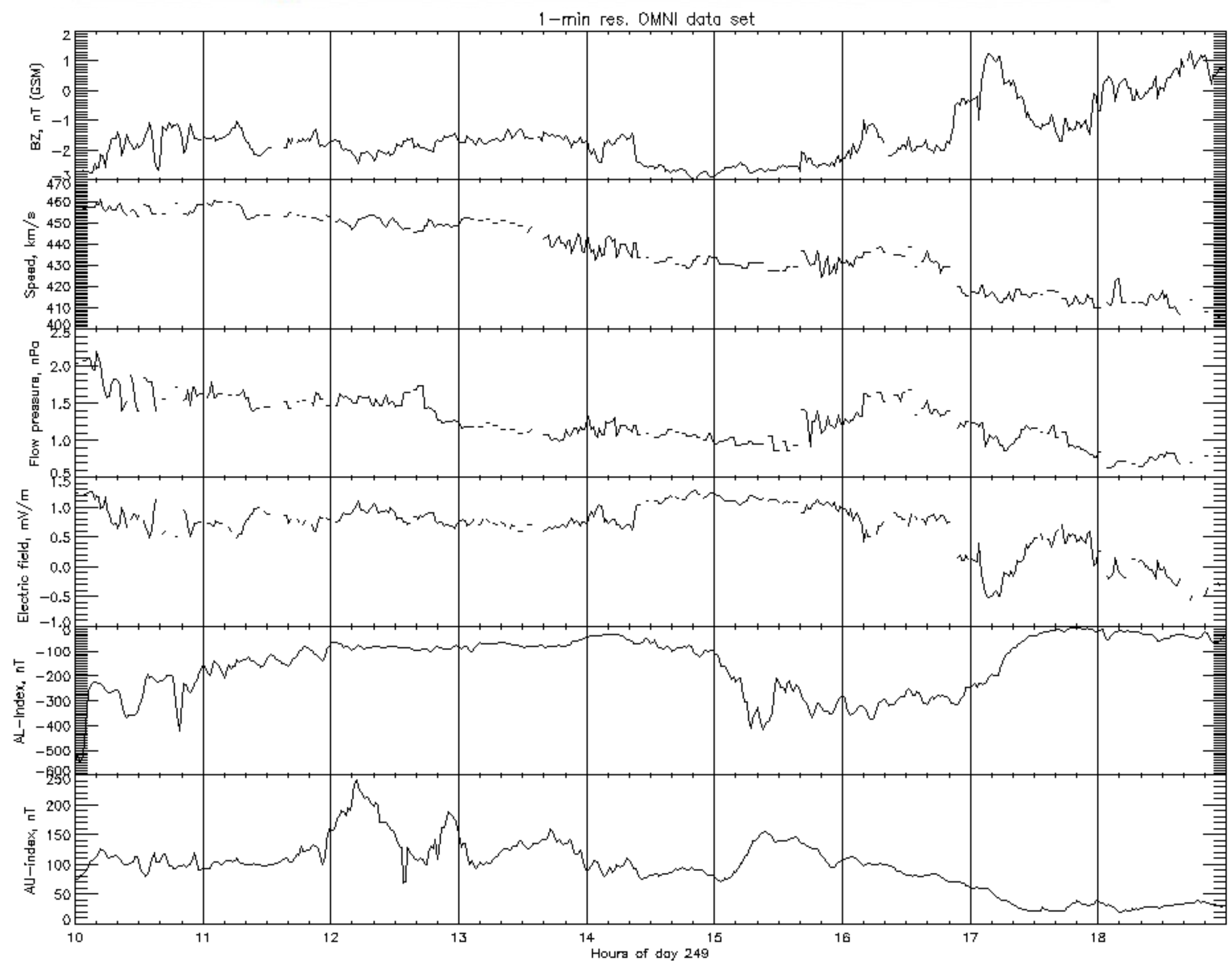

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