The Study of Continental-scale Poleward Medium Scale Ionospheric Traveling Disturbances Observed at Middle Ltitudes

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01 Background

1.1 Introduction of MSTIDs

1 **Definition:** MSTIDs are wave-like disturbances in the ionospheric plasma density.

2 **Characteristics:** spatial scale (100 - 500 km wavelength) and propagation (often 100 - 500 m/s).

3 **Primary Generation Mechanism:**

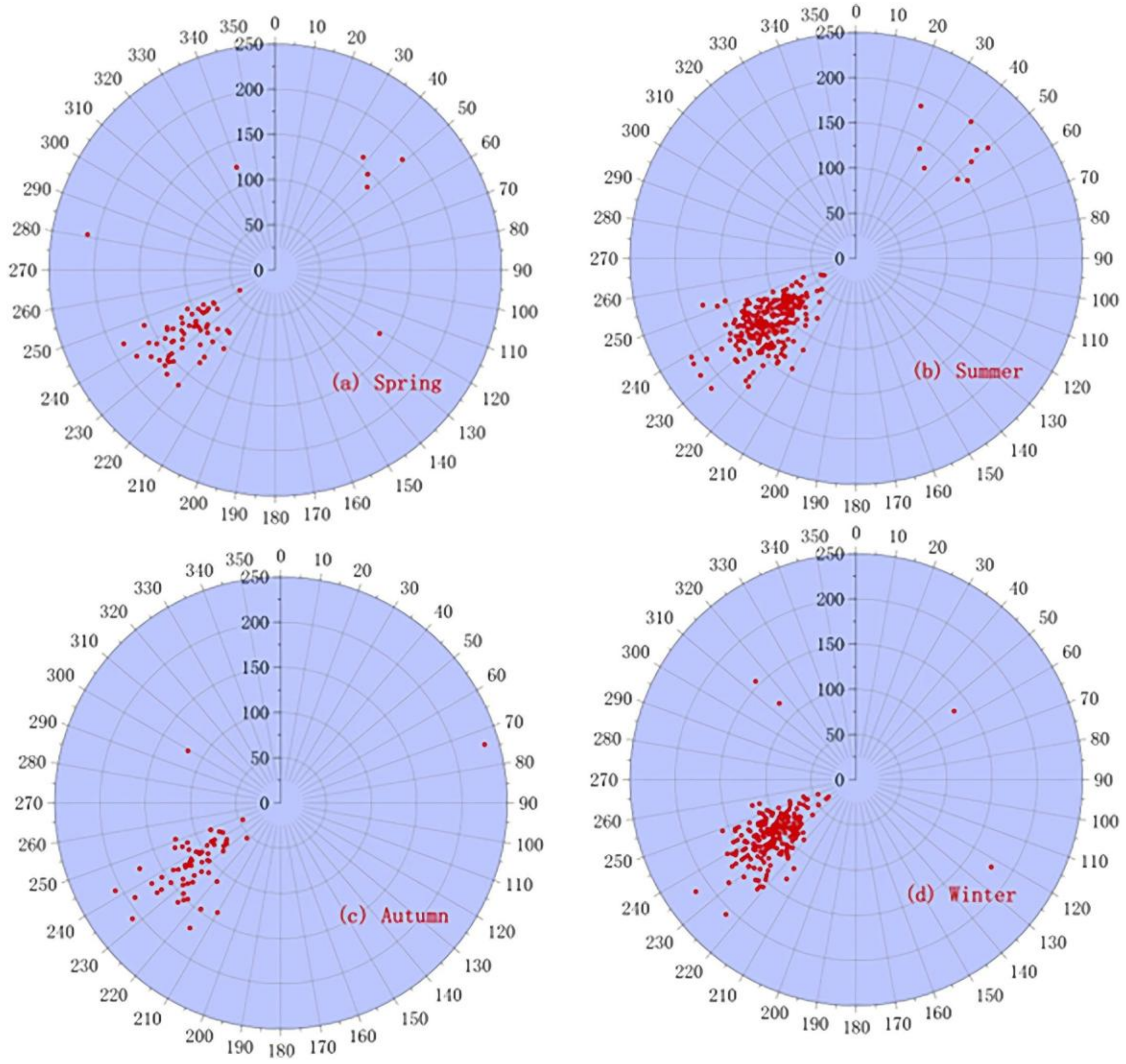
- **Atmospheric Gravity Waves** (AGWs): originate in the lower atmosphere, propagate upward into the thermosphere and ionosphere.
- **Perkins instability:** The interaction between the ionospheric background electric field and the electron density gradient results in the spontaneous growth of plasma wave-like disturbances.

4 **Other Contributing Factors:**

- **Neutral wind**: Gravity waves propagating in the direction opposite to that of the neutral wind typically exhibit a larger vertical wavelength, are less influenced by molecular viscosity, and have a higher probability of upward propagation.
- **Disturbances within the ionosphere**, such as polar and equatorial electric current anomalies, solar eclipse-induced ionospheric effects, and the diurnal terminator transitions caused by solar illumination on Earth's surface, may also contribute to ionospheric disturbances.
- **Polar vortex**: these observations suggest that polar atmospheric processes are primarily responsible for controlling the occurrence of high-latitude and midlatitude winter daytime MSTIDs.

1.2 Characteristics and mechanisms of poleward MSTIDs

➢ **In the mid-latitude region of the Asia**



The statistical results of the Xinglong airglow imager (40°N, 117°E) show that:

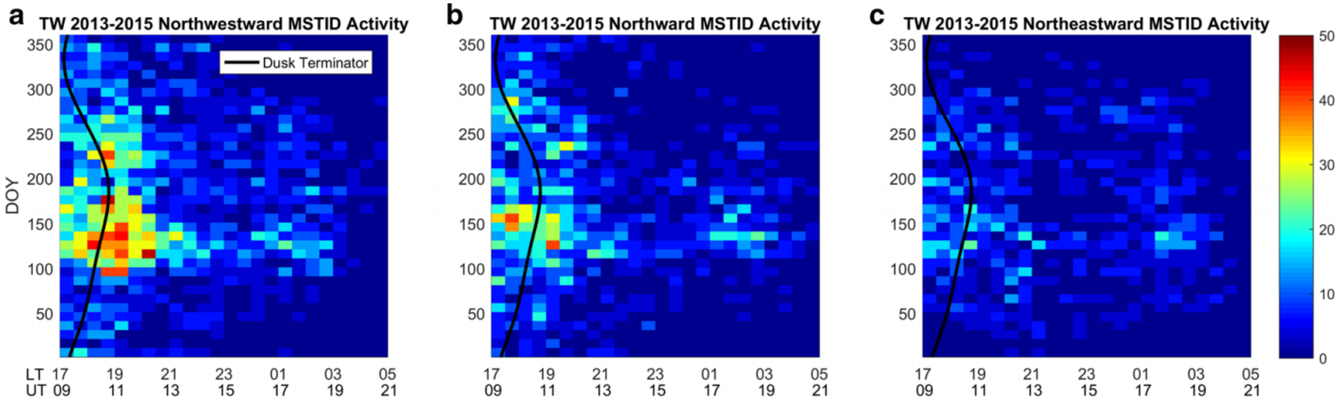
1. The occurrence rate of night-time poleward MSTIDs is extremely low, accounting for only about 4% of the total events.

2. The night-time poleward MSTIDs mainly occur in summer (northeastward), and there are also a few events in spring.

[Lai C. et al., 2023]

1.2 Characteristics and mechanisms of poleward MSTIDs

➢ **In the low-latitude region of the Asia**



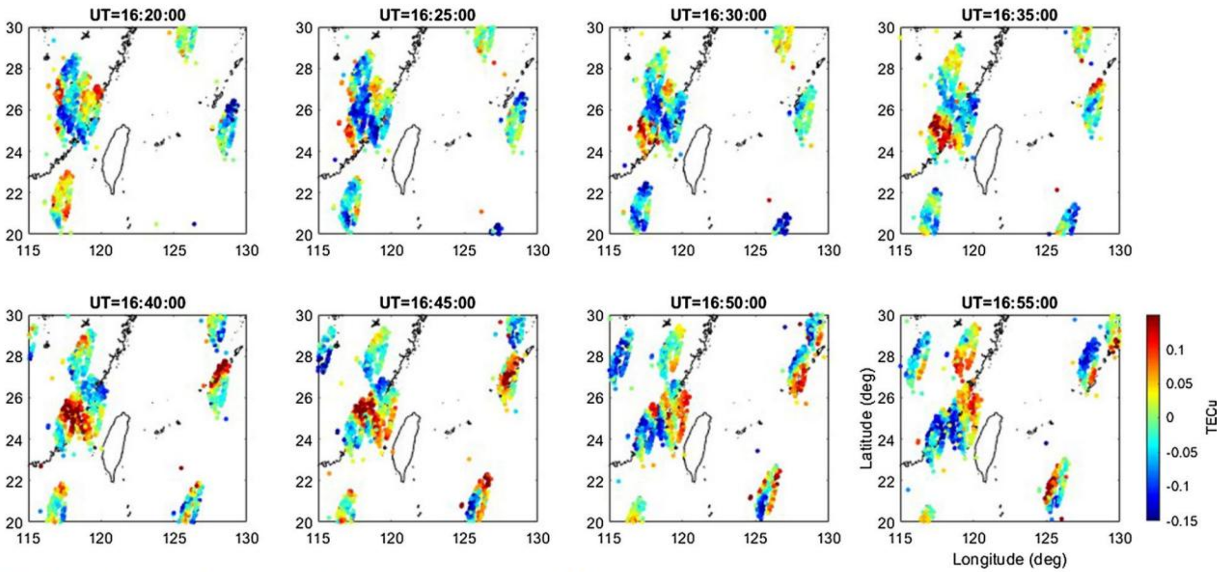


Fig. 9 Two-dimensional filtered GNSS-TEC maps over Taiwan on 29 April 2020

1. Poleward MSTIDs mainly occurs within 2 to 3 hours near sunset, with the northwest direction being dominant.
2. The characteristics of these MSTIDs and modeled atmospheric waves from the high-resolution Whole Atmosphere Community Climate Model (WACCM) suggest that nighttime MSTIDs in summer are likely connected to atmospheric gravity waves (AGWs).

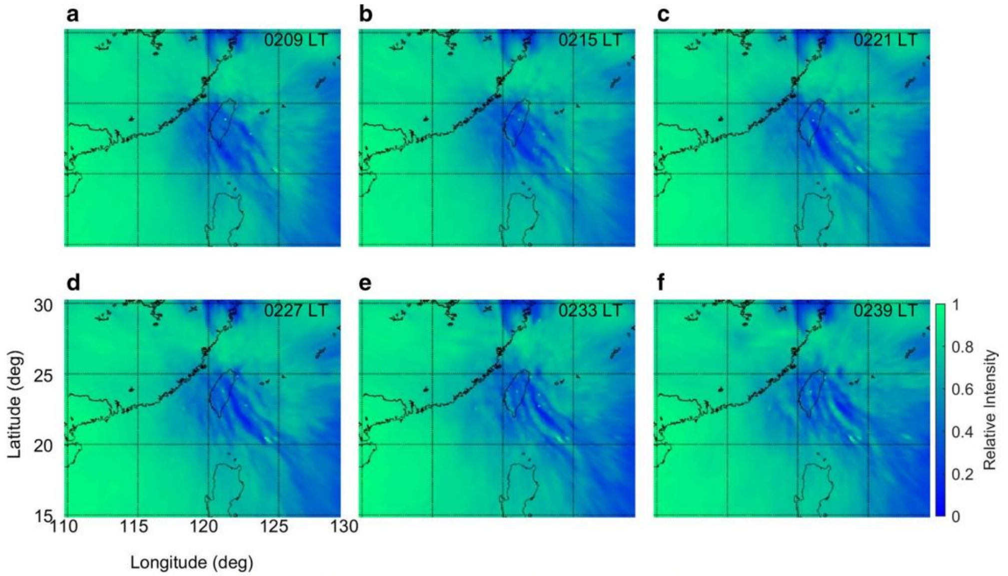


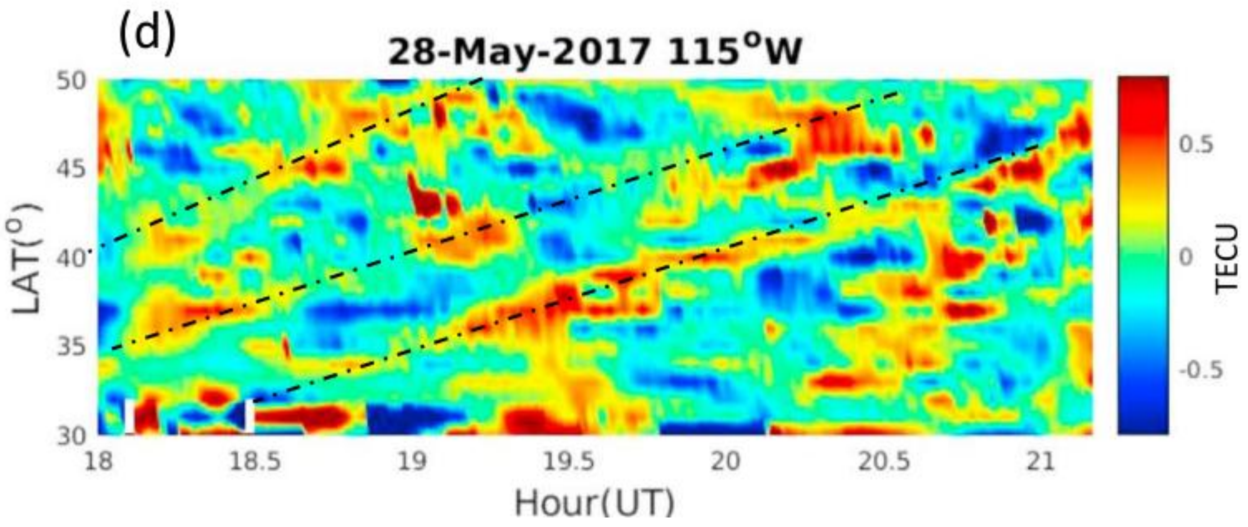
Fig. 8 The λ557 nm airglow images derived from Tainan Astronomical Education Area on 29 April 2020

[Lai C. et al., 2023]

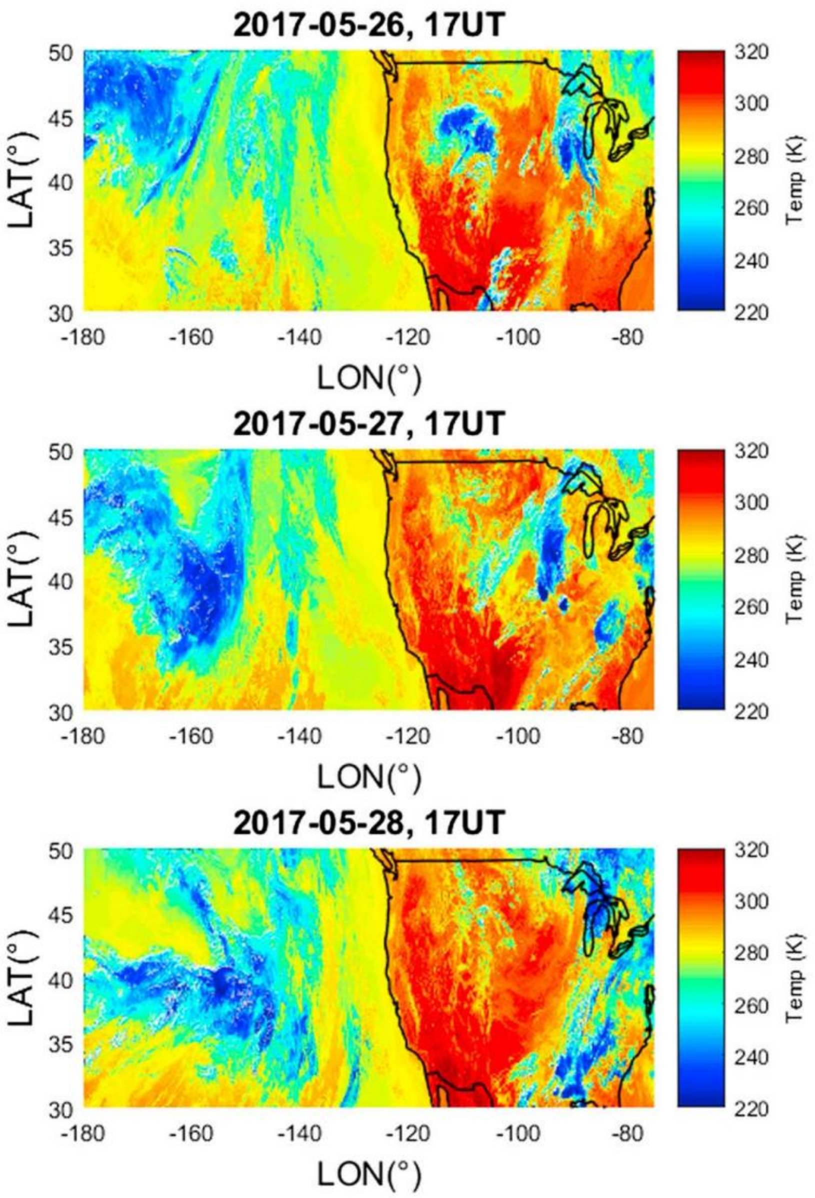
1.2 Characteristics and mechanisms of polarward MSTIDs

- **In the western region of the America**

Atmospheric gravity waves caused by intense atmospheric convection can trigger the poleward MSTIDs.



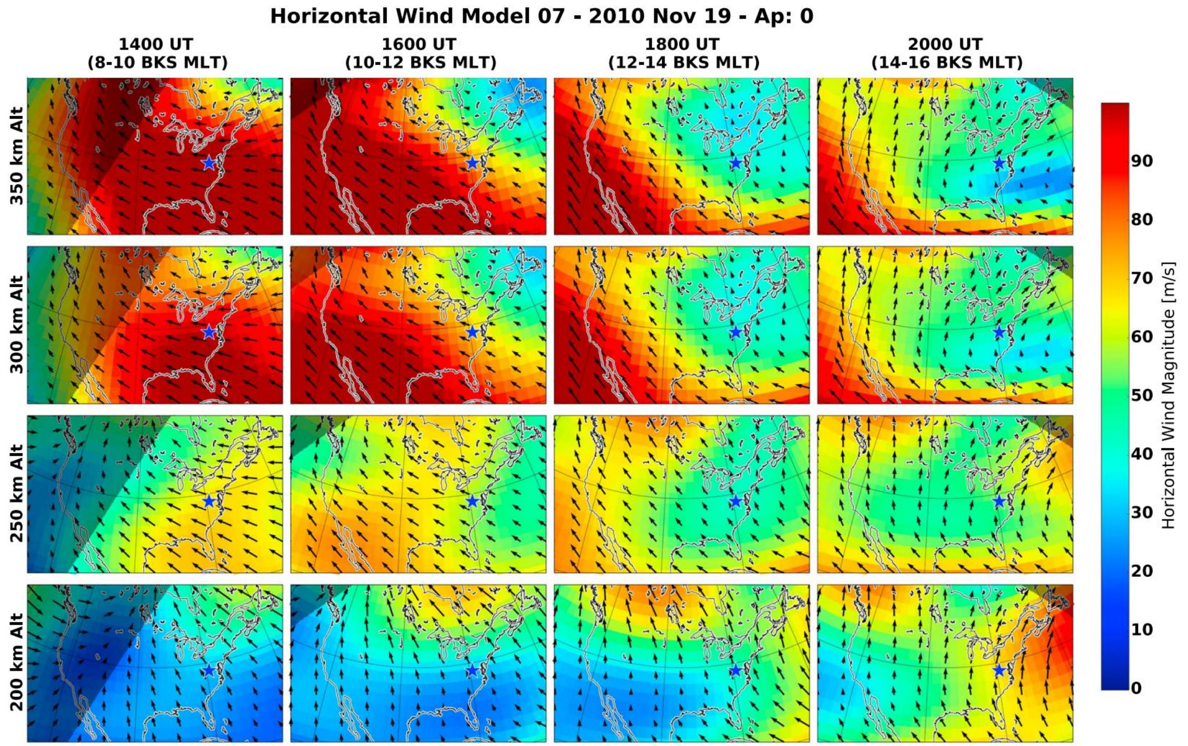
[O. F. Jonah. et al., 2018]

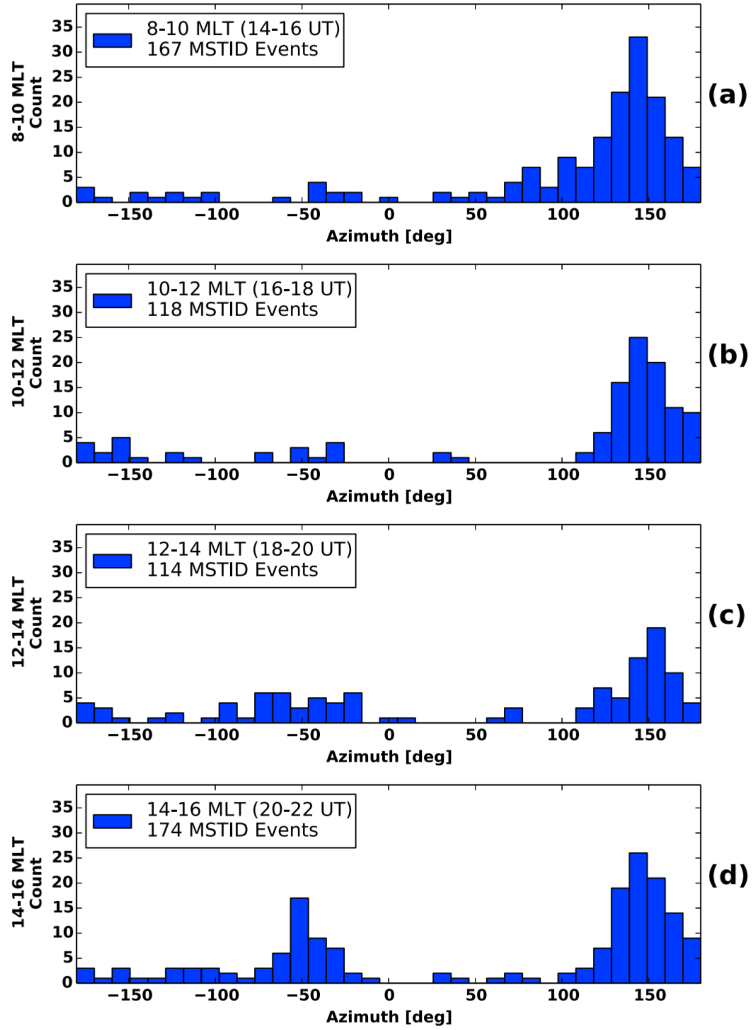


1.2 Characteristics and mechanisms of polarward MSTIDs

➢ **In the eastern region of the America**

The filtering of neutral wind might be the main cause of the occurrence of MSTIDs events spreading poleward.





[Frissell N. A. et al., 2014]

1.3 Scientific issues and research directions

- Previous studies on poleward MSTIDs have mostly been limited to a single station observation or in a localized region. What are the characteristics of their propagation in continental region, and what factors influence their process?

- The study investigated polarward MSTIDs in the mid-latitudes of the Northern Hemisphere by leveraging the long-term continuous observations and extensive field-of-view coverage provided by the SuperDARN radar network with the data from CN-DARN radars.

02 Observation

2.1 Instruments and data

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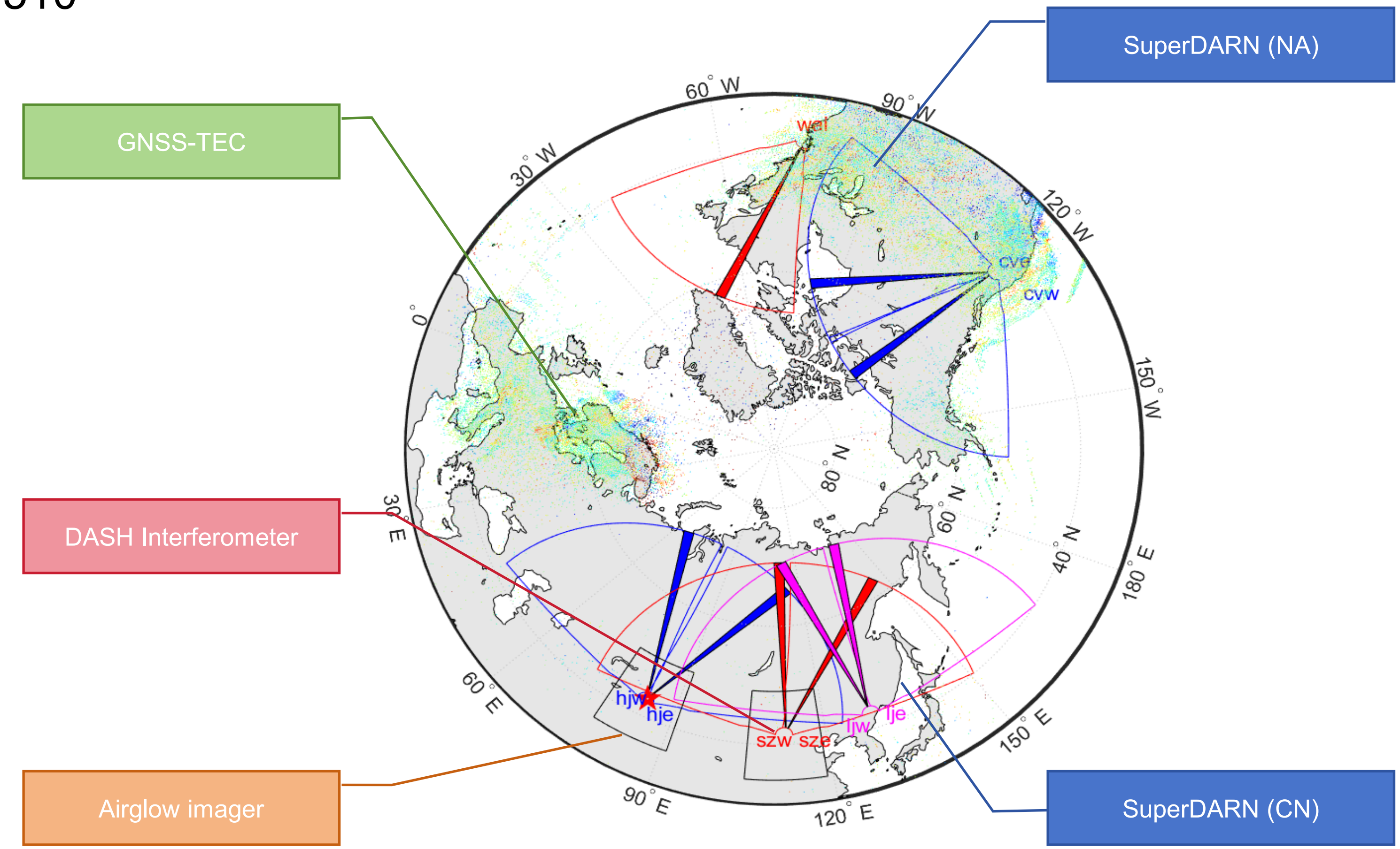
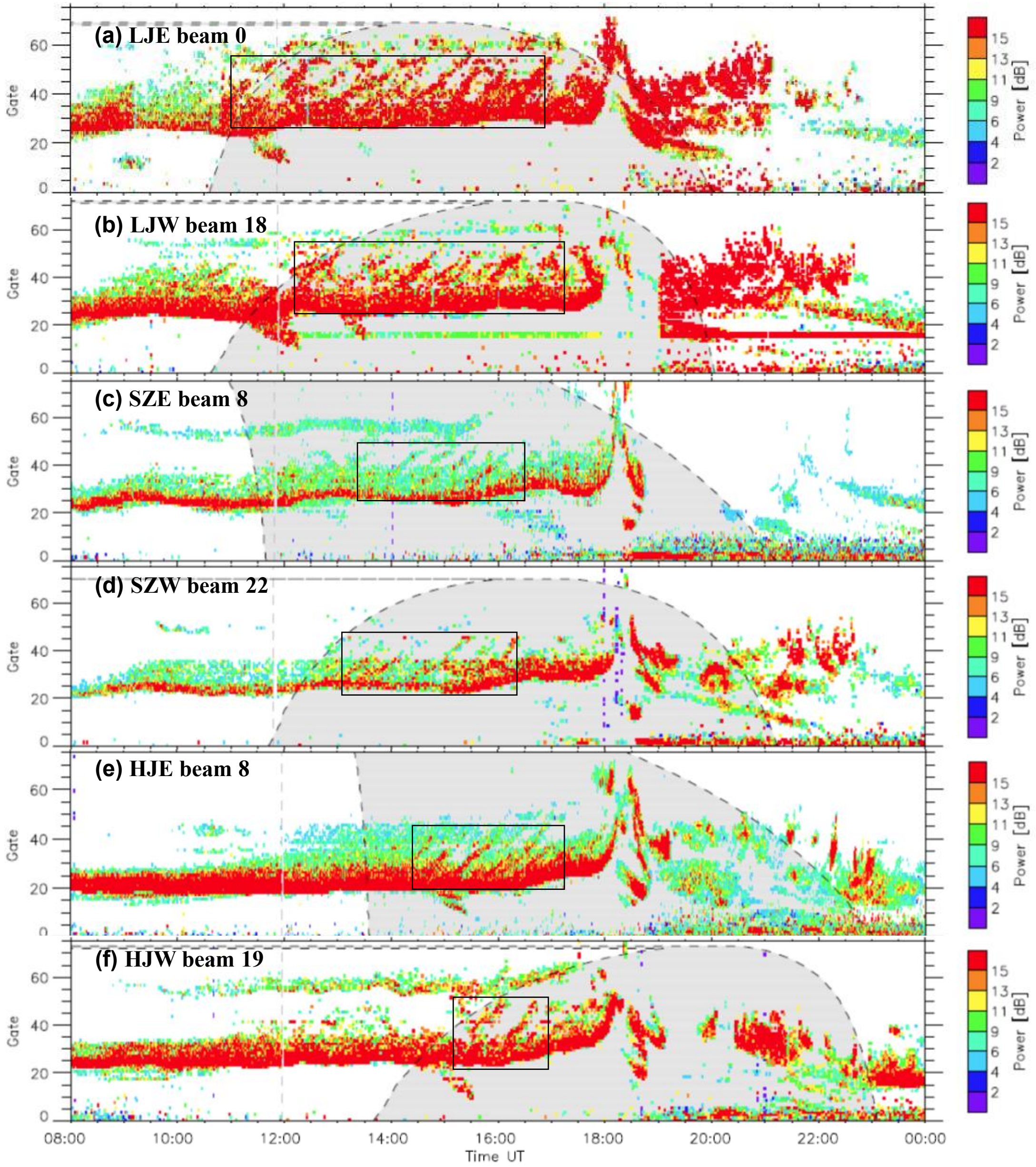
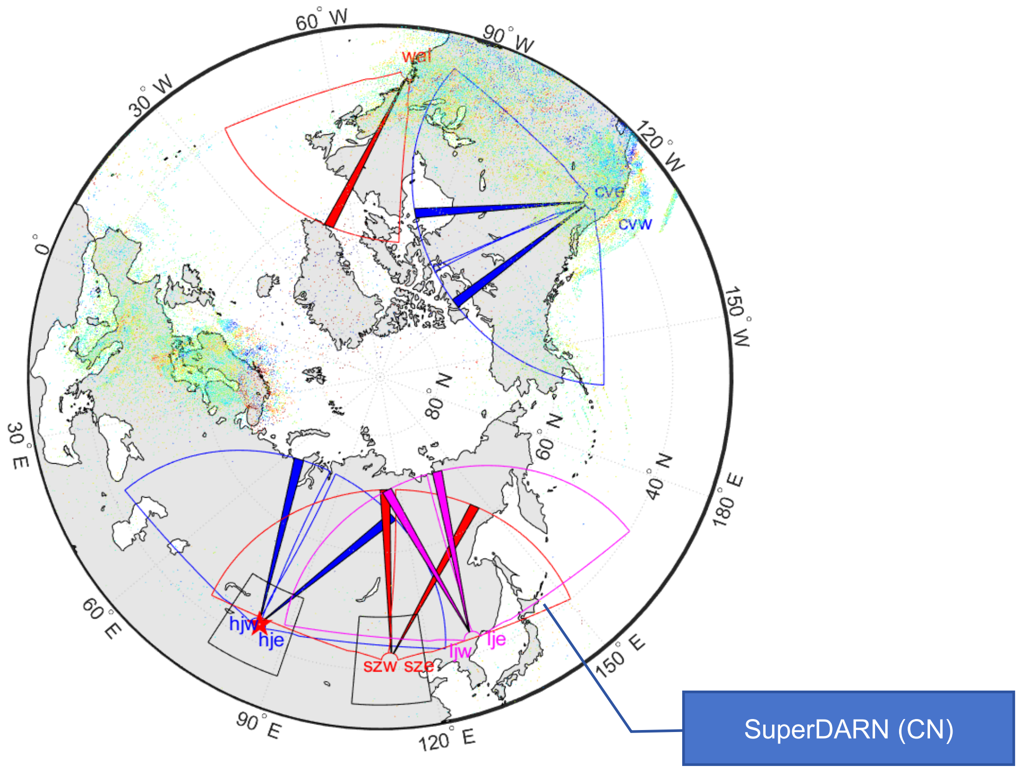


2.2 Observation in the Asia-- SuperDARN radars



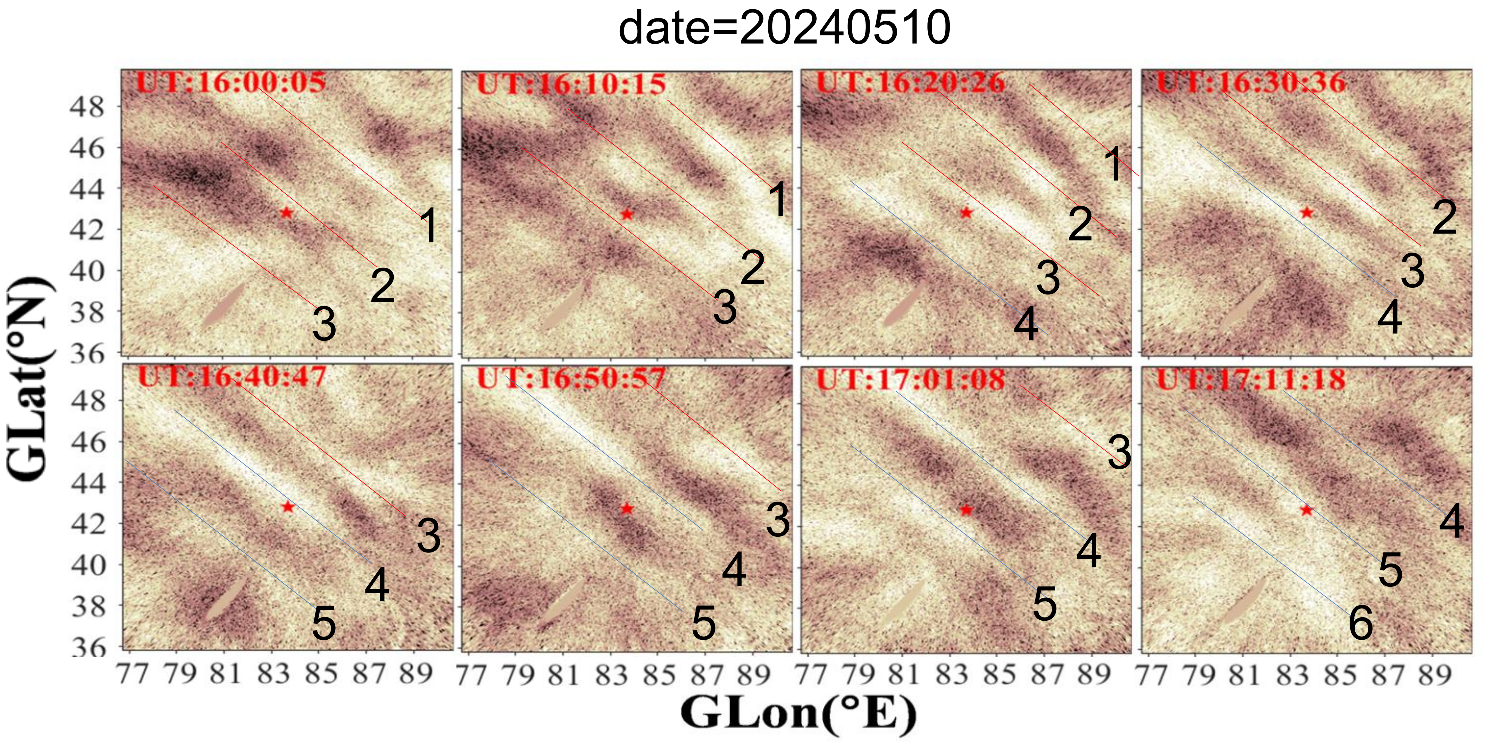
- The CN-DARN radars detected a large-scale, long-lasting (maximum: 6 hours) poleward MSTID event in May 10, 2024.

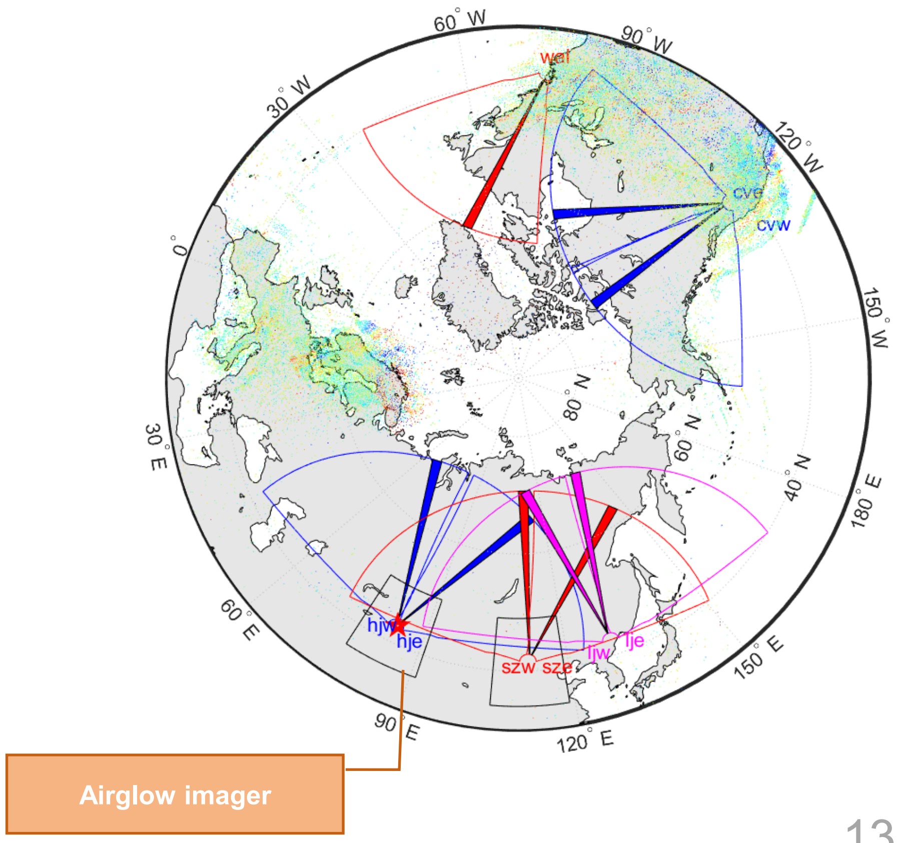
- This event occurred within 2 hours after sunset.



2.2 Observation in the Asia-- Airglow imager

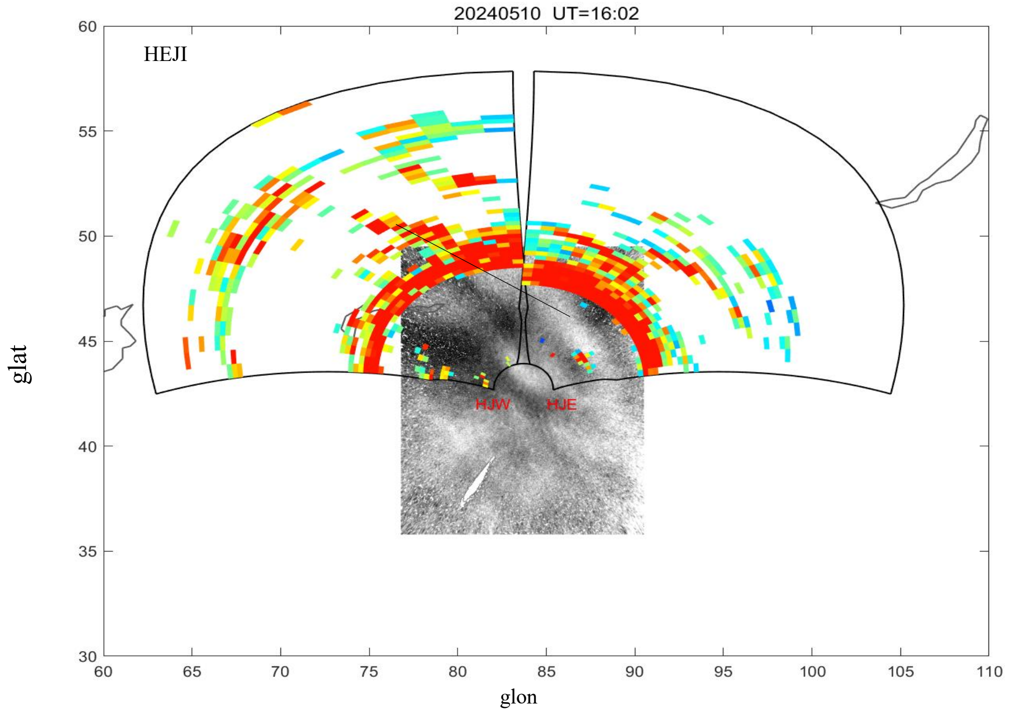
- The Hejing All-Sky Airglow Imager observed the poleward propagation MSTID event.
- This MSTID propagates in the northeast direction, with a wavelength of approximately 450 km and a wave velocity of approximately 270m/s.

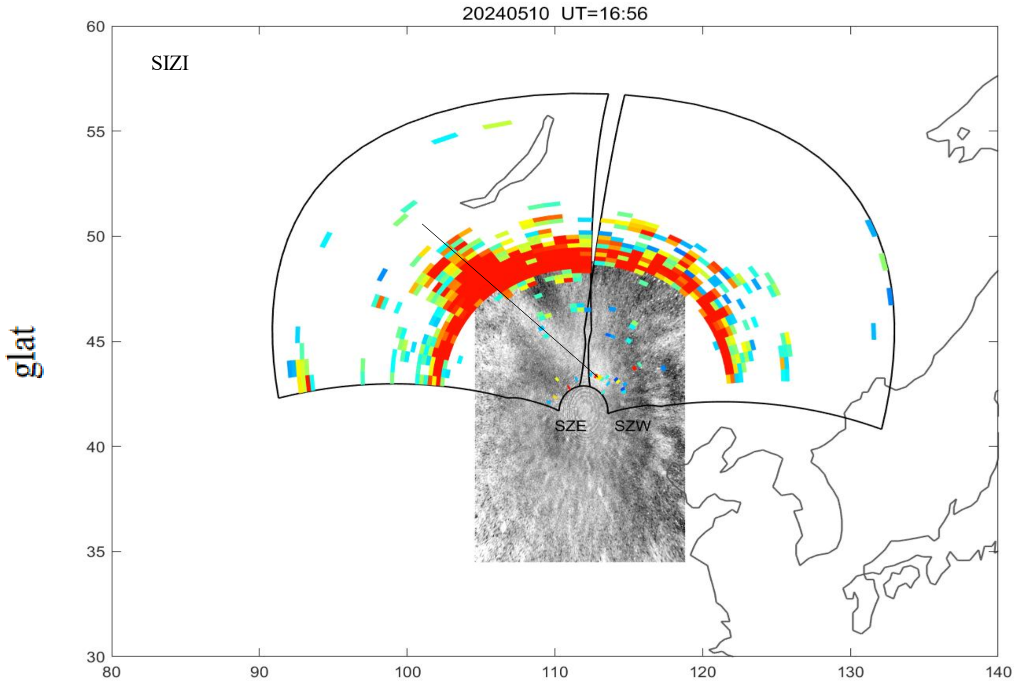




2.2 Observation in the Asia-- Airglow imager

➢ The observations of the polarward MSTID by the CN-DARN radars, Hejing All-Sky Airglow Imager and Siziwang All-Sky Airglow Imager are highly consistent.

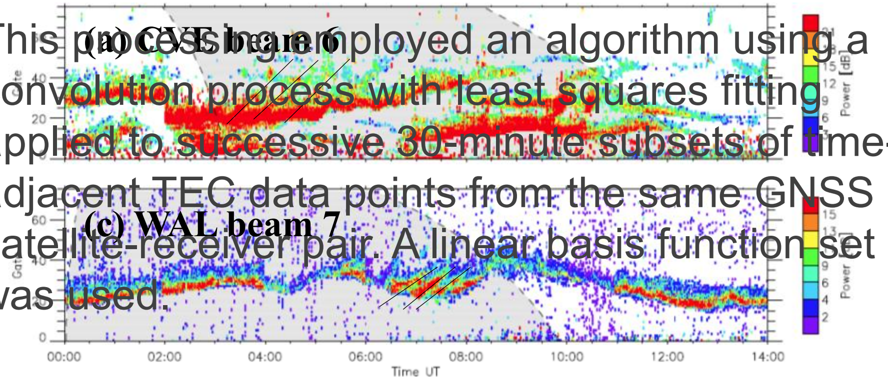


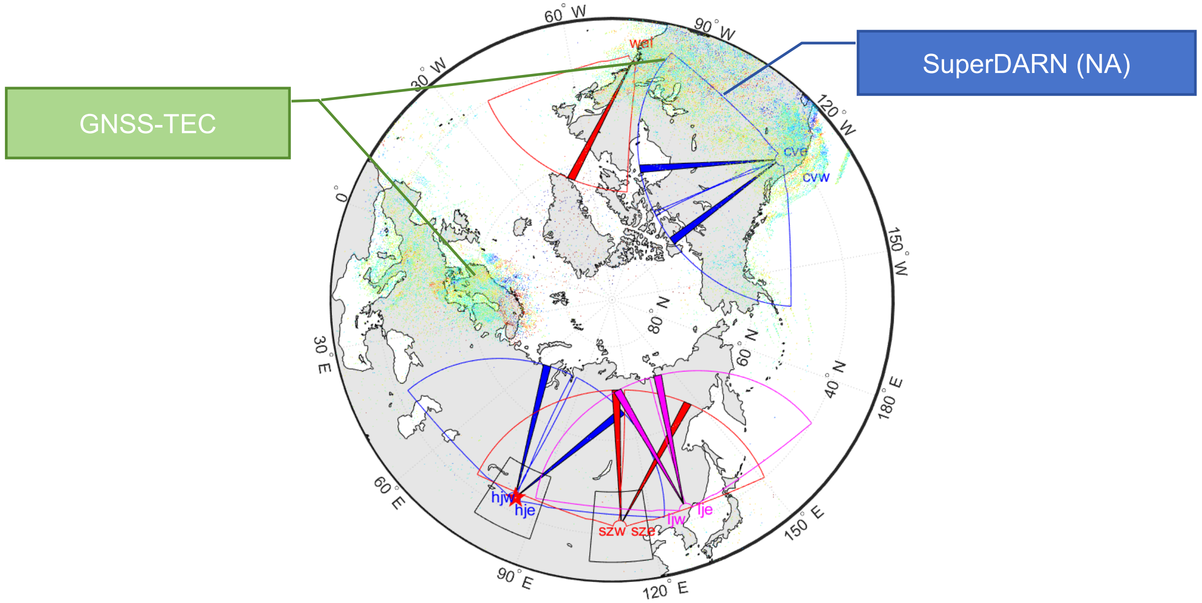


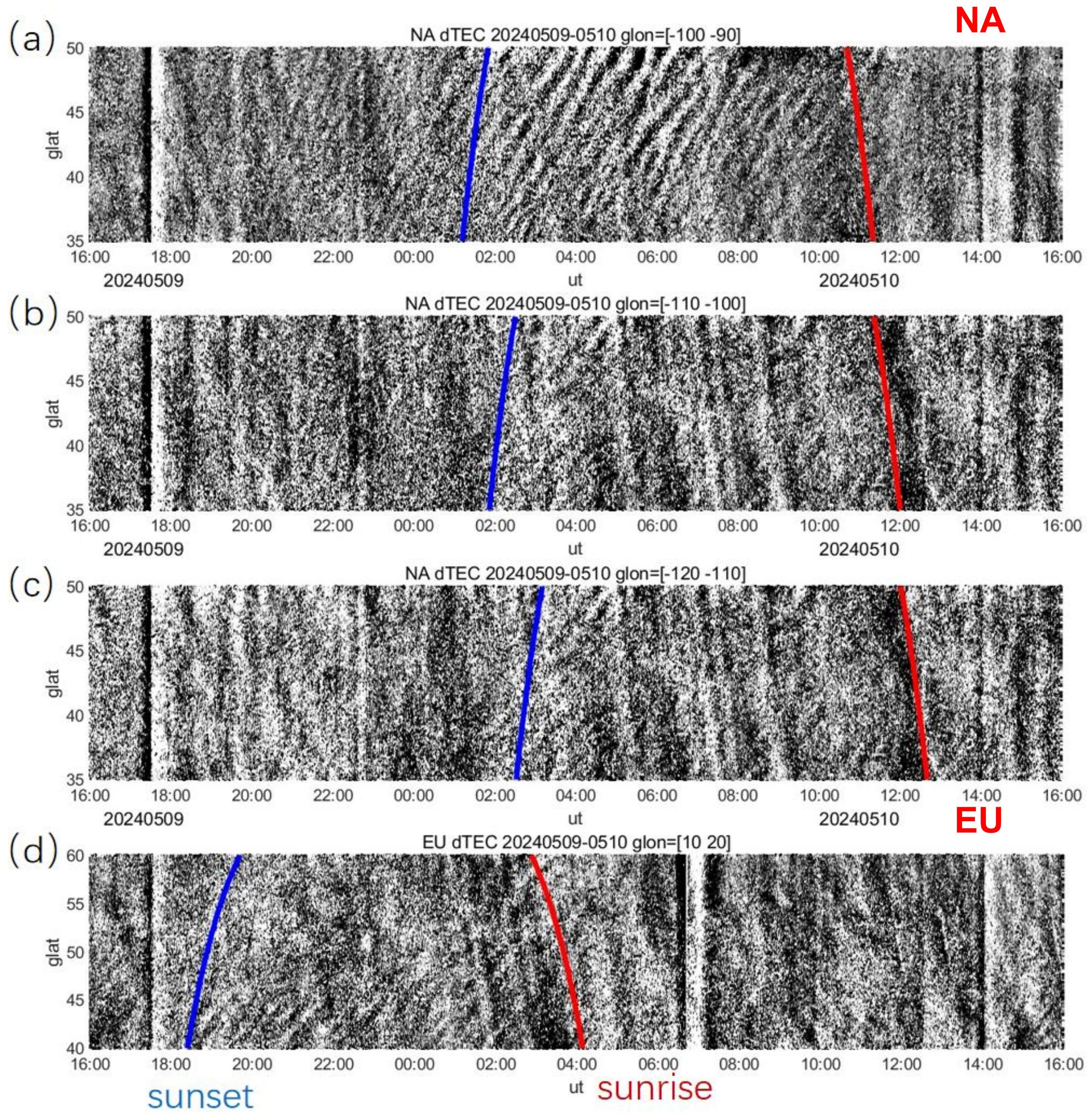
2.3 Observation in the America-- SuperDARN radars / GNSS-TEC

- Observational data obtained from the Americas and Europe also revealed MSTID signals propagating in the poleward direction during nighttime.

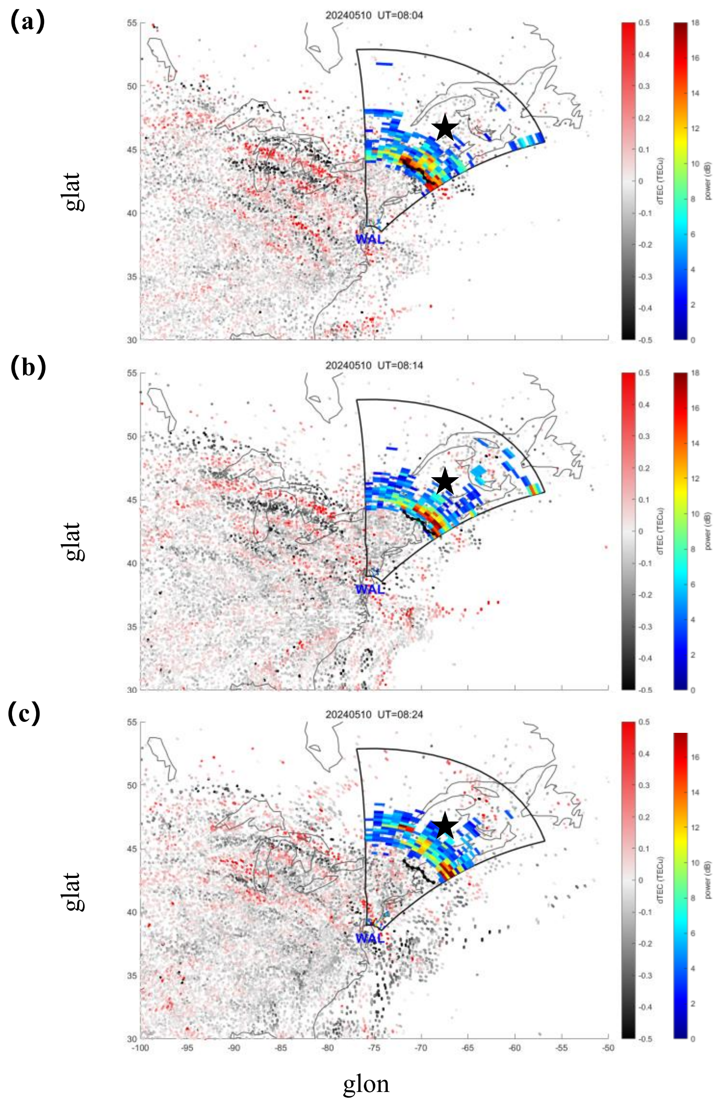
- This process has employed an algorithm using a convolution process with least squares fitting applied to successive 30-minute subsets of time-adjacent TEC data points from the same GNSS satellite-receiver pair. A linear basis function set was used.



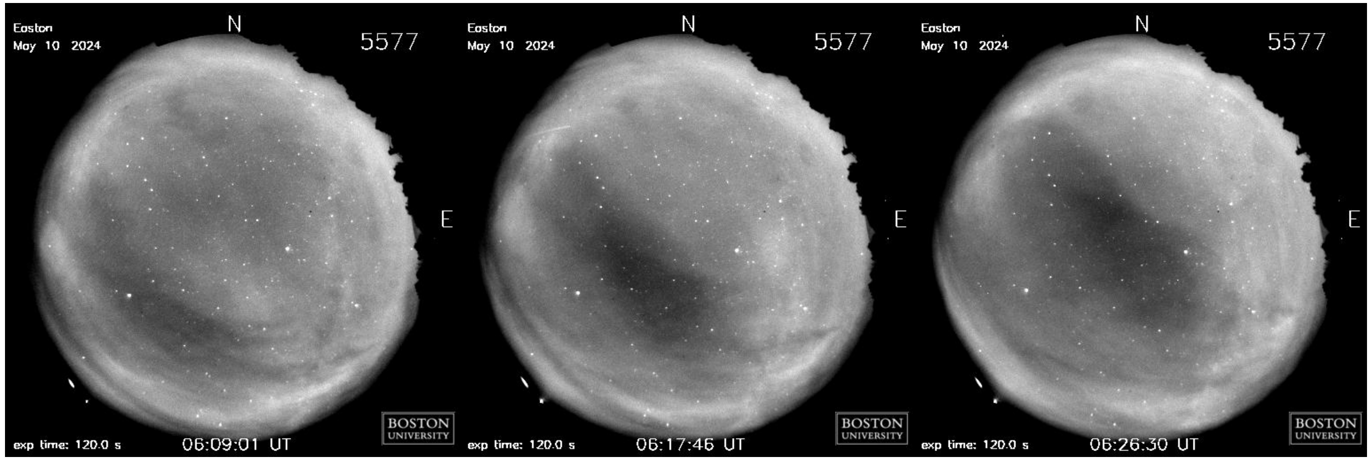




2.3 Observation in the America--GNSS-TEC / Airglow imager



- On May 10, 2024, the SuperDARN radar and GNSS-TEC data in the United States jointly recorded the nighttime northeastward propagation of MSTID.
- The Millstone airglow imager also observed MSTID spreading northeastward at night.



Summary: On May 10, 2024, post-sunset poleward MSTID were occurred in the Asia, America, and Europe, with the duration reaching up to more than six hours.

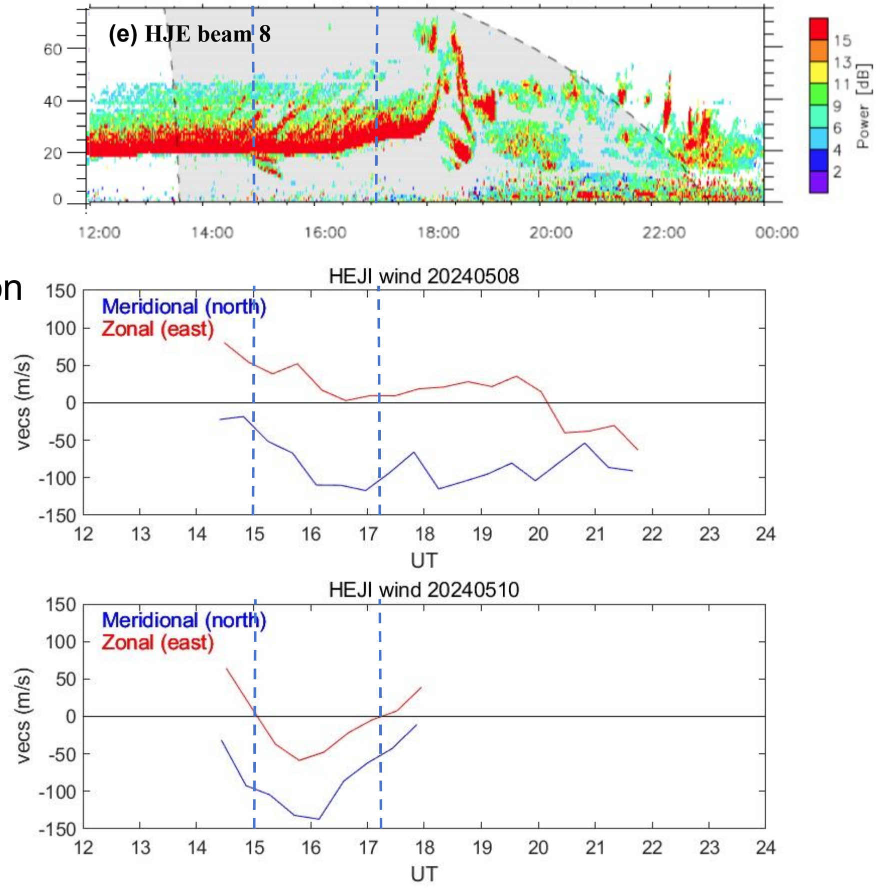
03 Discussing

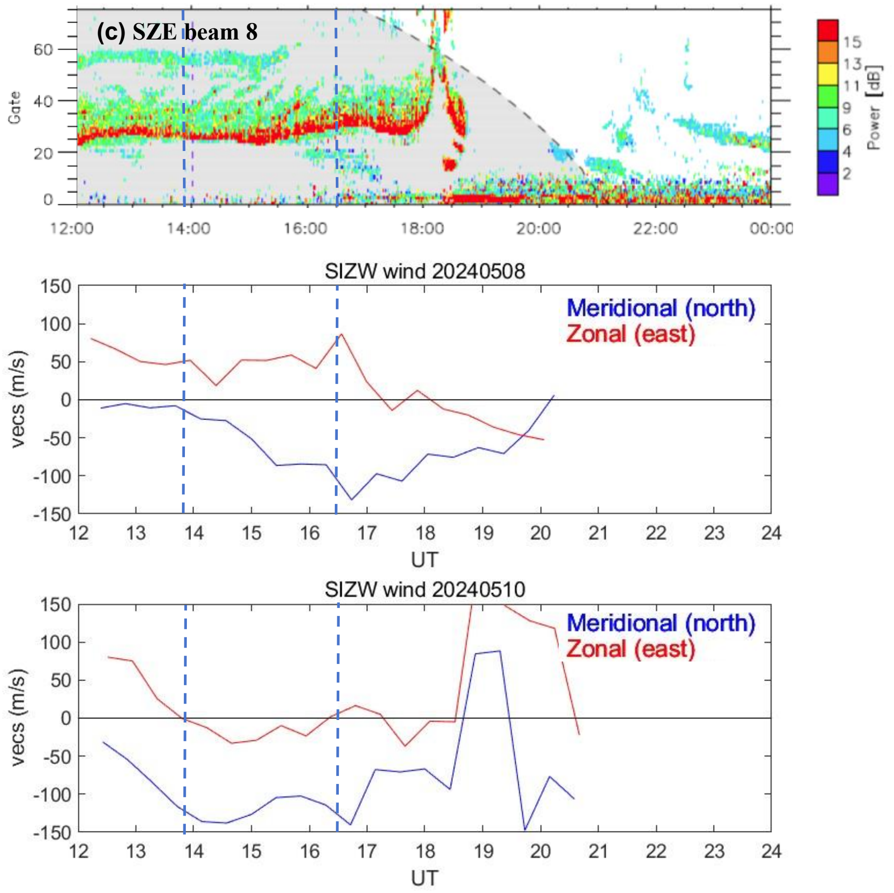
3.1 Observation of neutral wind

- After sunset on May 10, 2024, the neutral wind deflected southwestward, and the occurrence time was basically consistent with the polarward MSTID observed by radars.

Reference Wind Distribution
(Non-event)

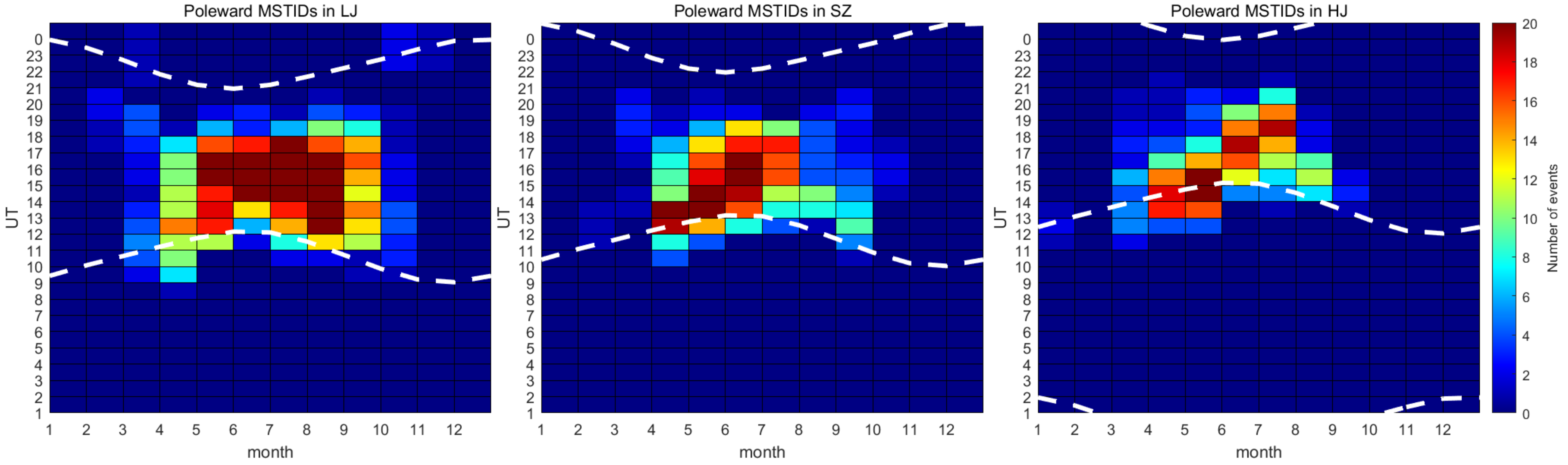
Disturbed flow (event)





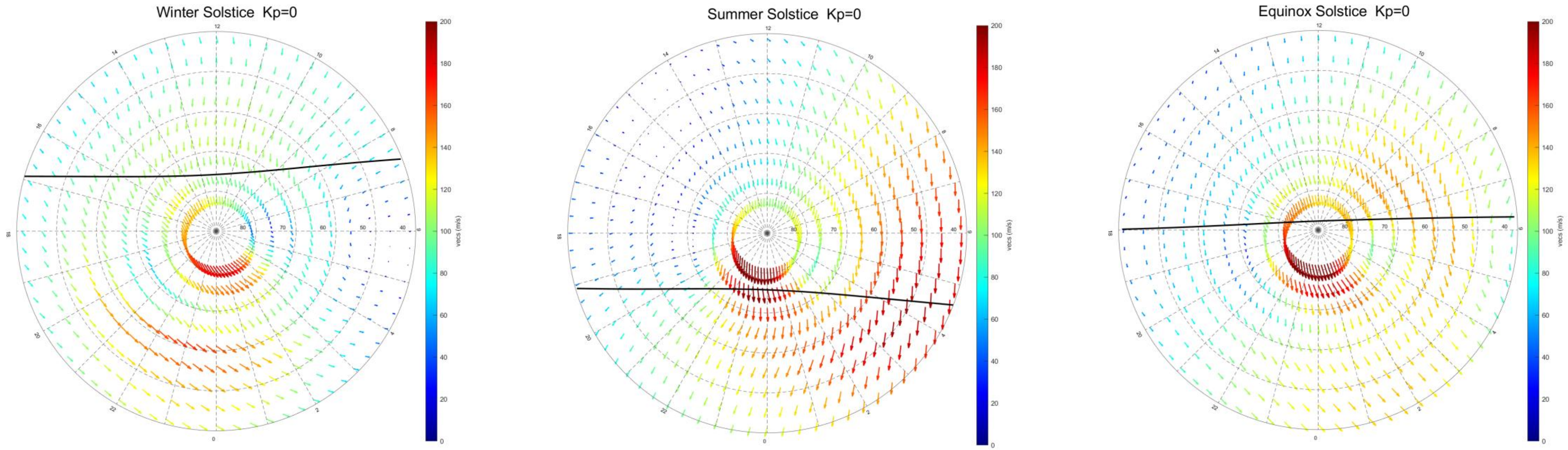
3.2 Statistics of seasonal variation of poleward MSTIDs

- **Seasonal Distribution:** predominantly occur in summer, with fewer events in spring and autumn, and are virtually absent in winter.
- **Diurnal Variation:** occurring primarily between sunset and midnight.
- **Longitudinal Dependence:** events are more frequent at Longjing (eastern site) than at Hejing (western site).



3.3 Simulation results of seasonal variation of neutral wind

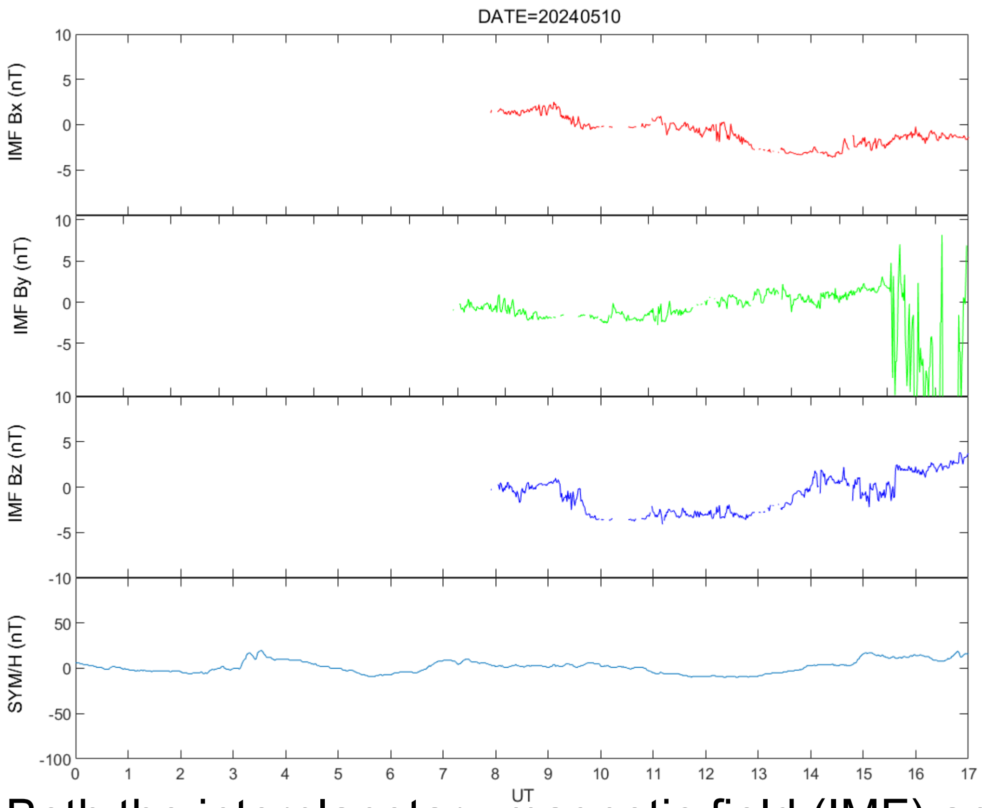
- The distribution of neutral winds during the geomagnetic quiet period shows seasonal and local time differences. The equatorial component is the strongest on the night side in summer, slightly weaker in equinox, and basically poleward in winter.

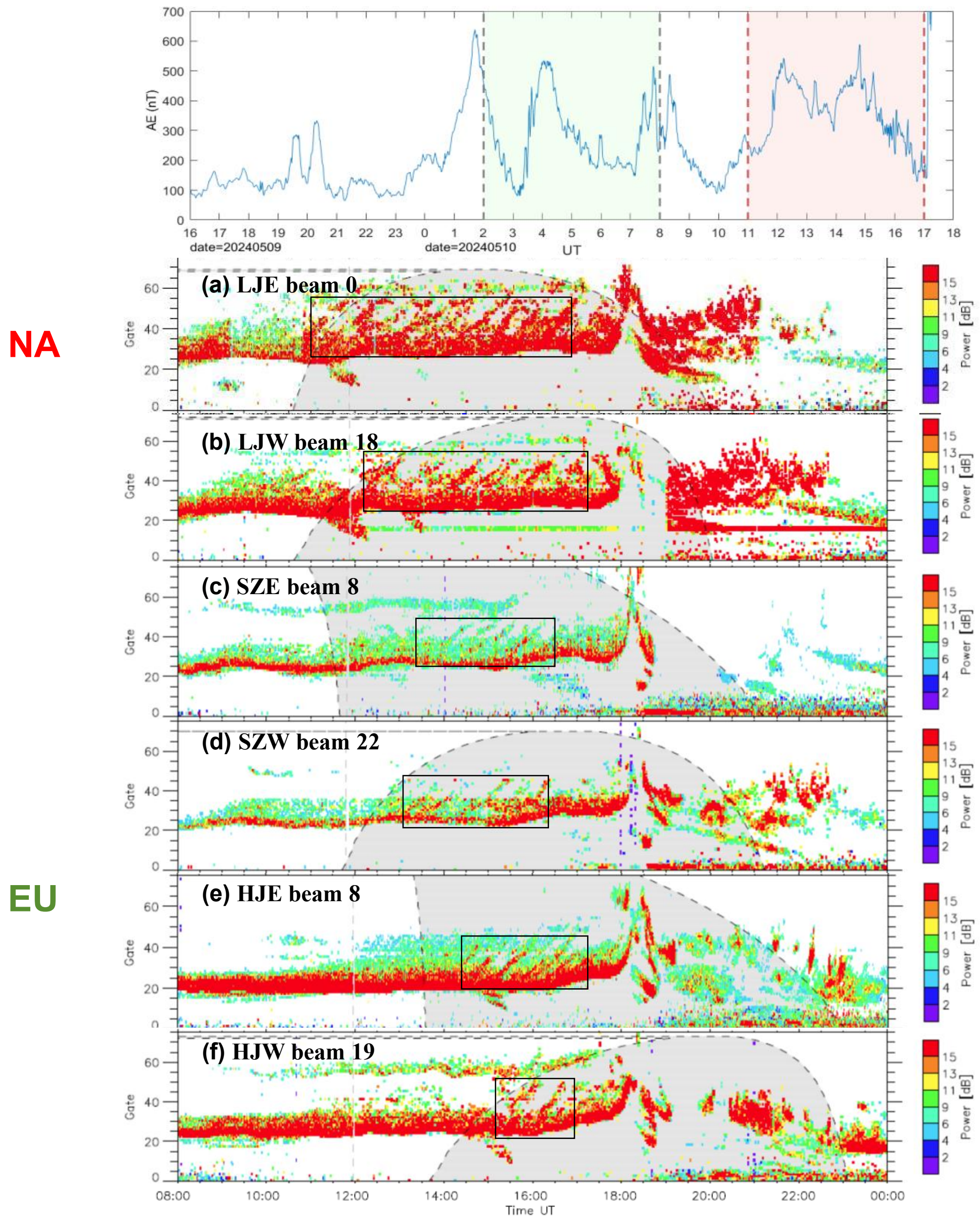


TIEGCM（Thermosphere-Ionosphere-Electrodynamics General Circulation Model）

Why are continental-scale poleward MSTID events uncommon? There may be other factors influencing the neutral winds

3.4 The conditions of the spatial environment

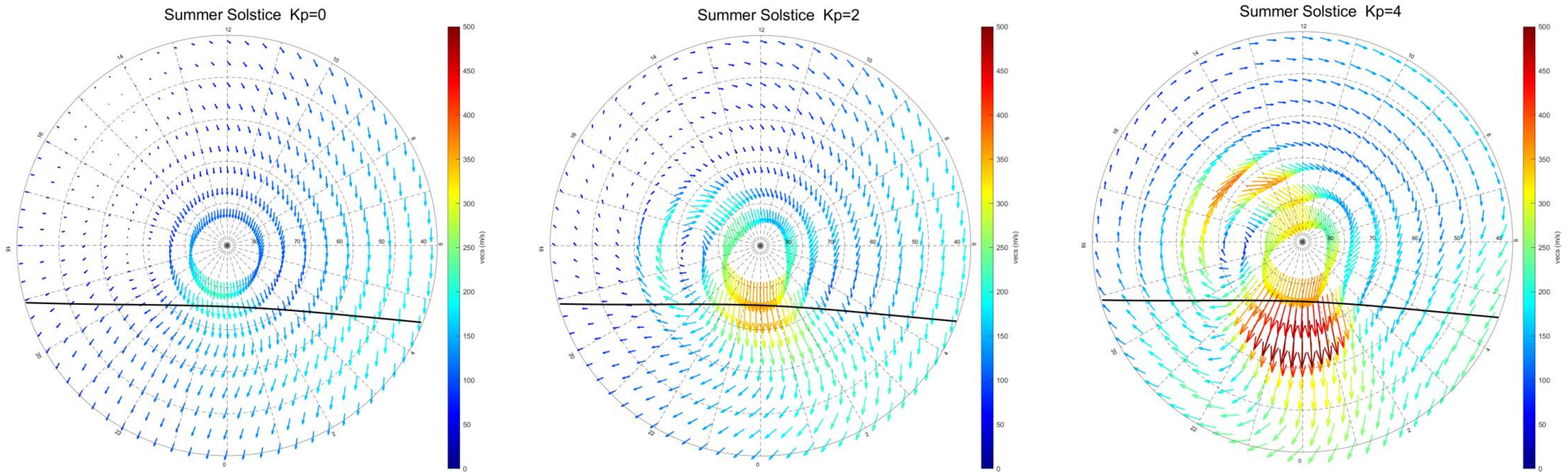




- Both the interplanetary magnetic field (IMF) and SYM-H index remained quiescent. The persistently negative Bz component facilitated sustained energy injection into the polar region.
- Poleward-propagating MSTIDs across all continents consistently coincide with enhancements in the AE index.

3.5 Simulation results of neutral wind--geomagnetic environment

- During geomagnetic disturbances, Joule heating and energetic particle precipitation extend to mid-latitudes, driving an enhancement of the equatorward component of the neutral wind. This enhanced flow then deflects westward due to the Coriolis force.



The combined effects of the background neutral wind field and global energy input from space weather maybe the generation mechanism for continental-scale poleward MSTIDs.

04 Summary

New observation:
Continental-scale poleward MSTID events have been detected for the first time using integrated observations from the SuperDARN radar network, all-sky airglow imagers, and GNSS.

Generation mechanism:
The combined effects of the background neutral wind field and global energy input from space weather maybe the generation mechanism for continental-scale poleward MSTIDs.

Thank You!