MSTIDs: Sources, Propagation Characteristics and Detection Techniques

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Outline

- ❑ Introduction
- ❑ Observational techniques
- ❑ Observational studies
  - Before 1980's
  - After 1990's
- ❑ Characteristics
  - Day and night, and seasonal dependency
  - Latitude and longitudinal dependency
- ❑ Sources or causative mechanisms
- ❑ Summary and unresolved problems

Introduction

Traveling ionospheric disturbances (TIDs) are wave like fluctuations of the electron density induced by gravity waves in the neutral atmosphere (Hines, 1960; Francis, 1974).

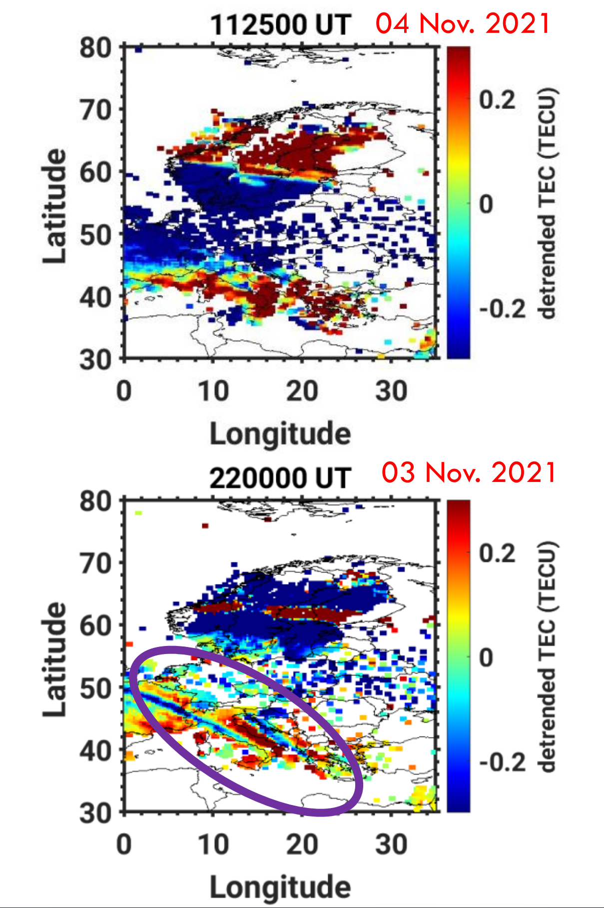
Types of TIDs

1) Large scale traveling ionospheric disturbances (LSTIDs)

- ✓ Period: 30 minutes-3 hours
- ✓ Horizontal speed: 400-1000 m/s
- ✓ Horizontal wavelength: 1000 km and above

2) Medium scale traveling ionospheric disturbances (MSTIDs)

- ✓ Period: 15-90 minutes
- ✓ Horizontal speed: 100- 250m/s
- ✓ Horizontal wavelength: several hundreds of kilometers



Observational techniques/instruments

- Ionosonde
- HF Doppler sounding
- Coherent and incoherent scatter radar
- SuperDARN radar
- Faraday rotation
- Airglow imager
- GNSS receivers
- Rocket soundings

Ionosonde-Juliusruh

Airglow imager-Gadanki

MU-Radar, Japan

Arecibo-ISR

Observational techniques/instruments

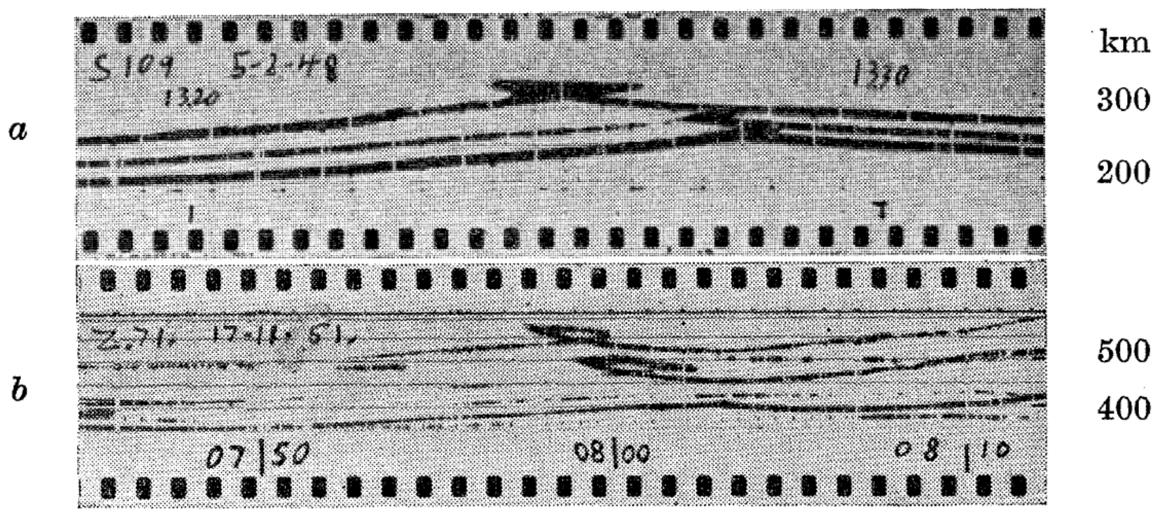
- CDSS measurement
- Satellites
  - Swarm
  - Gravity Field and Steady-State Ocean Circulation Explorer (GOCE)
  - Challenging minisatellite payload (CHAMP)

Swarm

GOCE

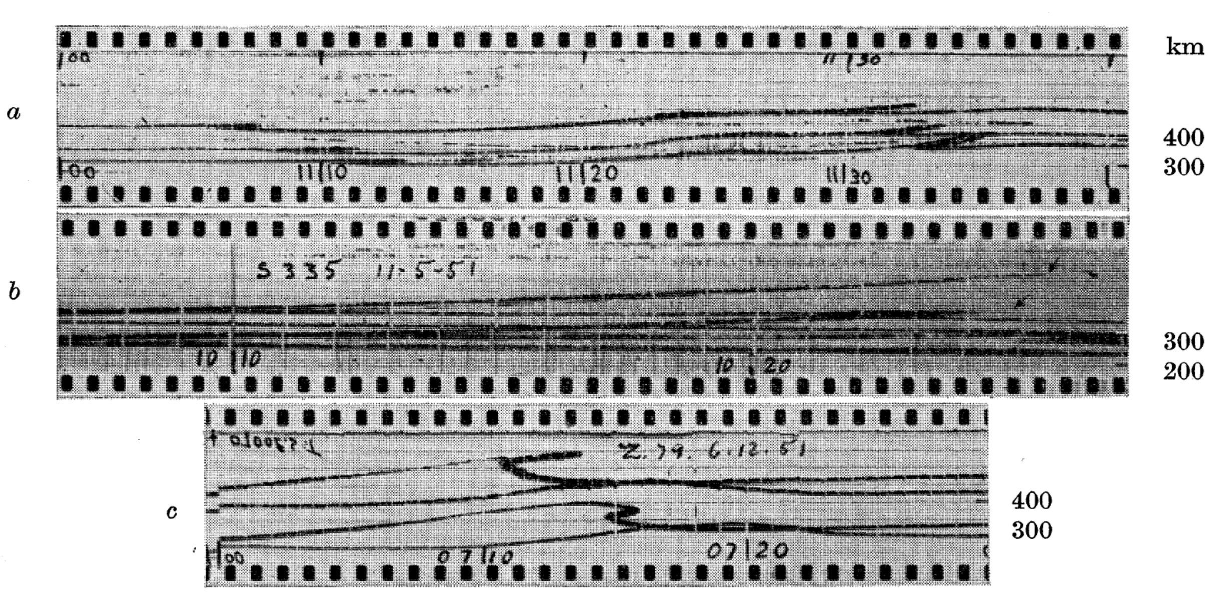
CHAMP

Observations: Before 1980's



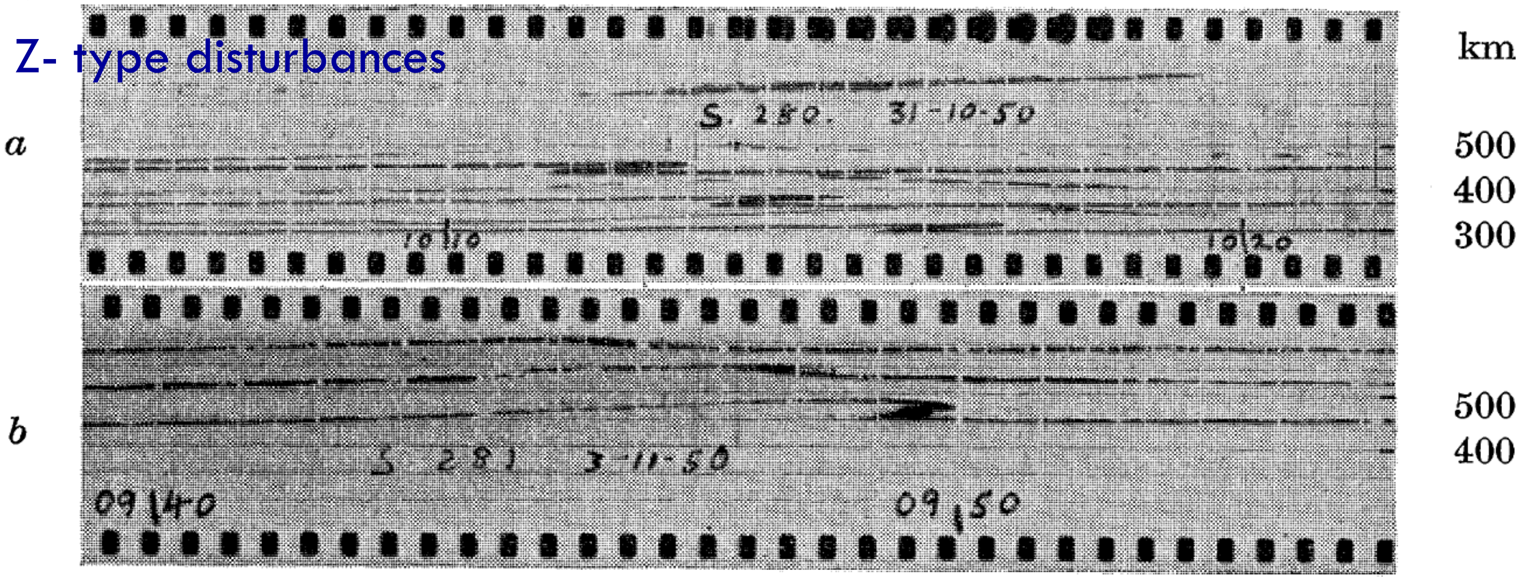
Loop or X-type disturbances

Munro (1953)



Y or branch type disturbances

Z- type disturbances



- ✓ All these features are caused by a same phenomena. That is TIDs

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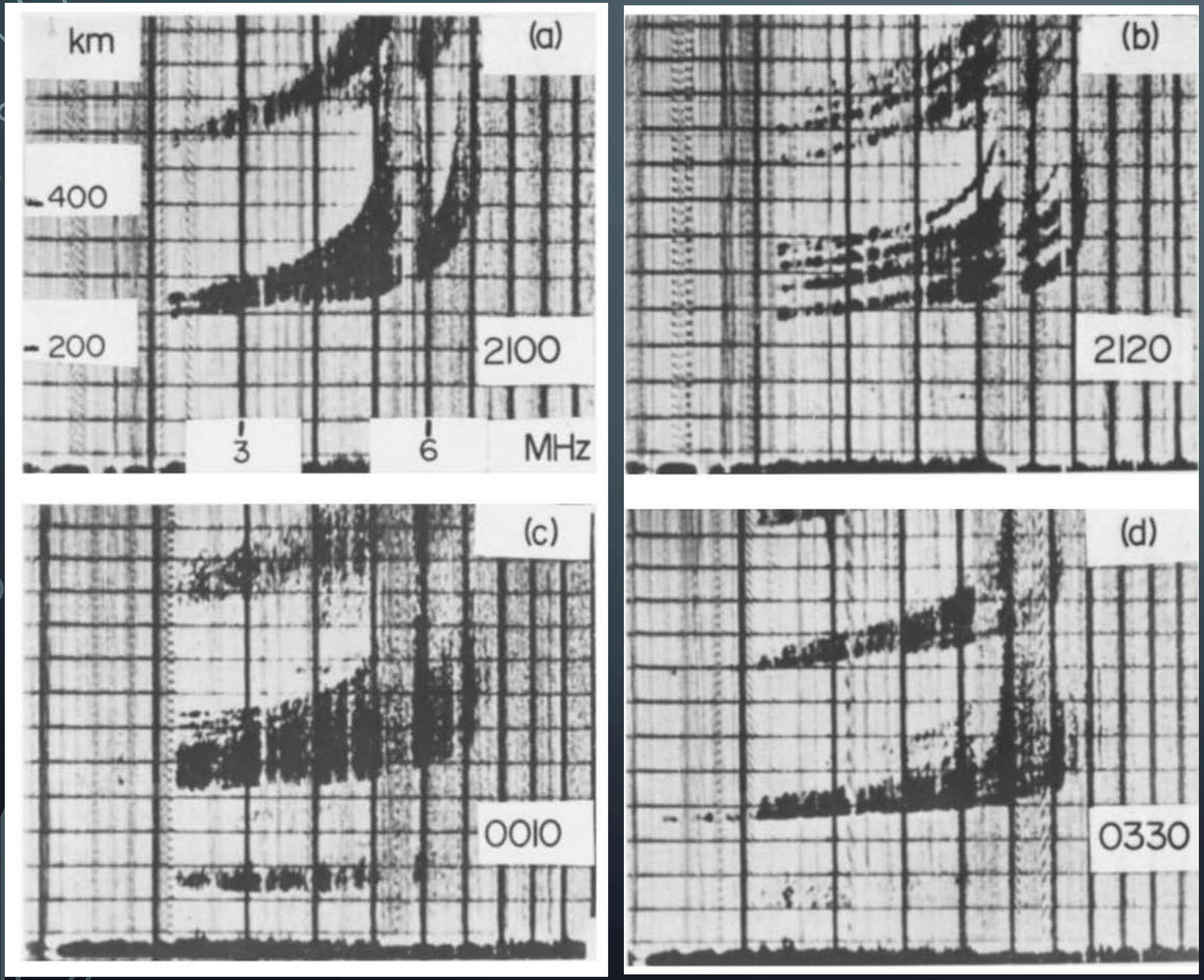
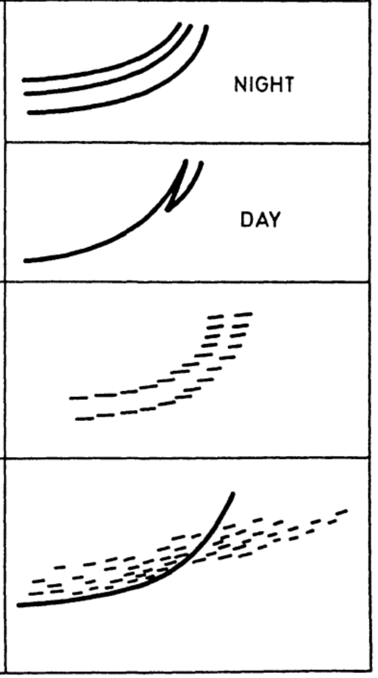
Range and frequency spread-F



IONOSPHERIC IRREGULARITIES

STRUCTURE SIZE	CHARACTERISTICS	EXAMPLE IONOGRAMS
(a) LARGE SCALE	WAVELIKE (STRONG SIGNALS)	NIGHT / DAY
(b) MEDIUM SCALE	QUASI-HORIZONTAL-TRACE SEGMENTS (STRONG SIGNALS)	
(c) SMALL SCALE	QUASI-HORIZONTAL PATCHES FIELD-ALIGNED COLUMNS? (WEAK SIGNALS <20 dB below STRONG SIGNALS)	



Bowman (1980; 1990)

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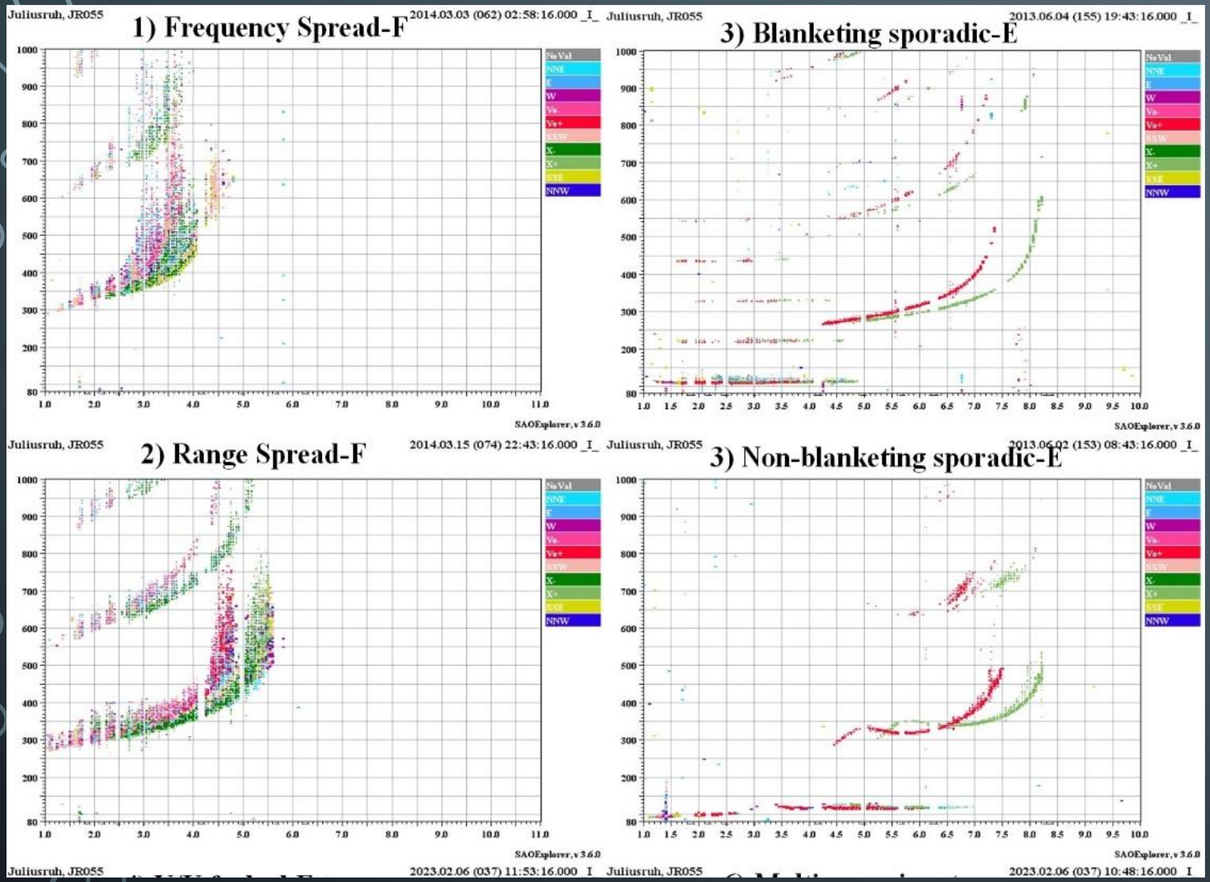

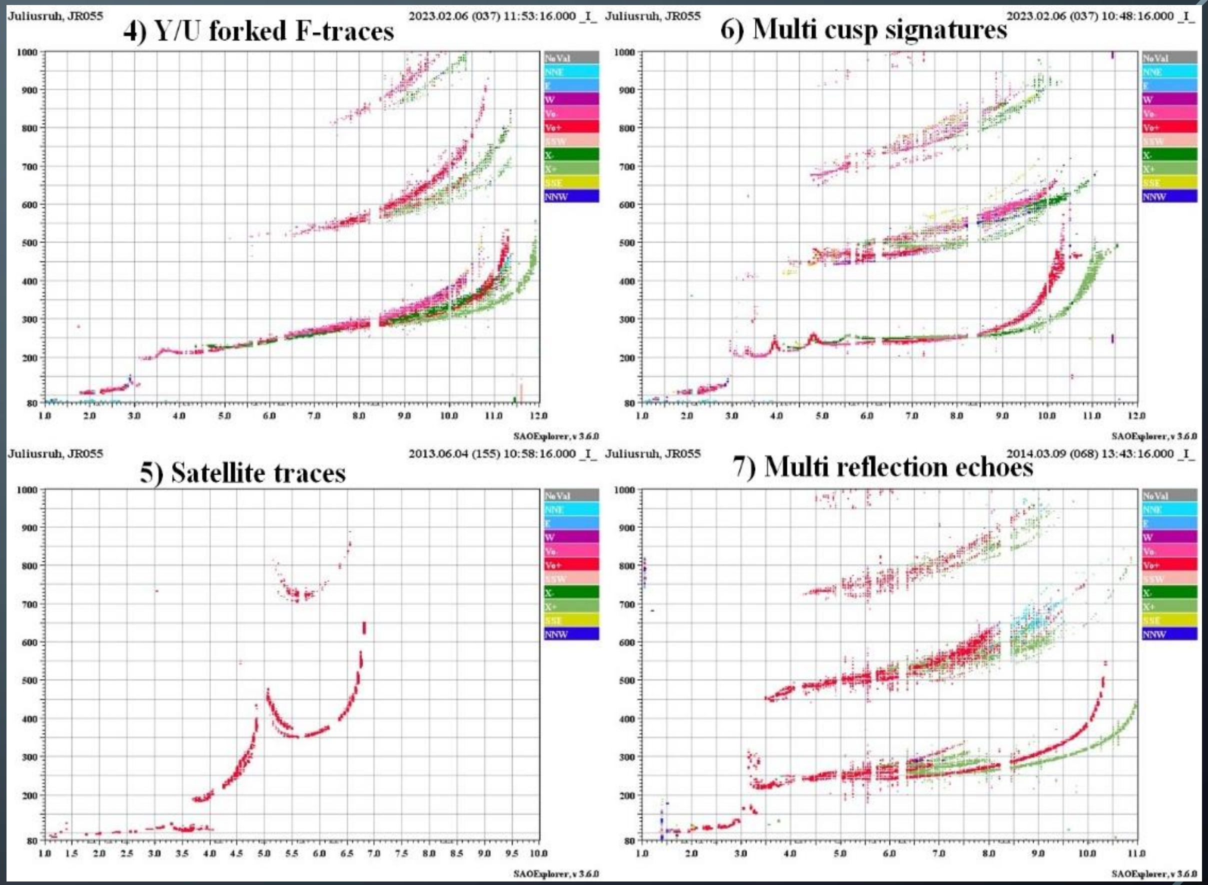

Credits: Mielich

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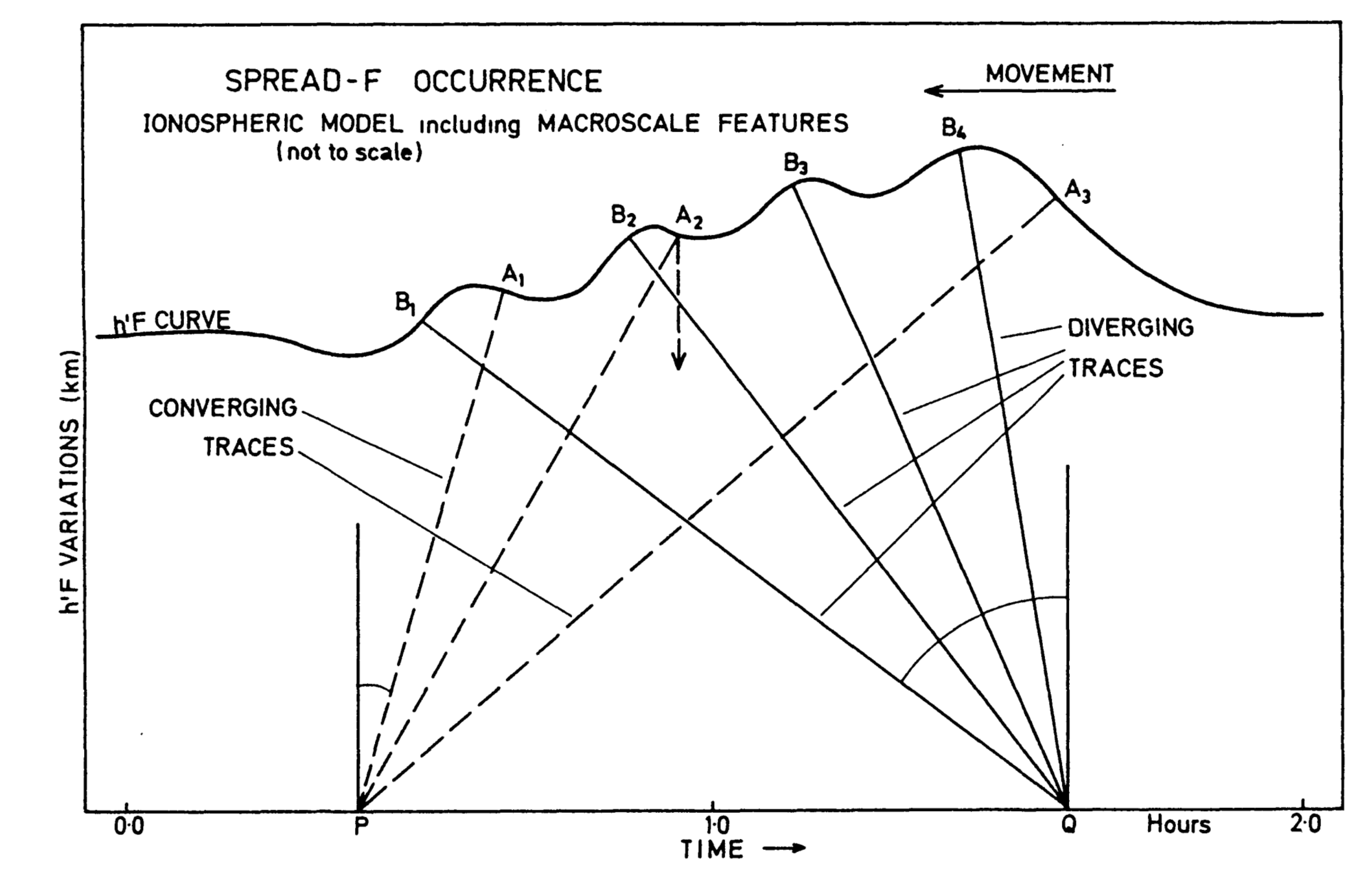
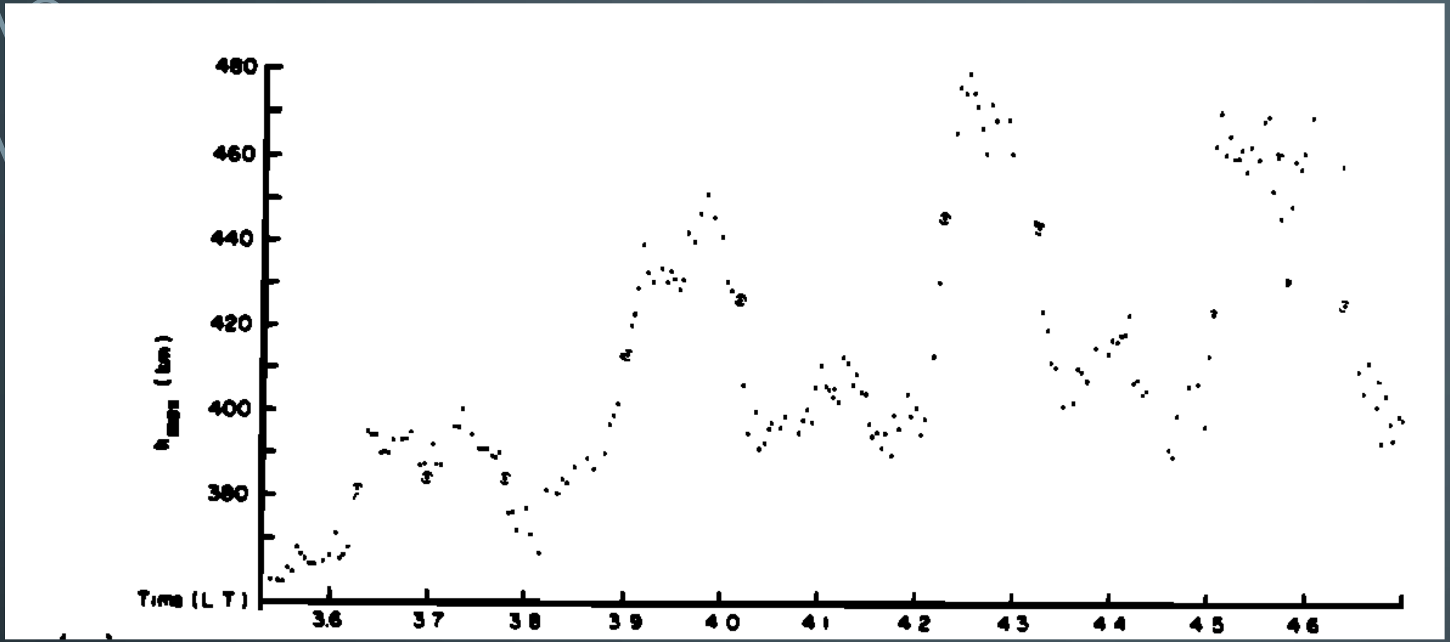
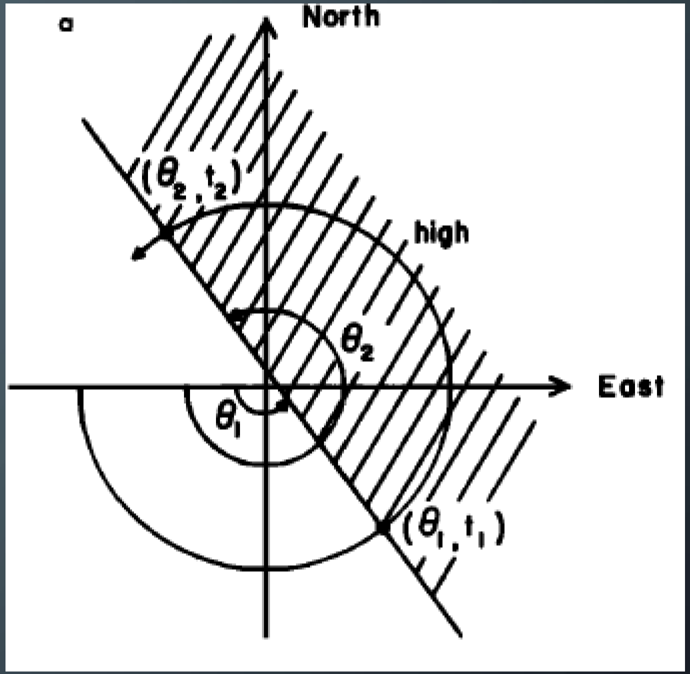
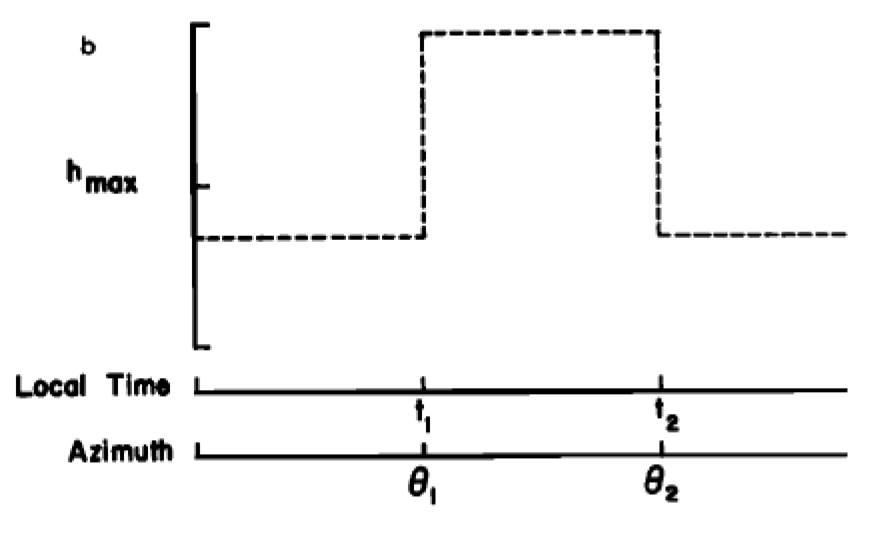


Bowman (1990)

Arecibo incoherent scatter radar (Nighttime)



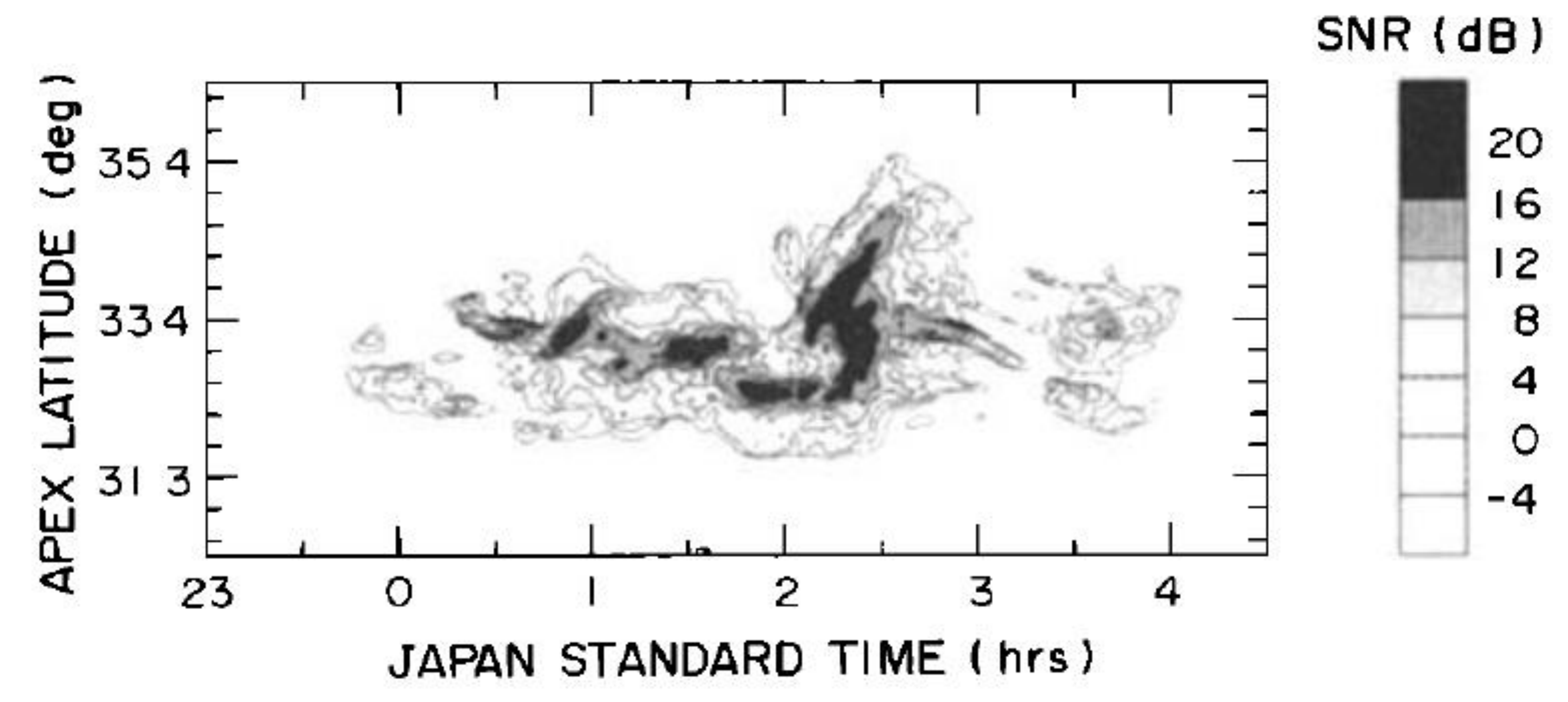




- ✓ Ionosphere above Arecibo has a well defined band like structure where the F region as a whole is high and low.
- ✓ The height maxima show variations upto 70 km.

Behnke (1979)

Field aligned irregularities in the mid-latitude ionosphere (nighttime)



Fukao et al. (1988)

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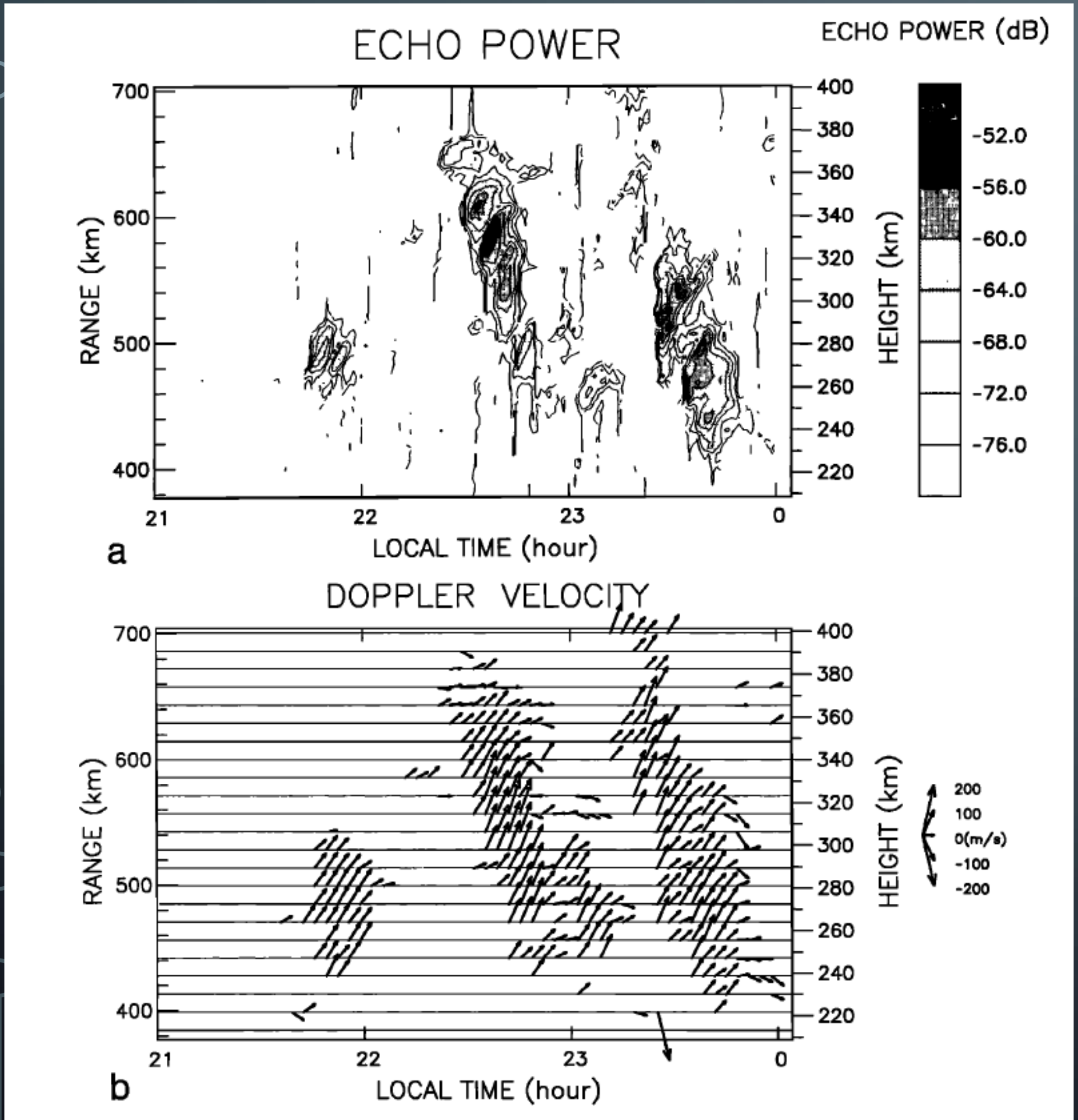
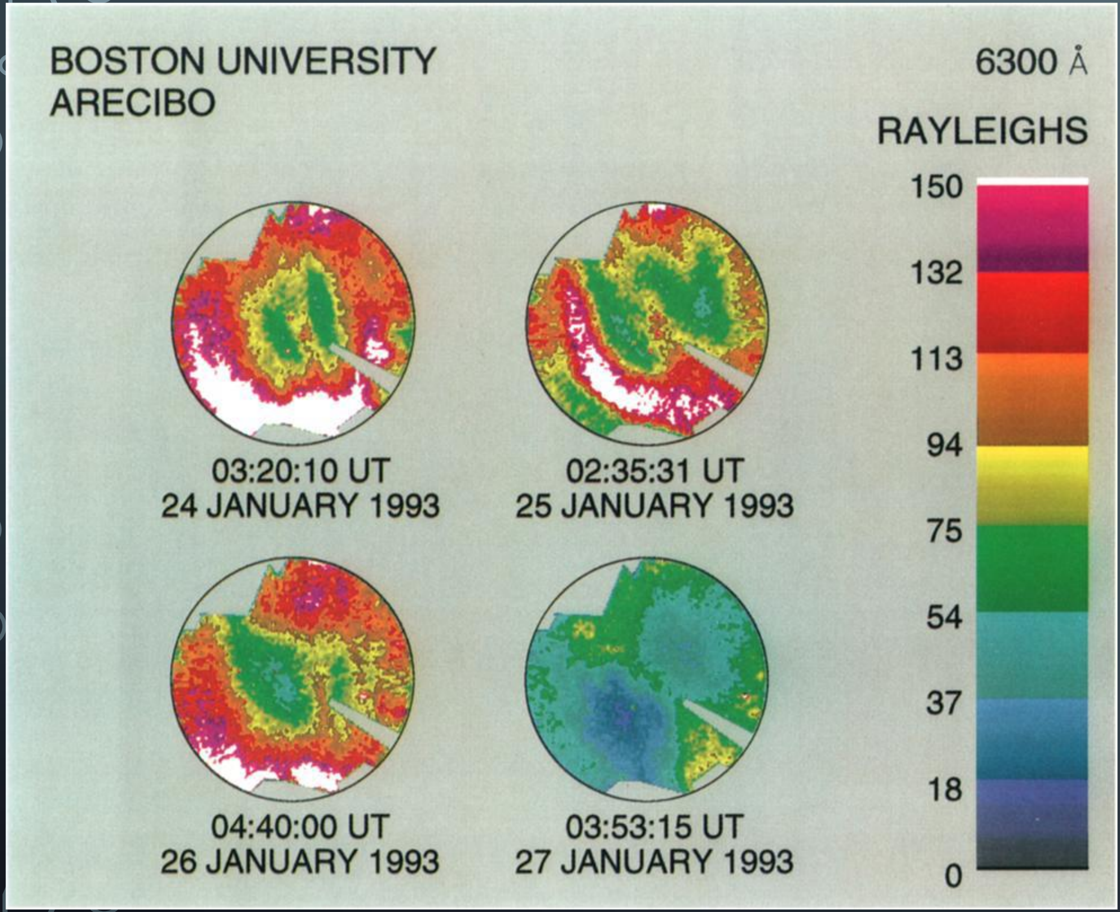


- ✓ Turbulent ionospheric phenomena the intense nonthermal scatter comes from irregularities oriented parallel to B.
- ✓ The strongest echoes correspond to irregularities at least 20 dB stronger than thermal backscatter at the same frequency from typical F region densities at the same range.
- ✓ These echoes occur during strong mid-latitude spread-F.
- ✓ The strongest echoes occur in large patches which display away Doppler shifts corresponding to irregularity motion upward and northward from the radar.
- ✓ The patches moved east to west in both cases at velocities of 125 m/s and 185 m/s, respectively.

Fukao et al. (1991)

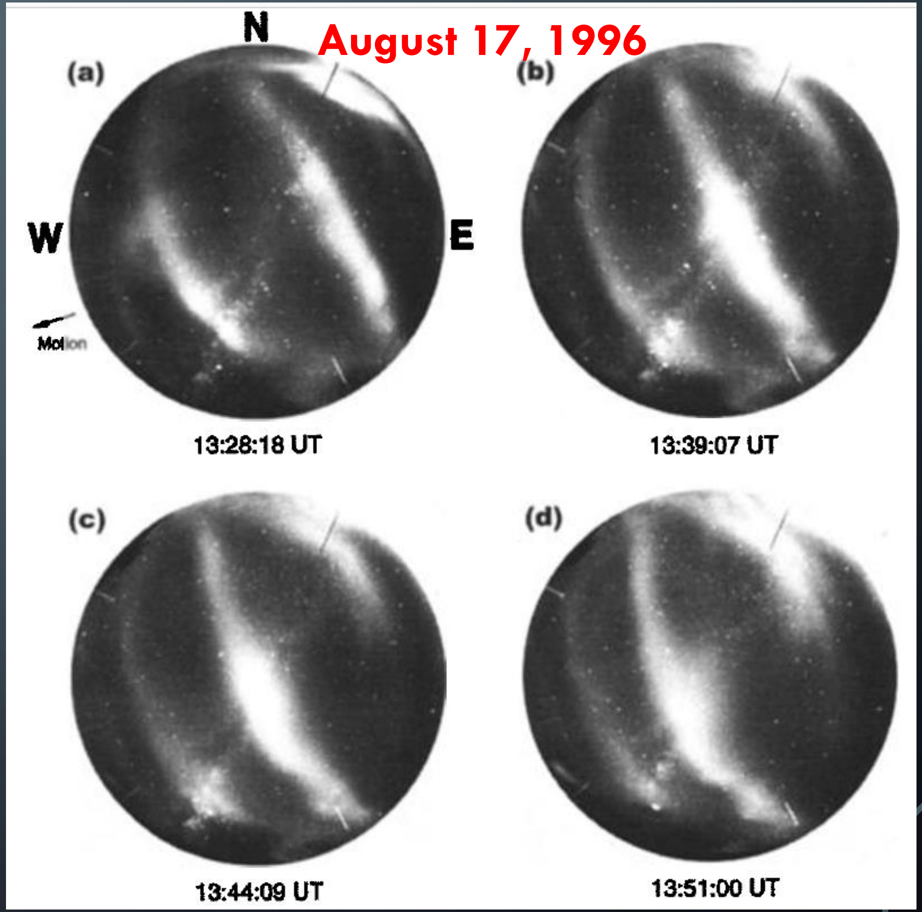
Observations: after 1990's

OI 630 nm airglow emission peaks around 250km



Mendillo et al. (1997)

Sporadic E Experiment over Kyushu, Japan



Taylor et al. (1998)

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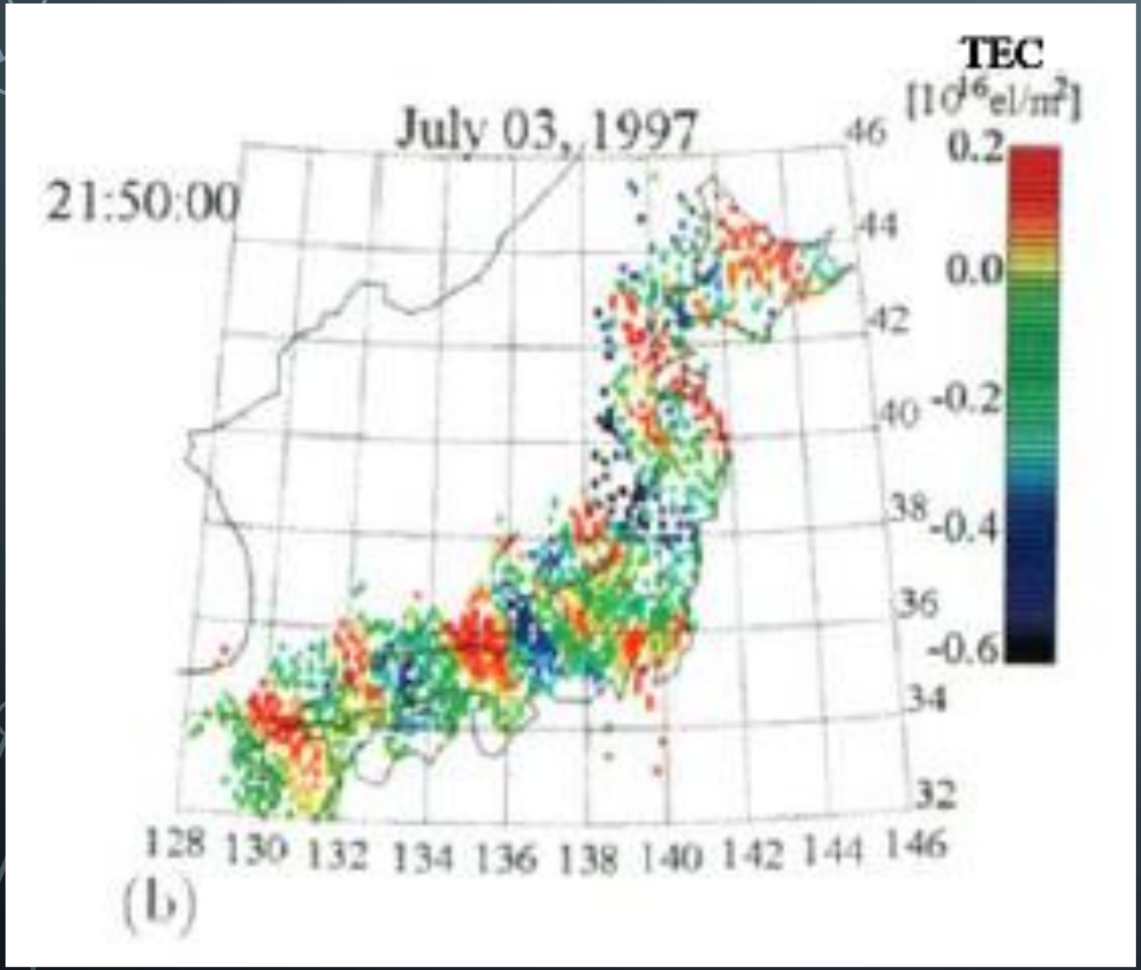
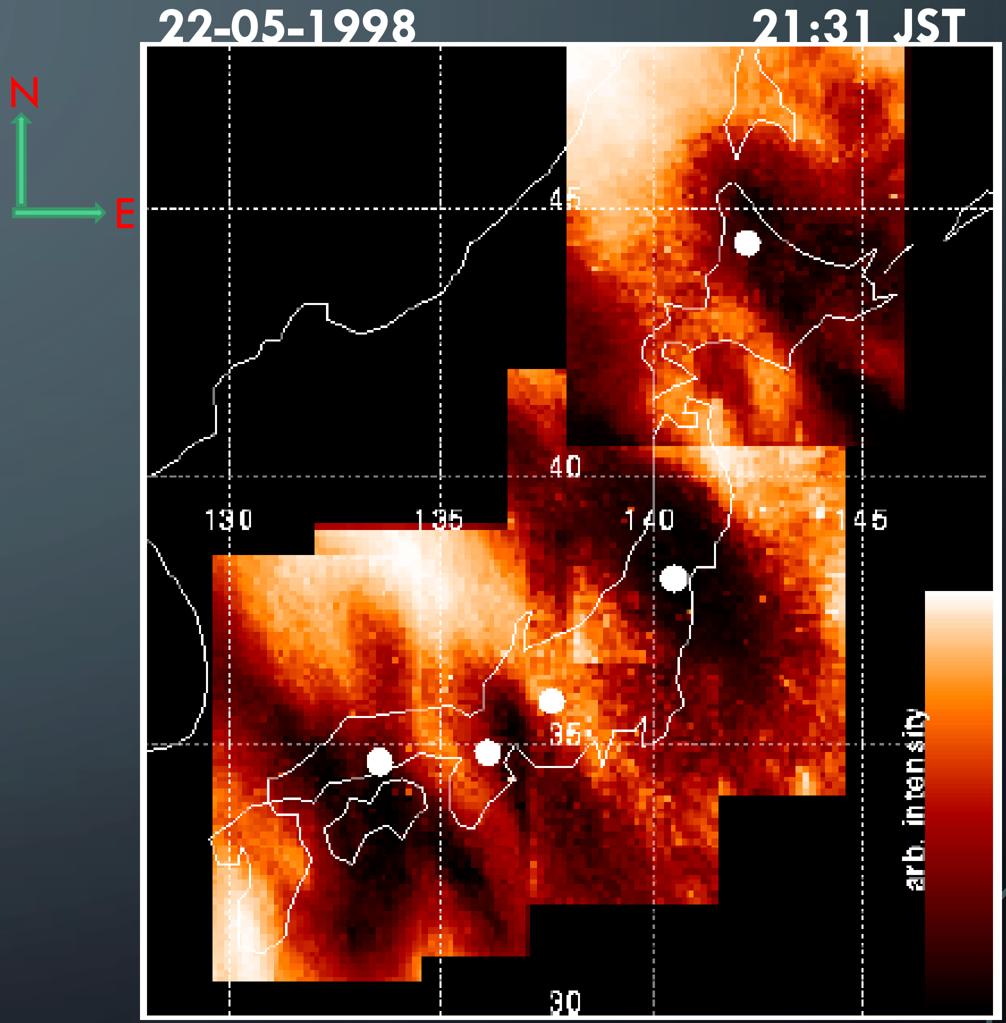
Detrended TEC using multiple GPS receiver network



Saito et al. (1998)

MSTID observation using 630 nm airglow emission



(Kubota et al. GRL, 2000; Saito et al. GRL, 2001)

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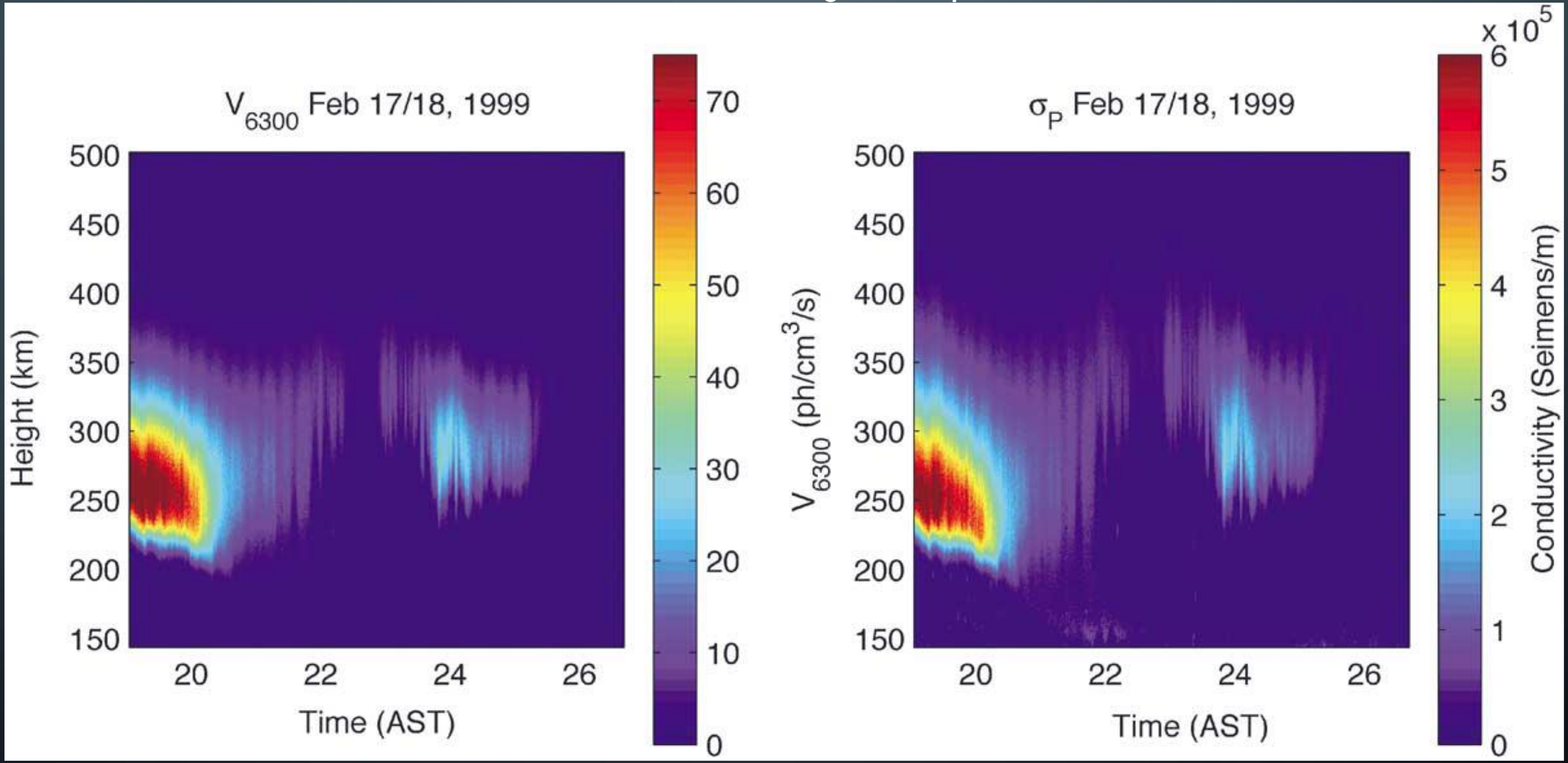
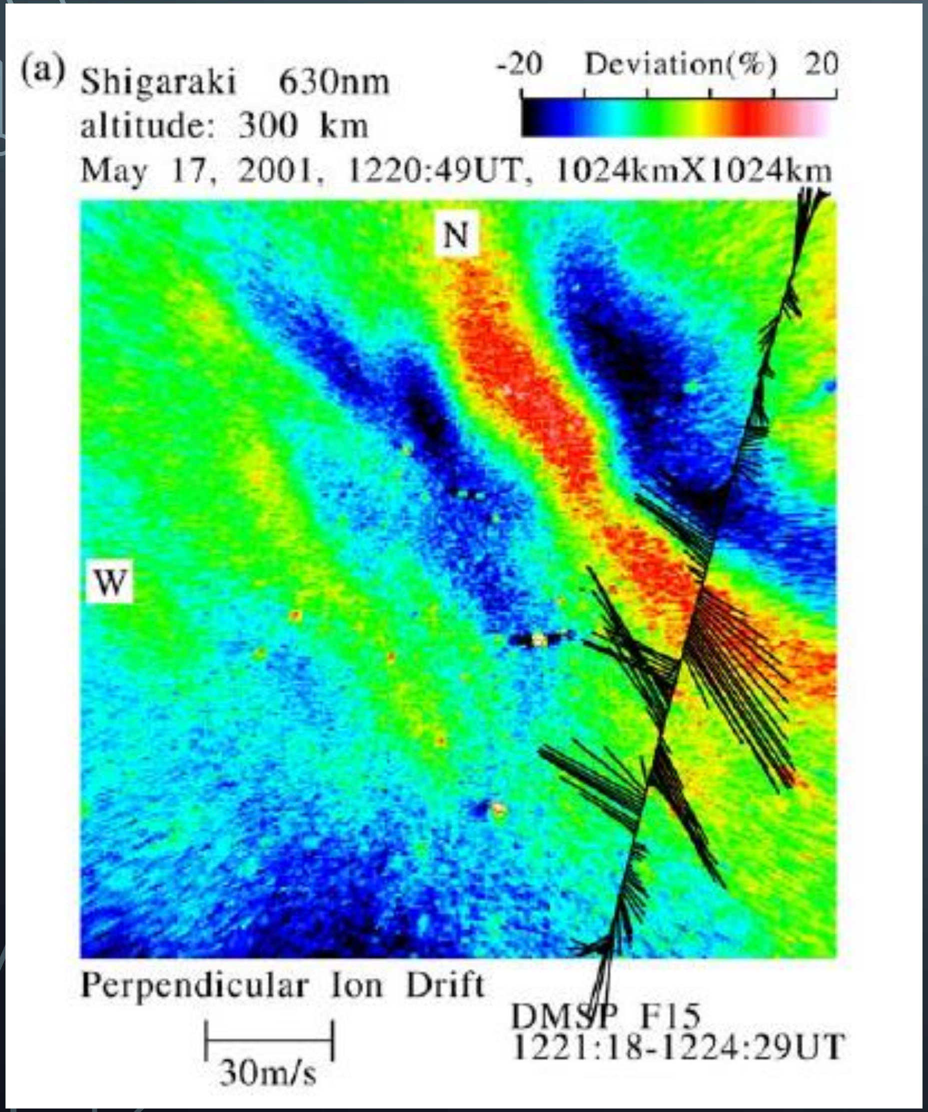
Electrical structure of airglow depletion



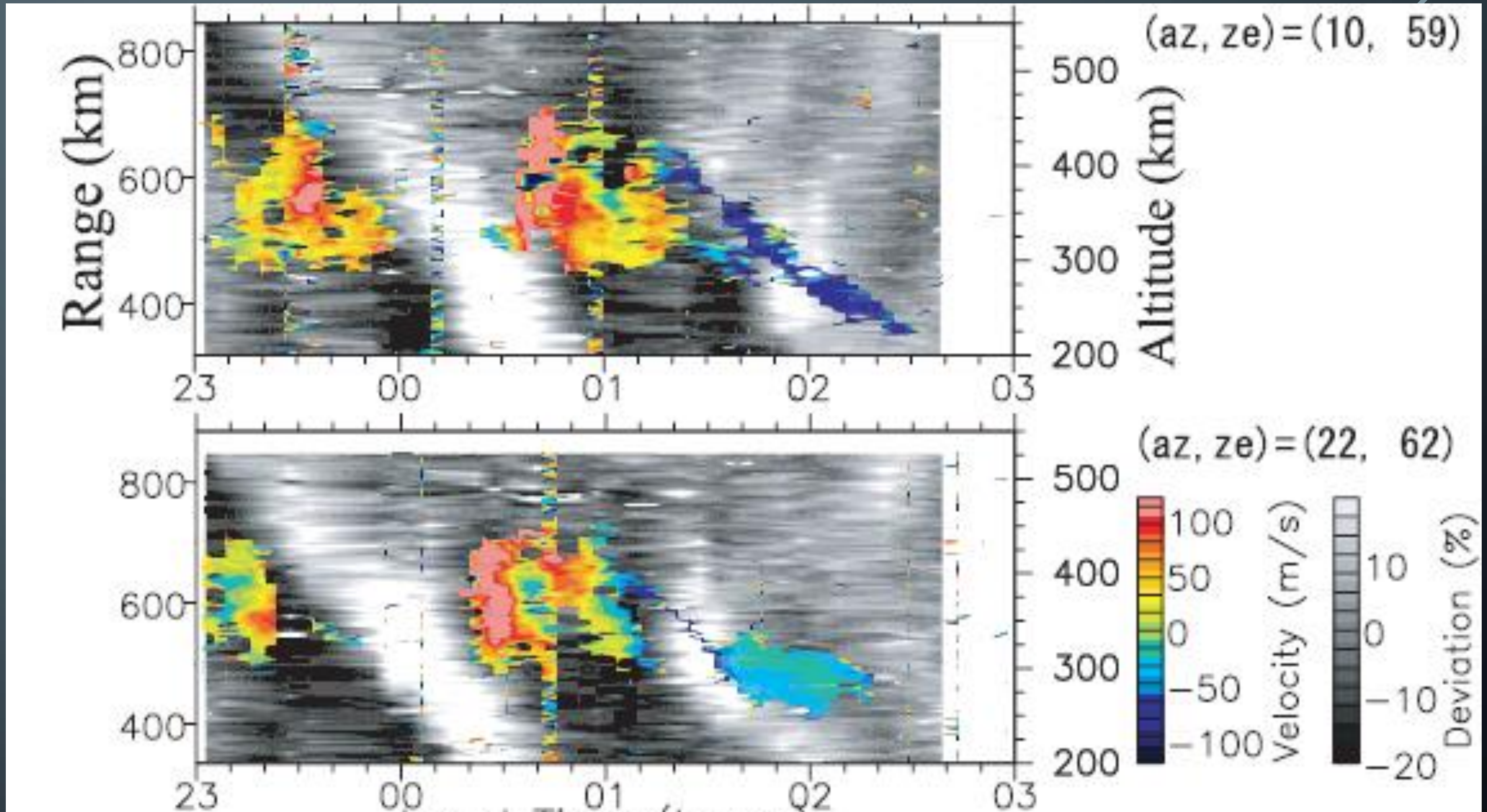
- ✓ **The F-region Pedersen conductivity is much lower in these structures than outside and suggest that this is related to a polarization electric field inside the structure.**

Kelley et al. (2000)

Spatial relationship between MSTIDs and field aligned irregularities



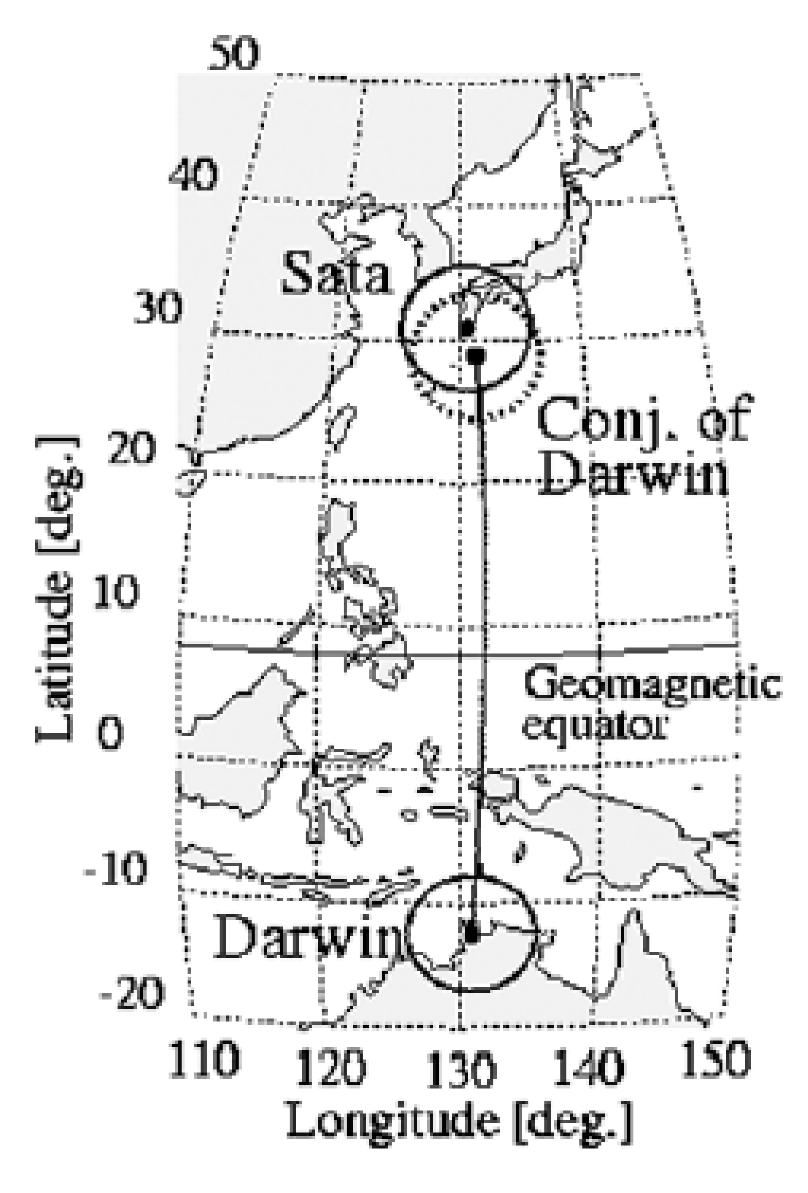
Shiokawa et al. (2003)

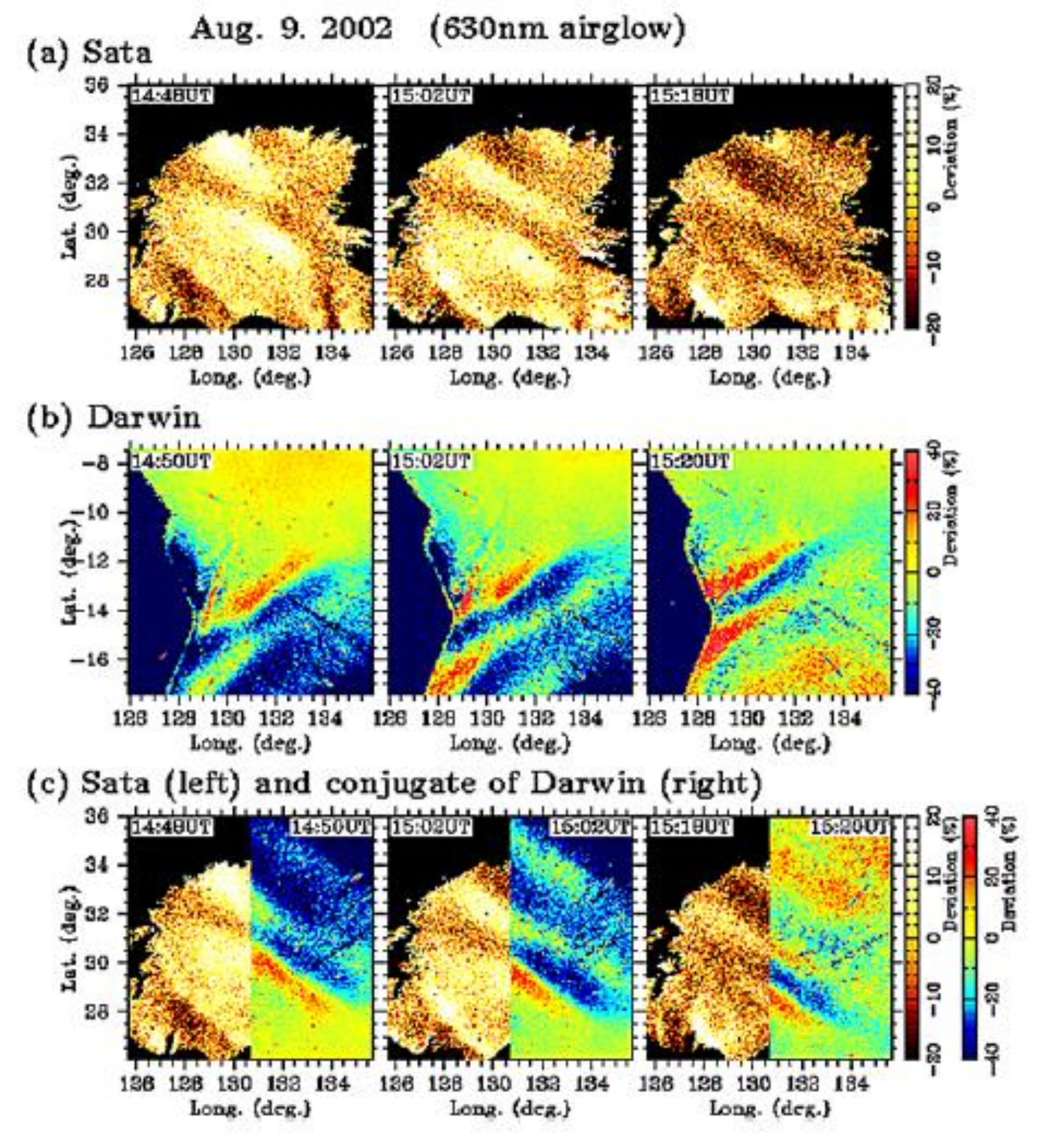


Otsuka et al. (2009)

- ✓ Nighttime MSTIDs are associated with electric field perturbations
- ✓ Mid latitude field aligned irregularities

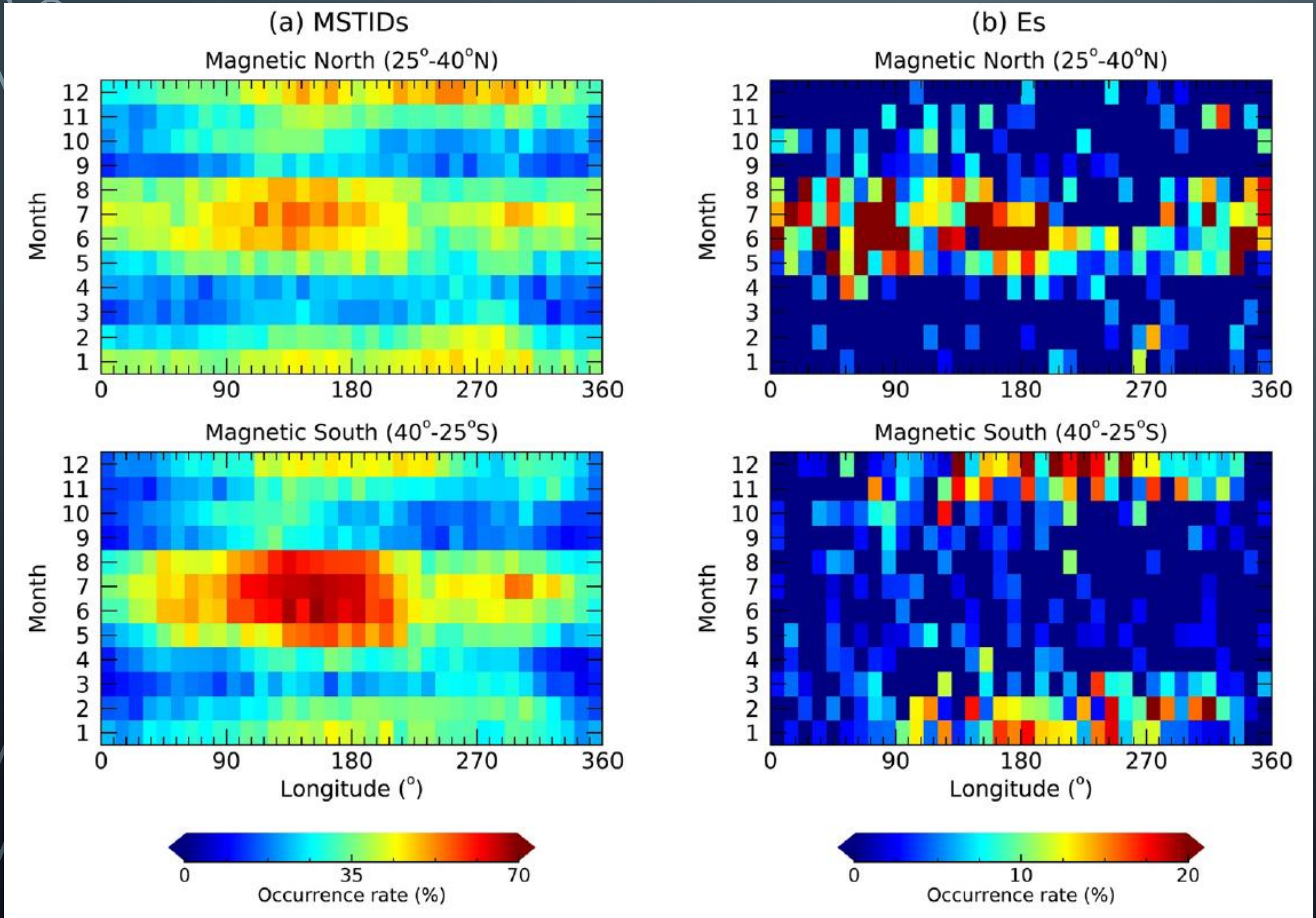
Geomagnetic conjugacy of nighttime MSTIDs





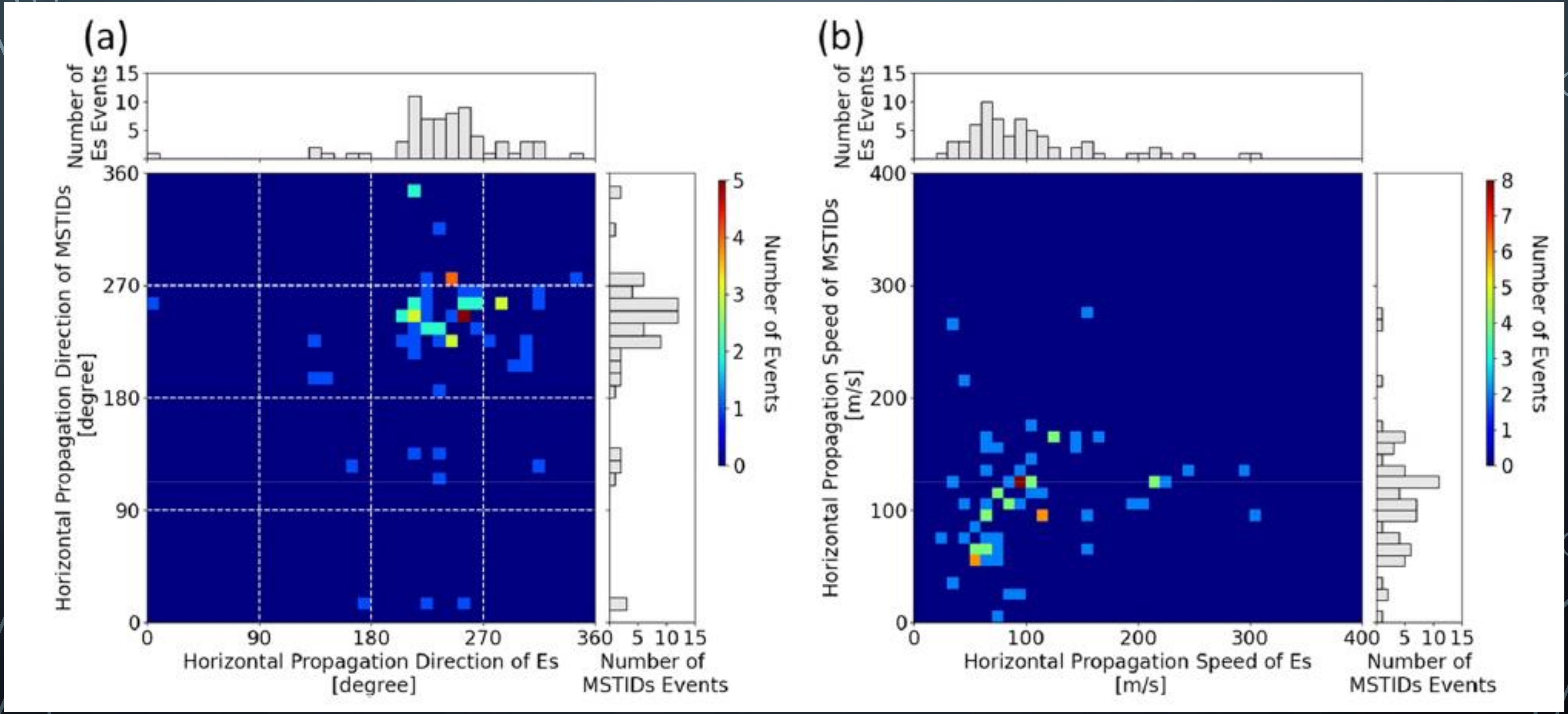
Otsuka et al. (2004)

Longitudinal variation of the nighttime MSTIDs



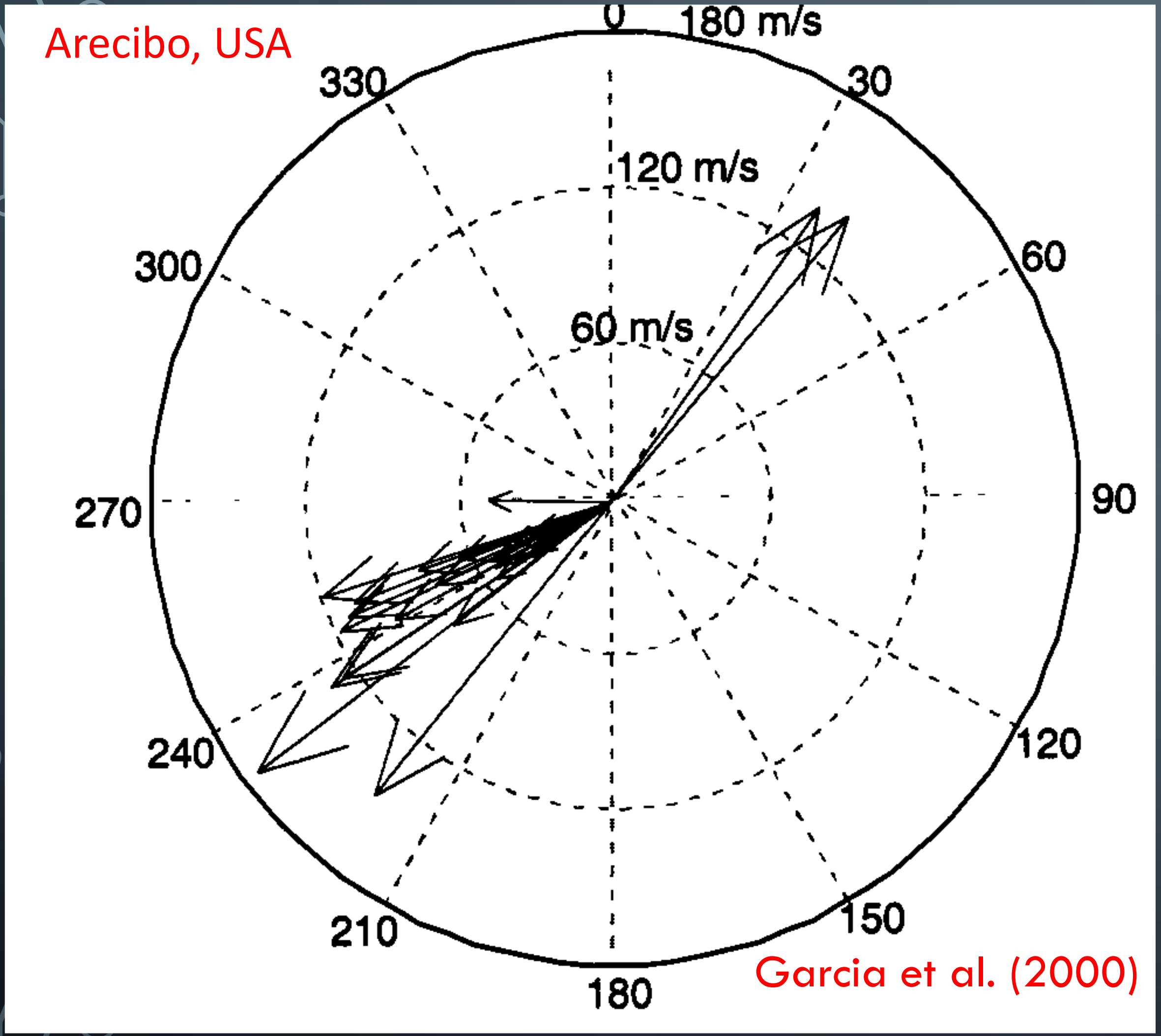
- ✓ Nighttime MSTIDs and sporadic Es layer occurrence show a clear seasonal and longitudinal variations

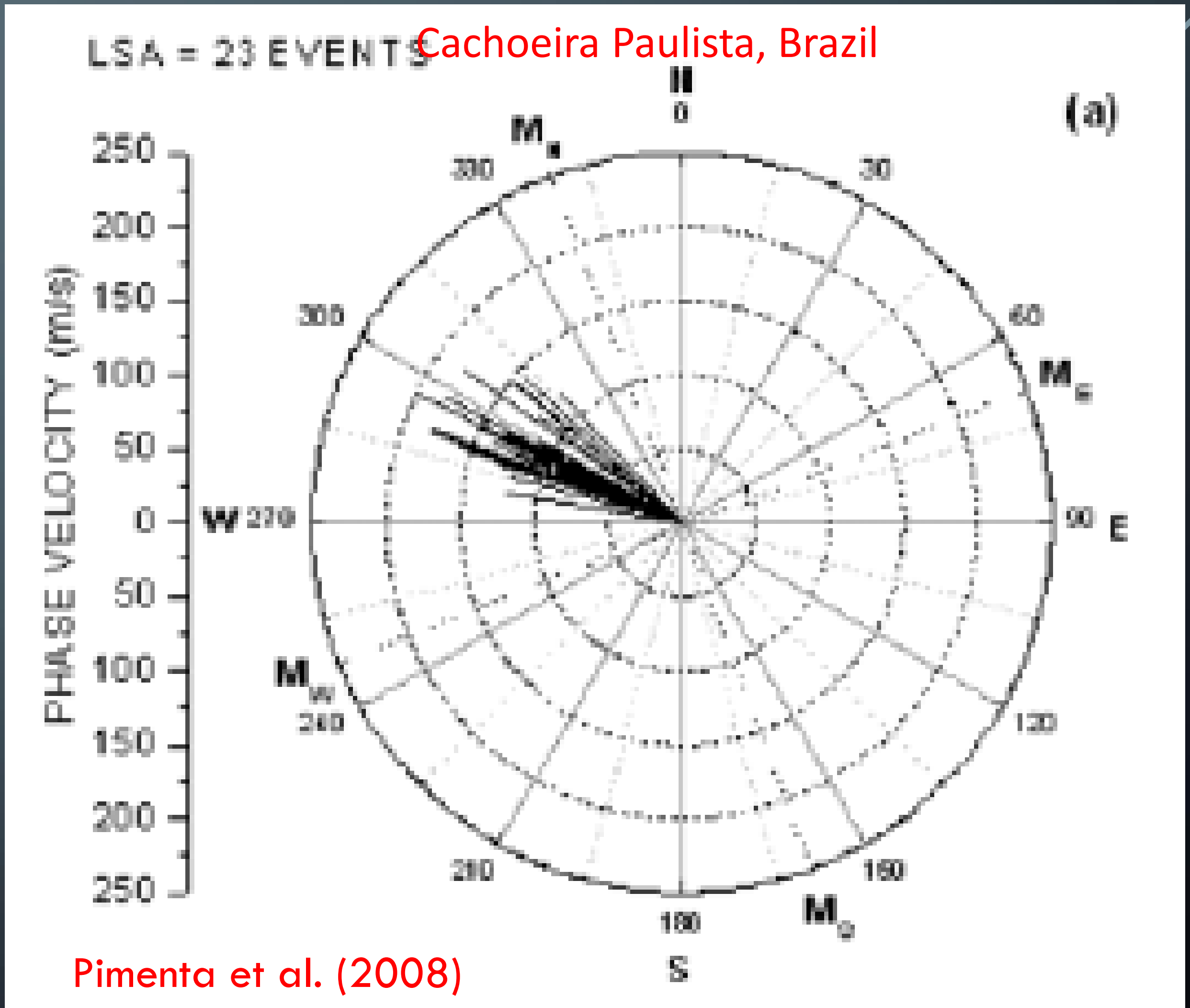
Propagation characteristics of Es layer and MSTIDs



Matsushima et al. (2022)

MSTIDs propagation characteristics

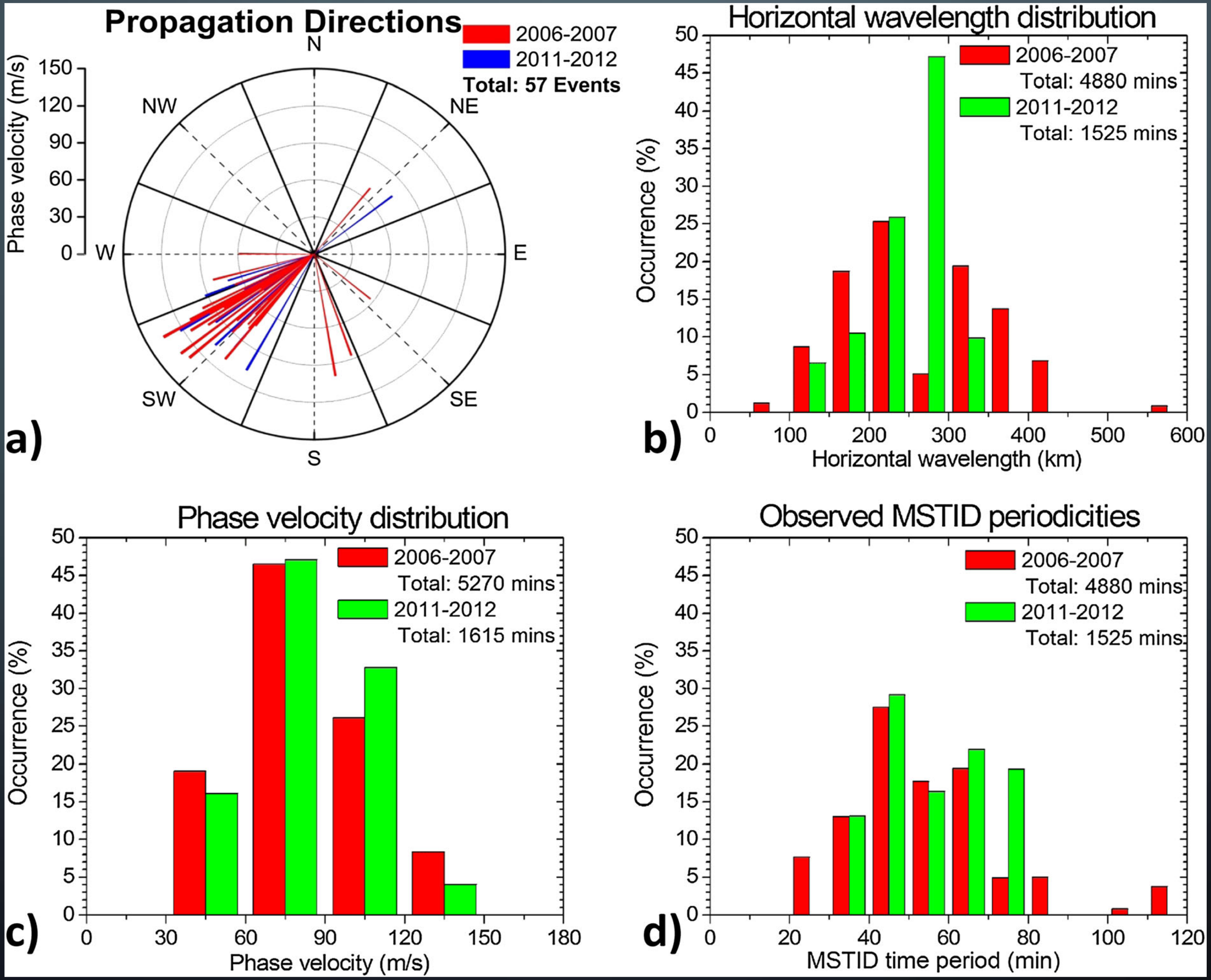




- ✓ Most the observed nighttime MSTIDs are propagate towards southwest in the northern hemisphere
- ✓ Most the observed nighttime MSTIDs are propagate towards northwest in the southern hemisphere

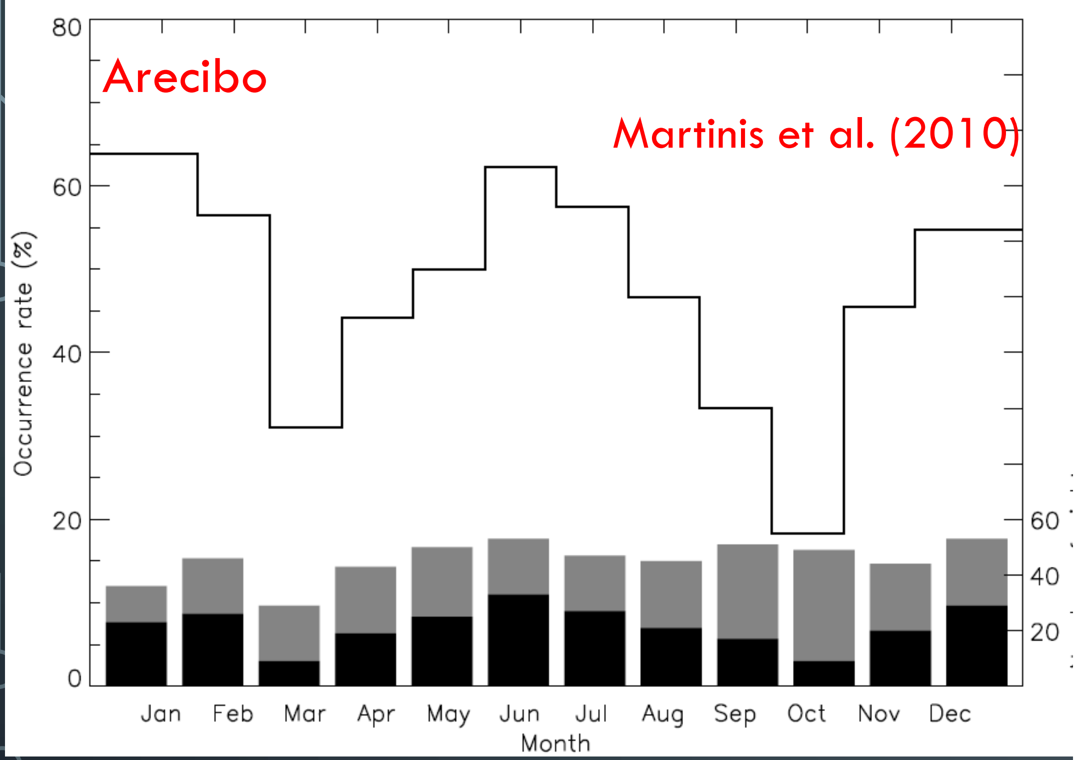
General characteristics of the MSTIDs- middle latitudes

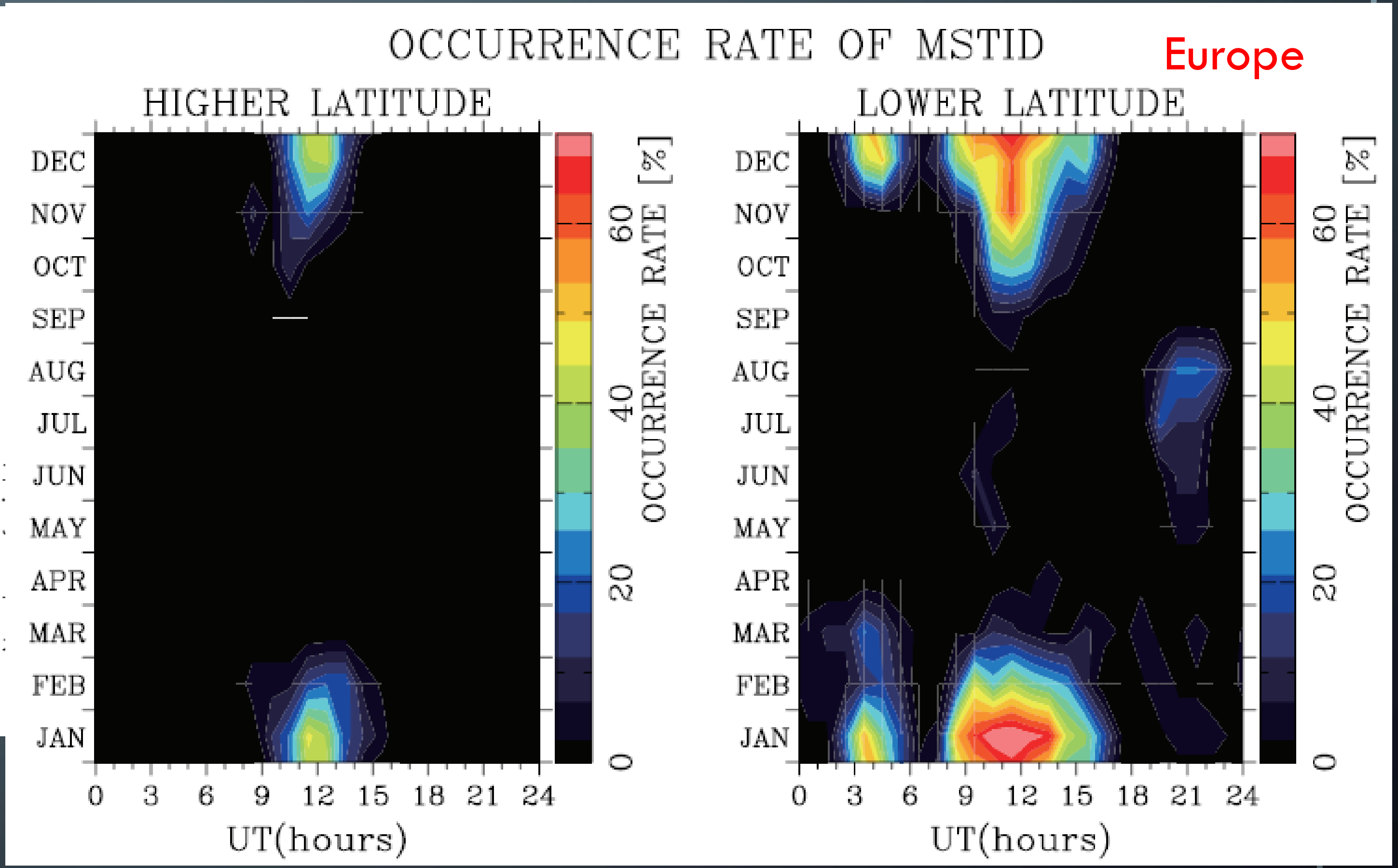
Yonaguni, Japan



Narayanan et al. (2014)

Seasonal variations of the MSTIDs occurrence



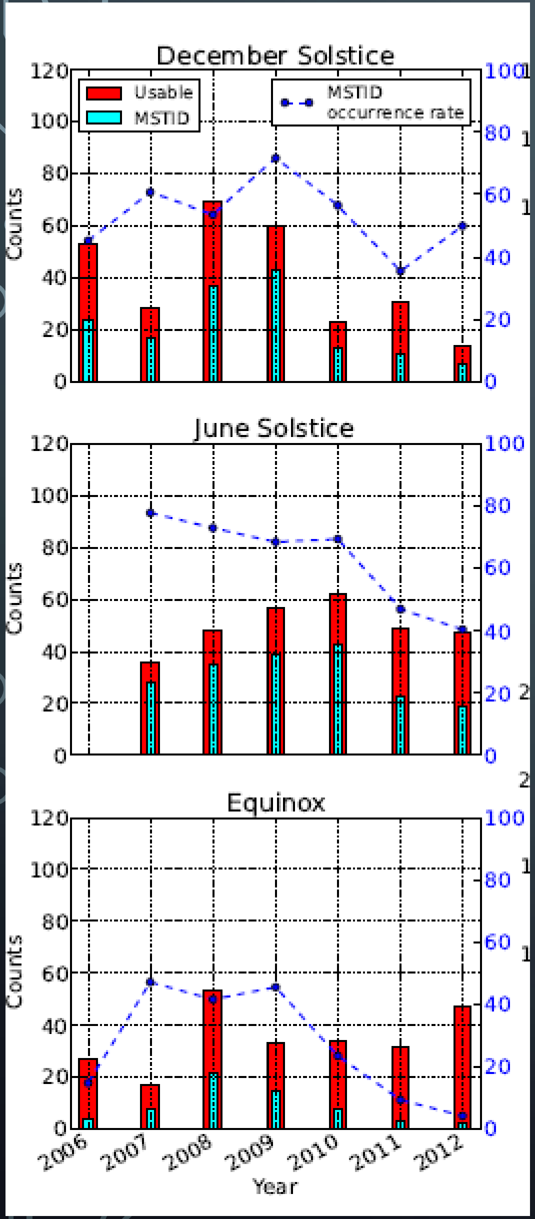


Nighttime MSTIDs occurrence show two peaks during the solstices over the American sector and Central Pacific.

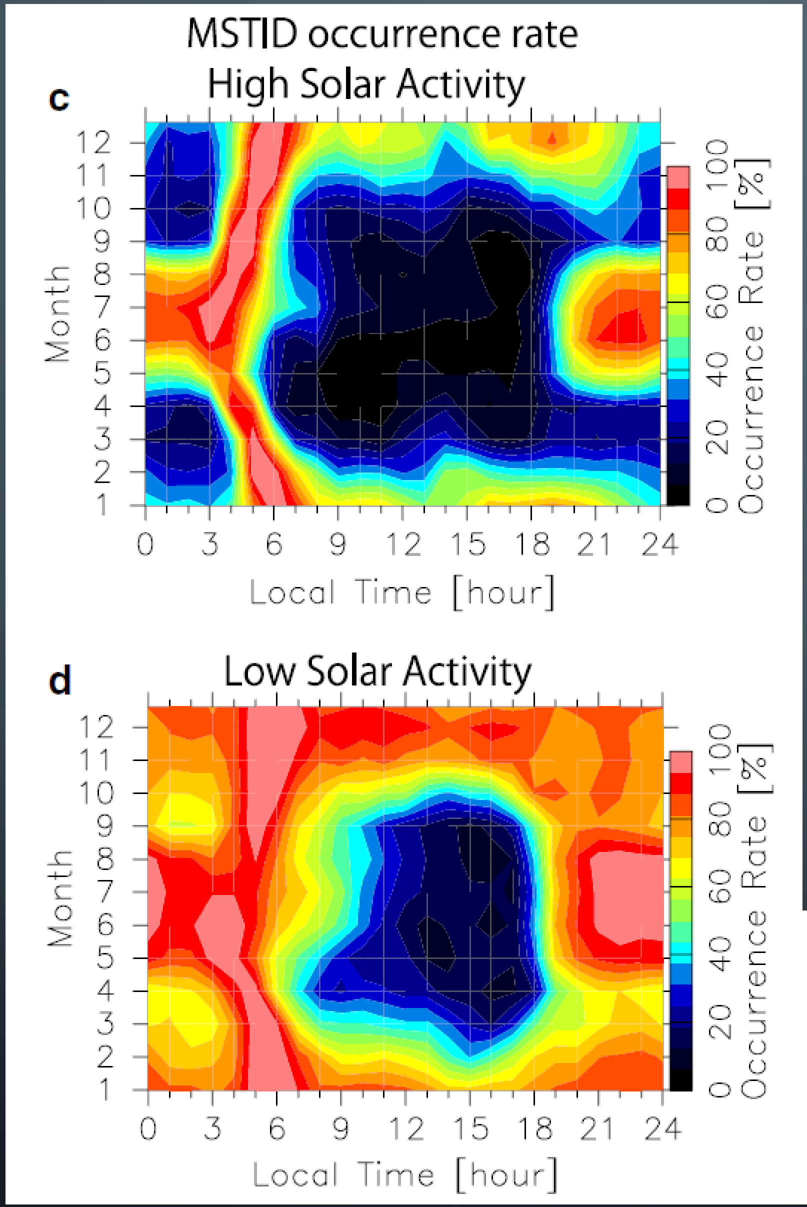
- ✓ Only summer solstice maxima over Europe
- ✓ Daytime MSTIDs occurrence maximum during winter

Otsuka et al. (2013)

Solar activity dependency of the nighttime MSTIDs

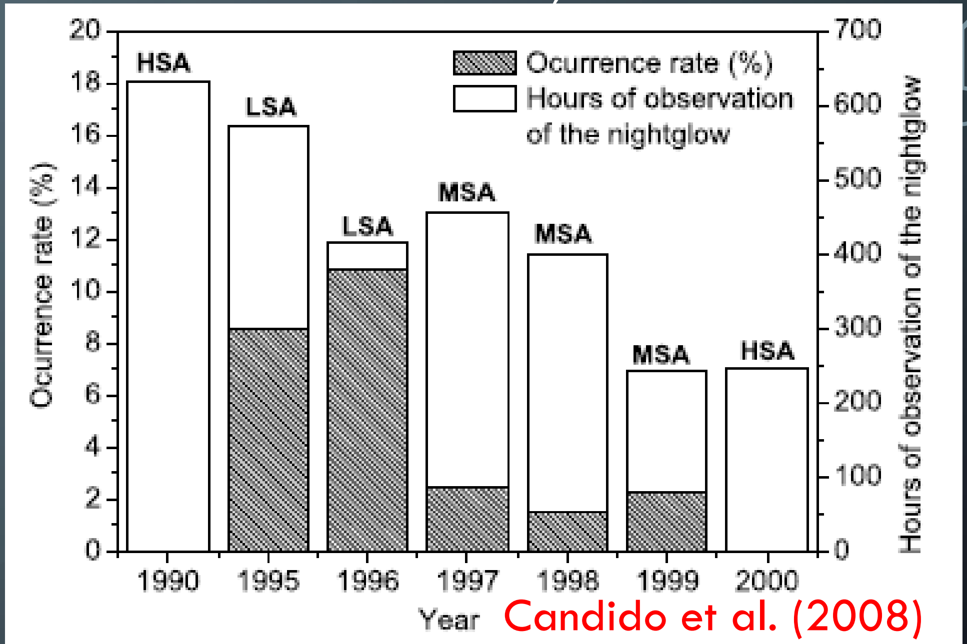


Duly et al. (2013)



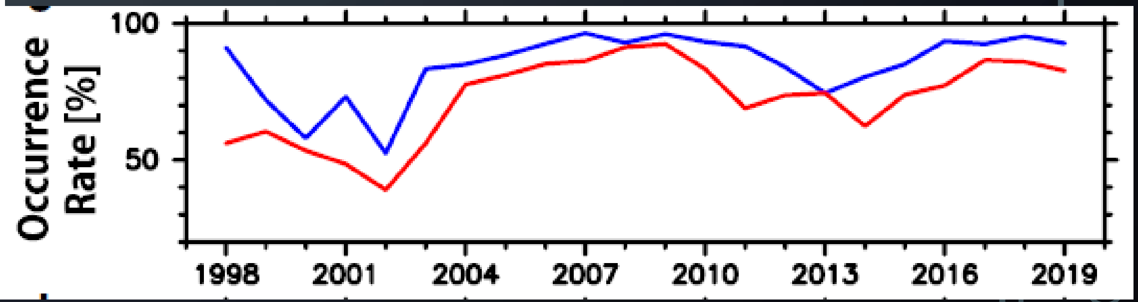
Otsuka et al. (2021)

Cachoeira Paulista, Brazil



Candido et al. (2008)

✓ Negative correlation with solar activity



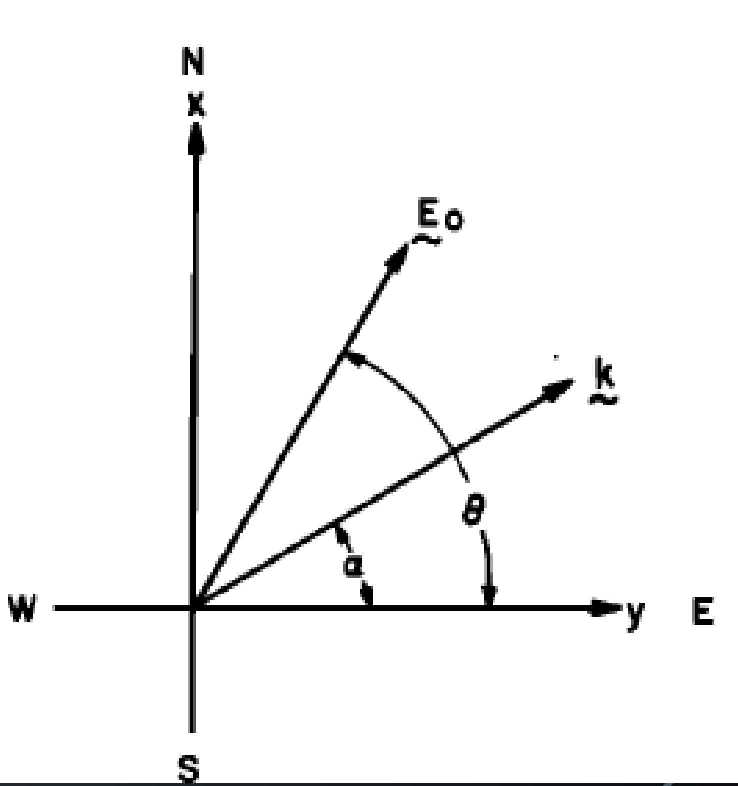
Sources of the nighttime MSTIDs

1. Perkins instability

$$\gamma = \frac{\Sigma_F}{\Sigma_T} \frac{\cos D \sin \alpha \sin(\theta - \alpha)|\vec{E}^m|}{BH}$$

$$\vec{E}^m = \vec{E}^r + \vec{U}_0 \times \vec{B}$$

$$\gamma_{max} \approx 3 \times 10^{-4} (\nu_{in})^{-1} \cdot \frac{\sin^2 D \sin^2(\theta/2)}{\cos\theta} \sec^{-1}$$



✓ It takes few hours the instability to grow. In other words, the growth rate is very slow.

Perkins (1973)

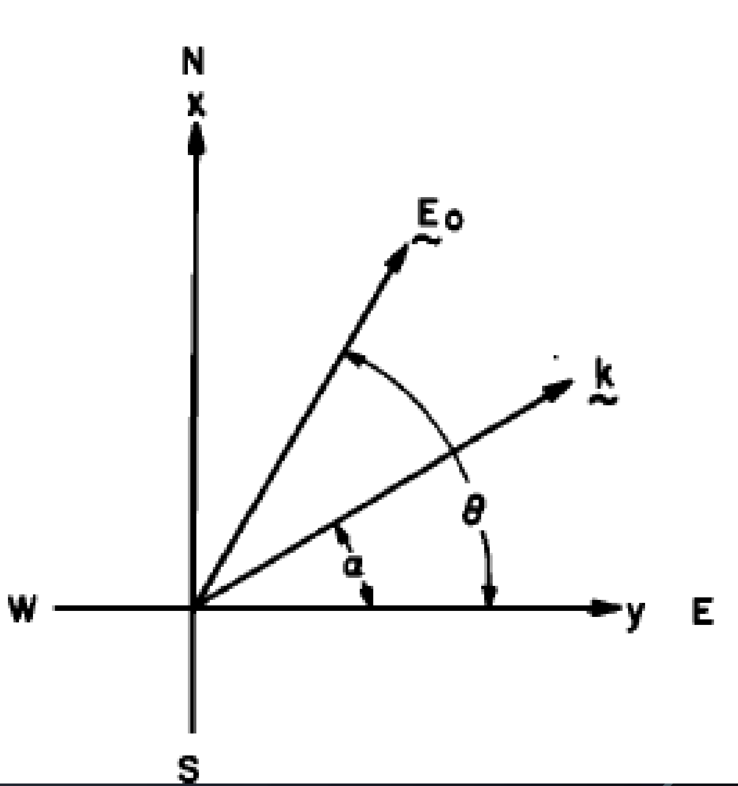
Miller et al. (1997)

Sources of the nighttime MSTIDs

2. Perkins instability and gravity waves

$$\gamma = \frac{\Sigma_F}{\Sigma_T} \frac{\cos D \sin\alpha \sin(\theta - \alpha)|\vec{E}^m|}{BH}$$

$$\vec{E}^m = \vec{E}^r + \vec{U}_0 \times \vec{B}$$



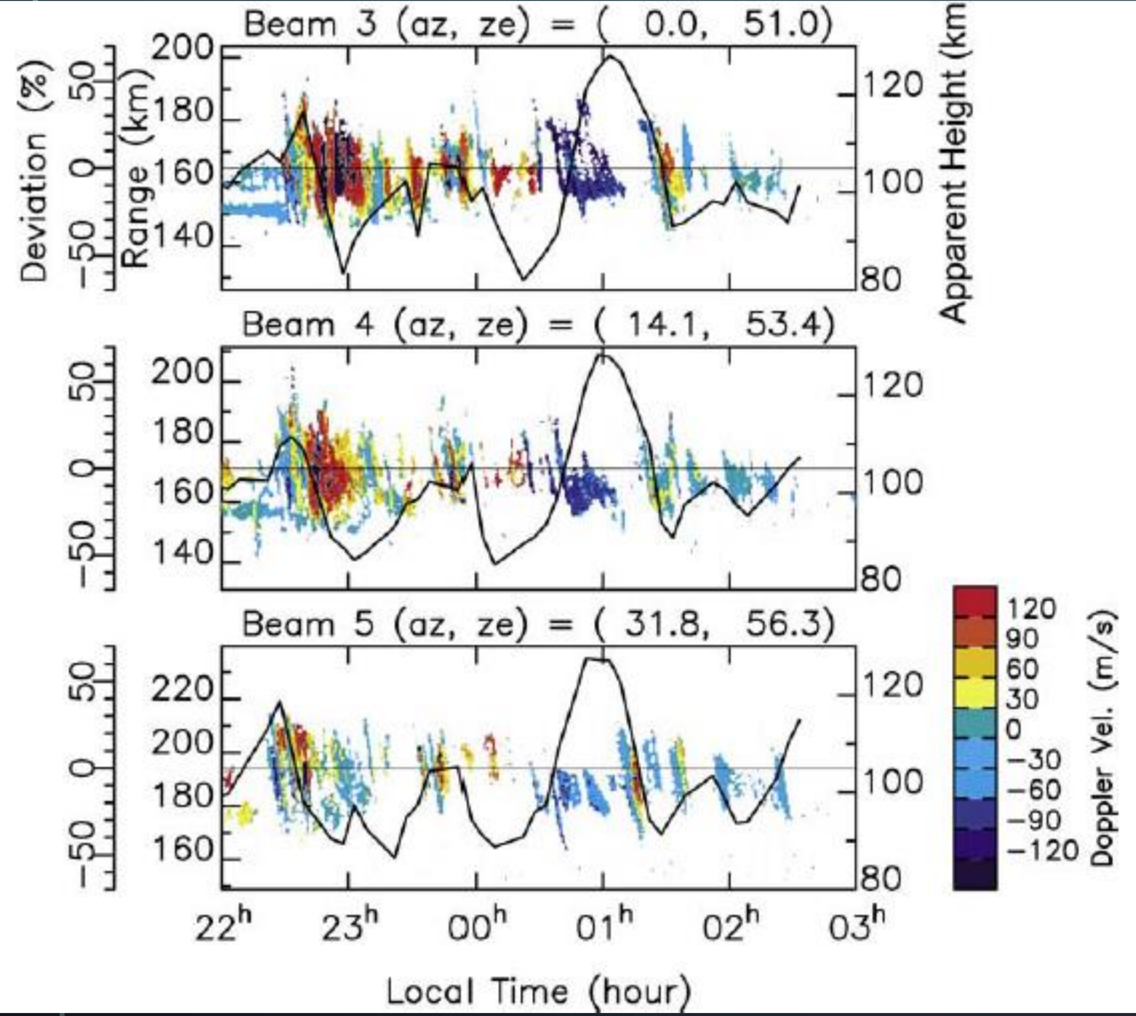
- ✓ Growth rate increases but it could not explain the directional preference of the MSTIDs

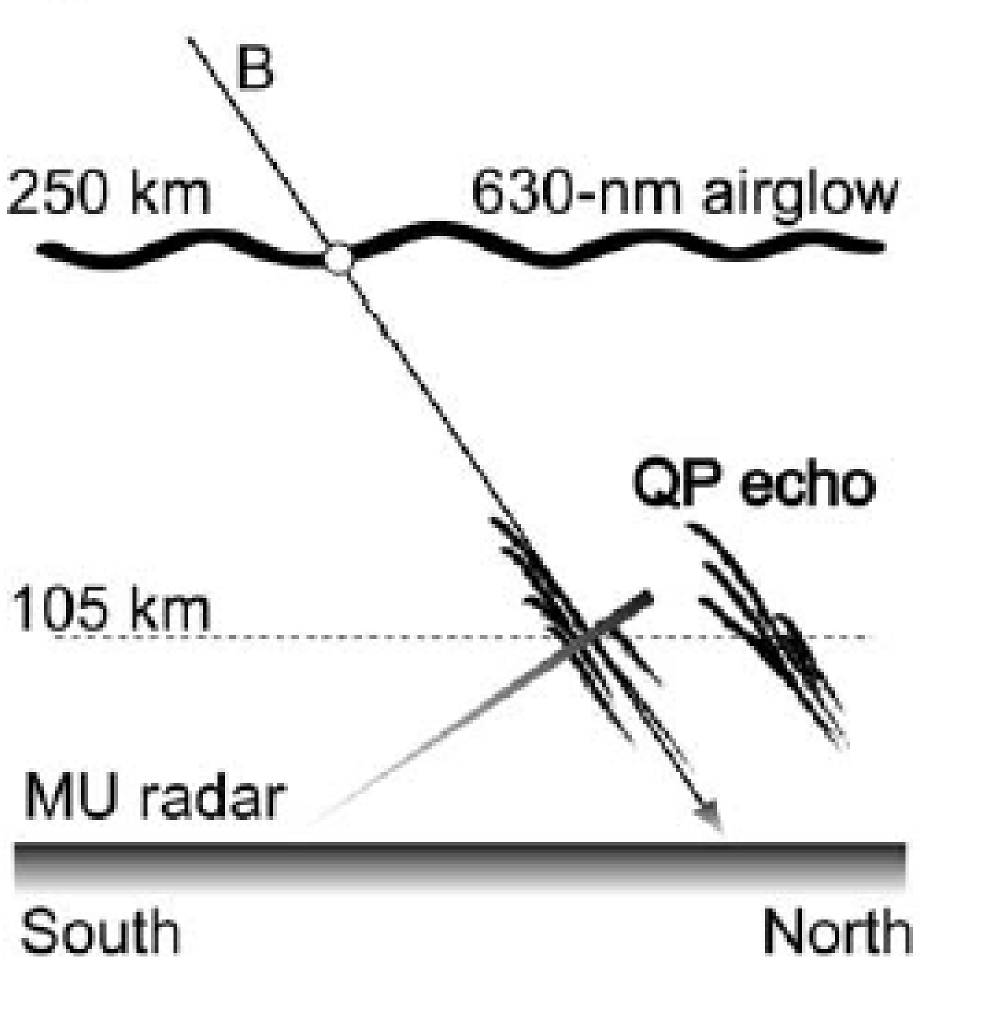
Perkins (1973)

Miller et al. (1997)

Sources of the nighttime MSTIDs

3. Es layer instability and Perkins instability

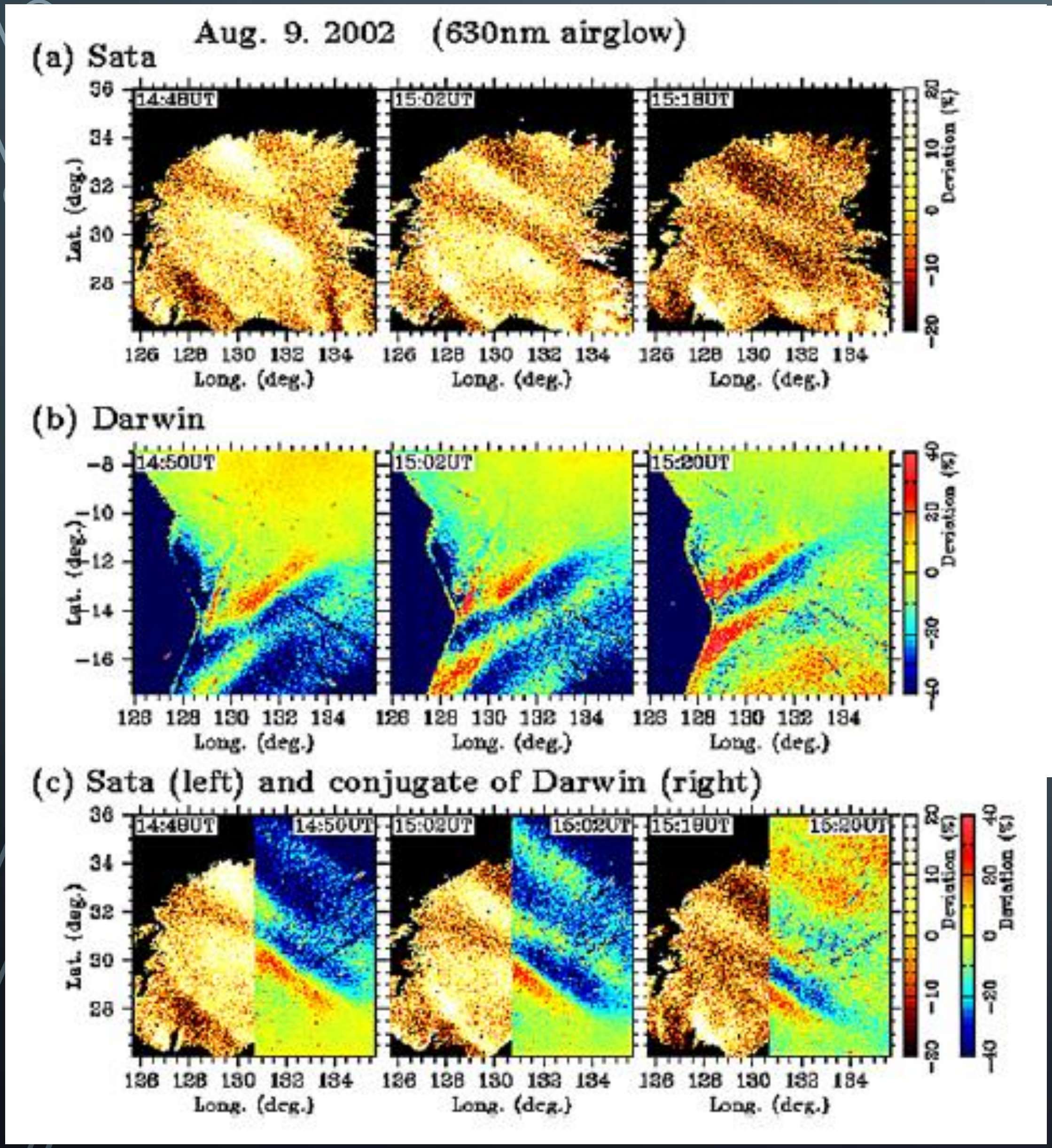


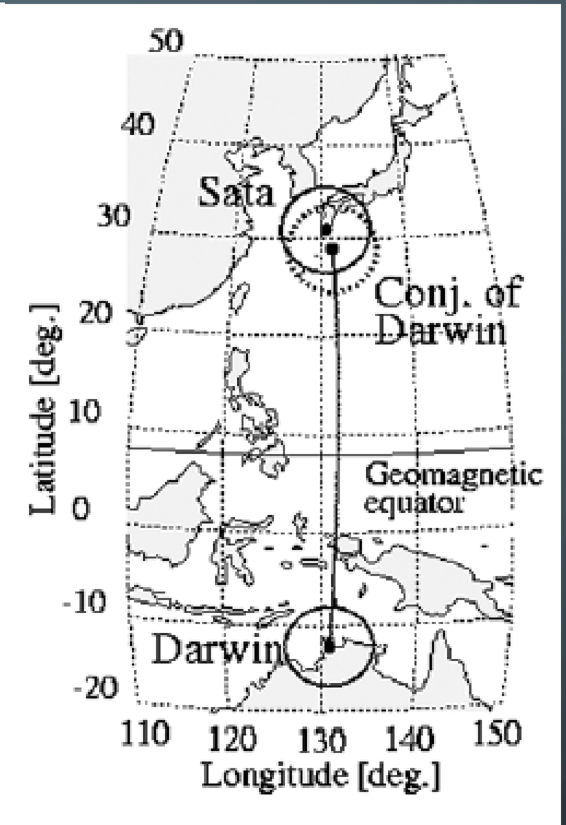


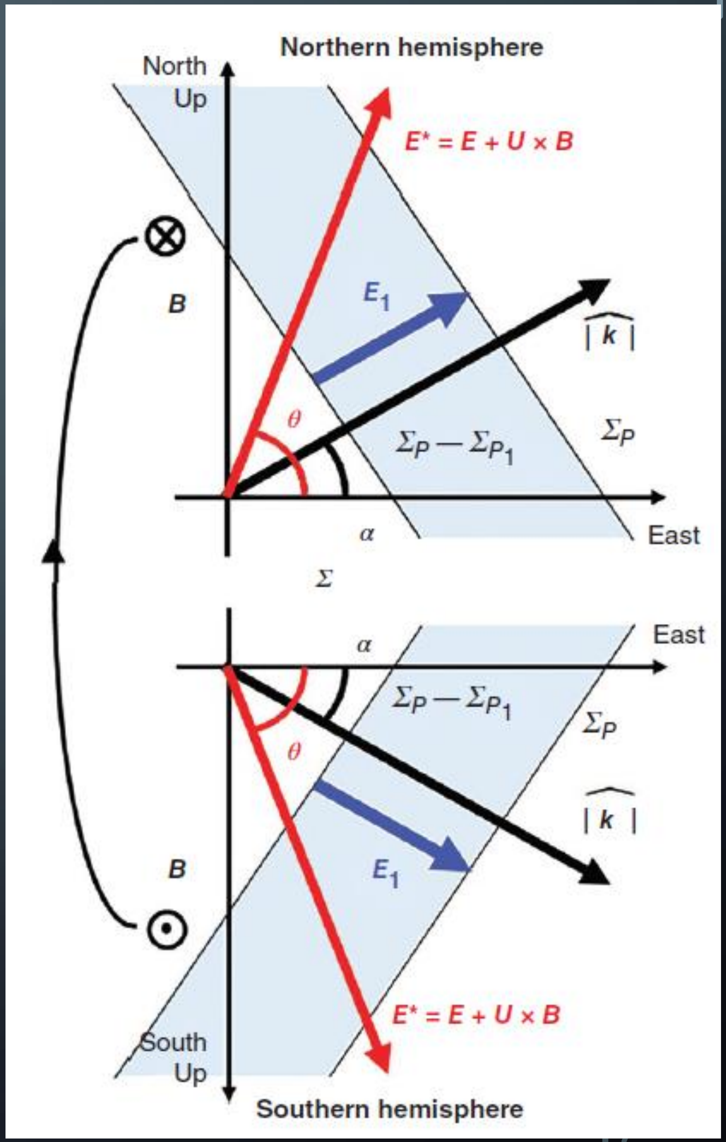
Otsuka et al. (2007)

Tsunoda (2001), Cosgrove (2007)

4. Interhemispheric coupling role on the generation of MSTIDs







Otsuka et al. (2004)

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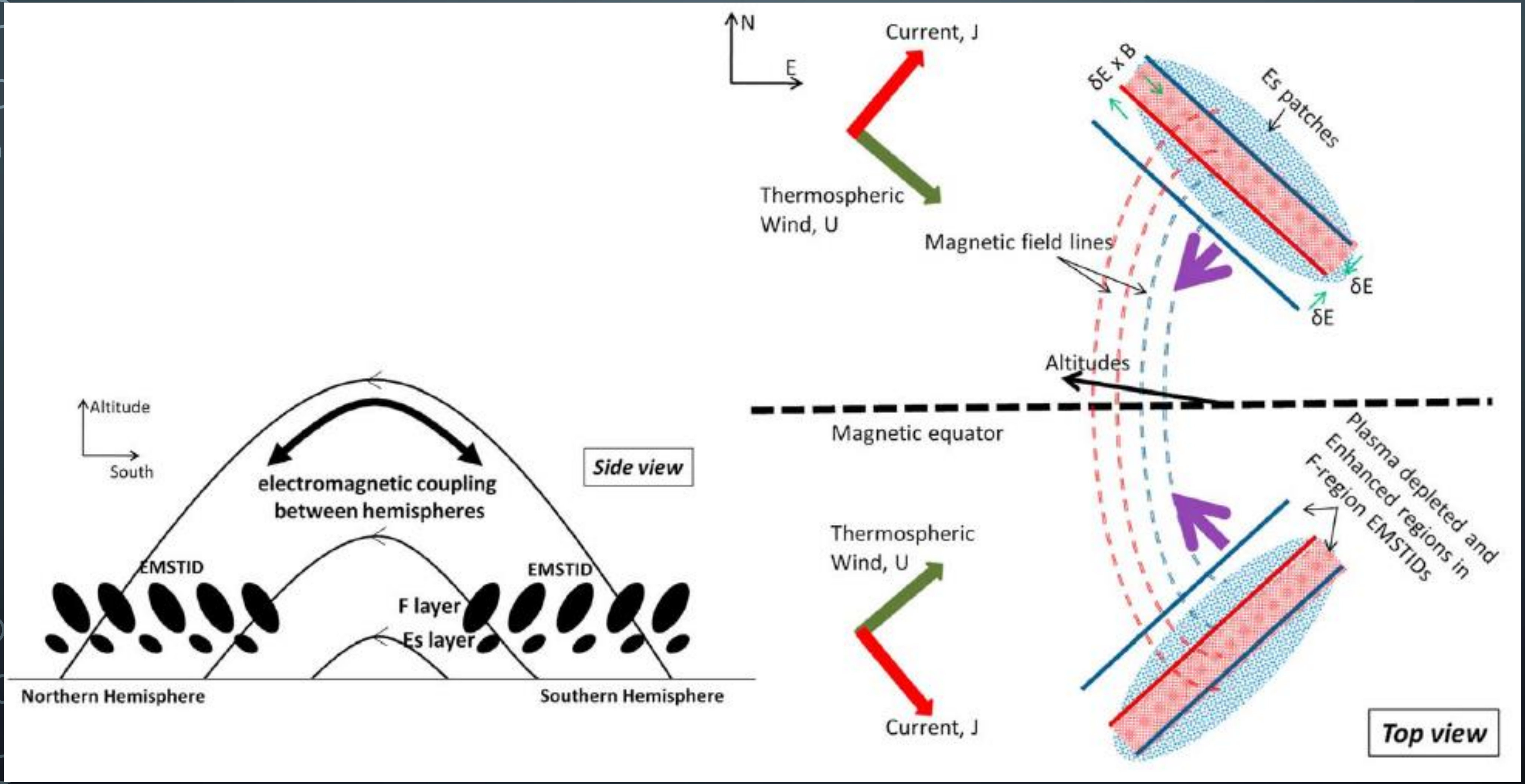
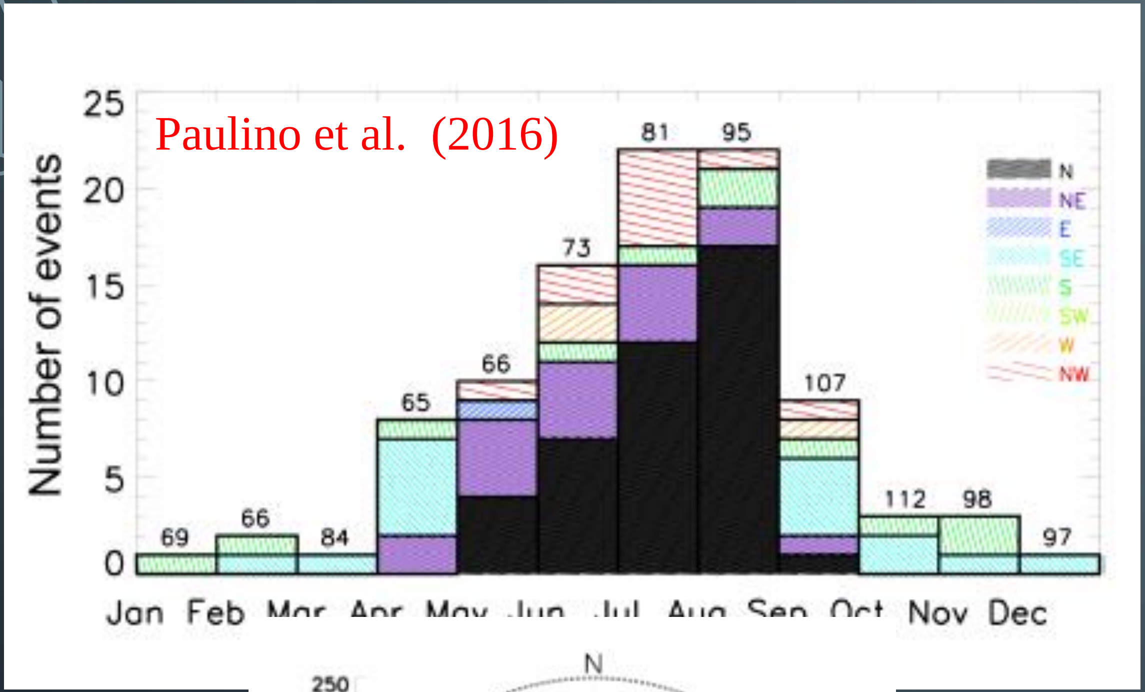
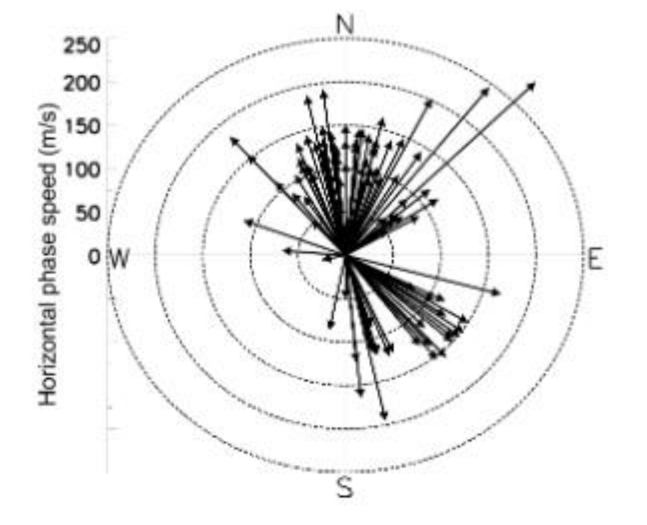


Saito et al. (1995) Narayanan et al. (2018)

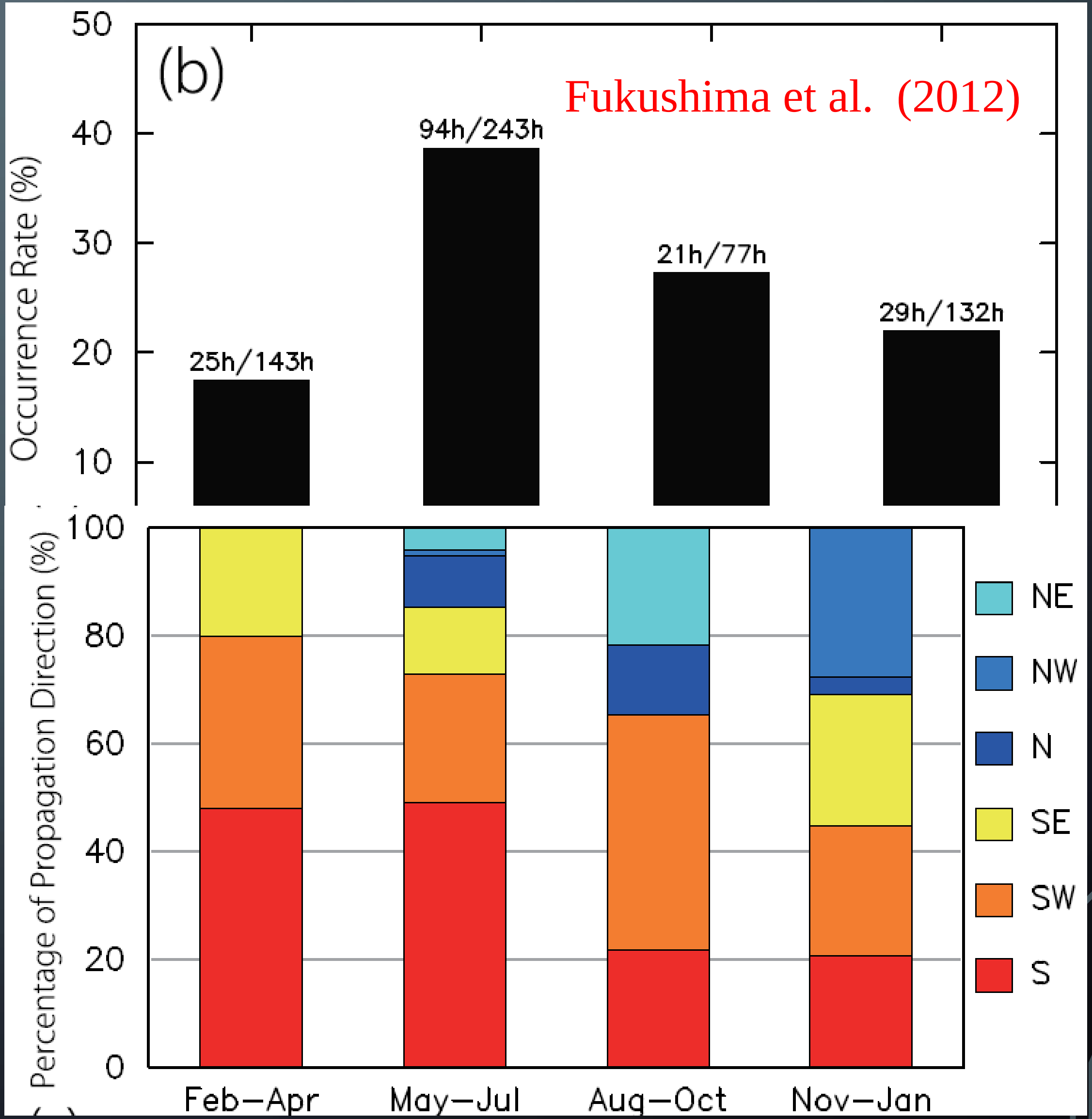
General characteristics of the nighttime MSTIDs- Low latitudes

São João do Cariri, Brazil

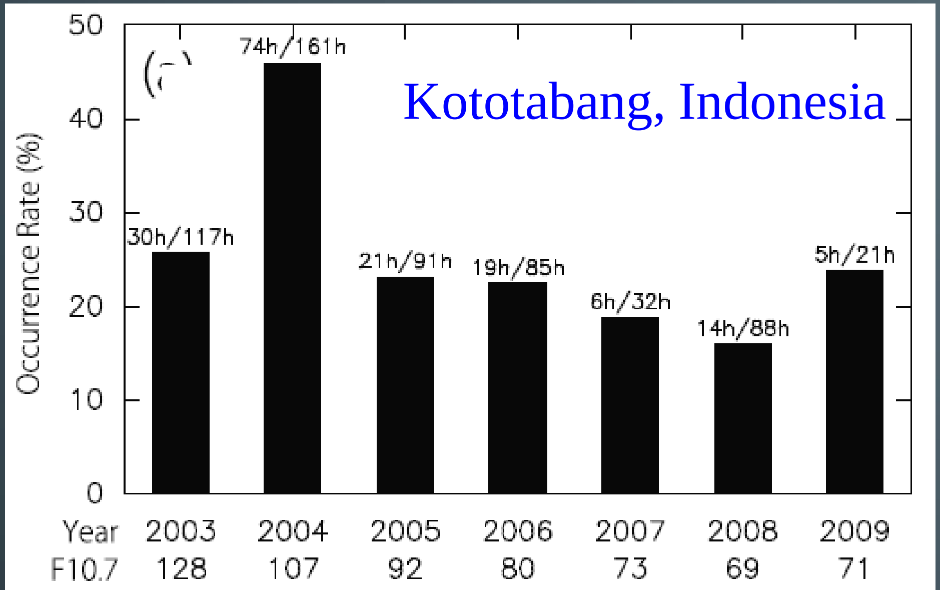


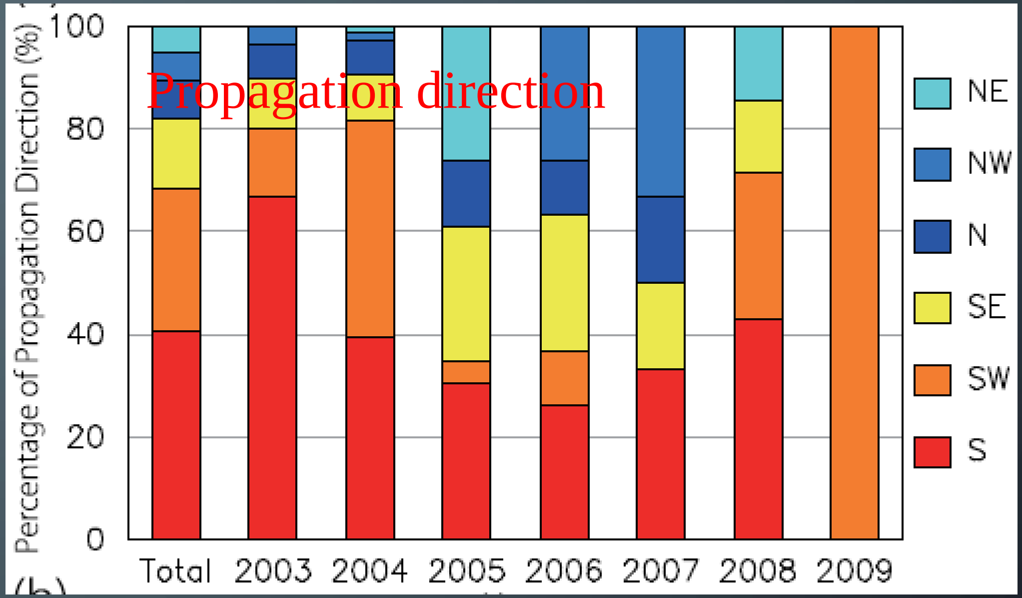


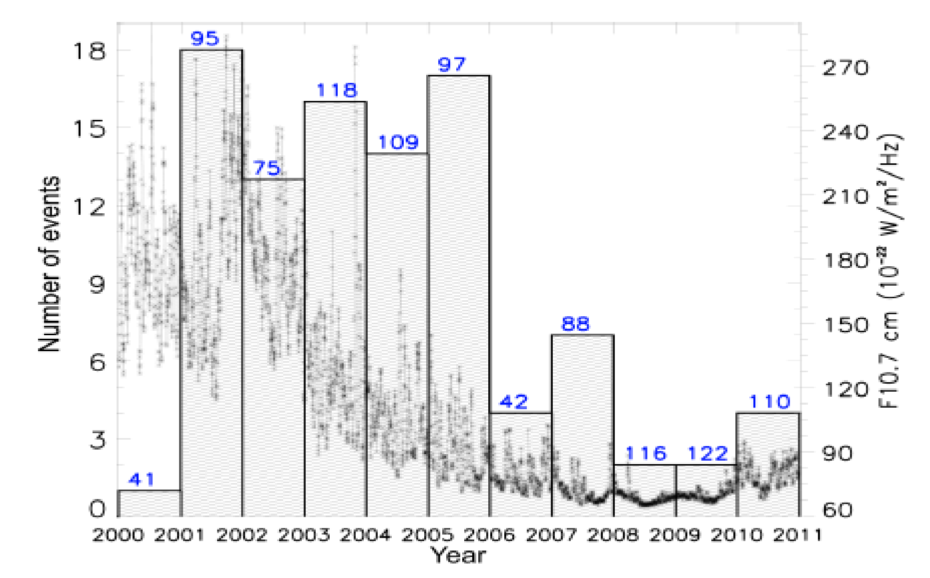
Kototabang, ,Indonesia



Solar activity dependency of the MSTIDs- Low latitudes





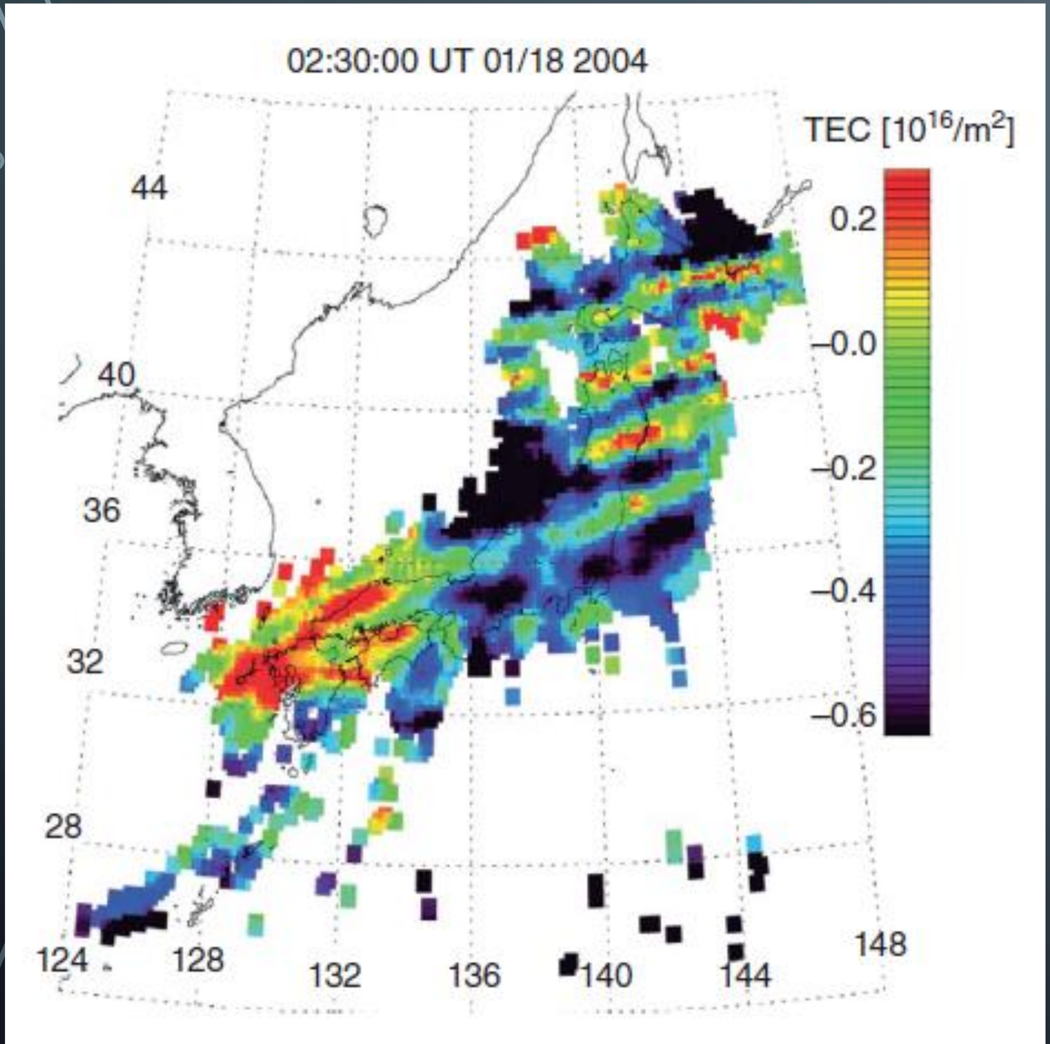


Paulino et al. (2016)

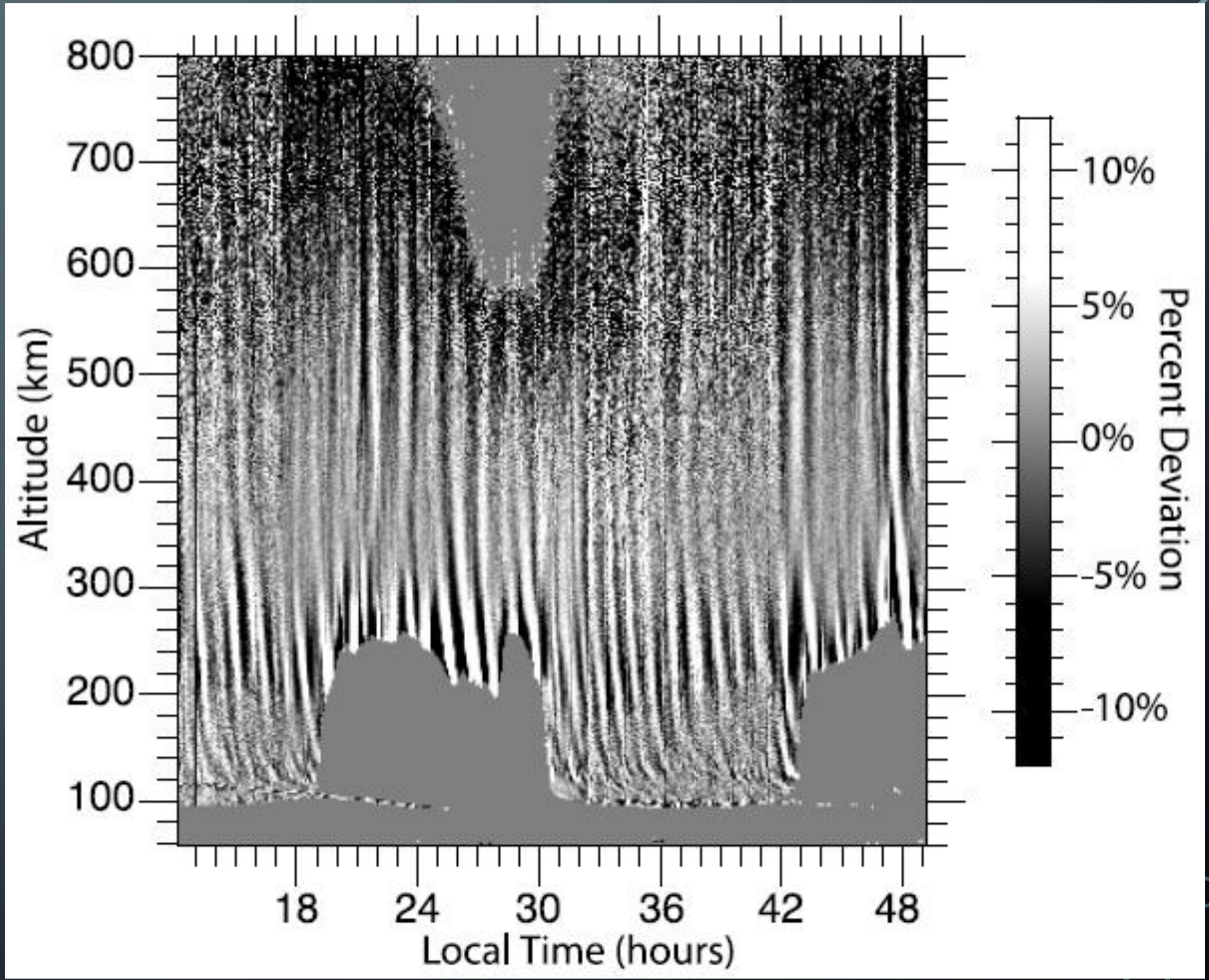
- ✓ Positive correlation with solar activity

Fukushima et al. (2012)

Daytime MSTIDs

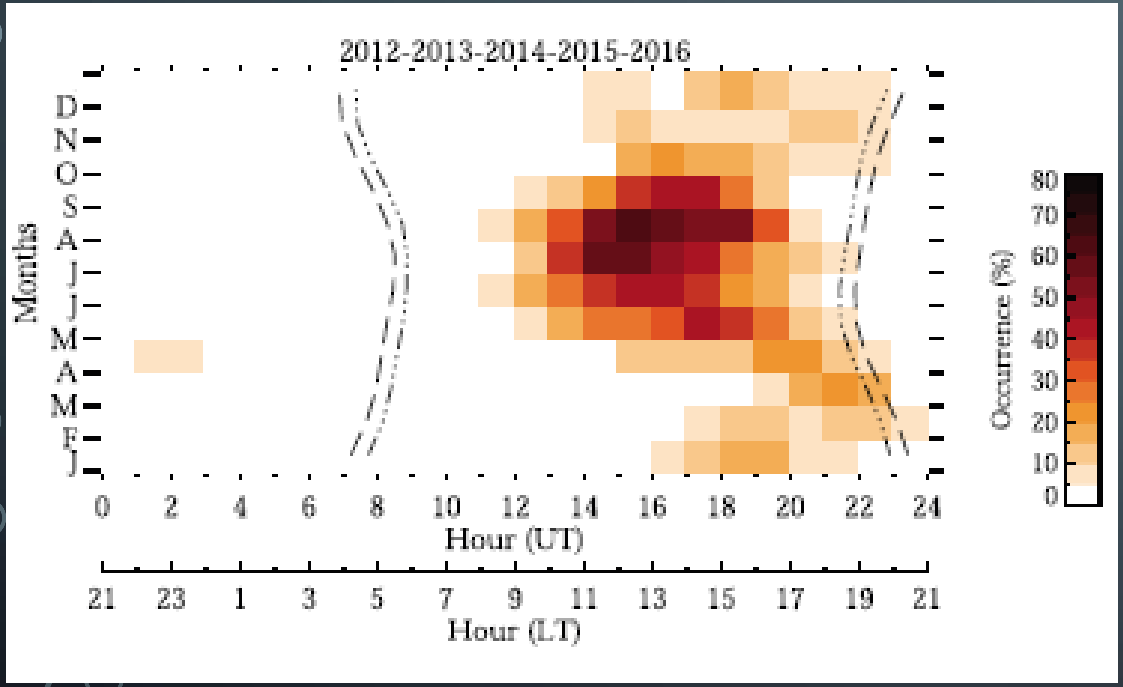


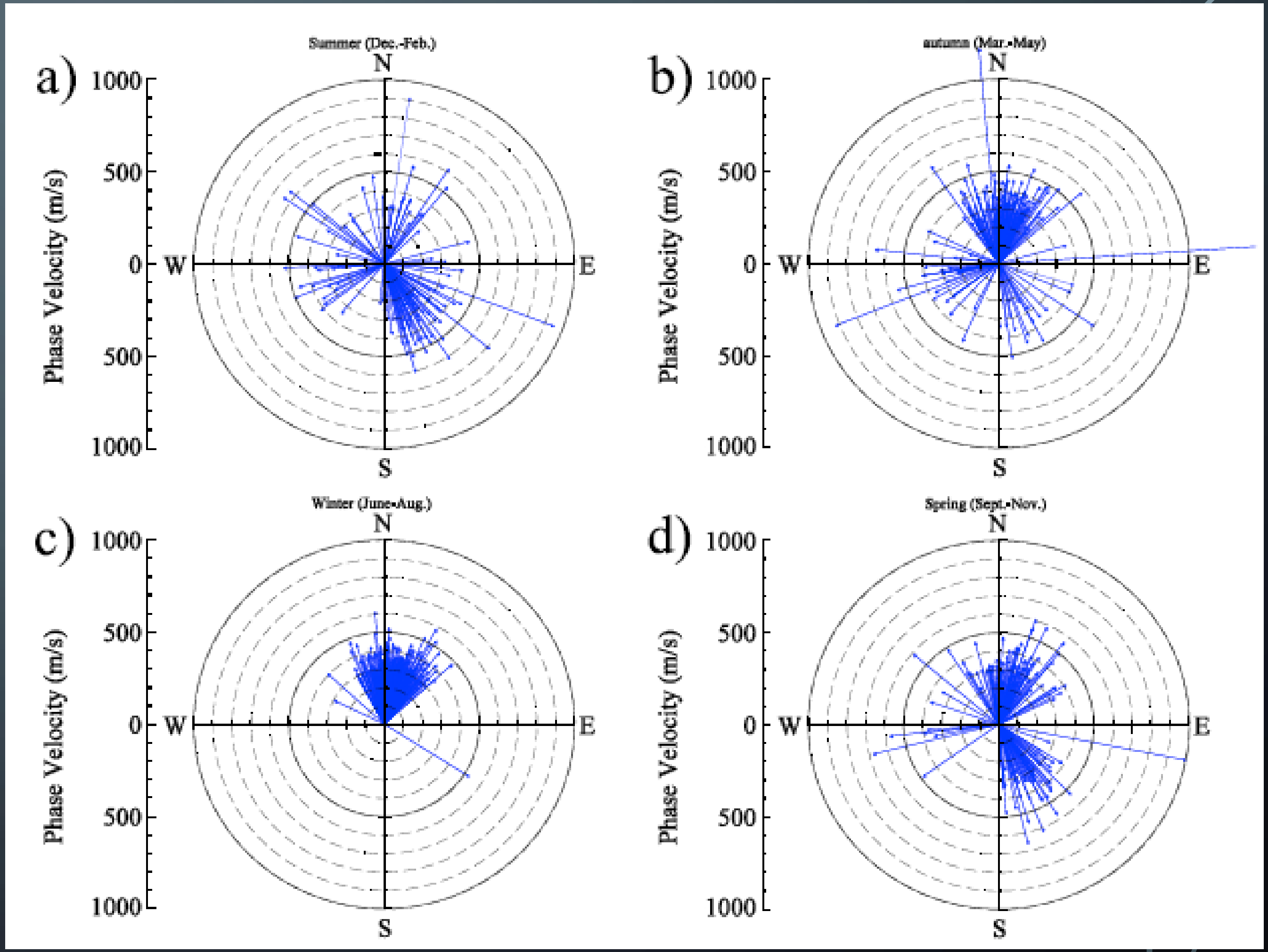
Otsuka et al. (2021)



Livneh et al. (2007)

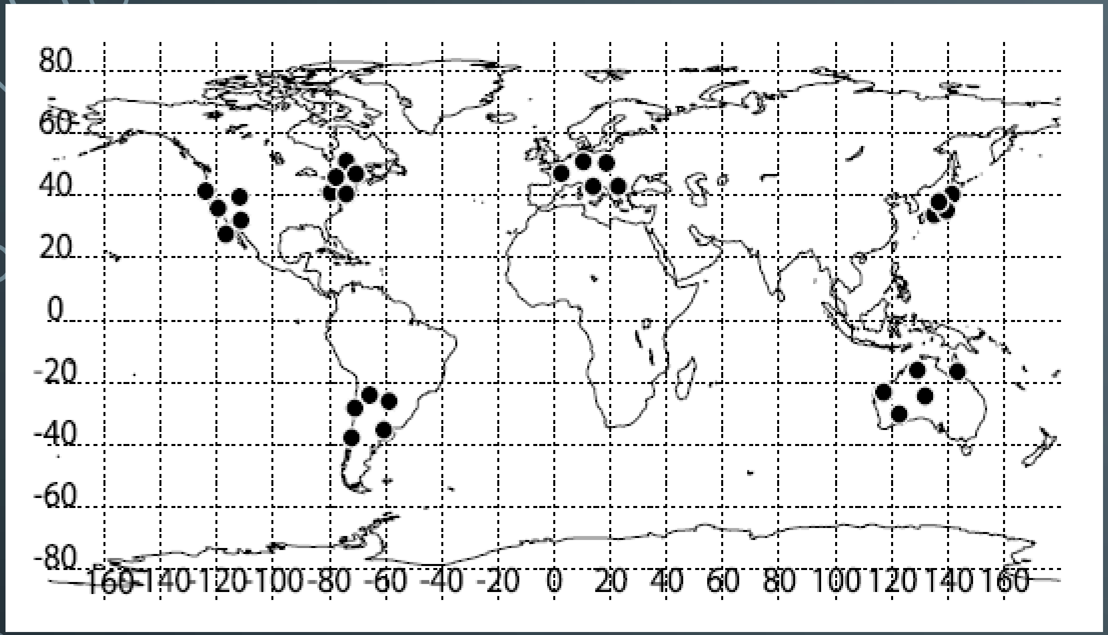
Seasonal variation of daytime MSTIDs over South America

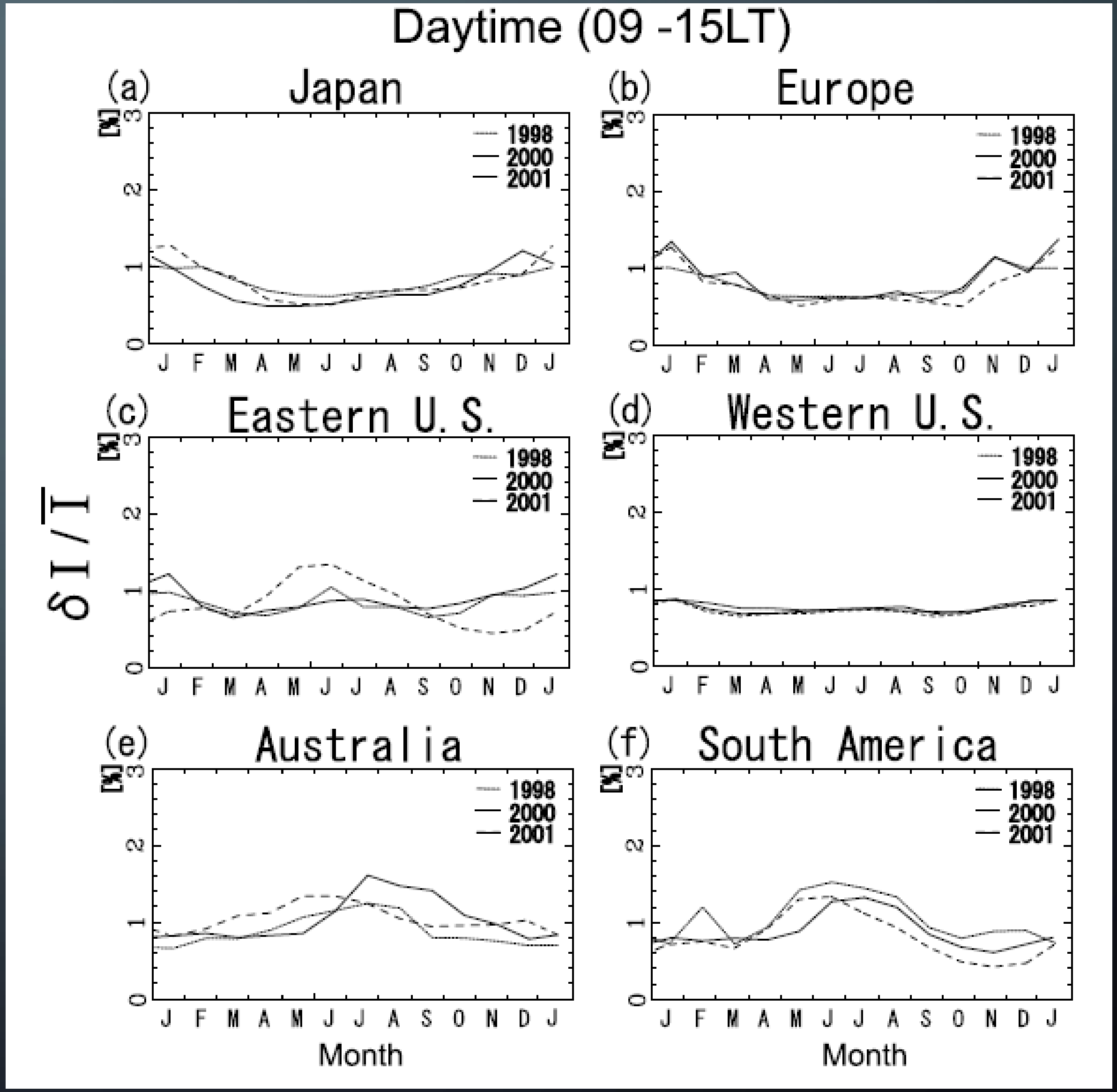




Figueiredo et al. (2018)

Seasonal and longitudinal variations of daytime MSTIDs

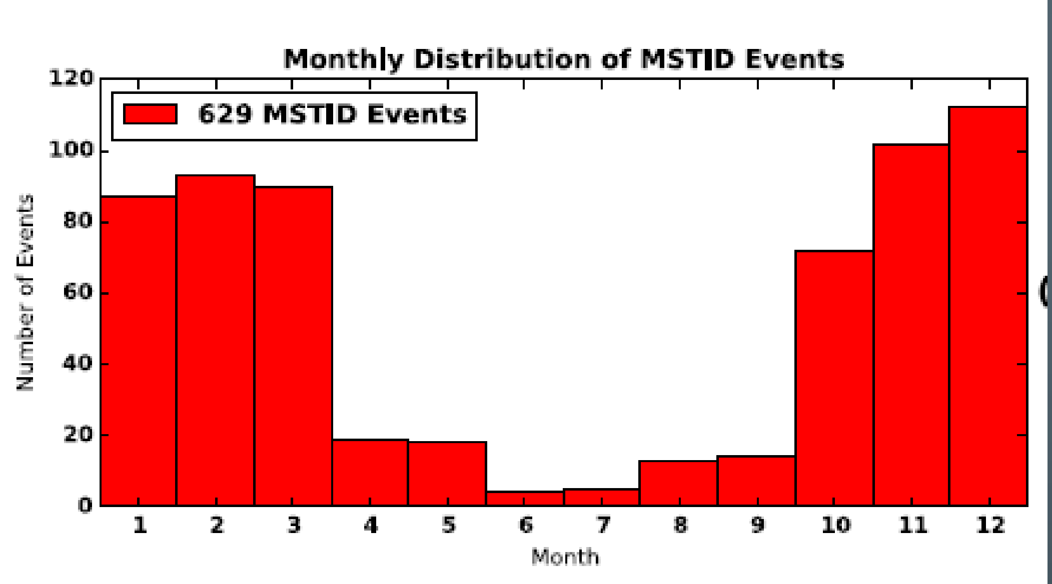


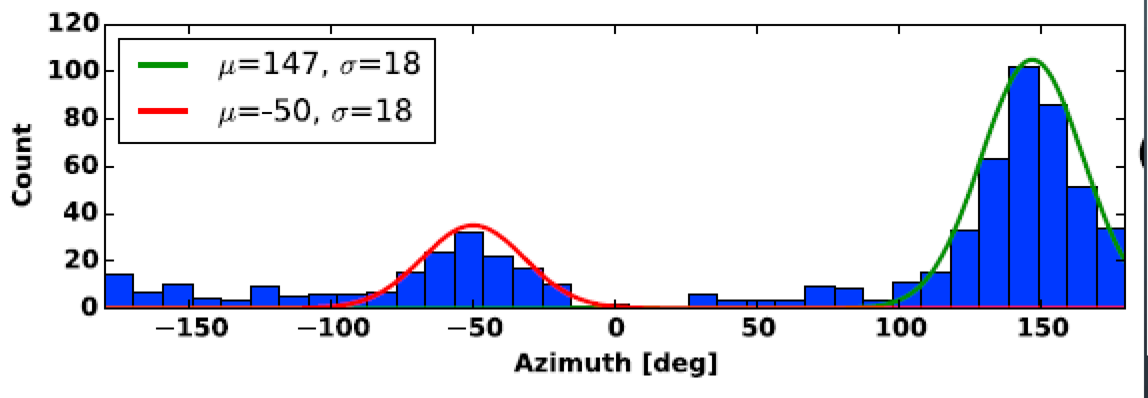


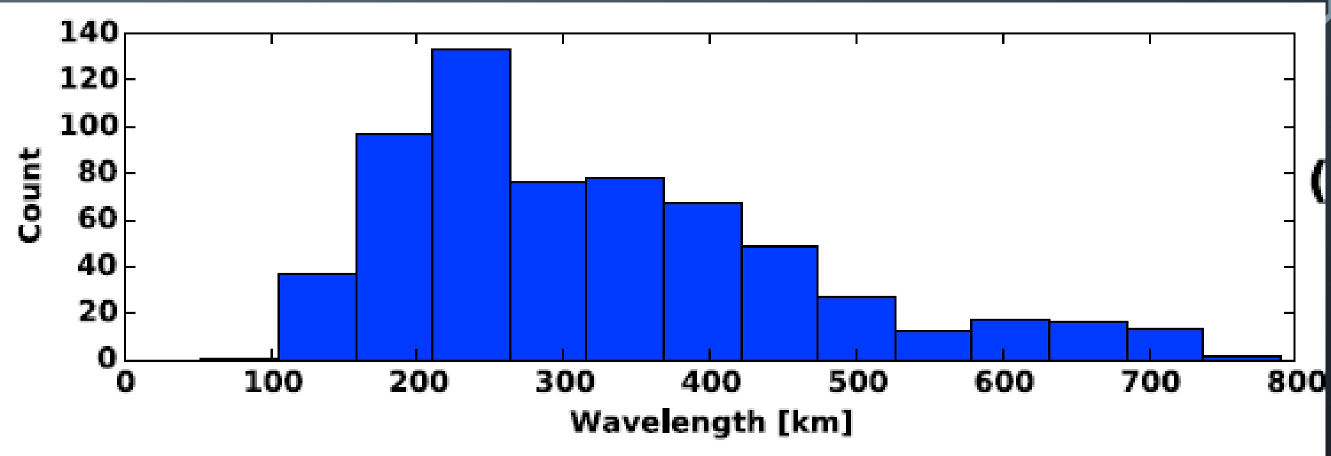
- ✓ Daytime MSTIDs activity are high in winter in all six regions.

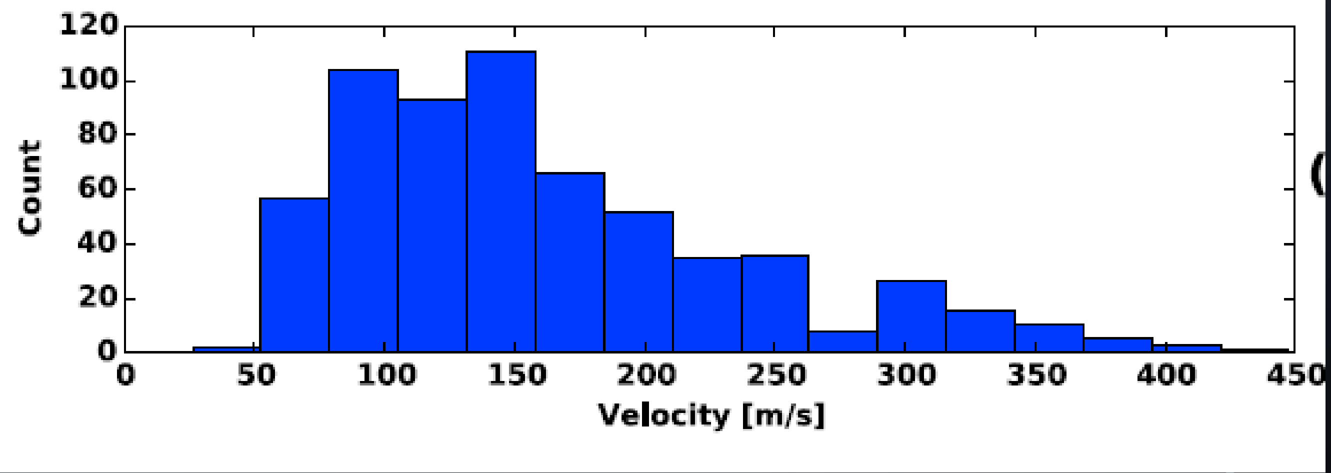
Kotake et al. (2006)

Daytime MSTIDs in high latitudes



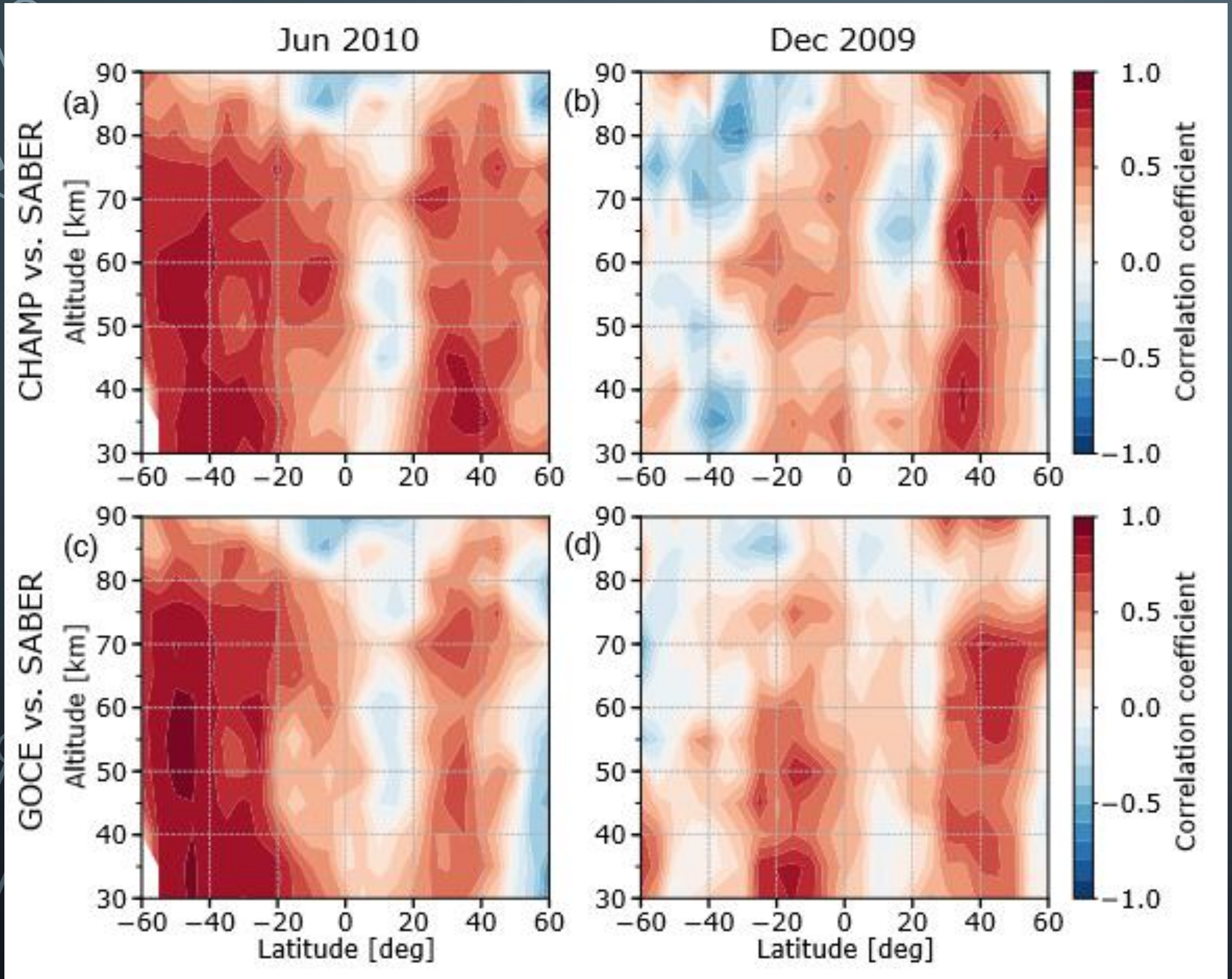






Frissell et al. (2014)

Sources from the middle and lower atmosphere



The correlation between GW momentum fluxes observed in the middle atmosphere (30–90 km) and GW-induced perturbations in the T/I.

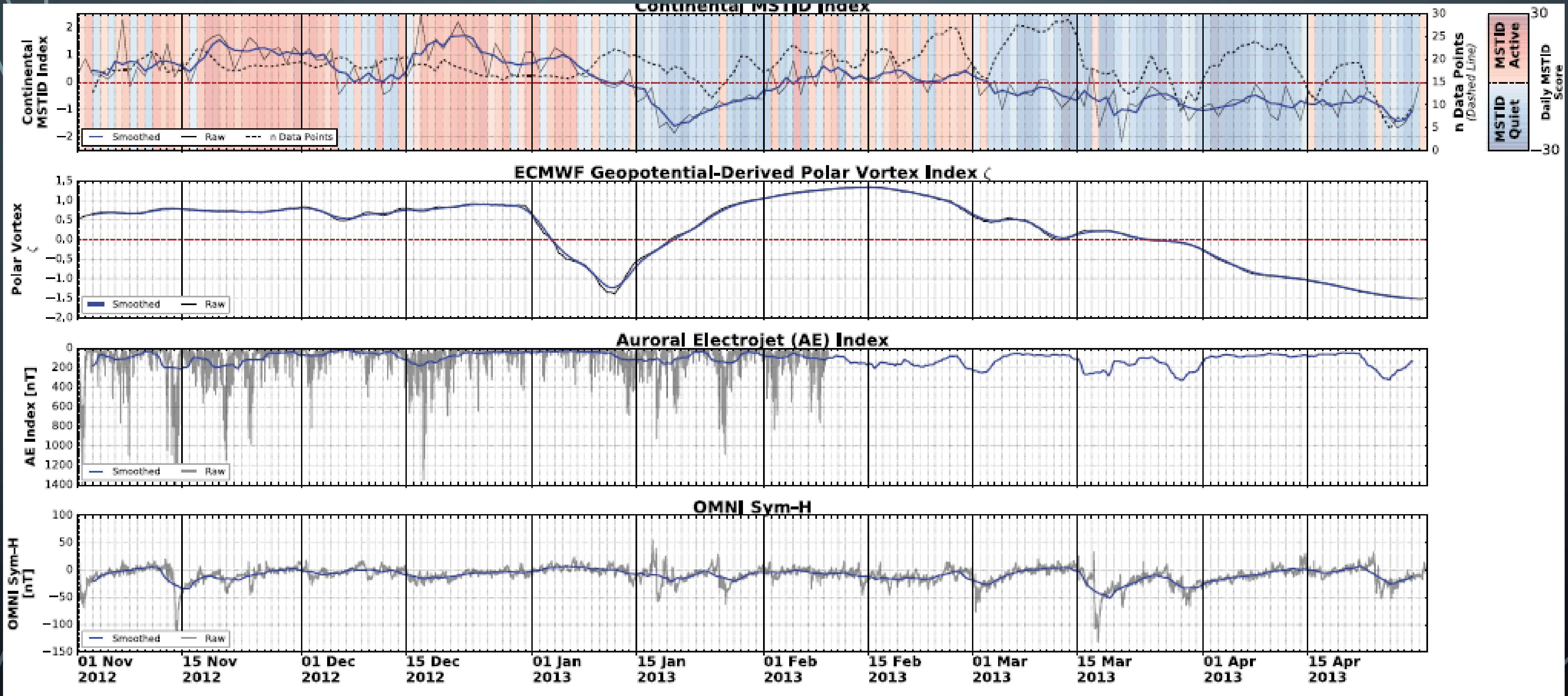
Two coupling mechanisms are likely responsible for these positive correlations:

(1) fast GWs generated in the troposphere and lower stratosphere can propagate directly to the T/I

2) primary GWs with their origins in the lower atmosphere dissipate while propagating upwards and generate secondary GWs, which then penetrate up to the T/I and maintain the spatial patterns of GW distributions in the lower atmosphere

Trinh et al. (2018)

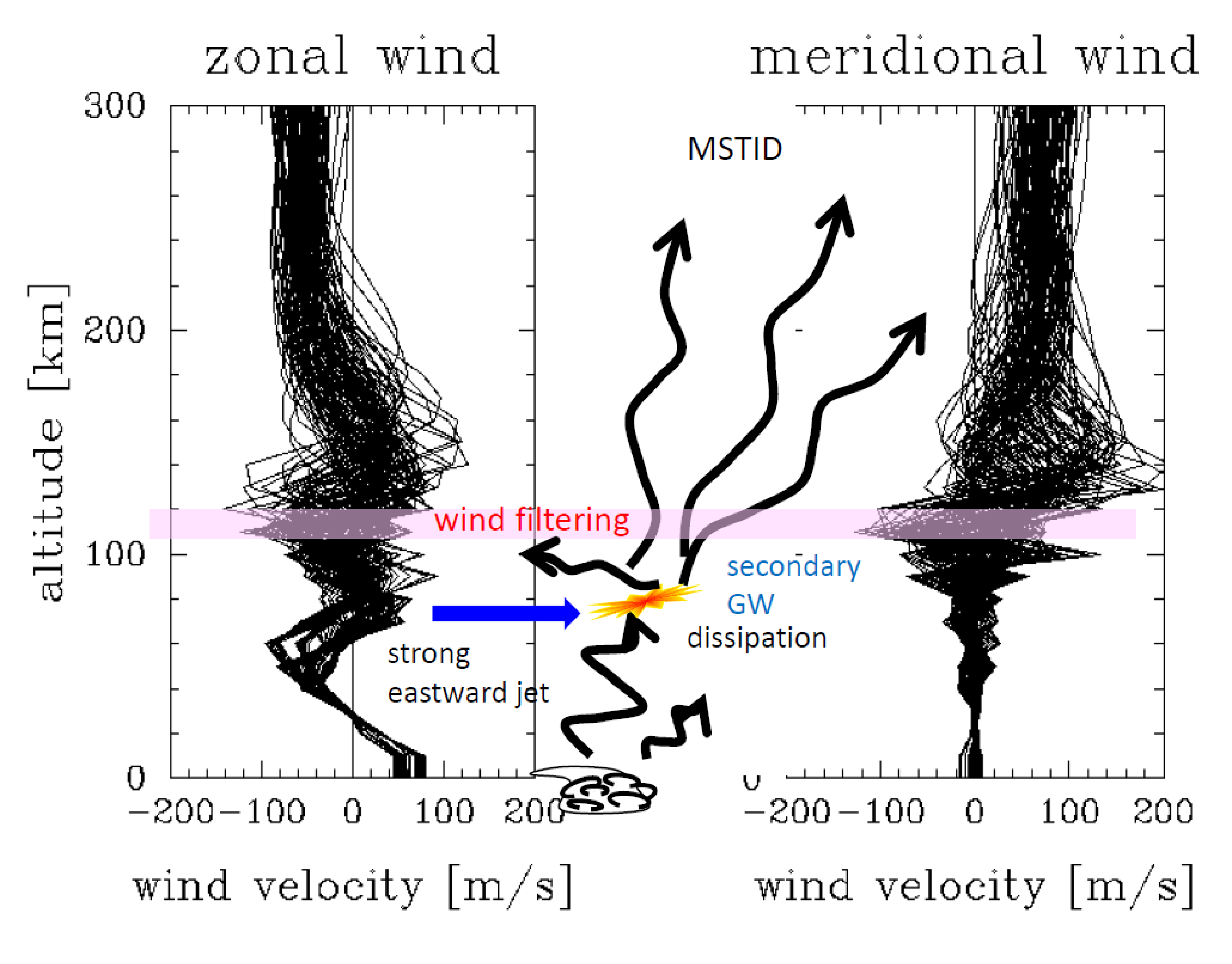
Polar vortex Vs daytime MSTDs



- ✓ MSTIDs occurrence is more during the strong polar vortex condition
- ✓ Wind filtering could be a probable reason

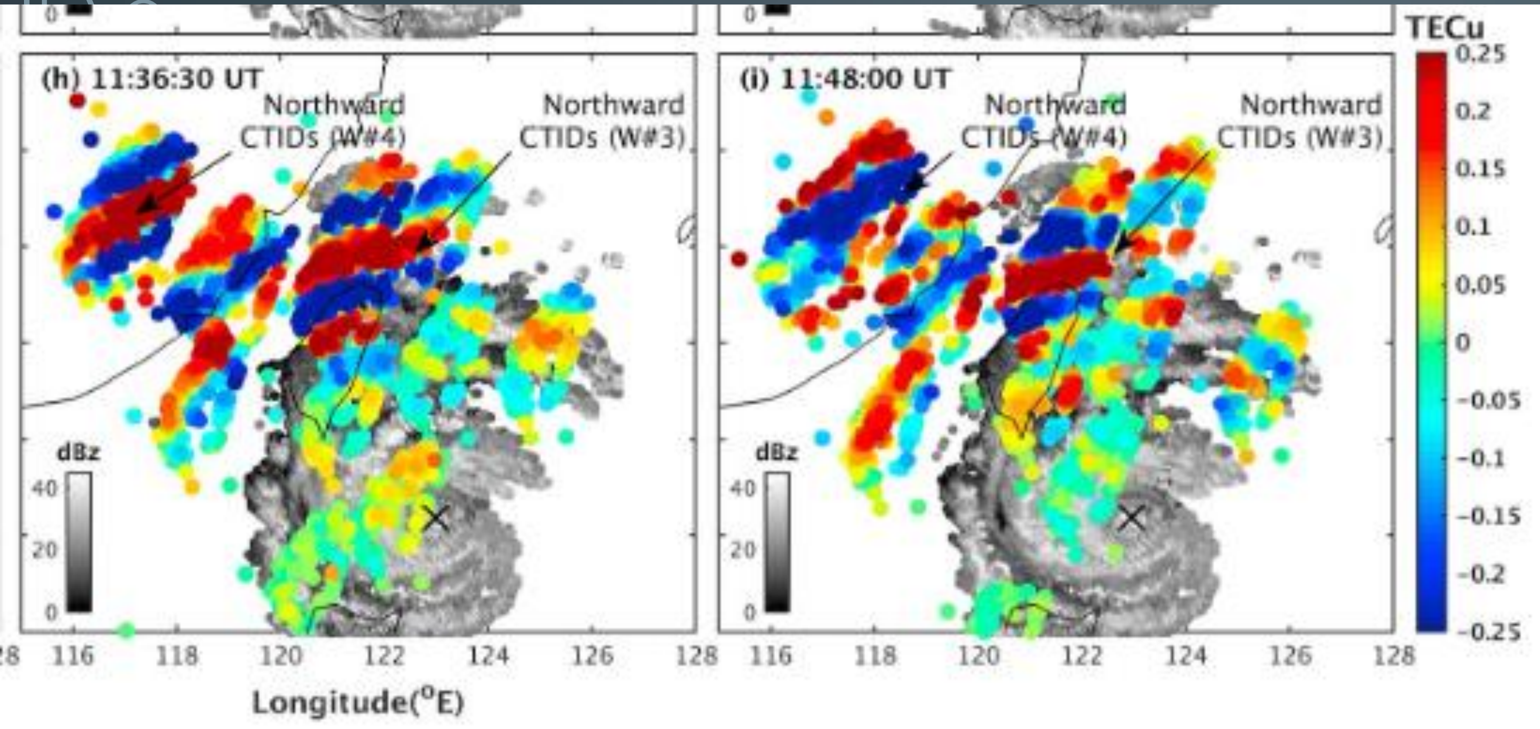
Frissell et al. (2016)

Schematic of GWs role on the vertical coupling

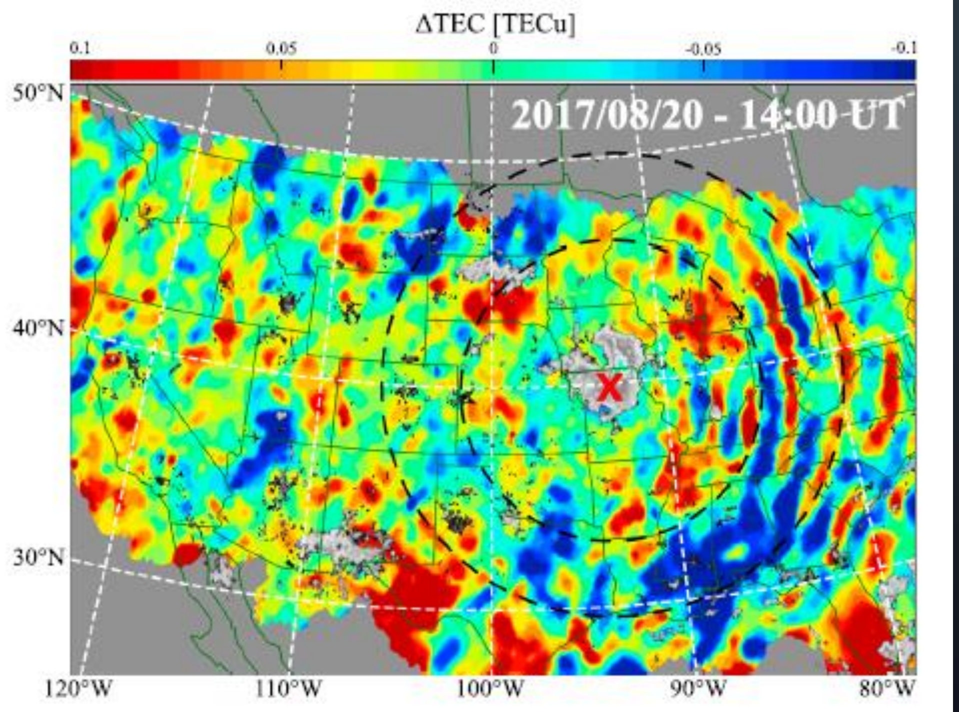


Credits: Otsuka

Concentric TIDs caused by Thunderstorms/Typhoon



Chou et al. (2017)



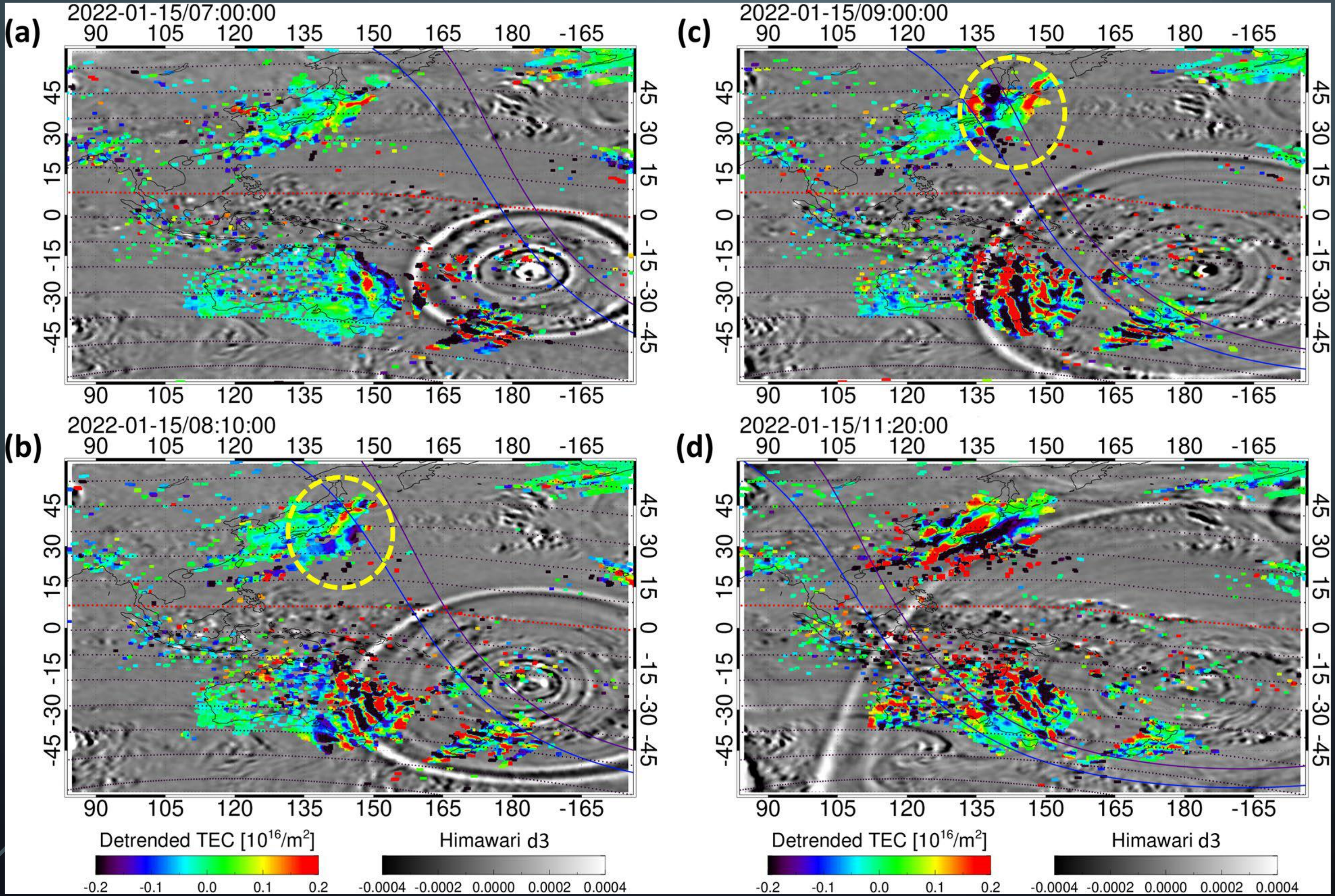
Mrak et al. (2018)

$$\lambda_z = \sqrt{\frac{T_b^2}{T_p^2 - T_b^2} \cdot \lambda_h^2}$$

$$\Theta = \arctan\left(\frac{\lambda_z}{\lambda_h}\right)$$

$$c_{gz} \approx \frac{\lambda_h^2 T_b^2}{\lambda_z T_p^3}$$

Earthquake/Volcano induced TIDs



Shinbori et al. (2022)

Summary and unresolved problems

- ✓ In general, the MSTIDs occurrence shows local time, seasonal, and solar activity dependency
- ✓ Daytime MSTIDs occurrence is high during the winter in the northern hemisphere
- ✓ Nighttime MSTIDs occurrence is higher during the solstice condition
- ✓ Mid-latitude nighttime MSTIDs show a negative correlation with solar activity. On the other hand, it depicts a positive correlation with solar activity in the equatorial latitudes.
- ✓ Generation of the nighttime MSTIDs is driven by the E and F region electric field associated coupling processes Perkins instability.
- ✓ Daytime MSTIDs are mainly caused by the upward propagating primary or secondary gravity waves

Problems:

- ➢ What is the threshold value of the Es layer that can cause the MSTIDs?
- ➢ What is the relation between spread-F and nighttime MSTIDs and ROTI?
- ➢ Which factor controls the directional preference of the daytime MSTIDs?