Statistical Analysis Study of Seasonal and Solar Activity Dependence on Nighttime MSTIDs Occurrence by SuperDARN Radars

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Contents

1. Introduction

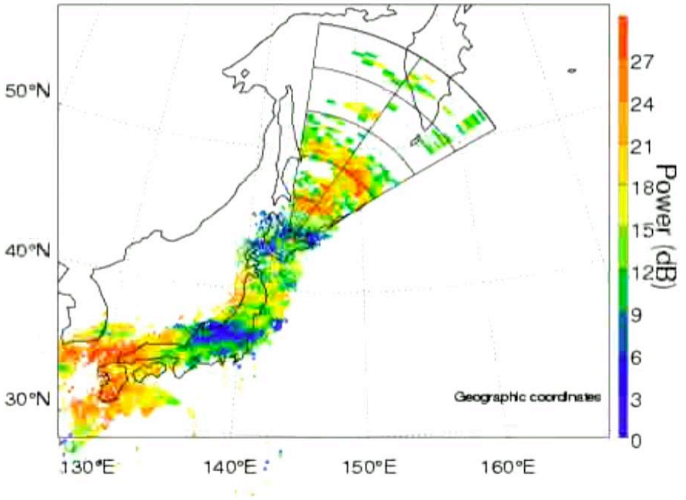
■ TID (Traveling Ionospheric Disturbance)

- Wave-like structures that propagate through the ionosphere
- They are classified as either Large-Scale(LSTID) or Medium-Scale (MSTID) based on their spatio-temporal scales.

	Time Period	Phase Velocity	Wavelength
LSTID	30 min to 3 h	400-1,000 m/s	Above 1,000km
MSTID	15-60 min	100-300 m/s	200-800 km

[Hunsucker, 1982 ; Kelley et al., 2023]

Focusing on MSTID in this study



【SuperDARN Hokkaido Radar 北海道-陸別HFレーダー】
https://cicr.isee.nagoya-u.ac.jp/hokkaido/site1/movie_gallery.html

1. Introduction

■ MSTID (Medium-Scale Traveling Ionospheric Disturbance)

Daytime MSTIDs

- caused by AGWs (Hines, 1960; Hooke, 1968)
- propagation direction is mainly south-southeastward (Ogawa et al., 2009)
- observed by instruments such as SuperDARN and GPS

Nighttime MSTIDs

- caused by Perkins instability (Shiokawa et al., 2003; Otsuka et al., 2004)
- propagation direction is mainly west-southwestward (Ichihara et al., 2013)
- observed by instruments such as SuperDARN, GPS and all-sky airglow imager

Focusing on nighttime MSTIDs in this study

1. Introduction

■ Observation of MSTIDs by SuperDARN

<u>Daytime MSTIDs</u>

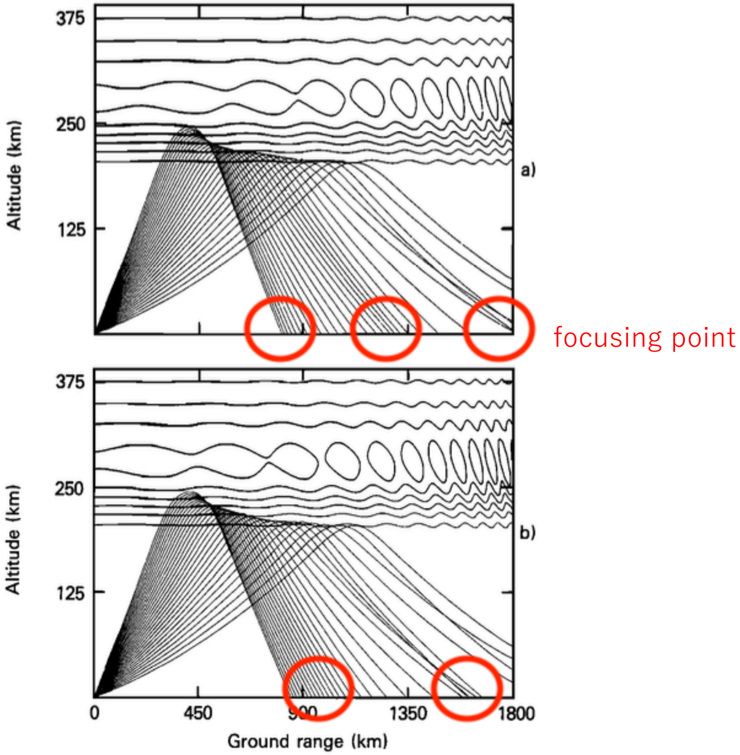
- Ground Scatter echo (GS echo)

→ echo power

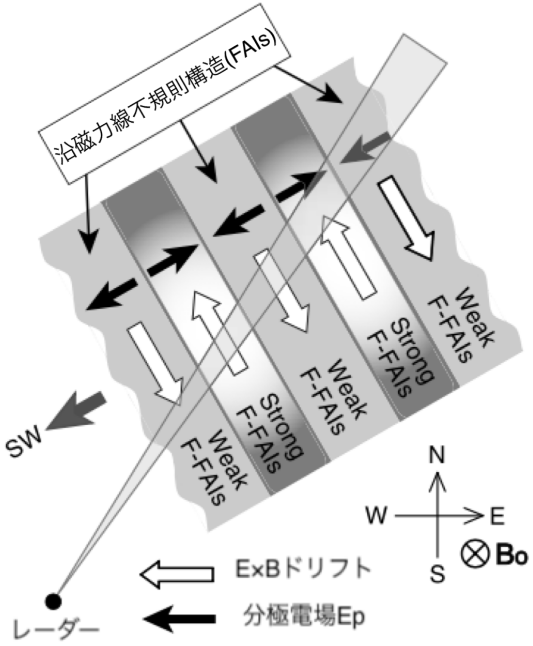
<u>Nighttime MSTIDs</u>

- Ionospheric echo (IS echo)

→ LOS doppler velocity



[Samson et al., 1990]

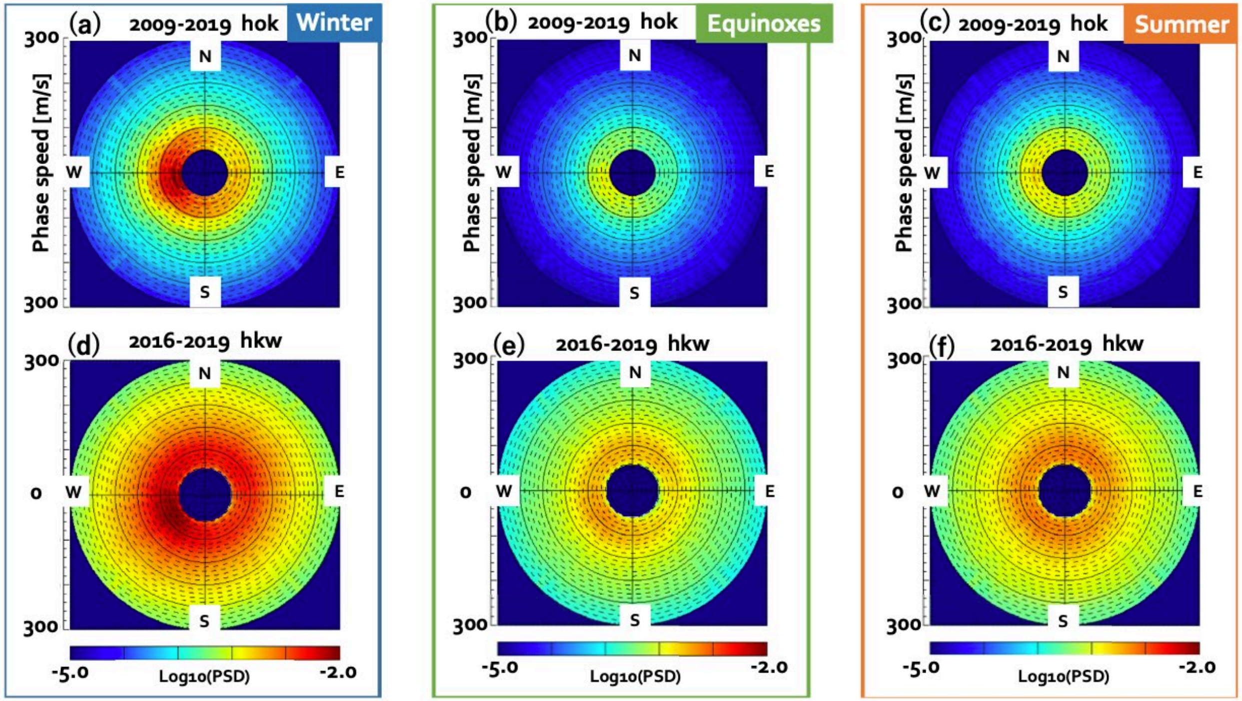


[Ogawa et al., 2009]

1. Introduction

■ Purpose of this study

Hazeyama et al. (2022)



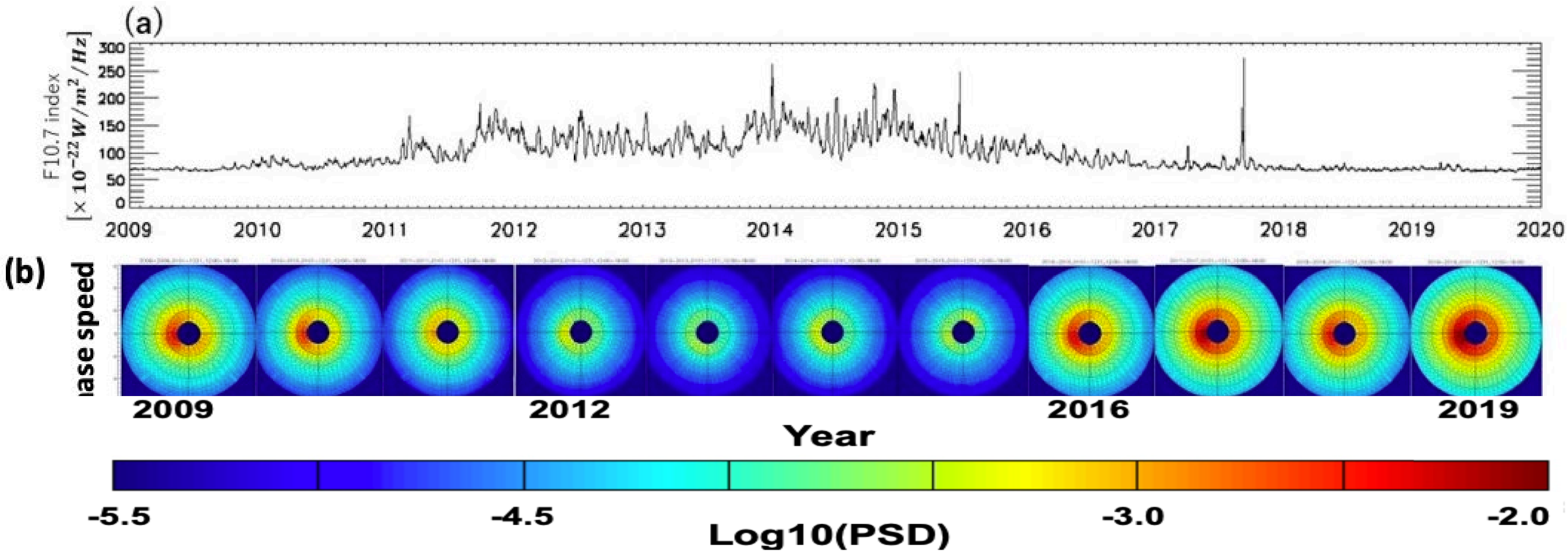
- Statistical analysis on nighttime MSTIDs using the SuperDARN radar data (hok: 2009-2019, hkw: 2016-2019)

→ Seasonal dependence of propagation direction

1. Introduction

■ Purpose of this study

<u>Hazeyama et al. (2022)</u>

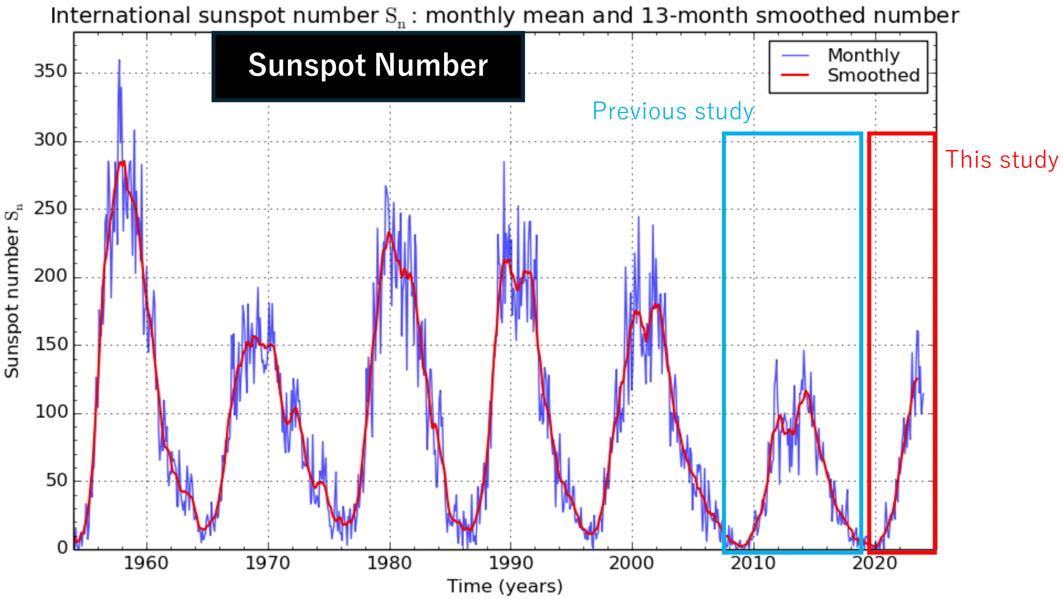


- Relationship between nighttime MSTIDs amplitude and solar F10.7 flux

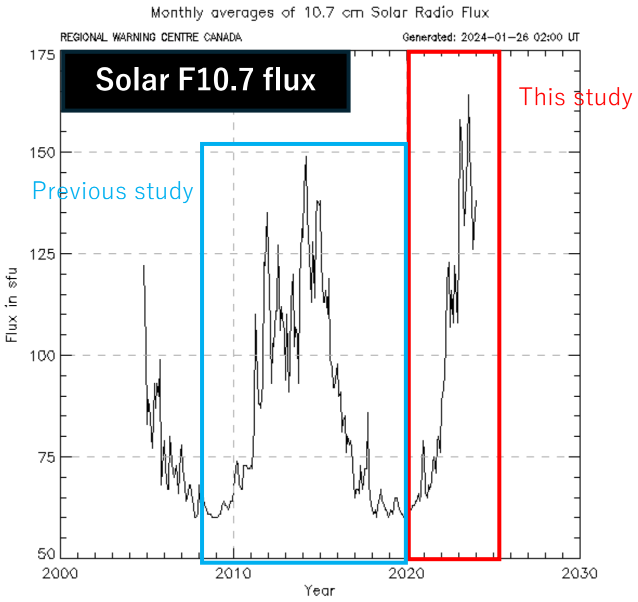
→ a negative correlation

1. Introduction

■ Purpose of this study



https://www.sidc.be/SILSO/monthlyssnplot



https://spaceweather.gc.ca/forecast-prevision/solar-solaire/solarflux/sx-5-mavg-en.php

- By analyzing the data from 2020 to 2023, the solar activity dependence can be examined in a new solar activity cycle.
- Statistical analysis for periods not yet analyzed in Hazeyama et al.(2022).

→ hok, hkw, cve, cvw: 2020-2023

2. Instruments and Methods

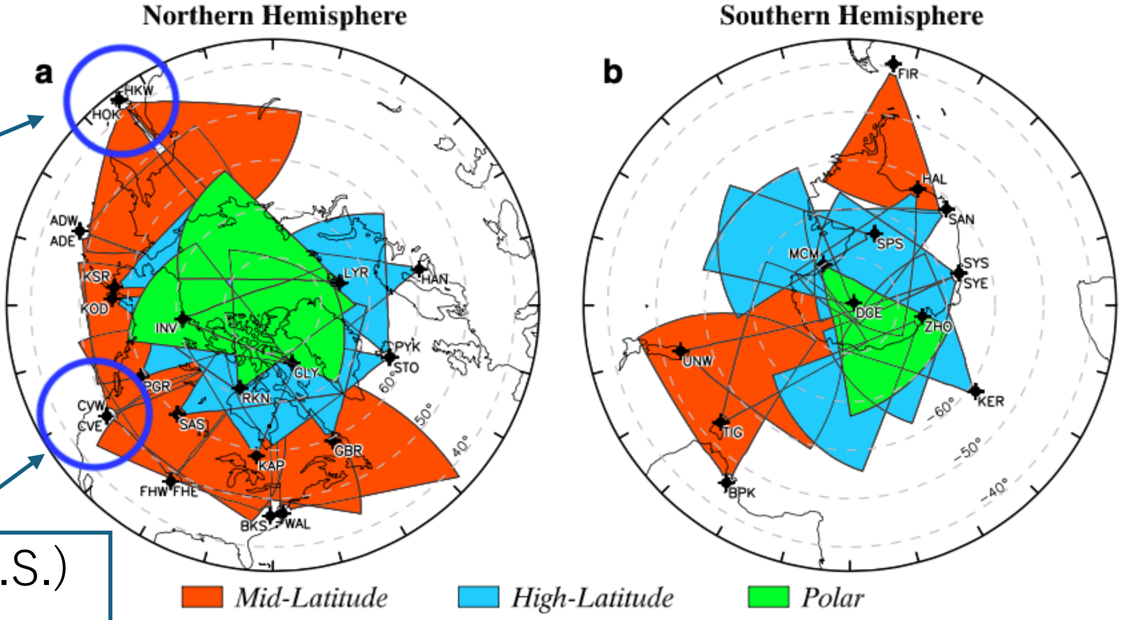
■ SuperDARN (Super Dual Auroral Radar Network)

- A global network of HF radars covering polar, high, and mid-latitudes in the Northern and Southern Hemispheres (Chisham et al., 2007; Greenwald et al., 1995; Nishitani et al., 2019)
- Observation the LOS doppler velocity of ionospheric scatter

Hokkaido (Japan)

HOK	43.53°N	143.61°E
HKW	43.54°N	143.61°E

Same geographic latitude region



[Nishitani et al., 2019]

Christmas Valley (Oregon, U.S.)

CVE	43.27°N	120.36°W
CVW	43.27°N	120.36°W

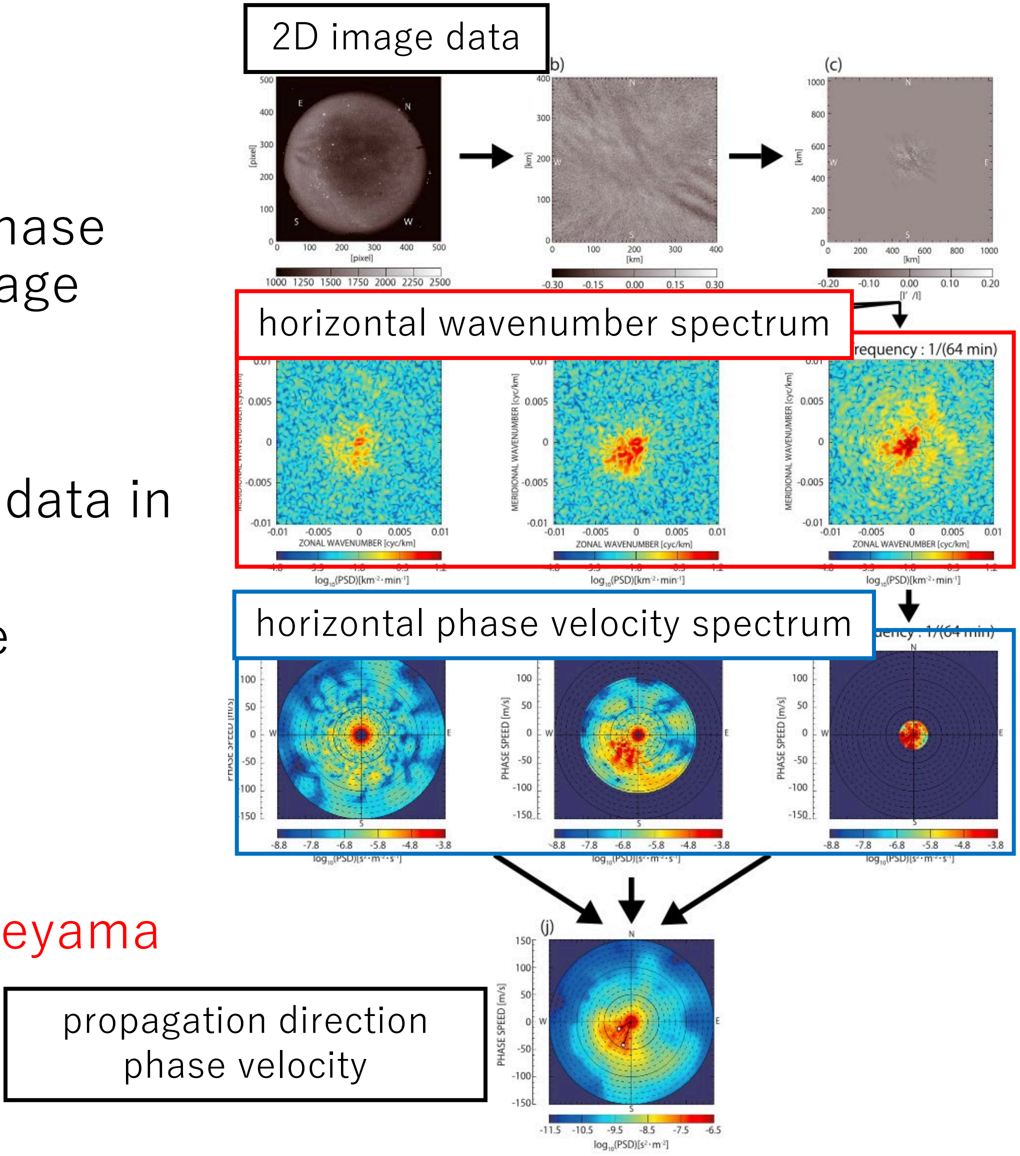
2. Instruments and Methods

■ 3D-FFT Method

A method for determining the direction of propagation and phase velocity of MSTID using 2D image data (Matsuda et al., 2014)

- Calculating large amounts of data in short time
- No bias caused by the people processing the data

Used the same method as Hazeyama et al. (2022)


2D image data

horizontal wavenumber spectrum

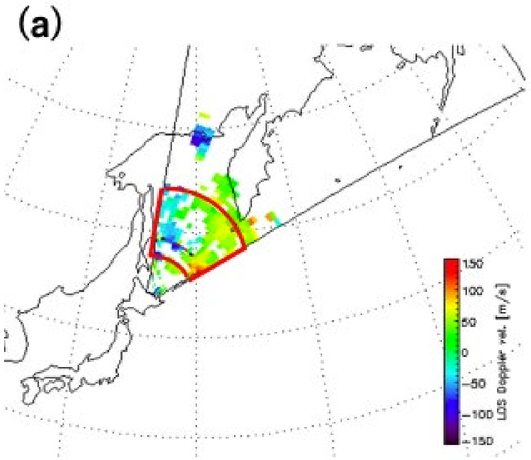
horizontal phase velocity spectrum

propagation direction
phase velocity

[Matsuda et al., 2014]

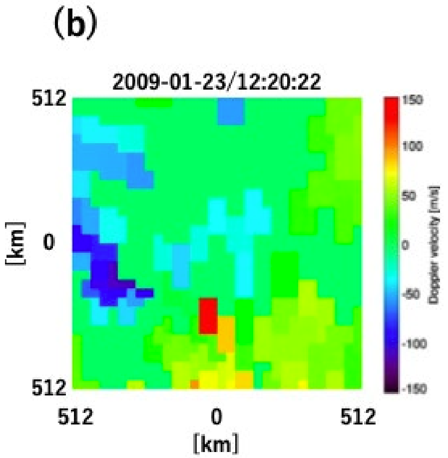
2. Instruments and Methods

■ 3D-FFT Method (Hazeyama et al., 2022)



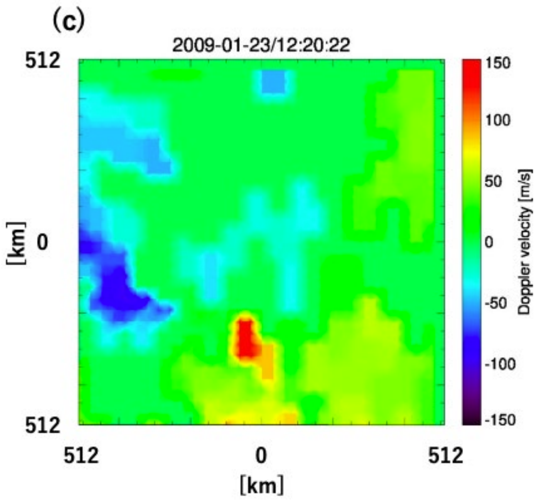
[Hazeyama et al., 2022]

the data in the area surrounded by the red lines were only considered



[Hazeyama et al., 2022]

32 × 32 pixels image data



[Hazeyama et al., 2022]

oversampled 512 × 512 pixels image data

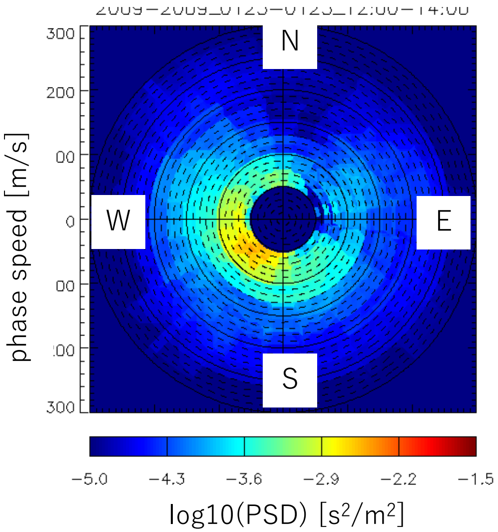


image after using the analysis program

2. Instruments and Methods

- Data sets and definition of season and time zone

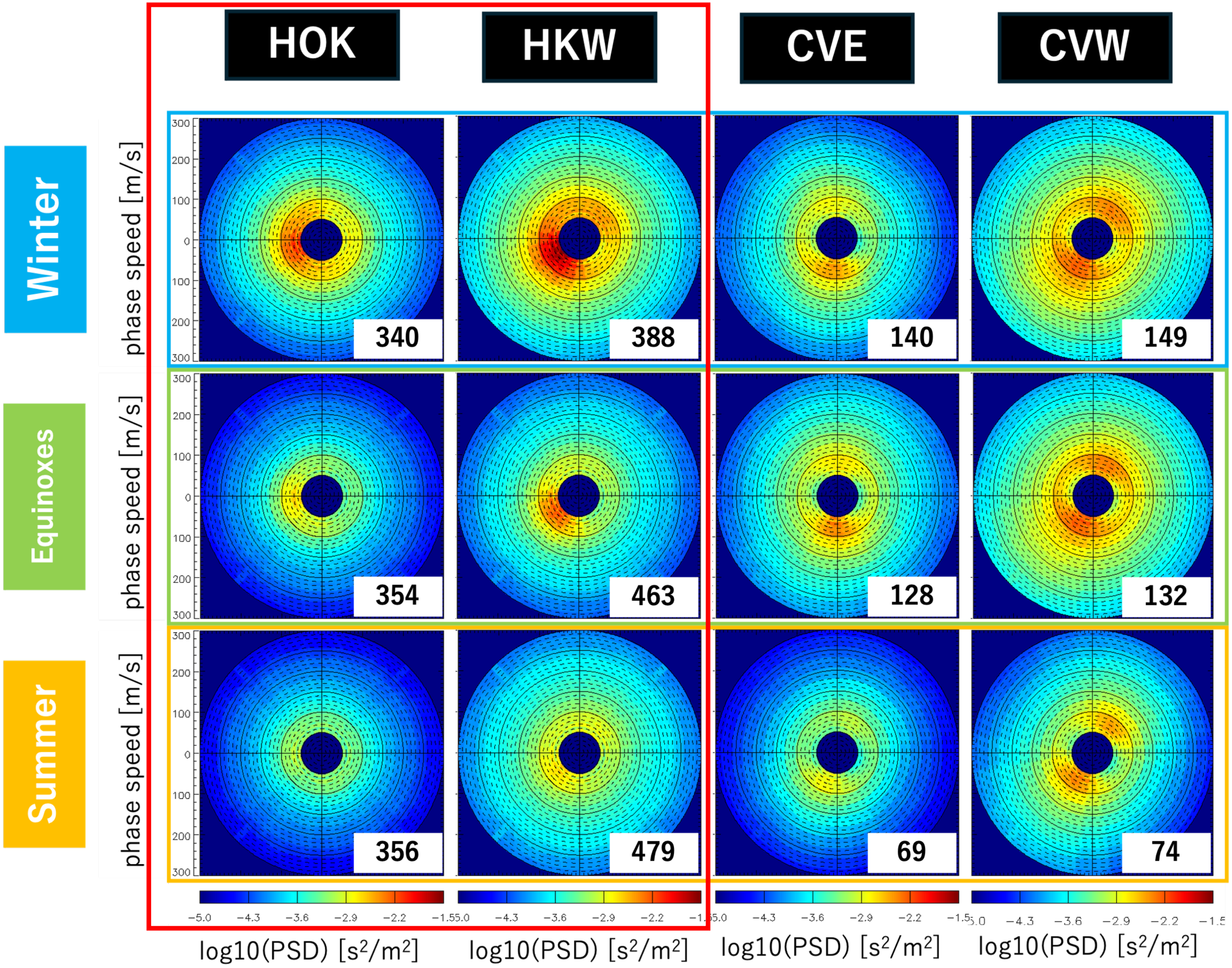
	Hokkaido East	Hokkaido West	Christmas Valley East	Christmas Valley West
Period	2020/1/1 – 2023/12/31			
Nighttime	12:00~18:00(UT) 21:00~3:00(LT)		4:00~10:00(UT) 20:00~2:00(LT)	6:00~12:00(UT) 22:00~4:00(LT)
Beam Number	7	7	12	12
Range Gate	16	19	24	24

* Hokkaido(Japan) : UTC+9, Christmas Valley(U.S., Oregon) : UTC-8

Definition of season		
Winter	Equinoxes	Summer
Jan., Feb., Nov., Dec.	Mar., Apr., Sep., Oct.	May., Jun., Jul., Aug

3. Results

- ■ Propagation direction of Nighttime MSTIDs



3. Results

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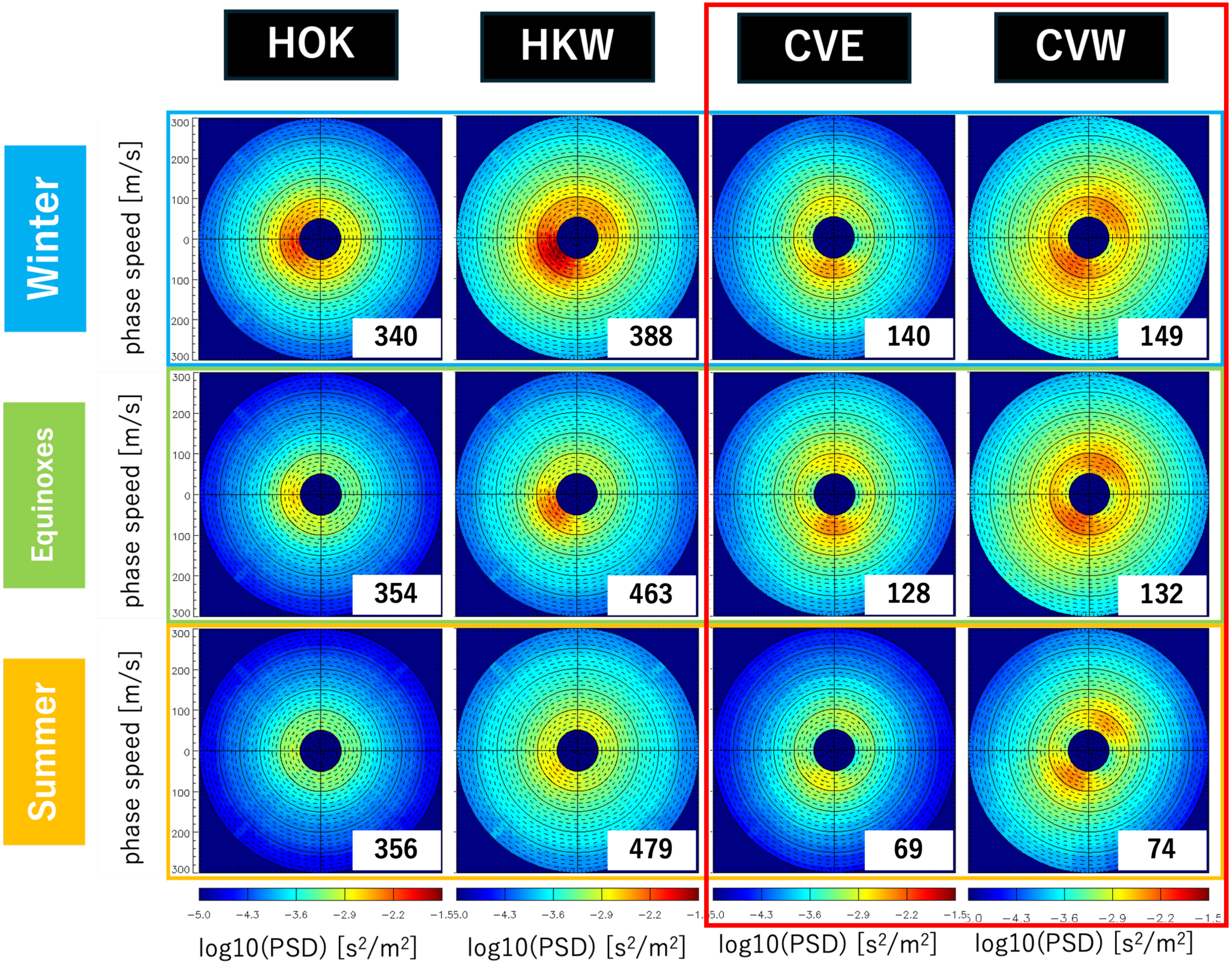
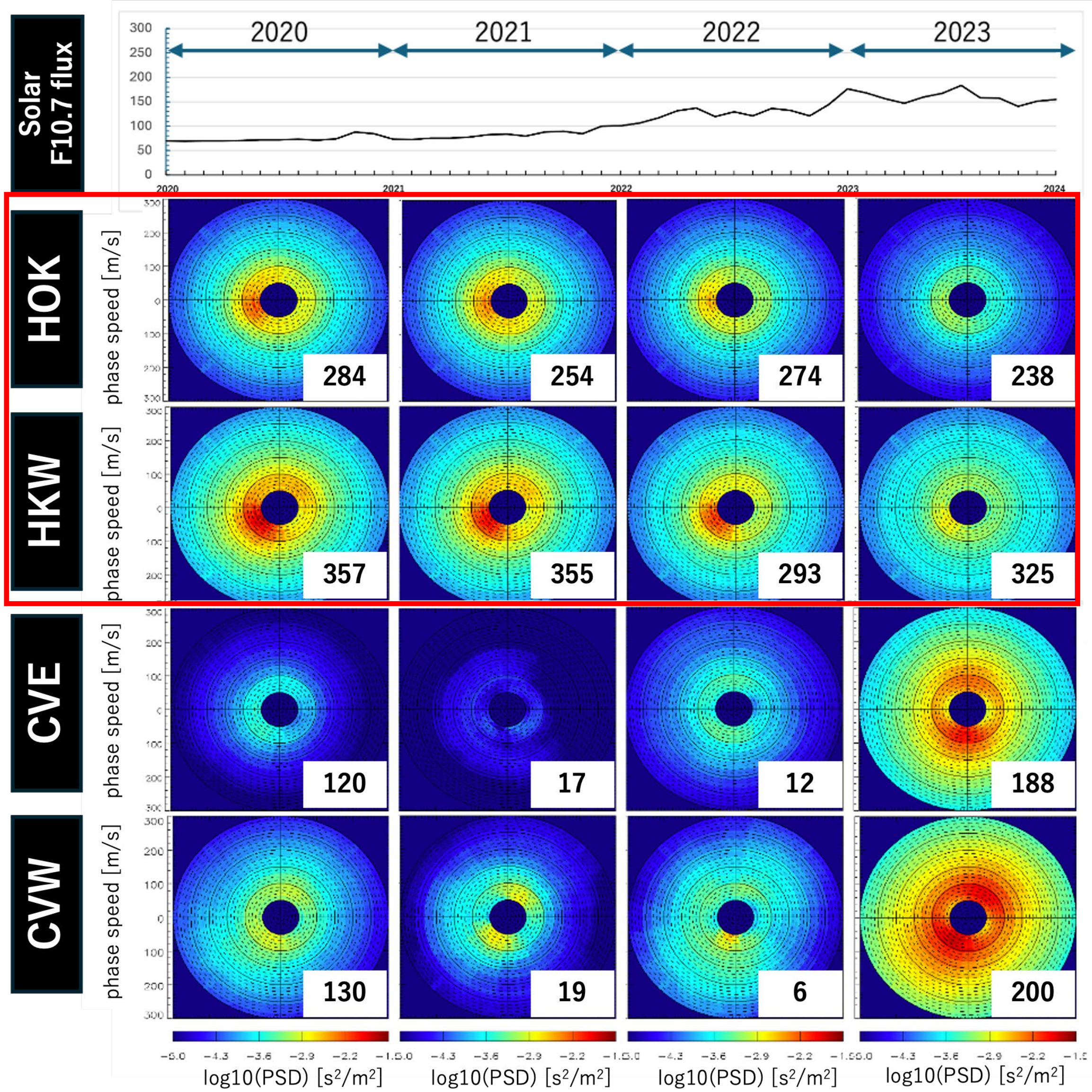


3. Results

- Solar F10.7 flux and Nighttime MSTIDs



Matsuoka+, SuperDARN Research meeting 2023

3. Results

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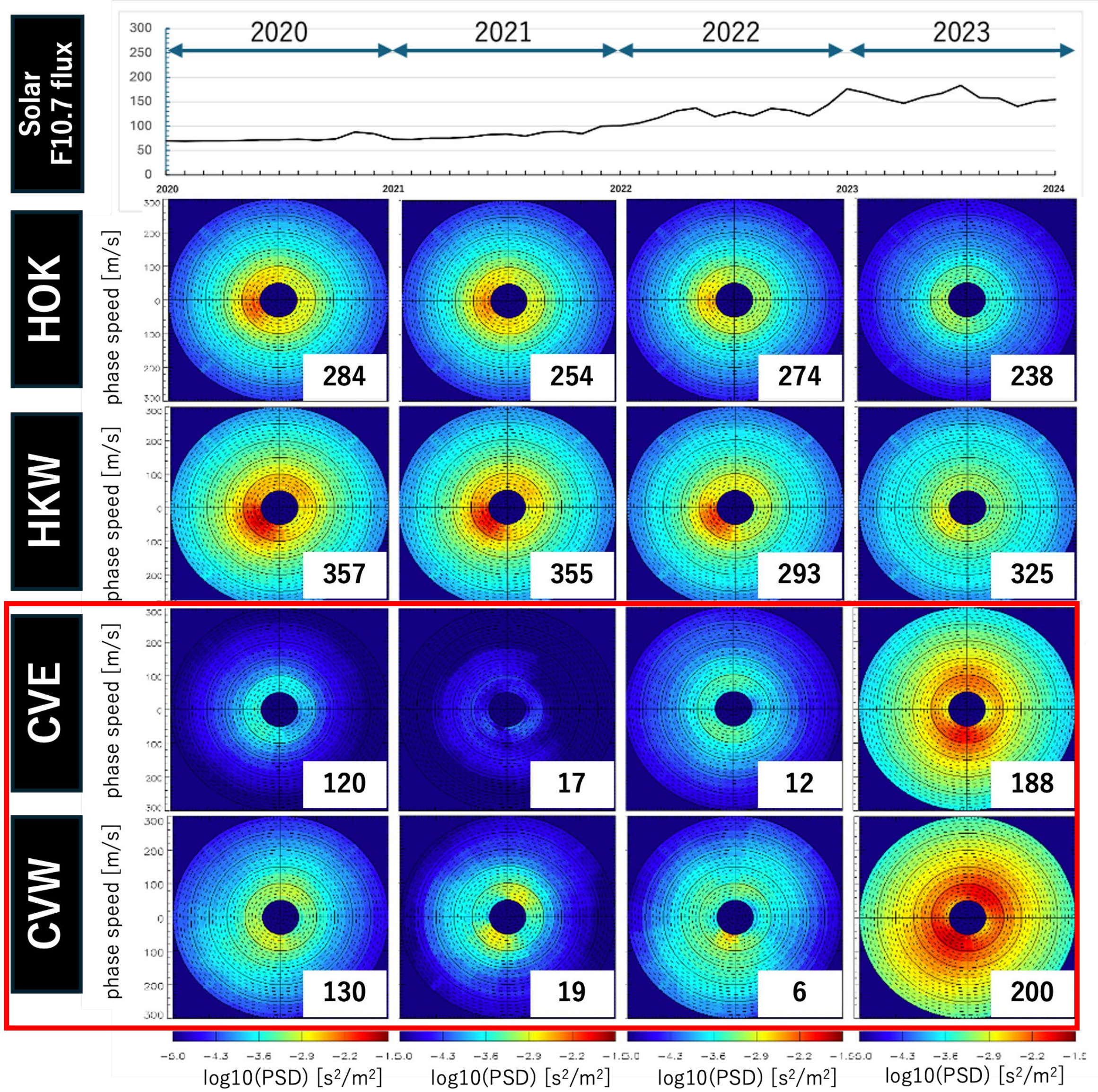


3. Results

- Solar F10.7 flux and Nighttime MSTIDs

HOK

Period: 2020/1/1 ~ 2022/12/31

Correlation coefficient: -0.431
Winter: -0.702
Equinox: -0.504
Summer: -0.556

HKW

Period: 2020/1/1 ~ 2023/12/31

Correlation coefficient: -0.432
Winter: -0.657
Equinox: -0.485
Summer: -0.469

CVE

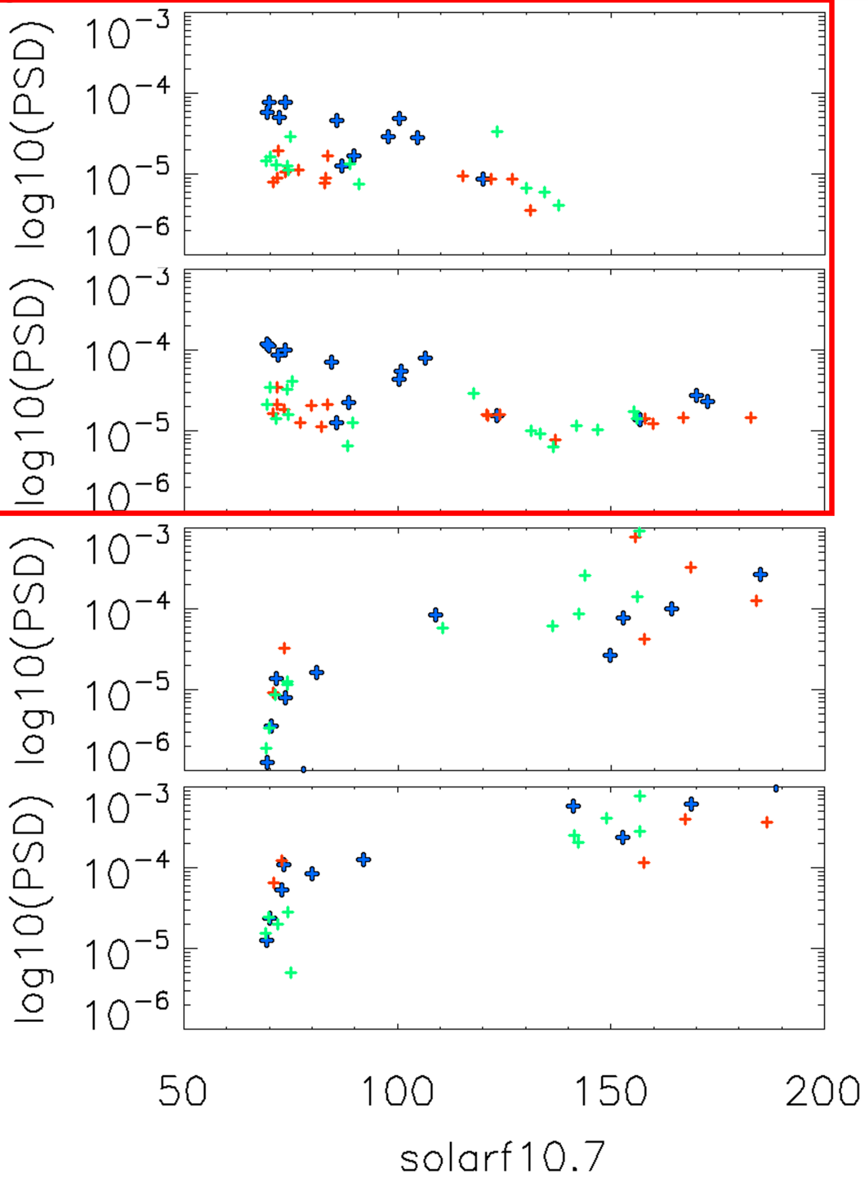
Period: 2020/1/1 ~ 2023/12/31

Correlation coefficient: 0.834
Winter: 0.838
Equinox: 0.926
Summer: 0.734

CVW

Period: 2020/1/1 ~ 2023/12/31

Correlation coefficient: 0.854
Winter: 0.896
Equinox: 0.946
Summer: 0.699



Matsuoka+, SuperDARN Research meeting 2023

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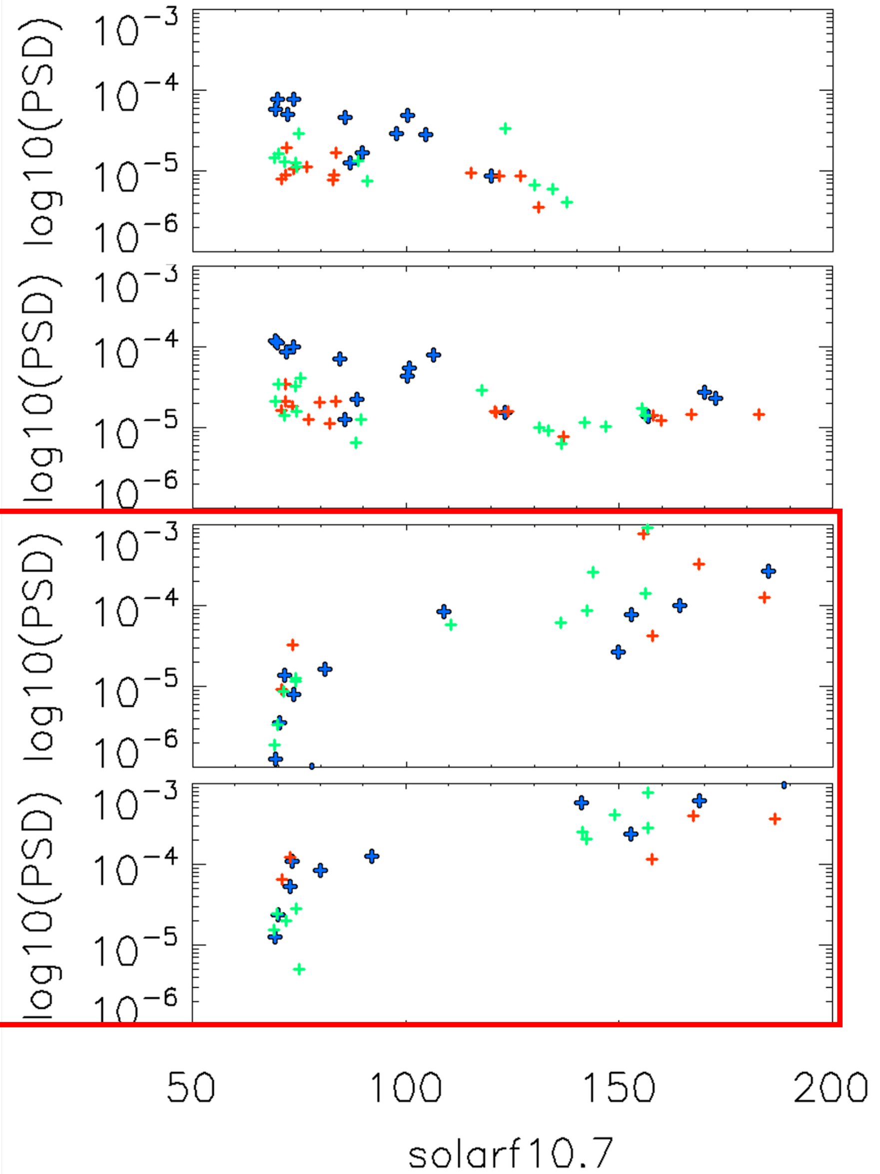


4. Discussion

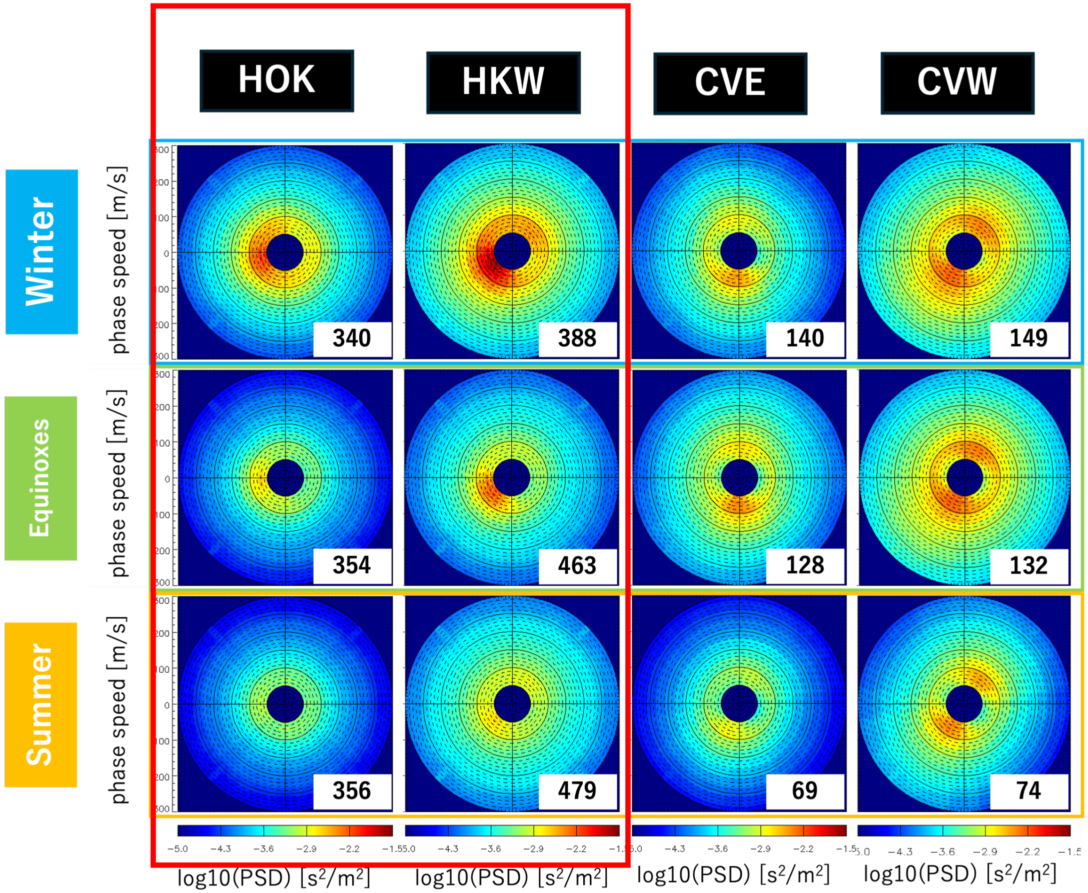
■ Seasonal Dependence

- The nighttime MSTIDs mainly propagate southwestward, and it is more dominant in winter than in summer.

● The southwestward-propagating MSTIDs are caused by the southward neutral wind in the Es layer (Yokoyama et al., 2009).

✓the southward neutral wind occurs more frequently in summer than in winter (Takahashi et al., 2013).

✓nighttime southwestward MSTIDs occur more often in summer (Takeo et al., 2017; Tsuchiya et al., 2018).

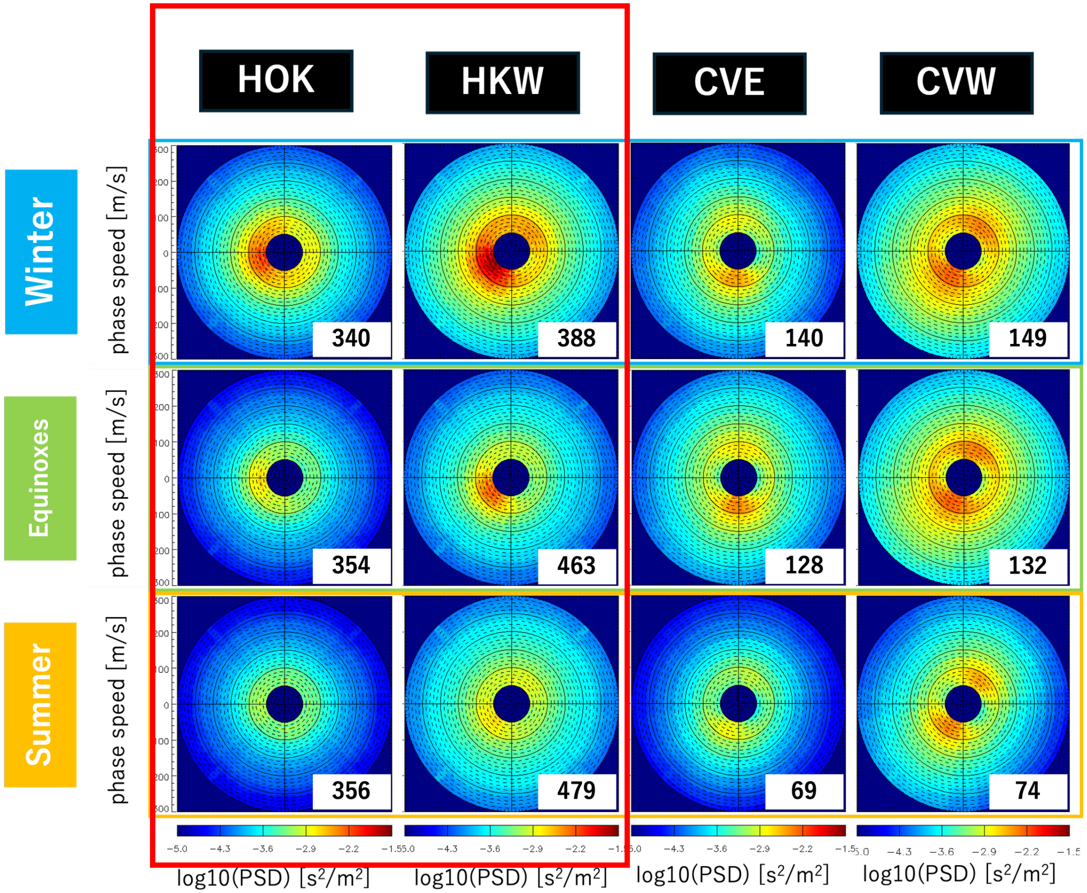


4. Discussion

■ Seasonal Dependence

Southwestward-propagating MSTIDs were more dominant in winter than in summer.

- More GS echoes are observed in summer and equinox due to the increase of background electron density.
- IS echoes are obscured, and the irregularities may not have been sufficiently captured by the radar measurement (Hazeyama et al., 2022).

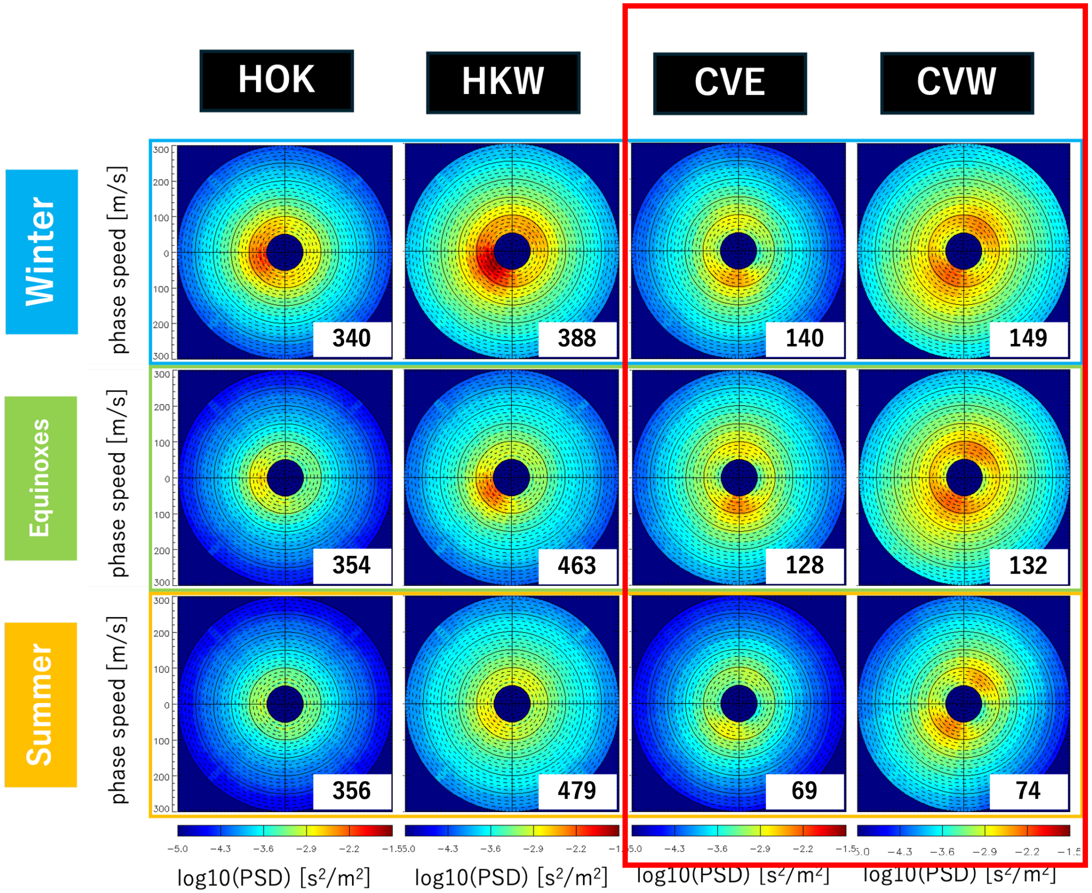


4. Discussion

■ Seasonal Dependence

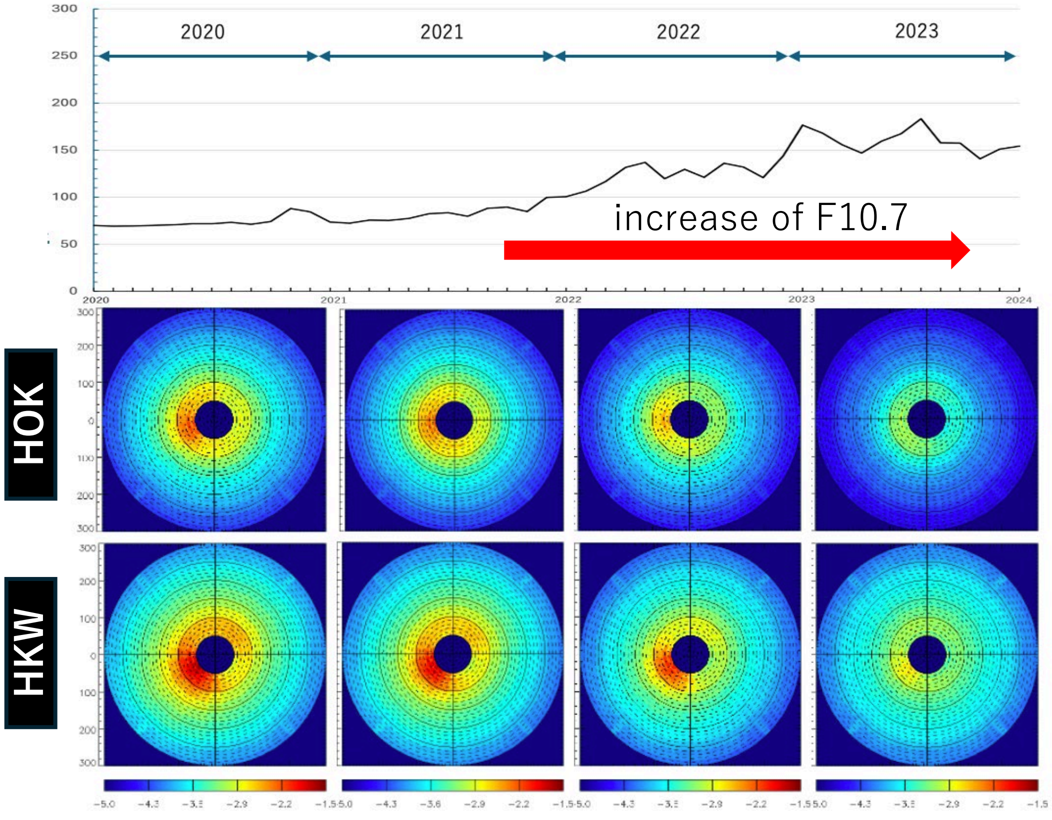
- The nighttime MSTIDs mainly propagate southwestward and northeastward.
- No seasonal dependence is observed.

This is most likely due to the low number of data analyzed in the summer, which prevented sufficient statistical analysis.

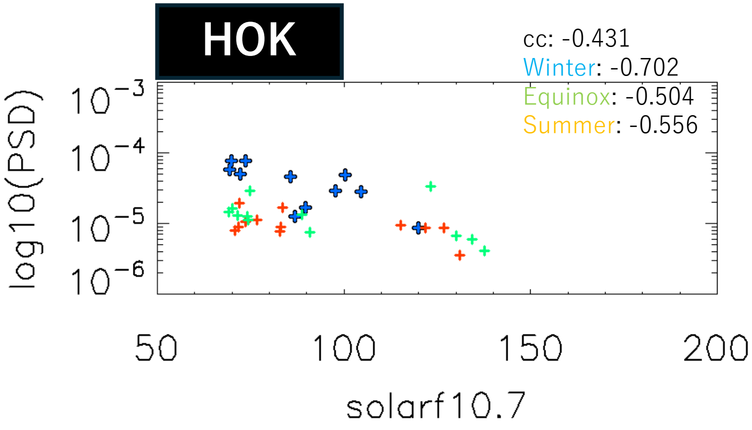


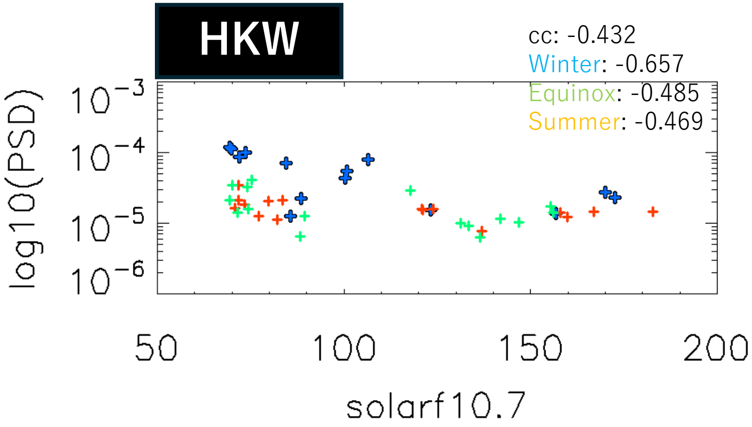
4. Discussion

■ Solar Activity Dependence



decrease of PSD (amplitude)





a negative correlation between the MSTID amplitude and the solar F10.7 index

→

The same is true for the correlation coefficient (more dominant in winter)

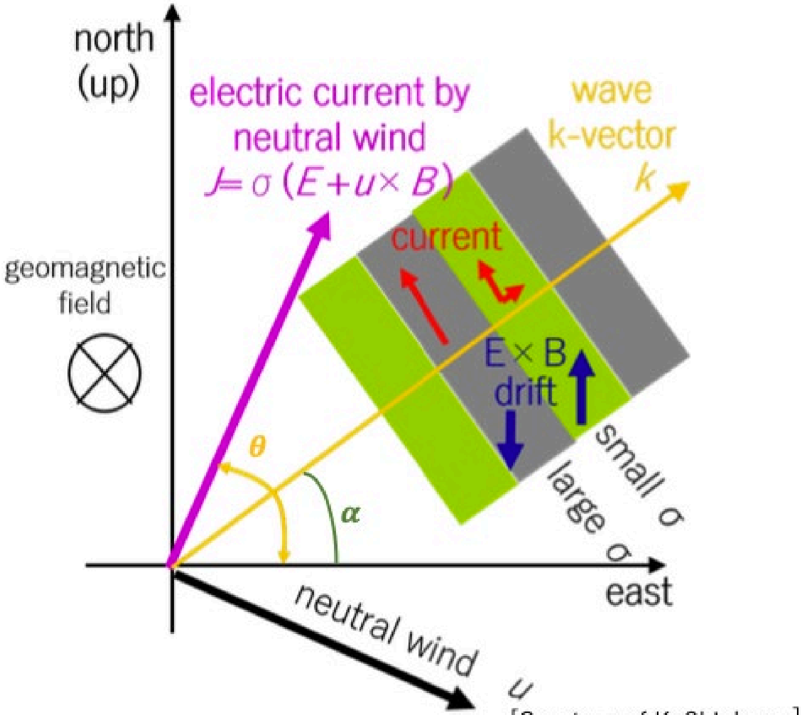
4. Discussion

■ Solar Activity Dependence

$\langle \nu_{in} \rangle$ and H_n have a positive correlation with the solar activity, according to MSIS model (Hedin, 1991)

⬇

- The Perkins instability decreases with increasing solar activity and smaller growth rate may result in weaker MSTIDs with less frequent occurrence.
- The solar activity dependence is most significant in winter, this effect is attributable to the seasonal variation of the background electron density (Hazeyama et al., 2022).



[Courtesy of K. Shiokawa]

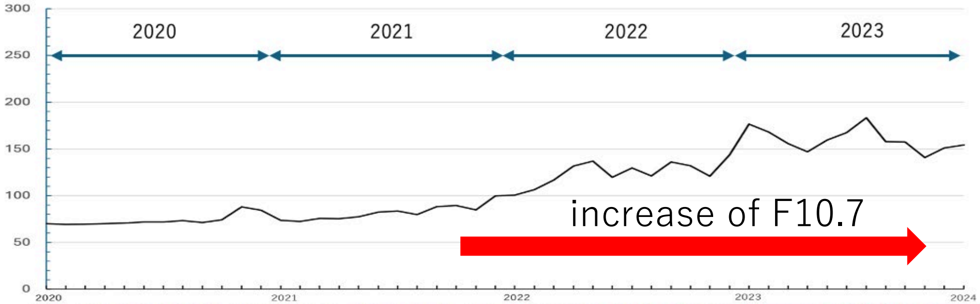
Perkins instability [Perkins, 1973]

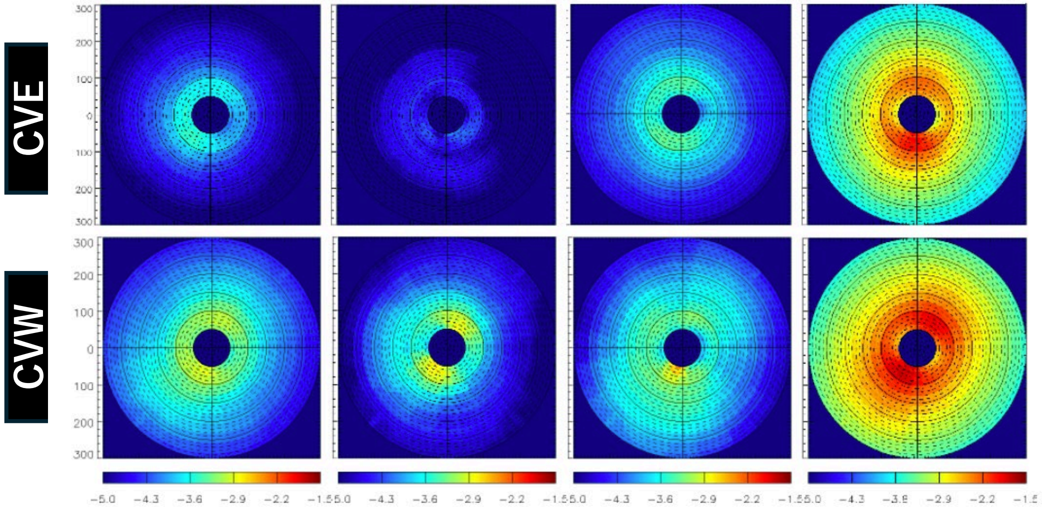
$$\gamma = \frac{g \sin^2 I}{\langle \nu_{in} \rangle H_n} \frac{\sin\alpha \sin(\theta - \alpha)}{\cos\theta}$$

g: acceleration of gravity
I: geomagnetic inclination
$\langle \nu_{in} \rangle$: height-integrated ion-neutral collision frequency
H_n: scale height of the neutral atmosphere

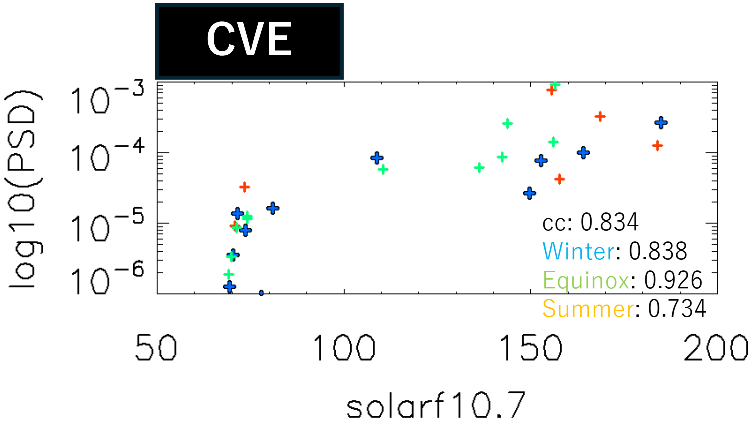
4. Discussion

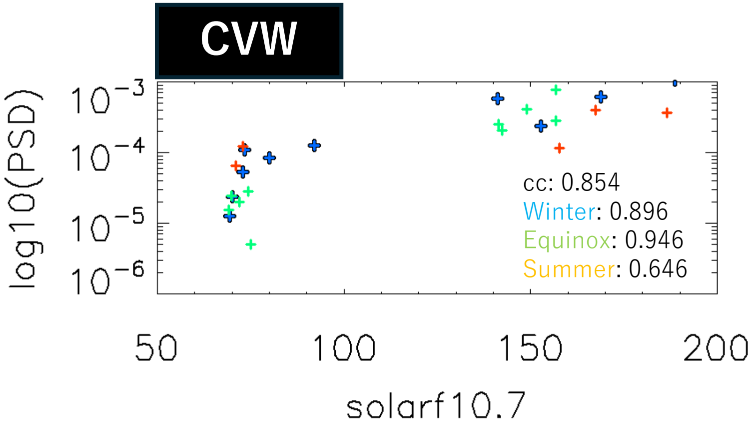
■ Solar Activity Dependence





increase of PSD (amplitude)





a positive correlation between the MSTID amplitude and the solar F10.7 index

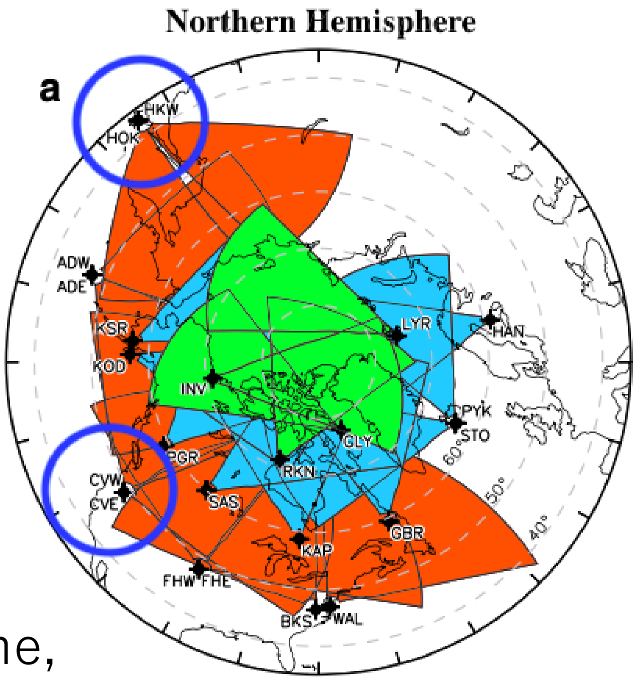
➡

The same is true for the correlation coefficient (more dominant in equinox)

4. Discussion

■ Solar Activity Dependence

	Geographic Latitude	Magnetic Latitude
HOK	43.53°N	35.70°N
HKW	43.54°N	35.71°N
CVE	43.27°N	48.84°N
CVW	43.27°N	48.84°N



[Nishitani et al., 2019]

The geographic latitudes are almost the same, but the magnetic latitudes are different.

Christmas Valley, which located in high magnetic latitude, may be more strongly affected by geomagnetic disturbances?

4. Discussion

■ Solar Activity Dependence

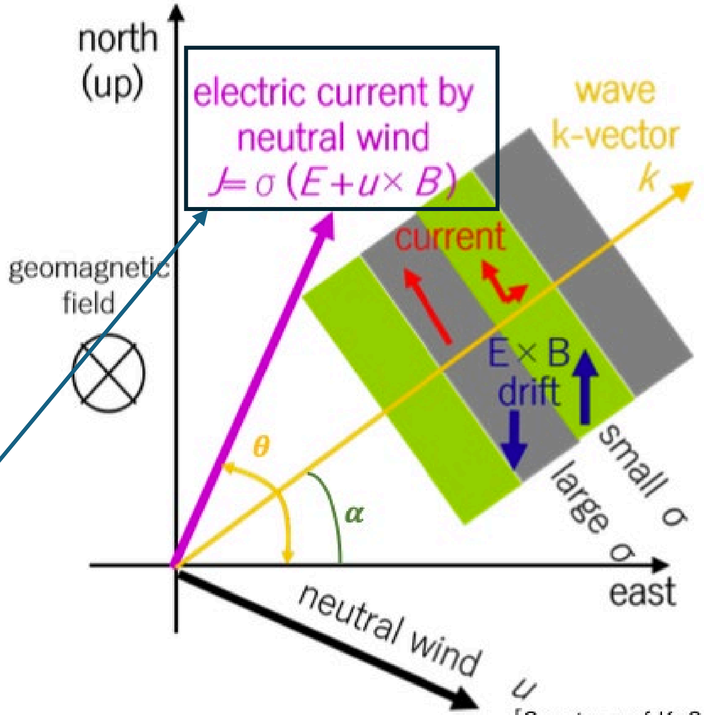
Geomagnetic disturbances

Plasma convection develops in the mid-latitudes

This convection electric field increases the electric field E that generates the Pedersen current

Polarization electric field increases and activates MSTID activity

Other previous studies have presented similar ideas. (ex. Kelley et al., 2023)



[Courtesy of K. Shiokawa]

Perkins instability [Perkins, 1973]

$$\gamma = \frac{g\sin^2 I}{\langle \nu_{in} \rangle H_n} \frac{\sin\alpha \sin(\theta - \alpha)}{\cos\theta}$$

[Perkins, 1973]

$$\gamma = \frac{cE\cos I}{BH_n} \sin\alpha \sin(\theta - \alpha)$$

5. Conclusion

3D-FFT method to the SuperDARN radar (hok, hkw, cve, cvw) from 2020 to 2023 and statistically analyzed characteristics of nighttime MSTIDs.

hok and hkw

- Similar observations to previous studies were obtained in this study.
- The propagation characteristics and seasonal dependence of nighttime MSTIDs are affected by the solar activity cycle, with the PSD of nighttime MSTIDs weakening when solar activity increases, which is most pronounced in winter.

cve and cvw

- Differences in nighttime MSTIDs characteristics were observed even at the same geographic latitudes (Hokkaido).
- Nighttime MSTIDs are affected by the solar activity cycle, but the degree of influence varies significantly with magnetic latitude.

Future Studies

- Analysis of radar in the same geographic latitude region as Hokkaido except for cve and cvw radar (ex. fhe and fhw)
- Analysis using radar data from the southern hemisphere (ex. bpk) might show different characteristics.