Statistical analysis of mid-latitude F-region ionospheric echoes using the SuperDARN Hokkaido East HF radar

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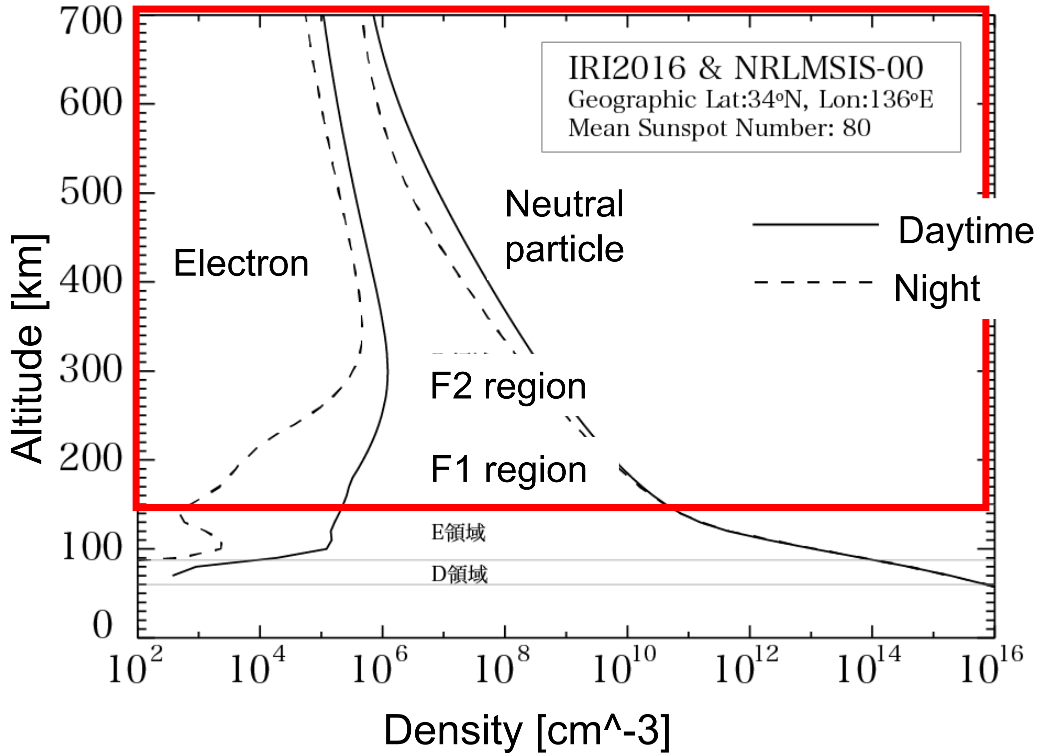
Contents

Introduction

Ionosphere

- The upper layers of the Earth's atmosphere are partially ionized.
- F-region is widely distributed (150- 1000 km) and has the highest electron density.
- The structure varies both temporarily and spatially.



Adapted from NICT(https://swc.nict.go.jp/knouledge/ionosphere.html)

Introduction

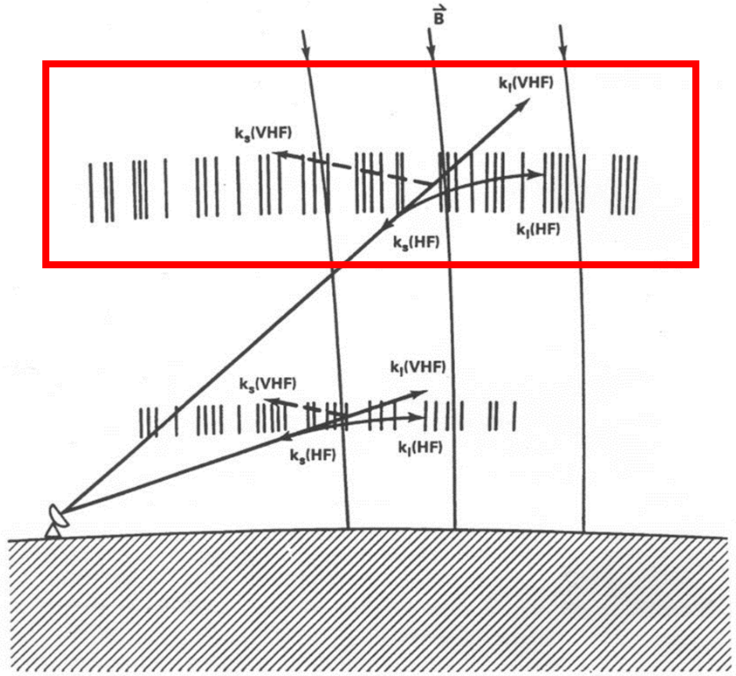
Ionospheric irregularities

The ionosphere has a non-uniform density structure.

It makes a negative effect on GNSS-based positioning.

Therefore, it is extremely important to understand the distribution and generation mechanisms of plasma irregularities in the F-region ionosphere.

The SuperDARN echo distribution provides information on the irregularity distribution.

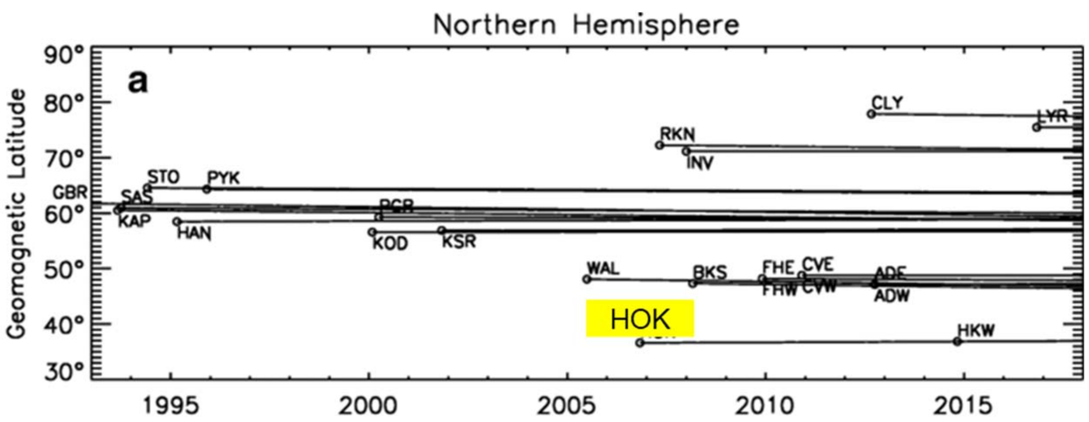


Greenwald et al.,1995

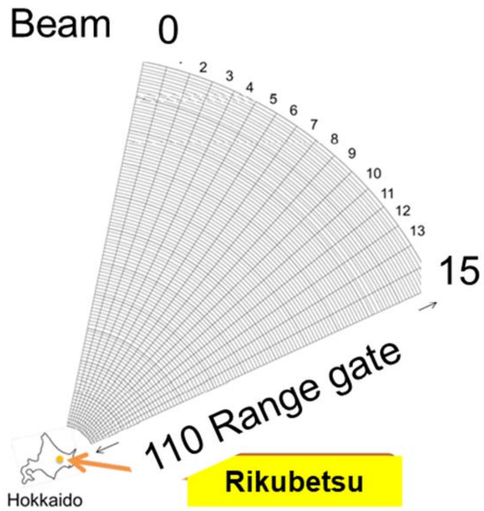
Instrumentation

SuperDARN (Super Dual Auroral Radar Network)

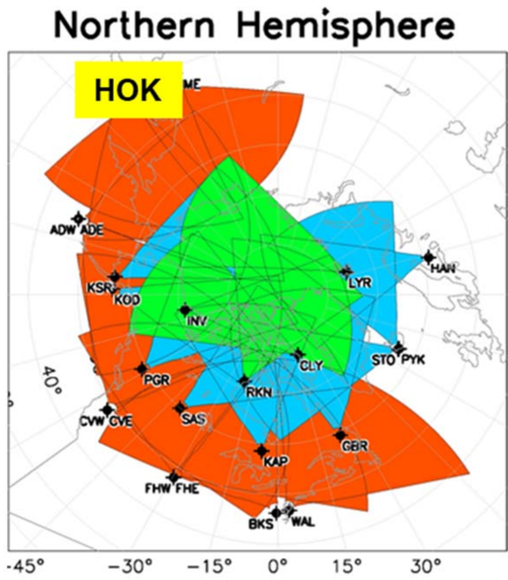
- Coherent backscatter radar
- 16 beams numbered 0-15 (HOK)
- 110 range gates numbered 0-109 (HOK)
- First range:180 km, range separation: 45 km
- Each beam is scanned every 1 min (normal scan)



Adapted from Nishitani et al., 2019



Adapted from Mori, Graduation thesis , 2008



Adapted from http://vt.superdarn.org/

Instrumentation

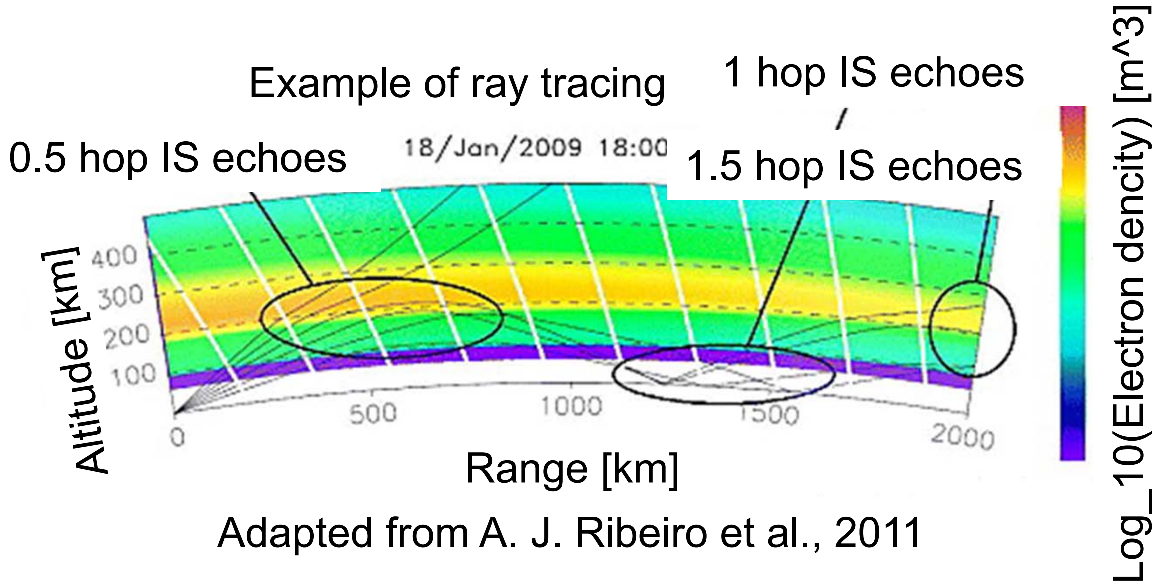
2 types of echoes are observed.

- Ionospheric backscatter echoes (IS echo)
- Ground/Sea backscatter echoes (GS echo)

3 parameters are observed for each pixel.

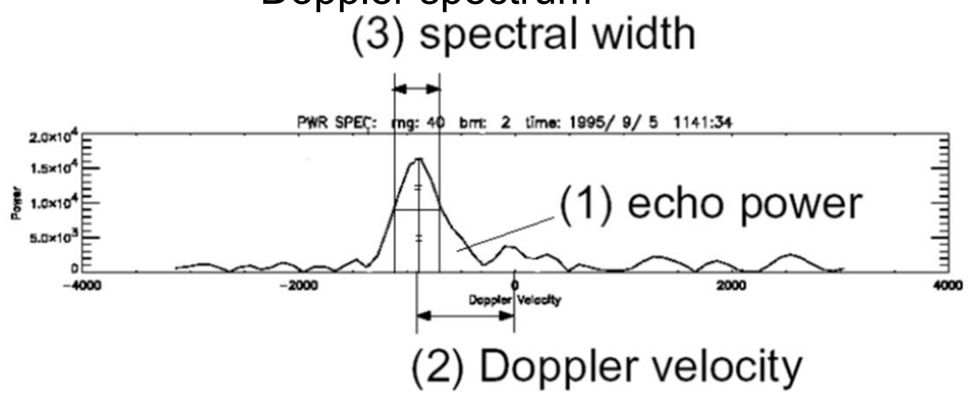
- Echo power
- Doppler velocity
- Doppler spectral width

Example of ray tracing



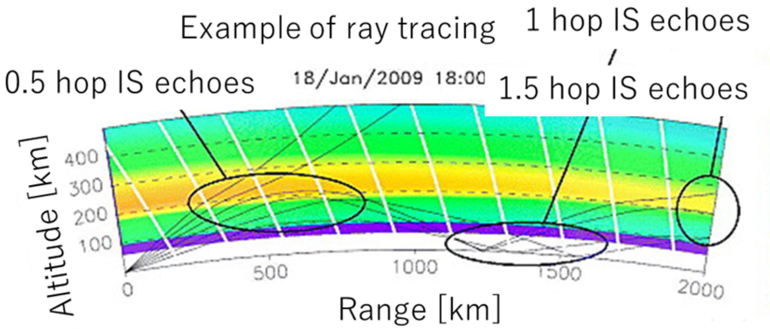
Adapted from A. J. Ribeiro et al., 2011

Doppler spectrum



Mori, Graduation thesis, 2008

Methods-Conventional method



Adapted from A. J. Ribeiro et al., 2011

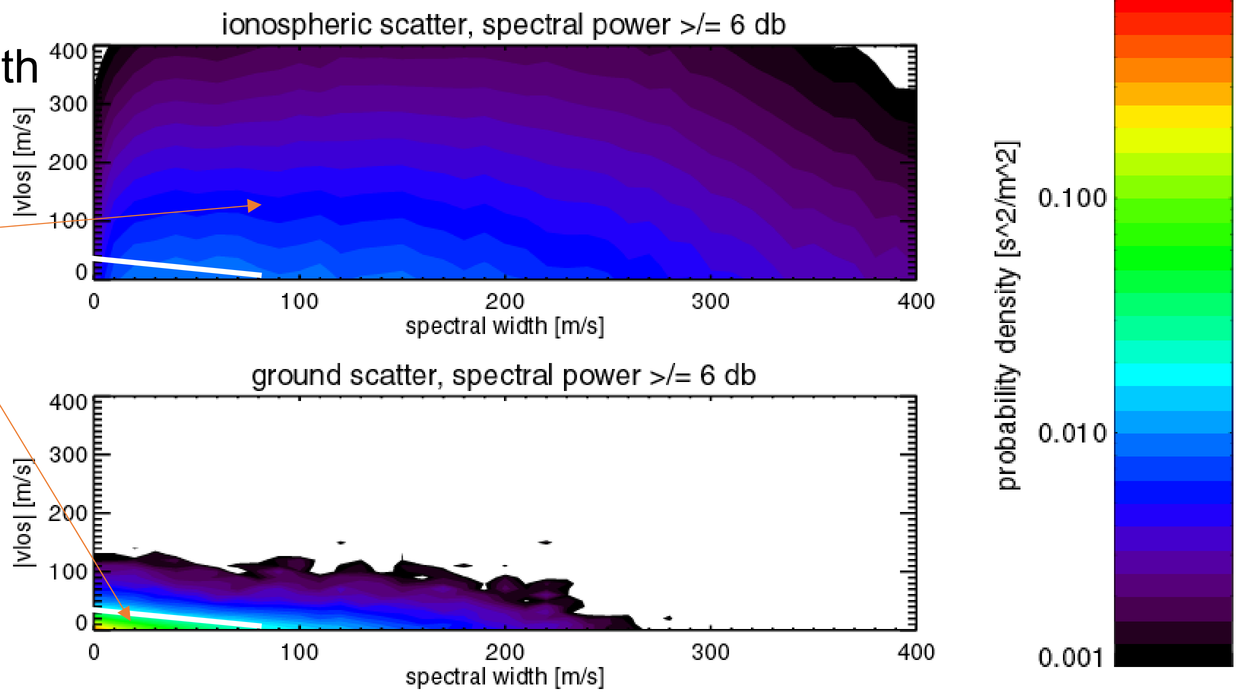
Standard SuperDARN identification method of IS and GS echoes.

$$|\mathbf{V}| - (\mathbf{30} - \frac{|W|}{\mathbf{3}}) > \mathbf{0}$$ → IS ehoes. [G. T. Blanchard et al. 2004]

V: Doppler velocity, W: Doppler spectral width

77% of IS echoes

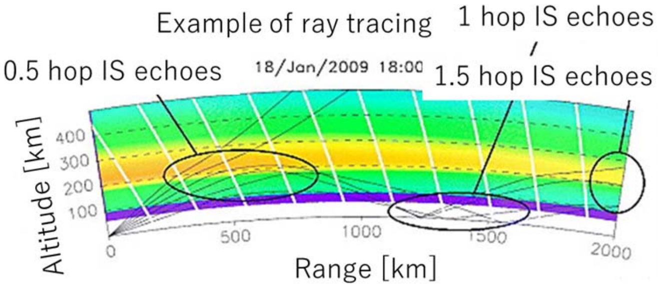
97% of GS echoes



- These criteria are based on the data from high latitude regions (e.g., Saskatoon, Kapuskasing).
- At mid-latitudes (e. g. HOK radar), the IS echoes' V and W are generally close to those of GS echoes.

Adapted from G. T. Blanchard et al., 2004

Motivation and Objectives



Adapted from A. J. Ribeiro et al., 2011

Understanding the structure and fluctuations of the ionosphere is important for HF, VHF, and UHF communications and positioning, but the mechanism of the generation of irregularities is still unclear.

On the other hand, conventional methods for distinguishing between IS/ GS echoes are designed for high-latitude regions and may not work properly at mid-latitudes.

Objectives

- Develop the identification method for mid-latitude ionospheric echoes, referring to the Ribeiro et al. (2011) algorithm.
- Obtain the distribution of IS echoes properly.

Proposed identification method

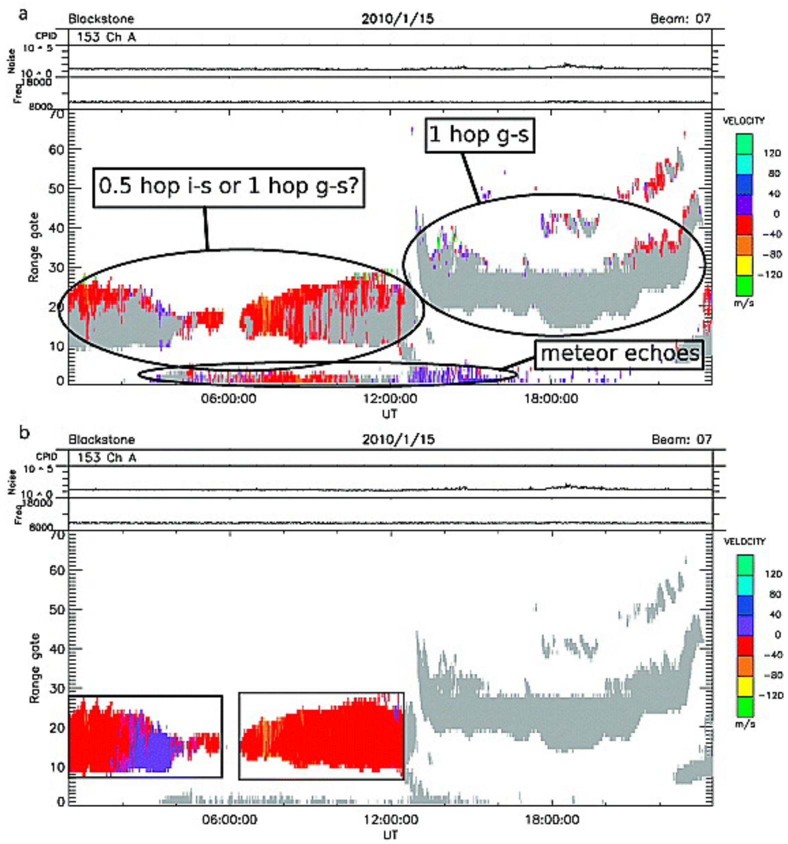
Based on Ribeiro et al. (2011)

Ionospheric echo identification method was developed based on Ribeiro et al., 2011.

Echo identification methods

The distinction is done by 3 processes.

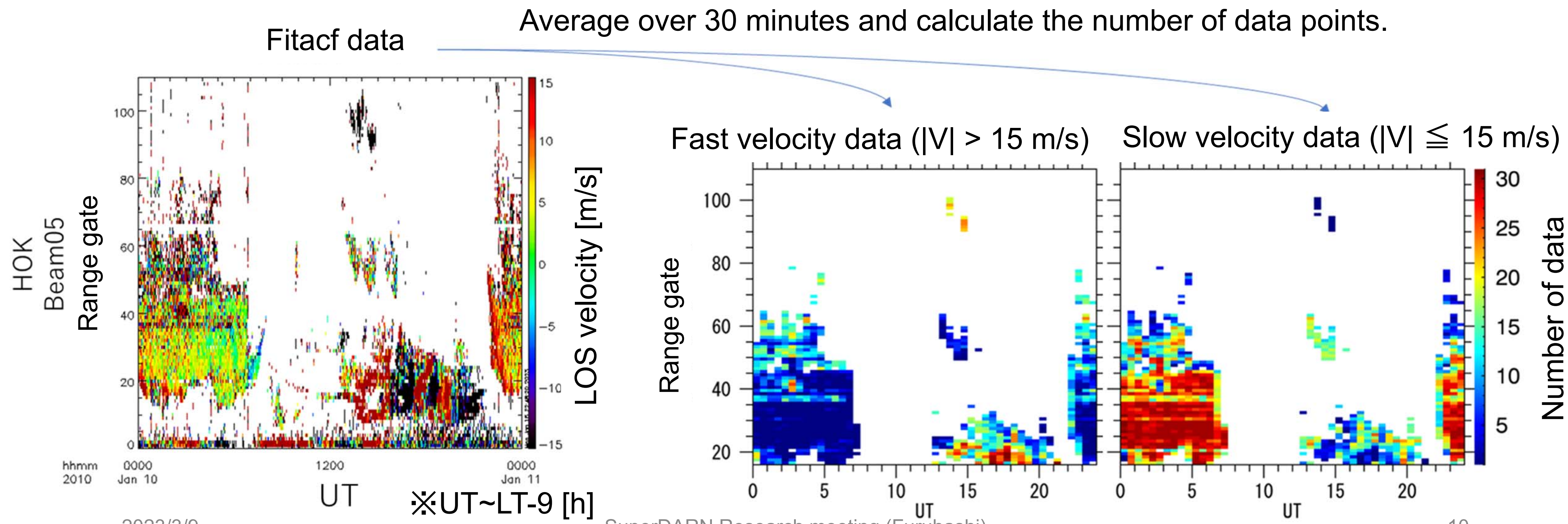
- Noise removal process
- Cluster search process
- Judgement process



Ribeiro et al., 2011

Method-Noise removal process

- Convert 1 min. data into 30 min. data by averaging.
- Remove echoes with the duration less than 15 per 30 minutes.
- Echoes with range gates 0-15 are removed so that we can focus on the F region echoes (beyond 900 km).



Method-Cluster search process

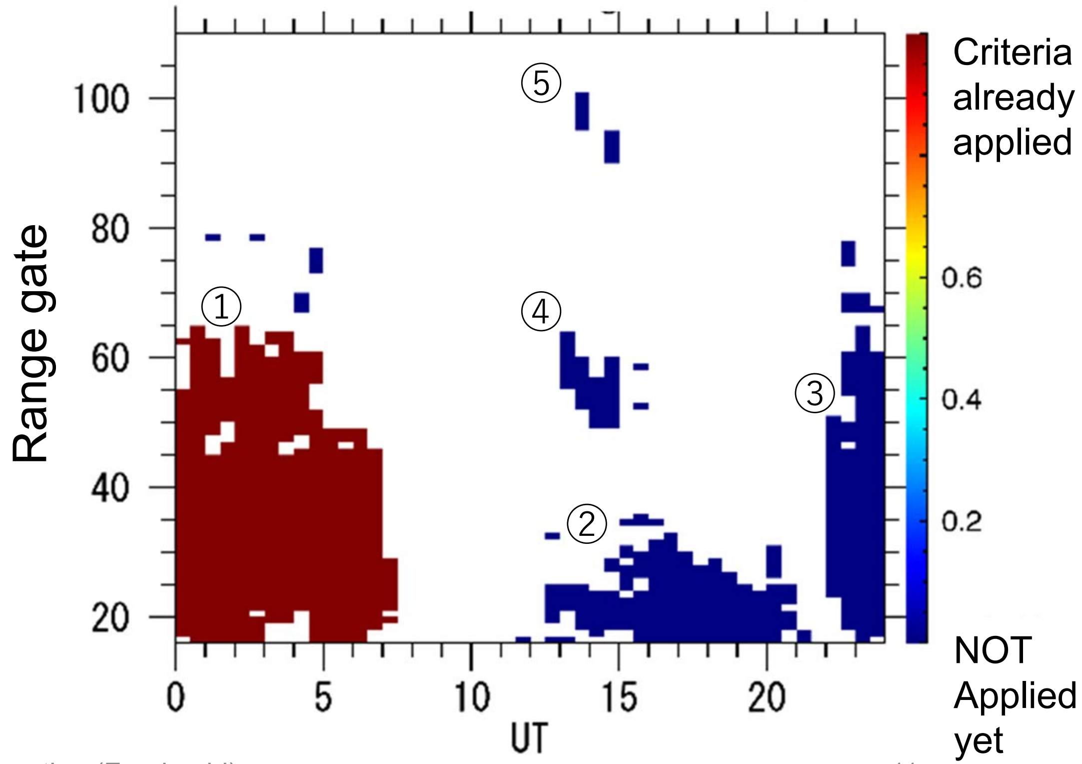
Conventional: Echoes are identified for individual pixels

Proposed: Echoes are identified according to the cluster

Cluster:

Group of temporally and spatially neighbored pixels echo are regarded as the same cluster.

Noise removed echo distribution



Method-Judgement process・condition

Calculate the following ratios at each time.

$$\boldsymbol{R} = \frac{\boldsymbol{Sum\ of\ wights\ of\ fast\ cells}}{\boldsymbol{Sum\ of\ weights\ of\ slow\ cells}}$$

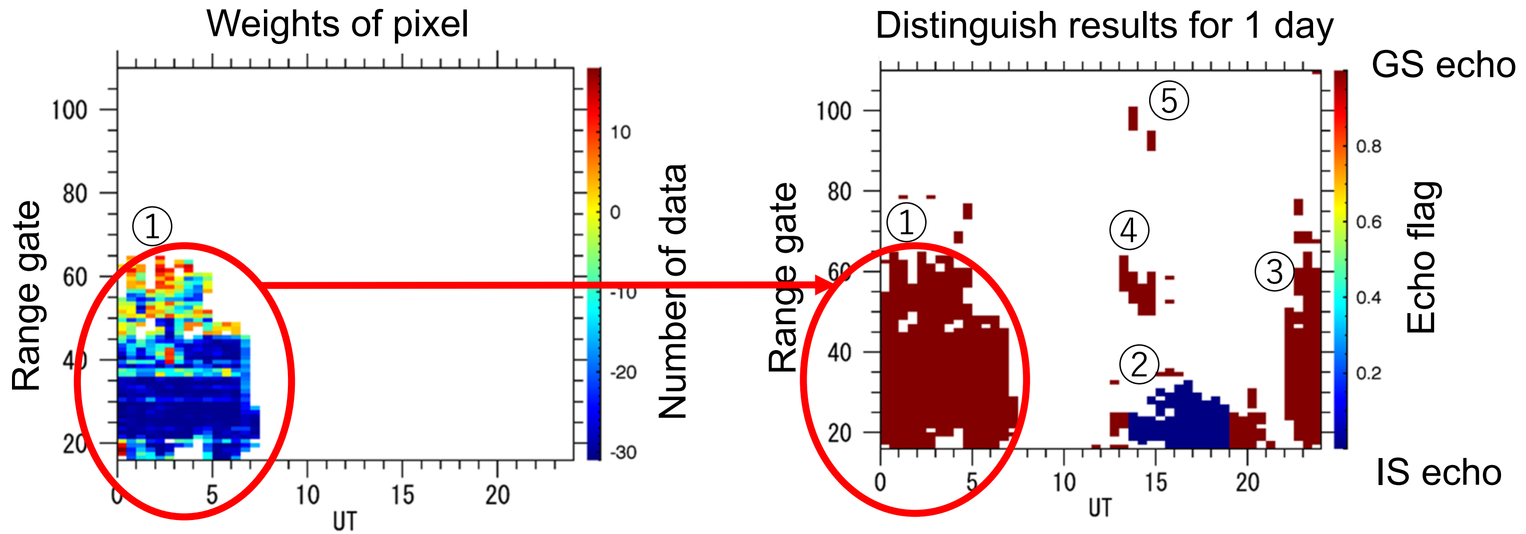
Fast : Group with |V| ≧15 m/s
Slow : Group with |V| < 15 m/s
Weight: Numbers of data in the |V| group with the median of |V|

If R > threshold then regarded as IS echoes, otherwise as GS echoes.

Thresholds were determined for the HOK radar through trial and error.

Threshold values for different duration

T. L. [h]	threshold
1-2	1.57
2-3	1.09
3-	0.66

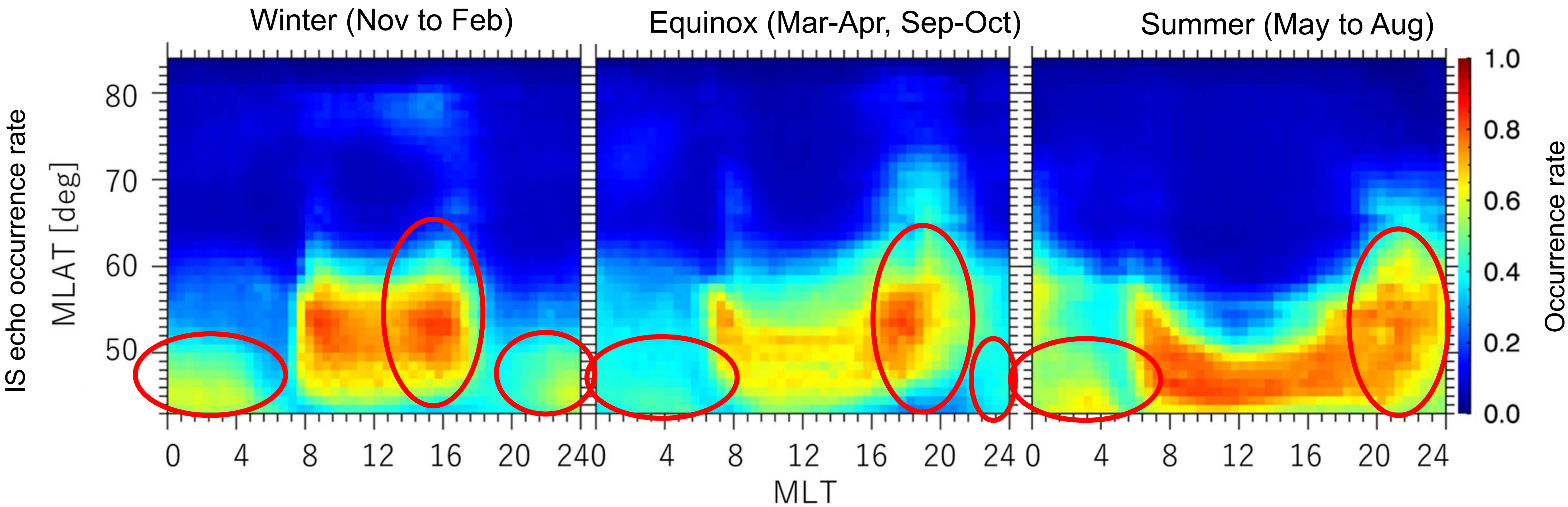


Results-Conventional method

Data: 2008/1- 2021/12、All beams

$$Occurence\ rate = \frac{IS}{Obs. - GS}$$

- Daytime: Extend toward the dusk side and approach U-shape closer to Summer.
- Night: Higher in Winter and Summer.
- Increased rates have the same distribution as the GS echoes.



Discussion-conv.

$$\text{Occurence rate} = \frac{IS}{Obs. - GS}$$

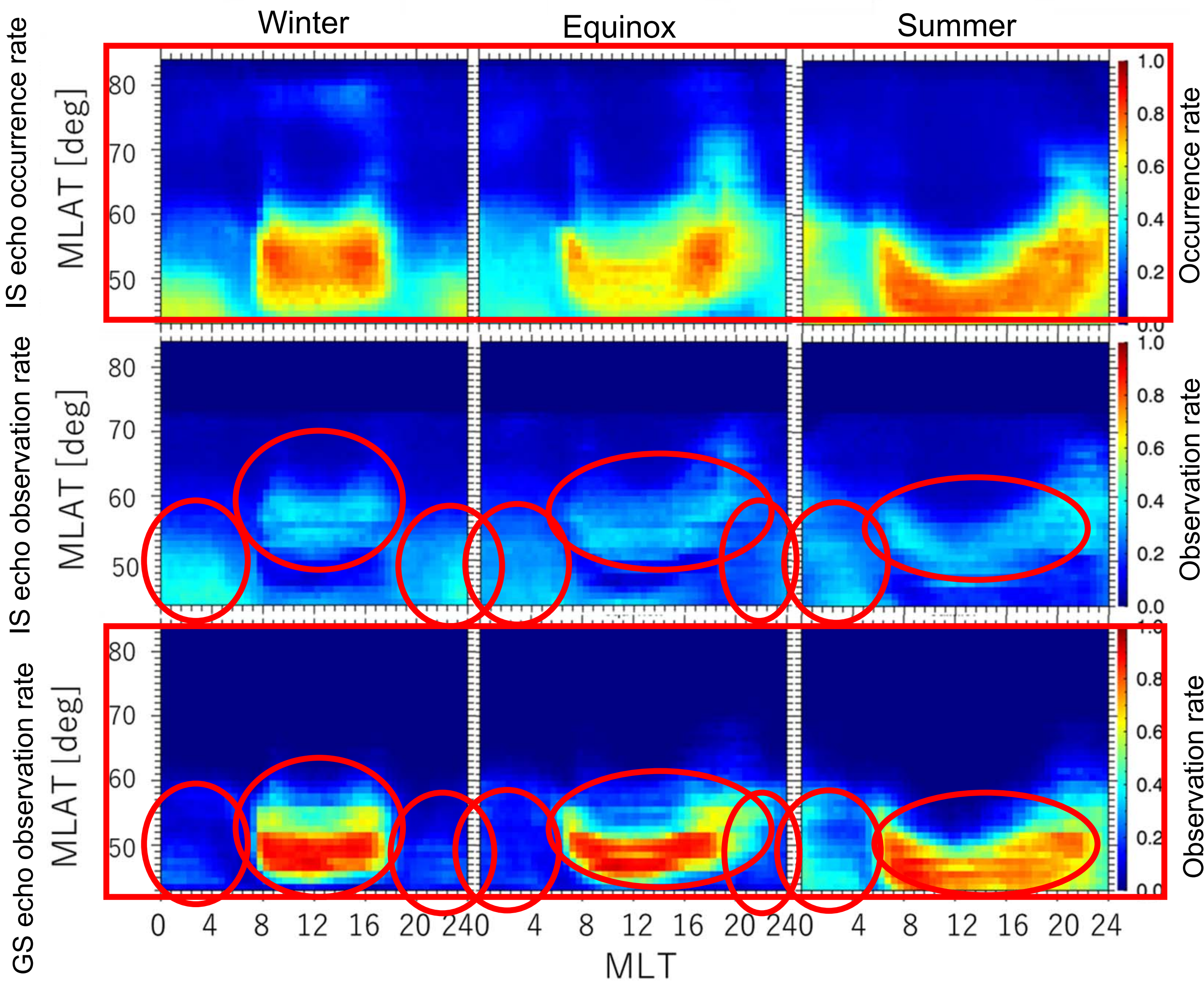
$$\text{Observation rate} = \frac{\text{Numbers of echoes}}{Obs.}$$

Daytime

- GS: Low lat., IS: High lat.
  →Possible contamination of GS into IS.

Night

- Winter, Equinox: IS > GS
- Summer: GS ≧ IS
  →Winter, Equinox echoes are dominated by IS, whereas summer echoes are unclear.

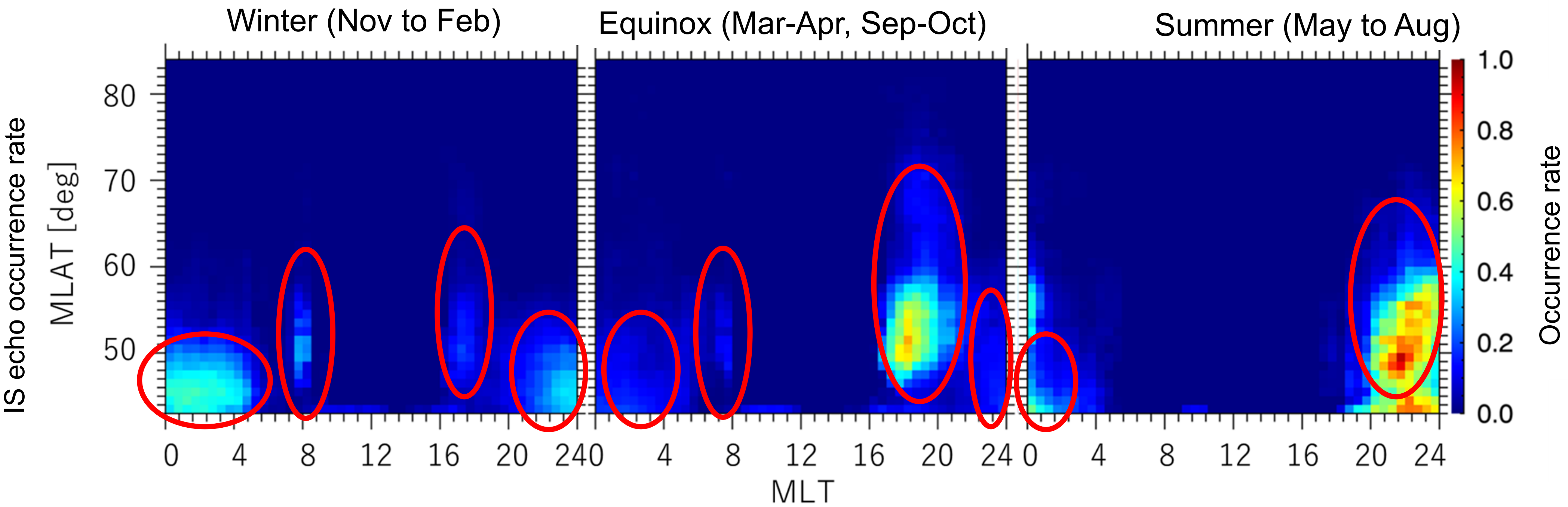


Results-proposed identification method

Data: 2008/1- 2021/12、 All beams

$$Occurence\ rate = \frac{IS}{Obs. - GS}$$

- Dawn: Weaker and earlier in Summer.
- Dusk: Stronger and later in Summer.
- Night: Higher in Winter and Summer.
- Most of GS echoes were successfully eliminated in the daytime.



Discussion-prop.

$$Occurence\ rate = \frac{IS}{Obs. - GS}$$

$$Observation\ rate = \frac{Numbers\ of\ echoes}{Obs.}$$

Daytime

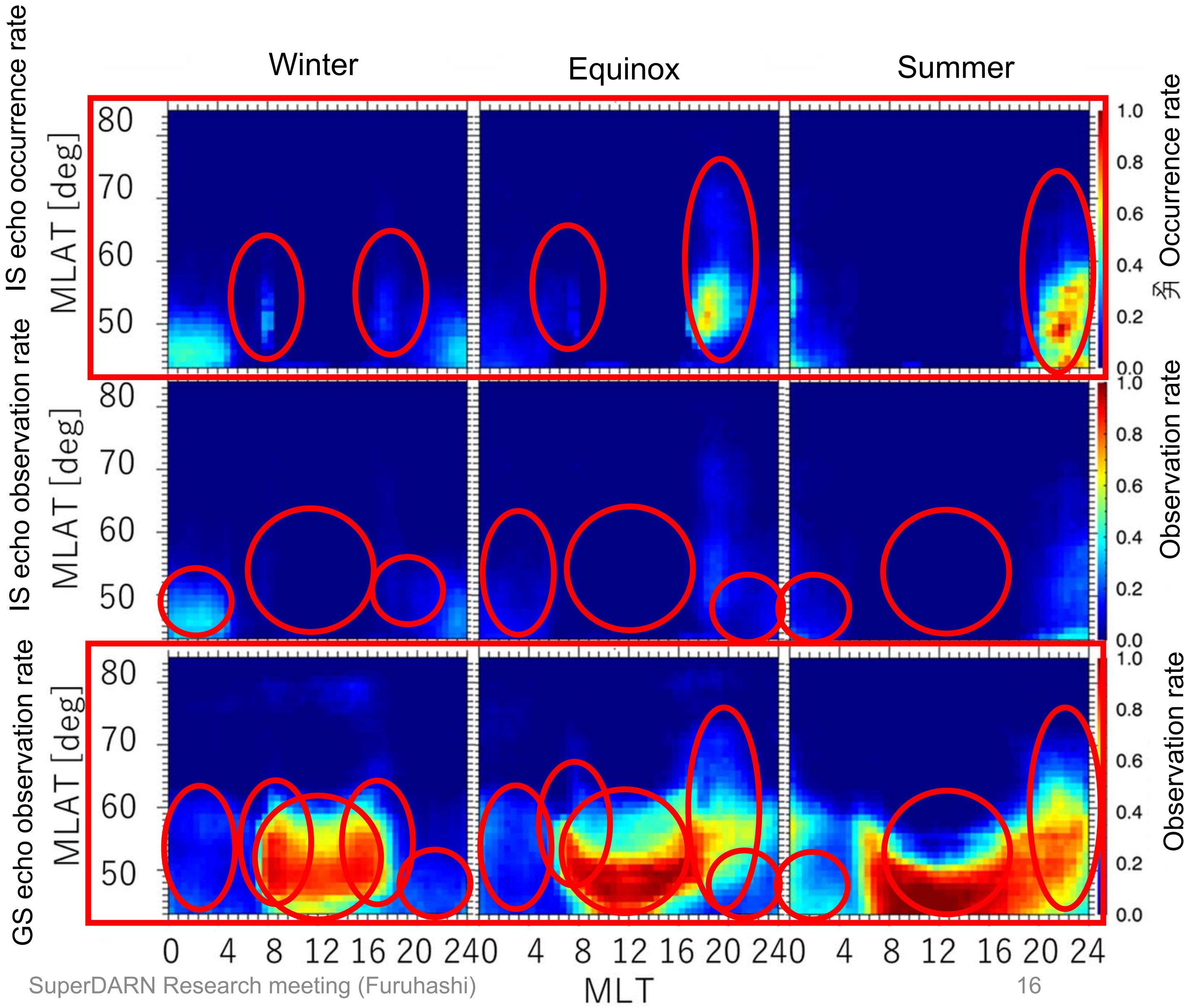
- GS for all seasons and no IS
  →Successfully eliminated daytime GS contamination into IS.

Night

- GS: Higher in Summer, IS: Higher in Winter
  →Winter: IS, Equinox: Unclear, Summer: GS

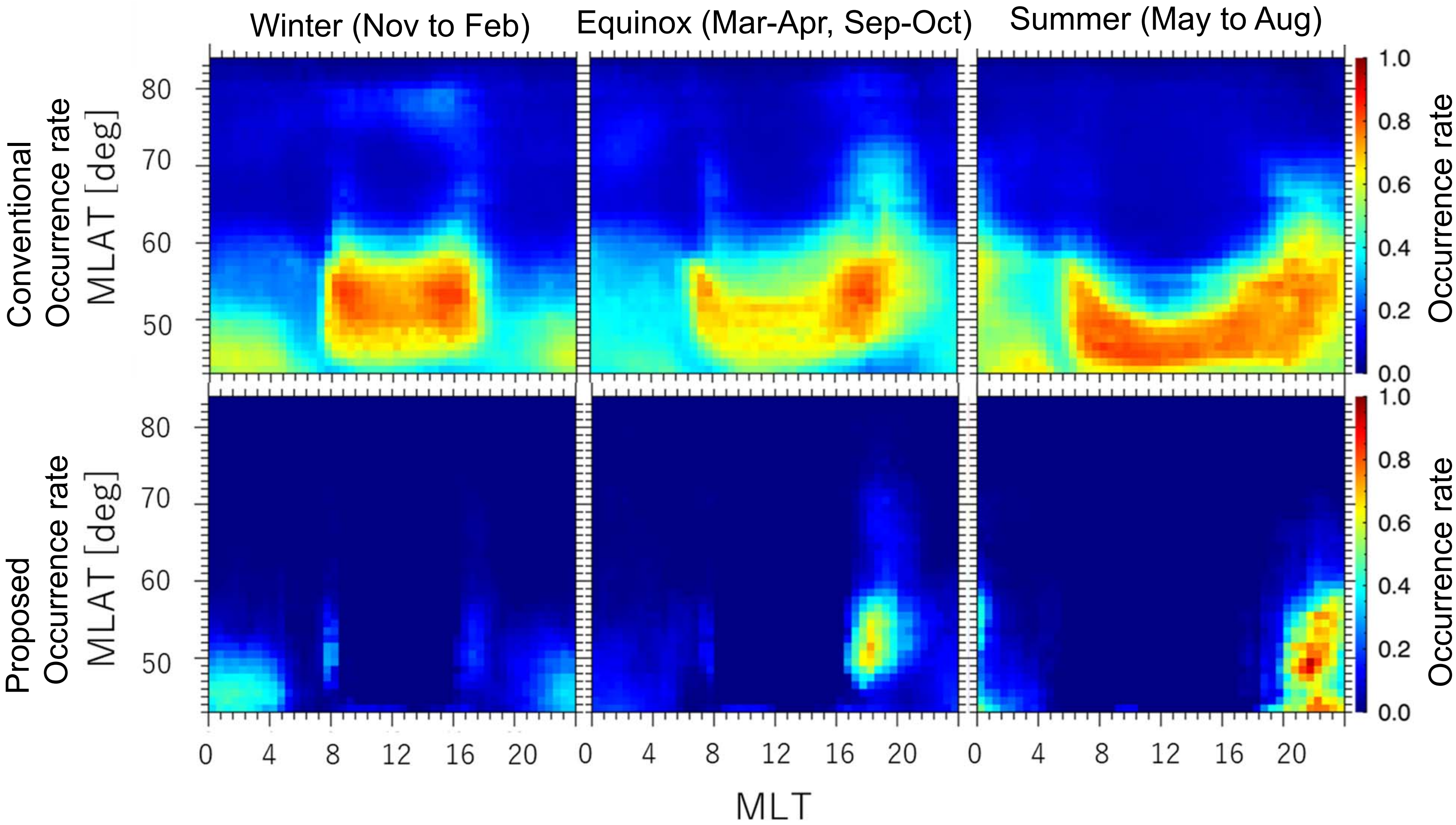
Dawn and Dusk

- Occ. increasing of GS at lower latitudes.
  →Possibly mixture of IS and GS。



Discussion-Comparison of occurrence rates

- No increase seen in the daytime.
  →Successfully eliminated daytime GS contamination into IS.
- Daytime and nighttime echoes are separated well in winter.
  →GS is distributed during the night in Summer.
  It is possible that GS and IS were identified as the same cluster.



Conclusion and Future issues

- **Objective** : Develop the identification method for mid-latitude echoes, based on the study by Ribeiro et al. (2011).

  →Our method succeeded in automatically identifying daytime and nighttime echoes in Winter, but there are still ambiguities (and rooms for improvement) in Summer and Equinox.

Issues and improvement:

- It is more difficult to identify echoes in Equinox and Summer.

  → IS and GS may be recognized as the same cluster. Using ray tracing results together may improve the cluster identification.

- The present threshold might not be the best.

  →One solution is to increase the numbers of data points for better threshold determination, by using more data etc. Changing the algorithm of setting weights may improve the cluster identification.

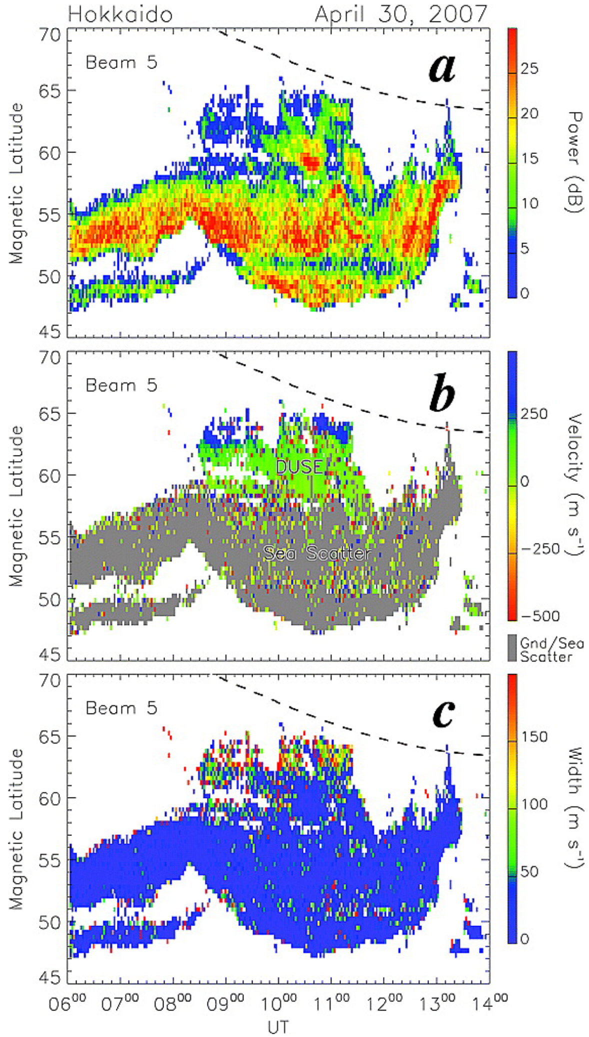
Thank you for listening!

Supplement

Duse (Dusk Scatter Event)

Seen at 59° -68° MLAT.

During magnetic quiet time, it continues for 2-3 hours after sunset.



K. Hosokawa and N. Nishitani (2009)

Supplement

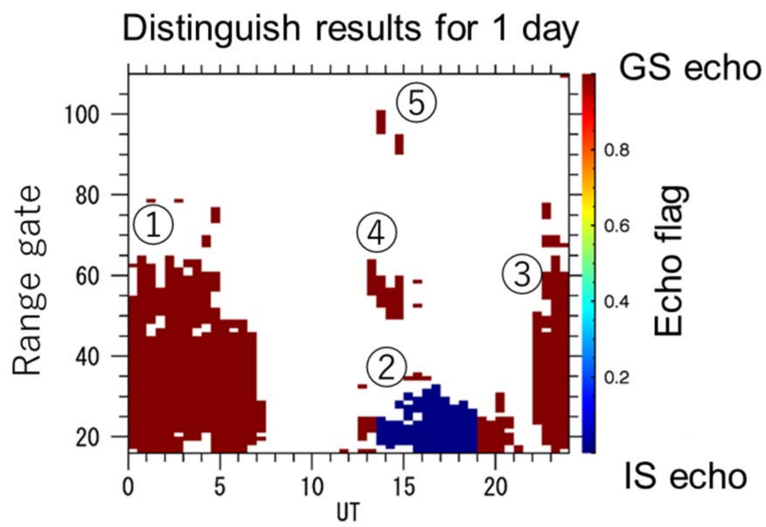
Try and error of thresholds

The thresholds are determined using 2010/1 data.

In particular, they are based on 2010/1/10 data.

The weights and thresholds were devised so that only cluster ② is IS echo, and others are GS echoes.

Then, thresholds were determined by checking each beam's IS and GS distribution in 2010/1.



Threshold values for different duration

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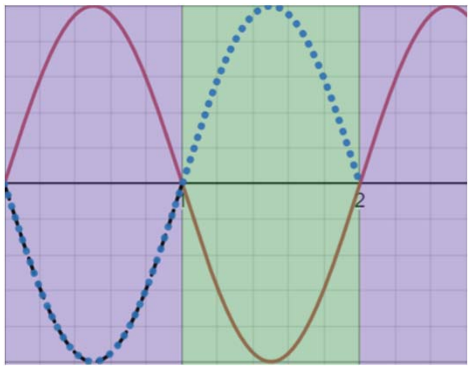
Supplement

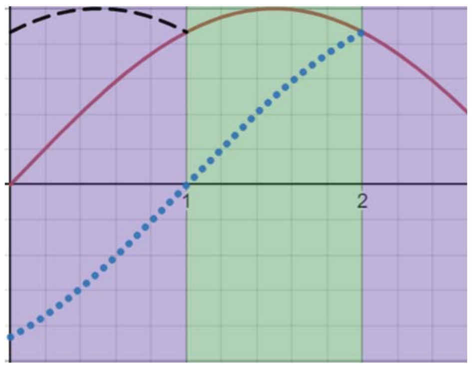
Echo detecting by SuperDARN

1. Irradiate HF waves toward the ionosphere.
2. If there are irregularities, it undergoes backscatter echoes.
3. The Doppler effect causes the returned scattered radio waves to be out of phase and the signal strength to change.

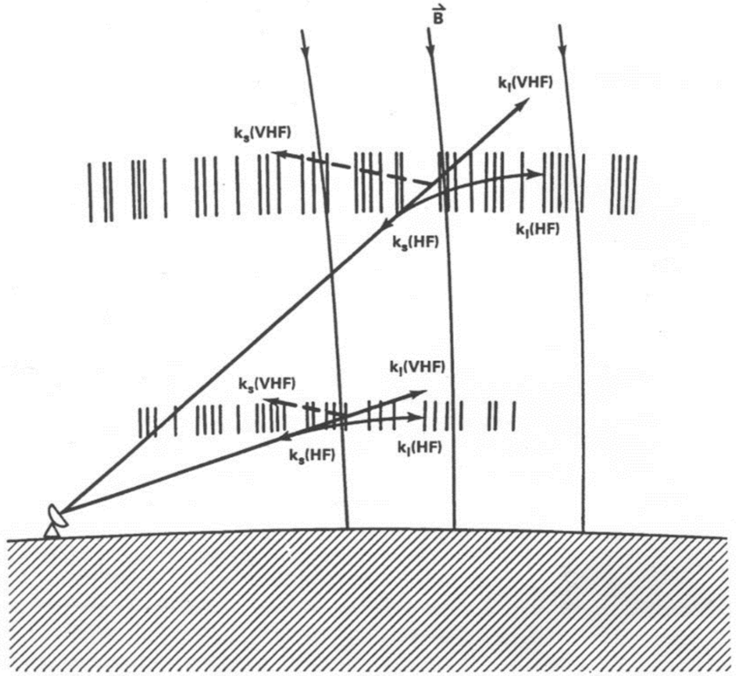
Reflected waves strengthen



Reflected waves weaken



Red: incident wave
Black: reflected wave 1
Blue: reflected wave 2

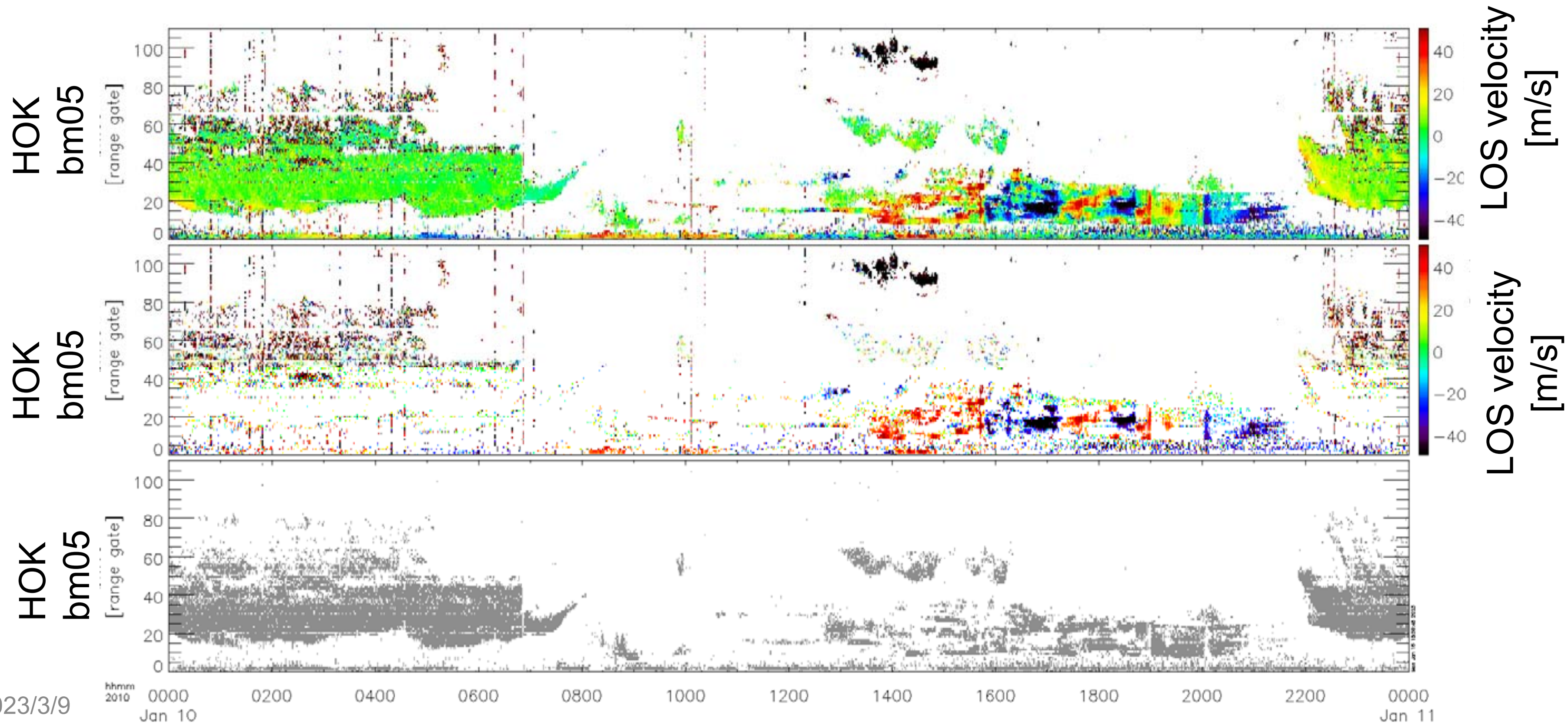


Greenwald et al. (1995)

Supplement

Example of data

Data: 2010/1/10 , beam5

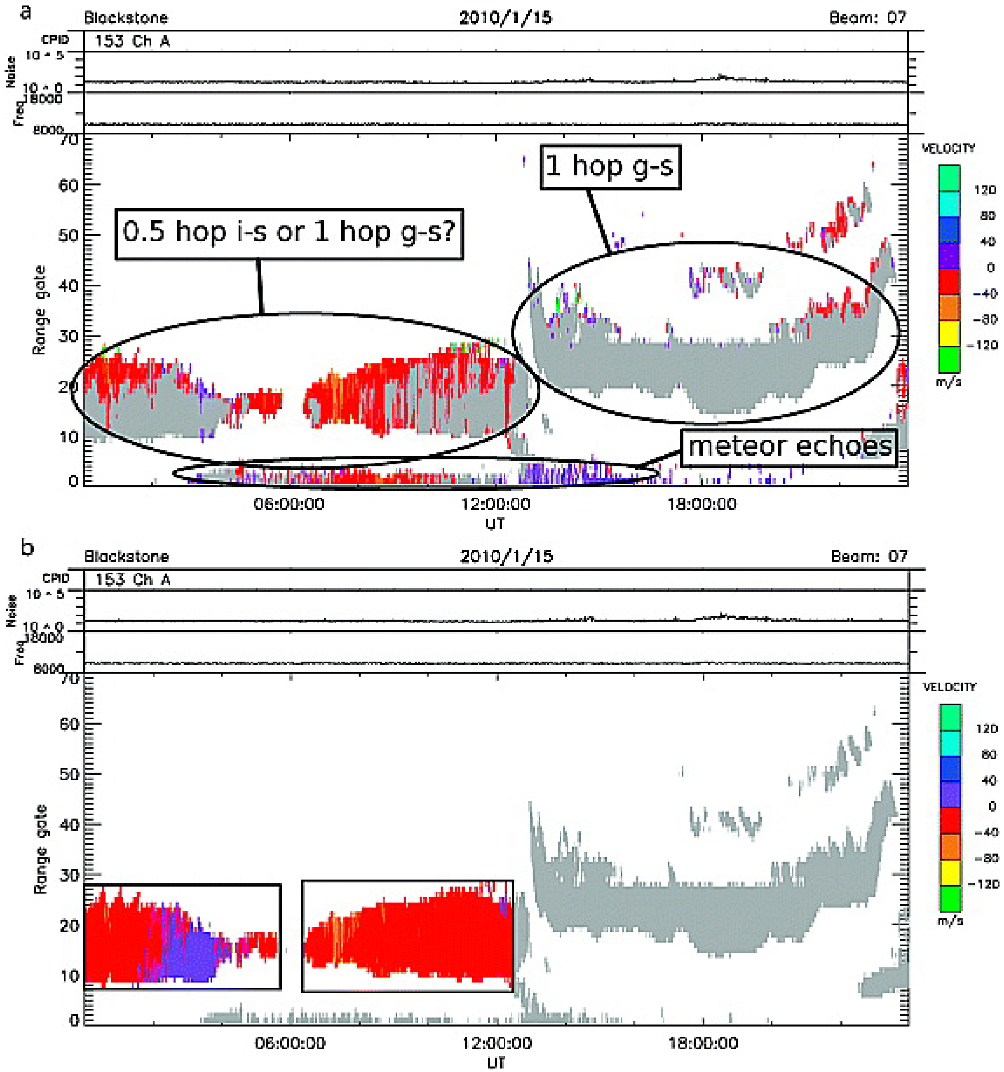


Supplement

A: original data

B: revaluation data

IS echoes are colored, and GS echoes are gray.



A. J. Ribeiro et al. (2011)

Supplement

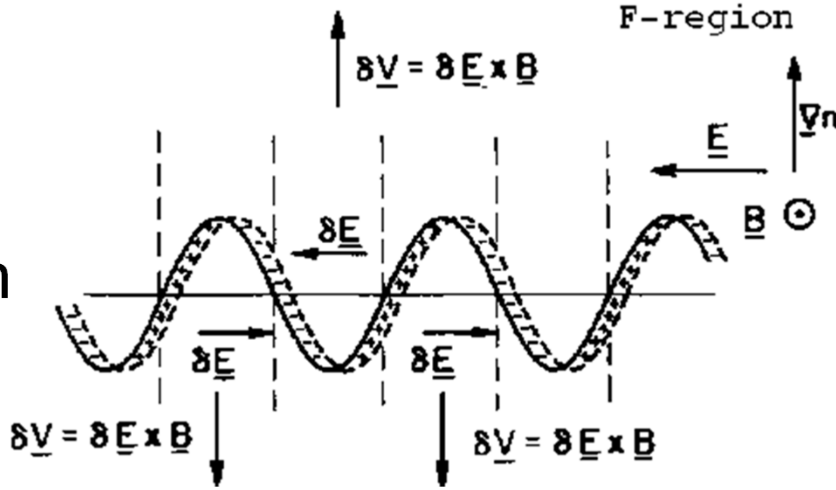
GDI(Gradient-Drift Instability)

Electron: moving along the magnetic field line

Plasma: moving away from the magnetic field line

A polarized electric field is generated.

→Plasma moves in the vertical direction by the E × B drift.



Adapted from https://www.ferzkopp.net/