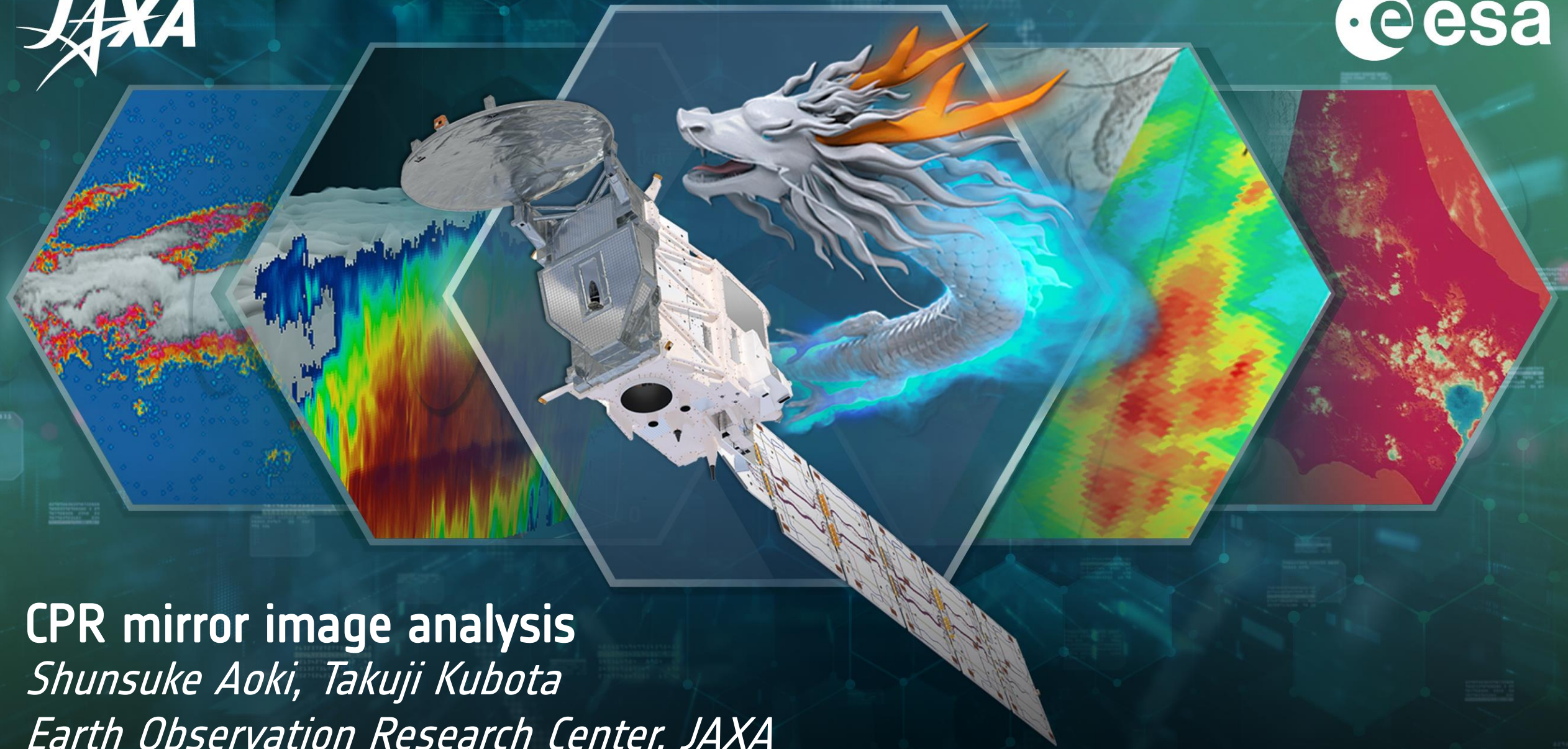

CPR mirror image analysis

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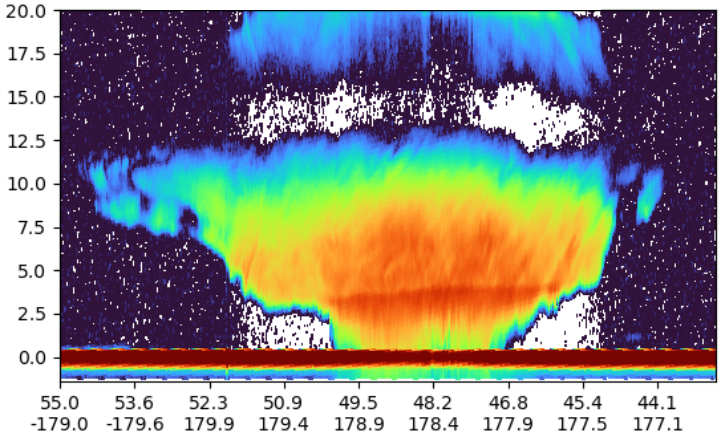
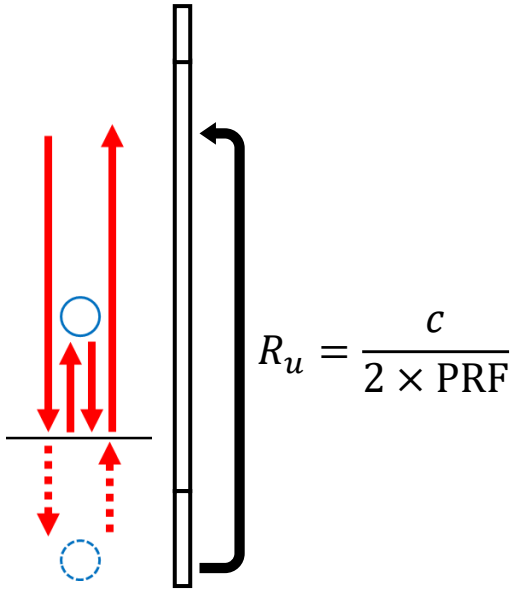
1st ESA-JAXA EarthCARE In-Orbit Validation Workshop
14 – 17 January 2025 | VIRTUAL EVENT

Introduction: second-trip echoes

- EarthCARE CPR frequently capture “mirror images” (Meneghini and Atlas 1986) and elongated tail-like echoes resulting from multiple scattering (MS tails; Battaglia and Simmer 2008).
  - ➢ These “second-trip echoes” take longer time to return and can overlap with the reception of subsequent pulses, leading to the appearance of false echoes at higher altitudes.
  - ➢ The extent of folding window (R_u) is determined by the pulse repetition frequency (PRF) .
- In EarthCARE CPR observations, a high PRF (R_u~$20 - 25$ km) is used to accurately measure Doppler velocities, making second-trip echoes more frequently appear compared to CloudSat (R_u~34 km).

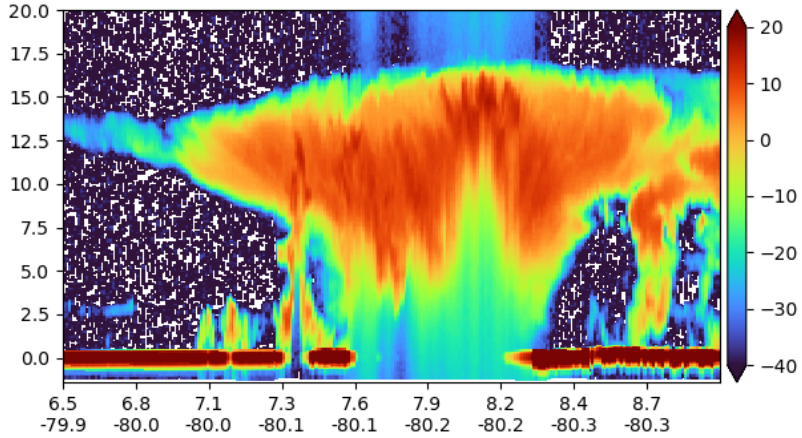
(a) Mirror images





$$R_u = \frac{c}{2 \times \mathrm{PRF}}$$

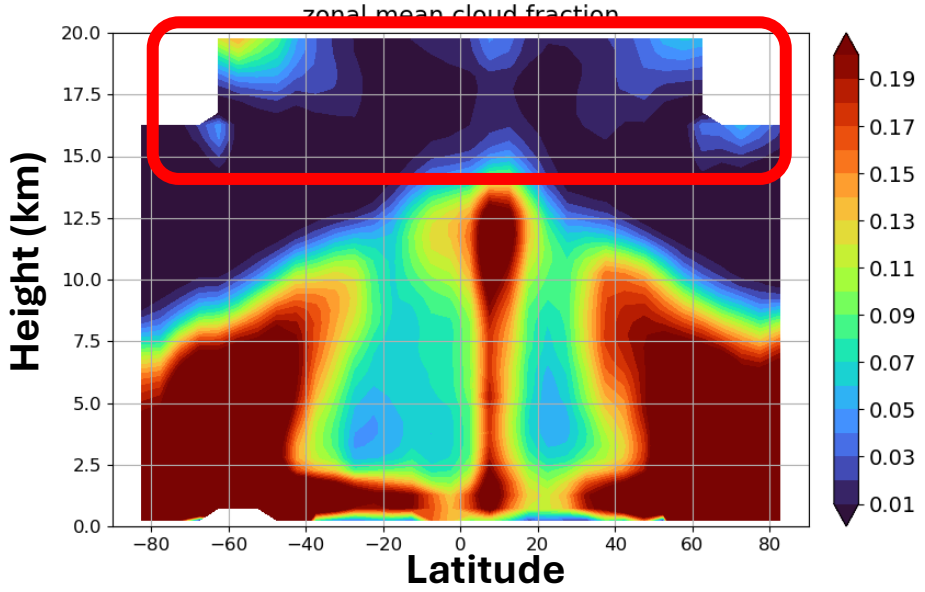
(b) MS tails



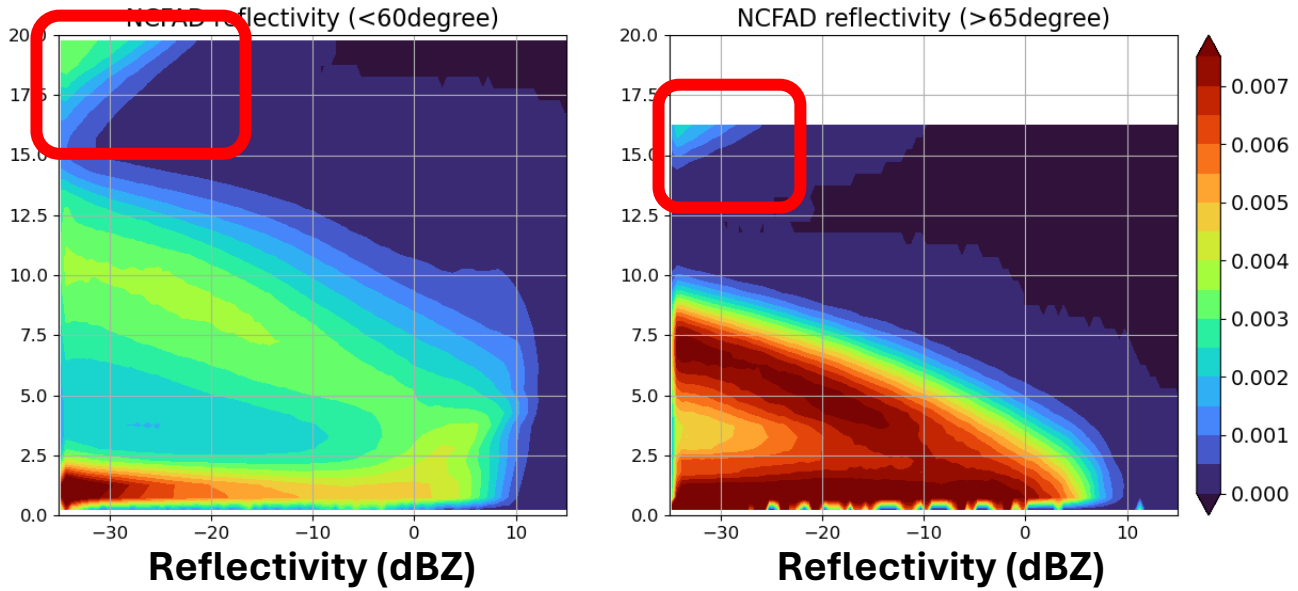
Height-distance diagrams of radar reflectivity in EarthCARE CPR observation (01418D, 01717A).

Zonal mean cloud fraction and CFAD

- These second trip-echoes are statistically significant and have a large impact on cloud fraction. Particularly in tropical regions, they overlap with cloud existence areas.
- In CPR L1b, these echoes remain, and they need to be addressed by the L2 algorithm.
- In this study, we tried to mask out these second-trip echoes using observational data.
  - ➢ This information will be provided as the “mirror_echo_flag” in the JAXA CPR L2 product (L2a CPR_ECO).



Zonal mean cloud fraction in Oct. 2024



Monthly mean NCFAD in Oct. 2024

Method: modelling of mirror images

Data : EarthCARE L2a CPR_ECO v0.5
Method : We estimated second-trip echoes following Battaglia (2021).

Modelling of the return power from the mirror :

$$Z(r_m) = Z(r_t) + 20\log_{10}\frac{r_m}{r_t} - 4A_{\text{surface}\to\text{target}} + 10\log_{10}\left[\frac{(H_{sat}-H_t)^2\Gamma^4\sigma_0}{\sigma_0 H_{sat}^2 + 11.04\Gamma^2\frac{H_t^2}{\theta_{3\,dB}^2}}\right],$$

From mirror

From target

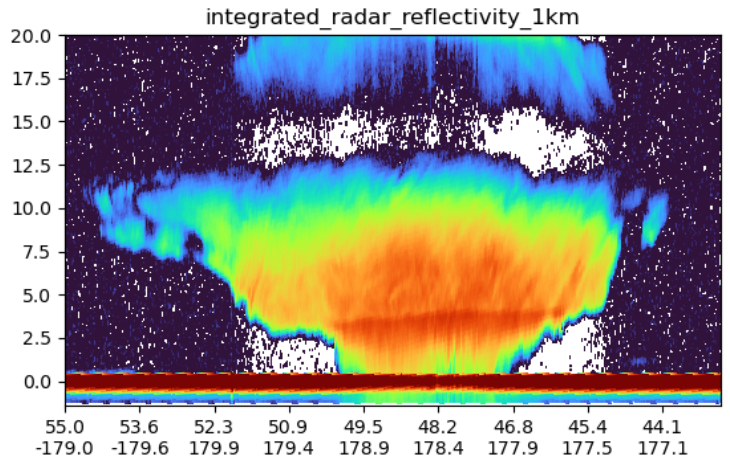
Sensitivity difference due to range distance

Attenuation during the four times the path from target to the surface (attenuation by gas/cloud/precipitation)

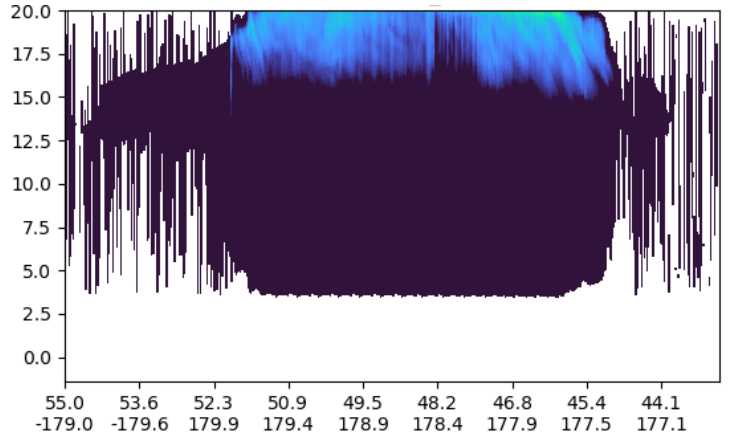
The specular reflection property of the surface of water
In the case of land, add −20dB because the dissipation is large.

r_t (r_m): the range of the target (mirror),
$\theta_{3dB}(= 0.095°)$: the antenna 3 dB beam width,
σ_0: surface normalized backscattering cross section,
$\Gamma(= 0.608)$: Fresnel reflection coefficient,
Ht ($Hsat$): the height of the target (satellite) from the surface.
$A_{s\to t}$ was calculated empirical formula of Protat et al. (2019), which was obtained from the 95 GHz airborne radar observations over tropical stratiform anvils.

Radar reflectivity (measured)



Mirror reflectivity (estimated)



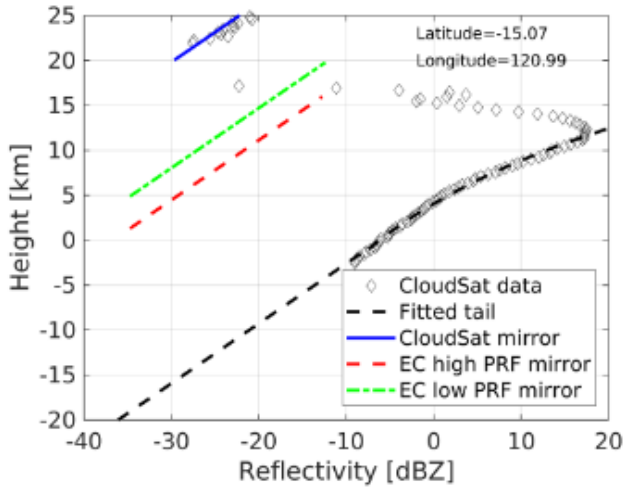
Method: modelling of MS tails

The occurrence frequency of MS tails is significantly less compared to mirror images. But they cause significant contamination on deep convective clouds.

After fitting the profiles of Z with

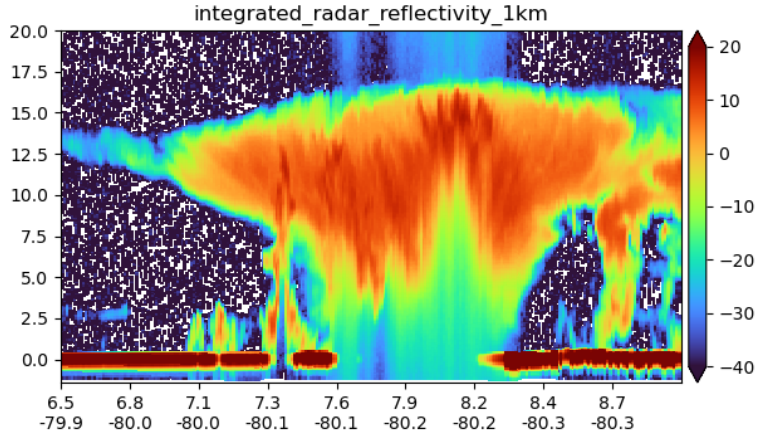
$$f(z) = A + B\exp(Cz),$$

sections where the slope is less than 1.5 dB/km were fixed at 1.5 dB/km. Prior to fitting, any ground surface echoes were removed. This calculation was conducted only in areas where convective echoes were strong and ground surface echoes were weak.

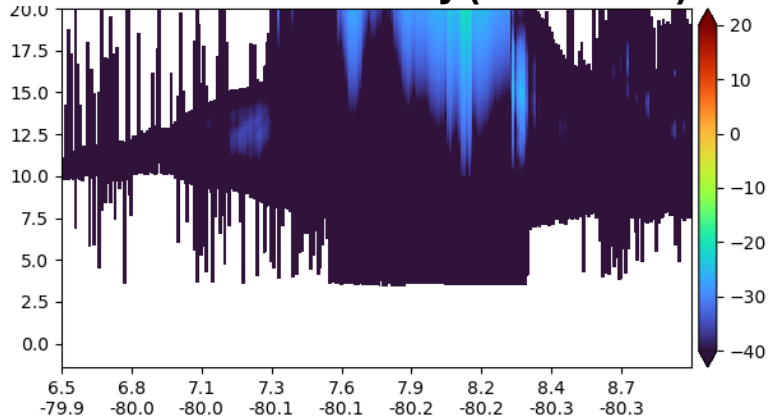


MS tails modeling for CloudSat (Battaglia 2021)

Radar reflectivity (measured)

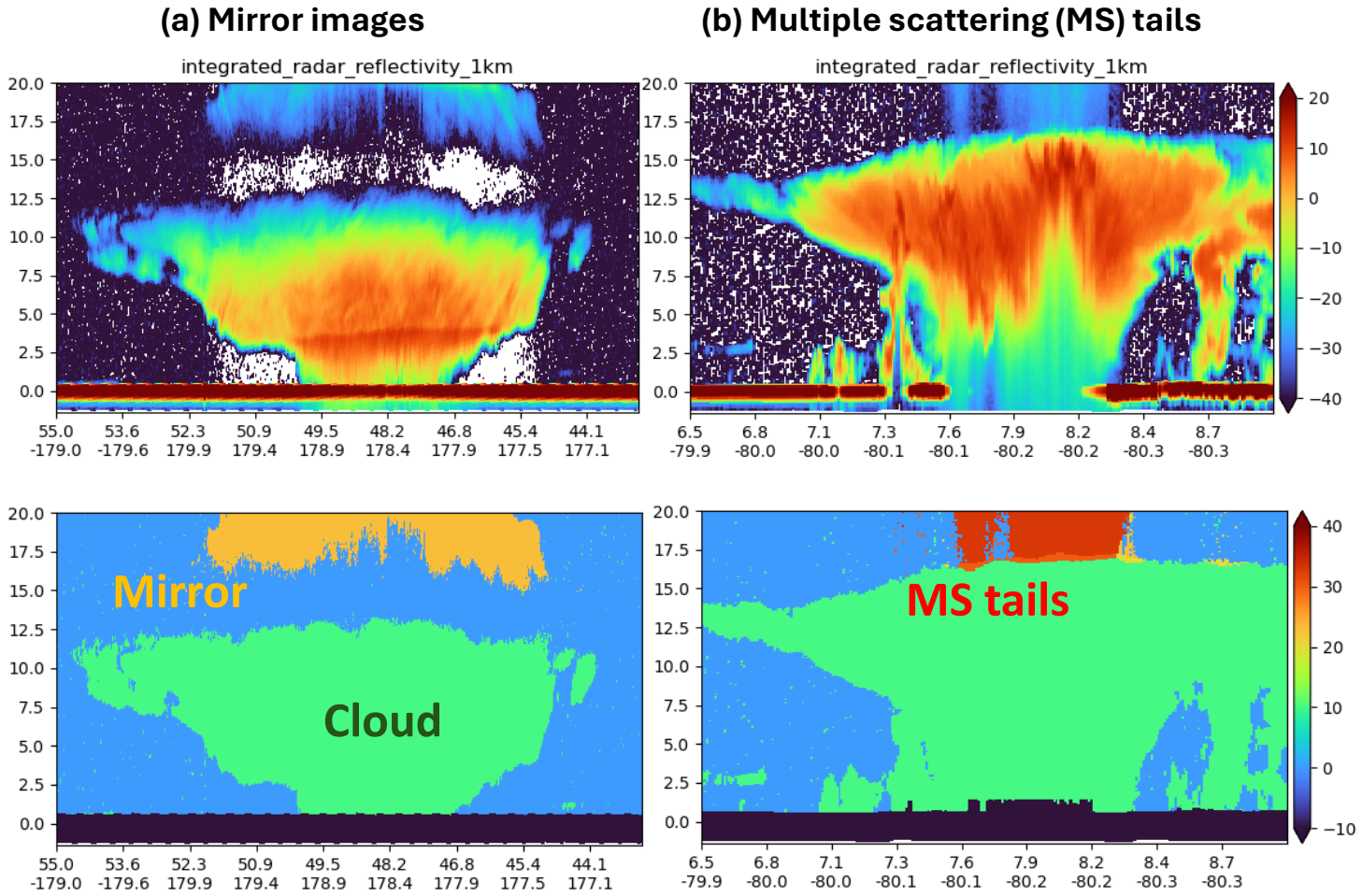


MS tail's reflectivity (estimated)



Results: case study

- A mask was created based on the estimated second-trip echo reflectivity.
- The mask was applied when the estimated values matched the observed values.
- This mask information will be provided as the “mirror_echo_flag” in the JAXA L2 product.



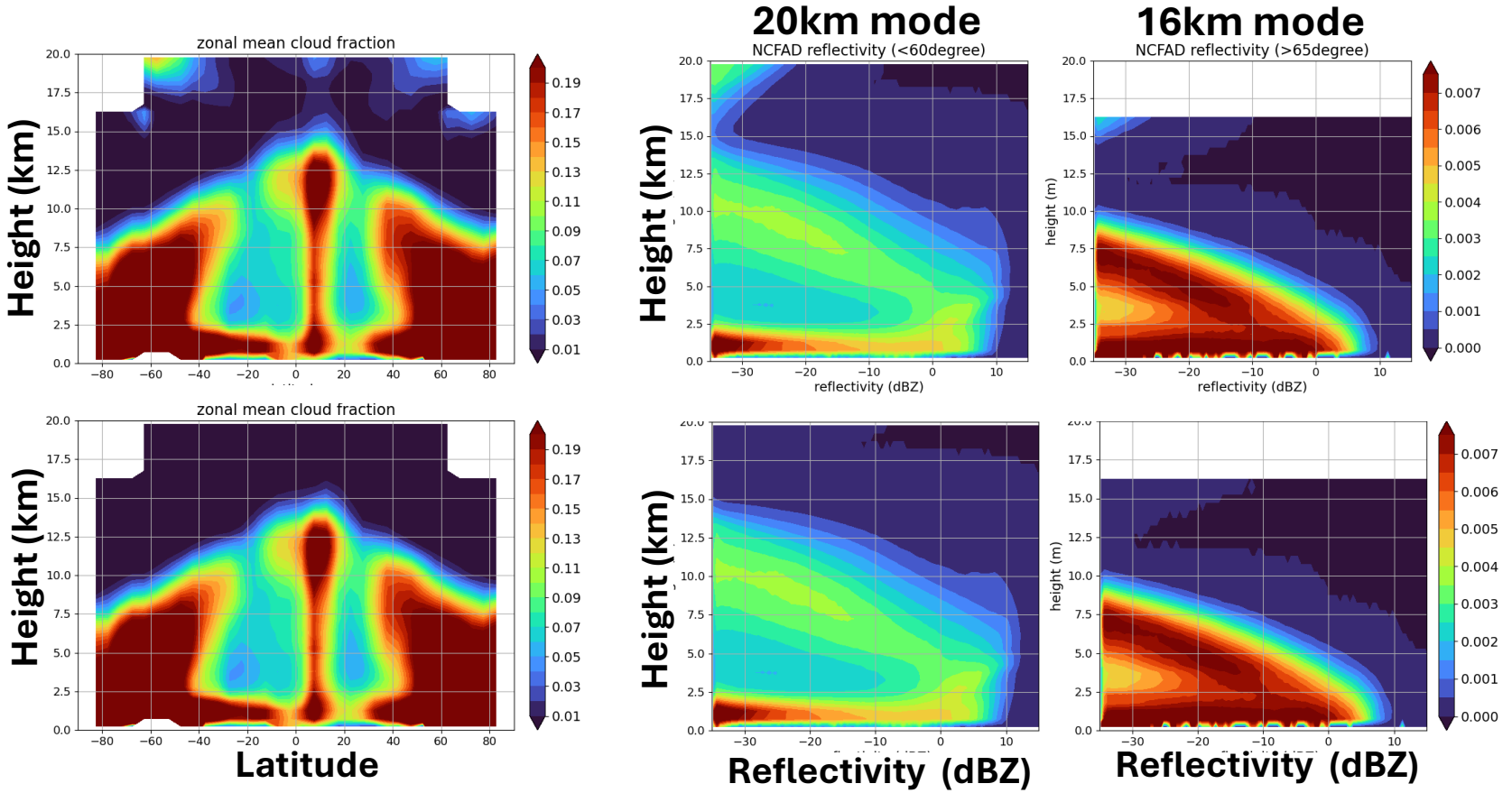
Height-distance diagrams of radar reflectivity and cloud mask of mirror images and MS tails in EarthCARE CPR observation.

Results: statistical analysis

- When the mask was applied for one month in October 2024, it was found that false echoes at higher altitudes were effectively removed from a statistical standpoint.

Before

After the mask has applied

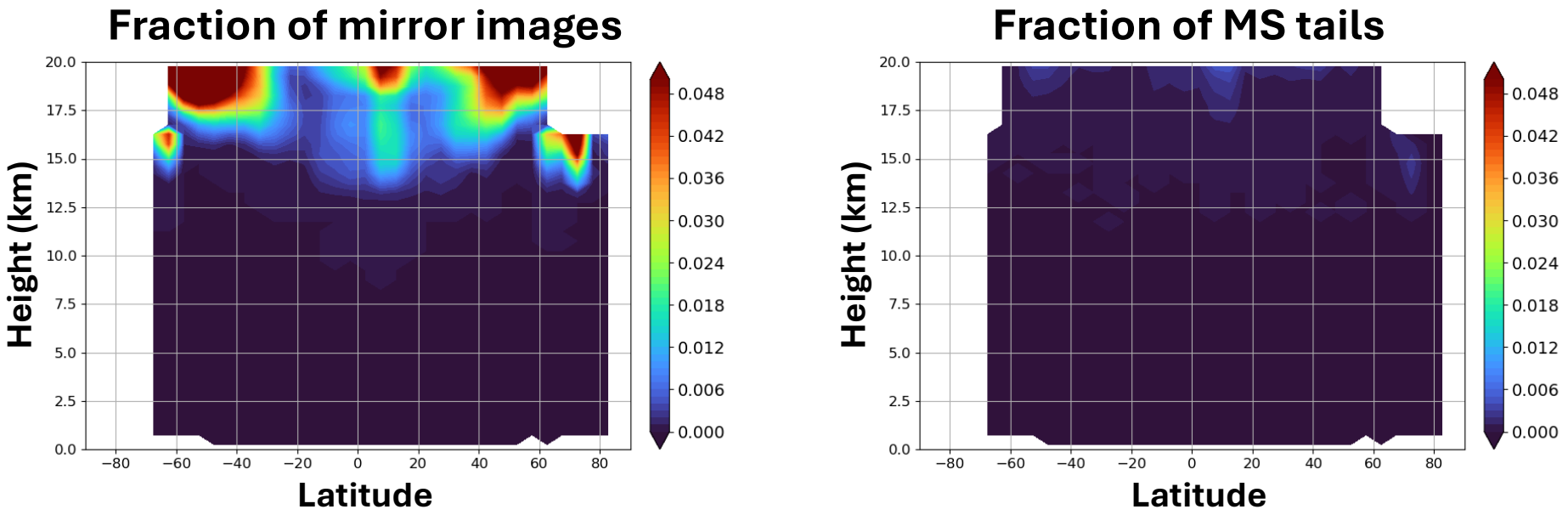


zonal mean cloud fraction in Oct. 2024

monthly mean NCFAD in Oct. 2024

Results: statistical analysis

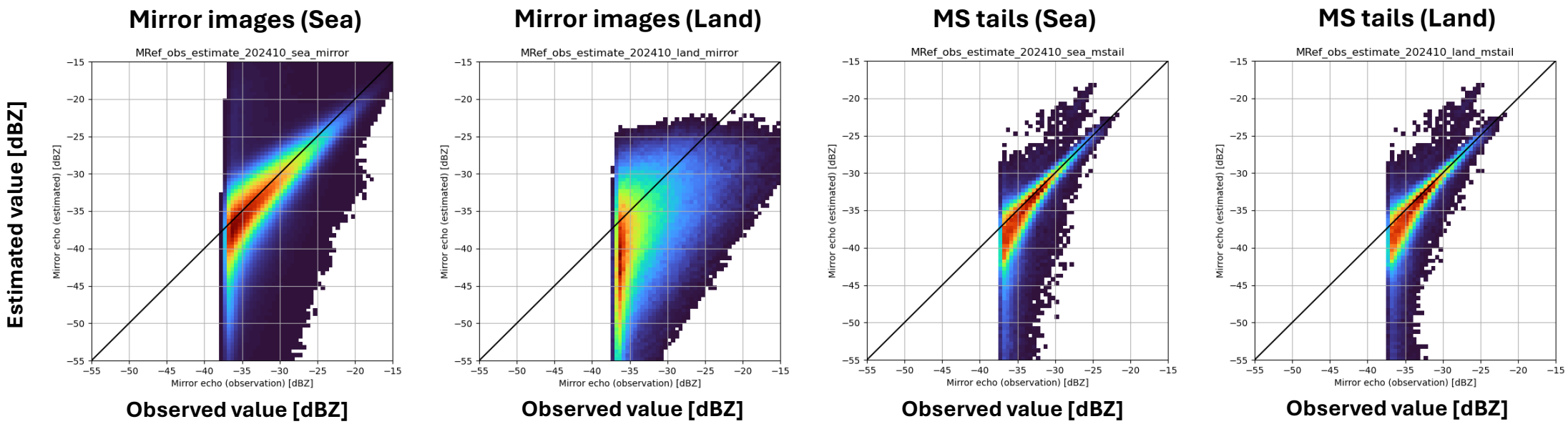
- Mirror images occur most frequently over mid-latitude oceans and are prominent in the stratiform precipitation regions of extratropical cyclones.
- The occurrence frequency of MS tails is about one-tenth that of mirror.



zonal mean fraction in Oct. 2024

Results: observed vs estimated reflectivity

A comparison between observed and estimated values was conducted for data from the same period. Mirror images were estimated well over the ocean, while further improvement is necessary for the estimation over land. MS tails were relatively well estimated.



Comparison between observed and estimated value of mirror images and MS tails.

Summary

- In EarthCARE CPR, due to the higher PRF, second-trip echoes appear more frequently than in CloudSat. They have a large impact on cloud fraction, particularly in tropical regions, where they overlap with cloud existence areas.
- We estimated reflectivity of mirror images and MS tails following Battaglia (2021), and removed the false echoes by applying a mask.
- The estimated second-trip echo reflectivity shows values close to the measured values, though challenges remain in estimating mirror images over land. Statistically, the mask functions well.
- The information presented here will be provided as the “mirror_echo_flag” in the JAXA CPR L2 product (L2a CPR_ECO).

Future work

- ➢ Comparison with ATLID cloud top height
- ➢ Statistical validation against CloudSat