Second-Trip Echoes Appeared in EarthCARE/CPR: Characteristics and Mitigation Performances in JAXA CPR L2a Product

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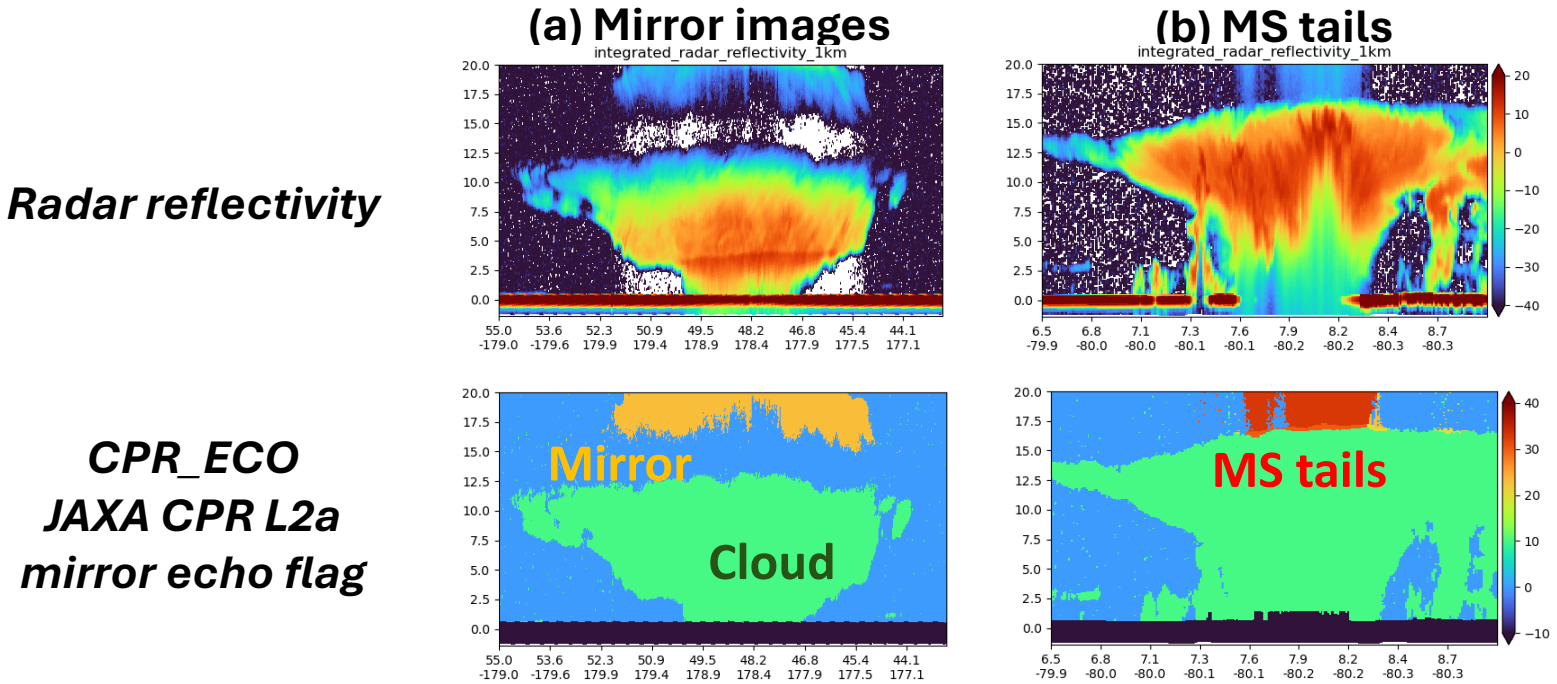
Second trip echoes in CPR

- EarthCARE CPR frequently capture second trip echoes at higher altitudes, such as “mirror images” (Meneghini and Atlas 1986) and elongated tail-like echoes due to multiple scattering (MS tails; Battaglia and Simmer 2008). This is because CPR operates with a higher PRF to ensure accurate measurements of Doppler velocities. They need to be addressed by the L2 algorithm.
- This information is provided as the “mirror_echo_flag” in the JAXA CPR L2a product (CPR_ECO).



Height-distance diagrams of radar reflectivity and cloud mask in EarthCARE CPR observation.

Focus of this presentation

Investigated the characteristics of the second-trip echoes observed by EarthCARE/CPR.

1. Check the performance of mirror echo flag in CPR_ECO (JAXA L2a) using ATLID.
2. Examine the differences in appearance of second-trip echoes for each observation mode (**20 km (High)** , **18 km (Middle)**, **and 16 km (Low) modes with different PRF**) and the degree of contamination near the cloud top.

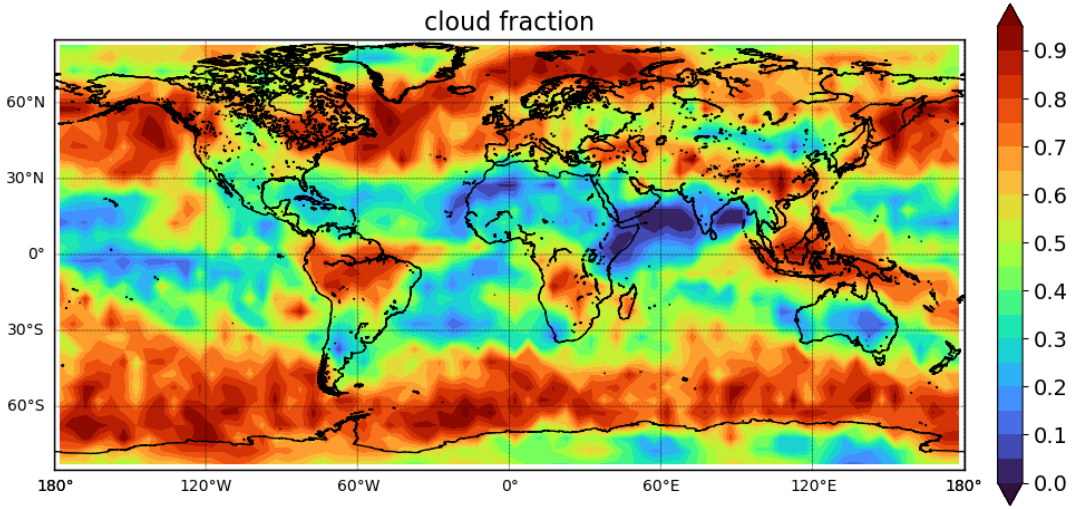
- Data
  - Mirror echo flag (calculated based on calculation introduced in Battaglia (2021))
  - Data from ATLID were used to compare cloud top heights obtained from CPR and ATLID.

	Period	CPR L2a	ATLID L2a	Domain
Analysis to check the performance using latest baselines	Feb. 6th 2025 - Feb. 28th 2025	CPR_ECO vBa (L1b baseline vCb)	ATL_CLA vAd (L1b baseline vAe)	Global
Analysis using globally fixed observation mode	Nov. 1th 2024 - Nov. 12th 2024	CPR_ECO vAd (L1b baseline vBa)	ATL_CLA vAa (L1b baseline vAc)	60S-60N (To compare the 20km mode)

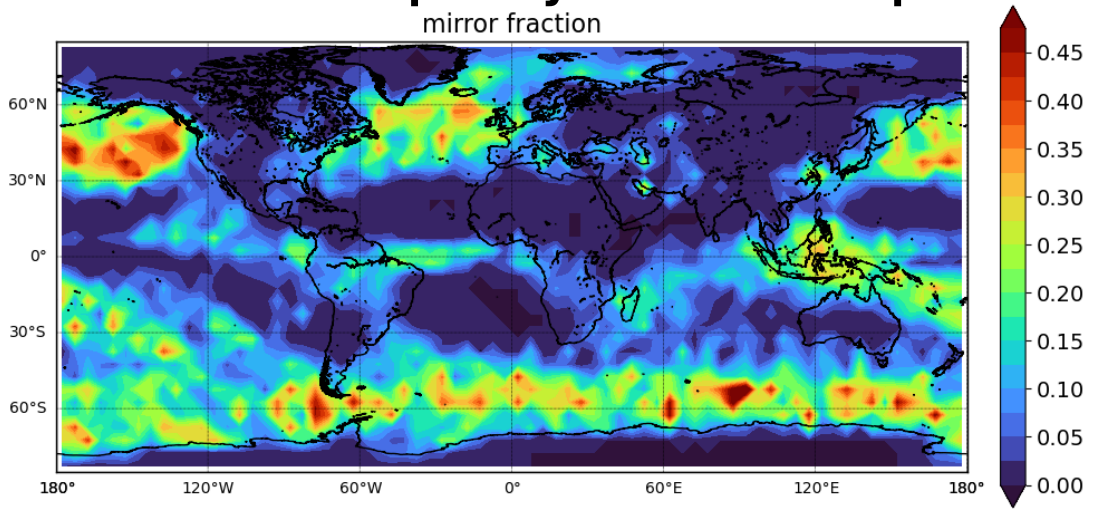
Geographical distribution of mirror

- Geographical distribution of second-trip echoes (mirror images + MS tails) in Feb 2025.
- Higher occurrence frequency of mirror in areas with frequent cloud presence.
- Particularly high over the ocean due to strong echo reflection at sea surface lead to mirror images, reaching nearly 50% in mid-latitude storm tracks.

Cloud fraction



Occurrence frequency of second-trip echoes

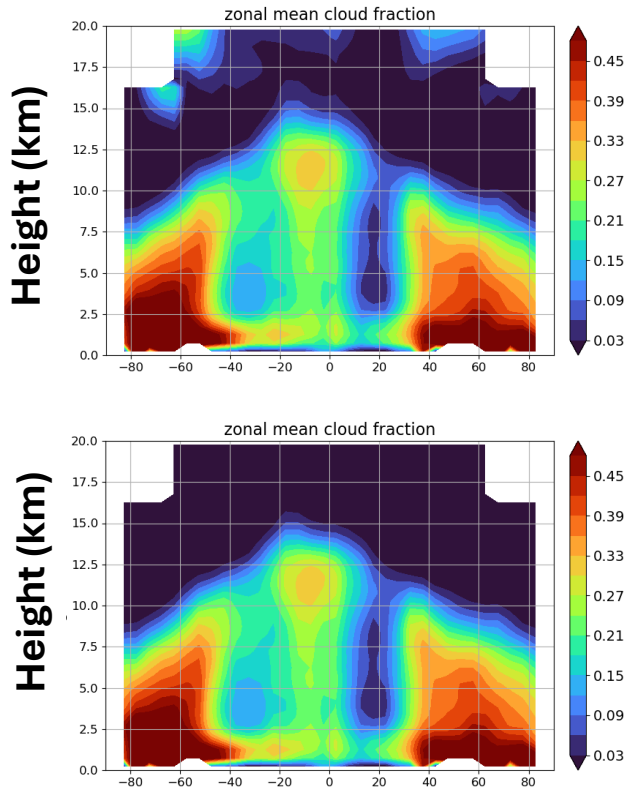


Statistical analysis of mirror

- When the mask was applied for one month in Feb 2025, it was found that false echoes at higher altitudes were effectively removed from a statistical standpoint.

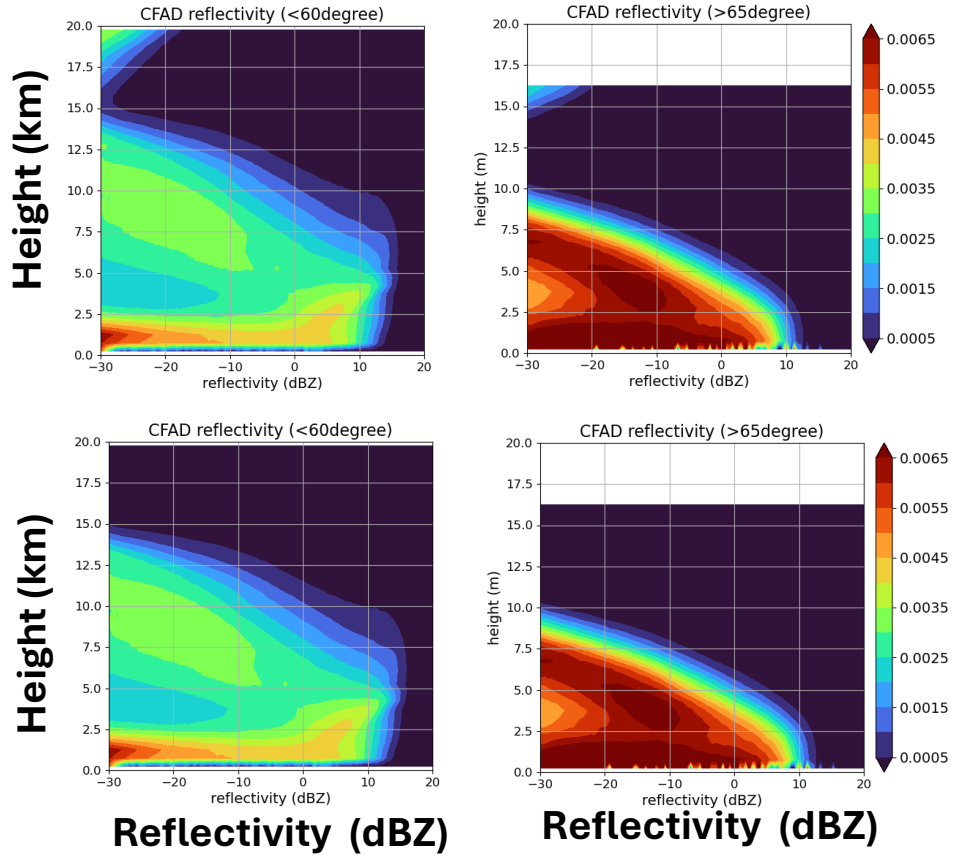
Before

After the mask has applied



zonal mean cloud fraction in Feb. 2025

20km mode **16km mode**



monthly mean CFAD in Feb. 2025

Mirror flag performance against ATLID CTOP

- To validate the CPR mirror flag, the cloud top height from ATLID was used.
- Due to ATLID's higher sensitivity, cloud top from ATLID is higher than those from CPR.

To match the sensitivity to CPR, a threshold was set for ATLID using backscatter integrated from the TOA.

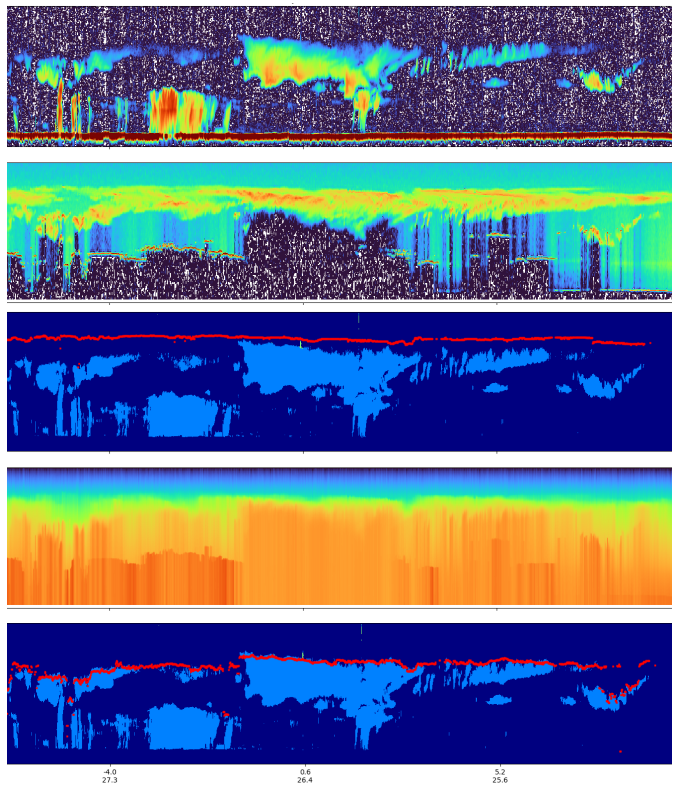
CPR
Radar reflectivity

ATLID
$\beta(z)$

CPR cloud mask
ATLID cloud top

ATLID
$\beta_{int}(z) = \int_{z}^{z_{TOA}} \beta(z')dz'$

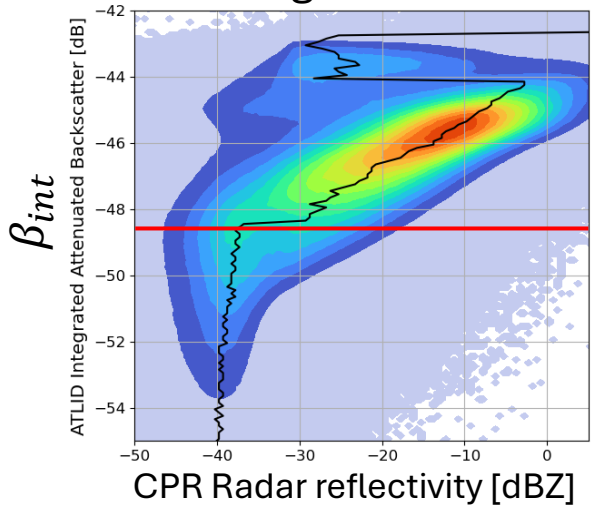
CPR cloud mask
ATLID cloud top
(modified)



- The threshold of β_{int} at which Z_{CPR} exceeds the noise level was determined.
- Taking into account the sensitivity differences of ATLID between day and night.

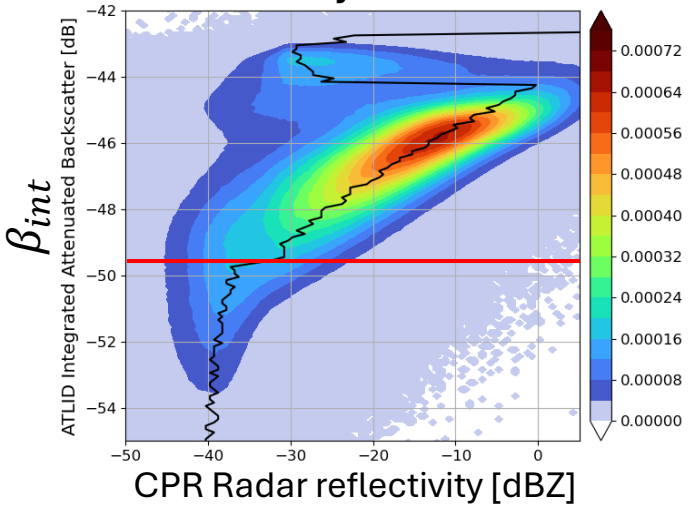
Histograms of $Z_{CPR} - \beta_{int}$

Night-time



$\beta_{int} > -48.5$ dB

Day-time

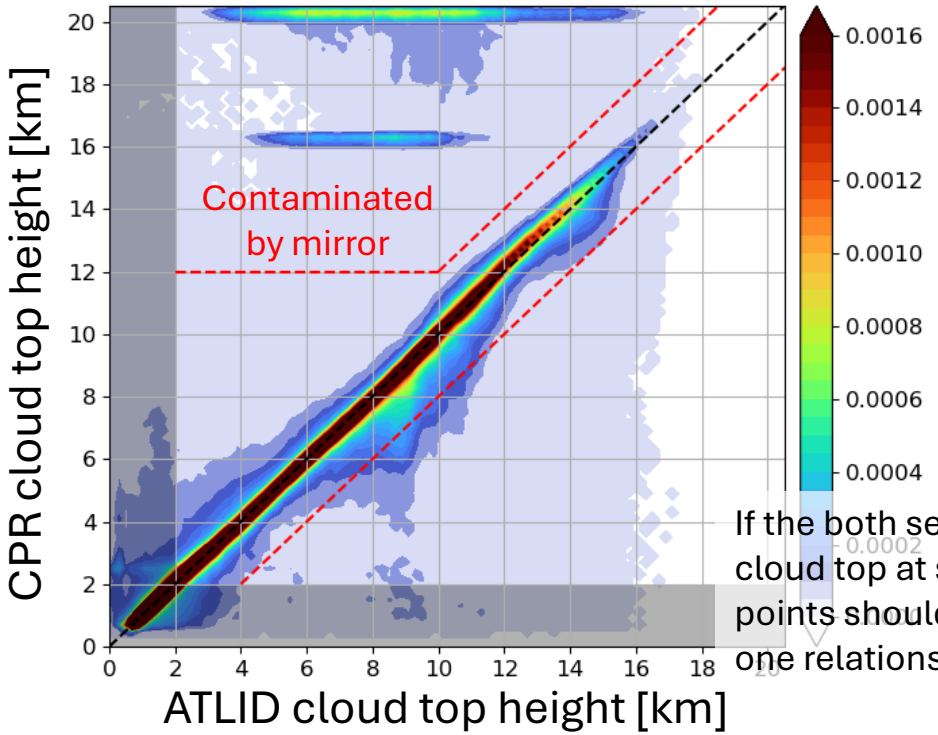


$\beta_{int} > -49.5$ dB

Cloud top height comparison: CPR-ATLID

- CPR sometimes misidentifies the observation limit heights (16 km or 20 km) as cloud tops.
- The region above the red line was considered contaminated by second-trip echoes.

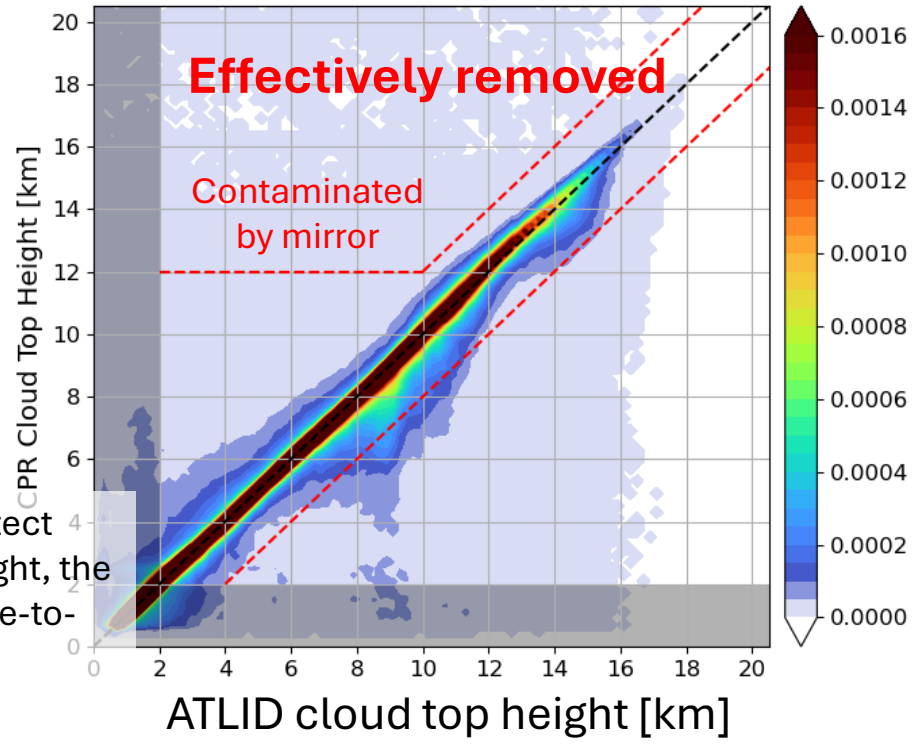
Before



Occurence frequency of mirror : 12.58%

If the both sensors detect cloud top at same height, the points should be in one-to-one relationship.

After the mask has applied



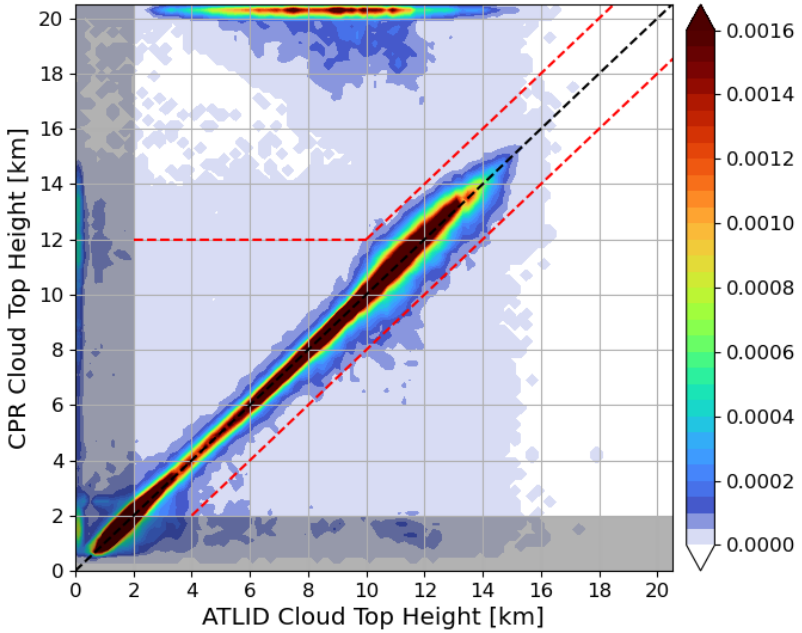
Occurence frequency of mirror : 0.55%

Removal rate: 95.6%

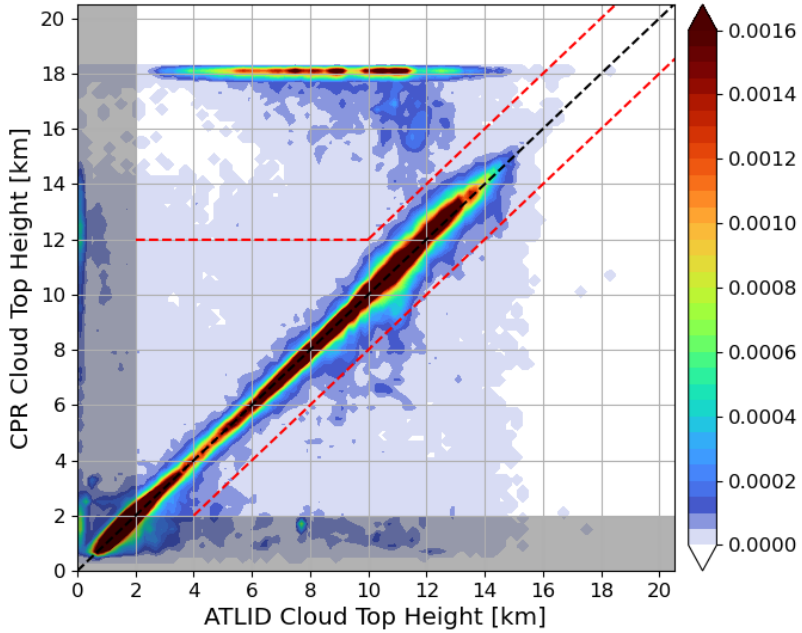
In Feb 2025, only rays with clouds detected by both sensors were used.

CPR-ATLID cloud top comparison for different observation mode (Before)

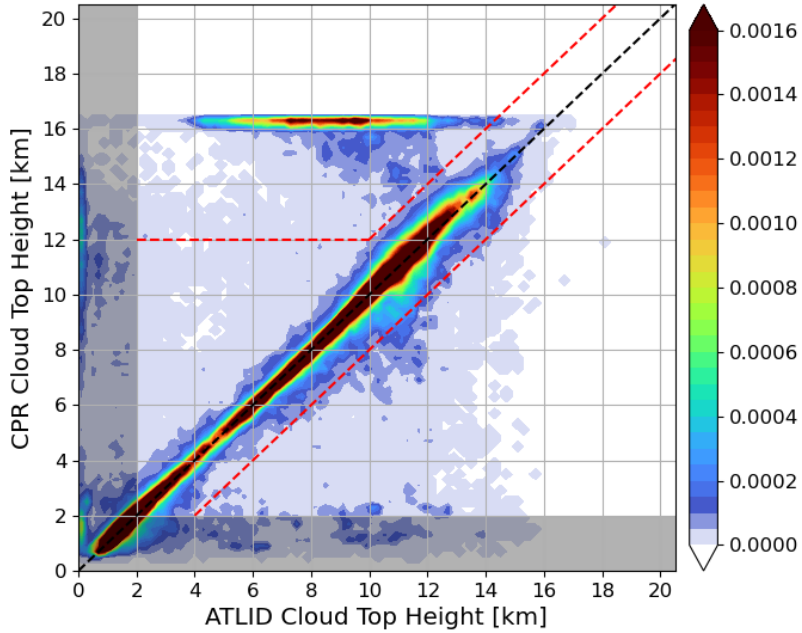
High mode (20km)
2024/11/1 – 11/5
Frame 2428 – 2502



Middle mode (18km)
2024/11/9 – 11/12
Frame 2553 – 2606



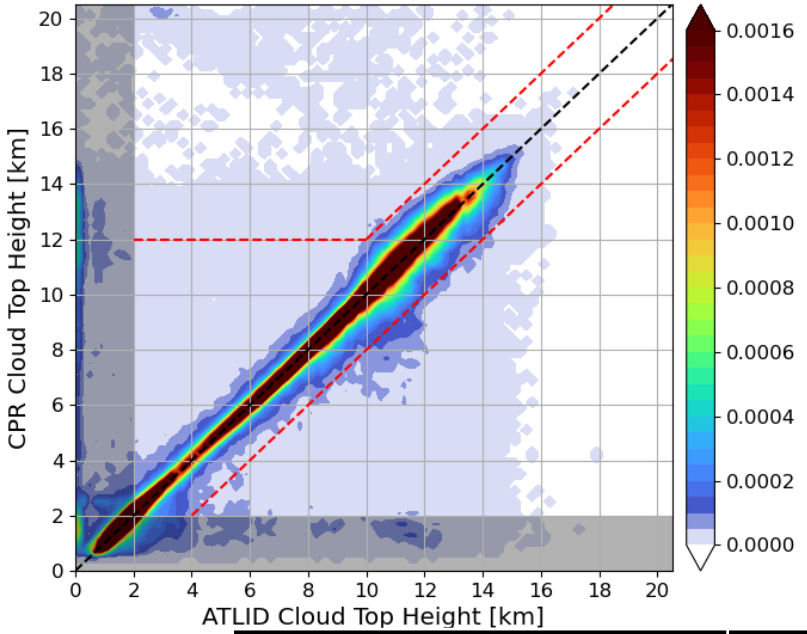
Low mode (16km)
2024/11/5 – 11/8
Frame 2504 – 2551



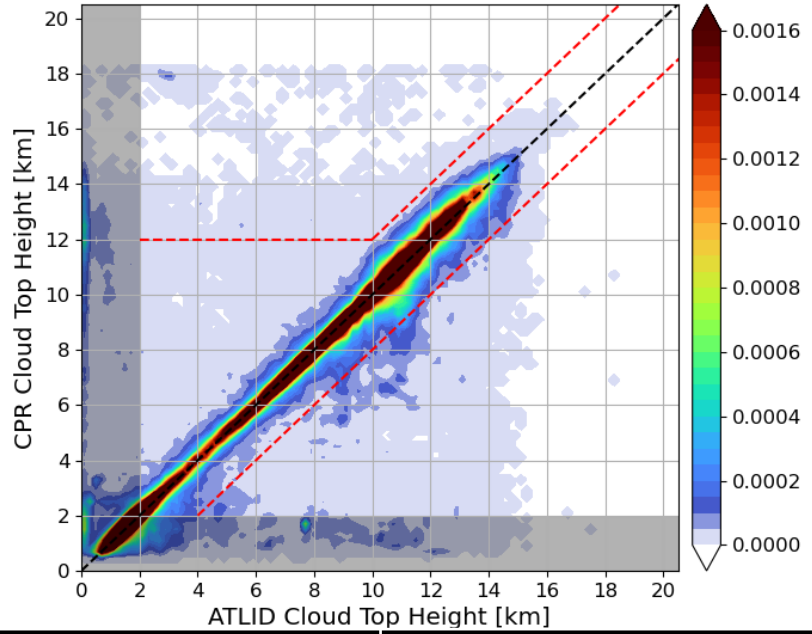
- We performed the same analysis in November 2024, when CPR operated in globally fixed observation mode.
- CPR has three observation modes with different PRF values and maximum observation heights: **20 km (High)** , **18 km (Middle)**, **and 16 km (Low) modes**
- Second-trip echoes appear in lower height in lower observation mode.

CPR-ATLID cloud top comparison for different observation mode (After the mask has applied)

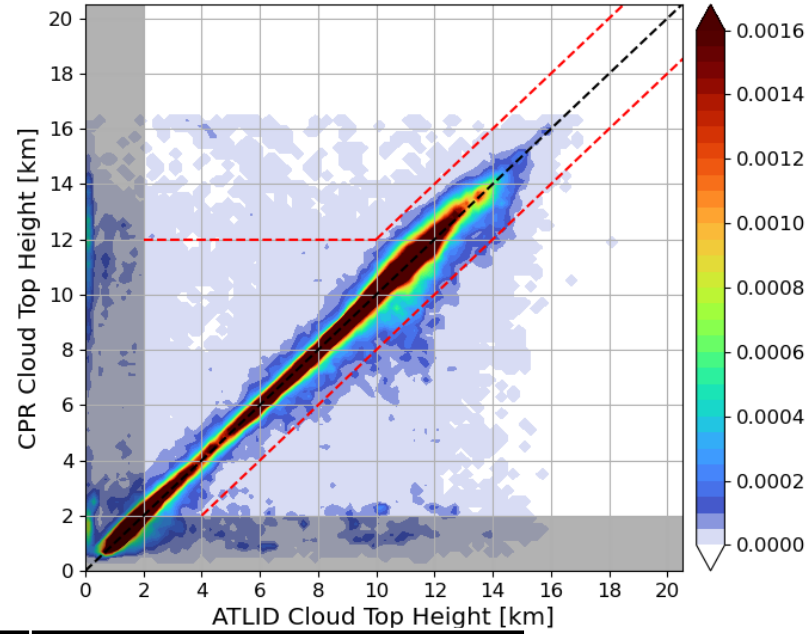
High mode (20km)
2024/11/1 – 11/5
Frame 2428 – 2502



Middle mode (18km)
2024/11/9 – 11/12
Frame 2553 – 2606



Low mode (16km)
2024/11/5 – 11/8
Frame 2504 – 2551



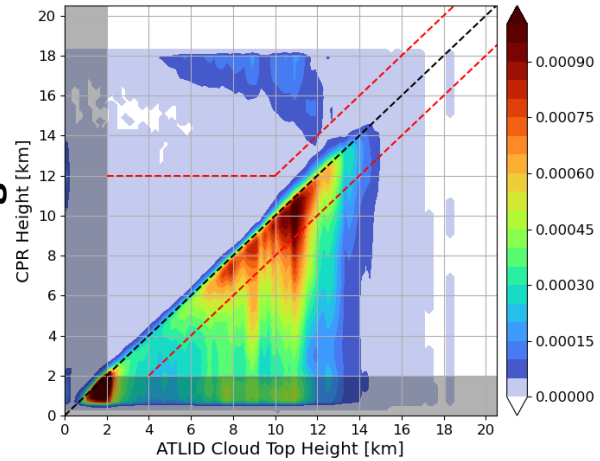
	High mode (20km)	Middle mode (18km)	Low mode (16km)
Before	16.17 %	16.46 %	12.40 %
After mask has applied	0.98 %	0.82 %	0.66 %
Removal rate	94.0 %	95.0 %	94.7 %

The mask works well in every observation mode!

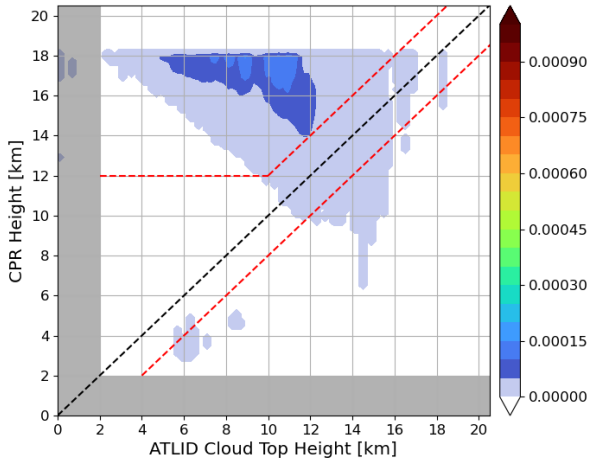
Second-trip echo contamination into cloud echo

- Imura-san's presentation yesterday: The **18 km (middle) mode** can balance the performance of Doppler velocity measurements and upper cloud observation.
- We checked the extent to which second-trip echoes overlap with actual clouds in the 18 km mode.
- Contamination by mirror images can occur when the cloud top is around 12-15 km, but both the frequency and reflectivity are low. If properly removed by masking, its impact is minimal.

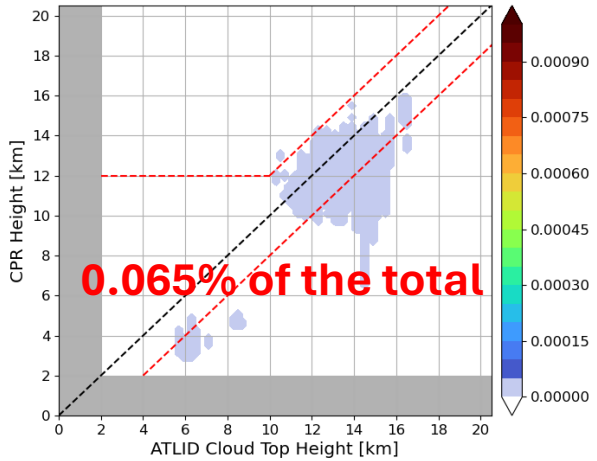
CPR Cloud fraction (relative to total #)



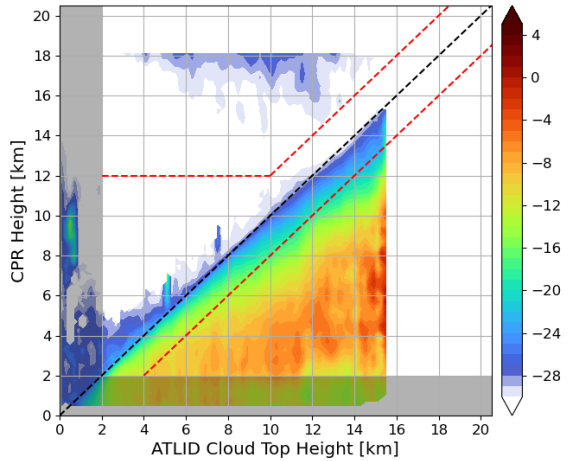
Second-trip echo fraction ($Z_{mirror,mstail}$>-35 dBZ)



Second-trip echo fraction that could not be removed by masking



CPR mean Reflectivity [dBZ]



Summary

- We investigated the characteristics of second-trip echoes observed by EarthCARE/CPR and the performance of mirror echo flag in CPR_ECO (JAXA L2a) using ATLID.
- It was confirmed that echo removal using masking was generally successful.
- No significant difference in removal performance was observed between the 20 km, 18 km, and 16 km modes.
- An investigation of the overlap between false echo and actual cloud echo in the 18 km mode showed that the ratio was quite small.

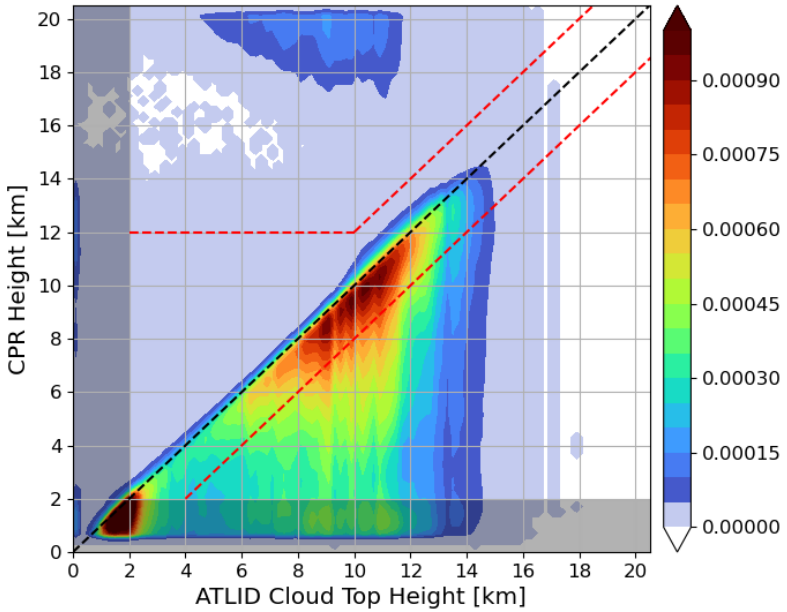
→ Support the use of 18km mode

Supplements

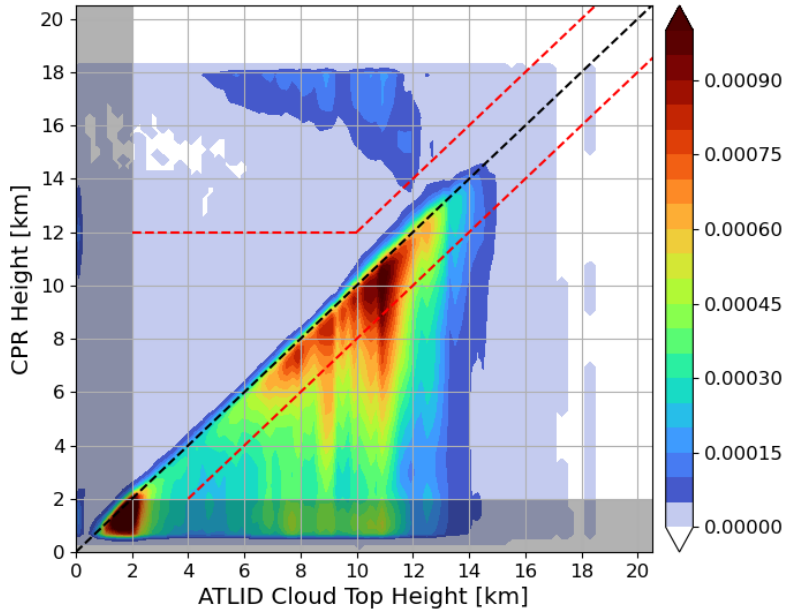
CPR-ATLID cloud top comparison for different observation mode (Before)

- Same as page 8 but for CPR cloud fraction

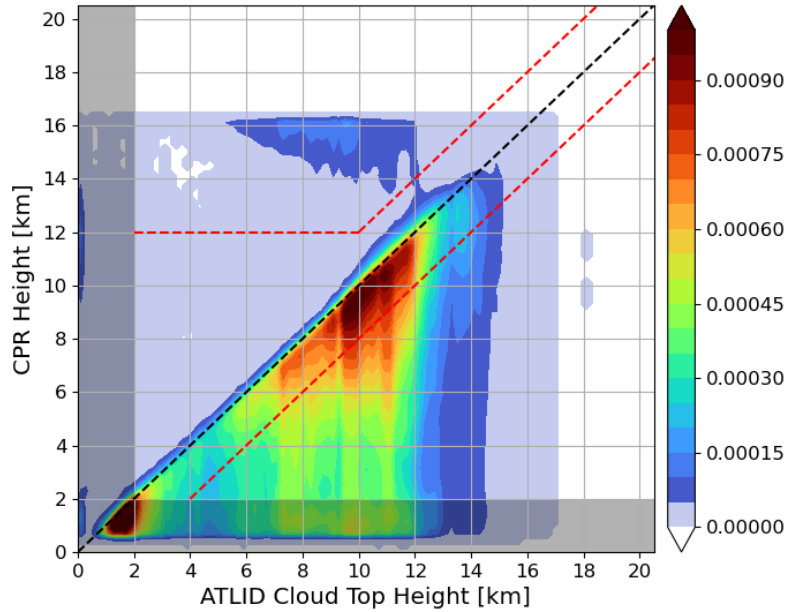
High mode (20km)
2024/11/1 – 11/5
Frame 2428 – 2502



Middle mode (18km)
2024/11/9 – 11/12
Frame 2553 – 2606



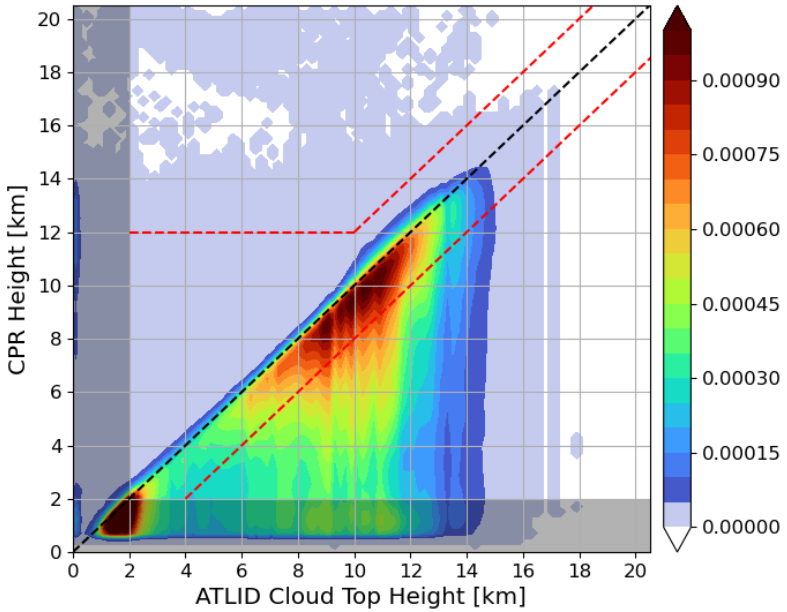
Low mode (16km)
2024/11/5 – 11/8
Frame 2504 – 2551



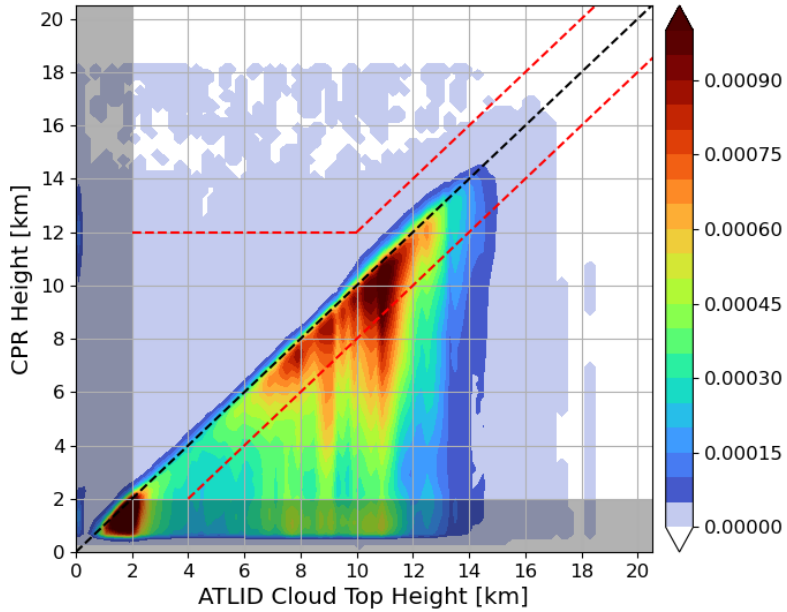
CPR-ATLID cloud top comparison for different observation mode (After the mask has applied)

- Same as page 9 but for CPR cloud fraction

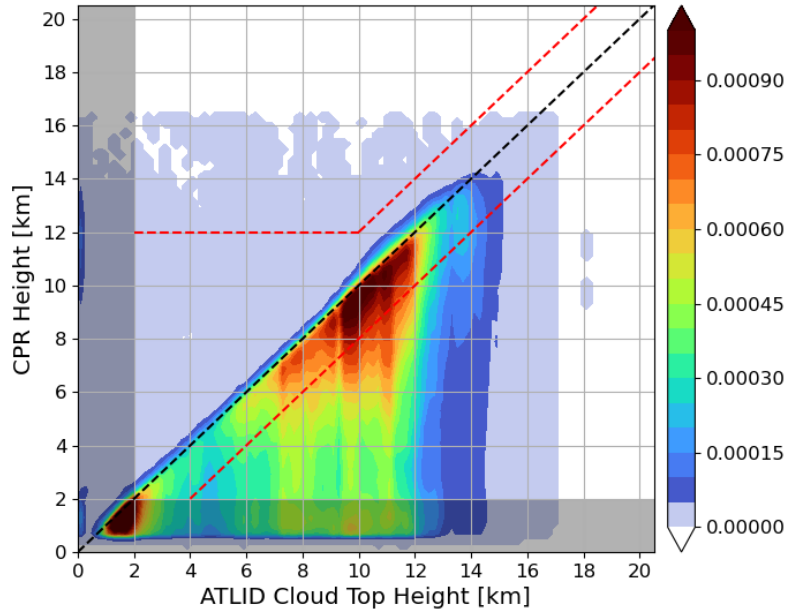
High mode (20km)
2024/11/1 – 11/5
Frame 2428 – 2502



Middle mode (18km)
2024/11/9 – 11/12
Frame 2553 – 2606



Low mode (16km)
2024/11/5 – 11/8
Frame 2504 – 2551



Method: modelling of mirror images

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

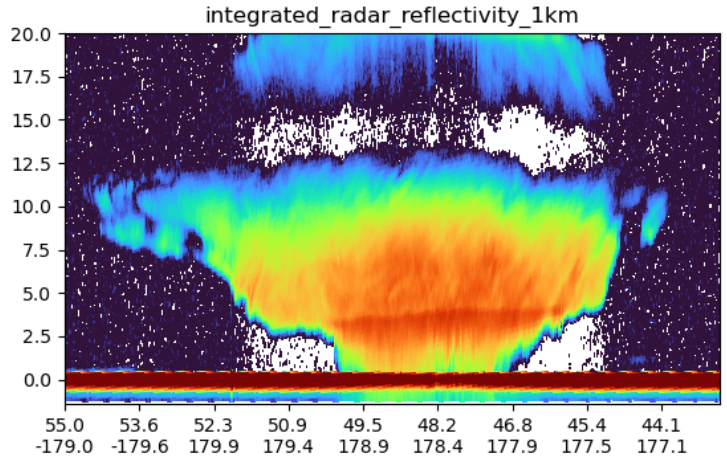
Sensitivity difference due to range distance

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

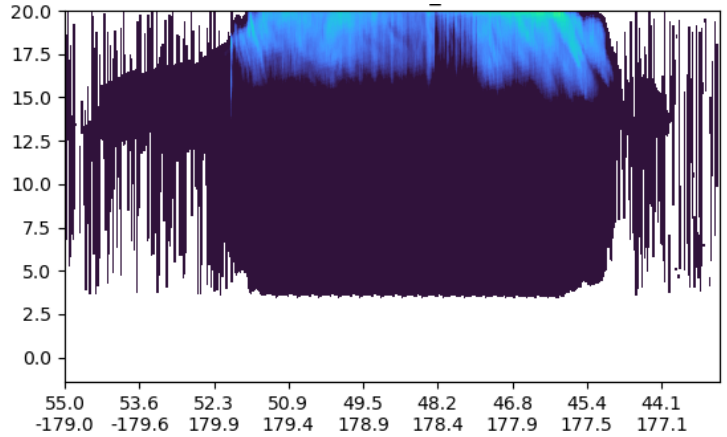
The specular reflection property of the surface of water
In the case of land, add −20dB because the dissipation is large.

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)



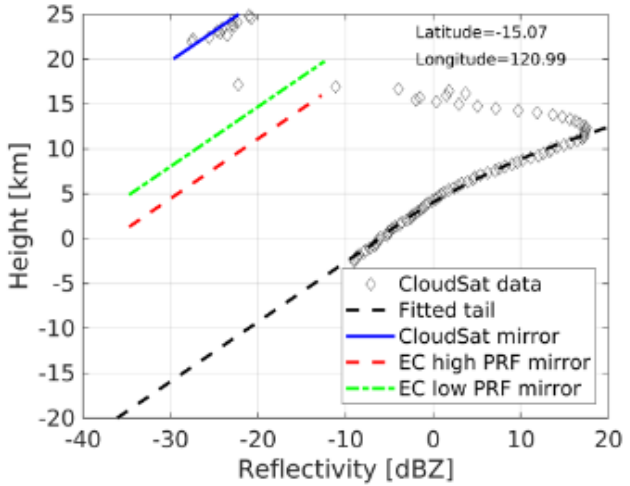
Method: modelling of MS tails

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

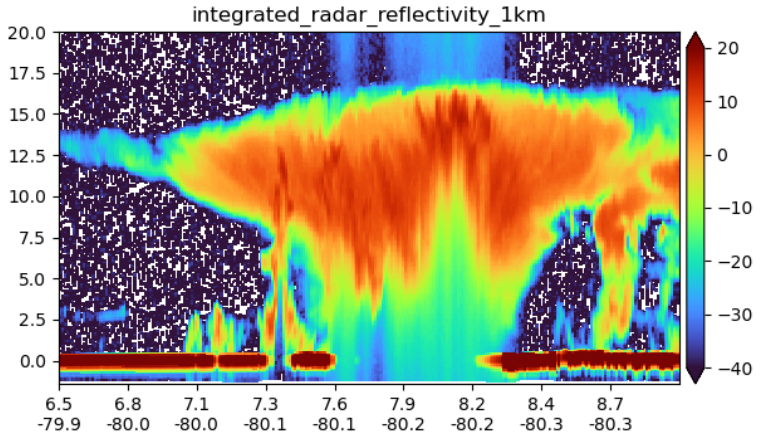
$$f(z) = A + B\exp(Cz),$$

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.

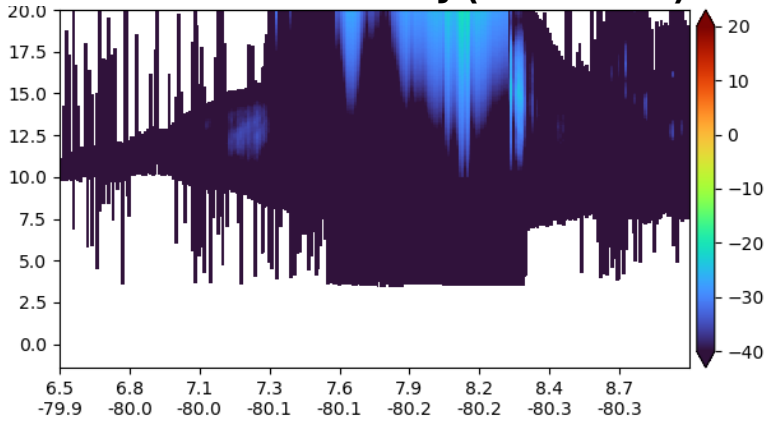


MS tails modeling for CloudSat (Battaglia 2021)

Radar reflectivity (measured)

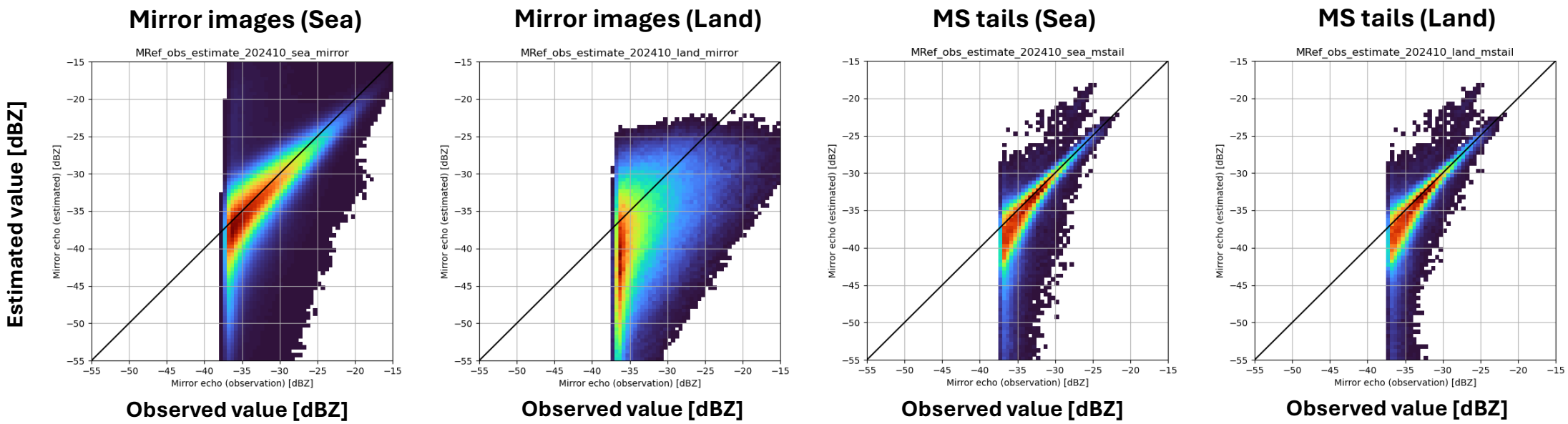


MS tail's reflectivity (estimated)



Results: 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.