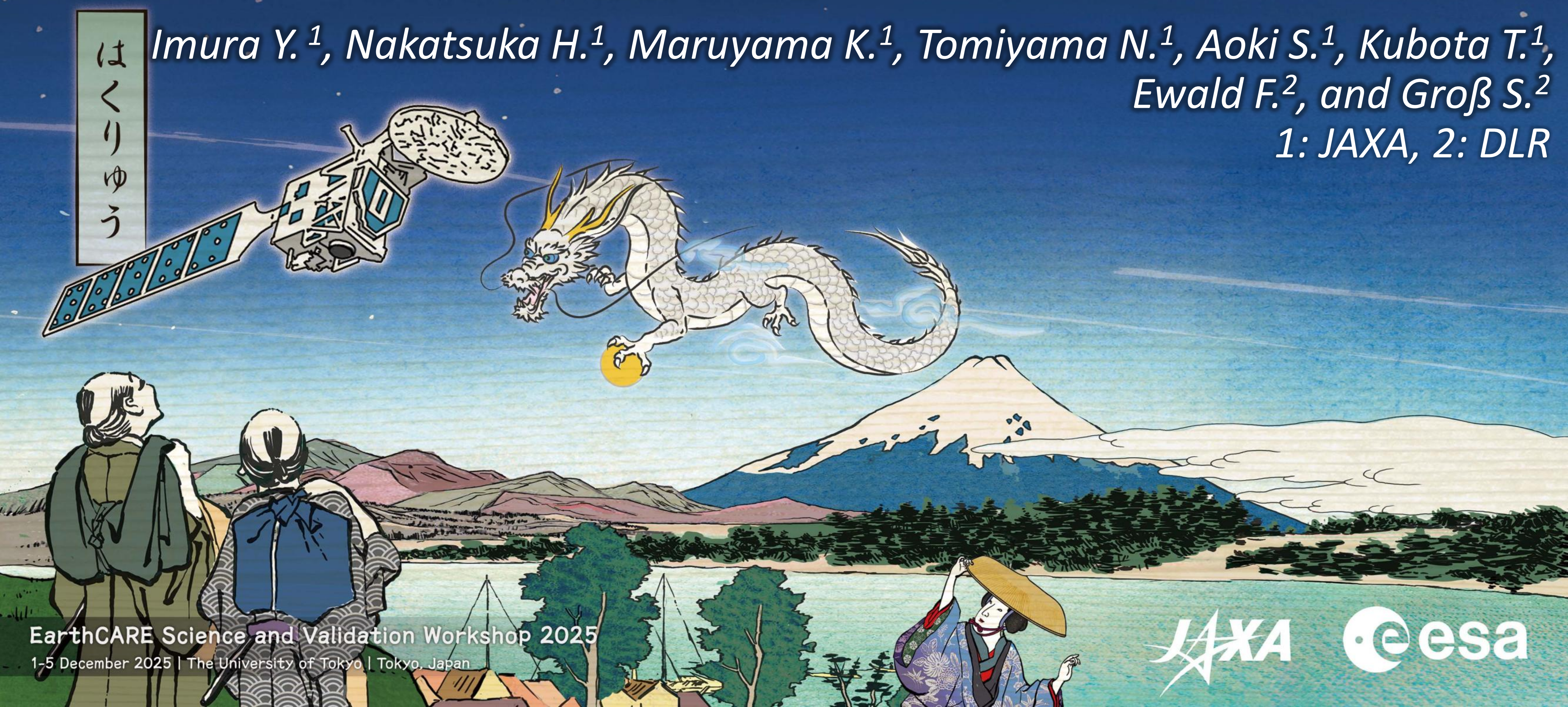
CPR L1b validation activity with DLR HALO/MIRA Doppler observations

Imura Y.[1], Nakatsuka H.[1], Maruyama K.[1], Tomiyama N.[1], Aoki S.[1], Kubota T.[1], Ewald F.[2], and Groß S.[2]

1: JAXA, 2: DLR



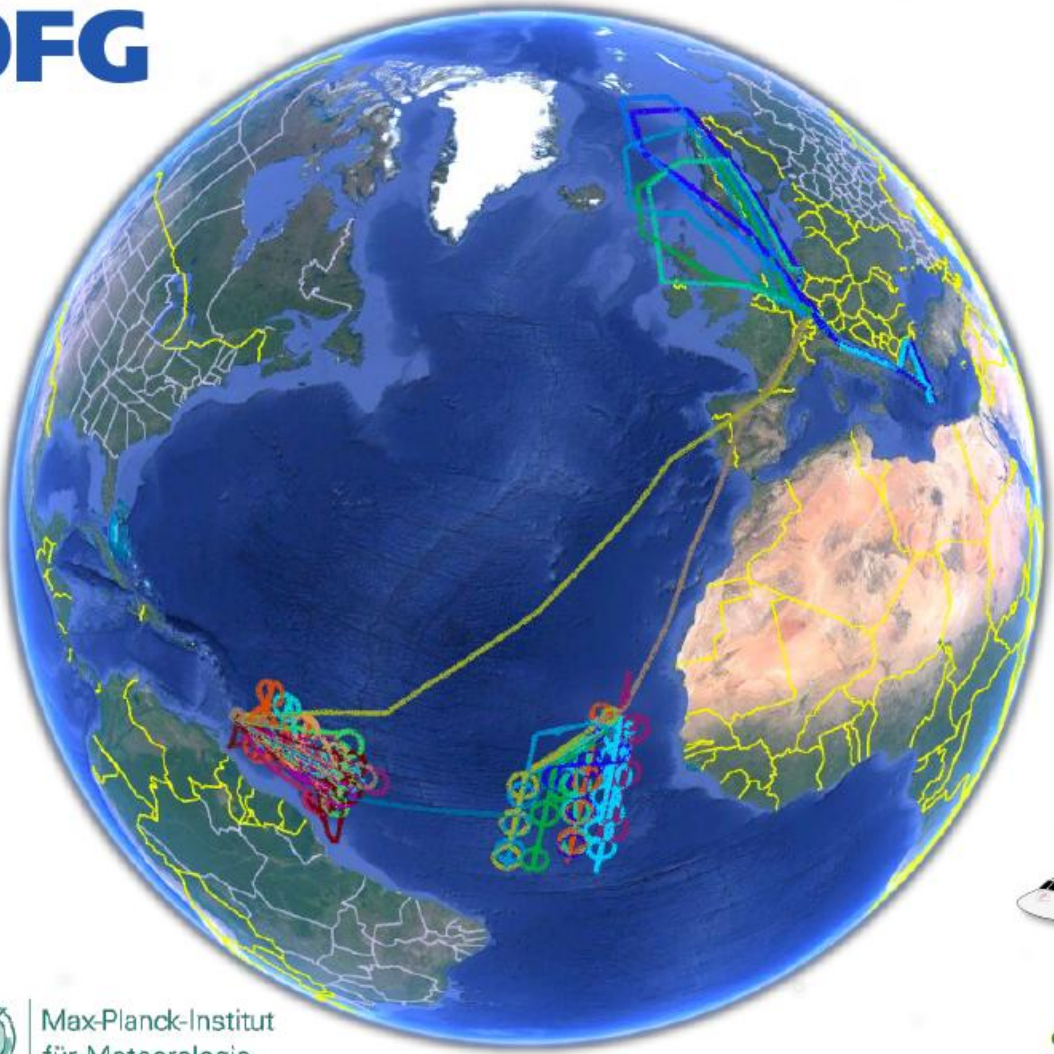
EarthCARE Science and Validation Workshop 2025
1-5 December 2025 | The University of Tokyo | Tokyo, Japan

CPR L1b Validation Activity

- Validation of the CPR L1b product is being conducted by JAXA and NICT using observations from ground-based and aircraft-borne cloud radars that operate in coordination with EarthCARE underflights (e.g., WINDAS; Kato et al., 2003, HG-SPIDER; Horie et al., 2000, HALO/HAMP; Ewald et al., 2019).
- These validation activities are essential for assessing CPR observation performance, including the measurement accuracy of cloud Doppler velocity that is first observed from space.
- This presentation introduces preliminary results from a direct comparison between CPR and an aircraft-borne radar (MIRA onboard the HALO aircraft) to investigate the statistical biases in CPR measurements.

PERCUSSION — A campaign with a focus on validation
Persistent EarthCARE underflight studies of the ITCZ and organized convection

DFG



Campaign period

09 Aug – 19 Nov 2024

Campaign locations

- Cape Verde / Sal: ITCZ, Aerosol
- Barbados: ITCZ, Convective organization
- Germany: Dedicated validation flights

PERCUSSION

ORCESTRA

Campaign duration – 9 weeks

- 296 flight hours (incl. transfer and certification)
- 28 Scientific flights: 11 (Sal), 10 (Barbados), 7 (Germany)
- 33 EarthCARE / 4 PACE underpasses
- Embedded within the *ORCESTRA* campaign:

MAESTRO
SAFIRE ATR-42

CELLO
INCAS King Air

BOW-TIE / PICCOLO
RV METEOR / SEA-Pol

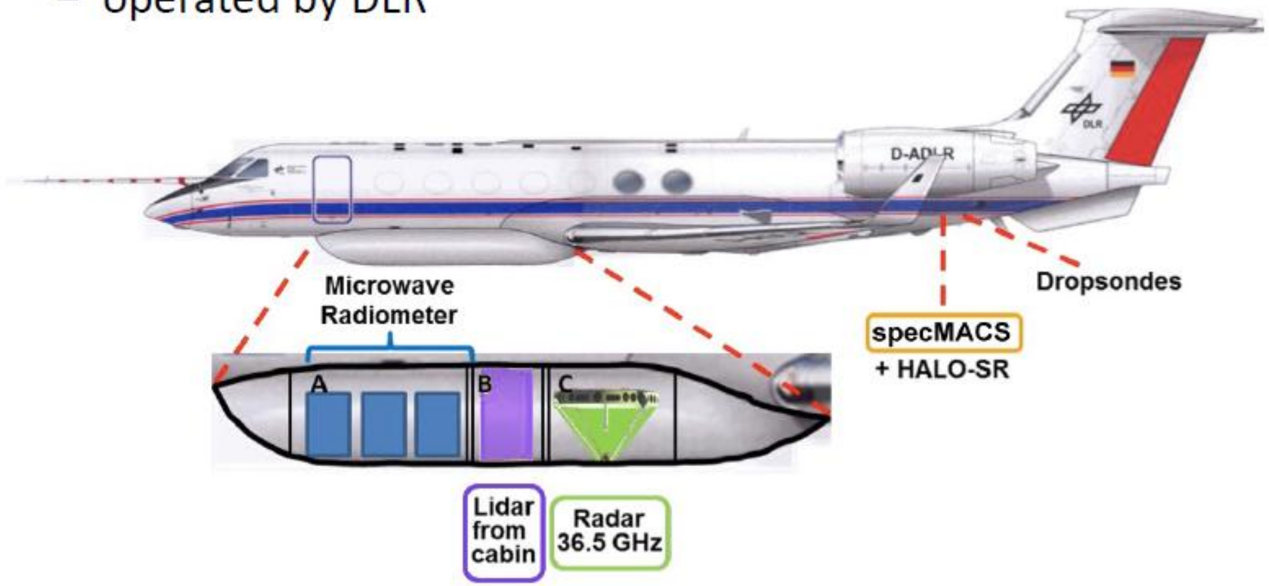
Max-Planck-Institut für Meteorologie

*Source: LPS 2025 presentation, Florian Ewald

DLR

The platform — the High Altitude and Long Range Aircraft
The HALO remote sensing payload — a unique validation asset

- G550, max. alt 15 km / max. range: 8000 km
- In operation since 2012
- operated by DLR



Scientific Instruments

HSRL-Lidar (WALES, 532 nm – Wirth et al. 2009)

Cloud Radar (HAMP MIRA, 35 GHz – Ewald et al. 2019)

Hyper-Spektral Imager (specMACS – Ewald et al. 2016)

Microwave Radiometer (HAMP passive – Mech et al. 2014)

✓ MIRA observes Doppler velocity from aircraft

✓ Off-nadir angle and aircraft motion corrected

Specification of MIRA and CPR

	HALO/MIRA	EarthCARE/CPR
Frequency	35.2 GHz	94.05 GHz
Pulse Power	30 kW	1.5 kW
Repetition rate	7.5 kHz	6.1-7.5 kHz
Antenna diameter	1 m	2.5 m
Beam width	0.6°	< 0.095°
Min. detect. Signal @10 km	−42 dBZ	< −35 dBZ

*Source: LPS 2025 presentation, Florian Ewald

Sensitivity correction of MIRA radar reflectivity

- MIRA operates at the Ka-band, while CPR operates at W-band.
  ⇒A correction is required to match their sensitivities to cloud particles.

- The radar reflectivity factor Z for both MIRA and CPR is defined as:

$$Z = \frac{\eta\lambda^4}{\pi^5|K|^2} \ (\eta\text{: radar reflectivity}, \lambda\text{: wavelength}, K\text{: normalizing dielectric factor})$$

- $|K|^2$ is 0.93 for MIRA, and 0.75 for CPR.
  ⇒To account for this difference, we apply a *K*-value correction to MIRA's radar reflectivity factor:

$$Z \propto |K|^{-2} \ \Rightarrow \ Z_W = Z_{Ka} + 10\log_{10}\left(\frac{|K_{Ka}|^2}{|K_W|^2}\right) \ (dBZ)$$

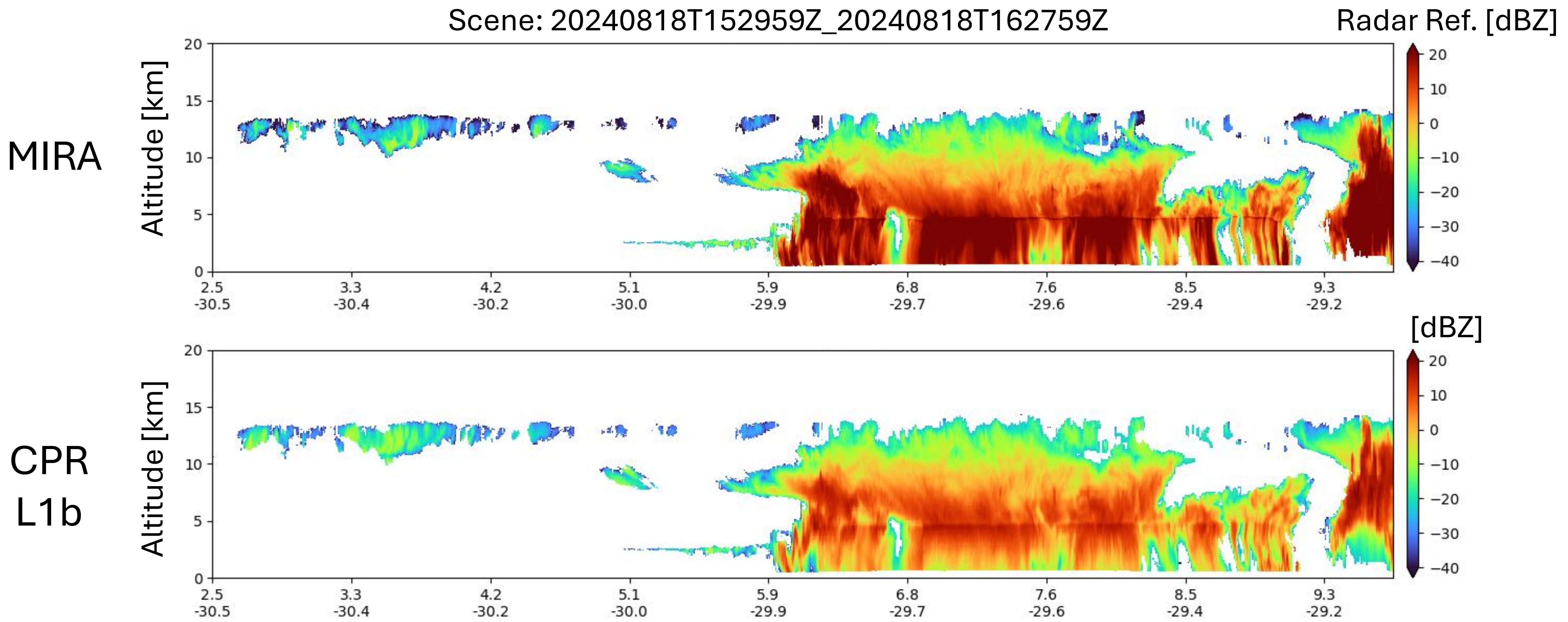
- Substituting the values $|K_{Ka}|^2 = 0.93$ and $|K_W|^2 = 0.75$:

$$Z_W \sim Z_{Ka} + 0.93 \ (dBZ)$$

- Focused on regions below 253 K, where ice clouds are dominant and *K*-value is stable.

Case study of comparison btw CPR and MIRA
Case of tropical convective cloud

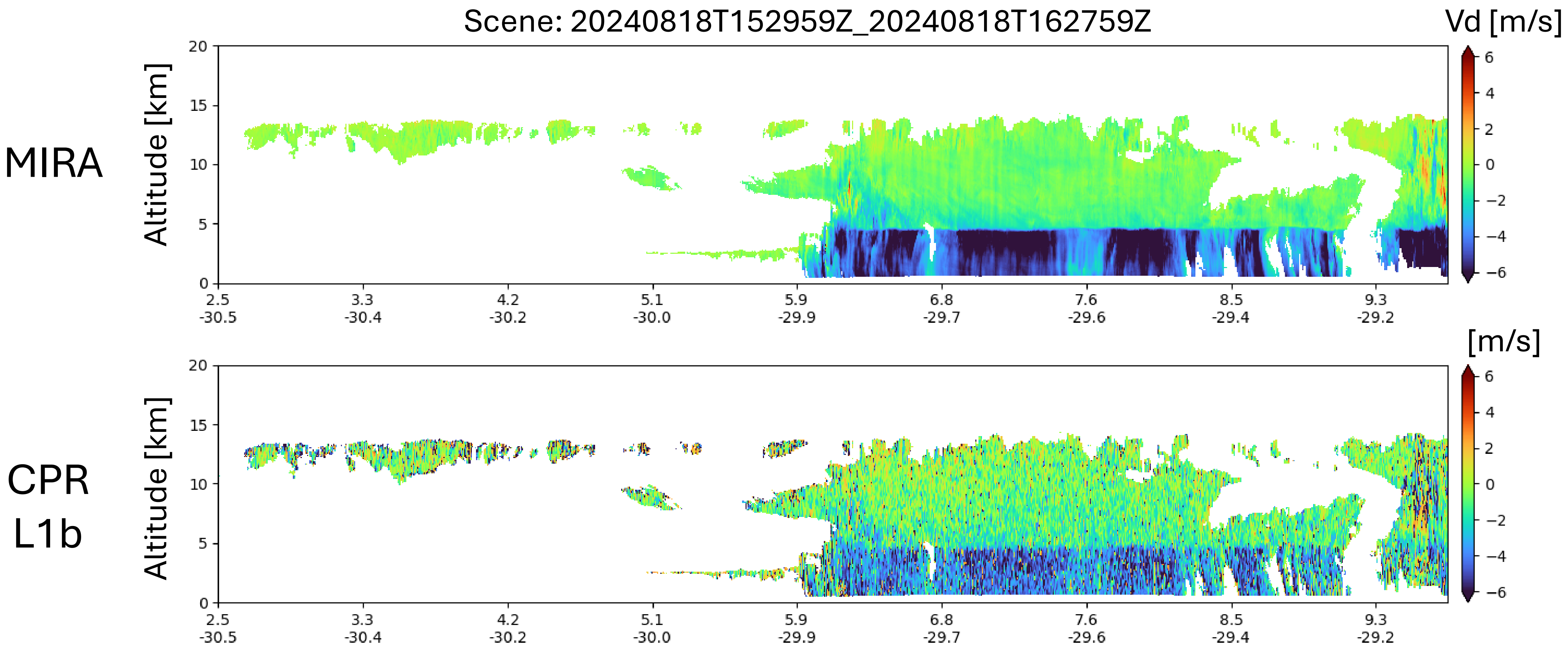
- Display only the cloud regions detected by both CPR and MIRA.
- CPR and MIRA show very good agreement in detecting mid- to high-level ice cloud regions.



*The upper and lower ticks on the horizontal axis indicate latitude and longitude, respectively
*Horizontally integrated at 500 m

Case study of comparison btw CPR and MIRA
Case of tropical convective cloud

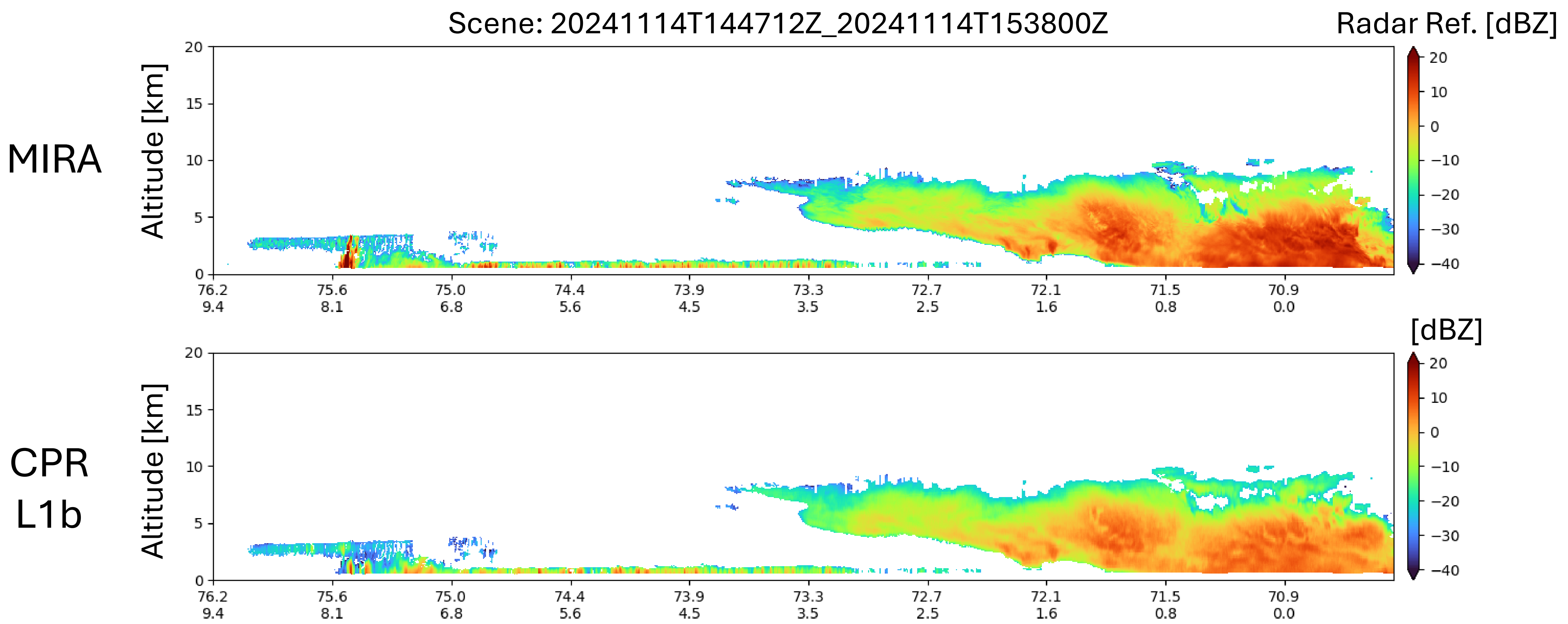
- Display only the cloud regions detected by both CPR and MIRA.
- CPR Doppler is noisier, but well captures the vertical structure of Doppler velocity.



*The upper and lower ticks on the horizontal axis indicate latitude and longitude, respectively
*Horizontally integrated at 500 m

Case study of comparison btw CPR and MIRA
Case of stratiform ice cloud in polar regions

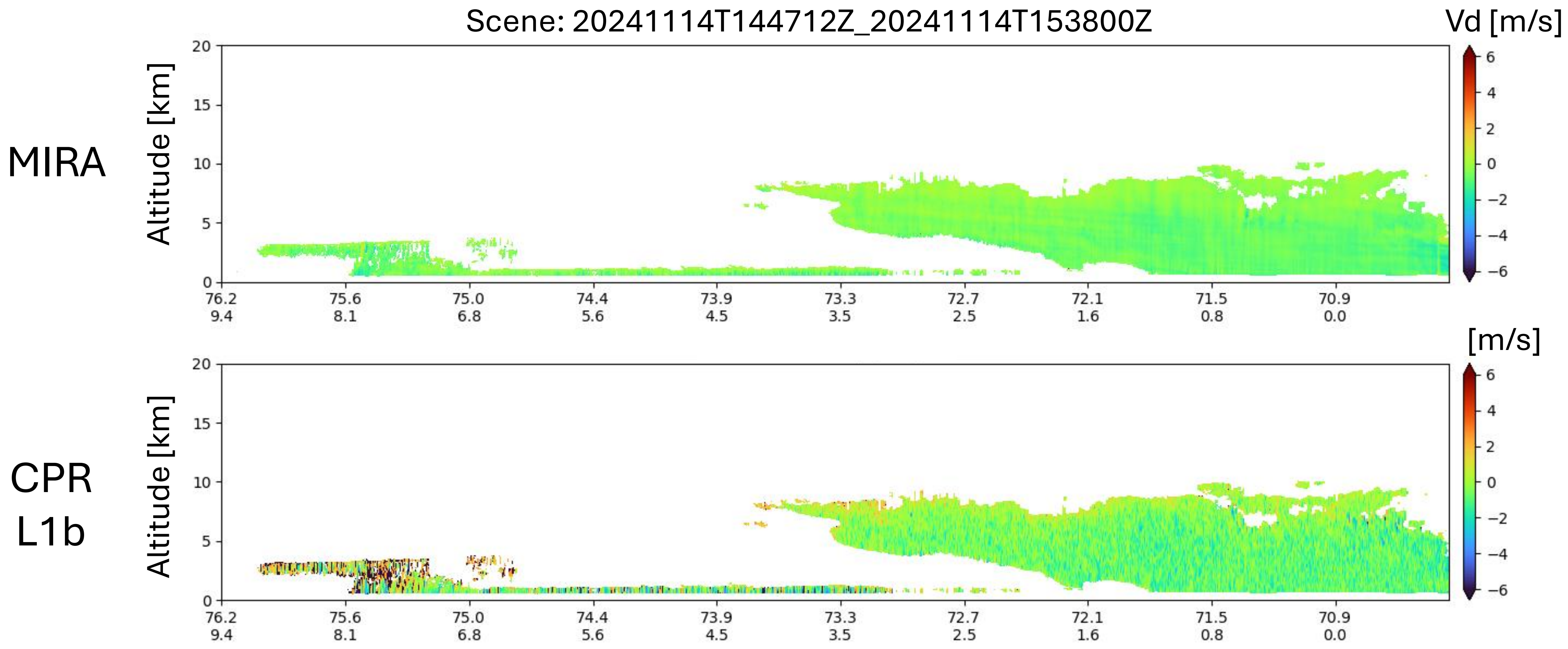
- Display only the cloud regions detected by both CPR and MIRA.
- CPR and MIRA show very good agreement in detecting stratiform ice cloud regions.



*The upper and lower ticks on the horizontal axis indicate latitude and longitude, respectively
*Horizontally integrated at 500 m

Case study of comparison btw CPR and MIRA
Case of stratiform ice cloud in polar regions

- Display only the cloud regions detected by both CPR and MIRA.
- CPR Doppler is noisier, but well captures the vertical structure of Doppler velocity.

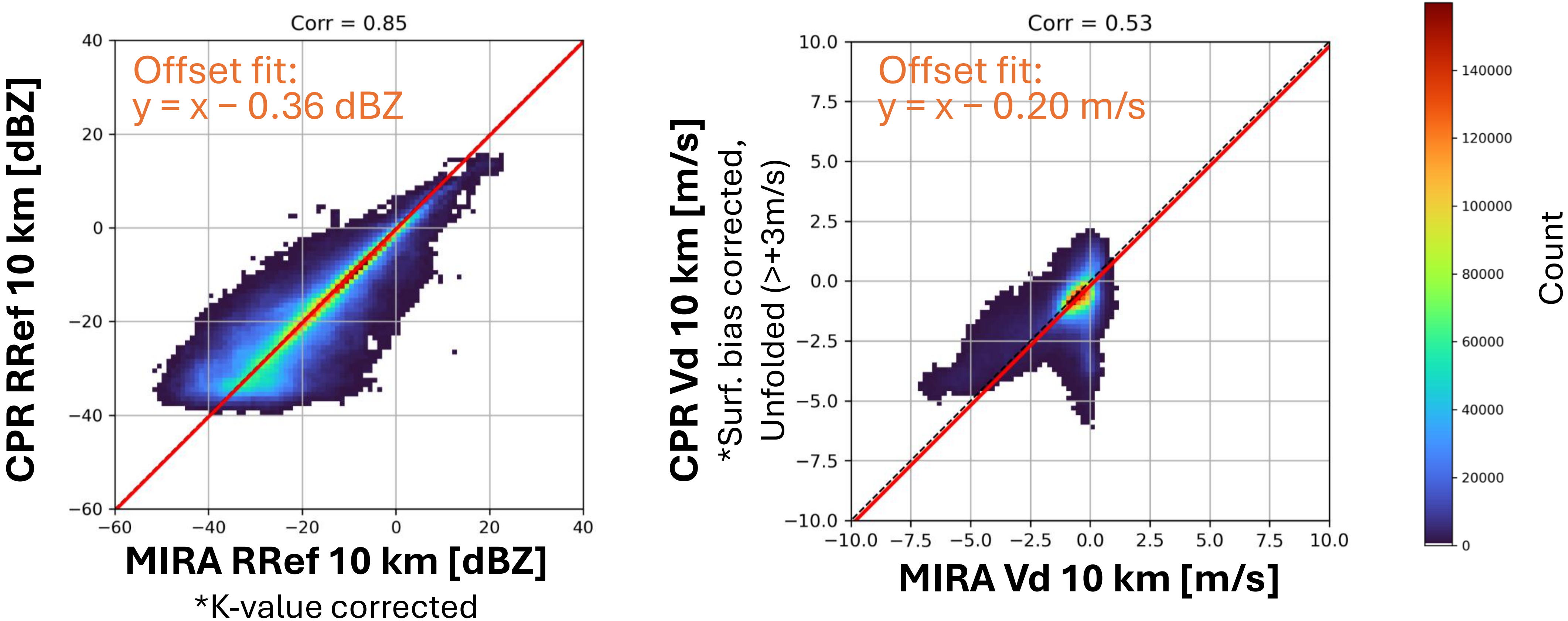


*The upper and lower ticks on the horizontal axis indicate latitude and longitude, respectively
*Horizontally integrated at 500 m

Consistency of radar reflectivity and Doppler velocity

- Radar reflectivity and Doppler velocity from CPR and MIRA show very good agreement.
- In the high Doppler velocity, CPR Vd tends to be underestimated compared to MIRA Vd.
  ⇒ Likely due to Mie-effects, larger raindrops with higher fall speeds contribute less to the average Vd at W-band causing the difference between Ka- and W-band in rain.

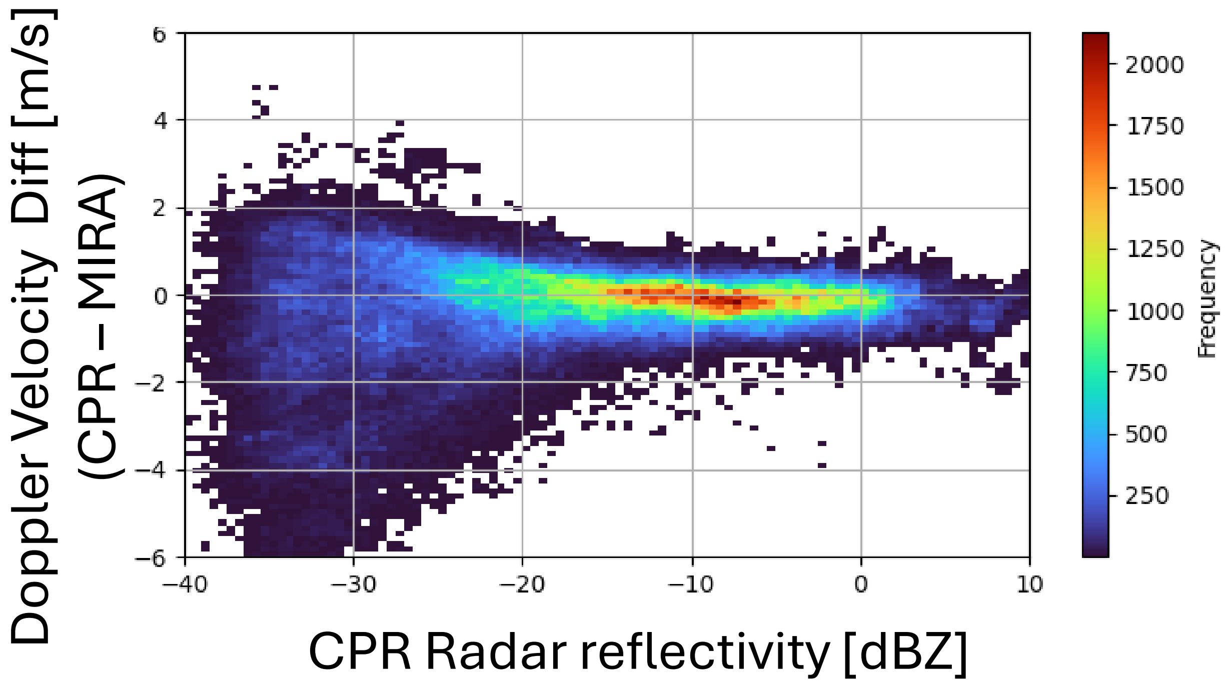
*Focusing on regions below 253 K

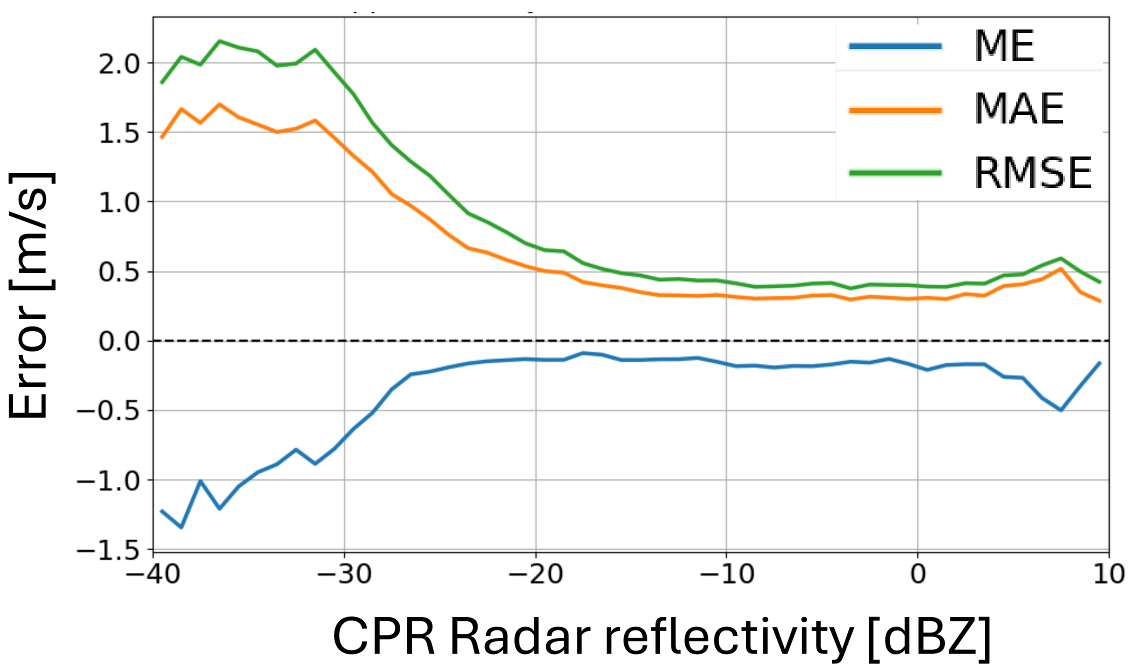


Doppler velocity difference relative to reflectivity

- The CPR Doppler velocity generally shows a negative bias relative to MIRA Doppler velocity.
- At higher radar reflectivity, deviations of Doppler difference become smaller.

  ⇒ Indicating higher measurement accuracy due to a higher S/N ratio.



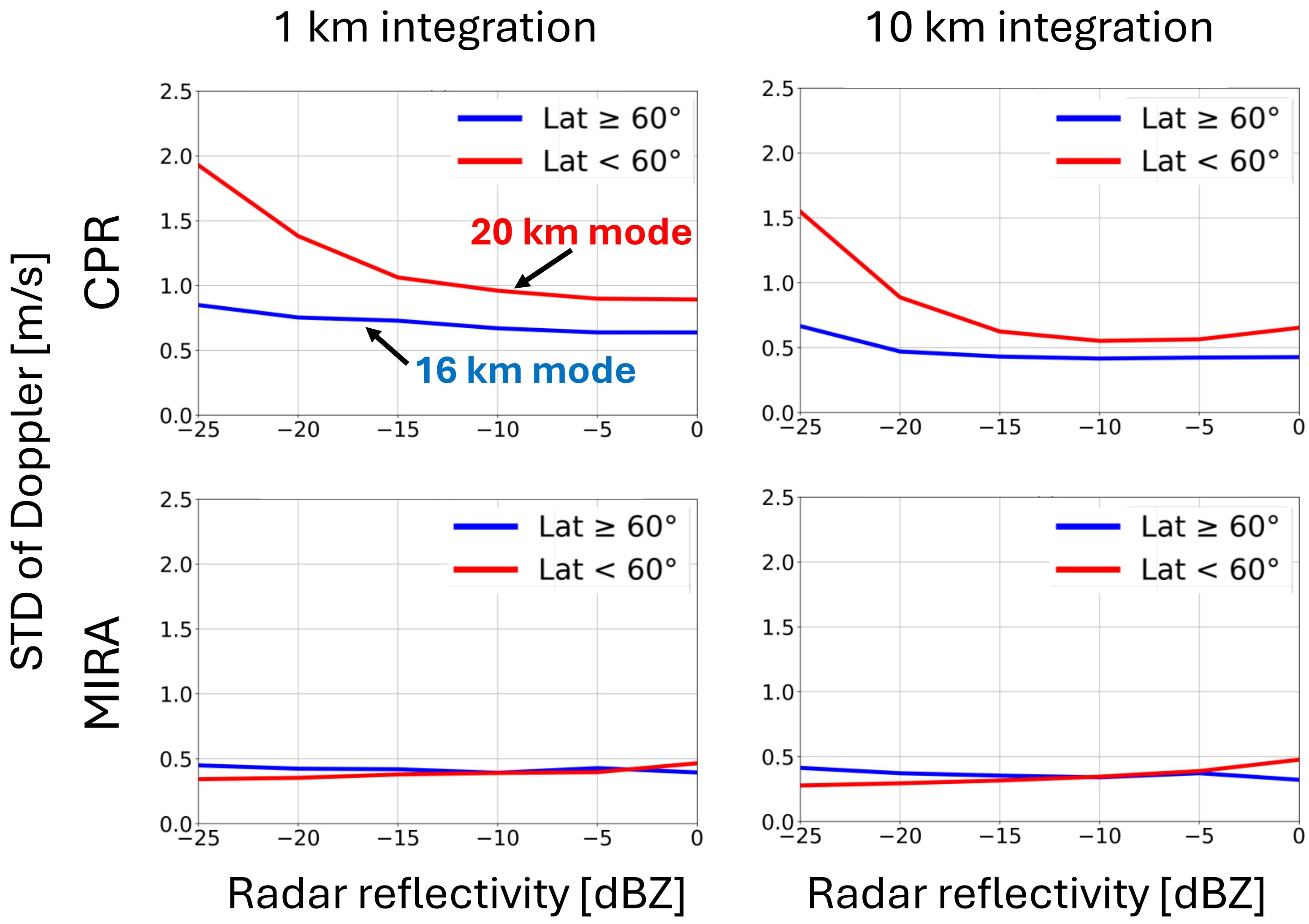


*Focusing on regions below 253 K

Standard deviation of Doppler velocity

- The standard deviation (STD) of CPR Doppler velocity decreases as radar reflectivity increases, owing to the reduction of random errors within the beam width as S/N ratio improves.

- The STD for MIRA is generally much lower than that for CPR, which is mainly attributed to its larger number of pulses sampling the same footprint, which reduces random noise by a factor of two compared to CPR. Therefore, MIRA's STD is closer to the natural atmospheric variability.

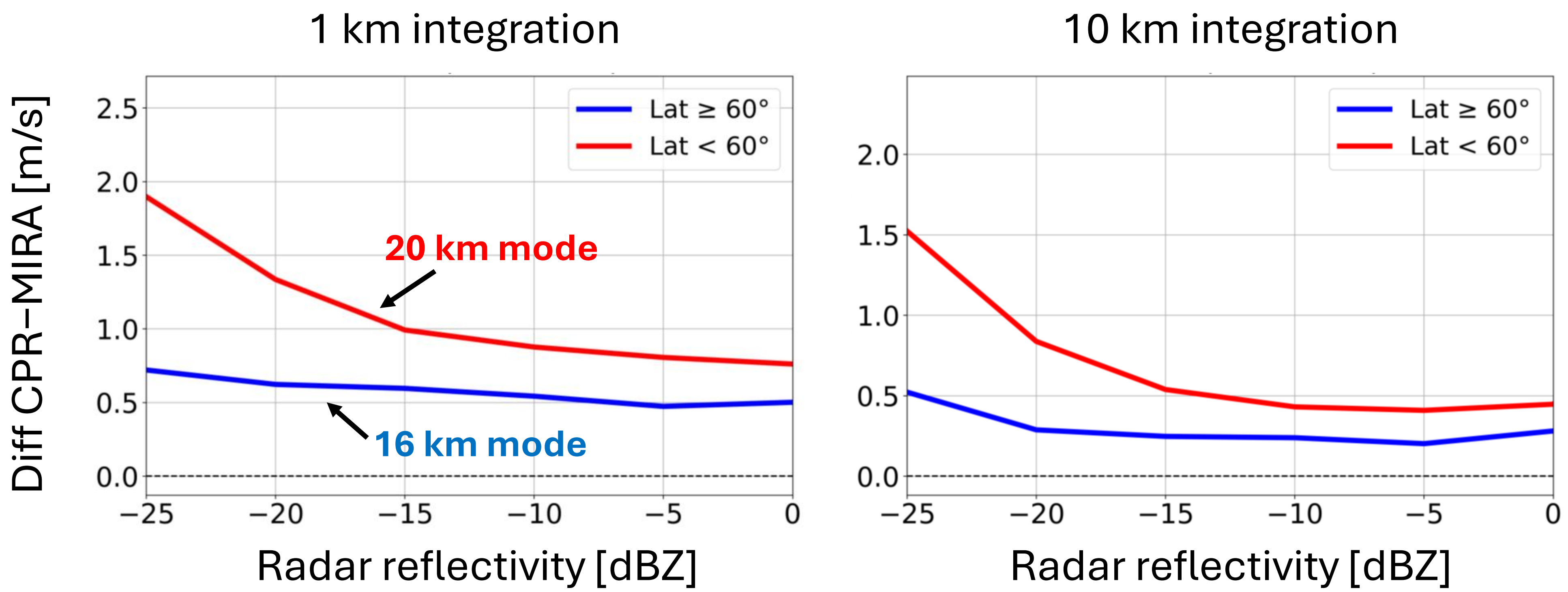


Standard deviation of Doppler velocity

- To remove the contributions of natural variability included in the CPR Doppler STD, we calculate the difference of Doppler STD between CPR and MIRA as follows:

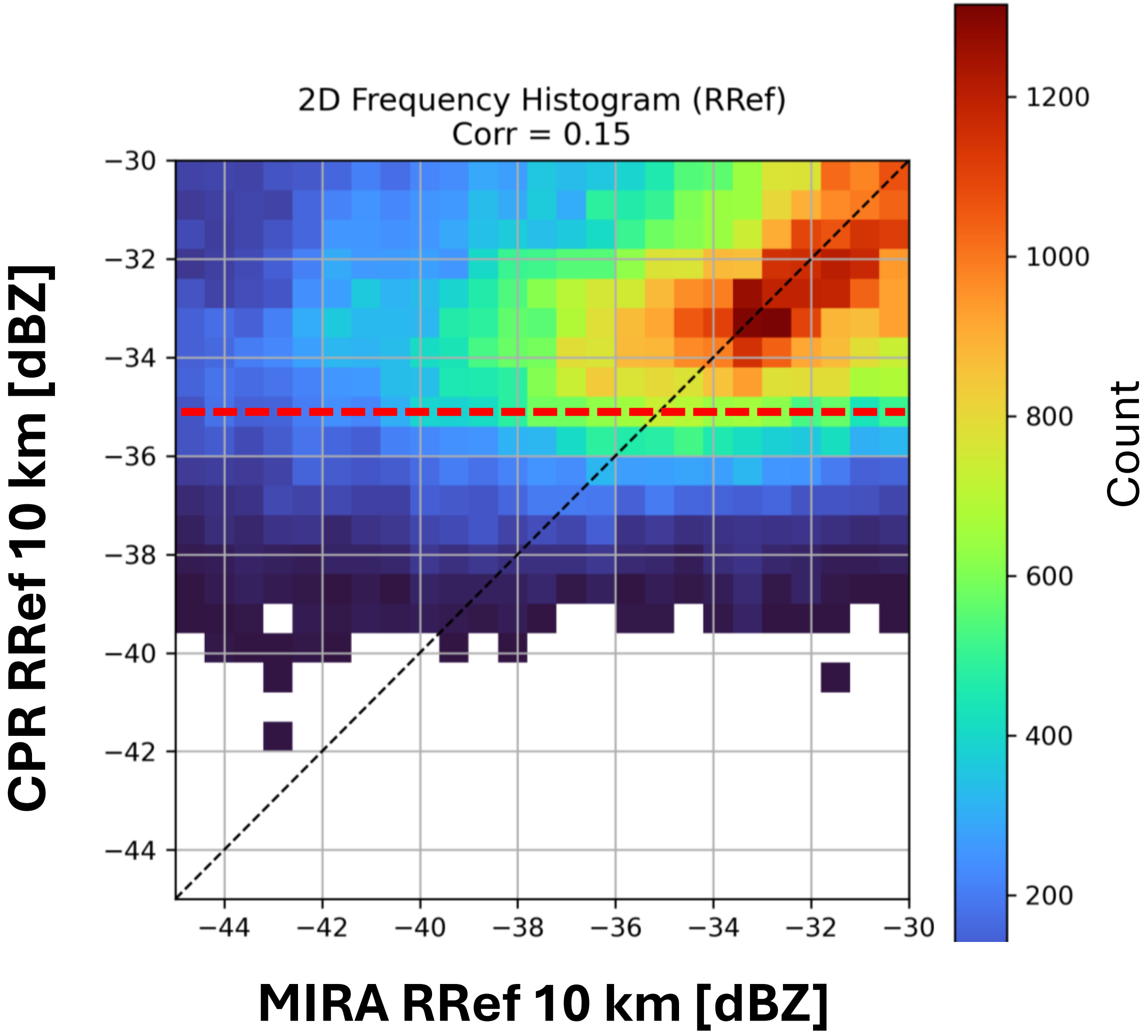
$$STD\ Diff = \sqrt{STD_{CPR}^2 - STD_{MIRA}^2}$$

- Assuming that MIRA captures the natural variability, the values in the bottom figures approximately represent the random errors arising from the spread of Doppler velocities within the CPR beam width.



Evaluation of cloud detectable sensitivity of CPR

- Evaluated minimal detectable sensitivity of CPR by comparing with MIRA.
  *Mission requirement: The sensitivity of the observed signal is defined as −35 dBZ at the TOA at 10 km integration.
- The right figure indicates that CPR is likely capable of detecting clouds with −35 dBZ.
- However, it is difficult precisely to determine the magnitude of minimum sensitivity, so we are considering an alternative analysis method.



*K-value corrected

Summary

- CPR L1b was validated through direct comparison with the MIRA radar onboard the HALO aircraft.
- CPR radar reflectivity and Doppler velocity show good agreement with MIRA, with mean offsets of –0.36 dBZ and –0.20 m/s, respectively.
- The Doppler STD from CPR can be more appropriately interpreted as random error when referenced to MIRA measurements.
- The minimal sensitivity of CPR appears to be far better than –35 dBZ, although further investigation is required to quantify the sensitivity.

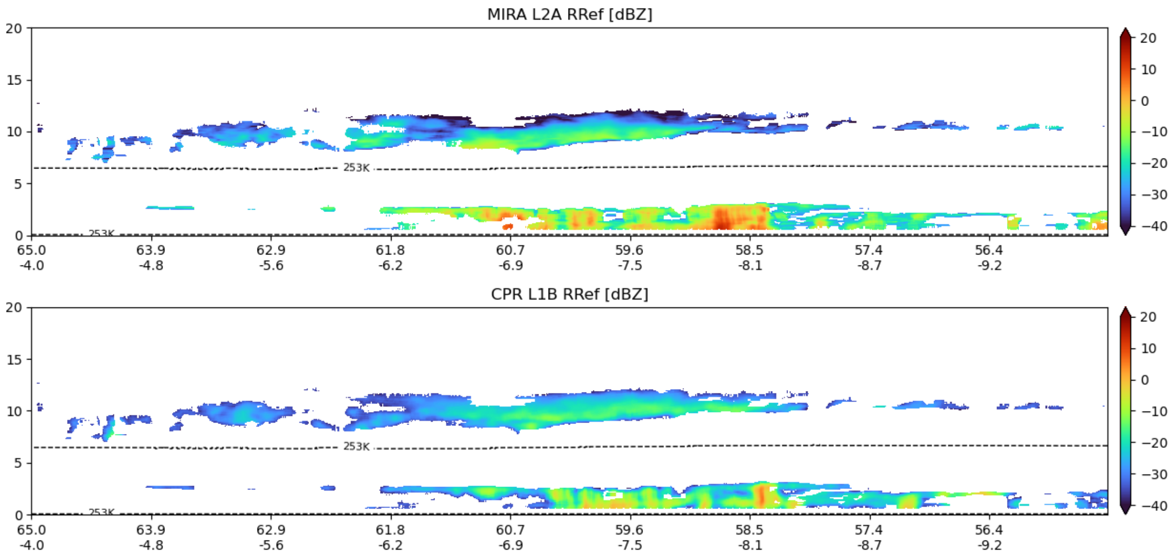
Appendix: Case study to evaluate CPR Doppler accuracy

- Mission requirement: Doppler Velocity : < 1.3m/s (under uniform clouds with reflectance of – 19 dBZ or more)
- We selected two cases featuring stable, homogeneous ice clouds with reflectivity of near −19 dBZ and temperature below −20℃.

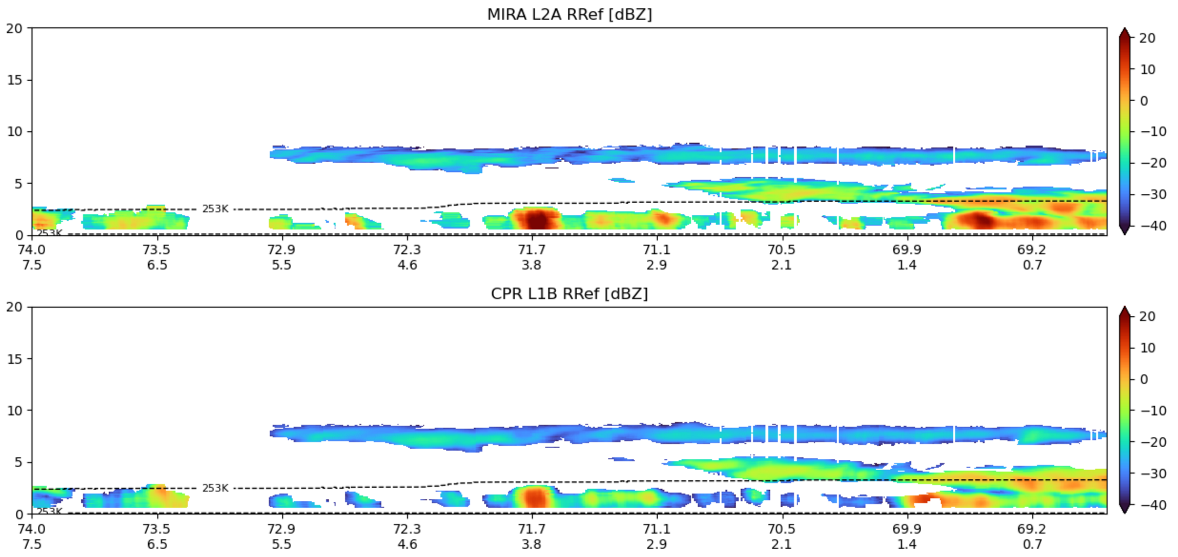
Case 1 | **Case 2**

MIRA

CPR



20241107T151618Z_20241107T164819Z

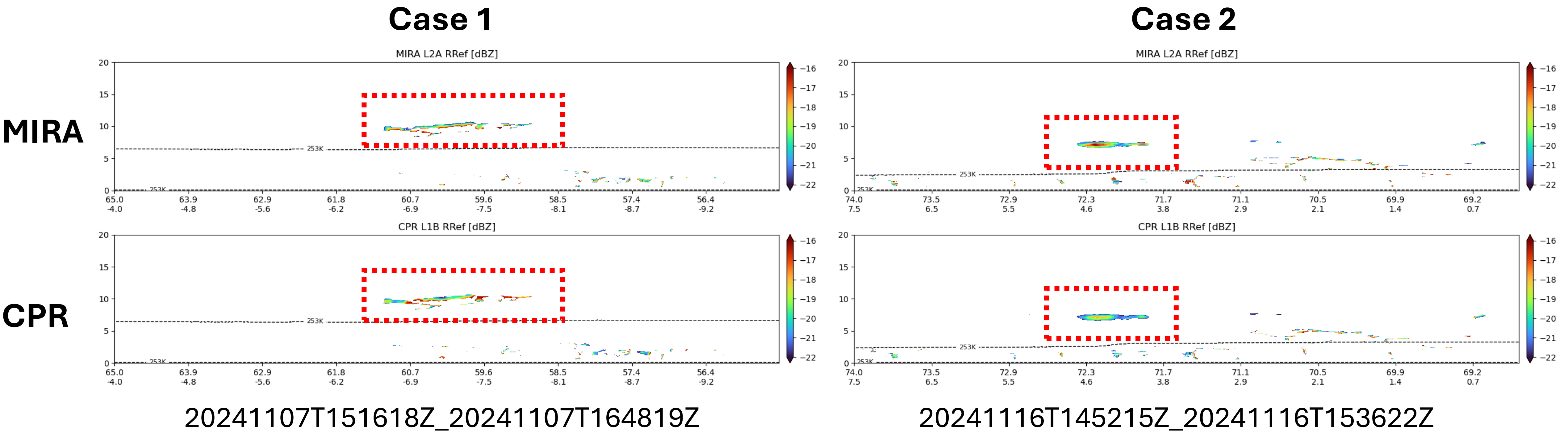


20241116T145215Z_20241116T153622Z

Color: **Radar reflectivity value at 10 km integration**

Appendix: Case study to evaluate CPR Doppler accuracy

- Mission requirement: Doppler Velocity : < 1.3m/s (under uniform clouds with reflectance of – 19 dBZ or more)
- We selected two cases featuring stable, homogeneous ice clouds with reflectivity of near −19 dBZ and temperature below −20℃.



Color: Radar reflectivity value at 10 km integration (−19 dBZ ± 3dBZ)

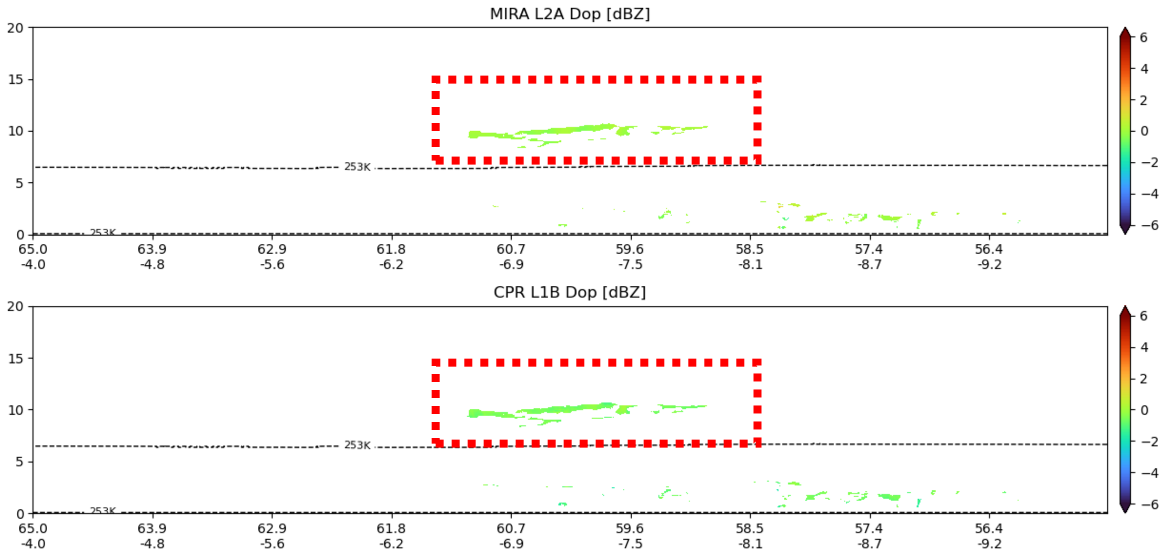
Appendix: Case study to evaluate CPR Doppler accuracy

- Mission requirement: Doppler Velocity : < 1.3m/s (under uniform clouds with reflectance of – 19 dBZ or more)
- We selected two cases featuring stable, homogeneous ice clouds with reflectivity of near −19 dBZ and temperature below −20℃.

Case 1

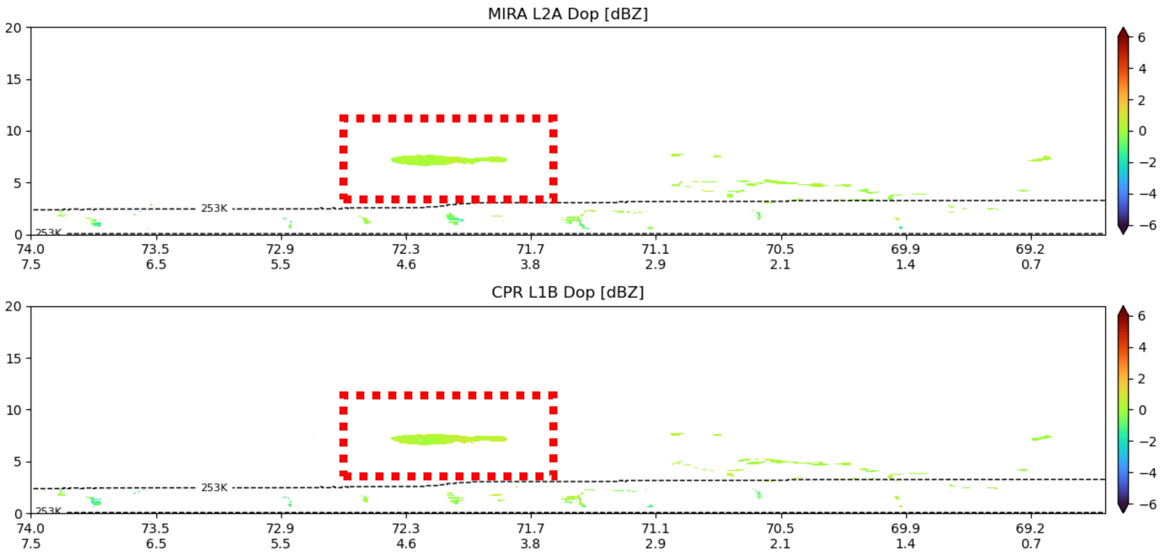
MIRA

CPR



20241107T151618Z_20241107T164819Z

Case 2

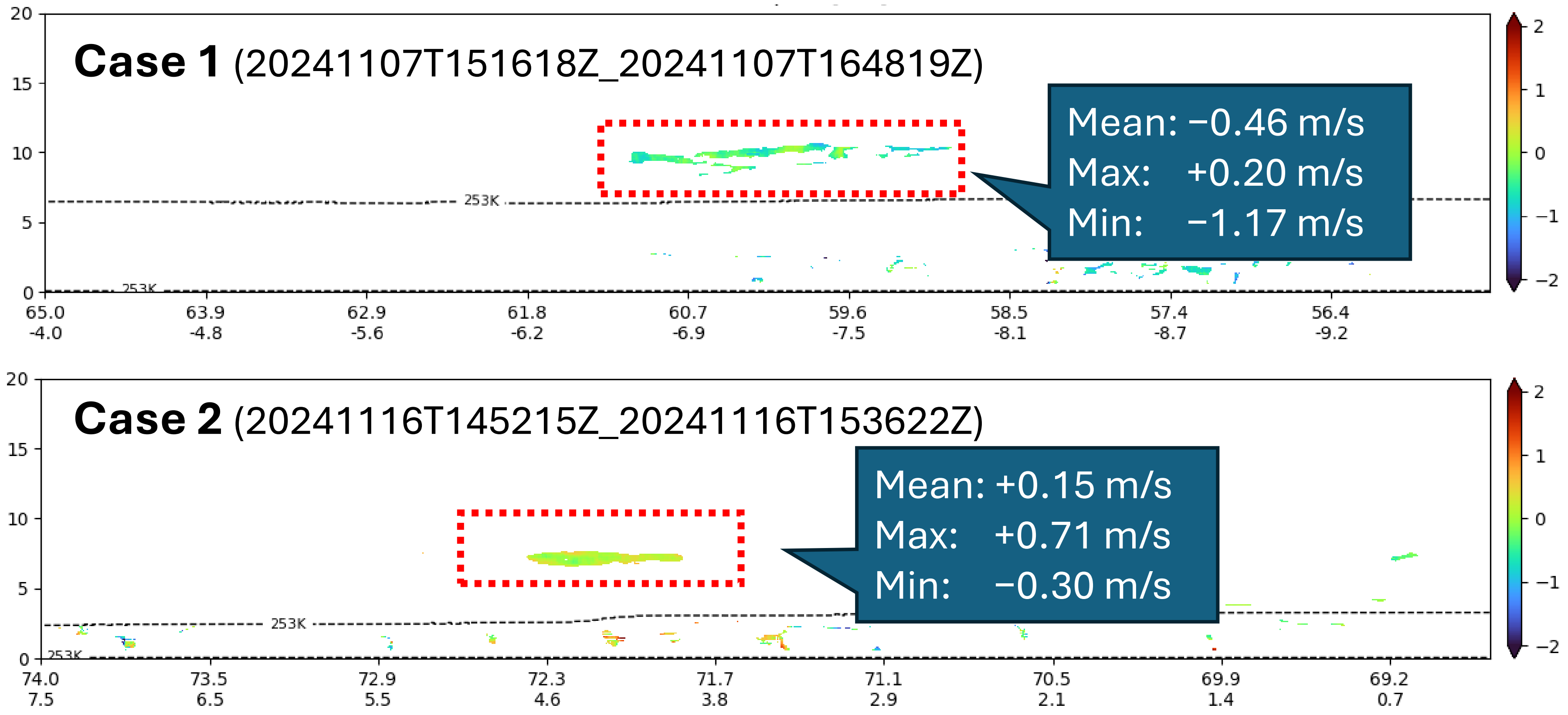


20241116T145215Z_20241116T153622Z

Color: Doppler velocity value at 10 km integration (−19 dBZ ± 3dBZ)

Appendix: Case study to evaluate CPR Doppler accuracy

- We calculated the Doppler velocity differences between CPR and MIRA.
  ⇒Confirmed that they fall within the required Doppler accuracy of 1.3 m/s



Color: Doppler velocity difference between CPR and MIRA [m/s] (−19 dBZ ± 3dBZ)