Validation of the EarthCARE CPR Doppler velocity measurements using surface-based observations

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Background & Motivation

Spaceborne Doppler radar observations can offer global observations of Doppler velocities, thus providing an unprecedented opportunity to help constraint weather and climate models.

In stratiform cloud systems, the CPR Doppler velocity can be used to estimate the hydrometeors characteristic size (i.e., mean volume-weighted diameter D_m) and/or their rime mass fraction.

In raindrops, an error of 0.2 ms^{-1} translate to an error of 0.05 and 0.15 mm, respectively, for D_m values less 0.8 than and greater than 0.8 mm.
(*Kollias et al., 2022, Front. Remote Sens.*)

In rimed particles, an error of 0.2 ms^{-1} translates to an error of 15% in the estimation of rime mass fraction.
(*Kneifel and Moisseev, 2020, J. Atmos. Sci.*)

Background & Motivation

- **High platform speed (~7.6 km/s)** introduces various **uncertainties and biases**

Doppler spectrum broadening (3.6-3.8 m/s) due to **high platform speed**

+ weak backscatter (low SNR) → **uncertainties**
+ non-uniform beam filling (NUBF) → **biases**
+ velocity folding (aliasing) → **biases** when true velocity exceeds V_{Nyq}

Antenna pointing errors from star tracker sampling, AOCS limitations and thermoelastic distortions

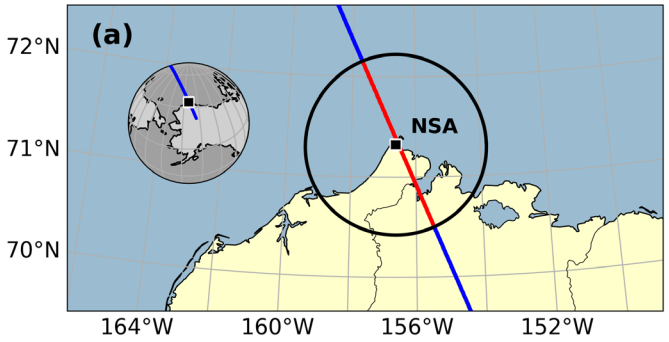
+ **high platform speed** → **biases** (e.g., 0.01° mispointing introduces a bias of 1.32 m/s) *(covered in Bernat's presentation)*

- **These errors** are corrected in **the C-PRO Level-2 algorithms**
- Validation with independent Doppler velocity measurements is required

Data Sources for Validation

Validation with surface-based Doppler radars at high-latitude sites

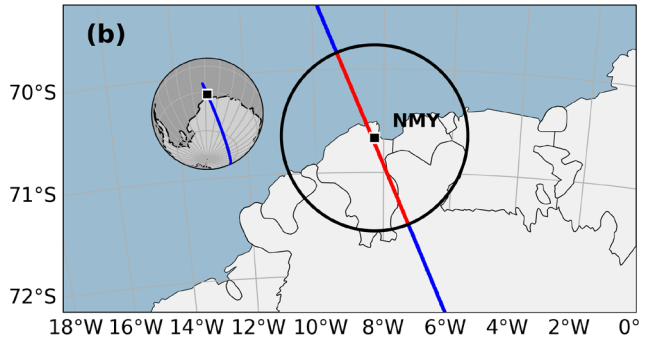
(1) ARM NSA (Arctic)



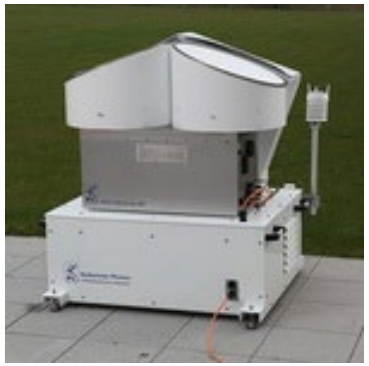
(71.32°N, 156.62°W)

KAZR (Ka-band, 35 GHz)

(2) ACTRIS Neumayer (Antarctica)



(70.66°S, 8.27°W)



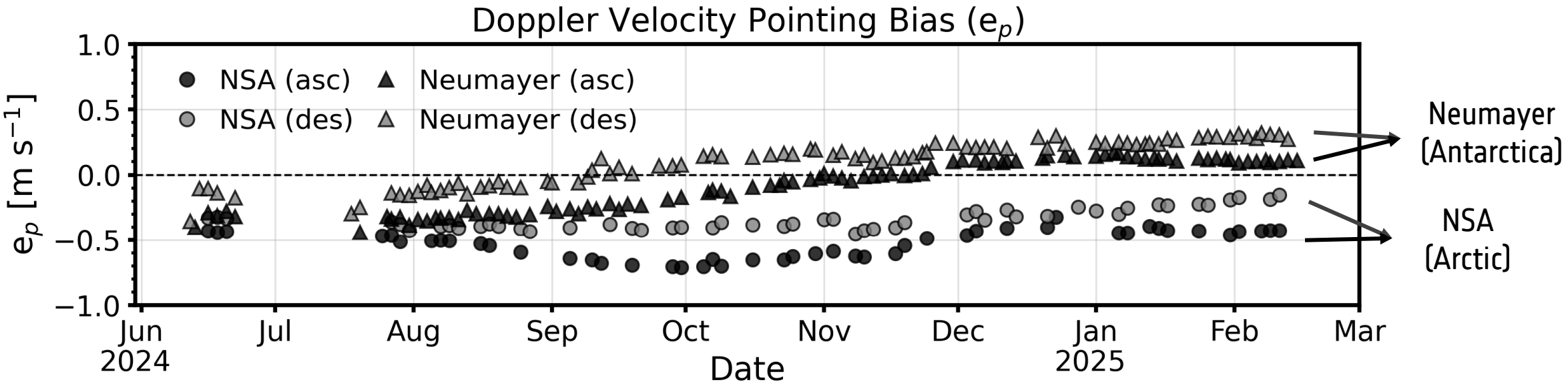
RPG-FMCW-94
(W-band, 94 GHz)

Why high-latitude sites?

- More frequent satellite overpasses (2-3 times more than mid-latitudes)
- Abundant ice clouds (more valid samples without liquid attenuation effects)
- Arctic region has frequent mixed-phase clouds (satellite measurement challenges)
- Distinct antenna pointing bias in the two locations (see next slide for details)

Comparison of Doppler velocity pointing bias (e_p) between two sites

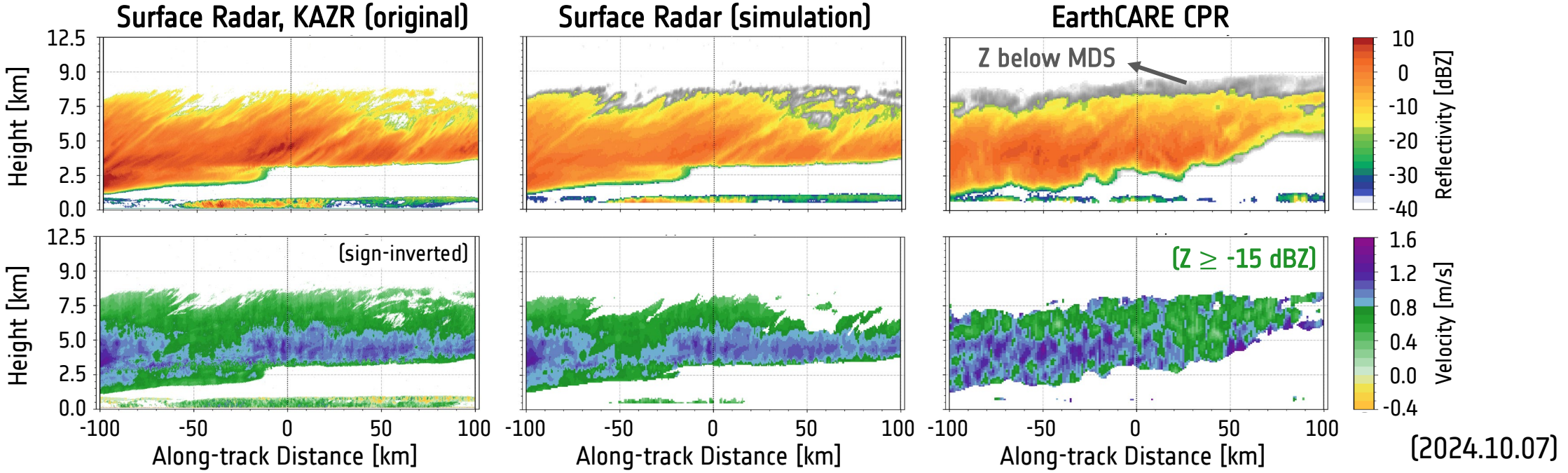
Antenna pointing bias is affected by thermoelastic distortions due to sunlight, varying with time and location. Thus, a constant bias correction cannot be applied.



variable name: **"Doppler velocity pointing bias"** in the C-CD file

Matching surface-based radar and EarthCARE CPR Doppler velocity data

- Observation Period: Jun 12, 2024 – Feb 15, 2025 (~8 months)
- Instrument Simulator: Orbital-Radar Tool (*Pfitzenmaier et al., 2024*), adjusting surface radar data to match CPR
- Data Filtering: Applying the same minimum detectable signal (MDS)
- Spatial Window:Within a 100 km radius of each site location
- Reflectivity Calibration: -1.9 dB (KAZR, NSA) and -0.7 dB (FMWC, Neumayer), derived following *Kollias et al. (2019)*



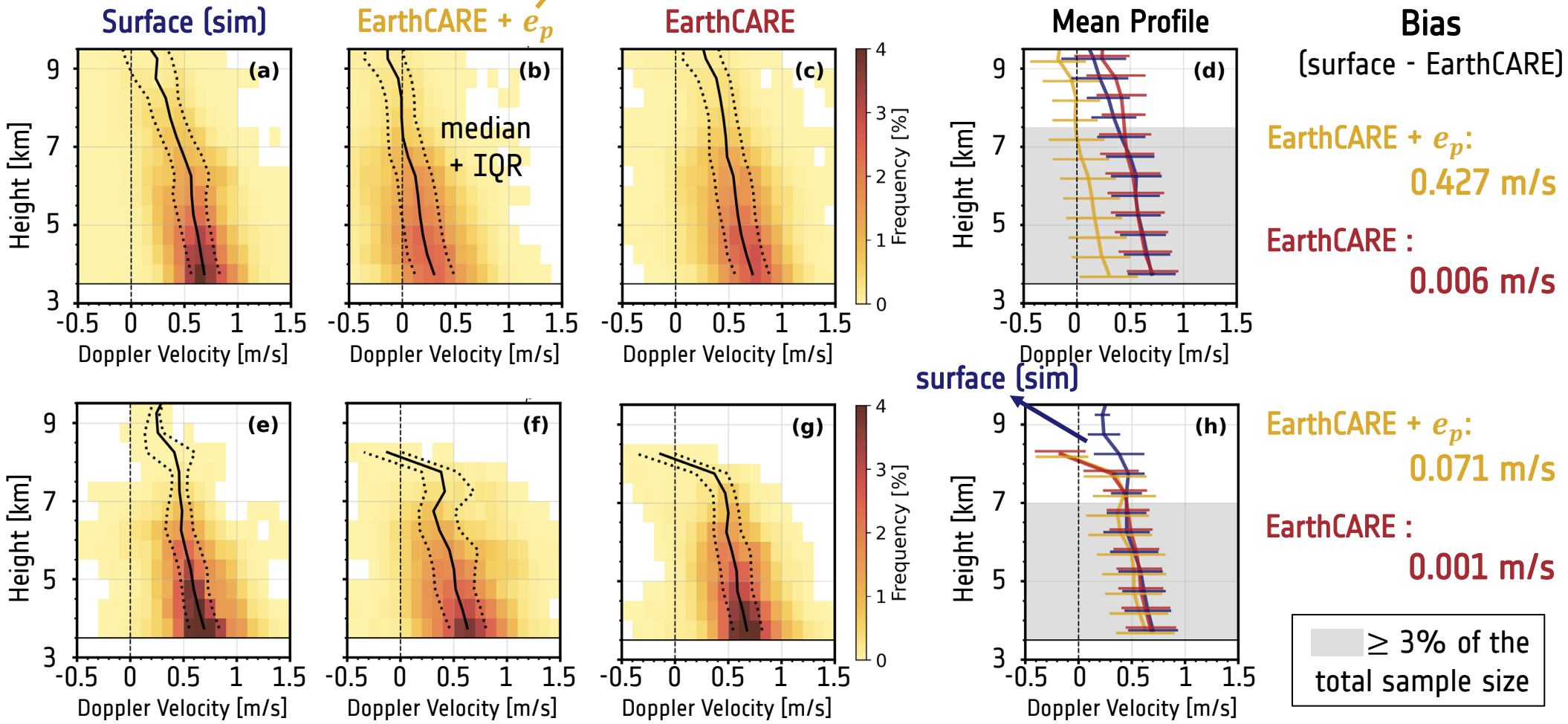
Validation Results (CFAD and mean profile)

(1) Ice clouds (height ≥ 3.5 km)

pointing bias

NSA
(Arctic)
Ka- vs. W-band

Neumayer
(Antarctica)
W- vs. W-band



Bias
(surface - EarthCARE)

EarthCARE + e_p:
0.427 m/s

EarthCARE :
0.006 m/s

EarthCARE + e_p:
0.071 m/s

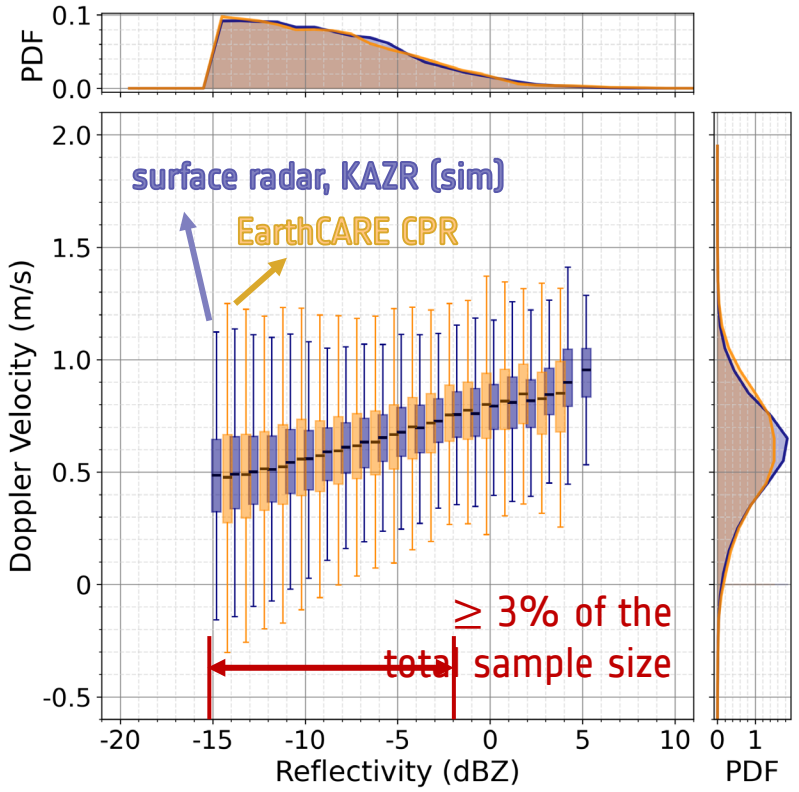
EarthCARE :
0.001 m/s

≥ 3% of the total sample size

Validation Results (Z-V relationship)

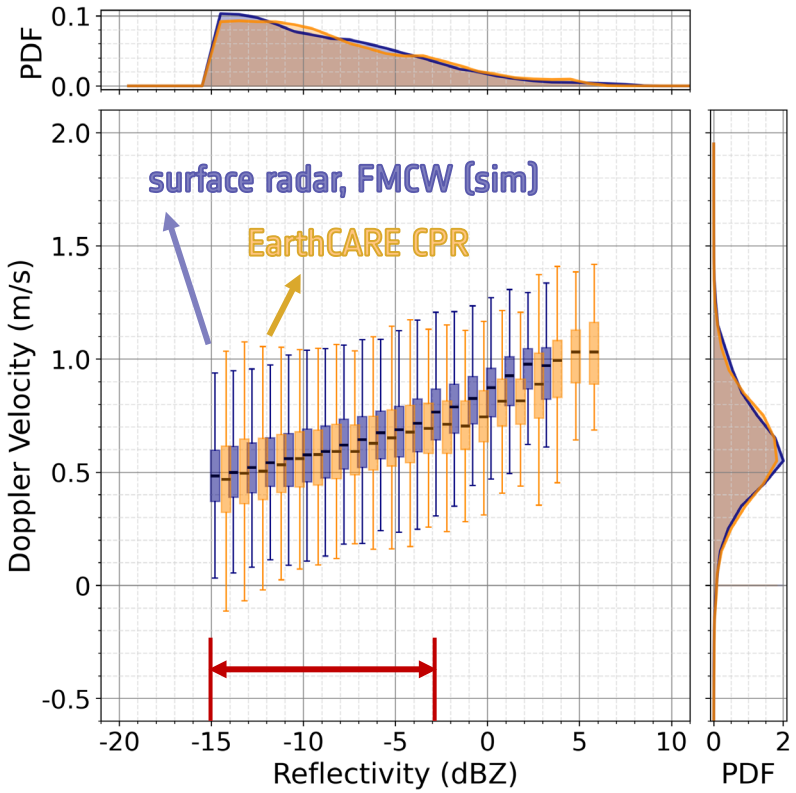
(1) Ice clouds (height ≥ 3.5 km)

NSA (Arctic)
(Ka- vs. W-band)



bias = 0.010 m/s

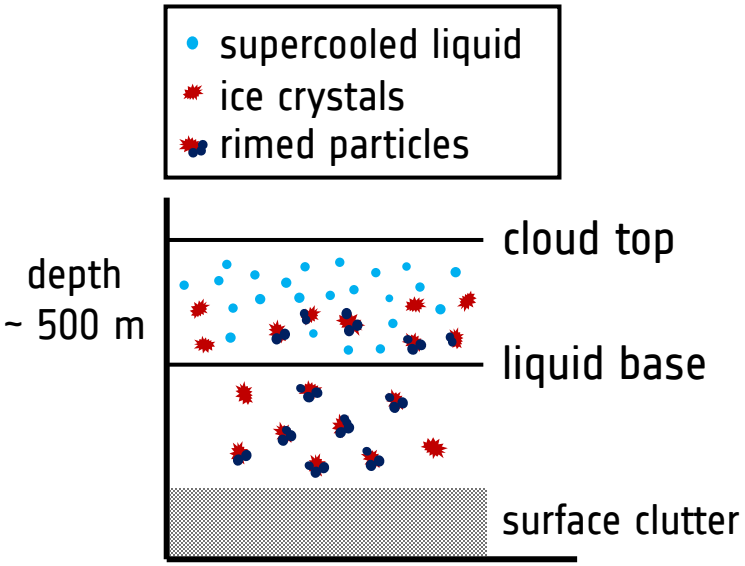
Neumayer (Antarctica)
(W- vs. W-band)



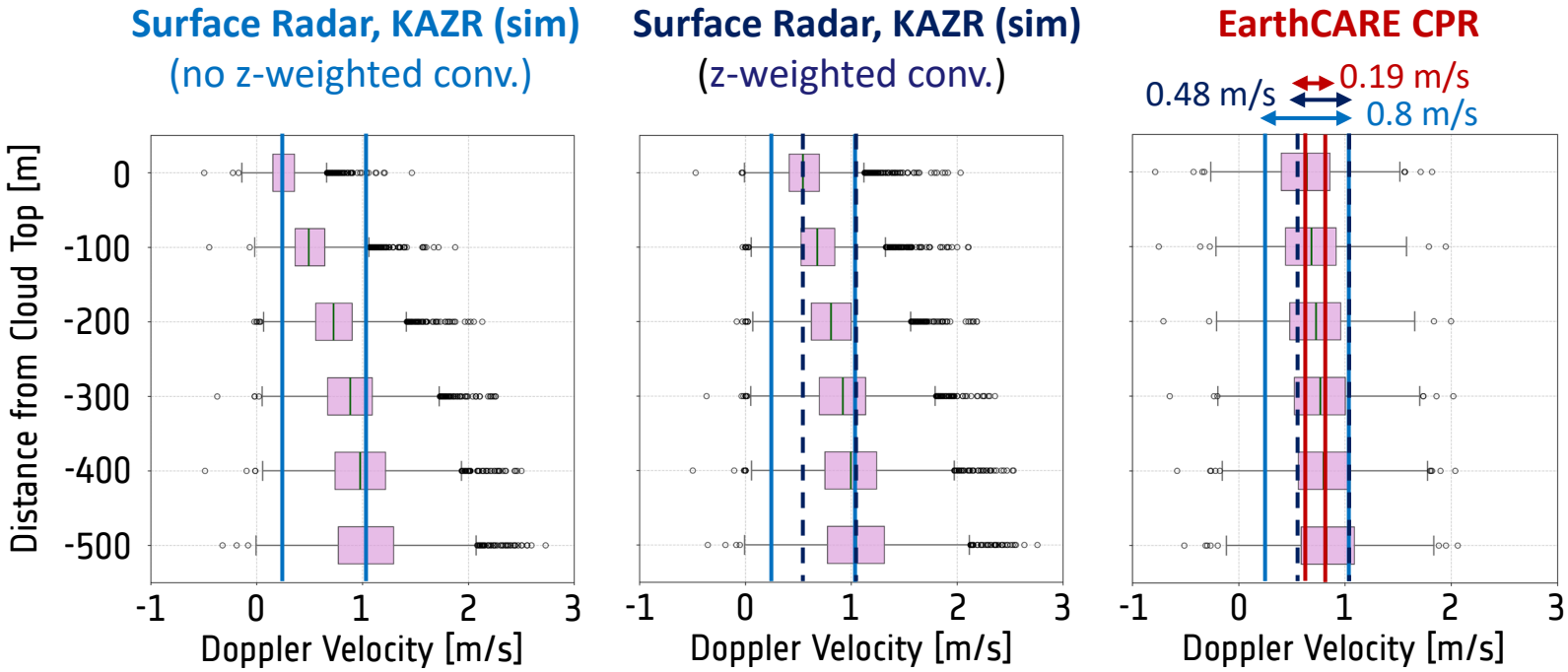
bias = 0.015 m/s

(2) Low-level mixed-phase clouds (CTH < 2.5 km)

Low-level mixed-phase clouds are particularly challenging to observe from satellites because of **strong vertical gradients** within **500 m from the cloud top,** which is **CPR's pulse length**



Low-level mixed-phase clouds
(conceptual model)



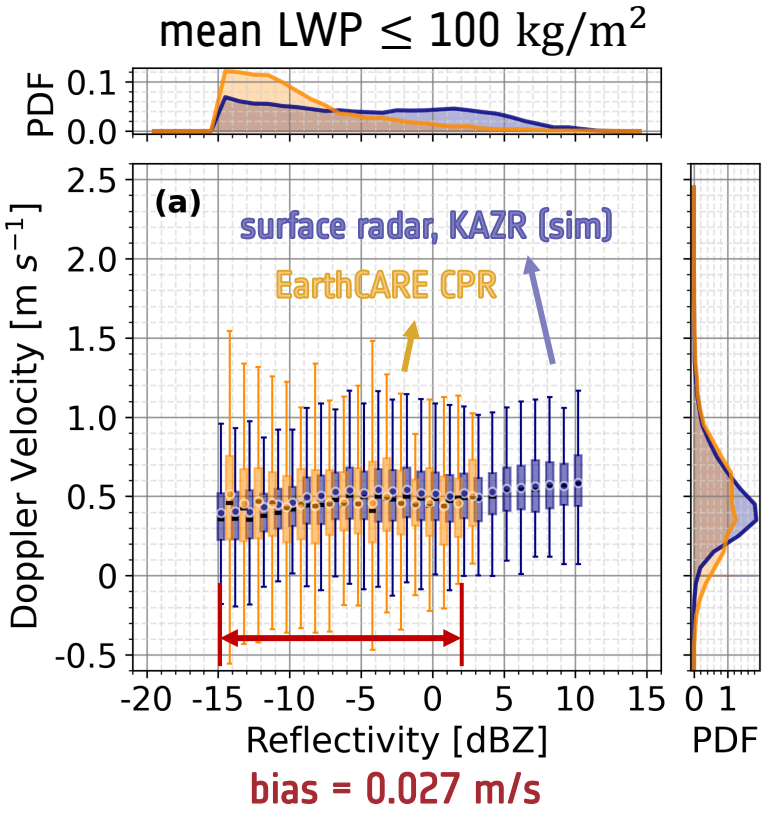
"Point Target Response effect"

Validation Results (Z-V relationship)

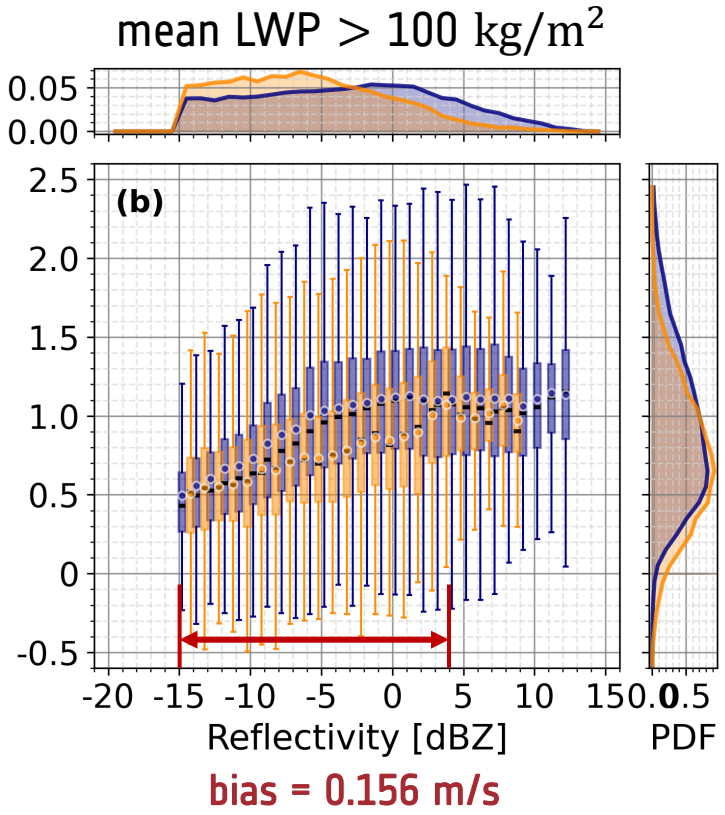
(2) Low-level mixed-phase clouds (CTH < 2.5 km)

NSA (Arctic)

(Ka-band vs. W-band)



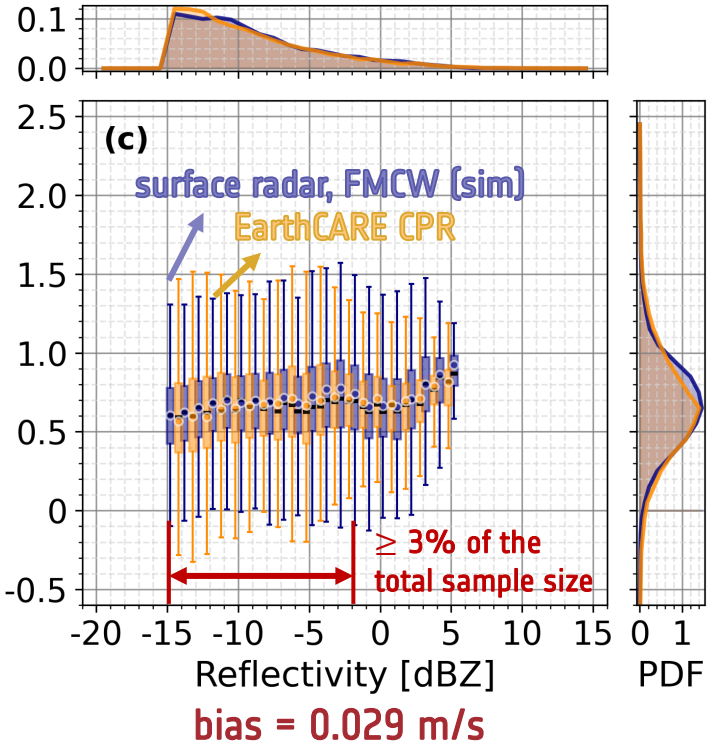
bias = 0.027 m/s



bias = 0.156 m/s

Neumayer (Antarctica)

(W-band vs. W-band)



bias = 0.029 m/s

Summary and Future Work

Summary

- **The quality-controlled CPR Doppler velocities** in the L2A C-PRO exhibit **near-zero biases** when statistically compared to surface-based observations from high latitude sites.
- **The L2A C-PRO antenna mispointing correction** is very important for establishing reliable CPR Doppler velocity measurements in stratiform cloud conditions.
- Additional work is needed to understand **the impact of the CPR pulse length** on the reported radar reflectivities and Doppler velocities in areas with large vertical gradients (i.e., mixed-phase clouds).

Future work

- Develop the first ever global climatology of hydrometeor's sedimentation rates
- Evaluate weather and climate models using appropriate forward simulators.

Thank you for your attention

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