

Comparison of EarthCARE 3D Scene Reconstruction Products with Ice Cloud Retrievals from Side-Looking W-Band Polarimetric Airborne Radar Observations

Cuong Nguyen¹, Zhipeng Qu², Howard Barker², Paloma Borque¹, Alexei Korolev², Keyvan Ranjbar¹, Ivan Heckman², Kenny Bala¹, Leonid Nichman¹, Natalia Bliankinshtein¹, Mengistu Wolde¹

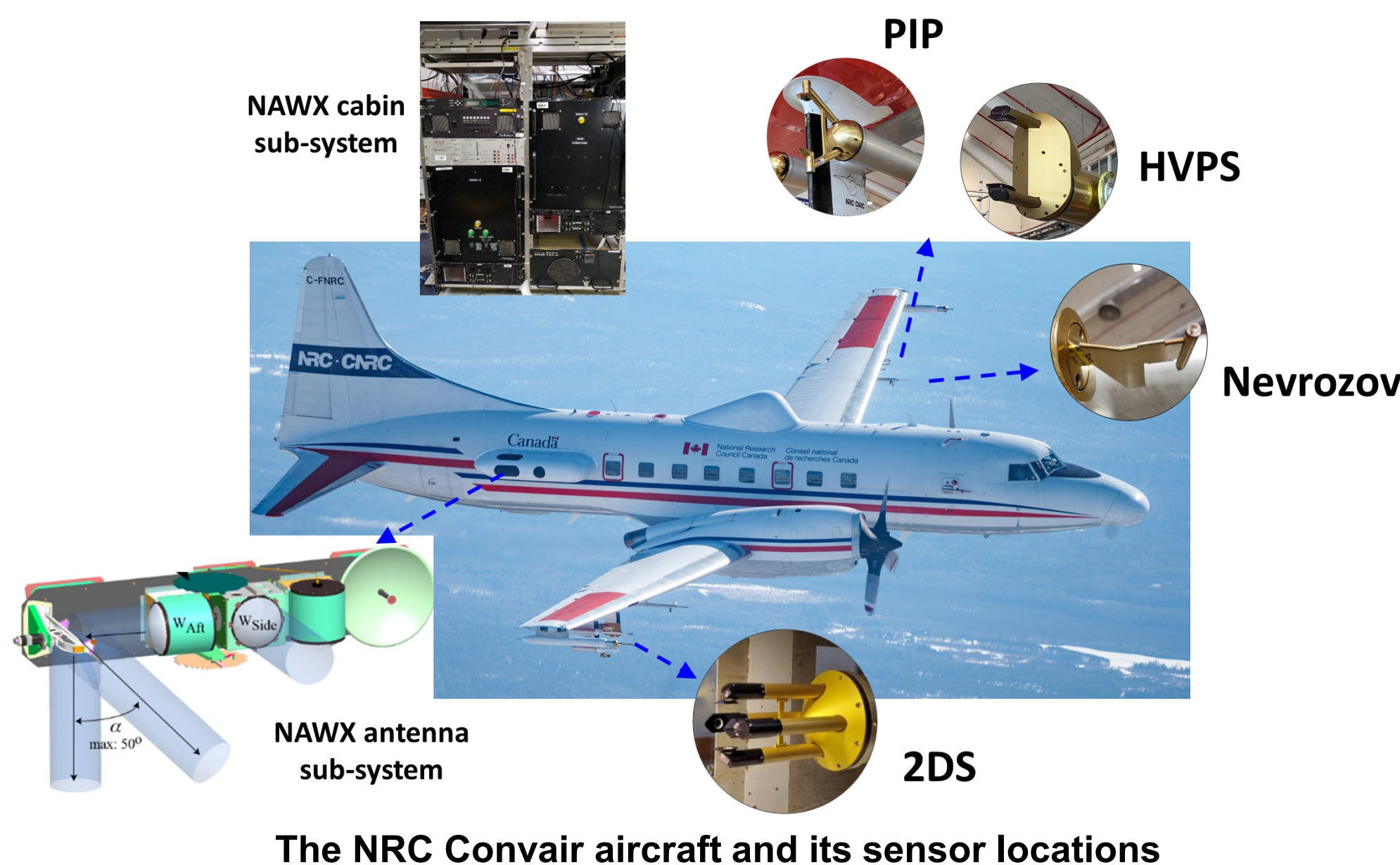
(¹) Flight Research Laboratory, National Research Council Canada, Ottawa, Canada, (²) Environment and Climate Change Canada, Toronto, Canada

Abstract

The 3D Scene Construction Algorithm (SCA) supports EarthCARE radiative closure assessments by extending nadir cloud and aerosol retrievals into three-dimensional scenes using Multi-Spectral Imager (MSI) radiance matching. Since the accuracy of the constructed scenes directly affects simulated radiative quantities, independent validation is essential. The EarthCARE Commissioning Calibration/Validation Campaign in Ottawa (ECALOT; October 2024–March 2025) provided a unique dataset for this purpose, including airborne observations from NRC Canada's Convair-580 research aircraft equipped with in situ cloud probes and side-looking dual-polarization W- and X-band NAWX radars. These radars provide off-nadir observations and retrievals of ice cloud microphysical properties, including ice water content, particle concentration, and mean volume diameter. In this study, 3D ice cloud fields generated from EarthCARE composite and synergy retrieval products are compared with ice cloud properties retrieved from the Convair-580 radar observations. The results provide an independent assessment of SCA performance and support the evaluation of EarthCARE ice cloud retrieval products.

Airborne Sensors and Data

- NRC Airborne W-band (NAWX) radar system: NAWX side antenna has dual-polarization capability and the pulsing scheme alternates between horizontal and vertical polarization.
- Cloud scattering and optical array probes: The PSD is composed of separate datasets from three probes: the CDP-2 (scattering probe, 2-50 μm), the 2DS (10-1280 μm), and HVPS3/4 (150-19200 μm) or PIP (100-6400 μm) if the data quality from HVPS is poor.
- Nevozov hot-wire probe: In this work, IWC is approximated as the difference between TWC and LWC.



Ice Microphysical Retrieval Using Radar Polarimetric Observations

Simulations by Lu et al. (2015) showed that the Ice Water Content–reflectivity (IWC–Z) relationship is highly sensitive to variations in ice particle size distributions (PSDs), resulting in uncertainties of up to one to two orders of magnitude. As a result, reflectivity-only retrievals are not recommended for accurate IWC estimation. Incorporating polarimetric radar variables significantly improves retrieval accuracy and reduces relative errors. Table 1 (Blanke et al., 2022) summarizes existing ice cloud retrieval methods. In this study, we apply the polarimetric retrieval approach of Nguyen et al. (2019), using coefficients derived for side-looking W-band radar observations.

Retrieval	Formula	Type	Reference
$D_m^1(Z_m)$	$1.45Z_m^{0.25}$	empirical	Skofronick-Jackson et al. (2019)
$D_m^2(Z_m)$	$1.06Z_m^{0.271}$	empirical	Matrosov et al. (2019)
$D_m(Z_m, K_{DP})$	$-0.1 + 2.0 \left(\frac{Z_m}{K_{DP}} \right)^{1/2}$	empirical	Ryzhkov and Zniec (2019)
$D_m(Z_m, K_{DP})$	$0.67 \left(\frac{Z_m}{K_{DP}} \right)^{1/3}$	empirical	Bukovčić et al. (2020)
$\log_{10}(IWC^1(Z_m, T))$	$0.06Z_m - 0.0197T - 1.7$	empirical	Hogan et al. (2006)
$\log_{10}(IWC^2(Z_m, T))$	$0.06Z_m - 0.0212T - 1.92$	model	Hogan et al. (2006)
$IWC(K_{DP})$	$0.903K_{DP} + 0.319$	empirical	Nguyen et al. (2019)
$IWC^1(Z_m, K_{DP})$	$(0.136K_{DP} + 0.037) \left(\frac{Z_m}{K_{DP}} \right)^{-\tau}$	empirical	Nguyen et al. (2019)
$IWC^2(Z_m, K_{DP})$	$4 \times 10^{-3} \left(\frac{Z_m}{K_{DP}} \right)^{-\tau}$	theoretical	Ryzhkov and Zniec (2019)
$IWC(Z_m, K_{DP})$	$0.31K_{DP}^{0.66} Z_m^{0.28}$	empirical	Bukovčić et al. (2020)
IWC_{COM}	$\begin{cases} IWC^1(Z_m, K_{DP}) & \text{if } Z_{COM} > 0.4 \text{ dB} \\ IWC^2(Z_m, K_{DP}) & \text{otherwise} \end{cases}$	theoretical and empirical	Carlin et al. (2021)
$\log_{10}(N(Z_m, Z_{DP}, K_{DP}))$	$0.1Z_m - 2\log_{10} \gamma - 1.33$	theoretical	Ryzhkov and Zniec (2019)
$\log_{10}(N(Z_m, IWC))$	$6.69 + 2\log_{10}(IWC) - 0.1Z_m$	theoretical and empirical	Carlin et al. (2021)

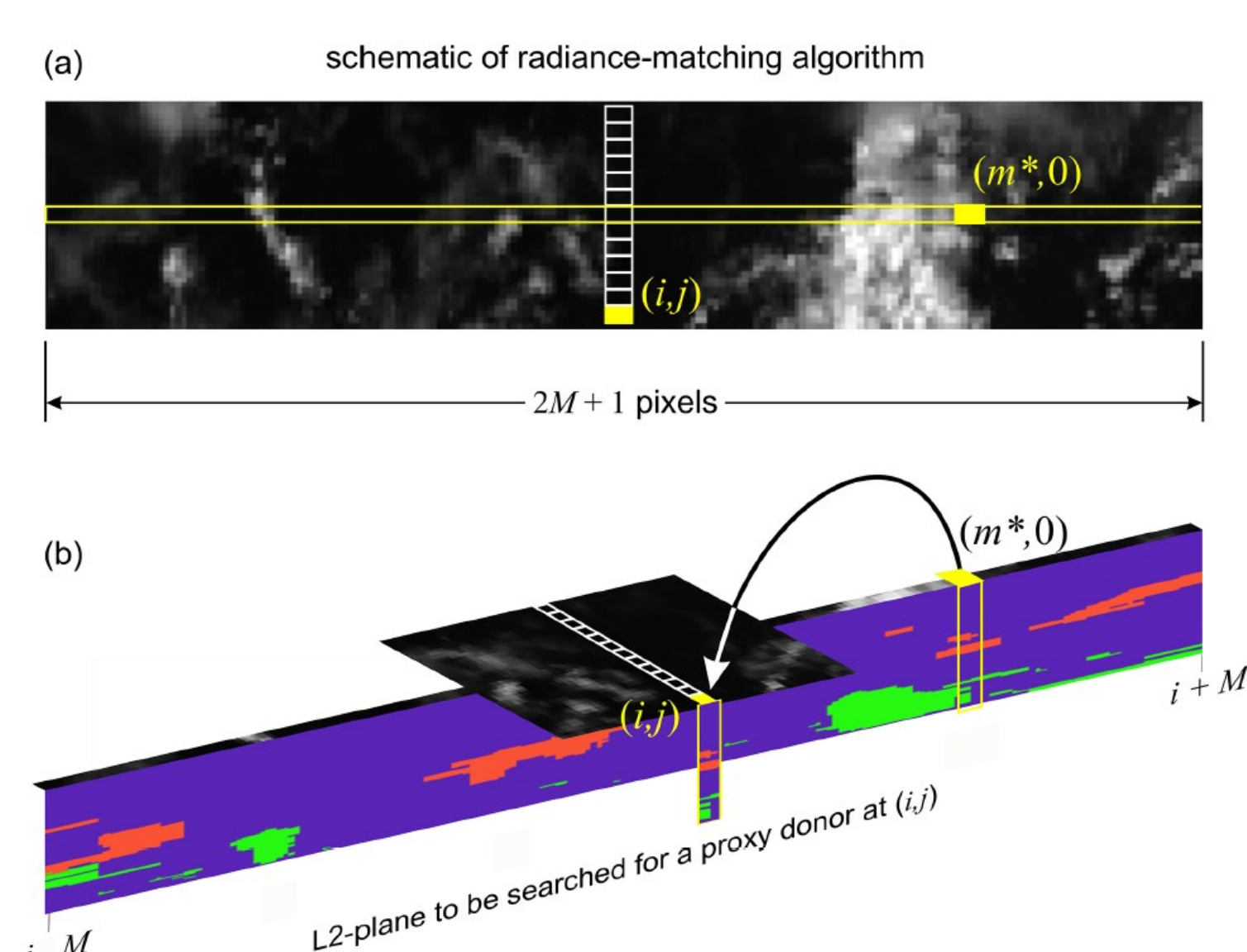
For mean volume diameter (D_m),

$$D_m = -0.1 + 2.0 \left(\frac{Z_{DP}}{K_{DP} \lambda} \right)^{1/2}$$

and number of concentration $N_t = f(IWC, Z, K_{DP}, Z_{DR})$. There's no ideal relation and we are working on the optimal choice for the dataset.

EarthCARE's Scene Construction Algorithm

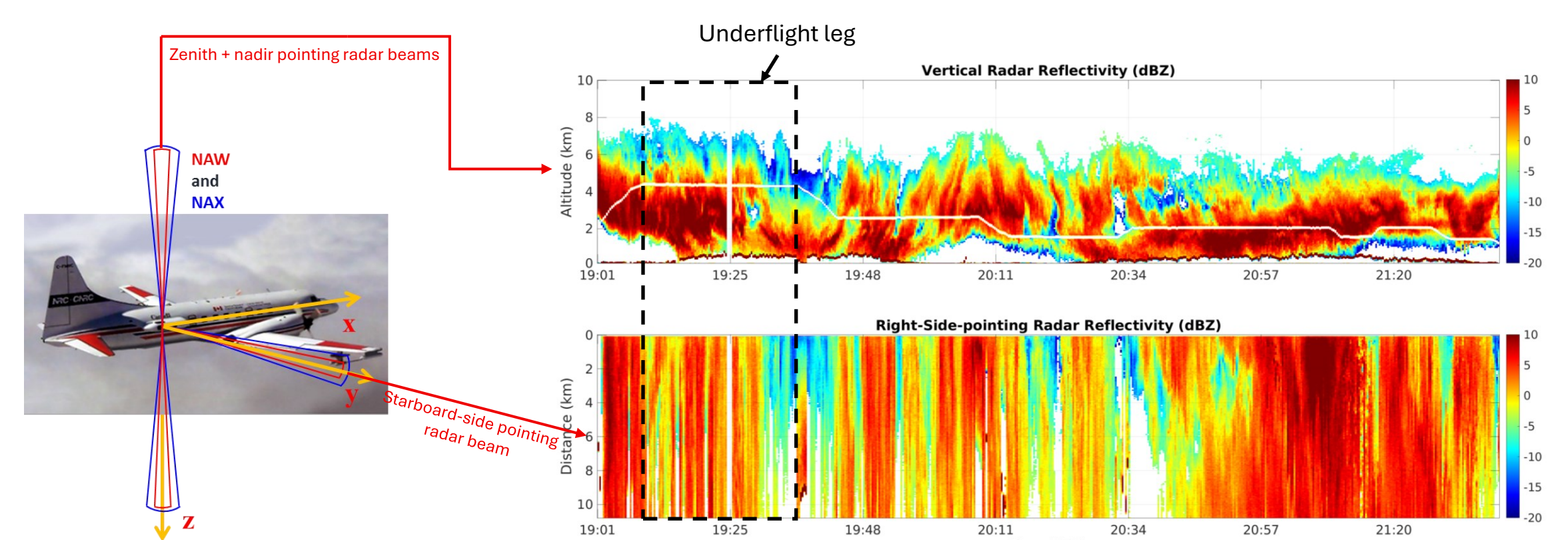
- MSI radiance matching at: 0.67, 2.21, 8.8 and 12 μm .
- Check solar zenith/azimuth angle differences.
- Limited searching distance (configurable), 200 km (BA), 400 km (BC).



SCA Validation with Side-Pointing Radar

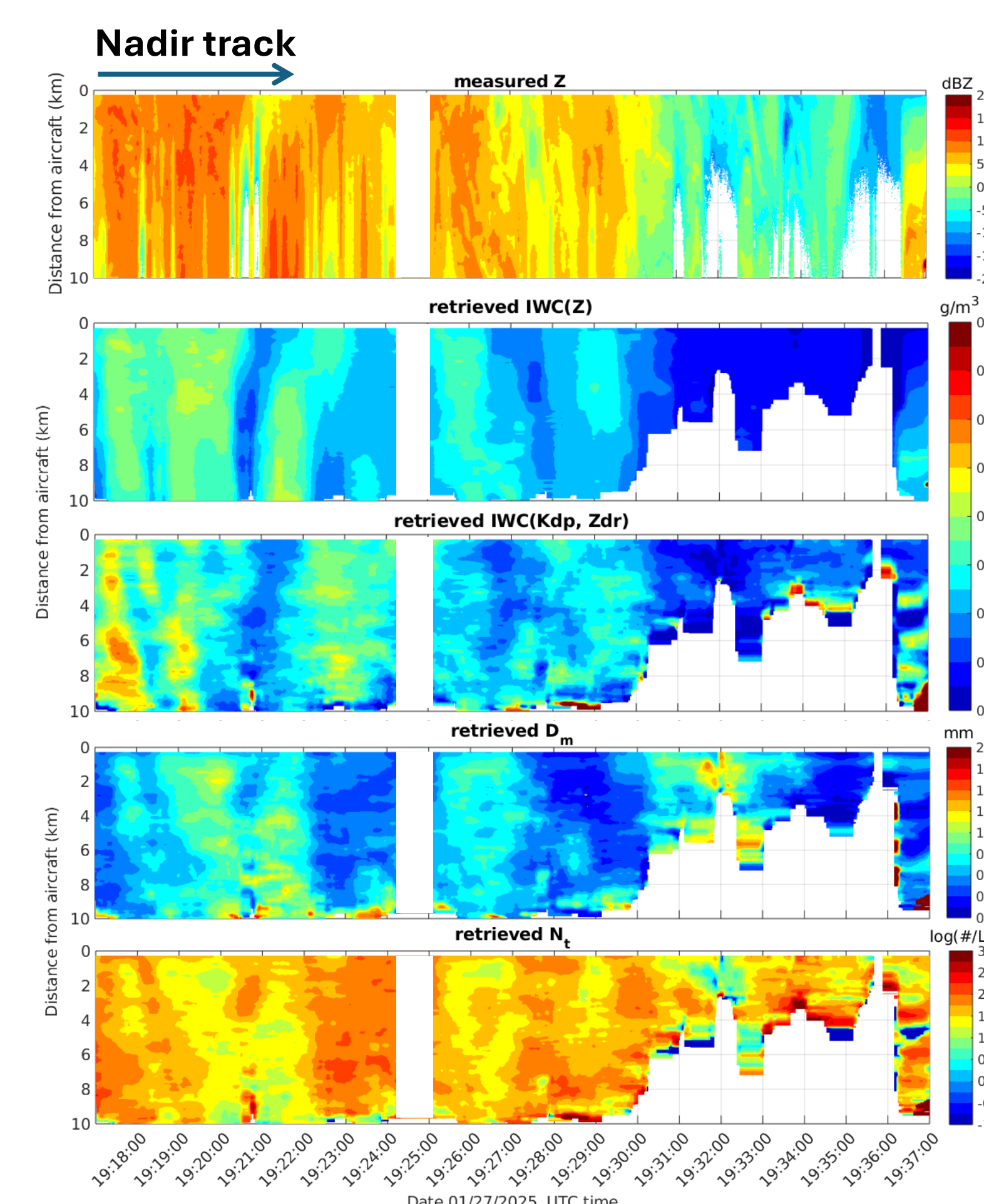
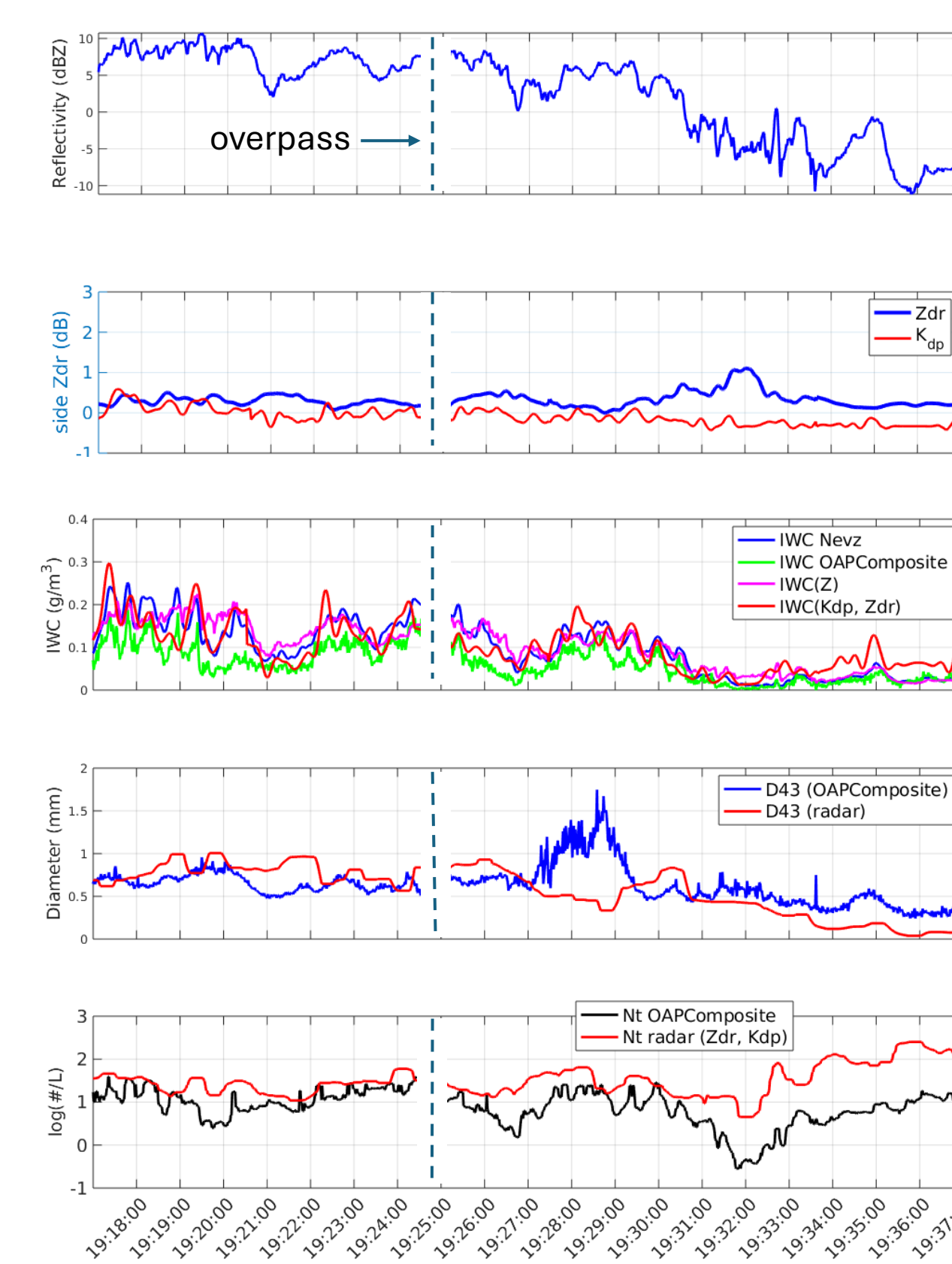
ECALOT Flight 6 (2025-01-25)

- Nimbostratus case (overpass time: 19:24 UTC) – Ice cloud.
- Convair-580 under-flight along EarthCARE track, with starboard-side pointing W-band radar beam.
- Radar products: Z, IWC, D_m , N_t .
- Reconstruction products:
 - Reflectivity at aircraft level.
 - Construction index: ACMB-3D Baseline BC (11.4)
- Validation range: across-track from 0 to 10 km at east side of the nadir track; along-track ~130 km



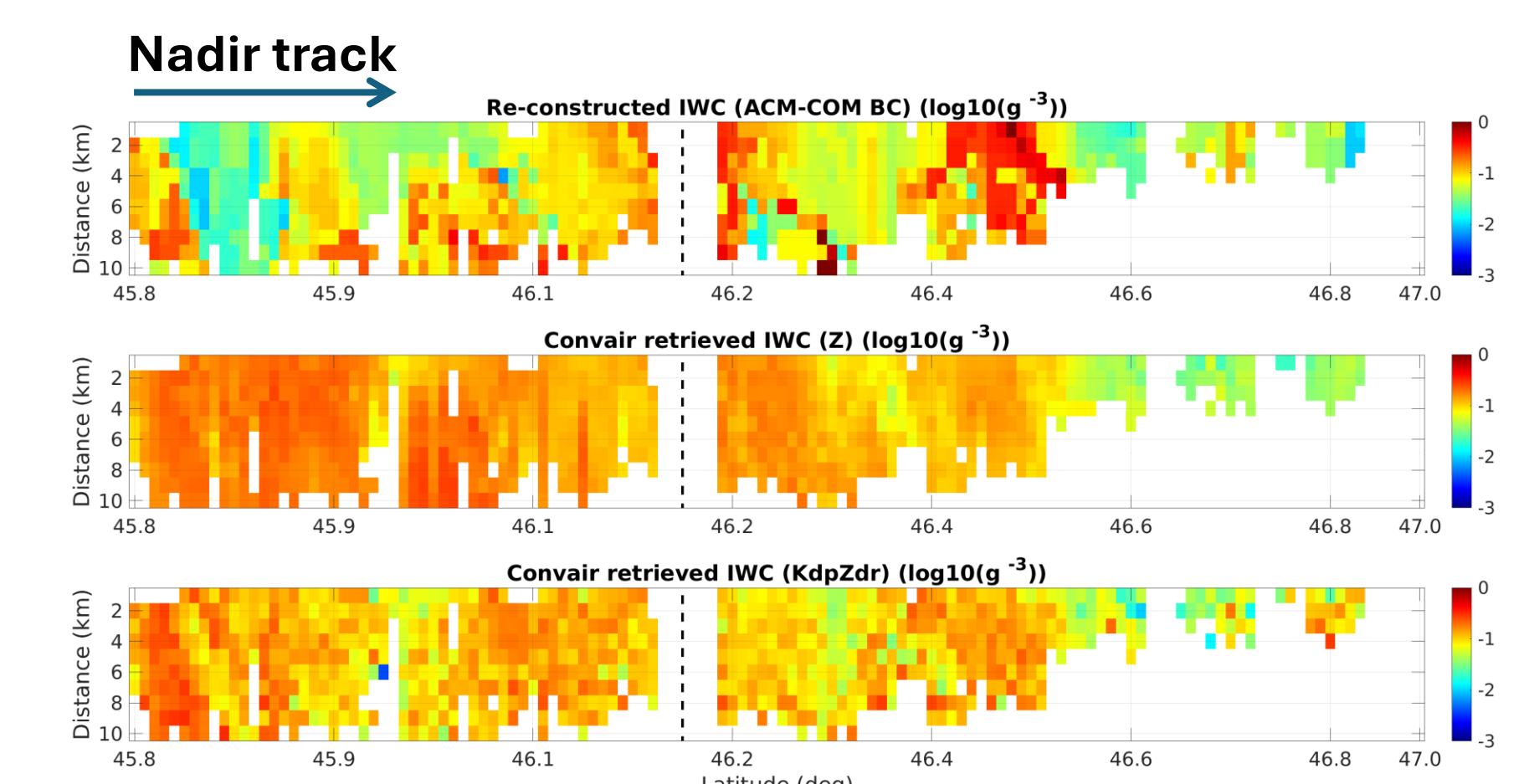
IWC, mean volume diameter, and number of concentration retrievals from radar

Radar observations 300 m from the aircraft and corresponding retrieved cloud microphysical parameters.

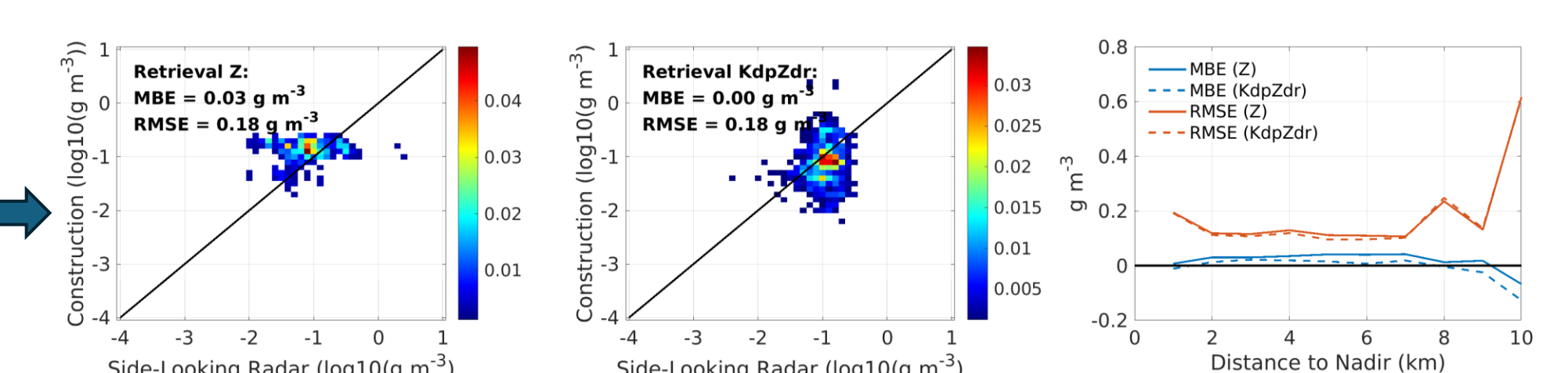


SCA IWC validation

- Scene construction using Nevzorov probe data.
- Z based IWC retrieval using $IWC = aZ^b$ where a and b are derived from the best-fit curve to the joint distribution of radar reflectivity (Z) and Nevzorov IWC.
- Radar polarimetric retrievals also employed coefficients optimized for this flight segment.
- Retrieved IWC was mapped onto the EarthCARE grid.



Statistics of SCA-constructed versus radar-retrieved IWC



Summary

- Very good agreement (up to 10 km cross track) for both IWC and radar reflectivity (Z, not shown).
- Better agreement obtained using the polarimetric IWC retrievals.
- Future work: Validate additional SCA-derived microphysical parameters using radar-retrieved D_m and N_t .

Acknowledgement: This work is supported by the NRC Environment Science focus area and the ESA Contract # 4000145188/24/NL/FFI. We gratefully acknowledge the NRC and ECC groups for their dedication during the preparation and execution of the field campaign. We also extend our sincere thanks to ESA and our collaborators for their valuable support throughout the project.