EarthCARE 2026 Science and Validation workshop

8–12 June 2026 | Rhodes House | Oxford, UK

Airborne validation of the EarthCARE Cloud Profiling Radar in Arctic cold-air outbreaks during the COMPEX-EC campaign

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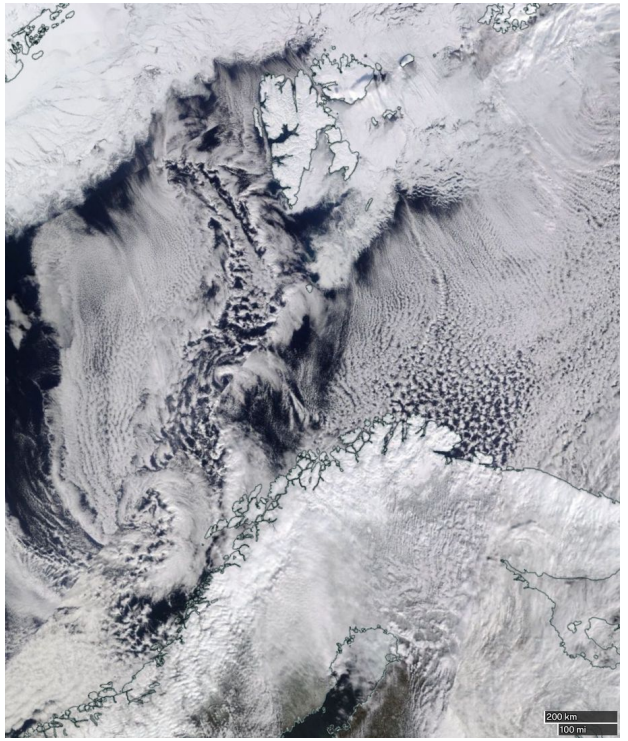
Clouds over cOMPIEX environment - EarthCARE

Polar 5 (AWI)
April 2 - 16, 2025
Kiruna, Sweden

Goals

Validation of EarthCARE satellite by airborne observations with an EarthCARE-like instrument suite

Analyze open cell structures at the outflow region of Arctic Cold Air Outbreaks (CAOs)



NASA Worldview – MODIS, April 04, 2025 © NASA

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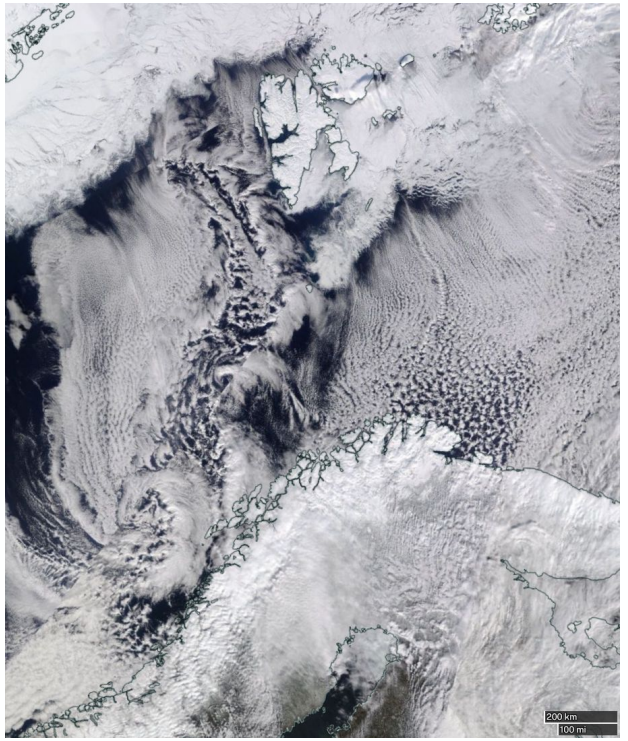
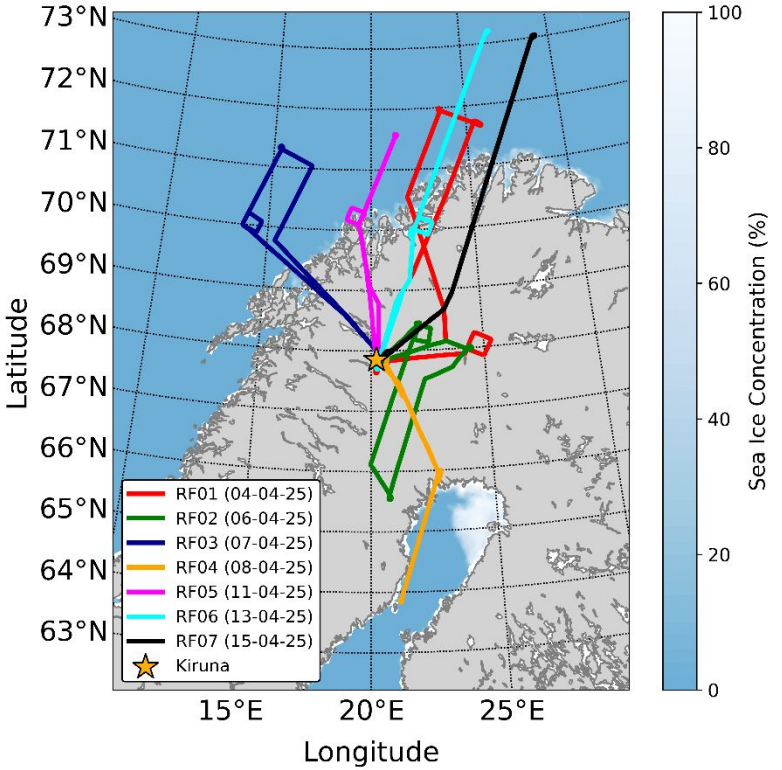
7 research flights from Kiruna with in total 31 flight hours

5.68 h of EarthCARE collocations on descending orbits



NASA Worldview – MODIS, April 04, 2025 © NASA



Instrumentation

Polar 5 - Alfred Wegener Institute operated by Kenn Borek Air
Basler BT-67 (DC-3 build in 1943)
up to 6 hours, range ~1000 km, height < 6 km

Microwave Radar/radiometer for Arctic Clouds (MiRAC)

Mech et al. (2019), AMT

94 GHz, FMCW, 89 GHz passive, 1 Hz, **25° tilted** in belly pod
Radar reflectivity, **Doppler velocity**, brightness temperature, liquid/ice water content, precip. rate, **liquid water path**

Parameter	EarthCARE CPR	MiRAC-A
Flight altitude	393 km	3-5.5 km
Flight speed	7666 ms^{-1}	~ 75 ms^{-1}
Frequency	94 GHz	94 GHz
Vertical resolution	500 m (100 m sampling)	18.3 m
Sensitivity	-35 dBZ (1 km alt)	-40 to -35 dBZ (@ 1 km)

Airborne Mobile Aerosol Lidar (AMALi)

Attenuated backscatter signal at 355 and 532 nm depol
Profiles of aerosol, cloud layers, cloud mask and top height

AVAPS dropsonde system

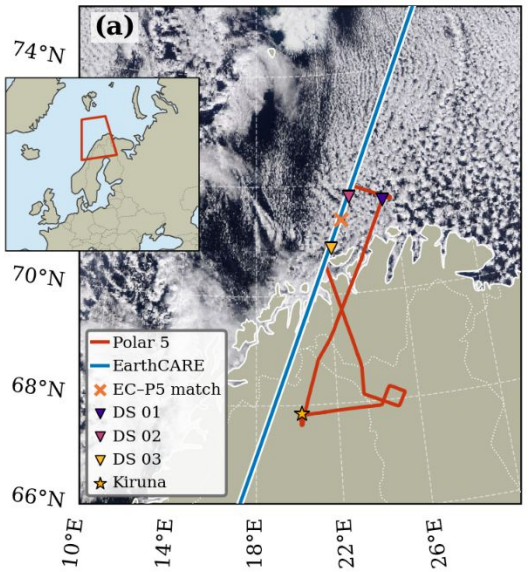
AISA EAGLE/HAWK

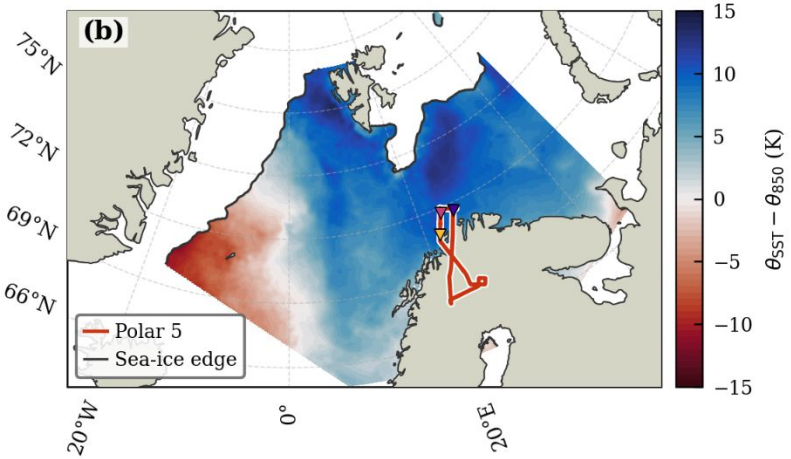
Broadband and spectral radiation

MW radiometer KT-19 fish-eye Nikon

MCAO event - April 4, 2025 - RF01

- Cold Arctic air over ice-free Barents/Norwegian Sea — MODIS shows well-organised cloud streets driven by strong surface heat fluxes (a)
- Strong instability: MCAO index +10–15 K; P5 flight track aligned with outflow direction (b)
- EarthCARE underpass (~13:51 UTC): Dropsondes provide direct in-situ validation beneath the satellite track





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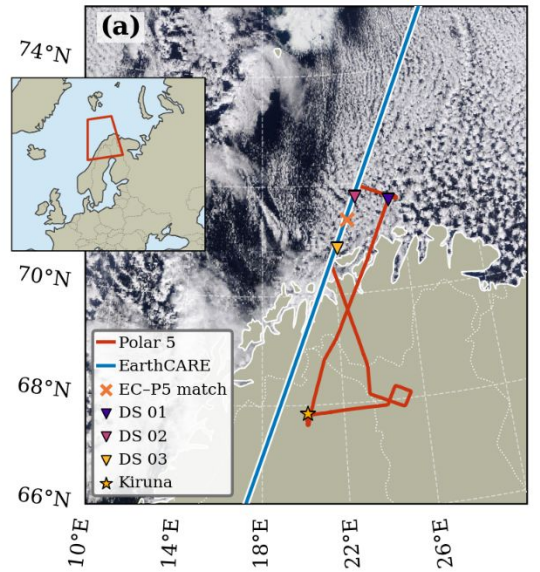
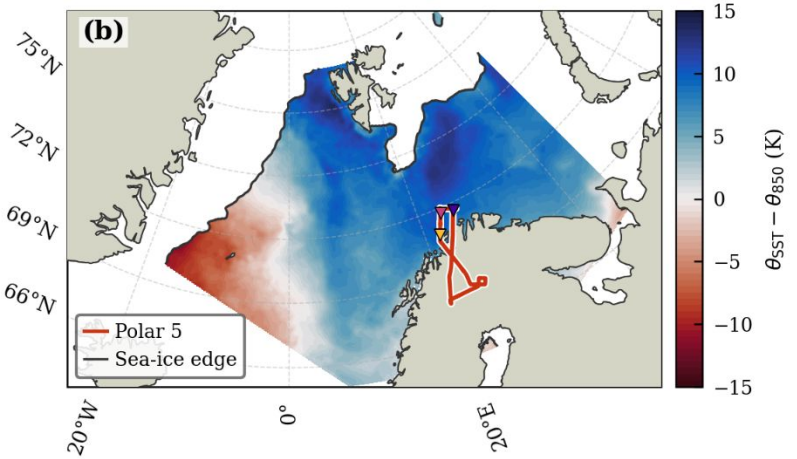
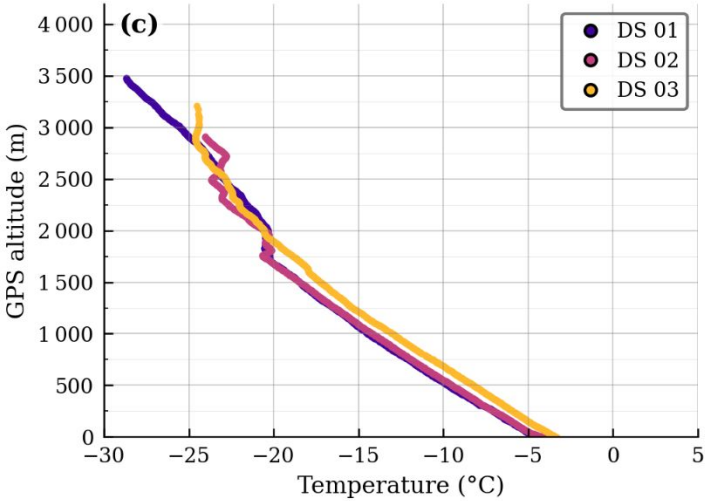
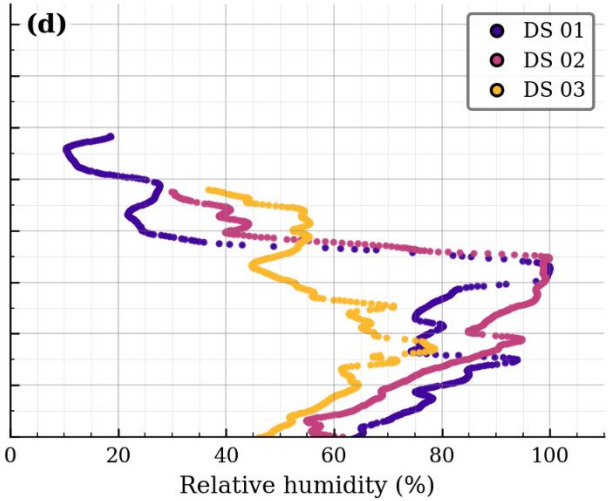
- Strong instability: MCAO index +10–15 K; P5 flight track aligned with outflow direction (b)
- EarthCARE underpass (~13:51 UTC): Dropsondes provide direct in-situ validation beneath the satellite track
- Consistent BL structure across all three sondes: Well-defined top at ~1.8 km, dry free troposphere above — cold-air in the BL from -20 to -5°C



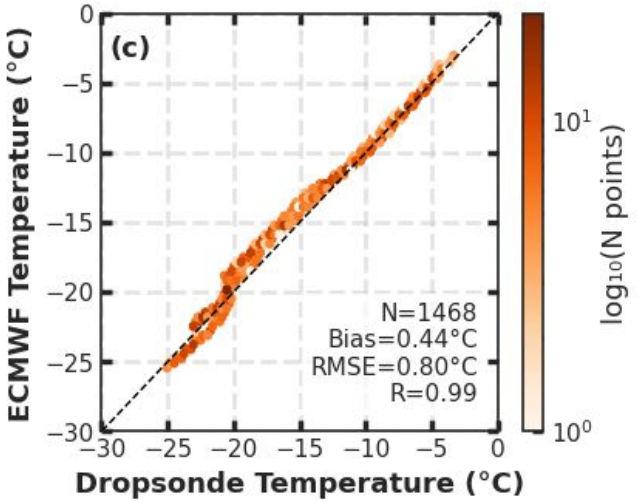


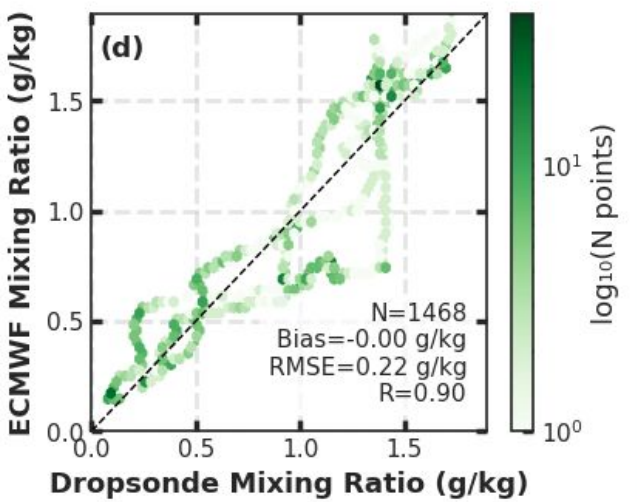


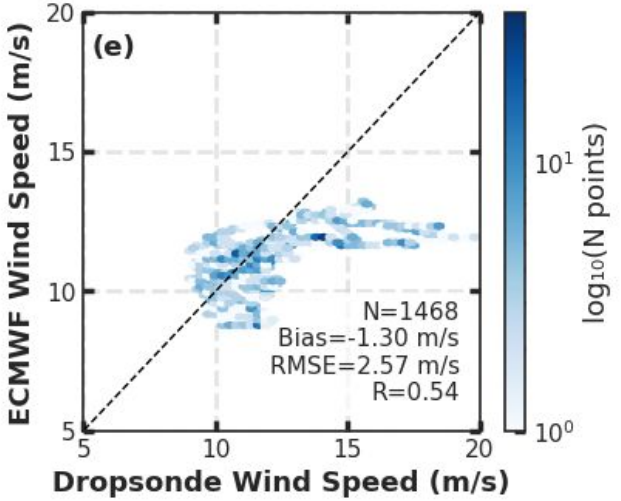


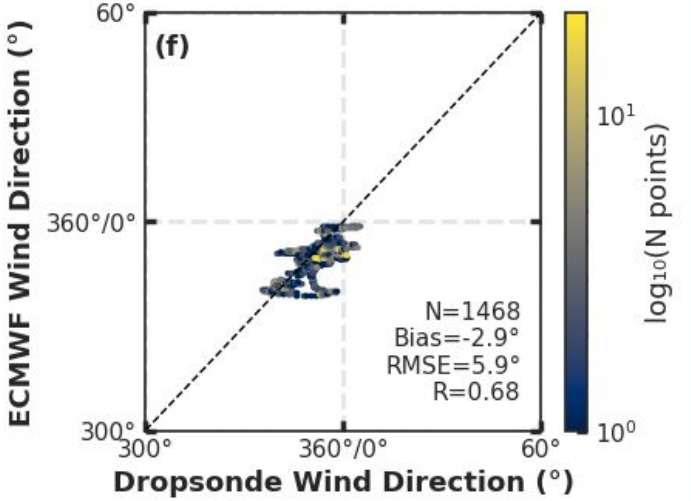
XMET vs dropsondes

- Good agreement in temperature and humidity profiles
  - ⇒ R between 0.9 and 0.99 and small bias
- Wind properties more critical, but good agreement though
  - ⇒ Bias in wind speed: 1.30 m/s, slightly underestimation of XMET
  - ⇒ Small variations in wind direction in the sampled MCAO area









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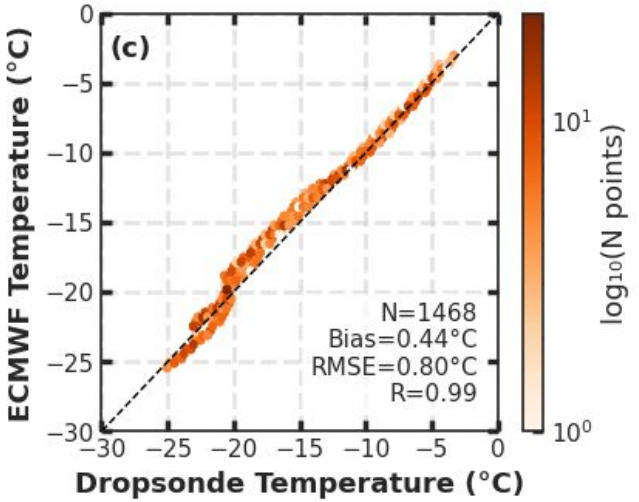
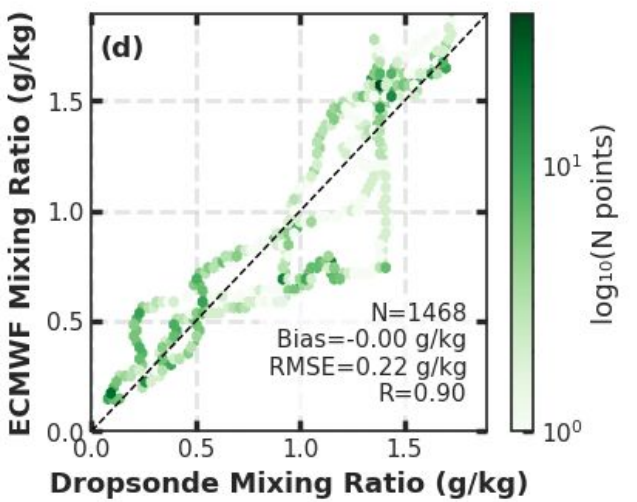
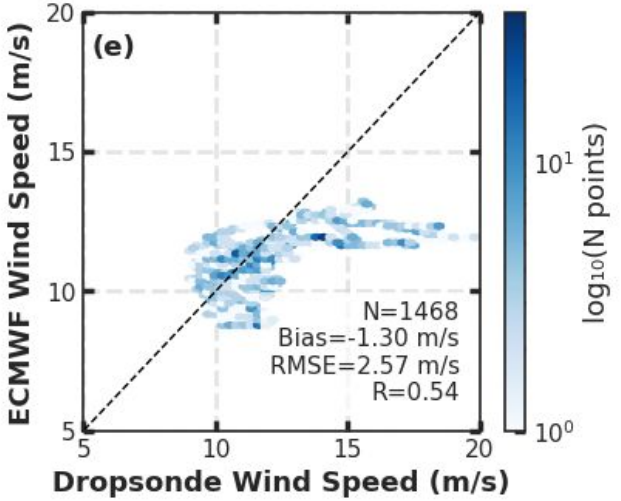
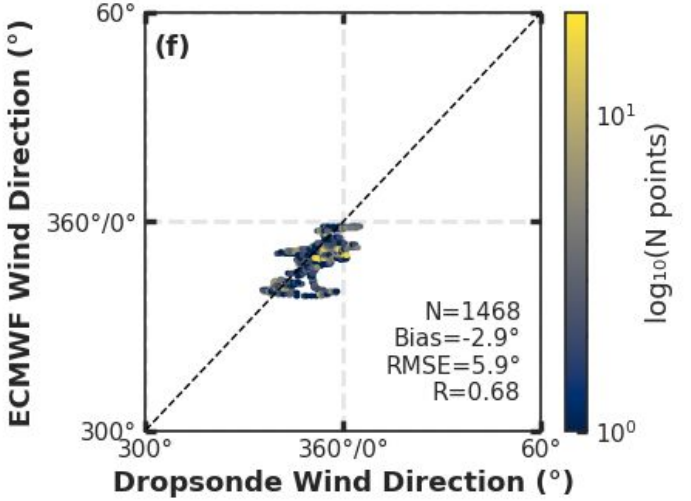
Wind field (XMET or reanalysis) needed for airborne Doppler correction









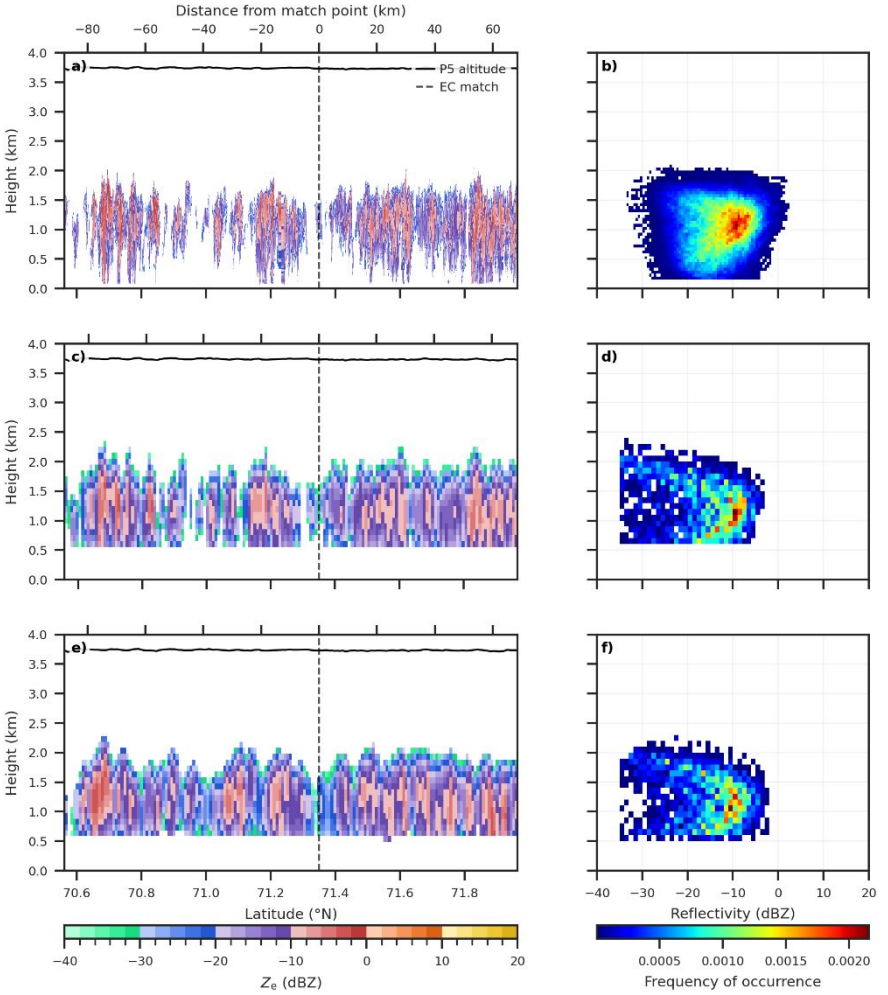
Reflectivities, CFADs

- MiRAC, Orbital radar simulator (ORA; Pfitzenmaier et al., 2025), and EarthCARE CPR all capture a low-level cloud layer between 0.5 – 2 km
- MiRAC shows narrower, more peaked distribution — ORA and EarthCARE smooth out fine-scale structure
- ORA reproduces EarthCARE CPR well, with slight underestimation at high-Ze tail

MiRAC

ORA

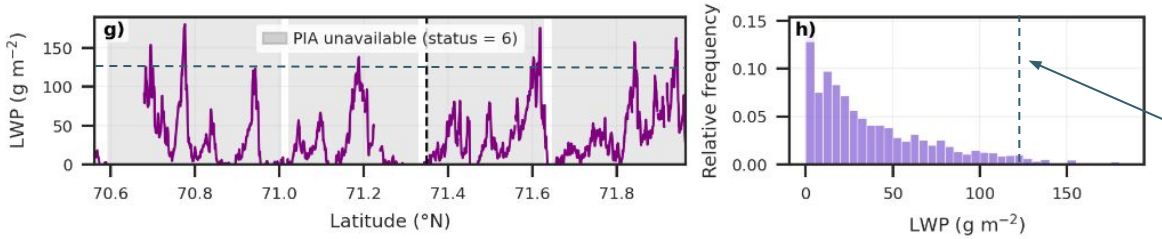
EC CPR
CFMR L2 BA



van Gelder et al. (2026), in preparation

Reflectivities, CFADs, and LWP

- MiRAC, Orbital radar simulator (ORA; Pfitzenmaier et al., 2025), and EarthCARE CPR all capture a low-level cloud layer between 0.5 – 2 km
- MiRAC shows narrower, more peaked distribution — ORA and EarthCARE smooth out fine-scale structure
- ORA reproduces EarthCARE CPR well, with slight underestimation at high-Ze tail
- LWP persistently low (20 – 150 g m^{-2}) with spatially variable on kilometer scales
- **EarthCARE PIA not available**: No cloud-free surface reference available → PIA status = 6

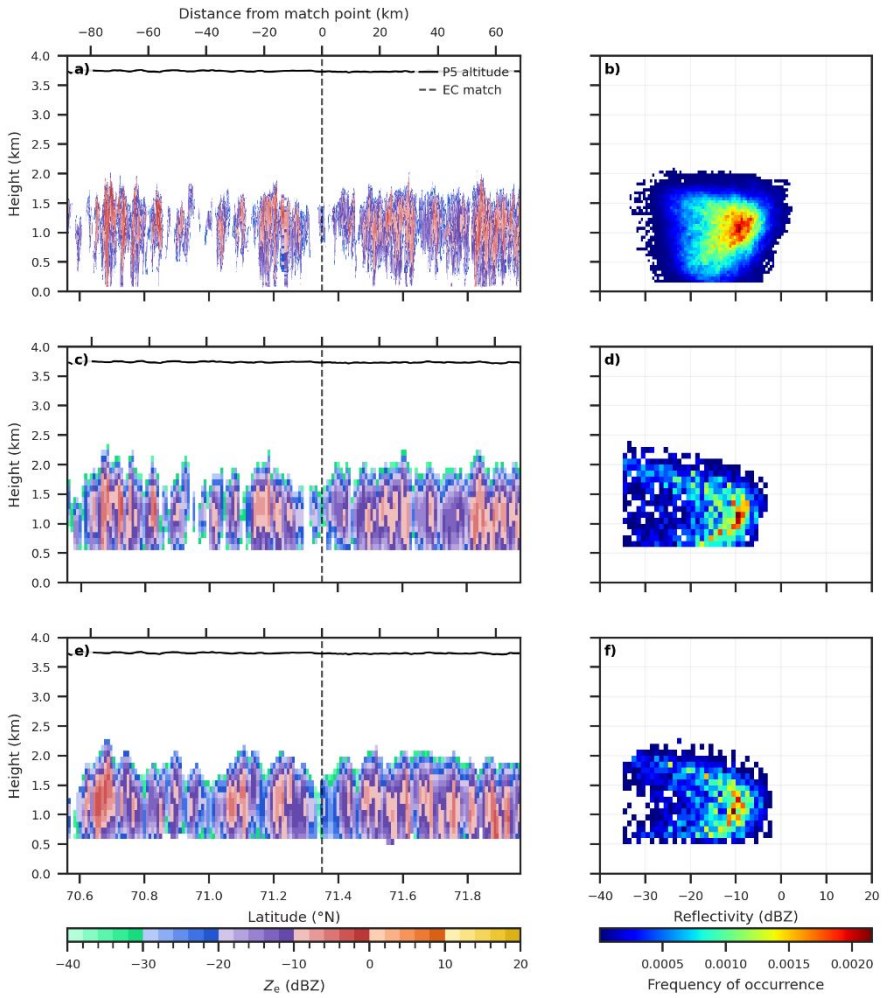


1 dB ≙ 125 g/m^2

MiRAC

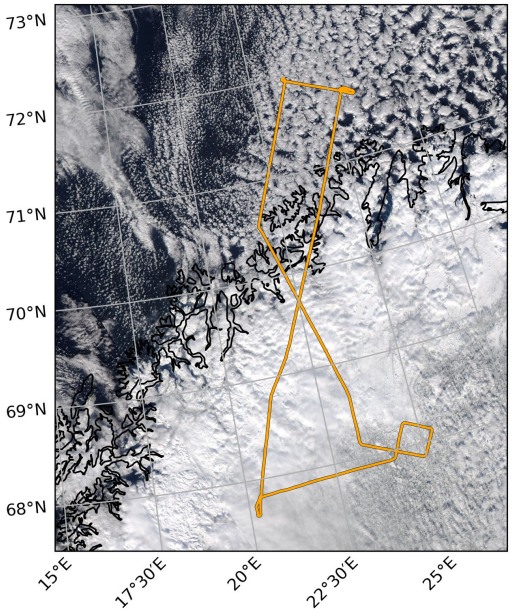
ORA

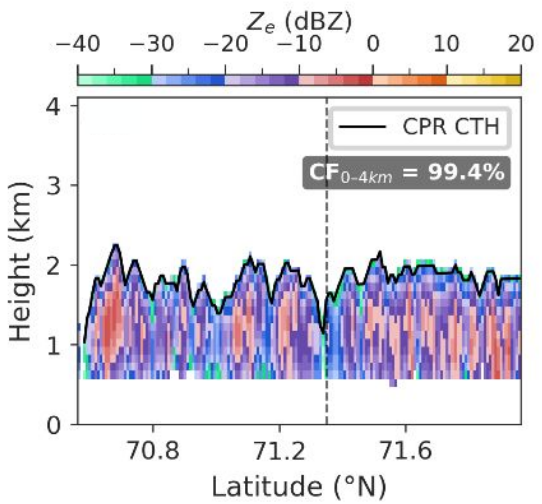
EC CPR
CFMR L2 BA

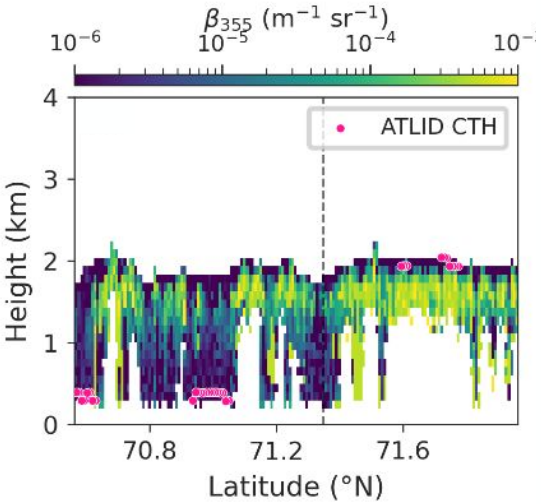


Cloud mask and top height

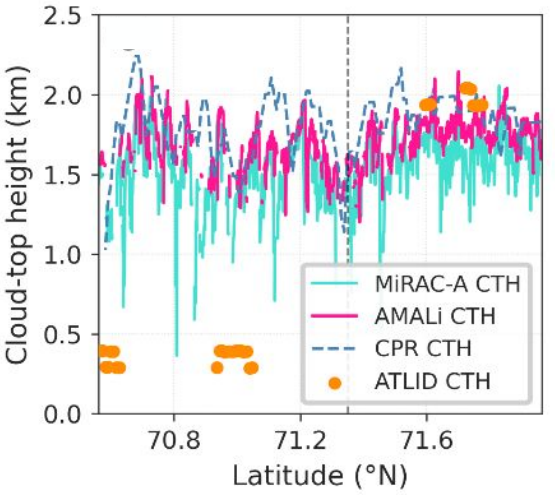
April 4, 2025

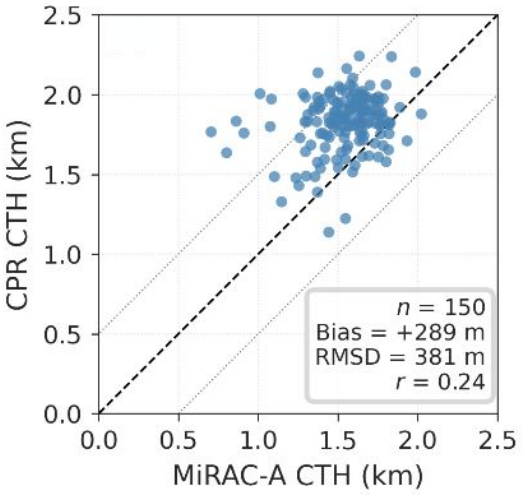






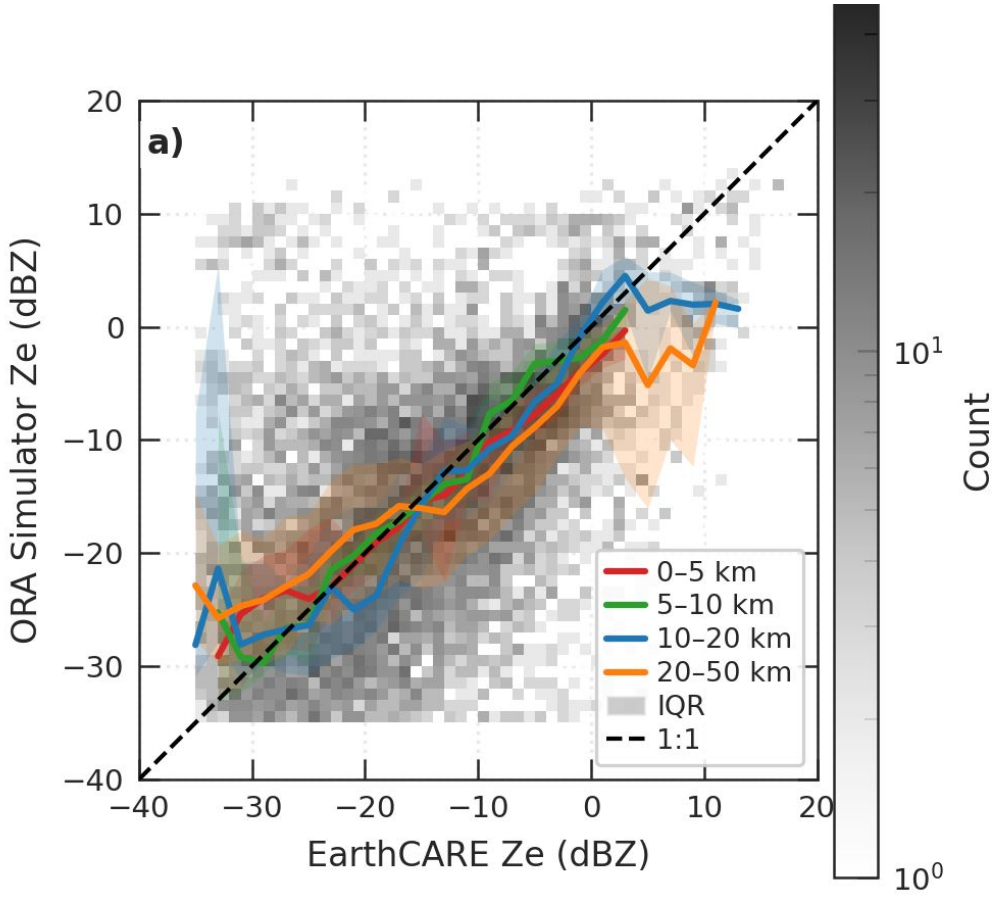
C-FMR 2A BA
A-CTH 2A BA
A-EBD 2A BA





- Cloud fraction **99 %** (CPR) and **91 %** (MiRAC-A)
- AMALi cloud tops **~180 m higher** than MiRAC-A → lidar sensitive to (supercooled) liquid, radar to ice
- higher CTH in CPR vs. MiRAC-A
- A-CTH retrieval does not detect CTH between 1.5 and 2 km, but instead clouds at 0.3 km

How good is the matching between single pixels?



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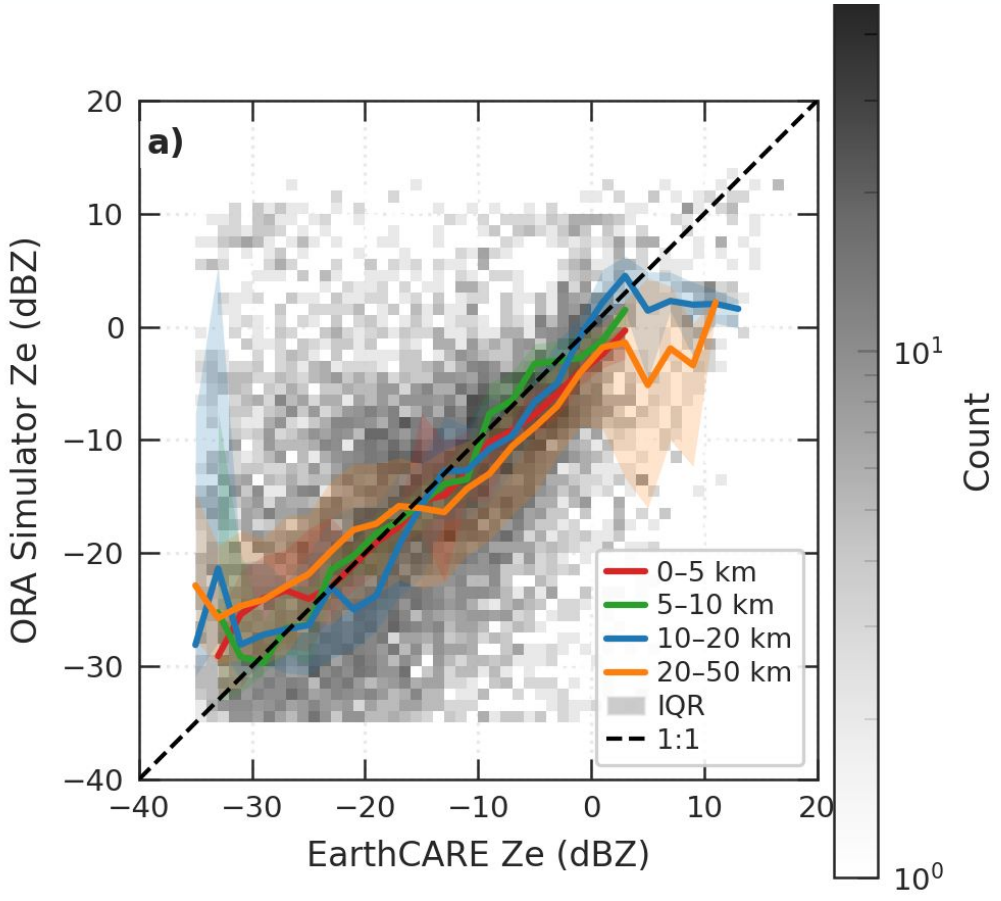


- **Close to collocation, EC & ORA match well; distribution gets broadened with greater distance between EC & ORA**
- **Ze agreement improves with proximity:** r = 0.50 (20–50 km) → r = 0.79 (0–5 km), RMSE 10.3 → 5.7 dBZ
- **Near-zero mean bias** (−0.02 dBZ): No systematic offset — large global RMSE (11 dBZ) reflects variability in scene and not instrument error

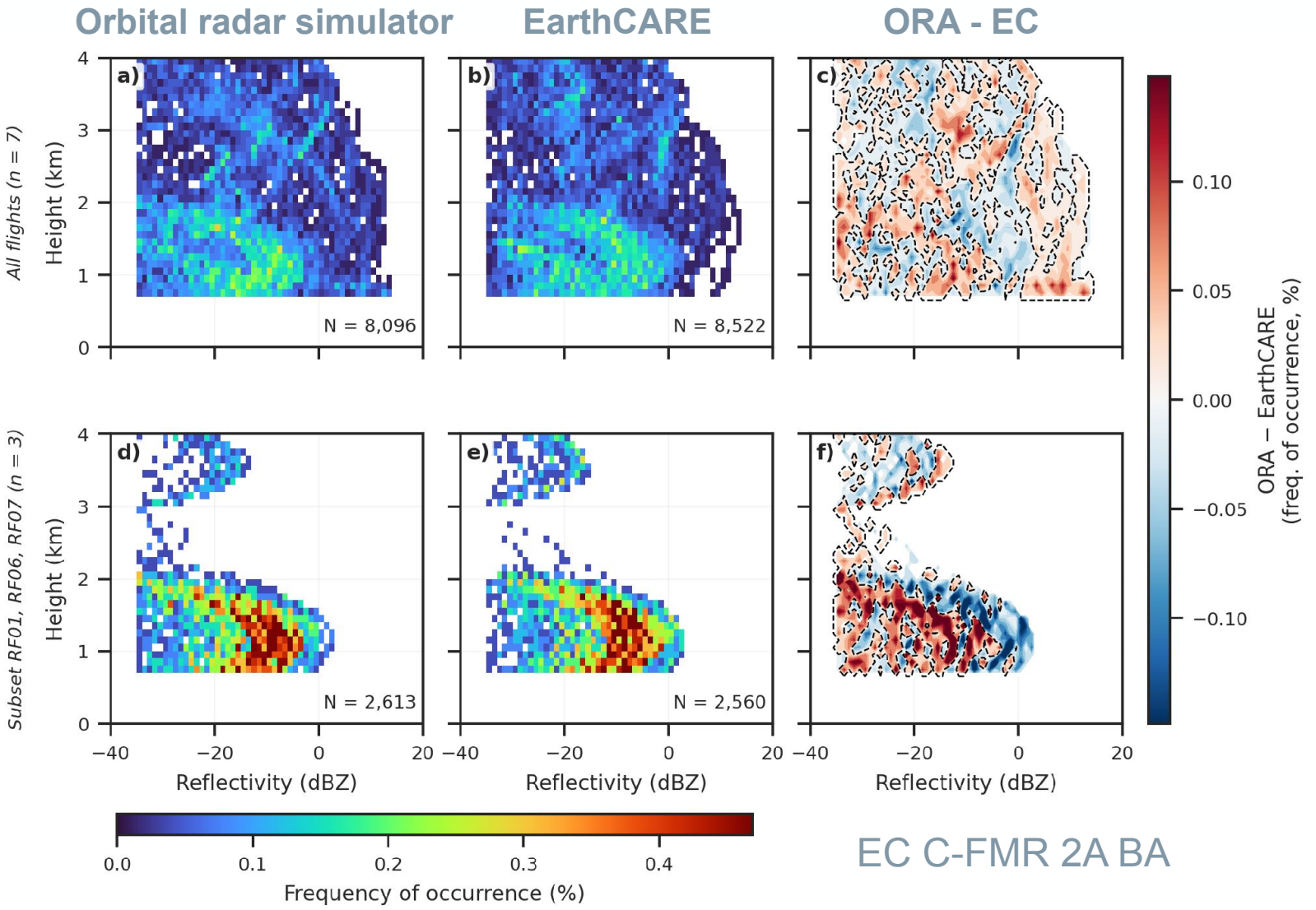
	N	Bias (dBZ)	RMSE (dBZ)	r
All (no limit)	13799	-0.02	11.02	0.45
0–5 km	596	-0.02	5.68	0.79
5–10 km	657	+0.99	7.34	0.69
10–20 km	1627	-0.15	9.27	0.65
20–50 km	3985	-1.62	10.28	0.50

Including all COMPEX-EC EarthCARE collocations

Data from within +- 50 km from match point

All seven flights (top row)

- ORA and CPR agree well overall, with maximum at **-10 dBZ at 1–1.5 km**
- ORA shows more signal > -10 dBZ at low levels



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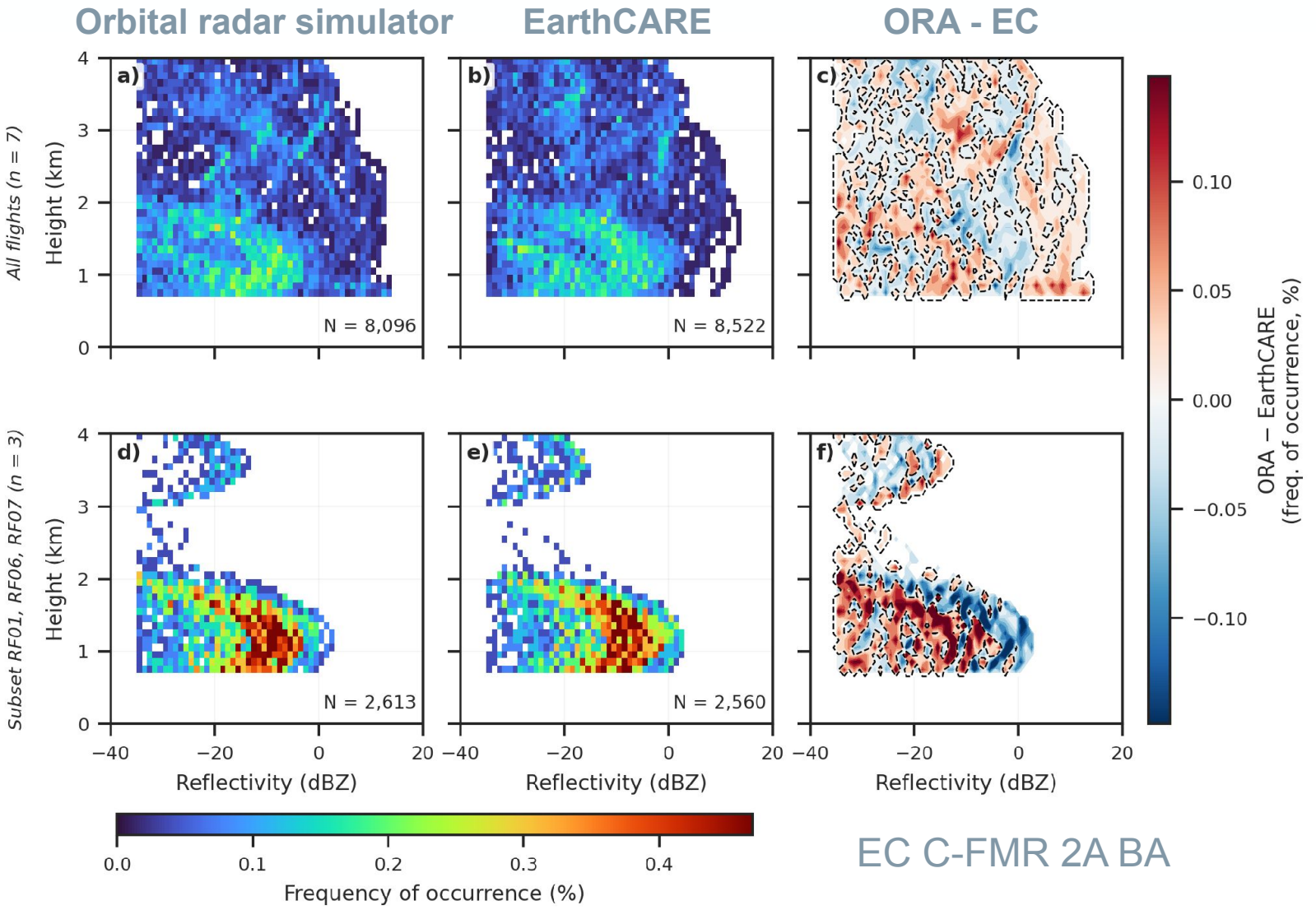
Subset of 4 MCAO flights (bottom row)

- **Convective mode** with a broad reflectivity spread (−35 to 0 dBZ) peaking around **1.0 km** captured by both
- EC **has less occurrence at 1–2 km** (red) at lower reflectivities while slightly **higher occurrence at higher reflectivities (>-5 dBZ)** (blue)



Summary

EarthCARE CPR can captures Arctic cloud structure

Overall good agreement compared to airborne measurements during 7 COMPEX-EC collocations

Collocation is critical as agreement improves with proximity

Spatial mismatch dominates uncertainty in cross-platform comparisons (correlation decrease from 0.79 (match) to 0.5 (50 km)

Instrument-specific sensitivities and characteristics reveal complementary strengths

EarthCARE CPR tends to overestimates CTH

ATLID CTH retrieval fails in some cases for CAO clouds

Summary & Outlook

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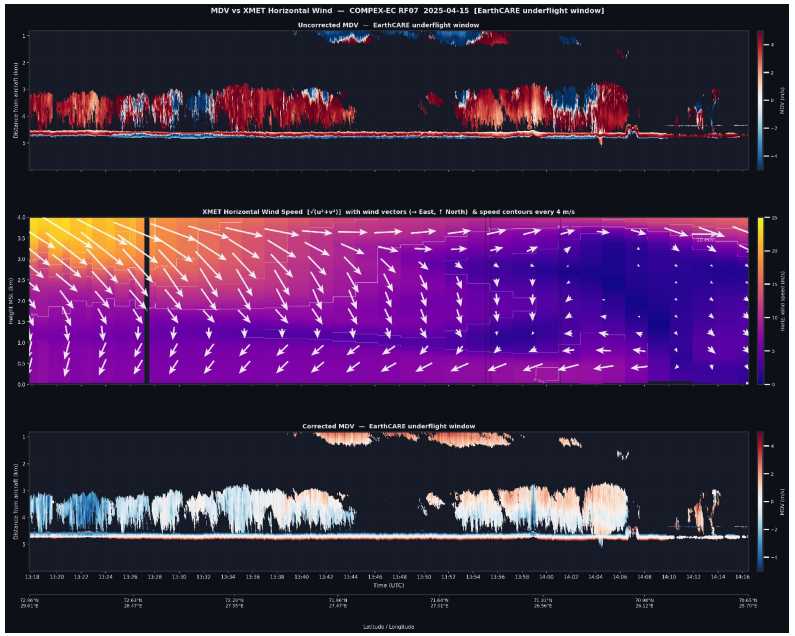
EarthCARE CPR tends to overestimates CTH
ATLID CTH retrieval fails in some cases for CAO clouds

Orbital radar simulator applied to MiRAC can mimic EarthCARE CPR observations
Apply ORA on MiRAC for all 84 RFs from 7 campaigns in Arctic in different seasons to estimate ECs CPR performance

Manuscript van Gelder et al. (2026) in preparation

Extend study to LWP, precipitation

Doppler velocity correction for Polar 5 ongoing and comparison to EC Doppler velocities



P015 Airborne Observations from the COMPEX campaign for EarthCARE Validation in the Arctic