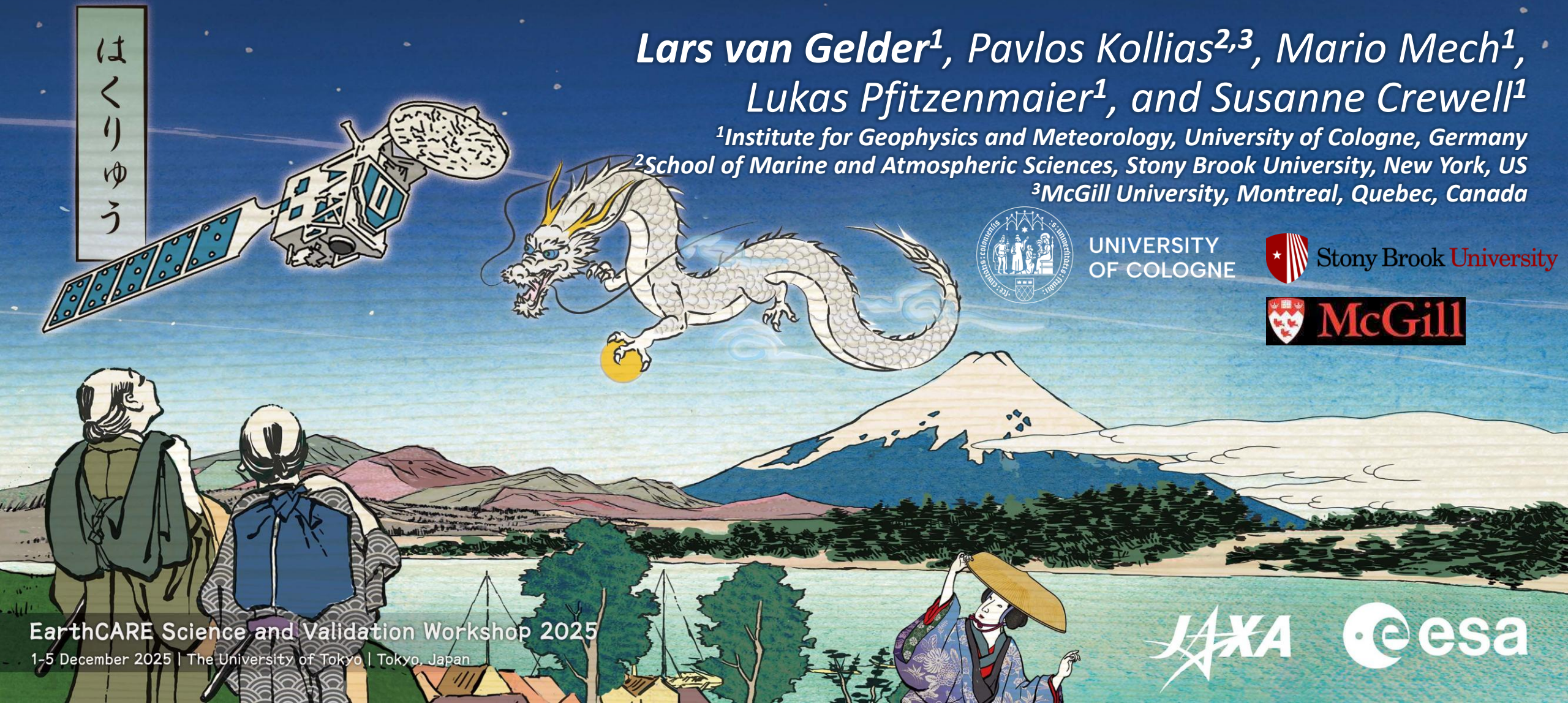
Validating EarthCARE's CPR in the Arctic: Results from the COMPEX-EC Airborne Campaign



***Lars van Gelder*[1], *Pavlos Kollias*[2,3], *Mario Mech*[1], *Lukas Pfitzenmaier*[1], *and Susanne Crewell*[1]**

[1]Institute for Geophysics and Meteorology, University of Cologne, Germany
[2]School of Marine and Atmospheric Sciences, Stony Brook University, New York, US
[3]McGill University, Montreal, Quebec, Canada

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

Clouds over cOMPlEX environment - EarthCARE

Polar 5 (AWI)
Kiruna, Sweden
April 02 to 16, 2025

7 research flights from Kiruna (+1 test flight in Bremen) with in total 31 flight hours

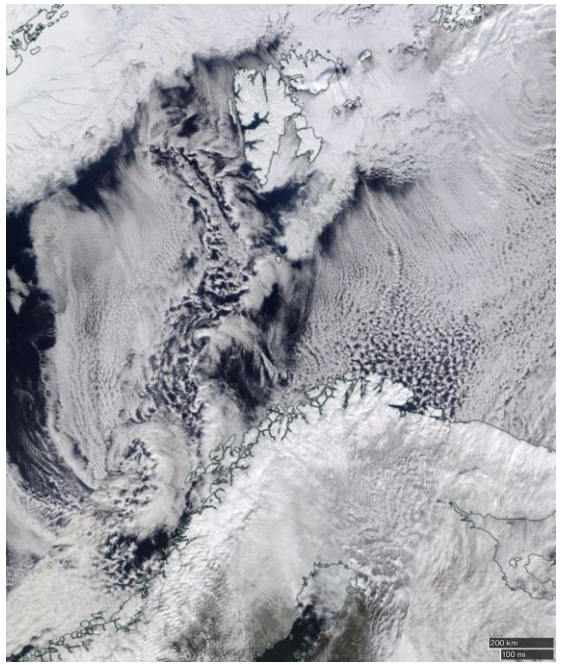
5.68 h of EarthCARE underflight in different weather situations

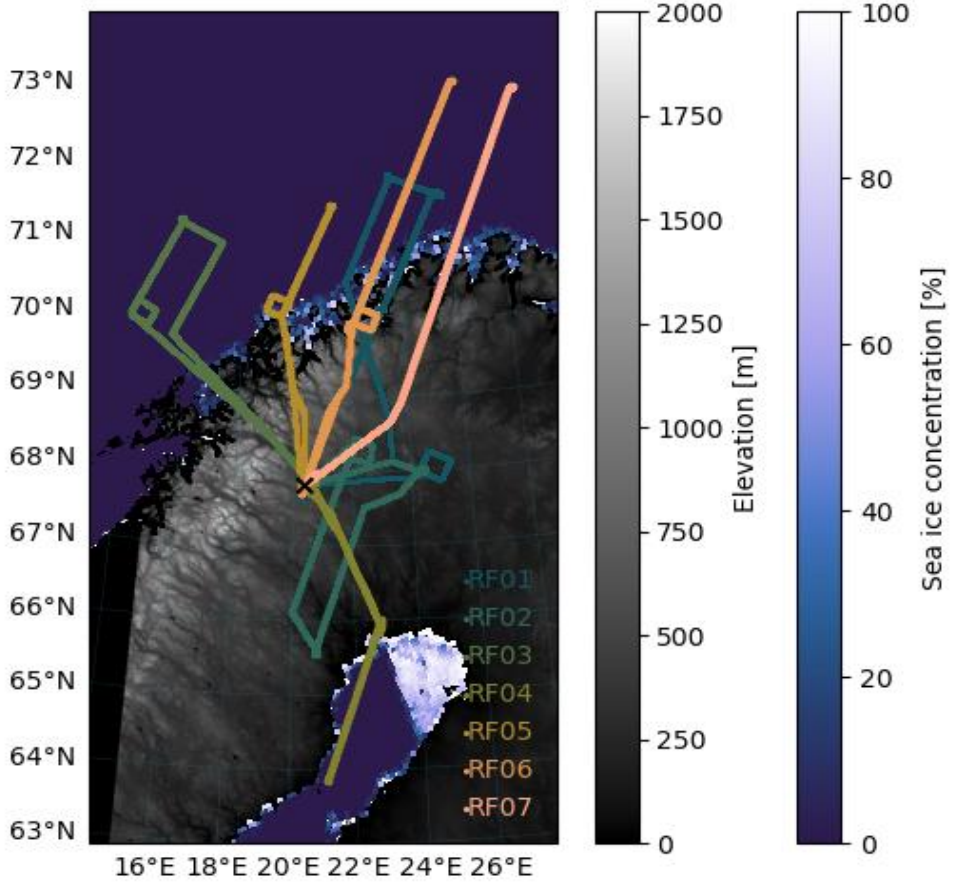
Goals

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

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

NASA Worldview – MODIS, © NASA





Instrumentation

Polar 5 - Alfred Wegener Institute
operated by Kenn Borek Air (CDN)
Basler BT-67 (former DC-3 build in 1943)
one-way range ~900 km, height < 5 km
Home base in Bremen, Germany

Microwave Radar/radiometer for Arctic Clouds (MiRAC)

Mech et al. (2019)

94 GHz, FMCW, dopplerized, 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**, vertical distribution

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)	-35 to -40 dBZ (1 km alt)

Dropsondes

- **Profiles of atmospheric prop.**
- **T, RH, P, u, v**

Airborne Mobile Aerosol Lidar (AMALi)

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

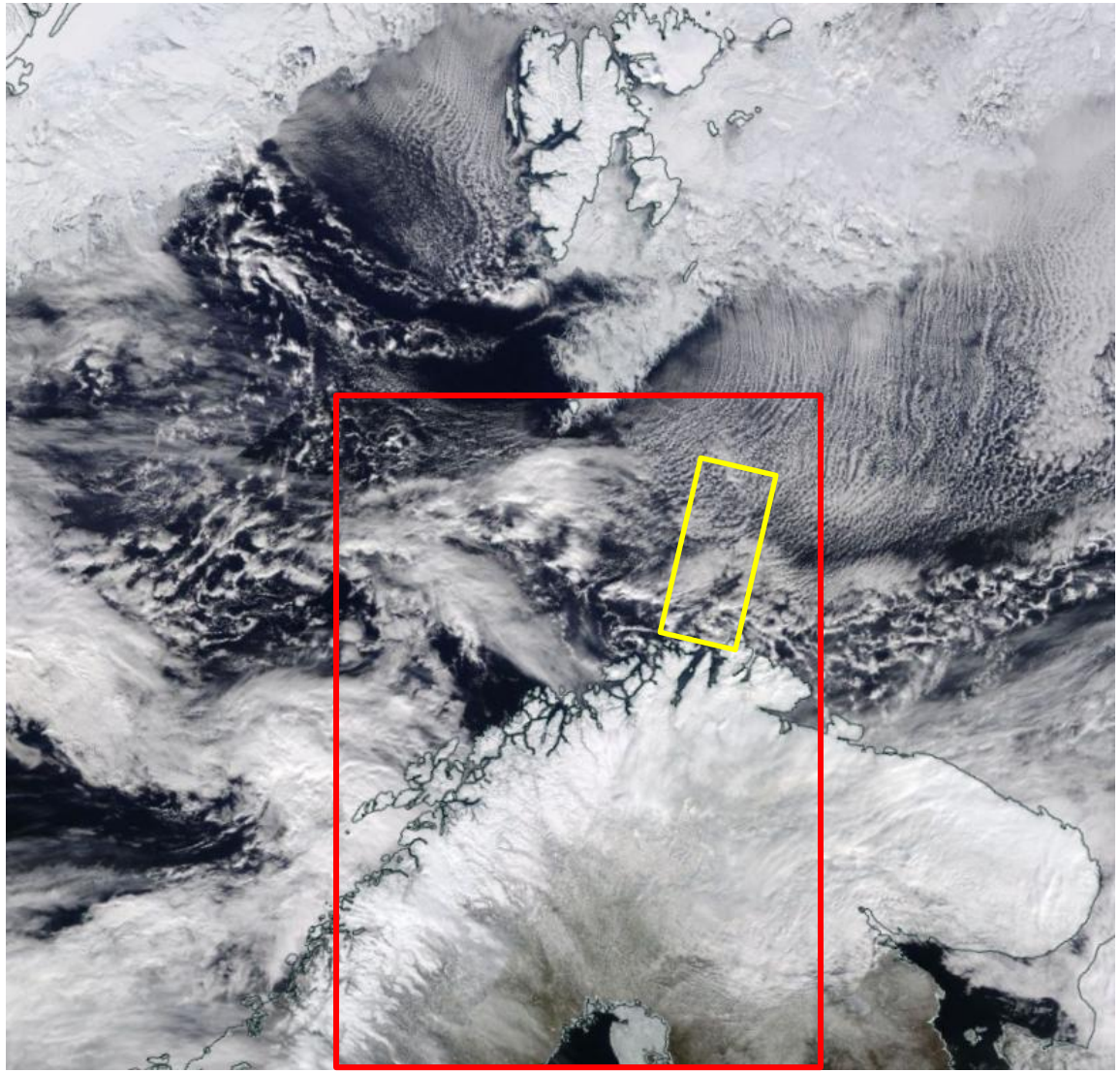
Broadband and spectral radiation

AISA EAGLE/HAWK

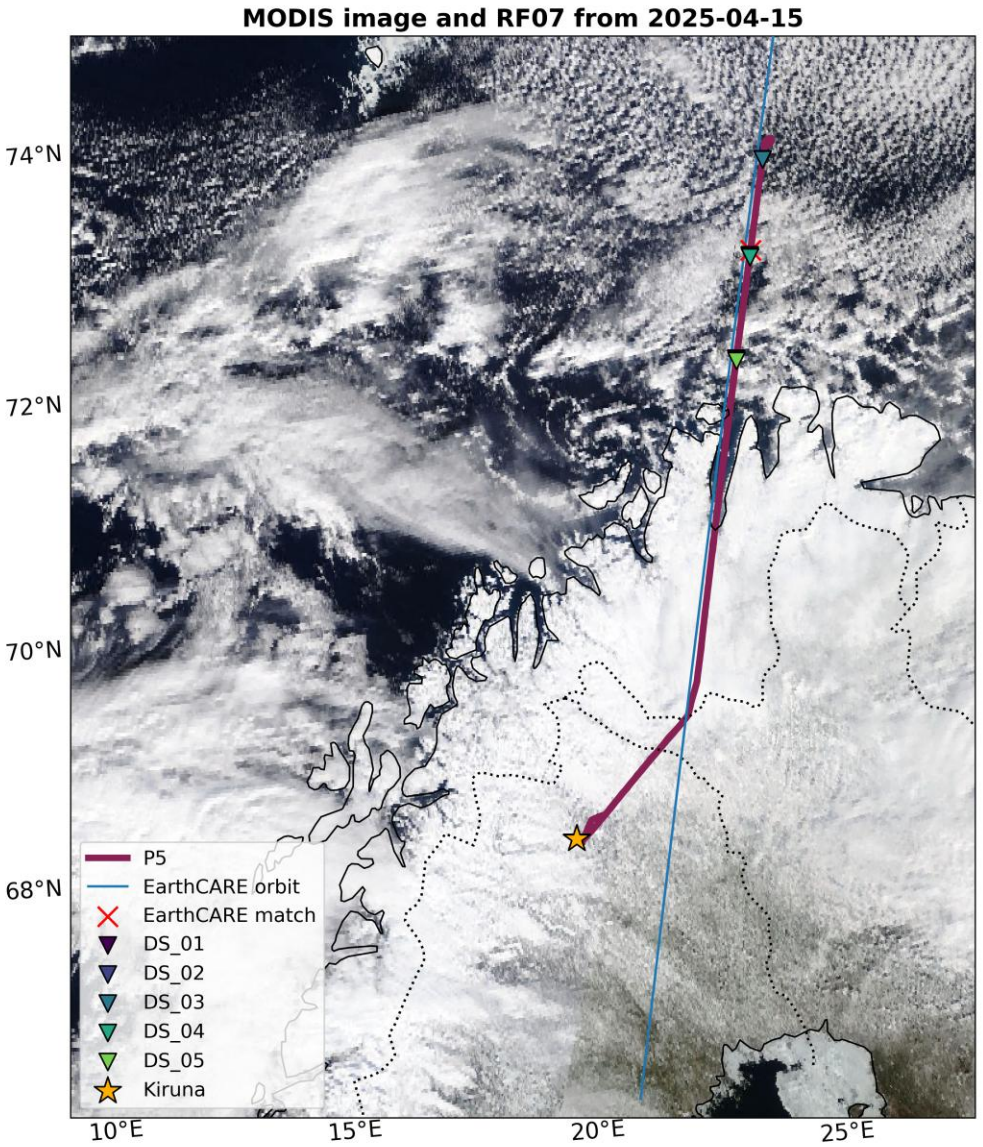
Imaging spectrometers

MW radiometer
KT-19
fish-eye
Nikon

Flight overview Research Flight 07

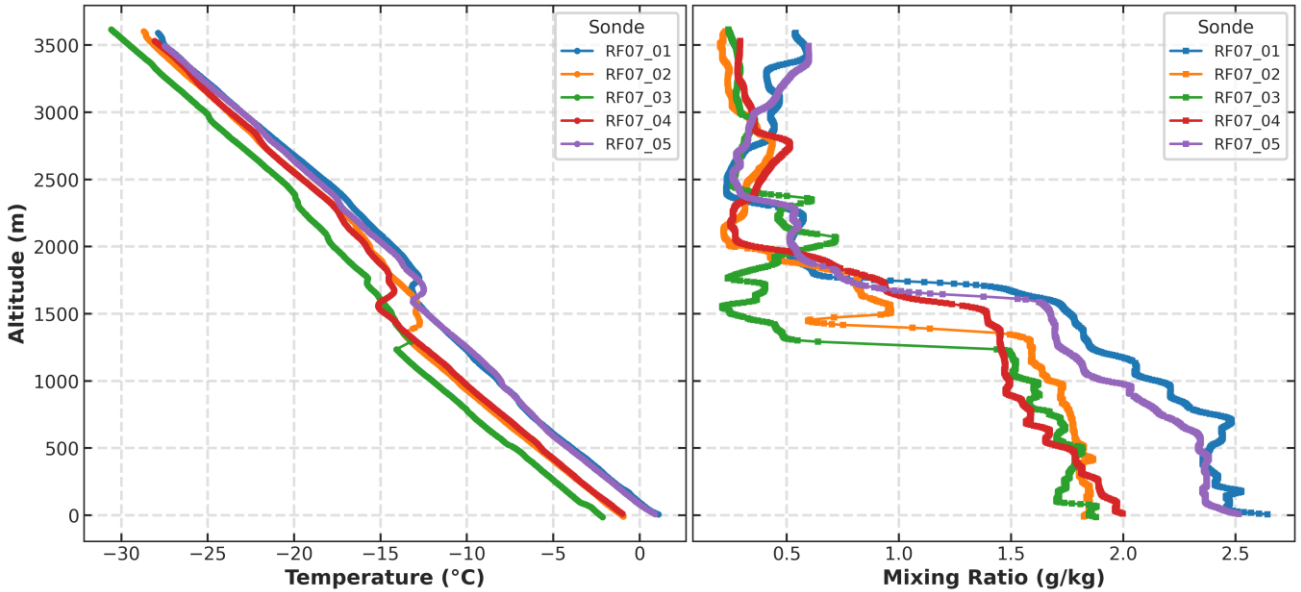


NASA Worldview – MODIS, © NASA

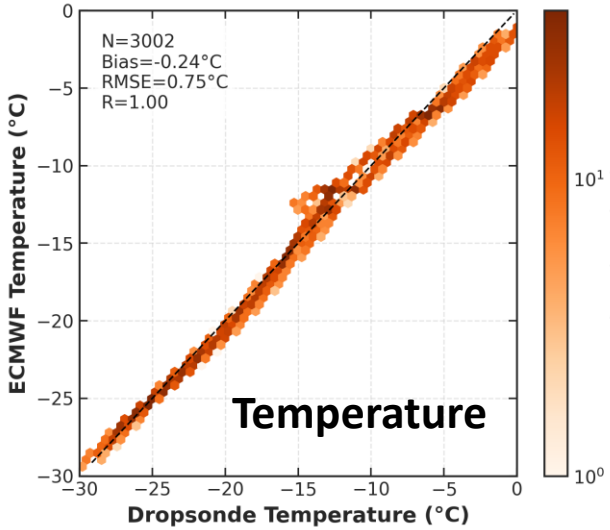


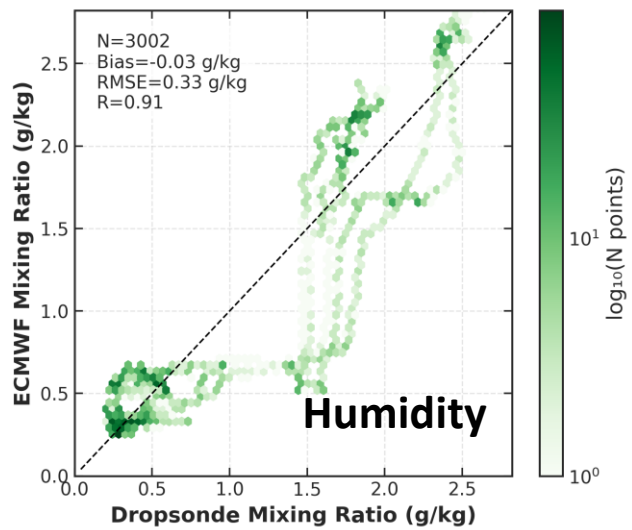
Dropsondes vs XMET RF07

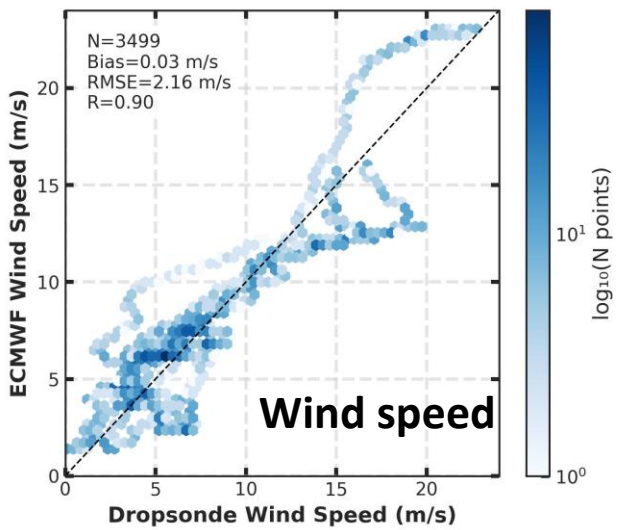
Dropsondes: Temperature

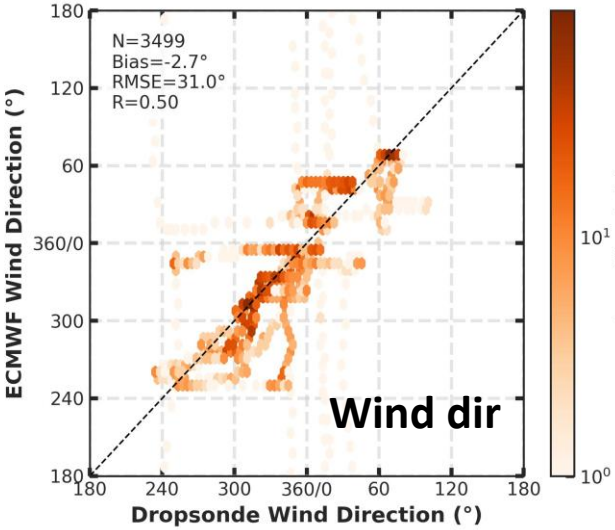


Dropsondes: Humidity









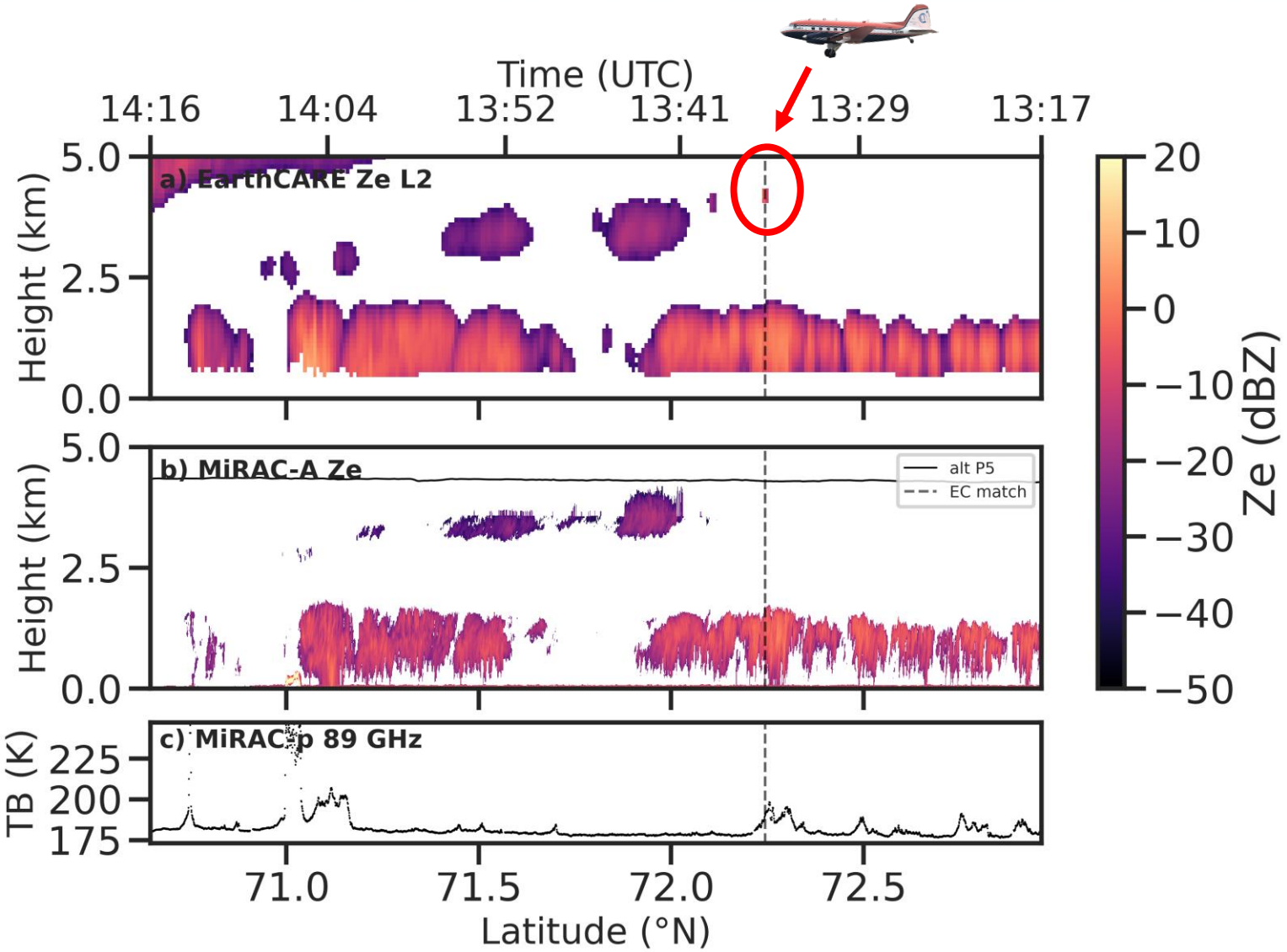
Quicklook RF07

- Polar 5 aircraft is visible in CPR_FMR Baseline **BA** product

- Quicklook: good agreement in radar reflectivity

- TB proportional to LWP

→ Derivation of LWP

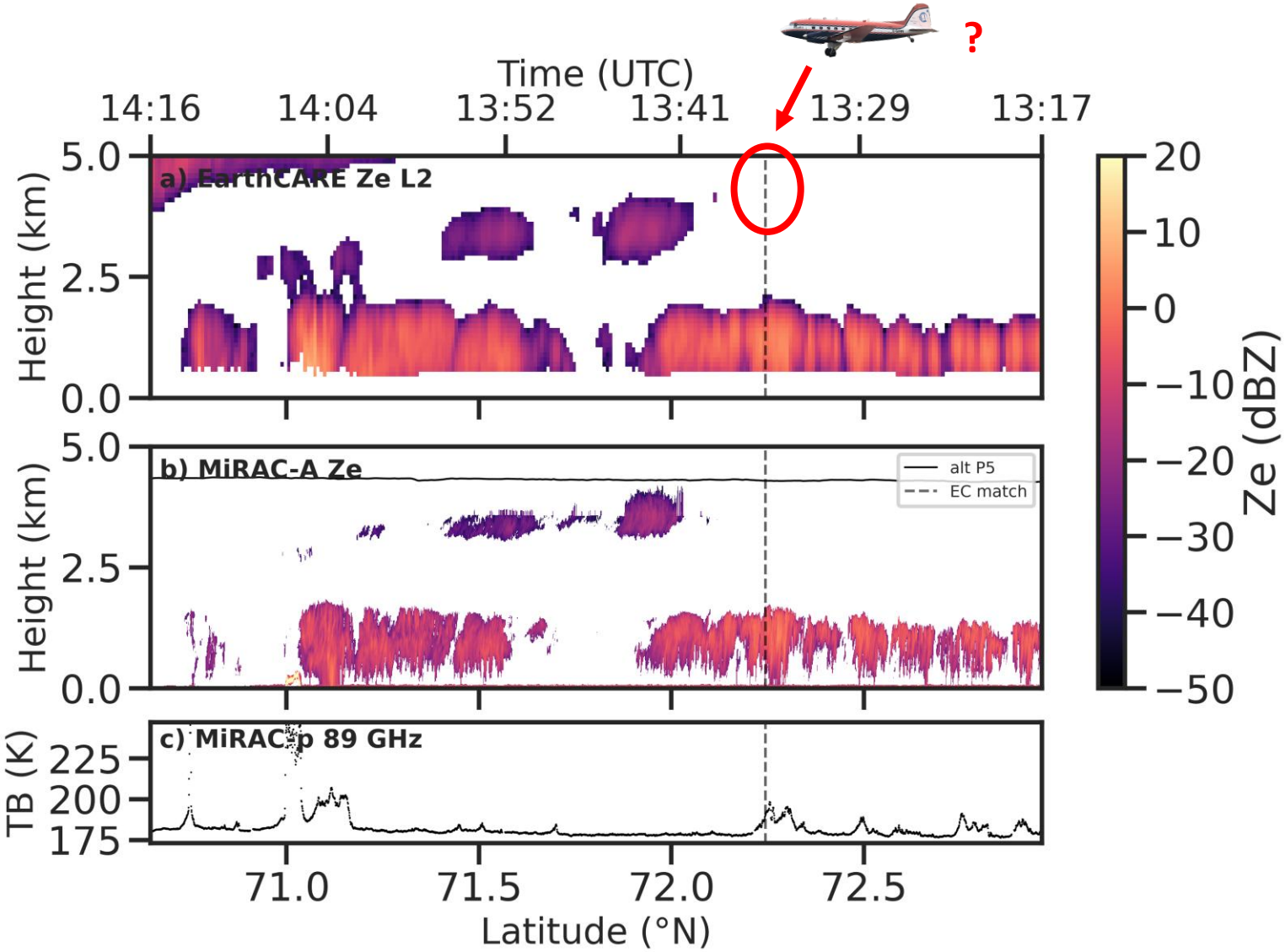


Quicklook RF07

- Polar 5 aircraft is **NOT** visible in CPR_FMR Baseline **AC** product

- Quicklook: good agreement in radar reflectivity
- TB proportional to LWP

→ Derivation of LWP



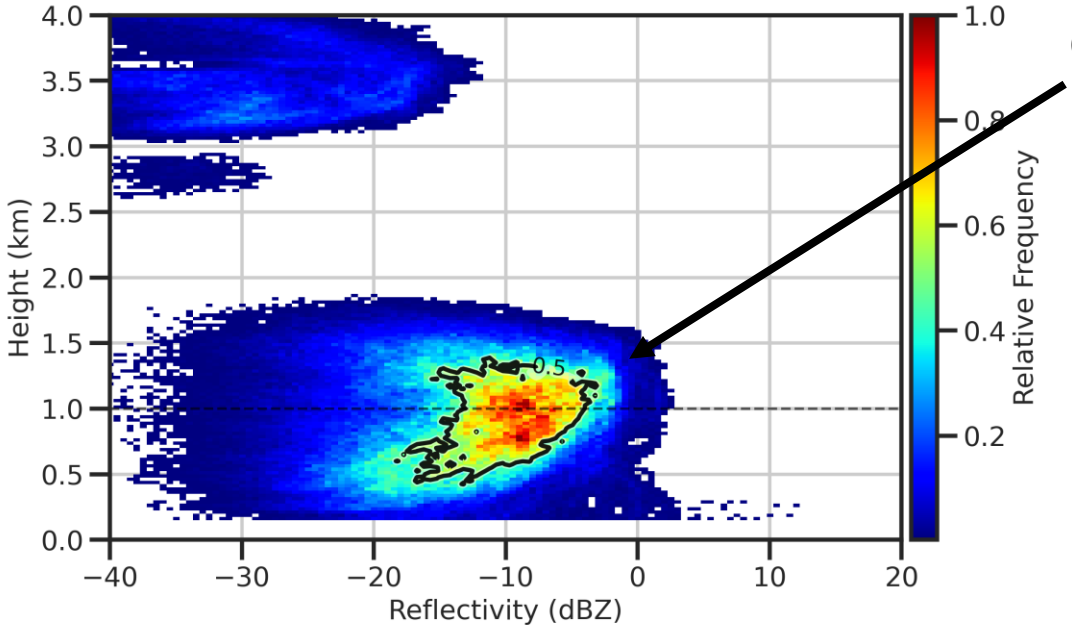
CFAD RF07 – April 15, 2025

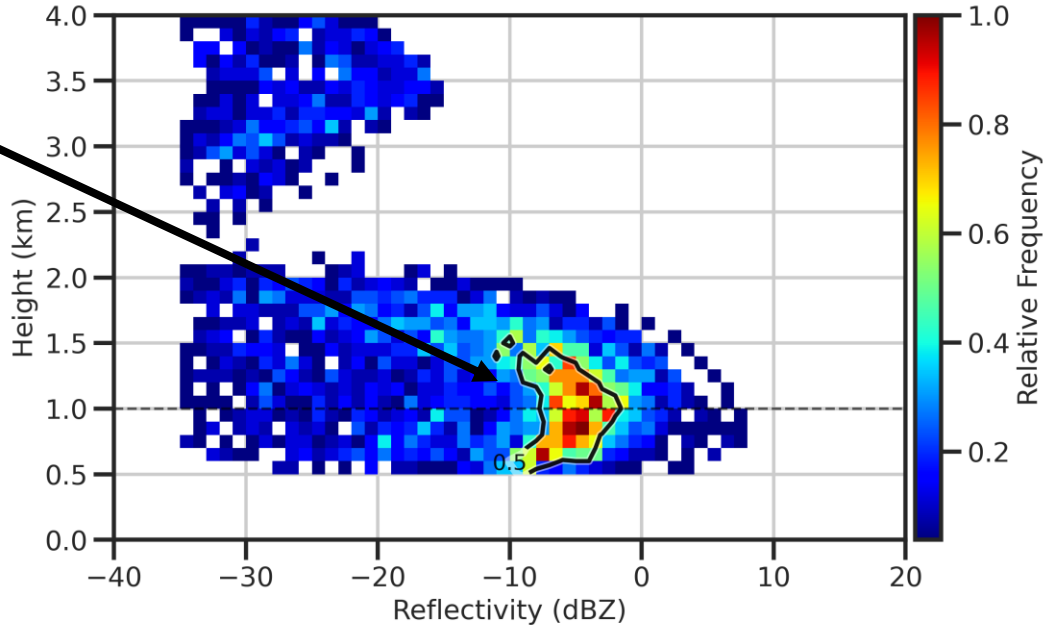
MiRAC (airborne)

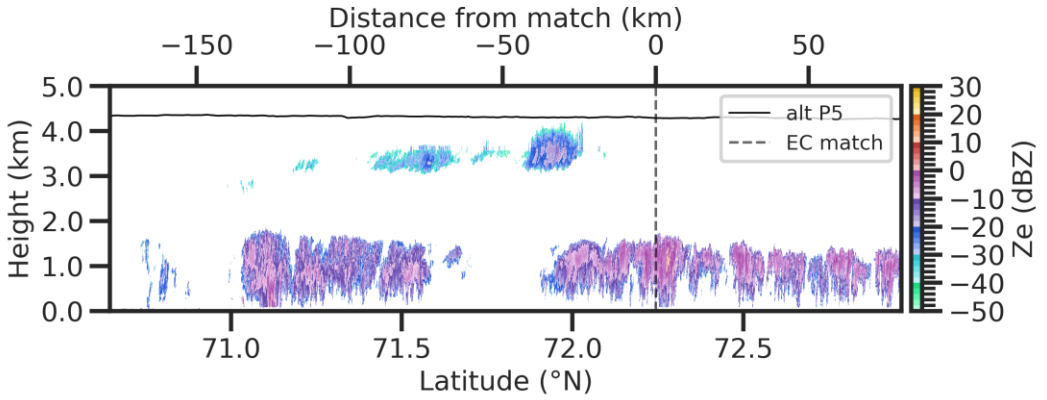
Peak of Ze with 2 dBZ difference

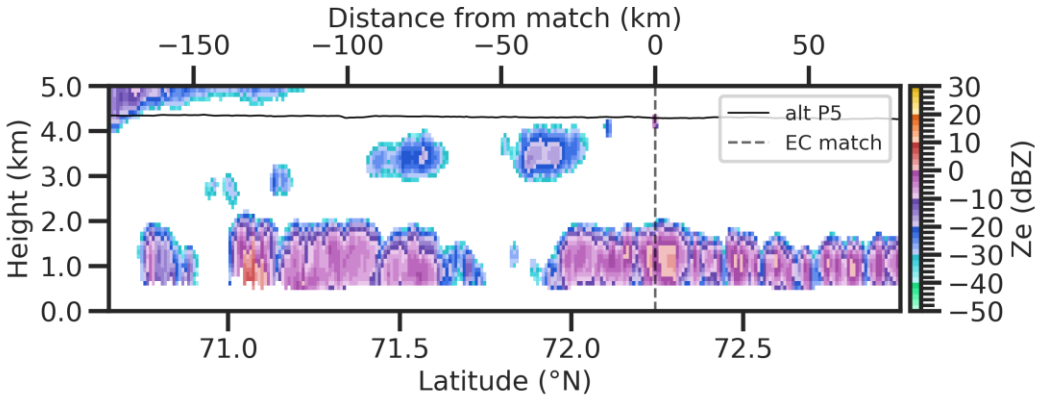
EarthCARE's CPR

Baseline BA



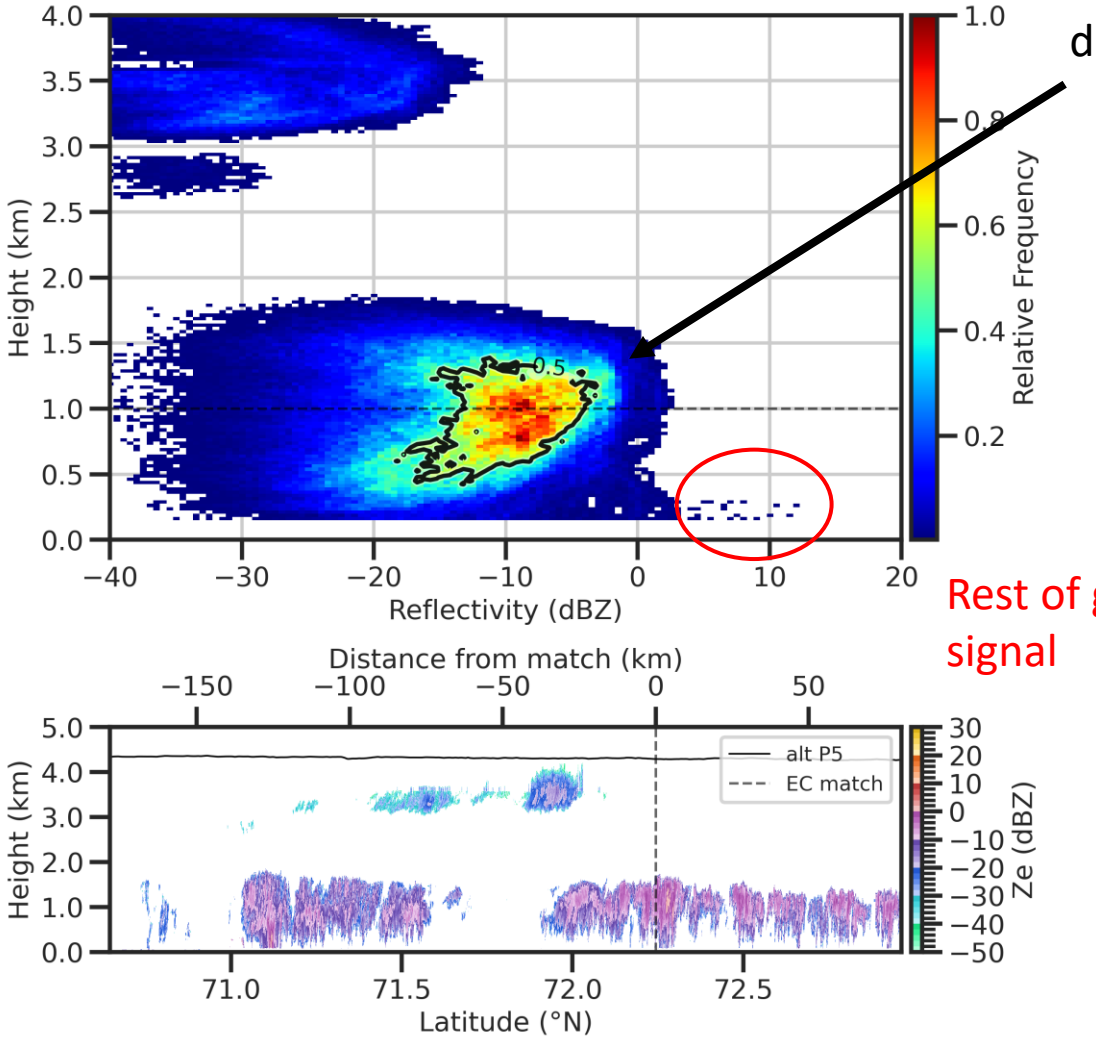






CFAD RF07 – April 15, 2025

MiRAC (airborne)

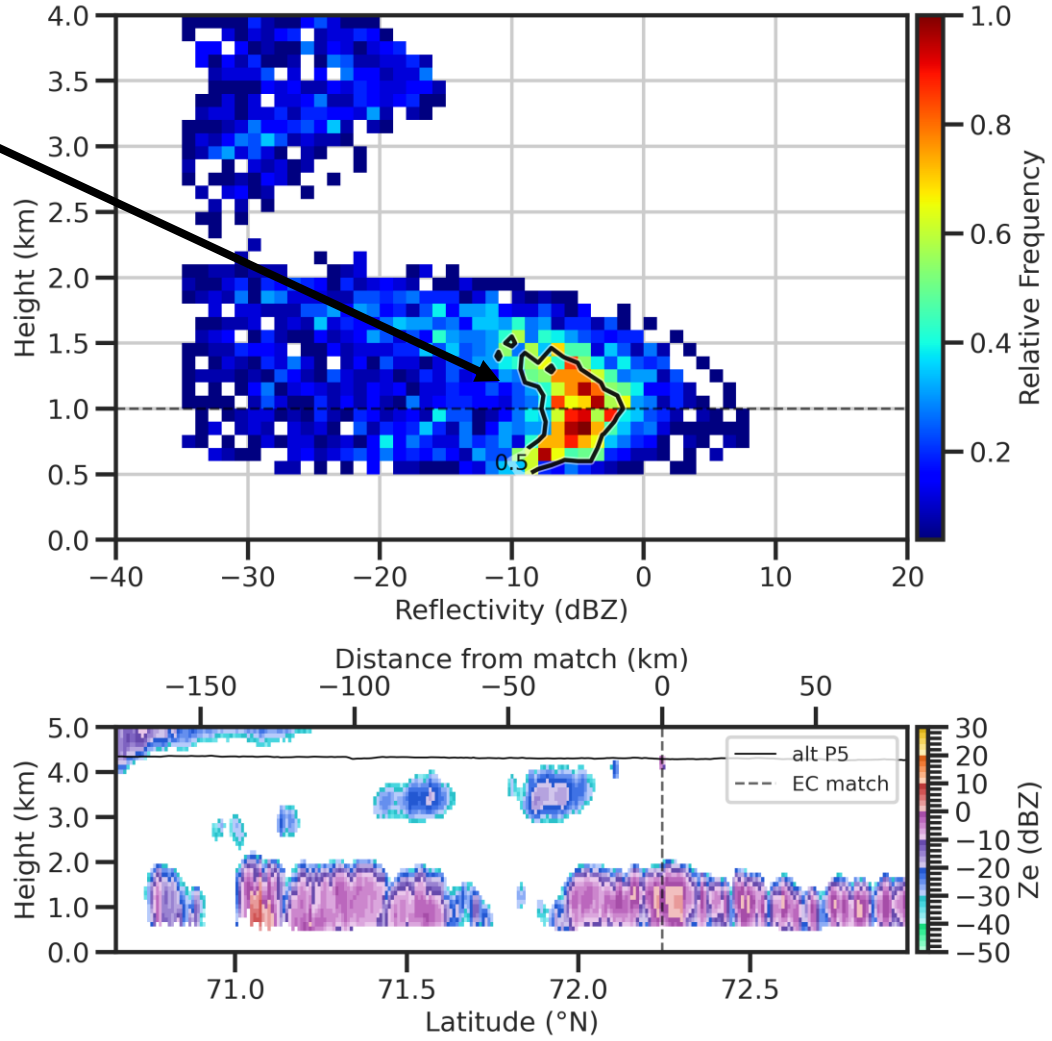


Peak of Ze with 2 dBZ difference

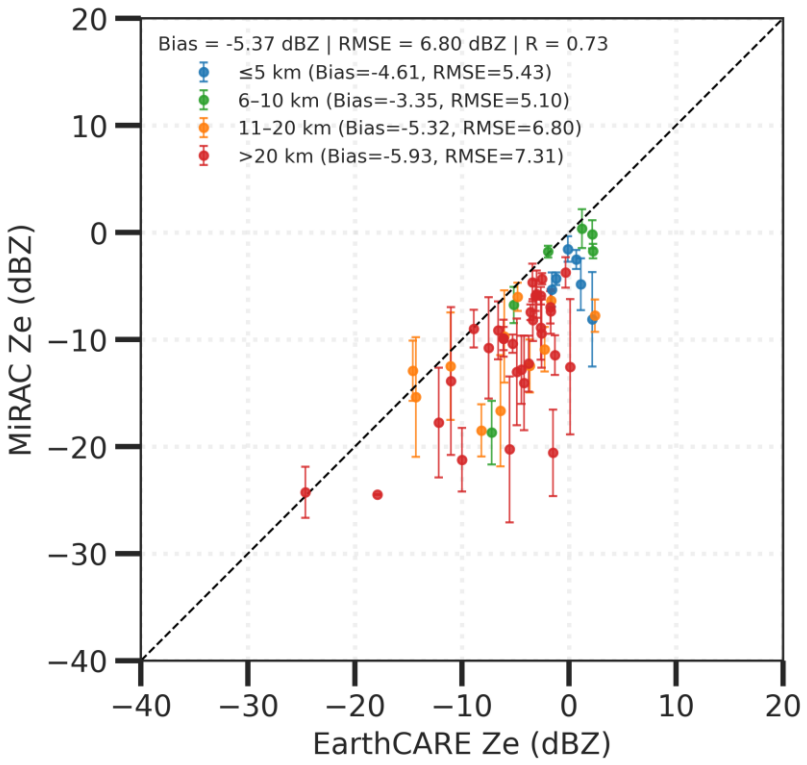
Rest of ground signal

EarthCARE's CPR

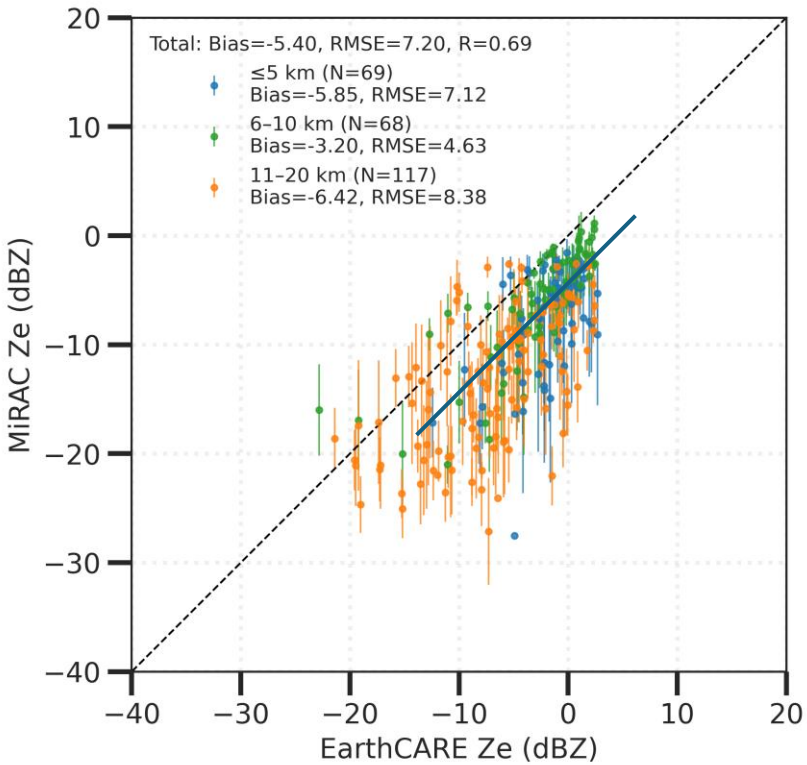
Baseline BA



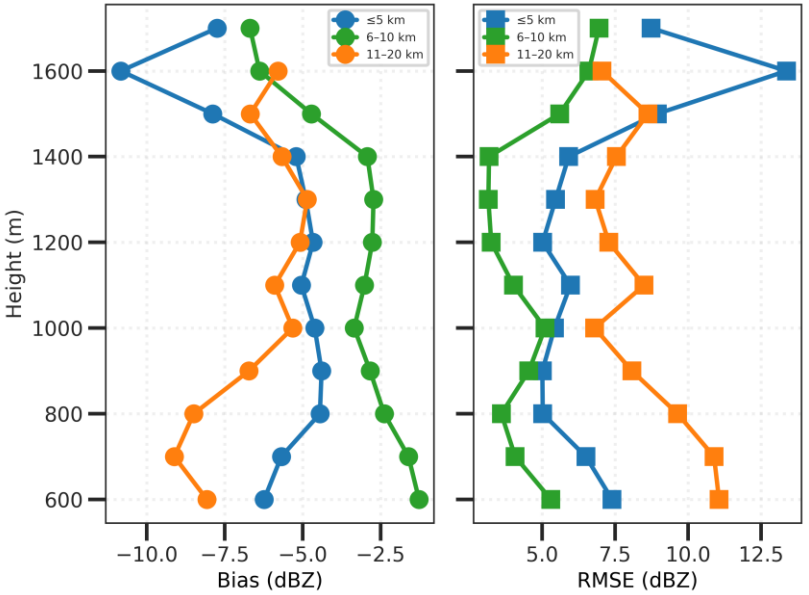
Preliminary statistics RF07



EC height ~1000m
MiRAC means from ± 50m of 1000m height



EC all available heights with signal
MiRAC mean from ± 50m of a certain height



Height-dependent bias and RMSE
of different distance clusters

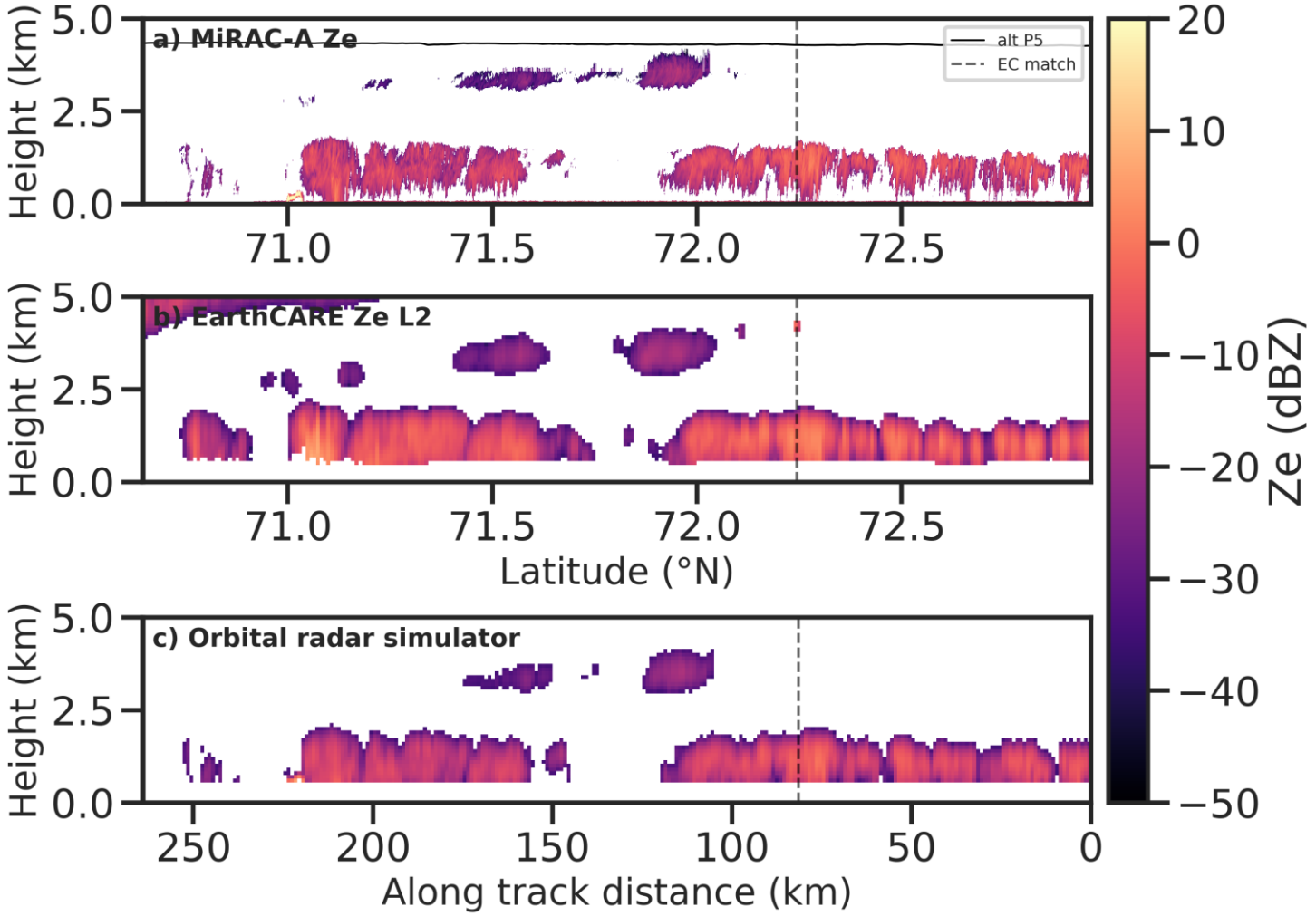
Calibration offset? → Needs to be corrected for MiRAC (in progress)

Orbital radar simulator

- Application of the orbital radar simulator (Pfitzenmaier et al., 2025)

- **Convert high-resolution airborne W-band radar reflectivities into synthetic EarthCARE CPR measurements**, applying EarthCARE's sampling geometry, pulse characteristics, sensitivity, and noise model

→ Ongoing: Statistical comparison of EarthCARE CPR L2 vs Orbital radar simulator output

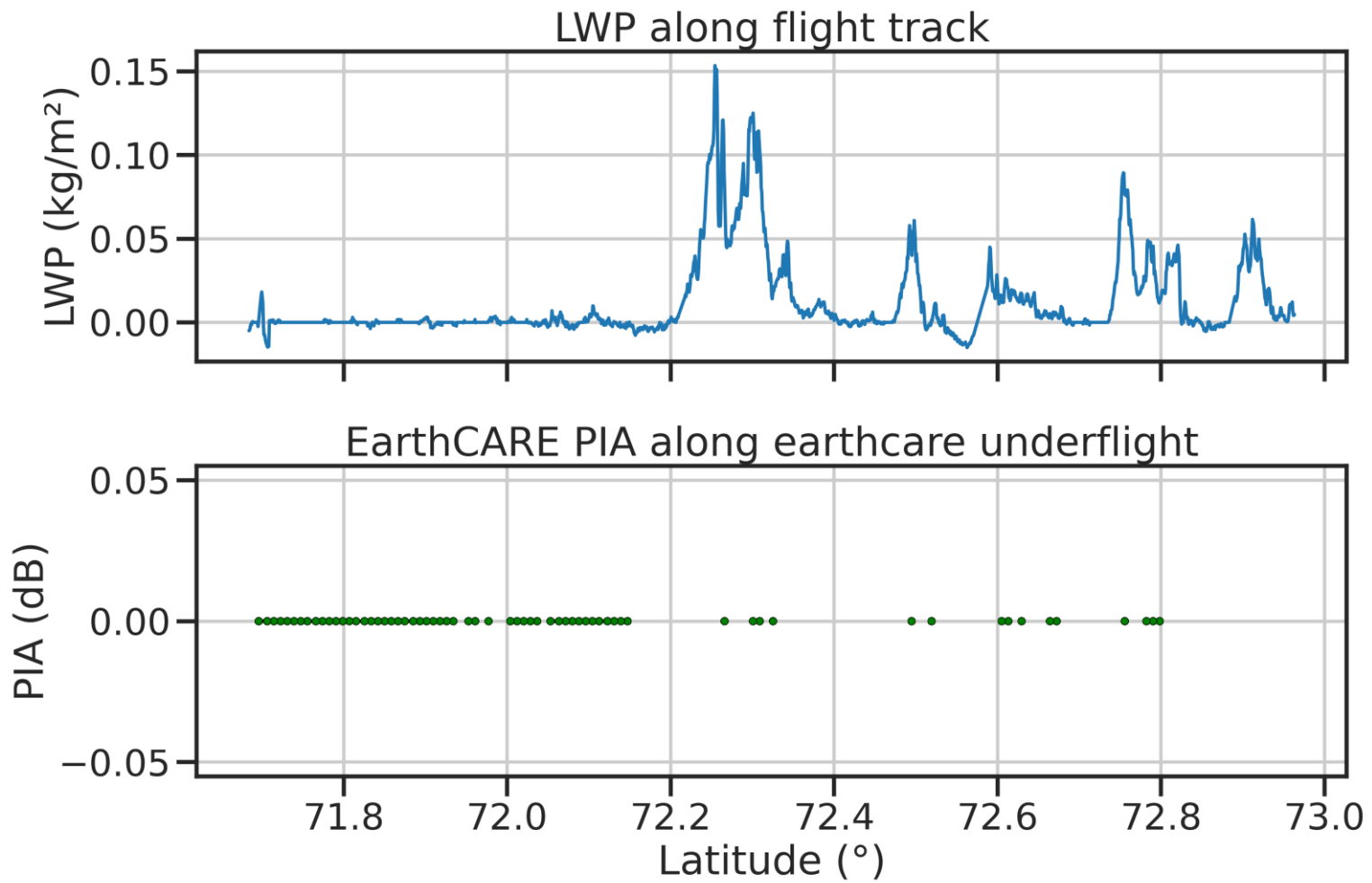


LWP and PIA

- Retrieve liquid water path (LWP) from Tb measurements
- Currently only over open ocean
- PIA shows no signals for this flight leg

→During patterns with LWP, PIA is not confident

Signal too weak → PIA limitations?

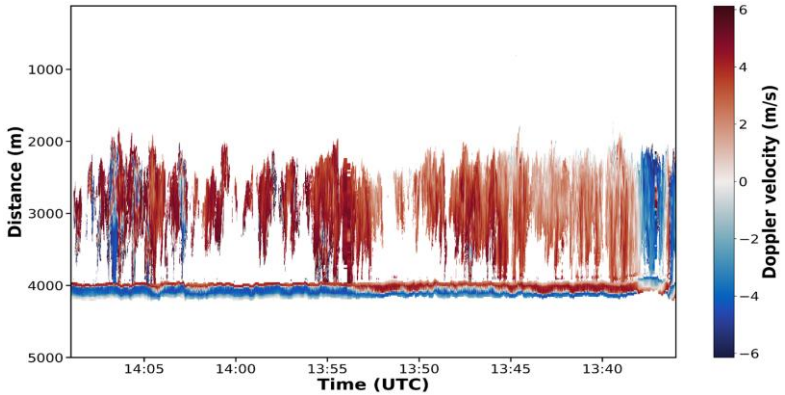


Doppler velocity retrieval (current status)

Aim:
Get terminal velocities from Doppler spectrum

→ MiRAC data need to be corrected for aircraft motion, horizontal wind and hydrometeors

Raw data



1. **Correct for ground** (Set to zero)

Roll

Pitch

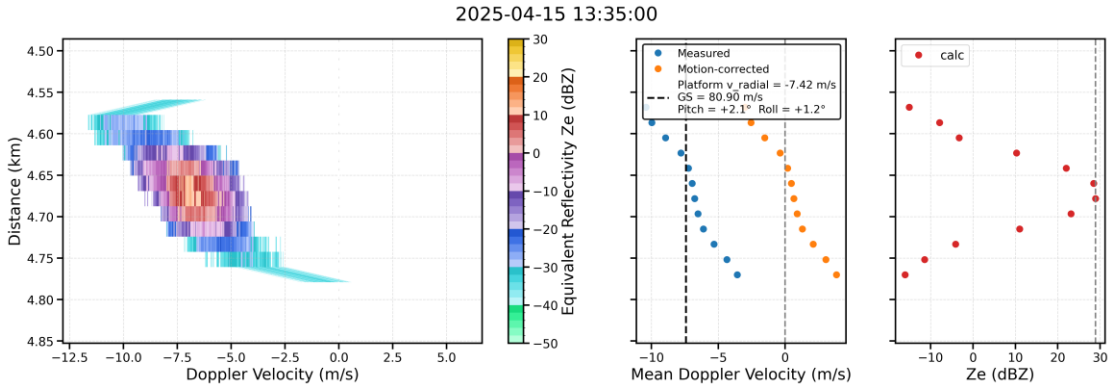
Vertical speed of aircraft

Ground speed

$$\boldsymbol{v}_{\mathrm{ac}} = \begin{bmatrix} v_{\mathrm{gs}} \\ 0 \\ v_{\mathrm{vertical}} \end{bmatrix} \qquad \hat{n}_{\mathrm{beam}} = \begin{bmatrix} \sin(\theta_{\mathrm{eff}})\cos(\phi_{\mathrm{roll}}) \\ \sin(\phi_{\mathrm{roll}}) \\ \cos(\theta_{\mathrm{eff}})\cos(\phi_{\mathrm{roll}}) \end{bmatrix}$$

$$v_{\mathrm{radial}} = -v_{\mathrm{gs}}\sin(\theta_{\mathrm{eff}})\cos(\phi_{\mathrm{roll}}) - v_{\mathrm{vertical}}\cos(\theta_{\mathrm{eff}})\cos(\phi_{\mathrm{roll}})$$

Applying folding



Qualify for each time point and flight

Shift Doppler spectrum signal in every height bin

2. Use **wind field** information to remove vertical component of horizontal wind fields

3. Hydrometeor fall velocities

Summary and Outlook

- COMPEX-EC campaign with **7 research flights** (including **EarthCARE underflights**) over **Northern Scandinavia and the Norwegian Sea**
- **Strong agreement** between dropsondes and XMET products (Wind **RMSE ≈ 2 m/s**)
- **EarthCARE CPR** and **MiRAC** reflectivities show **consistent patterns** along the underflight track
- Initial statistics indicate a **calibration offset of ~3–5 dBZ**
- **Reflectivity peak** for Arctic mixed-phase clouds at **~1 km altitude** and **–8 to –10 dBZ**
- Low-LWP case study shows **no detectable PIA signal**, highlighting **limitations in low-liquid mixed-phase clouds**

Outlook

- Expanded statistics from all flights (**Reflectivity, LWP/PIA, LIDAR data)**
- **Doppler velocity retrievals** for airborne observations in progress → insights into **Arctic cloud microphysics and dynamics**
- **Comparison and validation** with EarthCARE **best estimates**

More on poster by Mech et al. (Annex55) on COMPEX and COMPEX-EC