Airborne campaigns for better understanding Arctic amplification

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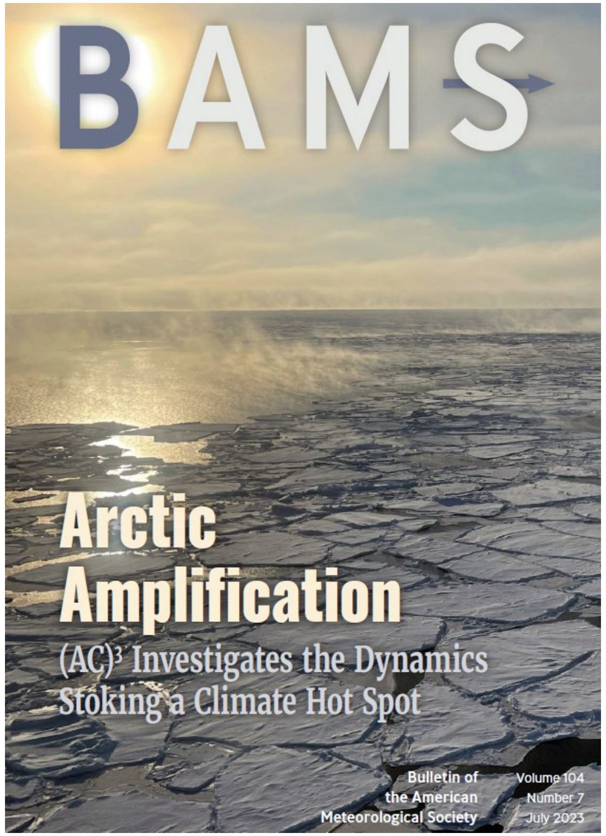
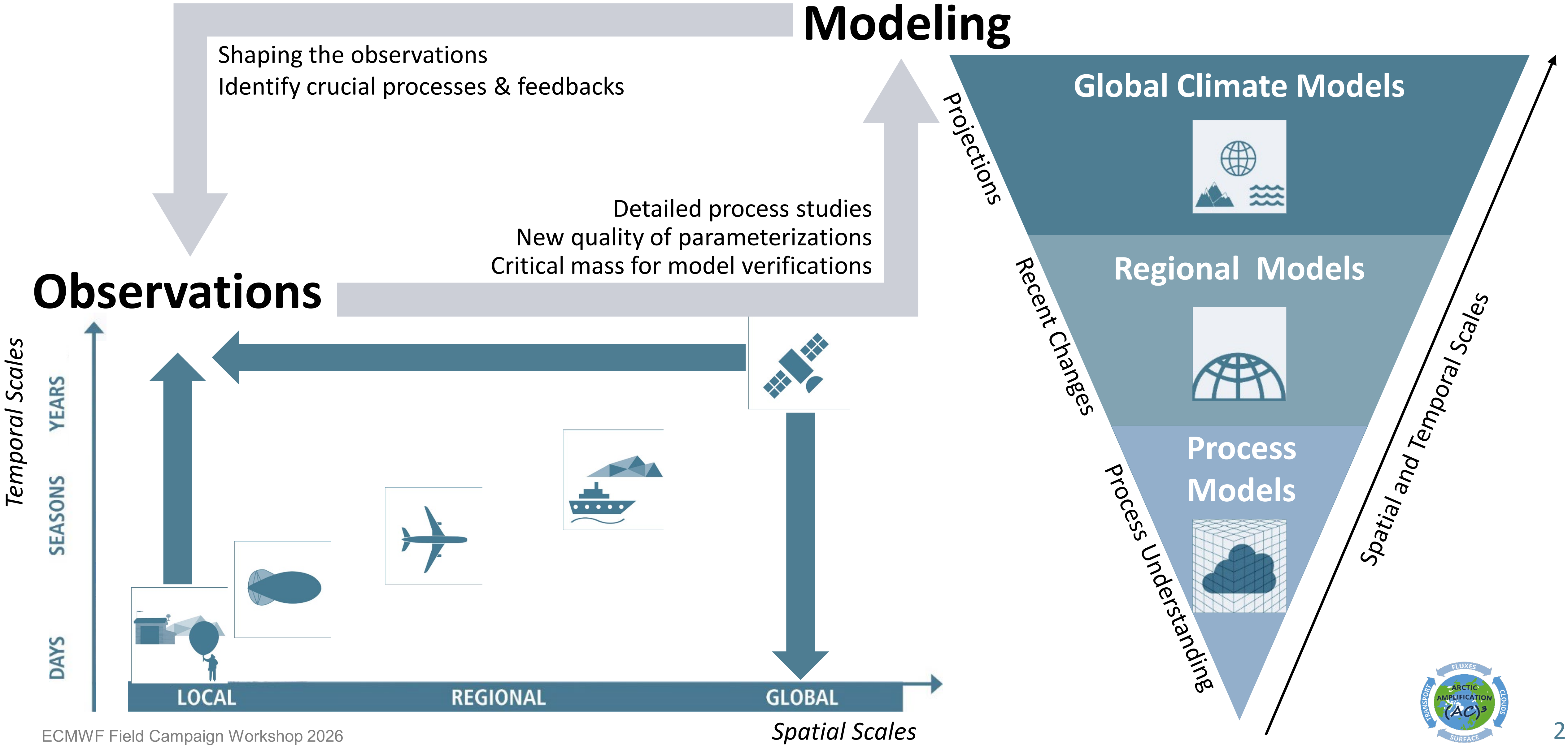
ARCTIC AMPLIFICATION (AC)³ — FLUXES, CLOUDS, SURFACE, TRANSPORT

- Causes and contributions to Arctic amplification
- Changes in and impact of meridional transports
- Identification of trends and future development

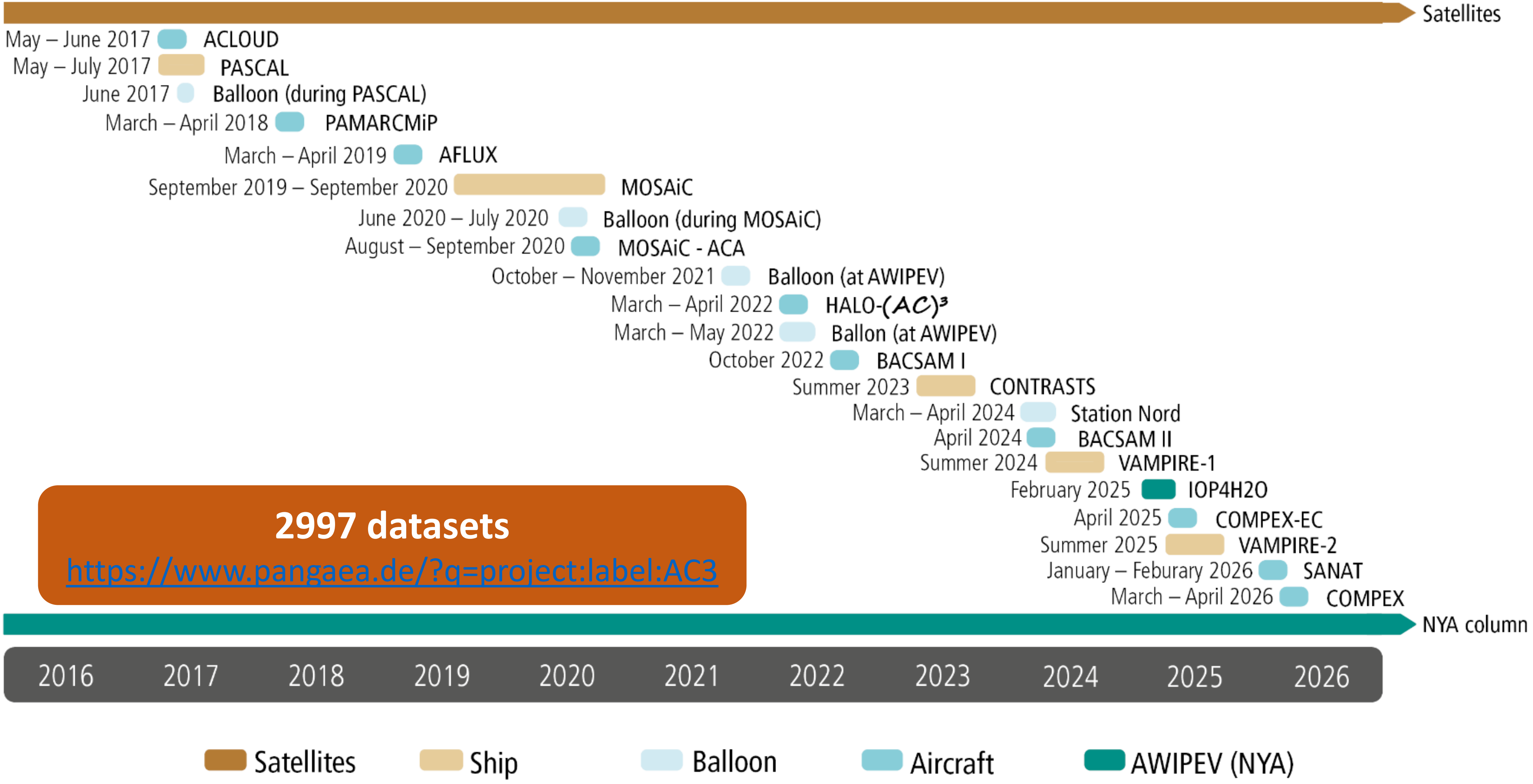


Wendisch et al., 2023

Our Approach: Combine Observations & Models



(AC)³ Delivered 12+ Years of Data



2997 datasets

https://www.pangaea.de/?q=project:label:AC3

Aircraft & Instrumentation

Polar 5 and Polar 6

Basler BT-67 (DC-3): 2300 km, 6 km, 1 t

In situ:
- cloud probes/residual
- aerosols
- chemistry
- trace gases
- turb./fluxes

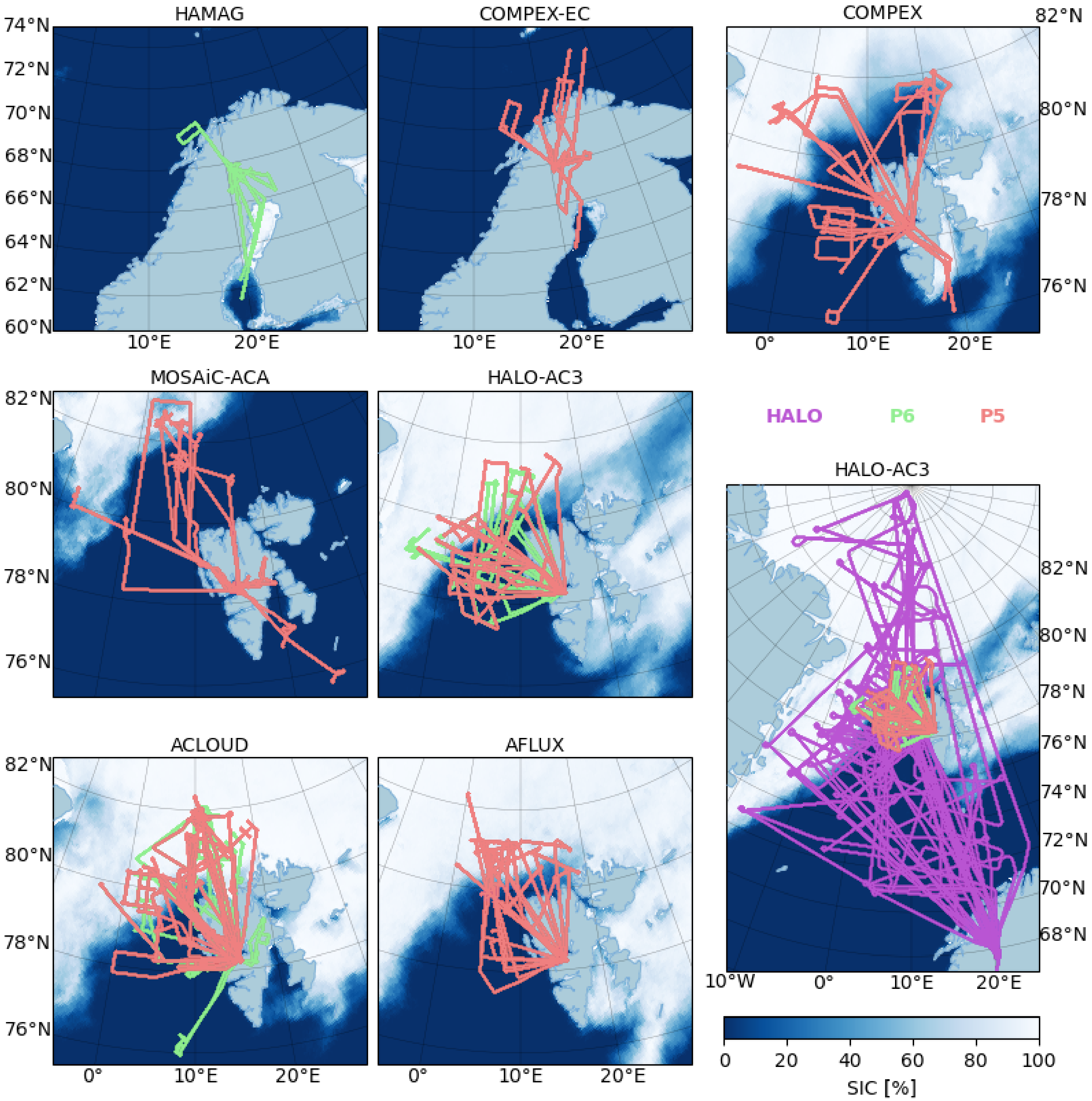
Remote sensing:
- MiRAC: 94 GHz FMCW radar + 89 GHz passive
- G-band DAR radar
- aerosol lidar
- IR, VIS, MW, radiation
- turbulence/fluxes
- dropsondes

High Altitude and LOng Range Research Aircraft

Gulfstream G550: 9000 km, 15 km, 3 t

Remote sensing:
- 35 GHz radar
- water vapor/aerosol lidar
- passive MW: 22-183 GHz
- IR, VIS
- radiation
- dropsondes

Arctic campaigns from Svalbard and Kiruna



ACLOUD: May/June 2017
Polar 5 (remote sensing) - 19 rfs, Polar 6 (in-situ) - 19 rfs

AFLUX: Mar/Apr 2019
Polar 5 (remote sensing + cloud in-situ) - 14 rfs

MOSAiC-ACA: Aug/Sep 2020
Polar 5 (remote sensing + cloud in-situ) - 10 rfs

HALO-(AC)³: Mar/Apr 2022
Polar 5 (remote sensing) - 13 rfs, Polar 6 (in-situ) - 13 rfs, and HALO

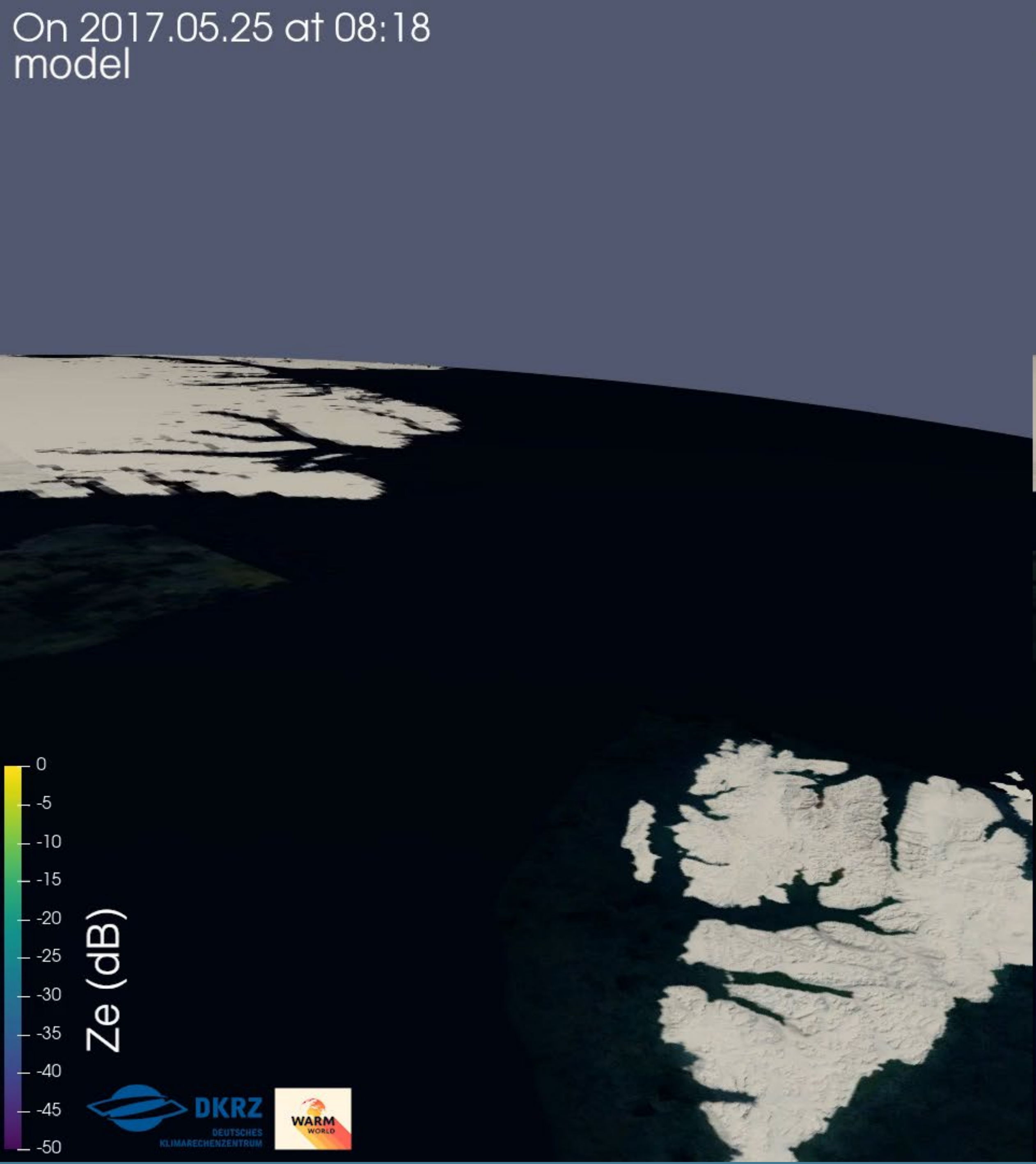
HAMAG: Feb 2024
Polar 6 (remote sensing) - 6 rfs

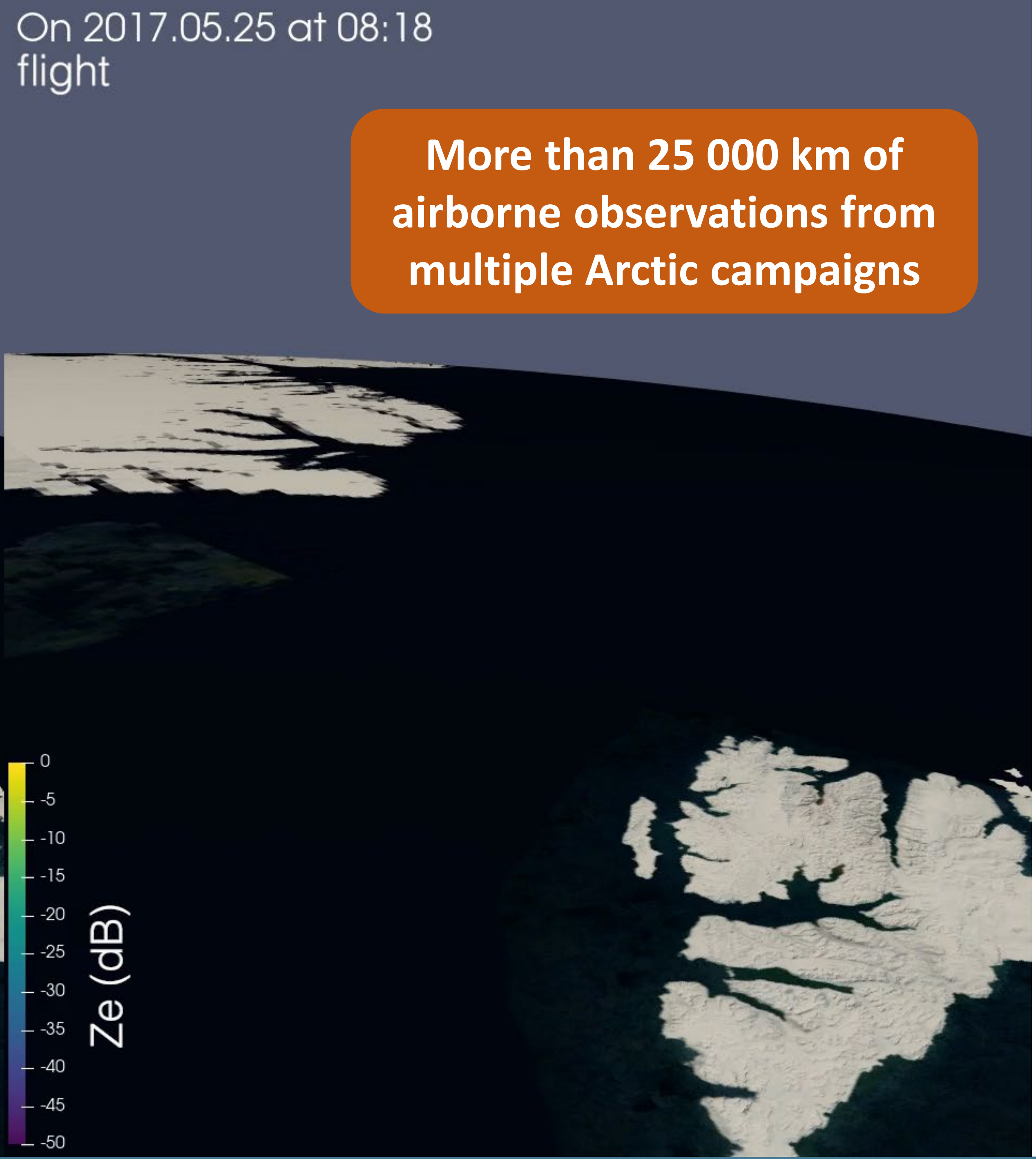
COMPEX-EC: Apr 2025
Polar 5 (remote sensing) - 7 rfs

COMPEX: Mar/Apr 2026
Polar 5 (remote sensing) - 15 rfs

> 100 research flights
> 400 flight hours out of Longyearbyen, and Kiruna

Data and products available on
https://igmk.github.io/how_to_ac3airborne/



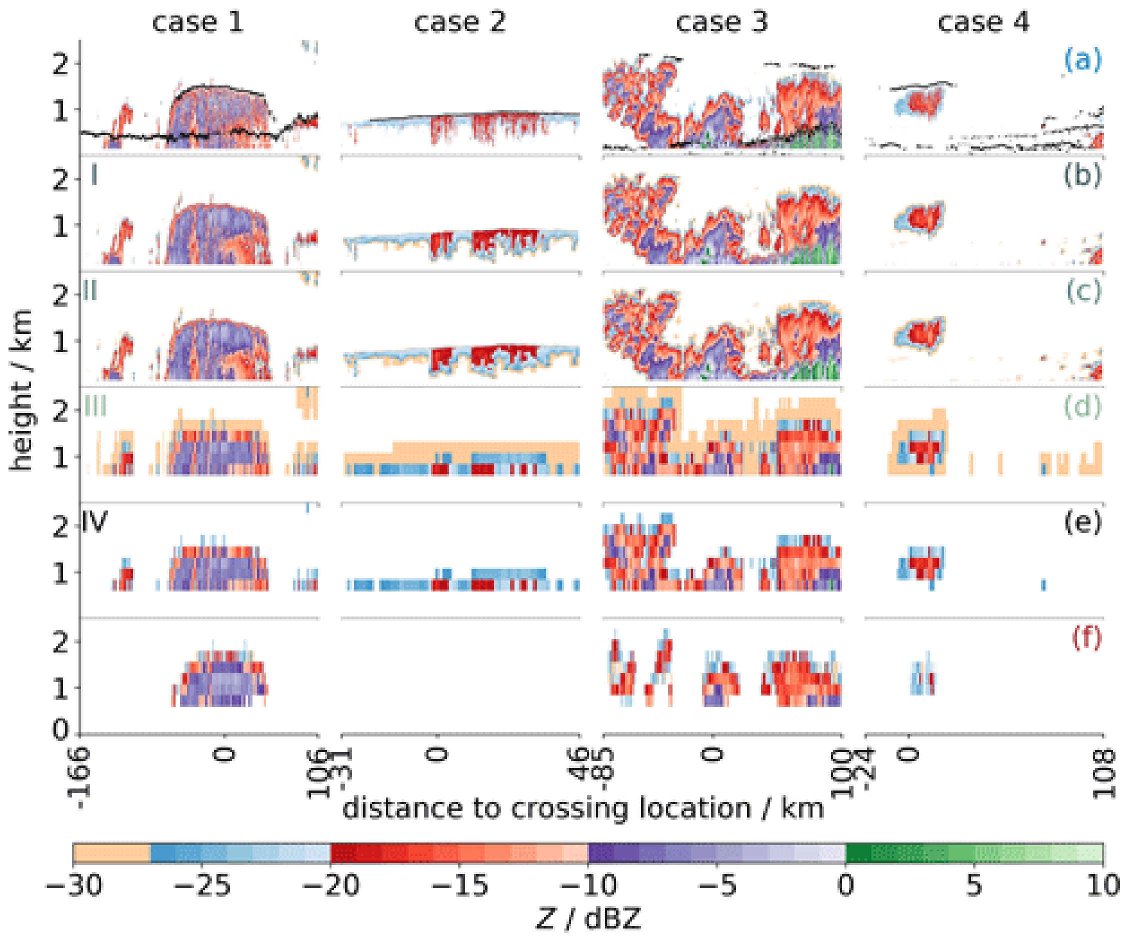


More than 25 000 km of airborne observations from multiple Arctic campaigns

Assessing Satellite Performance

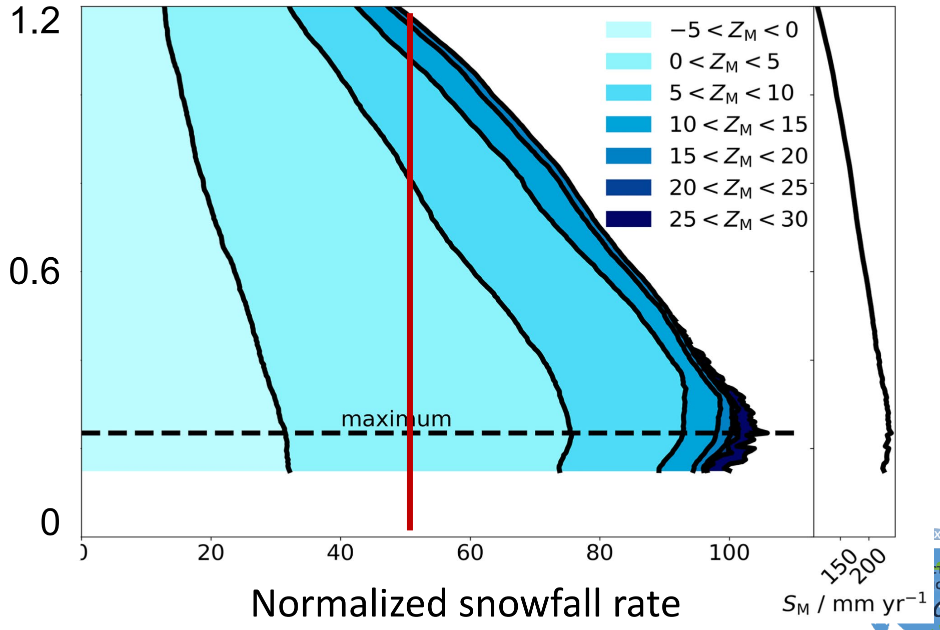
Cloudsat underflights

→ understanding resolution and sensitivity effects

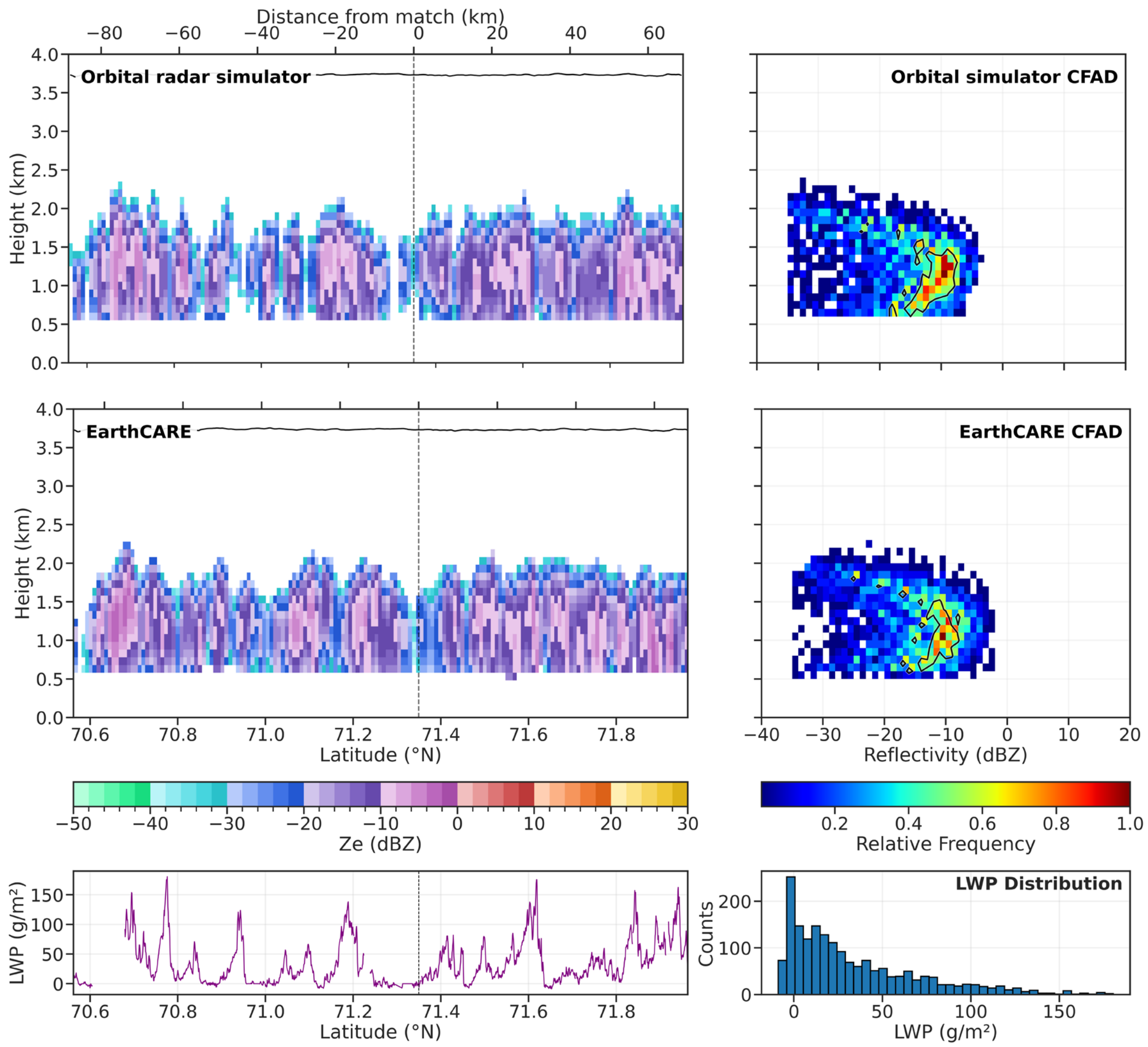


Schirmacher et al. (2023, AMT)

- Overestimation of cloud cover and cloud top height
- Reduction of snowfall rate by **factor 2** due to blind zone
  → Cloudsat misses shallow marine cold air outbreaks



Transitioning into the EarthCare Era



COMPEX - EC

Clouds over cOMPlEX environment - EarthCare

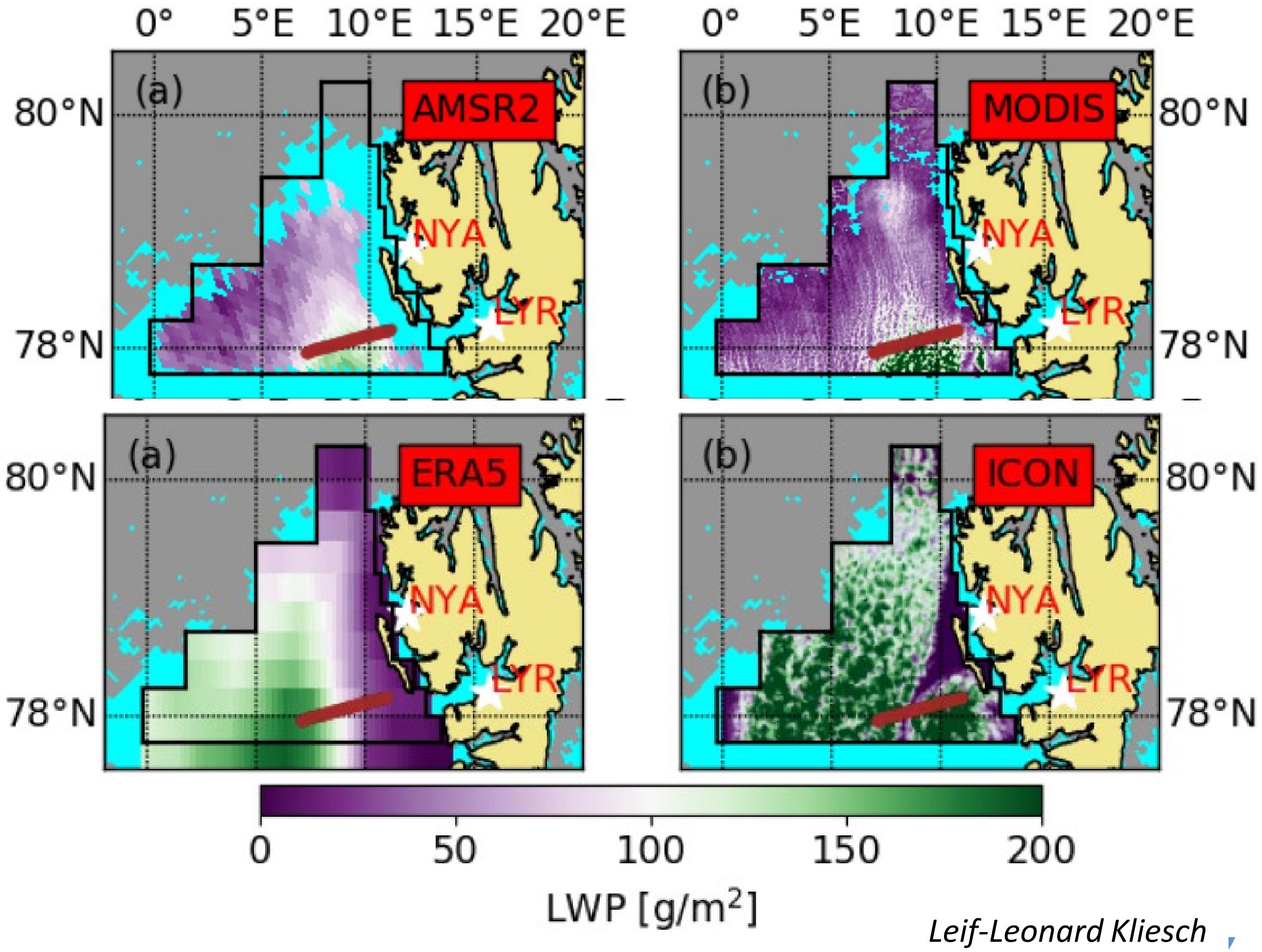
- Dedicated campaign in March April 2025 with 7 underflights – all low clouds!
- Use of suborbital radar simulator (Pfitzenmaier et al., 2025) yields excellent agreement
- Liquid Water path (LWP) could not be detected by EarthCare PIA

Lars van Gelder

Large problems in domain-wide LWP information

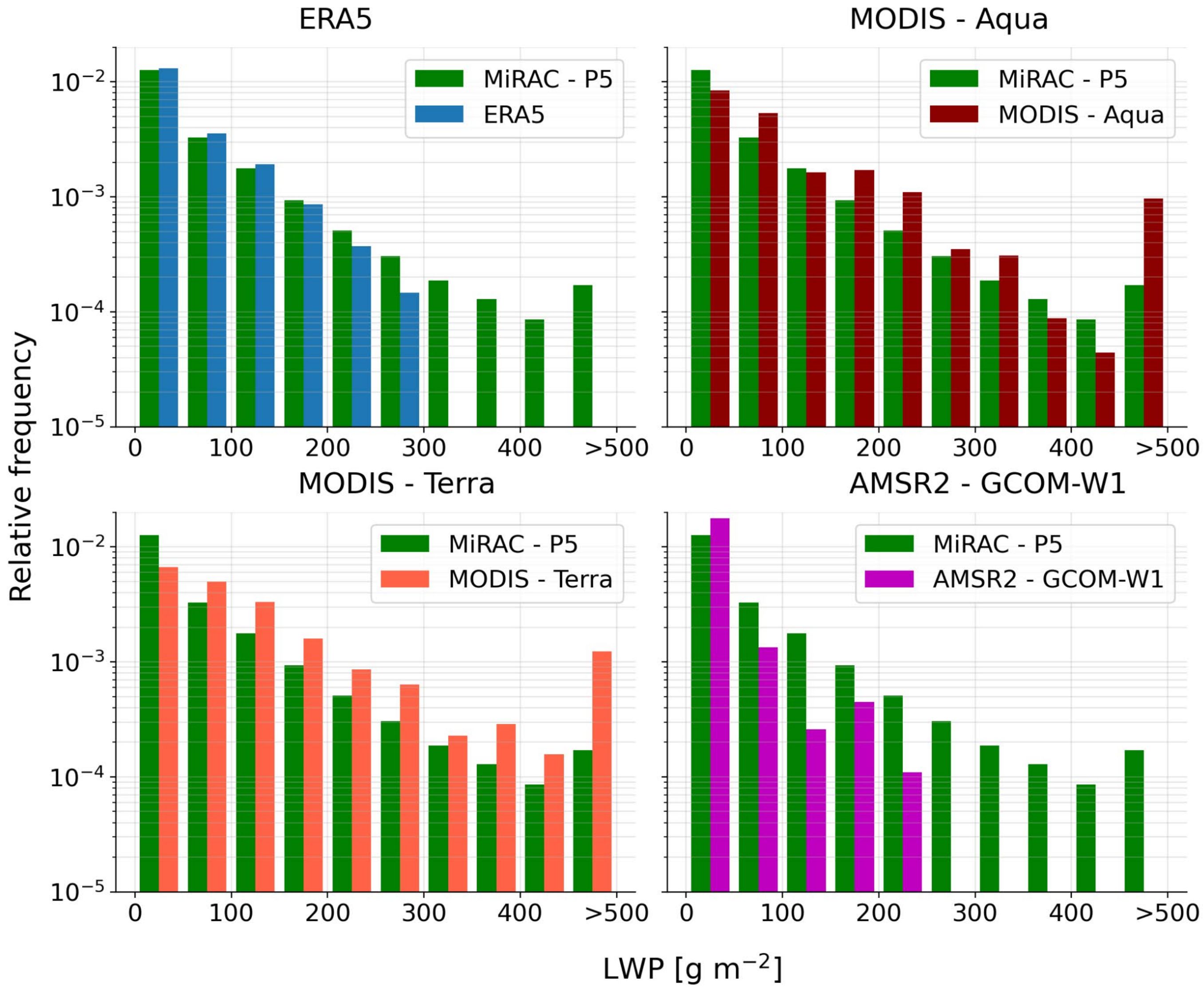
- **AMSR2:** Advanced Microwave Scanning Radiometer 2
  - coarse (15 km resolution)
  - only ocean
- **MODIS:** Moderate Resolution Imaging Spectroradiometer
  - visible-shortwave infrared (SWIR)
- **ERA5:** European reanalysis
  - coarse (30 km resolution)
  - few observations in Arctic
- **ICON:** Icosahedral Nonhydrostatic Model (run at DWD, Cologne..)
  - here 2 km resolution
  - no verification

Example: Marine Cold Air Outbreak May 2017



Leif-Leonard Kliesch

Intercomparison: All campaigns



Team up with CAESAR + ACAO campaign for thorough LWP MCAO study

- Both **Modis** products (Terra&Aqua) overestimates LWP strongly
- Differences between both **Modis** products particulary at high LWP (overpass time leads to different solar zenith angles)
- Low resolution products (ERA5, 0.5°; **AMSR2**, 0.25°) strongly under-estimate values above 200 g m^{-2}
- Satellite products show opposite biases: AMSR2 has more low and MODIS more high LWP

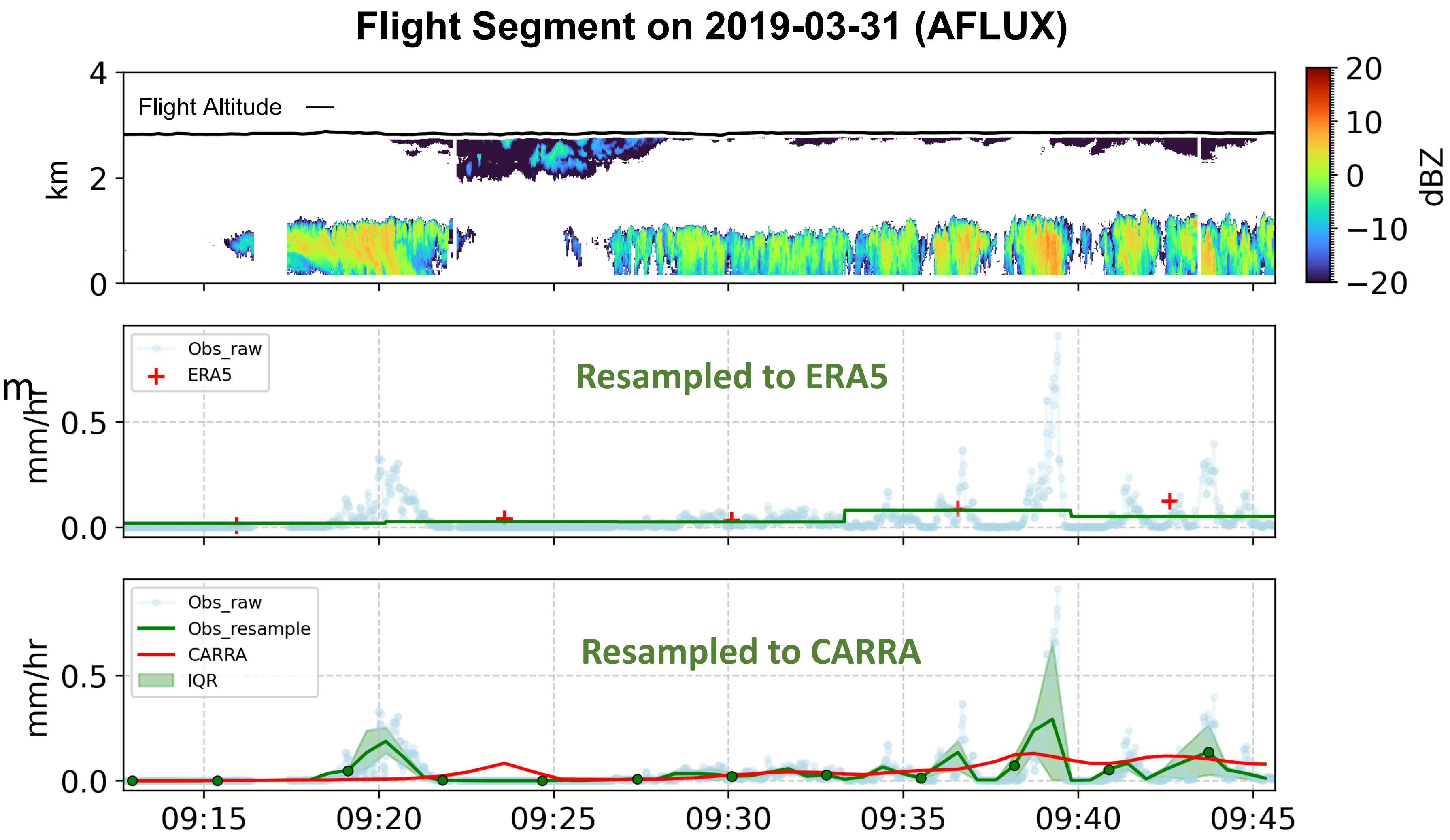
Problem of spatio-temporal matching

- Radar reflectivity (Z_e) values and corresponding derived snowfall rates matched to ERA5 and CARRA resolution

- Snowfall rates (S) derived from Z-S relation

$$Z_e = 9.2 \cdot S^{1.1}$$

adapted to MCAO based snowfall over Ny-Alesund (Schirmacher, PhD thesis, 2024)



Overall Snowfall Assessment

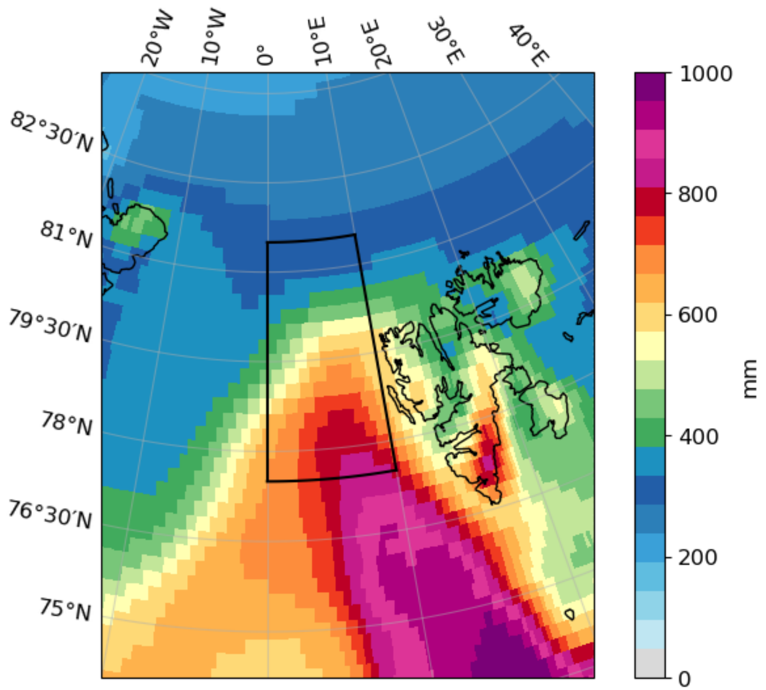
- Evaluate reanalysis quality with observed average snowfall rate for well-observed box
- **Matched airborne observations** show better agreement with ERA5 → CARRA underestimates

Observations	390 mm/y
CARRA	239 mm/y
ERA5	393 mm/y

- **CARRA climatology** (March to May, 1991-2021) of all precipitation climatology amounts to **80 %** of the ERA5 one
- MCAO related precipitation climatology shows even stronger reanalysis differences with CARRA being **64 %** of ERA5

	CARRA	ERA5	Ratio
All precip	433	549	0.79
MCAO precip	390	614	0.64

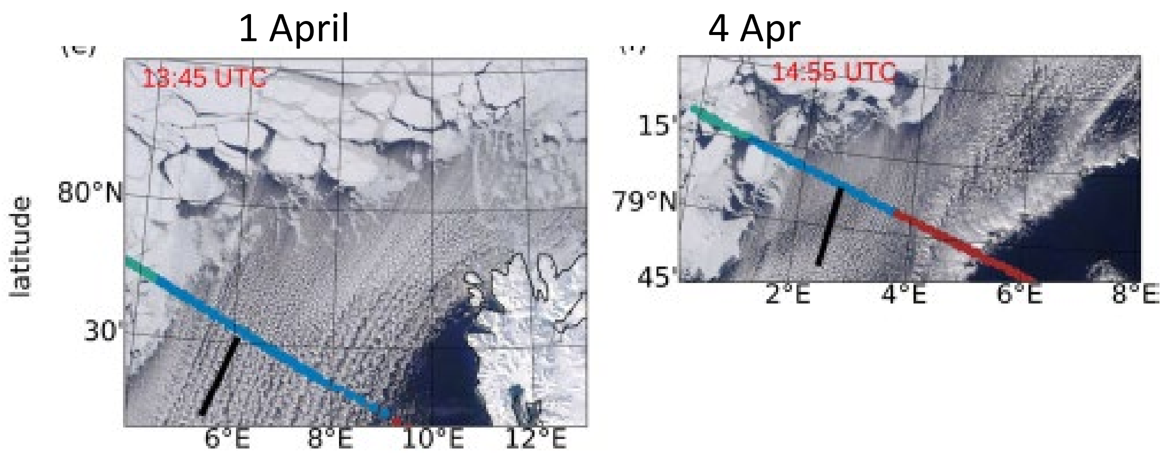
ERA5 Total Precipitation MAM



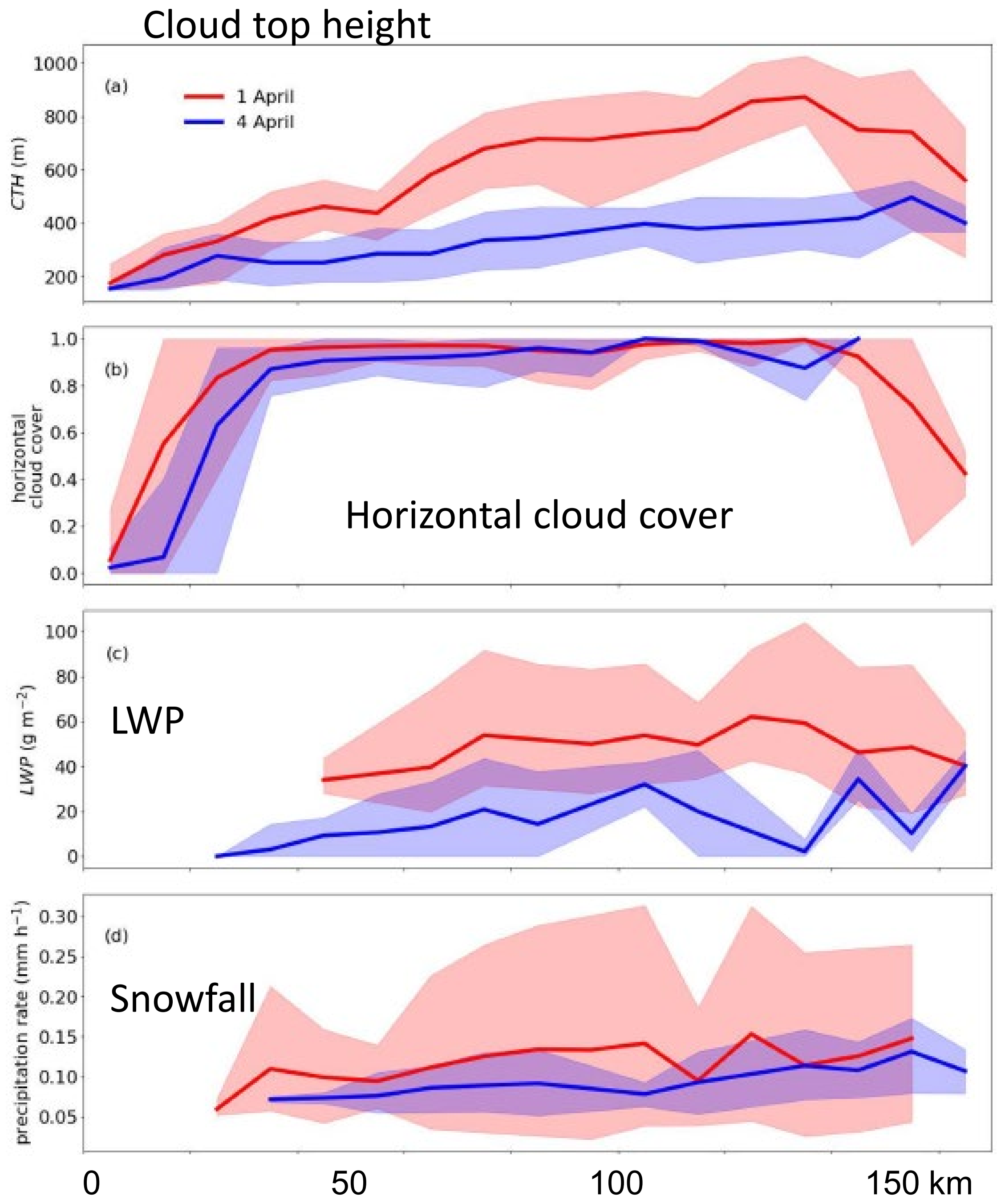
Differences in the timing of snowfall onset during MCAO's

Awadesh Pant

Initial MCAO Phase



- Cloud properties as function of fetch (distance travelled over open water)
- Identification of convective cells/rows and statistical assessment of their properties
- Snowfall starts immediately at sea ice edge
- difference in riming between both cases

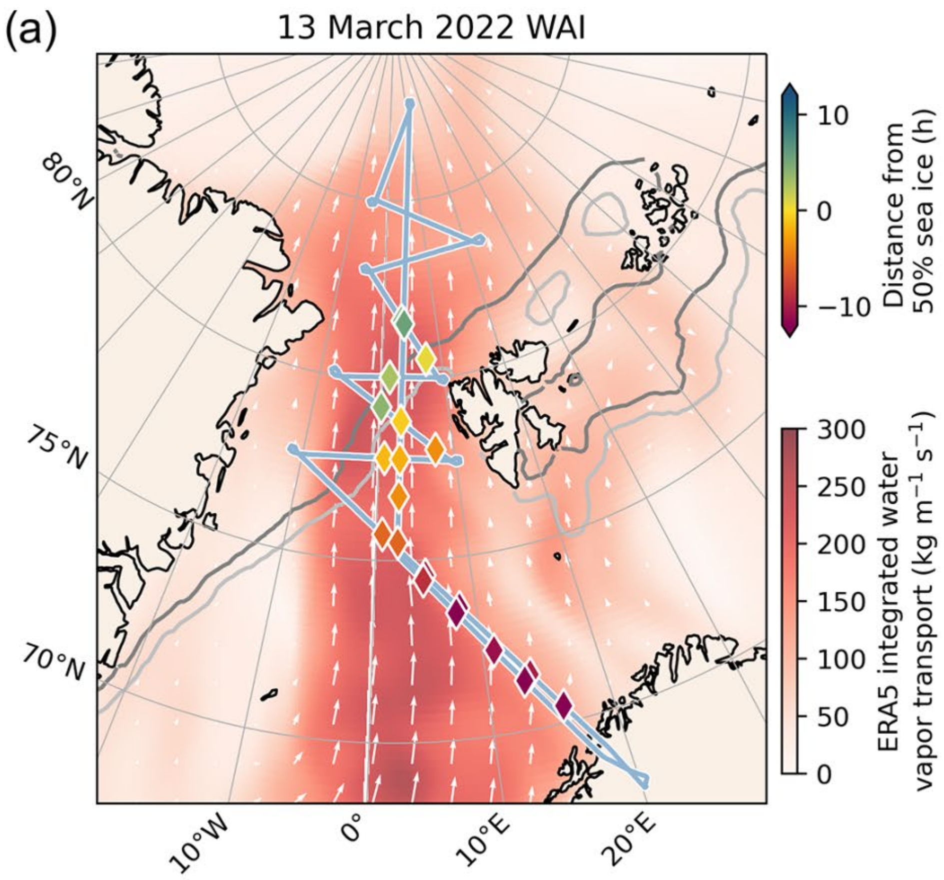


Schirmacher, et al, 2024: Clouds and precipitation in the initial phase of marine cold air outbreaks as observed by airborne remote sensing, Atmos. Chem. Phys. [*https://acp.copernicus.org/articles/24/12823/2024/*](https://acp.copernicus.org/articles/24/12823/2024/).

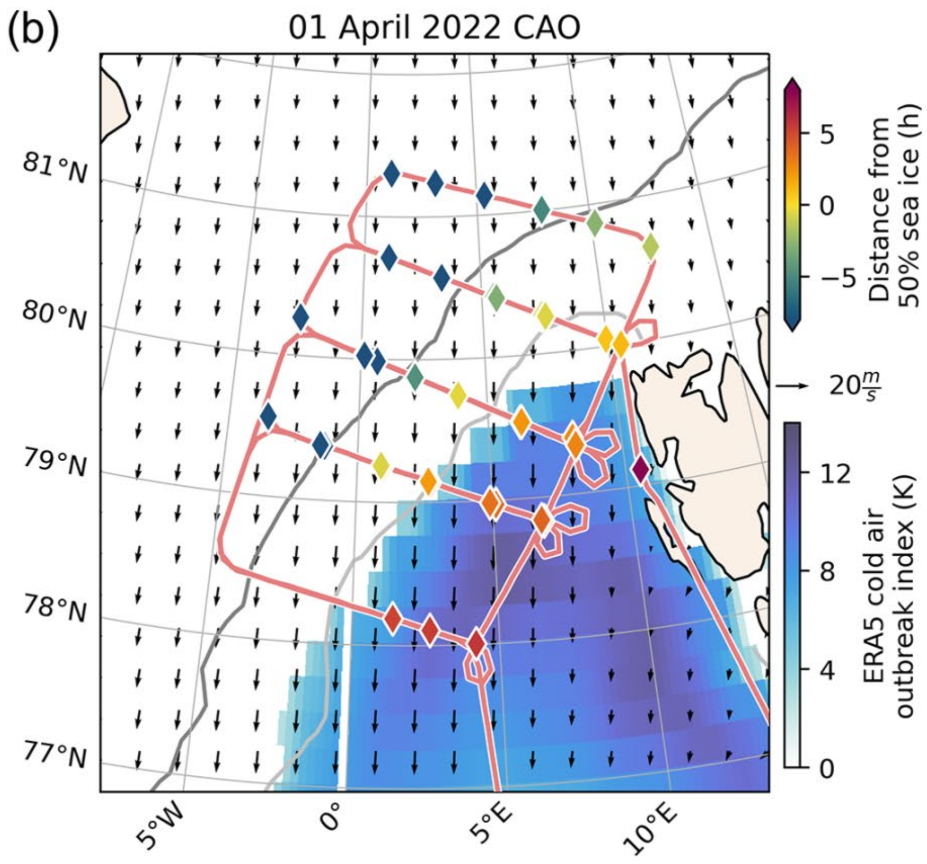
Airmass Transport and Transformation

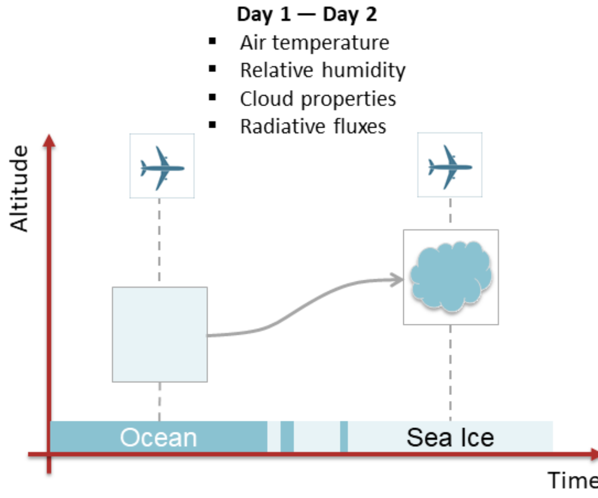
Examples of Quasi-Lagrangian Flight Strategy

Warm Air Intrusion



Cold Air Outbreak





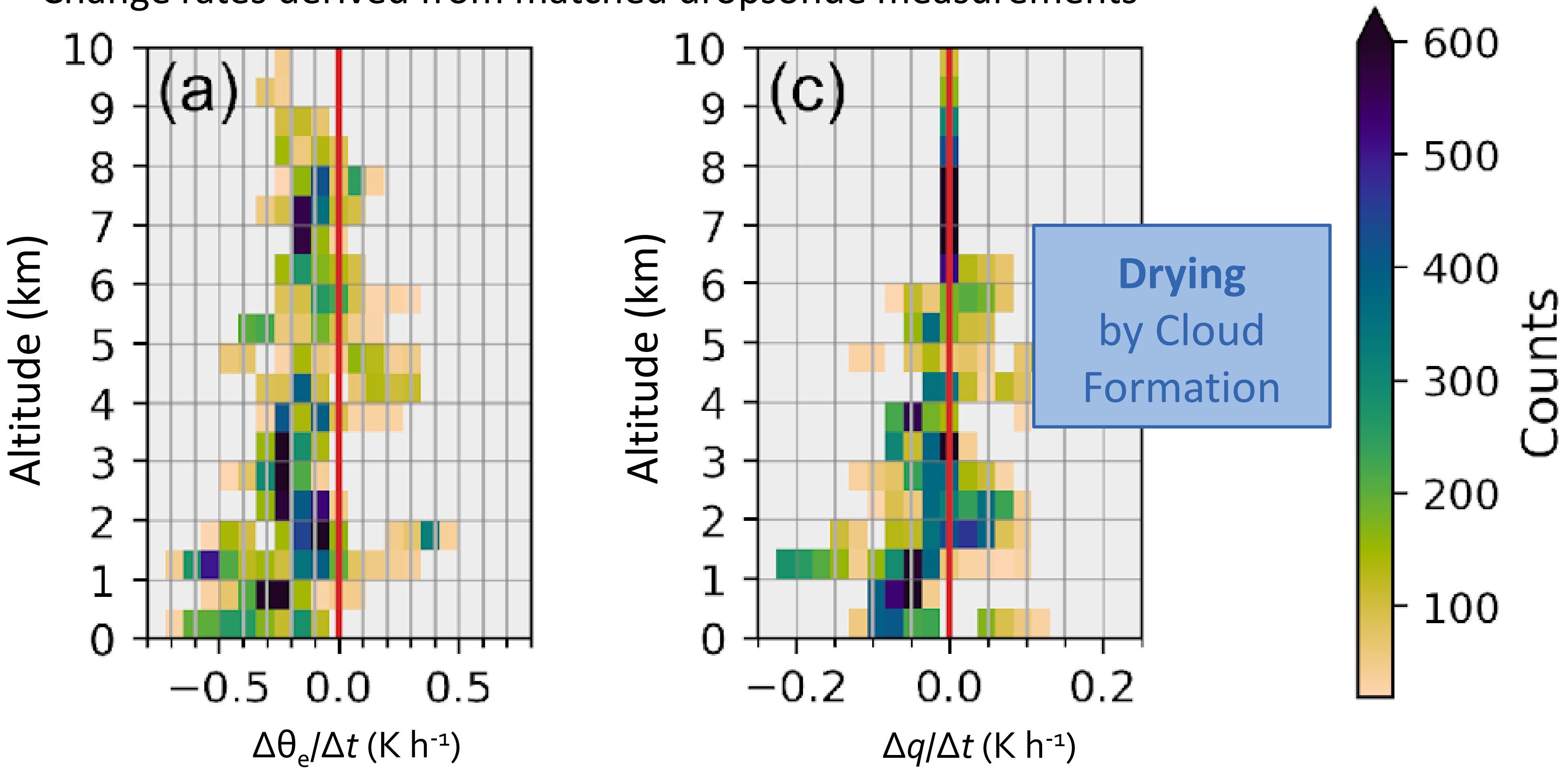
Wendisch, M., Kirbus, B., Ori, D., Shupe, M. D., Crewell, S., Sodemann, H., and Schemann, V.: Observed and modeled Arctic airmass transformations during warm air intrusions and cold air outbreaks, Atmos. Chem. Phys., 2025.

Warm Air Intrusion: Change Rates

Change rates derived from matched dropsonde measurements

Weak **Cooling**, Reaching High

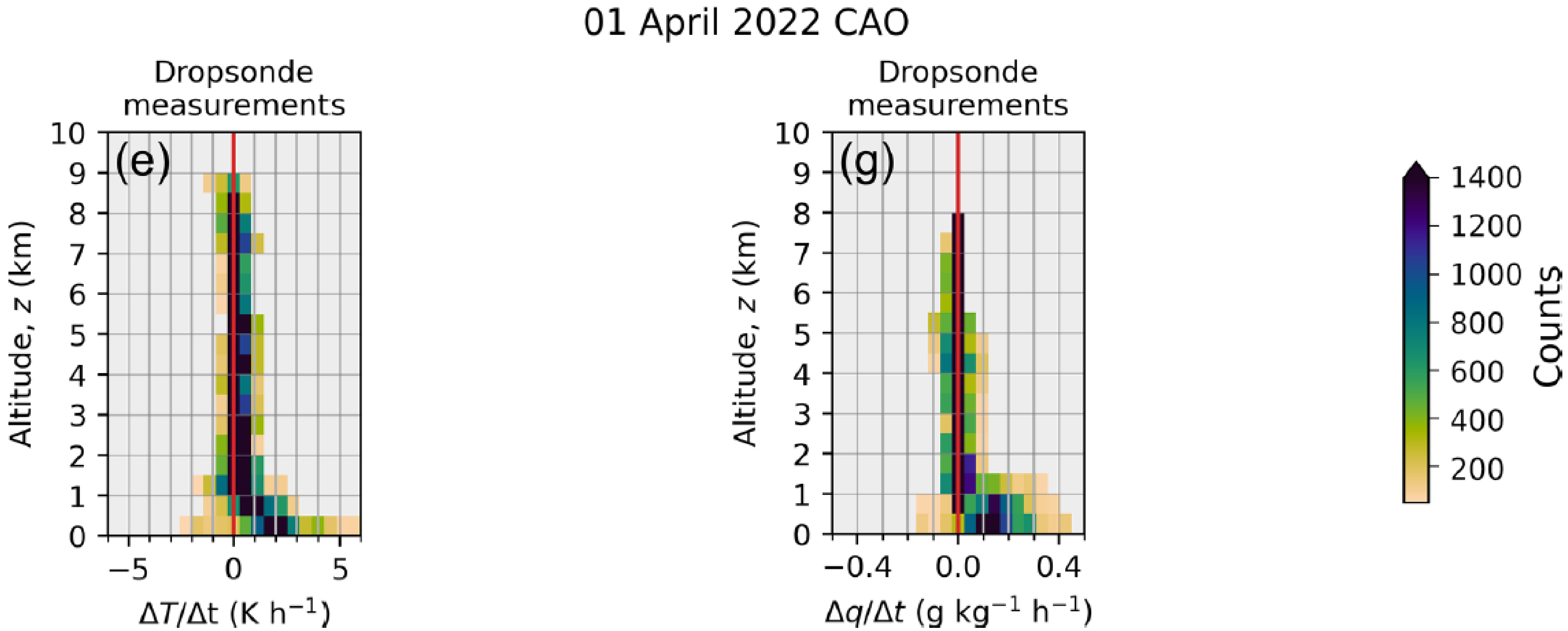
$$\frac{\Delta\psi}{\Delta t} = \frac{\psi_2 - \psi_1}{t_2 - t_1}$$



Drying by Cloud Formation

Wendisch et al. (2025), ACP

Cold Air Outbreak

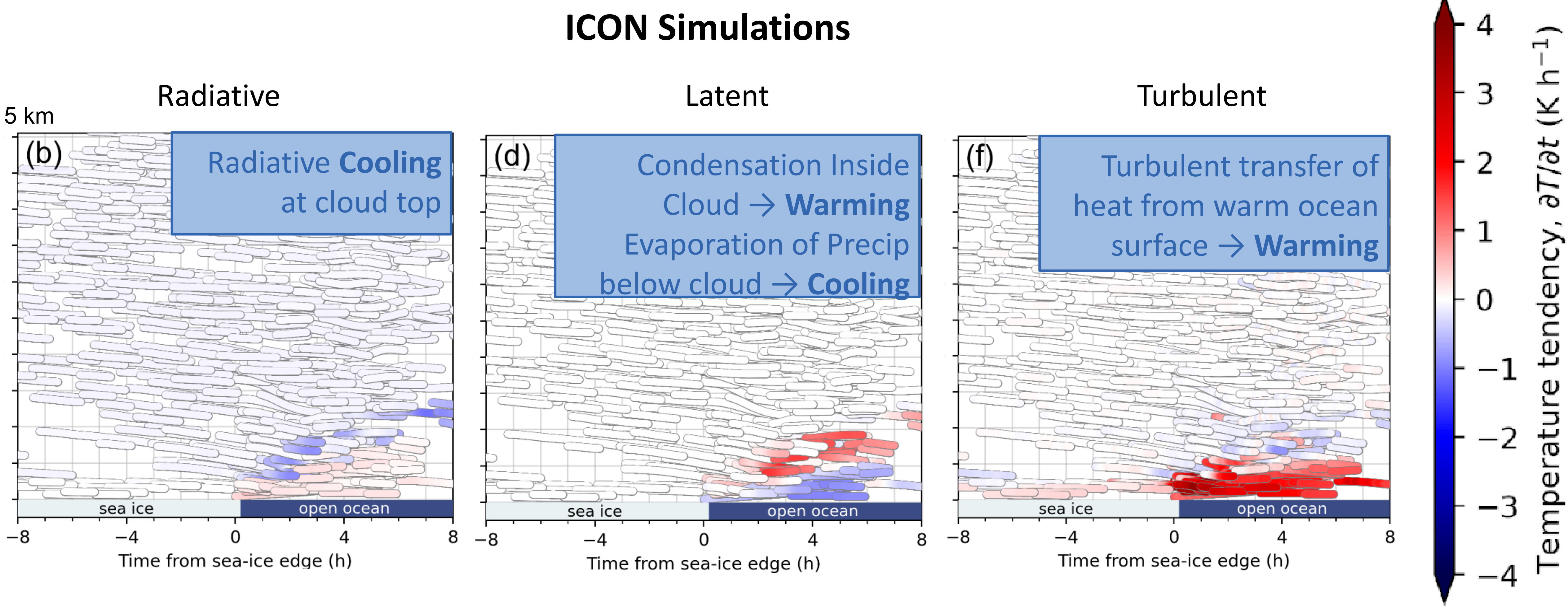


Warming Close to the Surface

Moistening by Ocean Surface

Wendisch et al. (2025), ACP

Cold Air Outbreak – Process Identification



Wendisch et al. (2025), ACP

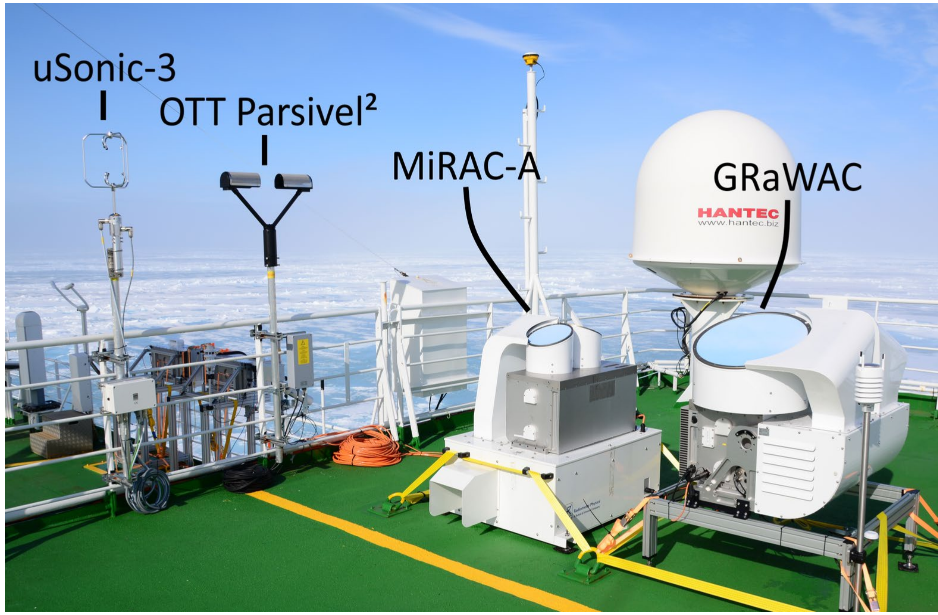
Clouds, Precipitation, and Energy Budget During **Meridional Airmass Transports** Into and Out of the Arctic: COntrasting Polar NIght & DAy (**CONIDA**)

CONIDA-Night (Polar Night):	November—December 2028
CONIDA-Day (Polar Day):	June—July 2029
Campaign base:	Kiruna (optional stopover in Longyearbyen)
Duration of campaign:	2 times 4 weeks
Proposed research flights:	2 times 100 hours
^Choice of mission time:	Contrasting polar night and day

Extension of HALO with submm radiometer, W-band Radar…

Summary and Conclusions

- $(AC)^3$ pursues integrated observational and modelling approach to understand Artic Amplification, its drivers and consequences
- Detailed airborne observations link various scales and are important for process studies, parametrization development, satellite and model evaluation,
- Clouds and precipitation LWP in the Arctic are still not well constrained by observations
  → exploit multiple campaigns airborne and shipborne campaigns e.g. Vampire



Unique collection of about 3000 datasets
https://www.pangaea.de/?q=project:label:AC3

Thank you, questions?

Polar 5 in Longyearbyen during a recent flight campaign ‘COMPEX’ (3/4 2026)

Photo Courtesy: Johanna Drude, UoC, IGMK