Transregional Collaborative Research Centre TRR 172

ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms (AC)³

Aircraft Observations in the Arctic during HALO—(AC)³ and Beyond

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Arctic Aircraft Campaign Workshop, Bergen (Norway), 1—4 June 2026

Vilhelm Bjerknes
Leipzig: 1912-1917
Bergen: 1917-1926

TRANSREGIO TRR 172 | LEIPZIG | BREMEN | KÖLN

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Universität Bremen
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AWI
TROPOS Leibniz-Institut für Troposphärenforschung

http://ac3-tr.de/ Funded by the German Science Foundation (Deutsche Forschungsgemeinschaft, DFG)

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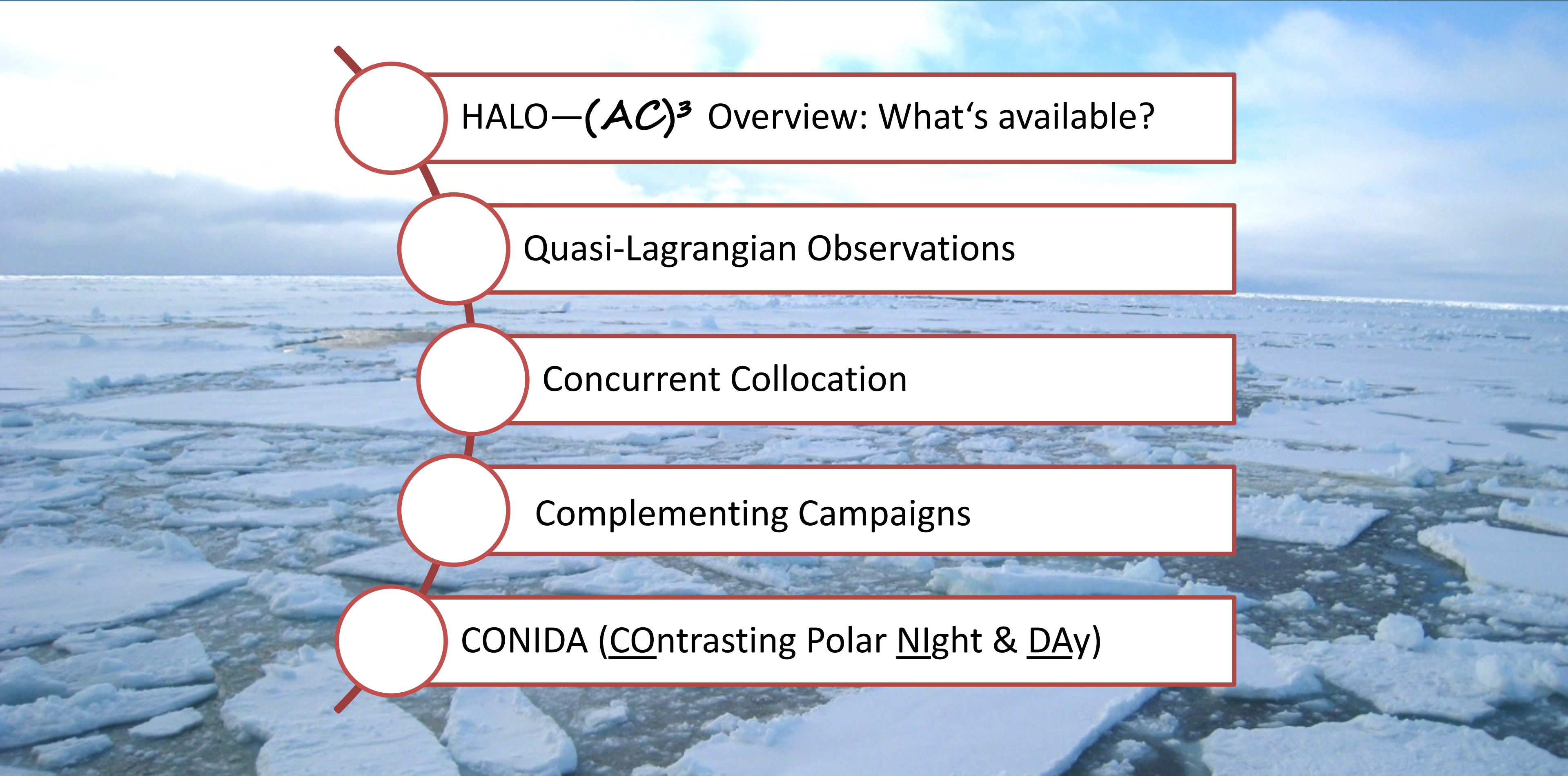


(AC)³ Delivered 12+ Years of Data

Satellites

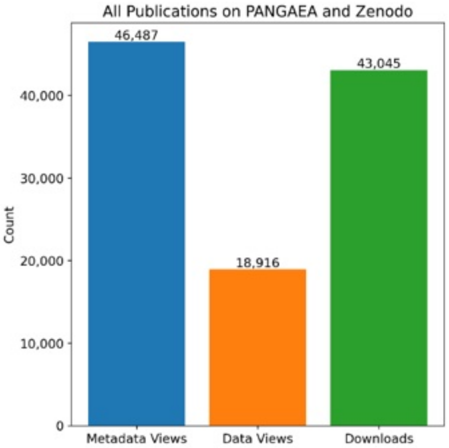
May – June 2017 🟦 ACLOUD
May – July 2017 🟨 PASCAL
June 2017 ⬜ Balloon (during PASCAL)
March – April 2018 🟦 PAMARCMiP
March – April 2019 🟦 AFLUX
September 2019 – September 2020 🟨 MOSAiC
June 2020 – July 2020 ⬜ Balloon (during MOSAiC)
August – September 2020 🟦 MOSAiC - ACA
October – November 2021 ⬜ Balloon (at AWIPEV)
March – April 2022 🟦 HALO-(AC)³
March – May 2022 ⬜ Ballon (at AWIPEV)
October 2022 🟦 BACSAM I
Summer 2023 🟨 CONTRASTS
March – April 2024 ⬜ Station Nord
April 2024 🟦 BACSAM II
Summer 2024 🟨 VAMPIRE-1
February 2025 🟩 IOP4H2O
April 2025 🟦 COMPEX-EC
Summer 2025 🟨 VAMPIRE-2
January – Feburary 2026 🟦 SANAT
March – April 2026 🟦 COMPEX

NYA column

2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026

10 Dedicated Aircraft Campaigns

All Publications on PANGAEA and Zenodo



2997 datasets
18 dedicated data papers
https://www.pangaea.de/?q=project:label:AC3

🟫 Satellites
🟨 Ship
⬜ Balloon
🟦 Aircraft
🟩 AWIPEV (NYA)

HALO—$(AC)^3$ Airborne Campaign: 07 March—12 April 2022

High Altitude and LOng Range Research Aircraft

18 flights, 147 flight hours, 347 dropsondes

HALO — remote sensing:

- 35 GHz radar
- Water vapor/aerosol lidar
- Passive MW, IR, VIS
- Radiation
- Dropsondes

Polar 5 & Polar 6

13 & 13 flights, 73 & 84 flight hours, 142 dropsondes

Polar 5 — remote sensing:

- 94 GHz FMCW radar
- Aerosol lidar
- Passive MW, IR, VIS
- Radiation, turb./fluxes
- Dropsondes

Polar 6 — in situ:

- Cloud probes/residual
- Aerosols
- Chemistry
- Trace gases
- Turb./fluxes

HALO—(AC)^3 Airborne Campaign: 07 March—12 April 2022

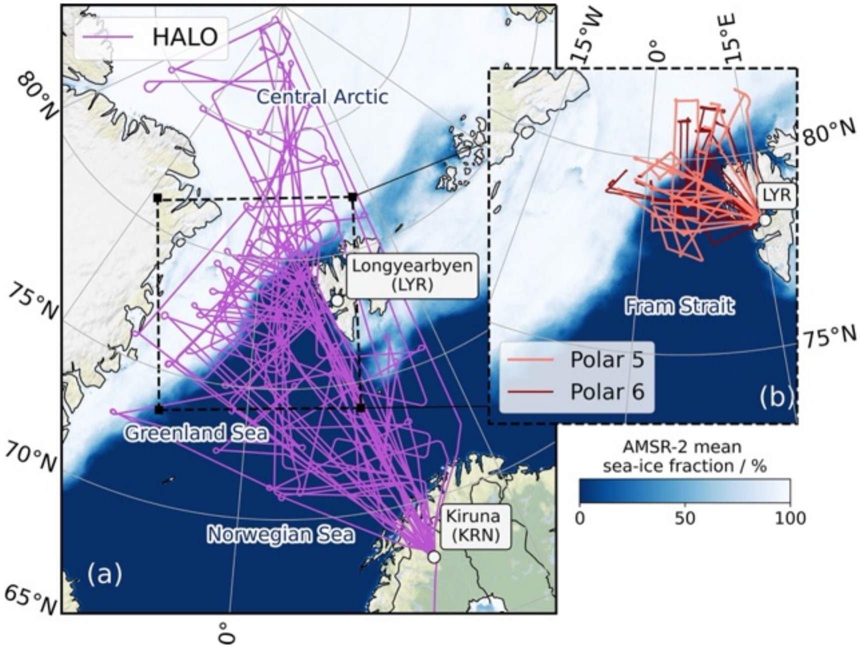


Fig. 1, Wendisch et al. (2024), ACP

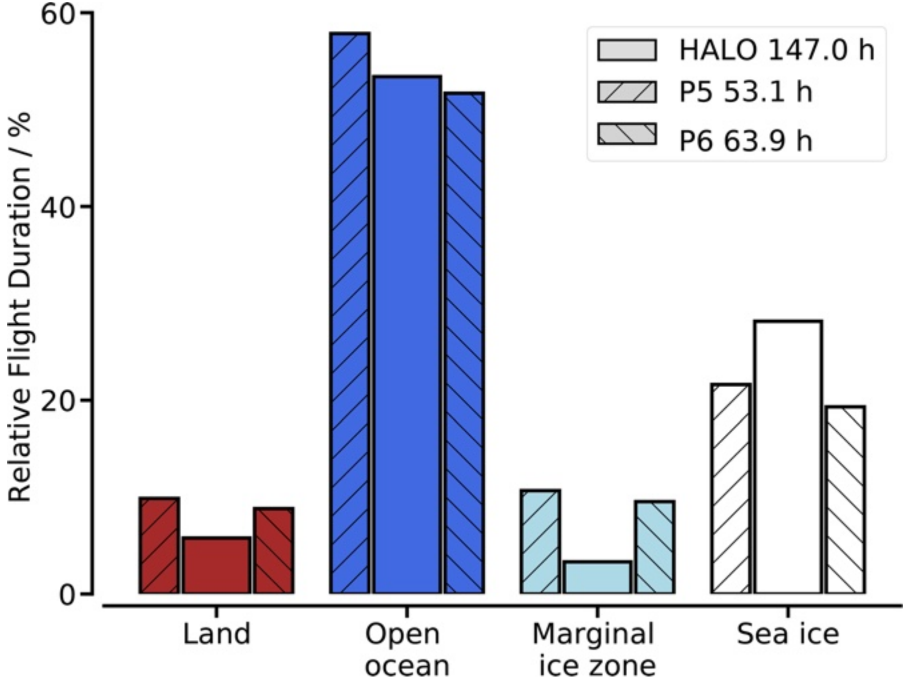
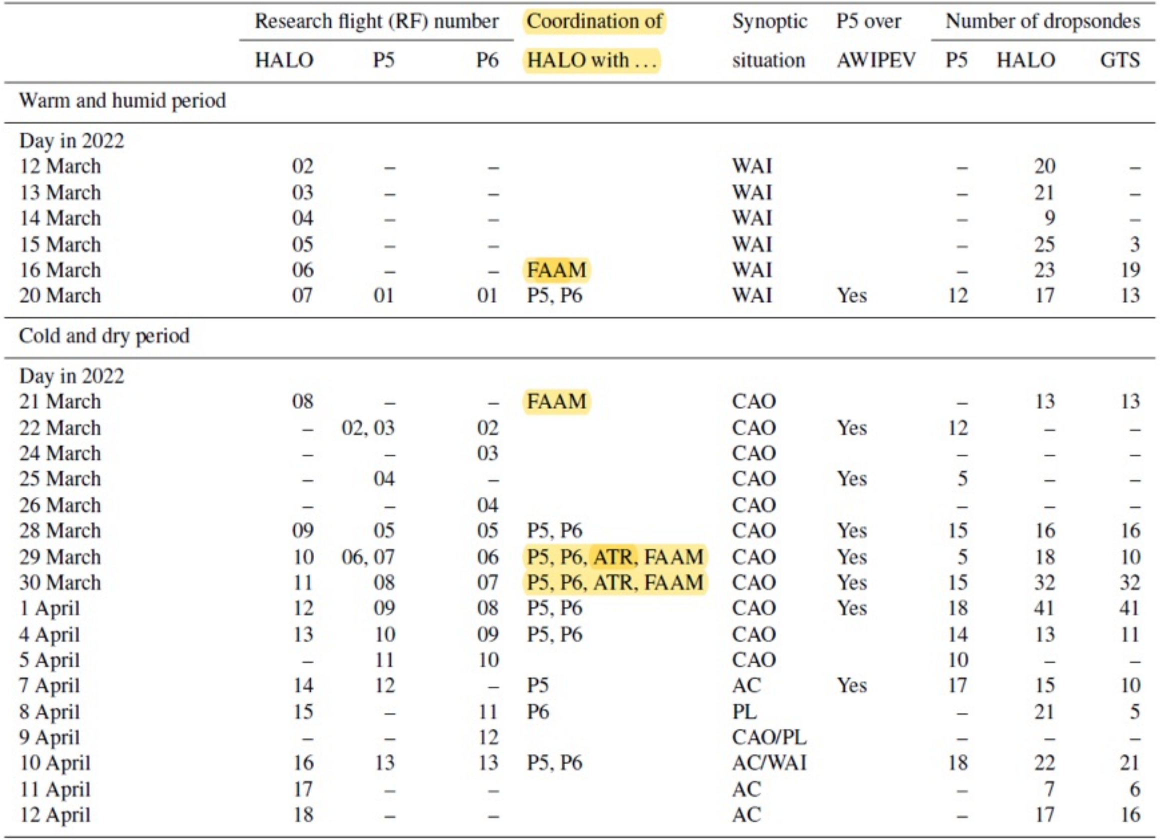


Fig. 2, Ehrlich et al. (2025), ESSD

HALO—(AC)^3 Airborne Campaign: 07 March—12 April 2022



	Research flight (RF) number			Coordination of	Synoptic	P5 over	Number of dropsondes		
	HALO	P5	P6	HALO with ...	situation	AWIPEV	P5	HALO	GTS
Warm and humid period									
Day in 2022									
12 March	02	–	–		WAI		–	20	–
13 March	03	–	–		WAI		–	21	–
14 March	04	–	–		WAI		–	9	–
15 March	05	–	–		WAI		–	25	3
16 March	06	–	–	FAAM	WAI		–	23	19
20 March	07	01	01	P5, P6	WAI	Yes	12	17	13
Cold and dry period									
Day in 2022									
21 March	08	–	–	FAAM	CAO		–	13	13
22 March	–	02, 03	02		CAO	Yes	12	–	–
24 March	–	–	03		CAO		–	–	–
25 March	–	04	–		CAO	Yes	5	–	–
26 March	–	–	04		CAO		–	–	–
28 March	09	05	05	P5, P6	CAO	Yes	15	16	16
29 March	10	06, 07	06	P5, P6, ATR, FAAM	CAO	Yes	5	18	10
30 March	11	08	07	P5, P6, ATR, FAAM	CAO	Yes	15	32	32
1 April	12	09	08	P5, P6	CAO	Yes	18	41	41
4 April	13	10	09	P5, P6	CAO		14	13	11
5 April	–	11	10		CAO		10	–	–
7 April	14	12	–	P5	AC	Yes	17	15	10
8 April	15	–	11	P6	PL		–	21	5
9 April	–	–	12		CAO/PL		–	–	–
10 April	16	13	13	P5, P6	AC/WAI		18	22	21
11 April	17	–	–		AC		–	7	6
12 April	18	–	–		AC		–	17	16

Wendisch et al. (2023), ACP

HALO—(AC)³ Airborne Campaign: 07 March—12 April 2022

Dropsonde Measurements

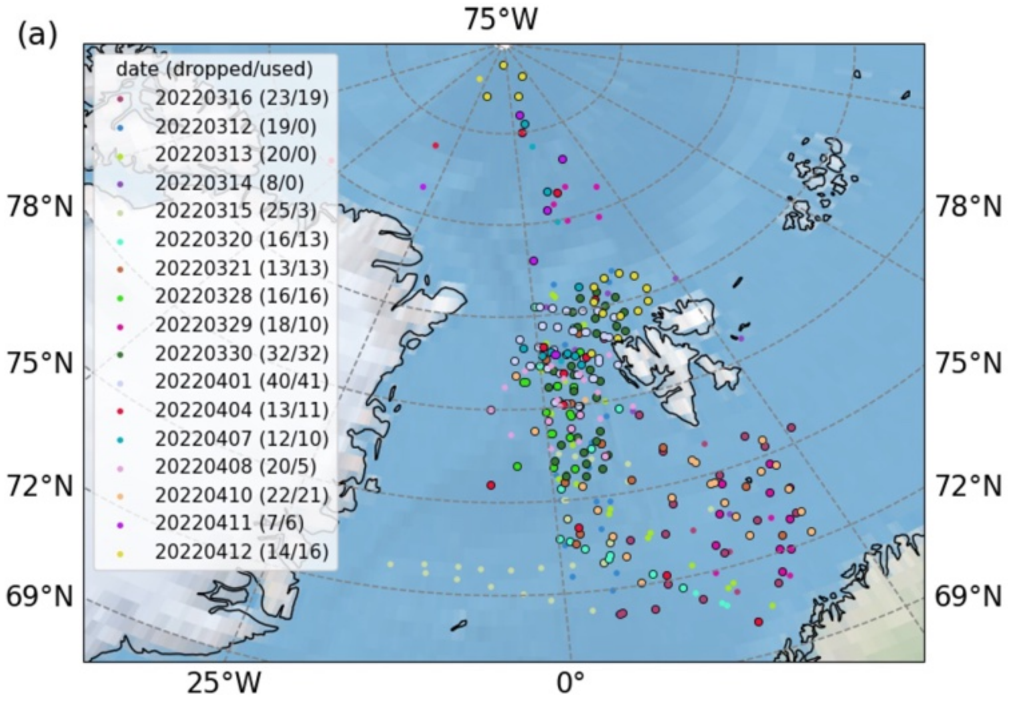
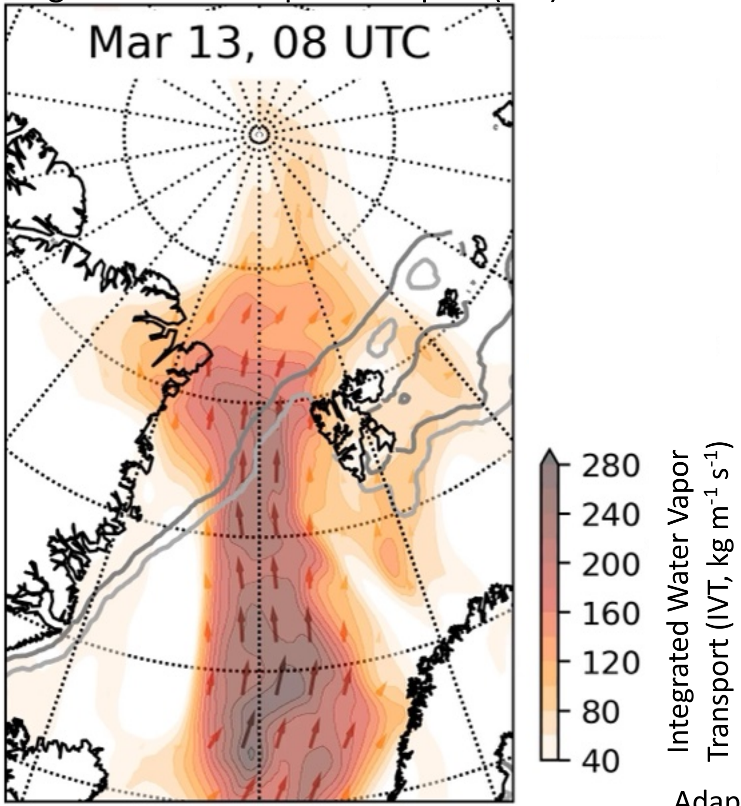


Fig. 3a, Ehrlich et al. (2025), ESSD

HALO—(AC)³: A Quasi-Lagrangian Sampling Strategy

Integrated Water Vapor Transport (IVT)

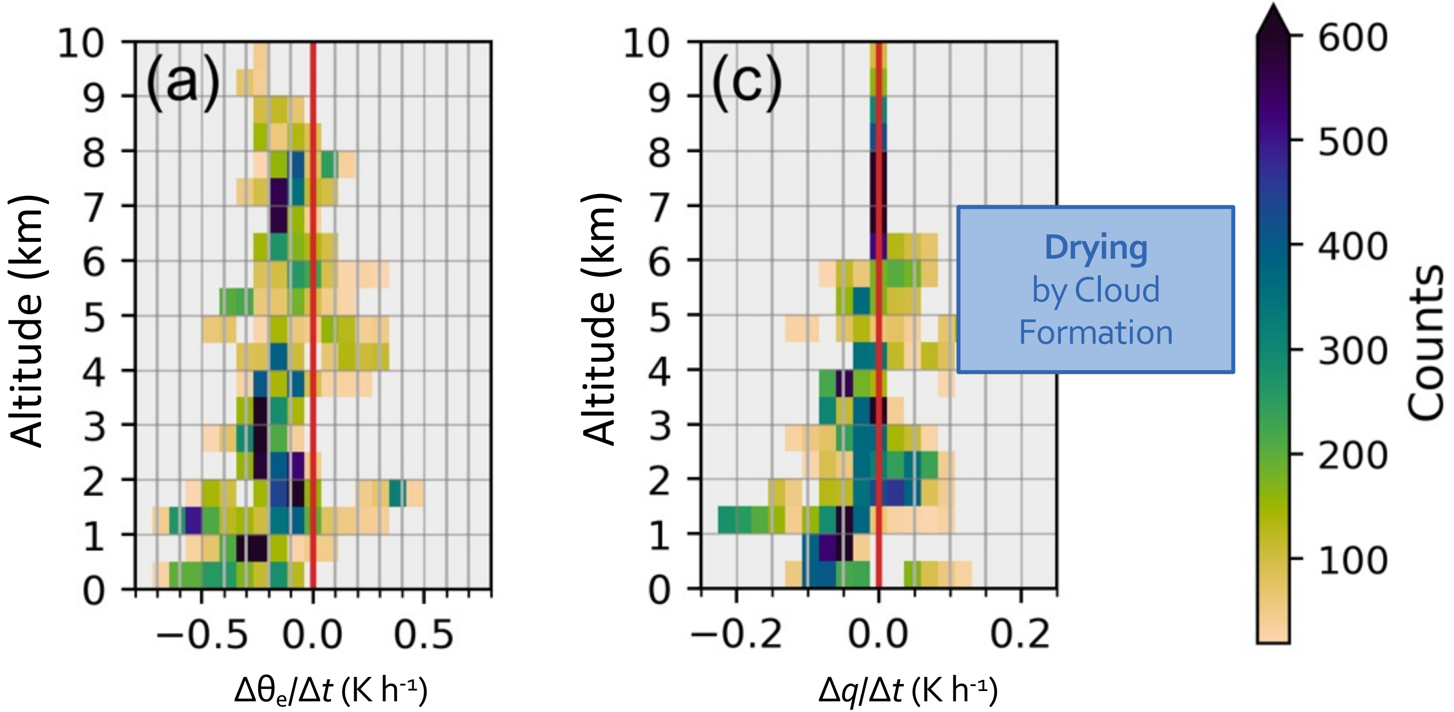


$$\frac{\Delta\psi}{\Delta t} = \frac{\psi_2 - \psi_1}{t_2 - t_1}$$

Adapted from Fig. 3, Wendisch et al. (2024), ACP

HALO—(AC)³: Warm Air Intrusion: 13 March 2022

Weak **Cooling,**
Reaching High



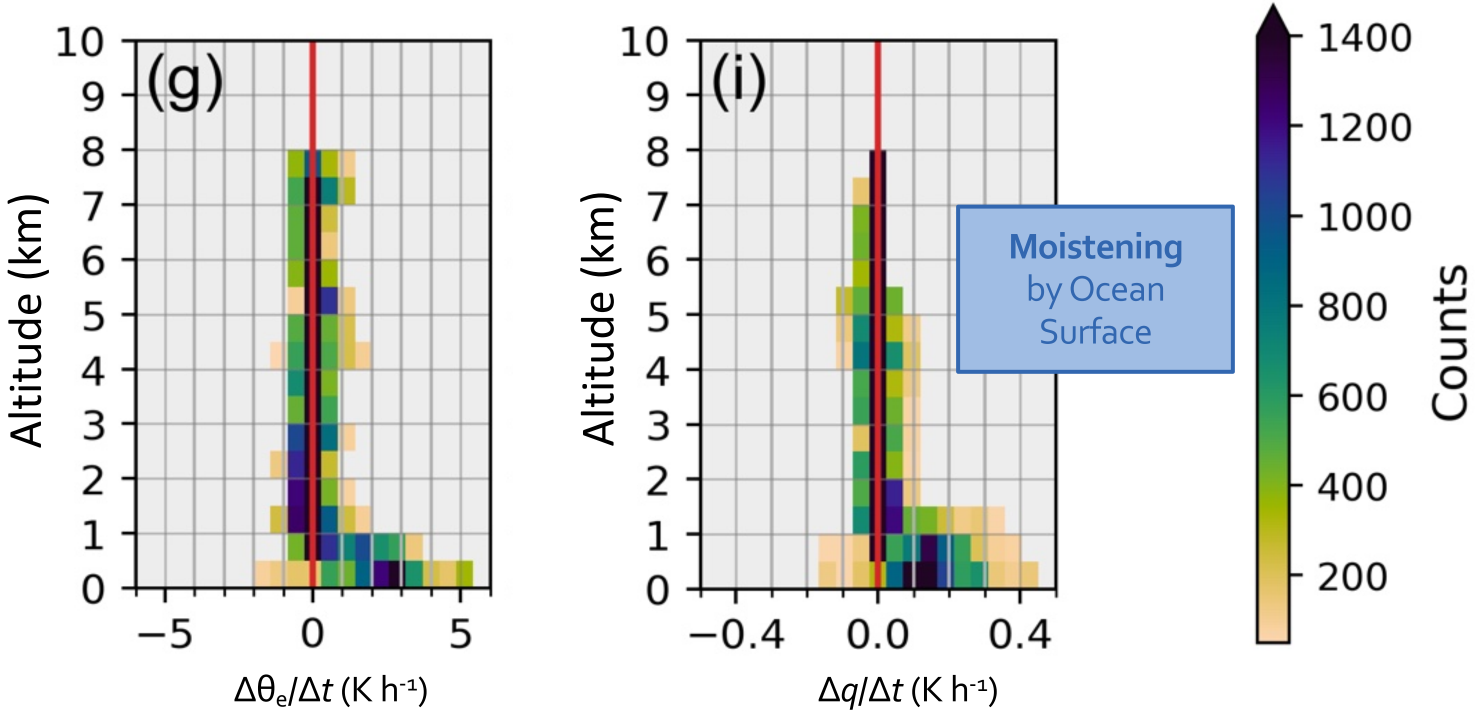
Drying
by Cloud
Formation

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

Wendisch et al. (2025), ACP

HALO—(AC)^3: Cold Air Outbreak: 01 April 2022

Warming Close to the Surface



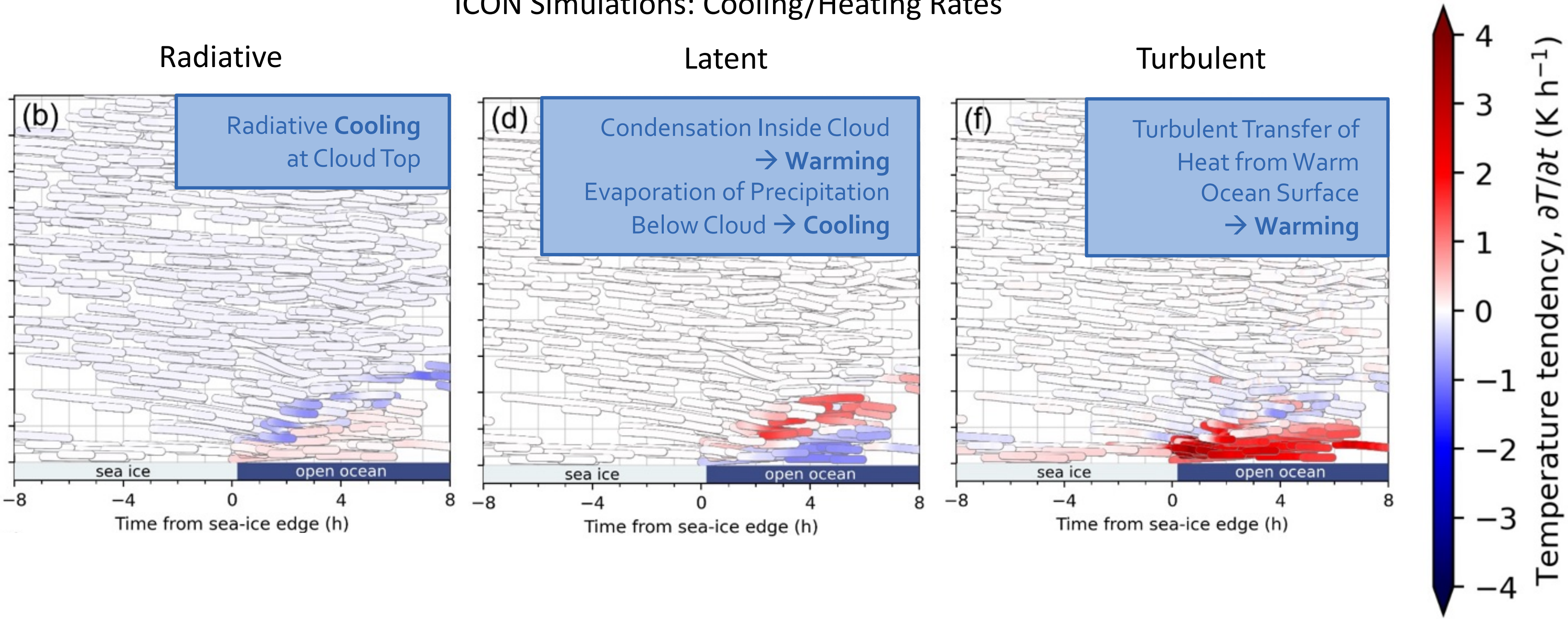
Moistening by Ocean Surface

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

Wendisch et al. (2025), ACP

HALO—(AC)³: Cold Air Outbreak: 01 April 2022

ICON Simulations: Cooling/Heating Rates



Radiative **Cooling** at Cloud Top

Condensation Inside Cloud → **Warming**

Evaporation of Precipitation Below Cloud → **Cooling**

Turbulent Transfer of Heat from Warm Ocean Surface → **Warming**

Wendisch et al. (2025), ACP

More Results from Aircraft Observations in the Arctic during HALO—(AC)^3 and Beyond

- HALO—(AC)^3: ACP/AMT Inter-Journal Special Issue (22 papers):
  https://acp.copernicus.org/articles/special_issue1272.html

- Further papers from HALO—(AC)^3 and (AC)^3 in general:
  https://ac3-tr.de/pages/publications.html

- Concurrent Collocation
  - Satellite—Aircraft—Dropsondes—Ground-Based/Ship
  - Different Platforms
  - Reanalysis—Simulations

- Complementing Campaigns
  - HALO—(AC)^3, AFLUX, COMPEX-AC, CAESAR, ARCSIX
  - Different Seasons
  - Reanalysis—Simulations

Concurrent Collocation: Aircraft (HALO/Polar 5/Polar 6)

Cloud Vertical Structure: **Reflectivity**

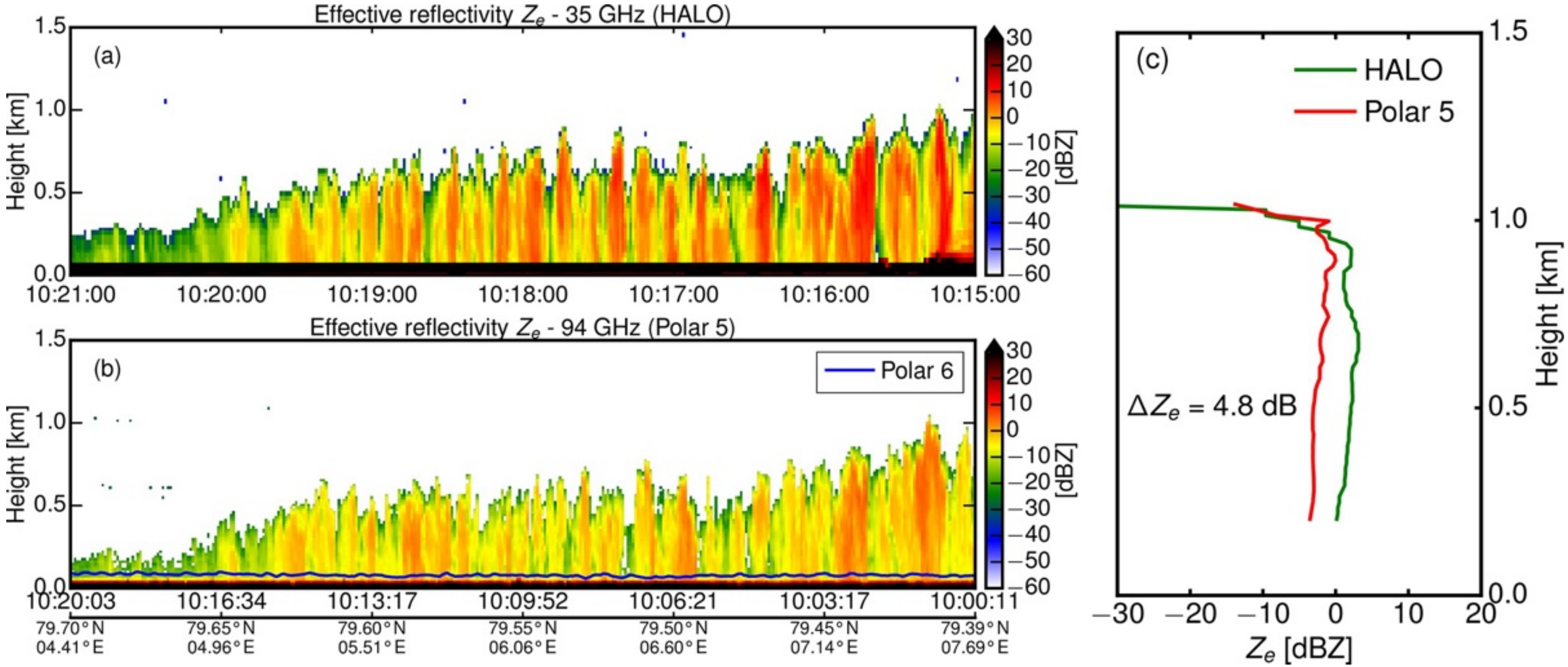


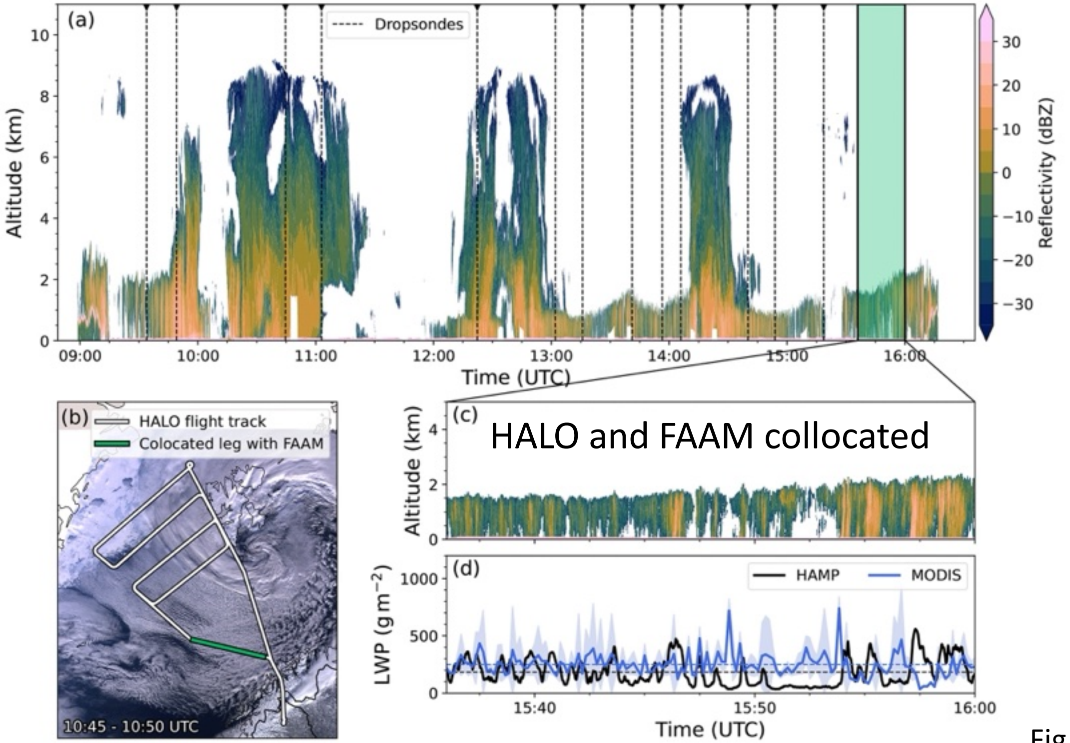
Fig. 7, Ehrlich et al. (2025), ESSD

Concurrent Collocation: Aircraft (HALO/FAAM)—Satellite (MODIS)

CAO on
21 March 2022

Cloud Layer Properties: **LWP**

RF08: HALO—(AC)³



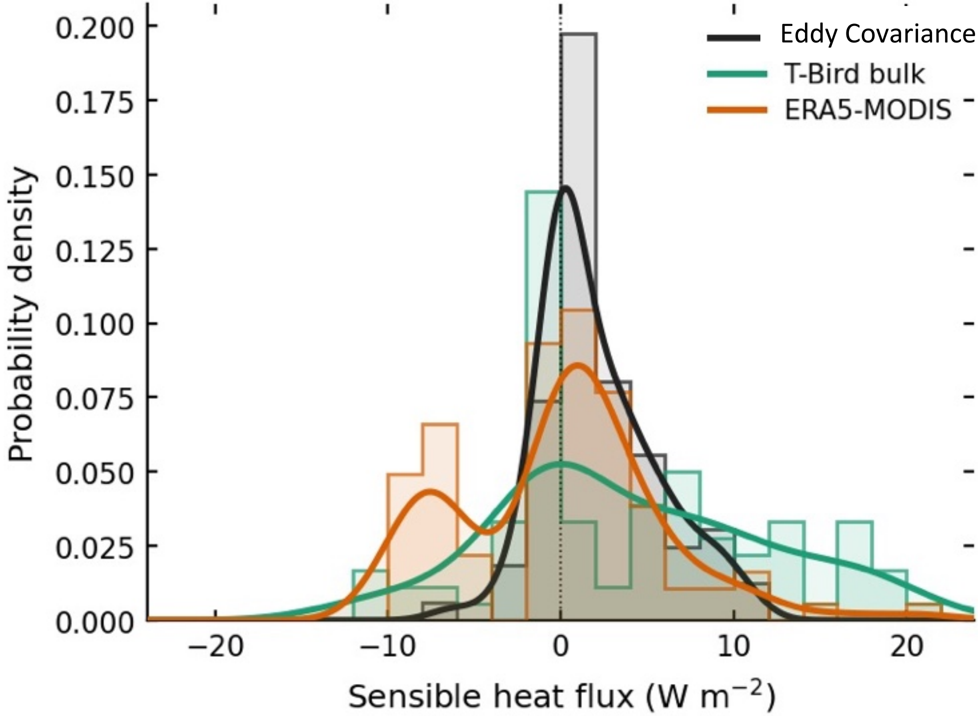
HALO and FAAM collocated

Fig. 8, Wendisch et al. (2024), ACP

Concurrent Collocation: Aircraft (P6), T-Bird (P6), Satellite (MODIS)-Reanalysis (ERA5)

Atmospheric Energy Fluxes: **Sensible Heat Flux**

BACSAM II



Adapted Fig. 5, Müller et al. (2026), for Submission

Concurrent Collocation: Aircraft (HALO)—Satellite (MODIS)

Surface Properties: **Skin Temperature**

HALO—(AC)³

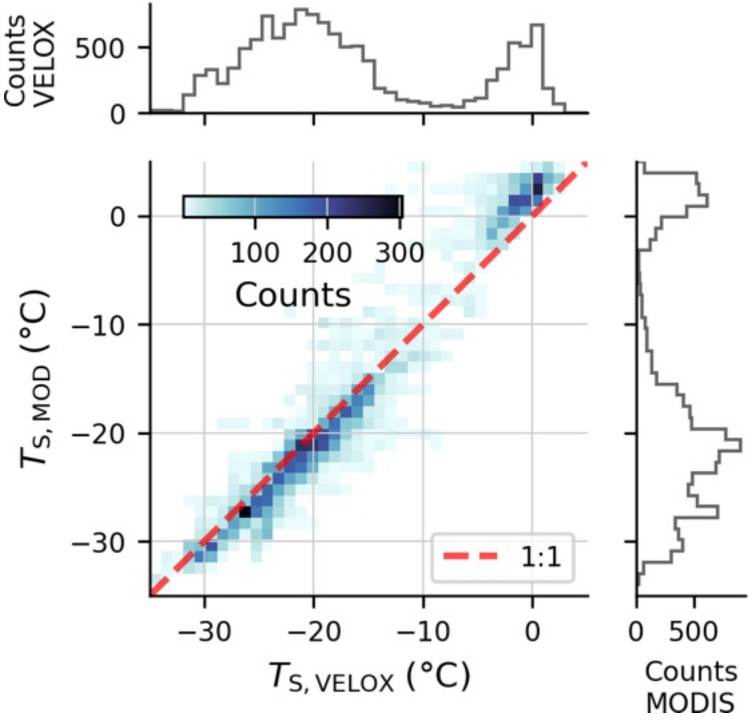
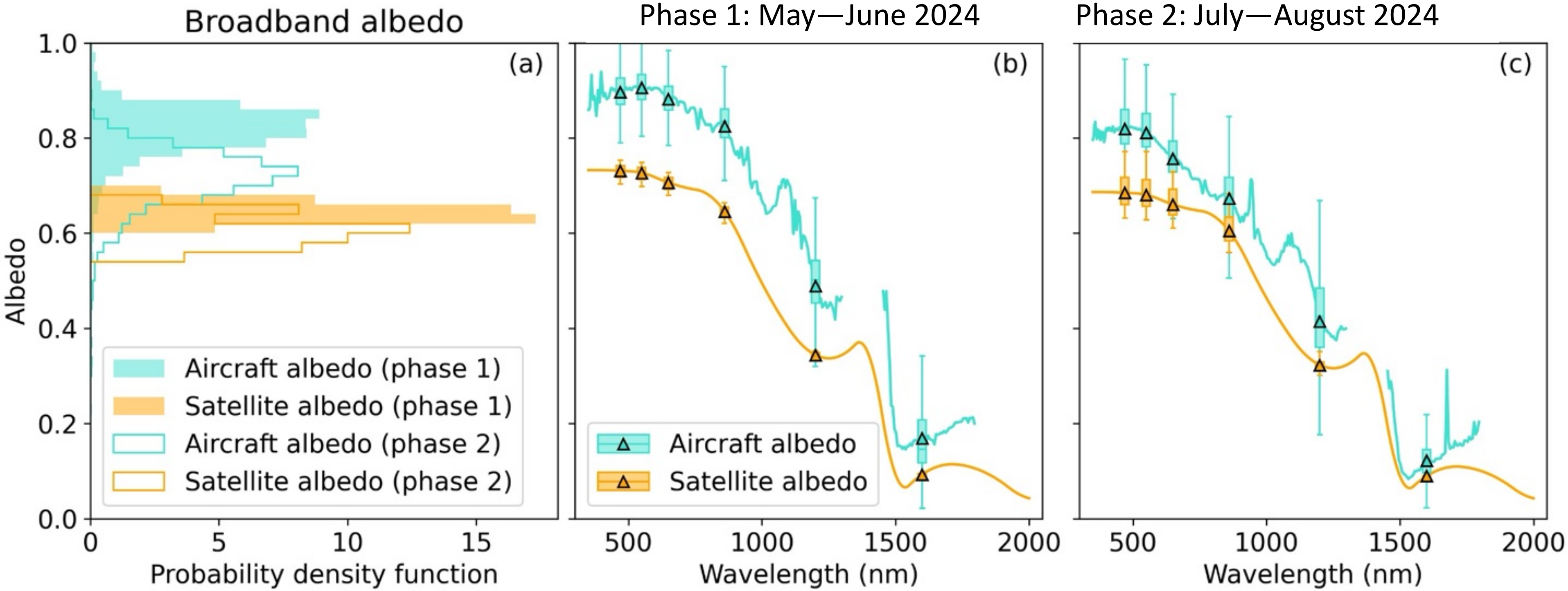


Fig. 8, Müller et al. (2025), ACP

Concurrent Collocation: Aircraft (P3)—Satellite (MODIS)

Surface Properties: **Albedo**

ARCSIX



Phase 1: May—June 2024

Phase 2: July—August 2024

Fig. 8, Becker et al. (2026), EGUsphere [preprint]

Concurrent Collocation: Satellite (MODIS)—Aircraft (P3)

Derived Properties: **Cloud Radiative Effect (CRE)**

ARCSIX

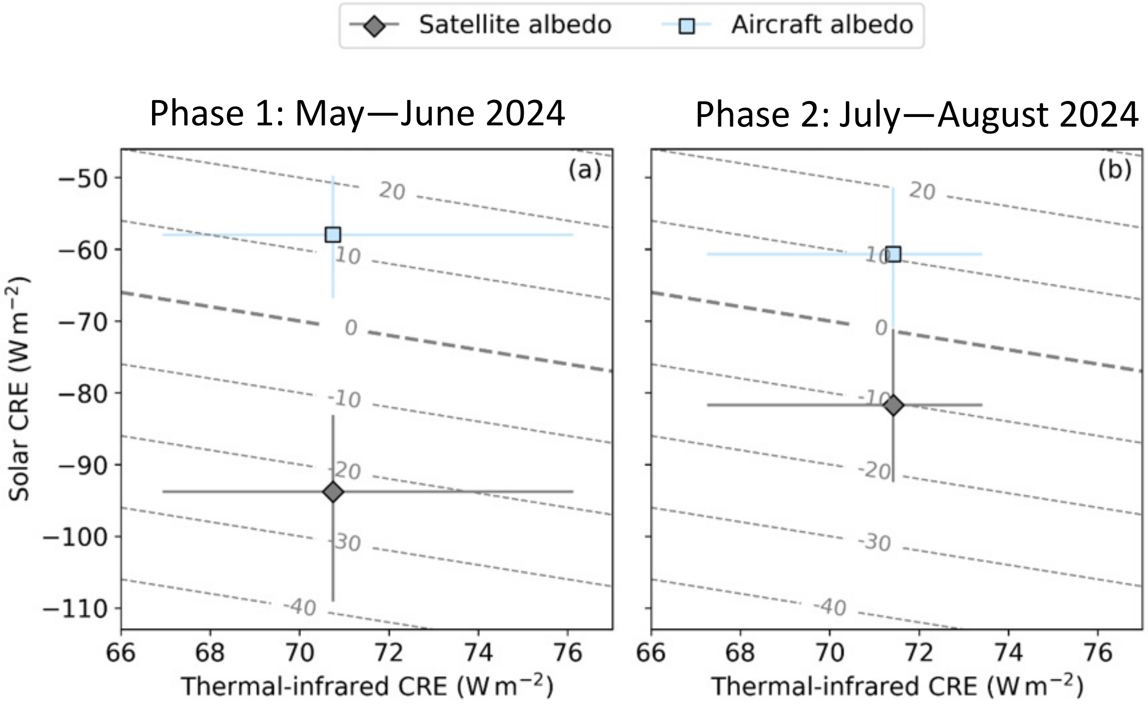
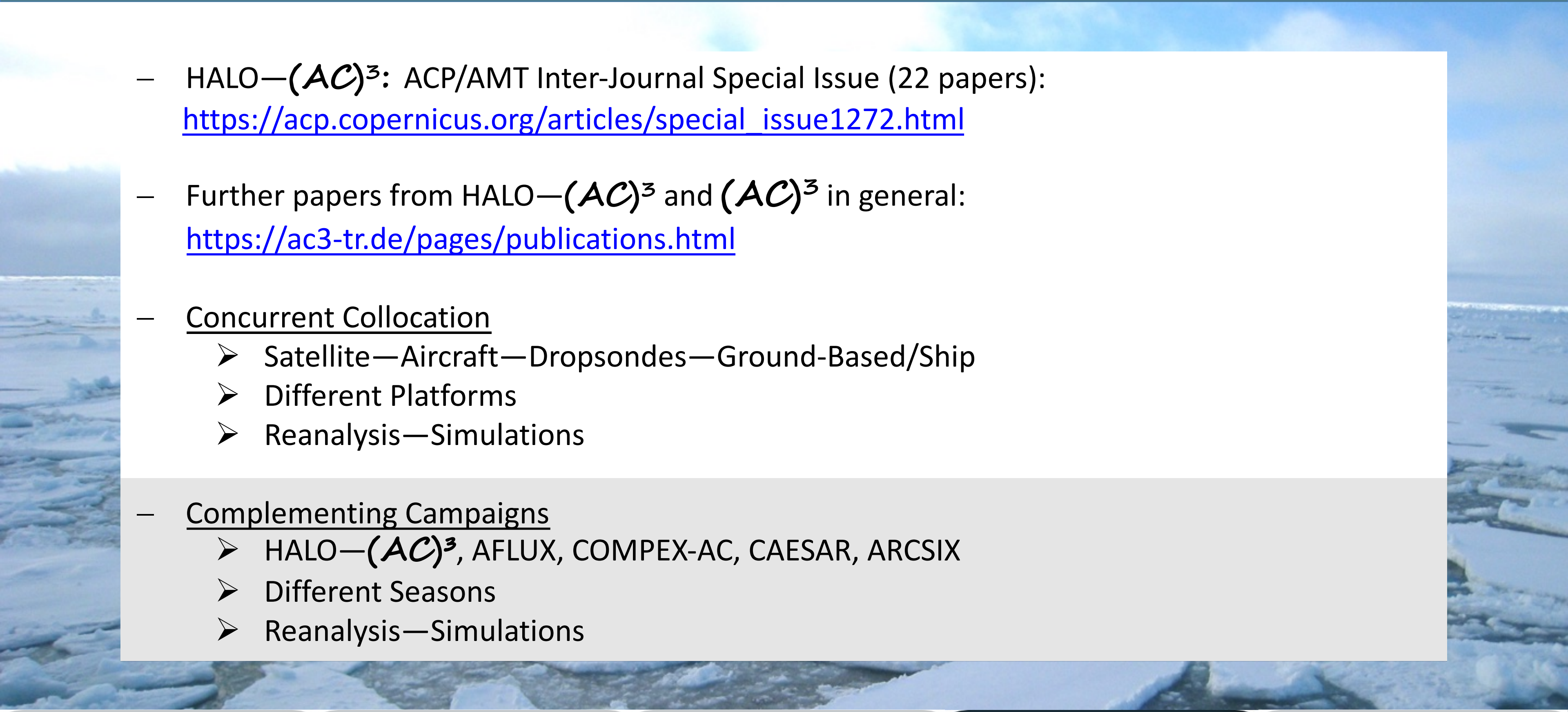


Fig. 9, Becker et al. (2026), EGUsphere [preprint]

More Results from Aircraft Observations in the Arctic during HALO—(AC)^3 and Beyond



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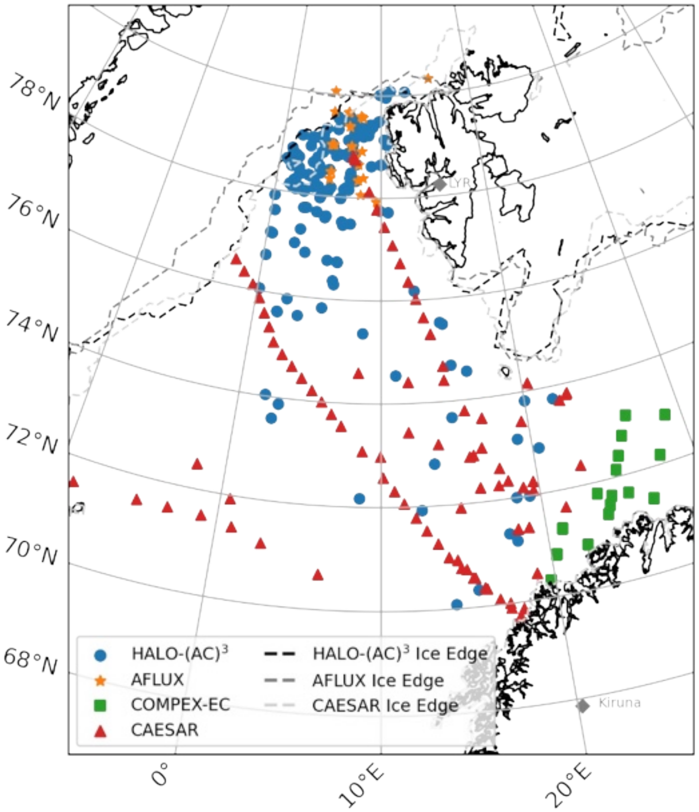
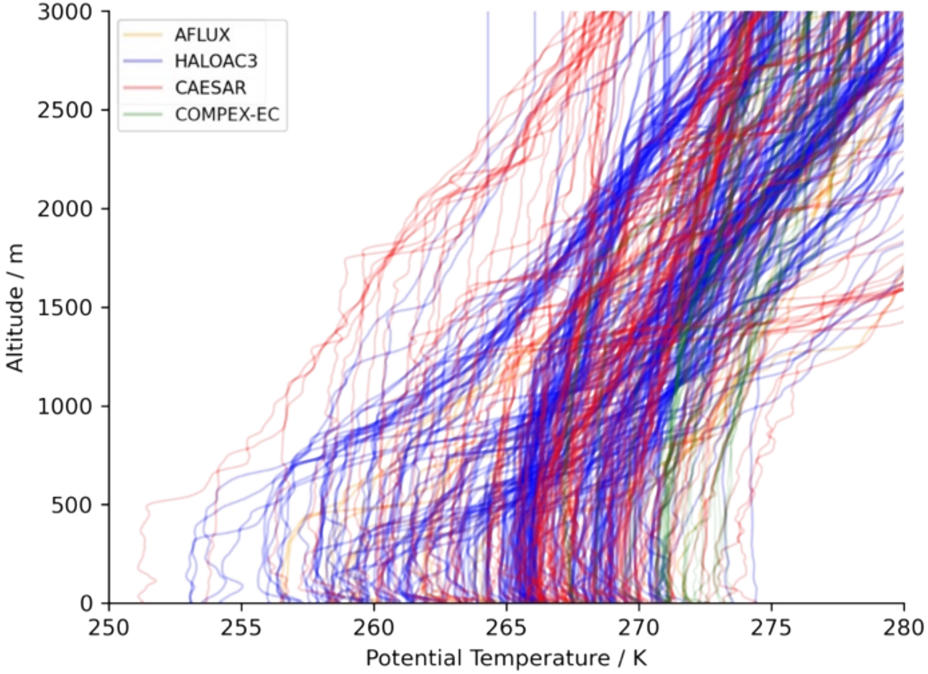
Complementing Campaigns: HALO—$(AC)^3$, AFLUX, COMPEX-EC, CAESAR

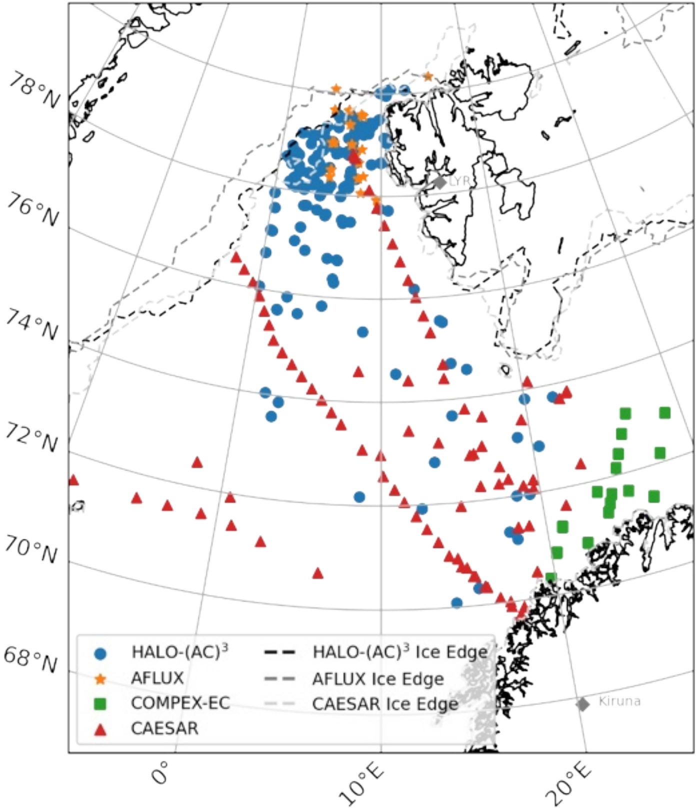


Dropsonde data

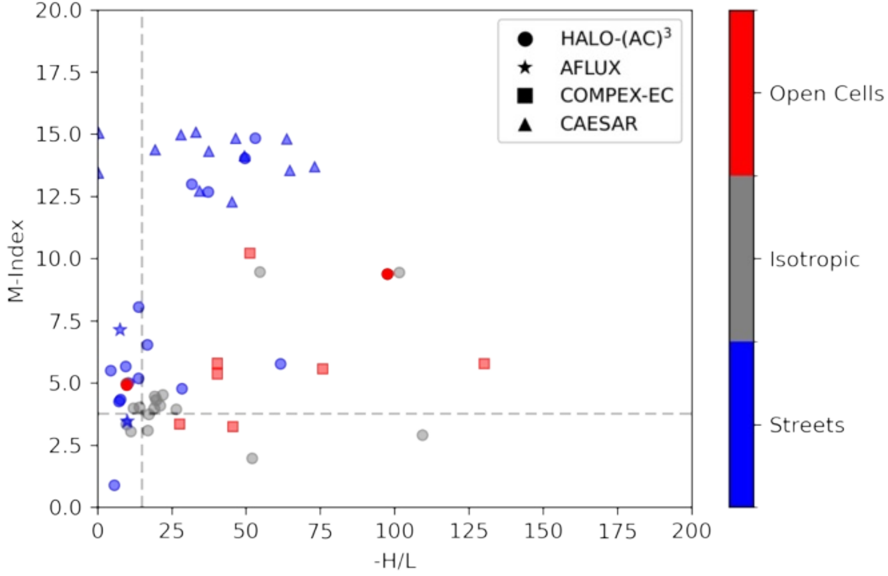


Klingebiel et al. (2026), for Submission

Complementing Campaigns: HALO—(AC)³, AFLUX, COMPEX-EC, CAESAR



Dropsonde data



Klingebiel et al. (2026), for Submission

Plans for Future Combined Campaigns

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

— Two HALO campaigns —

Part 1: CONIDA-Night

Manfred Wendisch, Michael Schäfer, Anna Luebke (Leipzig University)

Mario Mech, Roel Neggers, Susanne Crewell (University of Cologne)

Henning Dorff, Felix Ament(University of Hamburg)

Georgios Dekoutsidis, Silke Groß (DLR)

Micha Gryschka (Leibniz University Hannover)

CONIDA-Night: What do we propose?

General Goal

- Observe and model airmass transformations during WAIs and CAOs

Why should we care?

Because WAIs and CAOs …

- … link Arctic and mid-latitude weather and climate
- … trigger/drag feedback mechanisms (lapse rate, surface albedo) that determine Arctic amplification
- … involve airmass transformations as a result of important processes that models struggle to realistically account for: e.g., cloud/precipitation development, changes in the energy balance

Therefore, we propose:

- Observations: Follow airmass transformations during WAIs and CAOs applying a quasi-Lagrangian approach
- Modeling: Test the ability of numerical models to reproduce the measurements

WAI … Warm Air Intrusion; CAO … Cold Air Outbreak

CONIDA-Night: Why do we focus on clouds and energy budget?

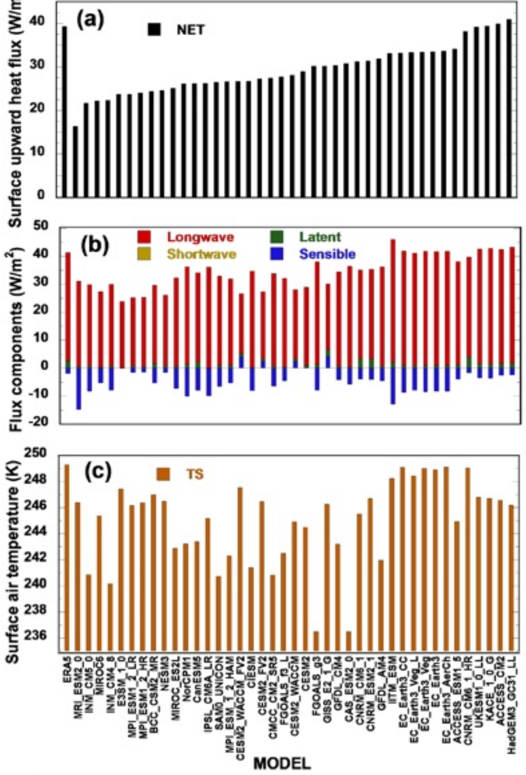
Tao et al. (2025): 41 CMIP6 climate models, for winter!

- Range of net surface heat fluxes: 15—40 W m^{-2}
- Major contributor—TIR radiation: 24—46 W m^{-2}
  → Model spread in surface temperature: 13 K
- Main uncertainty: downward TIR radiation by clouds over sea ice
- Specific due to low water vapor concentrations below clouds
- Representation of clouds crucial for net surface heat fluxes

Solomon et al. (2023): 7 state-of-the-art weather forecast models

- Models struggle to maintain liquid clouds at cold temps in winter
- Three challenges with the models: representation of the …
  - … Radiative impact of clouds
  - … Interaction of atmospheric heat fluxes with sub-surface fluxes (snow and ice properties)
  - … Relation between stability and turbulent heat fluxes

Averaged over the Arctic, DJF 2005—2014



TIR … Thermal Infrared; Tao et al. (2025), Sci. Rep

CONIDA-Night: What data do we need?

Instrument	Operating Institution	Observable	Derived products
HAMP (Mech et al., 2014)	MPI-M UNI-H UNI-K DLR-IPA	• Brightness temperature at 26 selected microwave frequencies between 22 and 183 GHz • Profiles of radar reflectivity, depolarization ratio & Doppler velocity	• Integrated water vapor • Temperature + humidity profiles • Cloud, snow & rain water path • Target classification • Rain rate
WALES (Wirth et al., 2009)	DLR-IPA	Profiles of: • Backscatter coefficient (532 nm, 935 nm, 1064 nm), • Color ratio of backscatter, particle linear depolarization ratio (all at 532/1064 nm), and • Particle extinction coefficient (at 532 nm wavelength).	• Water vapor profile (from 935 nm channels)
SMART (Wendisch et al., 2016)	UNI-L	• Spectral nadir radiance (300-2200 nm), • Spectral upward and downward irradiance (300-2200 nm), cloud top albedo	• Cloud thermodynamic phase • Liquid and ice water path • Cloud optical thickness, effective radius
BACARDI (Ehrlich et al., 2023)	UNI-L MPI-M DLR-FX	• Broadband downward and upward solar- and thermal-infrared irradiance	• Cloud Radiative Forcing (CRF)
VELOX (Schäfer et al., 2022)	UNI-L MPI-M	Two-dimensional fields of • broadband and spectral brightness temperatures between 7.7 µm and 12.0 µm • measured with 100 Hz and 640 x 512 pixel resolution	• Cloud Mask • Cloud top temperature • Cloud thermodynamic phase
Dropsondes	DLR-IPA	Profiles of: • Relative humidity, • Temperature, and • Horizontal wind.	-
BAHAMAS	DLR-FX	In-situ observations of T, q, u, v, w, 100 Hz data, GPS	-

NEW: 2 New Large Wingpod Instruments (pending)

- ➢ HELICS, Evi Jäkel (UNI-L)
  → For CONIDA-Day only
  HEmispheric and spectral Imaging multi-Camera System
- ➢ HAMPng-SMR, Mario Mech (UNI-K)
  → HALO Microwave Package next generation - Sub-Millimeter Radiometer

CONIDA-Night: What data do we need?

Funded by DFG within the "Large Infrastructure Initiative"

Extension of the HALO Microwave Package (HAMP)

→ next generation **Sub-Millimeter Radiometer** (SMR, Uni Köln): 14 frequencies, 183 and 448 GHz → Ice clouds

→ **W-Band Radar** (WBR, Uni Hamburg) → Microphysical cloud properties

CONIDA-Night: How do we want to implement the campaign?

Approved mission time slot:	Polar Night: November—December 2028 Polar Day: June—July 2029
Campaign base:	Kiruna (optional stopover in Longyearbyen)
Proposed duration of campaign:	2 times 4 weeks
Proposed research flights:	2 times 100 hours
Reasons for choice of mission time:	Contrasting polar night and day
Reasons for choice of mission base:	Close to main Arctic entrance/exit gates for WAIs and CAOs

WAI … Warm Air Intrusion; CAO … Cold Air Outbreak

CONIDA-Night: Envisioned Collaboration

Schmale et al. (2025), Elem. Sci. Anth., Ardyna et al. (2026) in review

Tara Polar Station

Research Vessel built to drift in the Arctic sea ice for the next 20 years (10 expeditions)

In-situ and remote sensing observations of aerosols, clouds, radiation

JAMC2027

The international polar science community is invited to the
Joint $(AC)^3$ – MOSAiC Conference (JAMC27)

Drivers and Impacts of a Changing Arctic

The "Joint $(AC)^3$ - MOSAiC Conference 2027 (JAMC27)" offers a forum for open, multi-disciplinary scientific exchange on the overarching theme of "Drivers and Impacts of a Changing Arctic." The international polar research community is invited to present and discuss scientific results achieved over the past decade, including findings from $(AC)^3$, MOSAiC, and other Arctic research activities.

Objectives are:

- Summarize recent advances in Arctic amplification, circulation, sea ice decline, ocean change, and coupled systems
- Cover physical, chemical, biological, and human systems across all scales
- Include observations (lab, ground, airborne, satellite) and modeling (process to global)
- Focus on Arctic; Antarctic topics also welcome
- Improve understanding, modeling, and policy relevance
- Support future research coordination and next-generation polar scientists

Abstract submissions will open in late October 2026

SAVE THE DATE

Leipzig March 8 - 12, 2027
Leipzig University Campus, Germany

https://jamc27.com