Airborne observations of Arctic mixed-phase clouds, precipitation, and water vapor with state-of-the-art remote sensing instrumentation in the vicinity of Svalbard

Mario Mech[1], S. Schnitt[1], A. Ehrlich[2], M. Klingebiel[2], N. Risse[1], I. Schirmacher[1], M. Wendisch[2], and S. Crewell[1]

[1]University of Cologne, Institute for Geophysics and Meteorology, Cologne, Germany

[2]University of Leipzig, Leipzig Institute for for Meteorology, Leipzig, Germany

contact: mario.mech@uni-koeln.de

UNIVERSITY OF COLOGNE

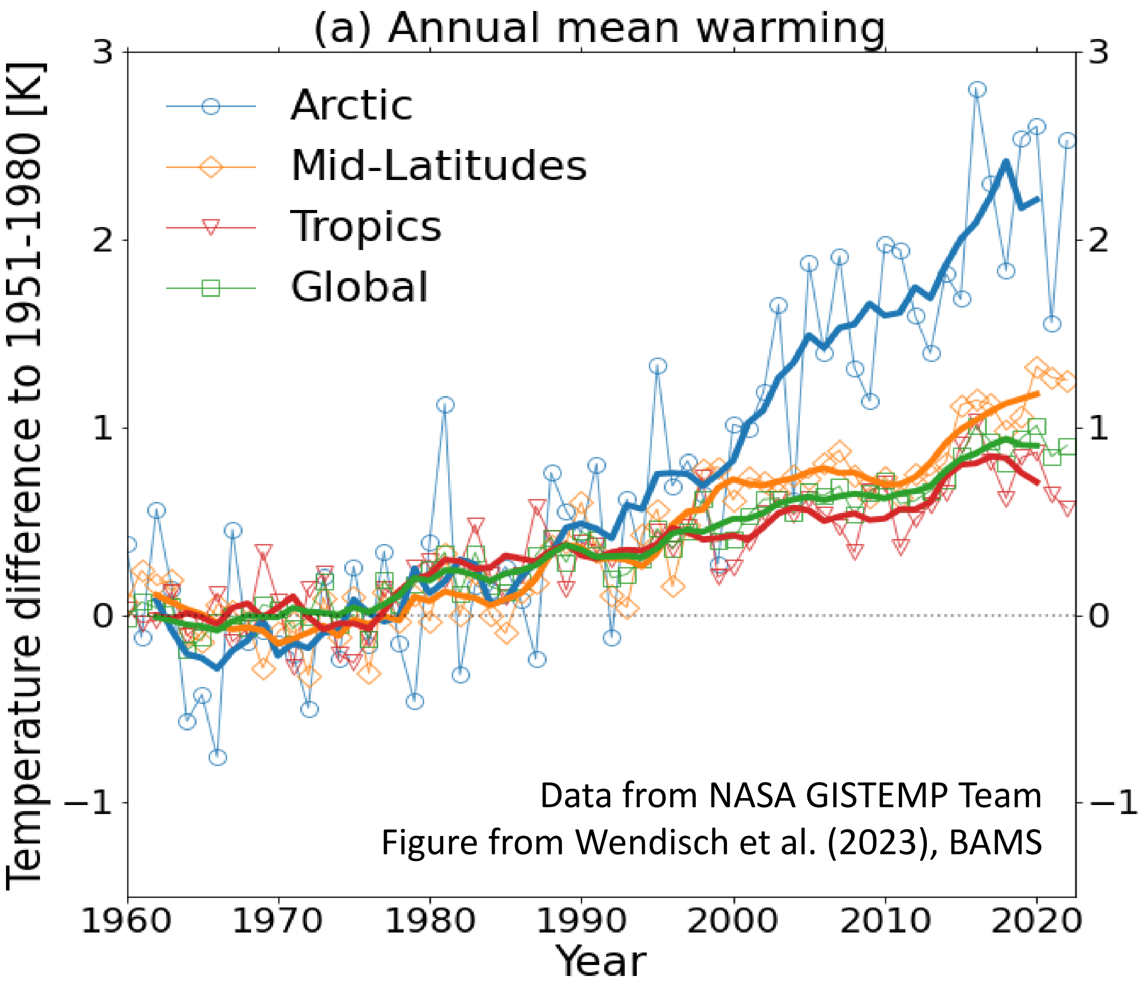
UNIVERSITÄT LEIPZIG

IPWG-11 - July 15 - 18, 2024, Tokyo, Japan

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

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

UNIVERSITÄT LEIPZIG
Universität Bremen
University of Cologne
TROPOS Leibniz Institute for Tropospheric Research
AWI



Aircraft & Instrumentation

Polar 5 and Polar 6

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

Polar 5 — remote sensing:

- 94 GHz FMCW radar + 89 GHz passive
- aerosol lidar
- passive MW (22-58 or 183-340 GHz)
- IR, VIS
- radiation
- turbulence/fluxes
- dropsondes

Polar 6 — in situ:

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

High Altitude and LOng Range Research Aircraft

Gulfstream G550: 9000 km, 15 km, 3 t

HALO — remote sensing:

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

Airborne campaigns

Comprehensive airborne campaigns within the AC³ project with Polar 5, Polar 6, and HALO in the Arctic

More than 100 flights out of Longyearbyen (Svalbard - Polar 5 and Polar 6) and Kiruna (Sweden - HALO)

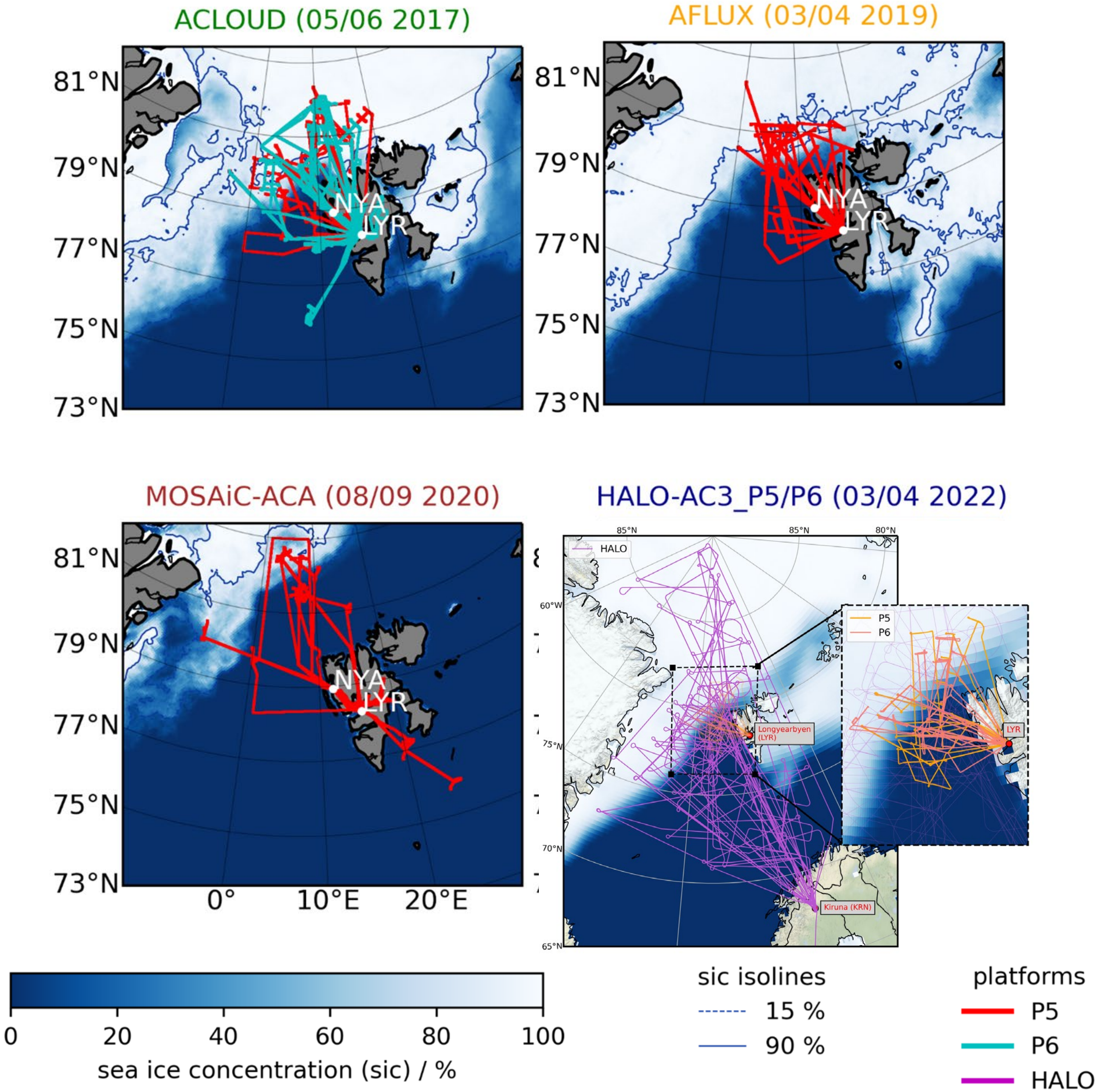
Different seasons - over ocean, MIZ, and ice

Collocations with each other and satellites

Ehrlich et al., 2019, ESSD (ACLOUD); Mech et al., 2022, Nature Sci. Dat. (AFLUX+MOSAiC-ACA); Ehrlich et al., 2024, sub. ESSD (HALO-(AC)3)

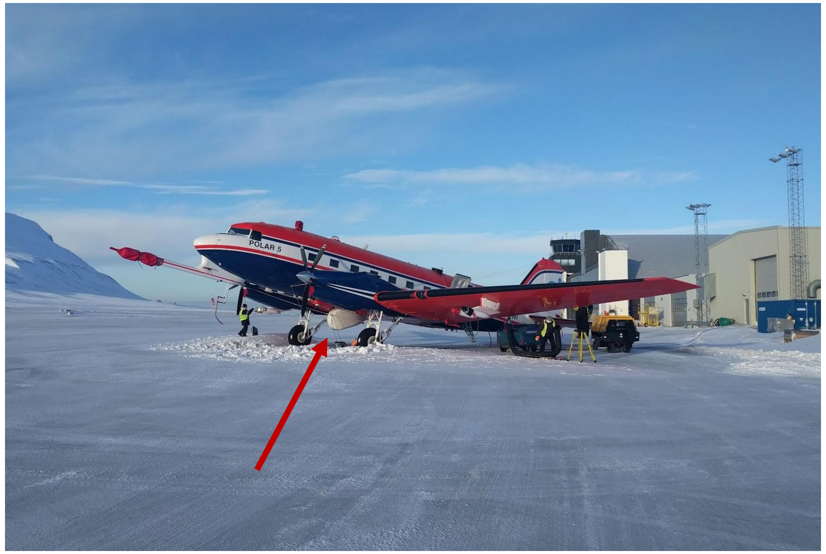
Data access and examples:

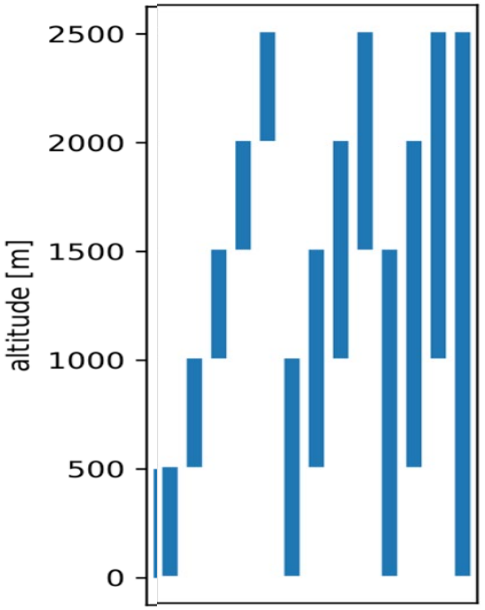
https://igmk.github.io/how_to_ac3airborne/



Liquid water path derived from airborne observations over the sea-ice-free Arctic ocean

Mario Mech, Max Ringel, Nils Risse, Susanne Crewell and many others





dropsonde (+ERA5)
over ocean
artificial clouds

PAMTRA

$$\mathrm{LWP} = c_0 + \sum_{i=1}^{3} c_i \cdot T_B^i$$

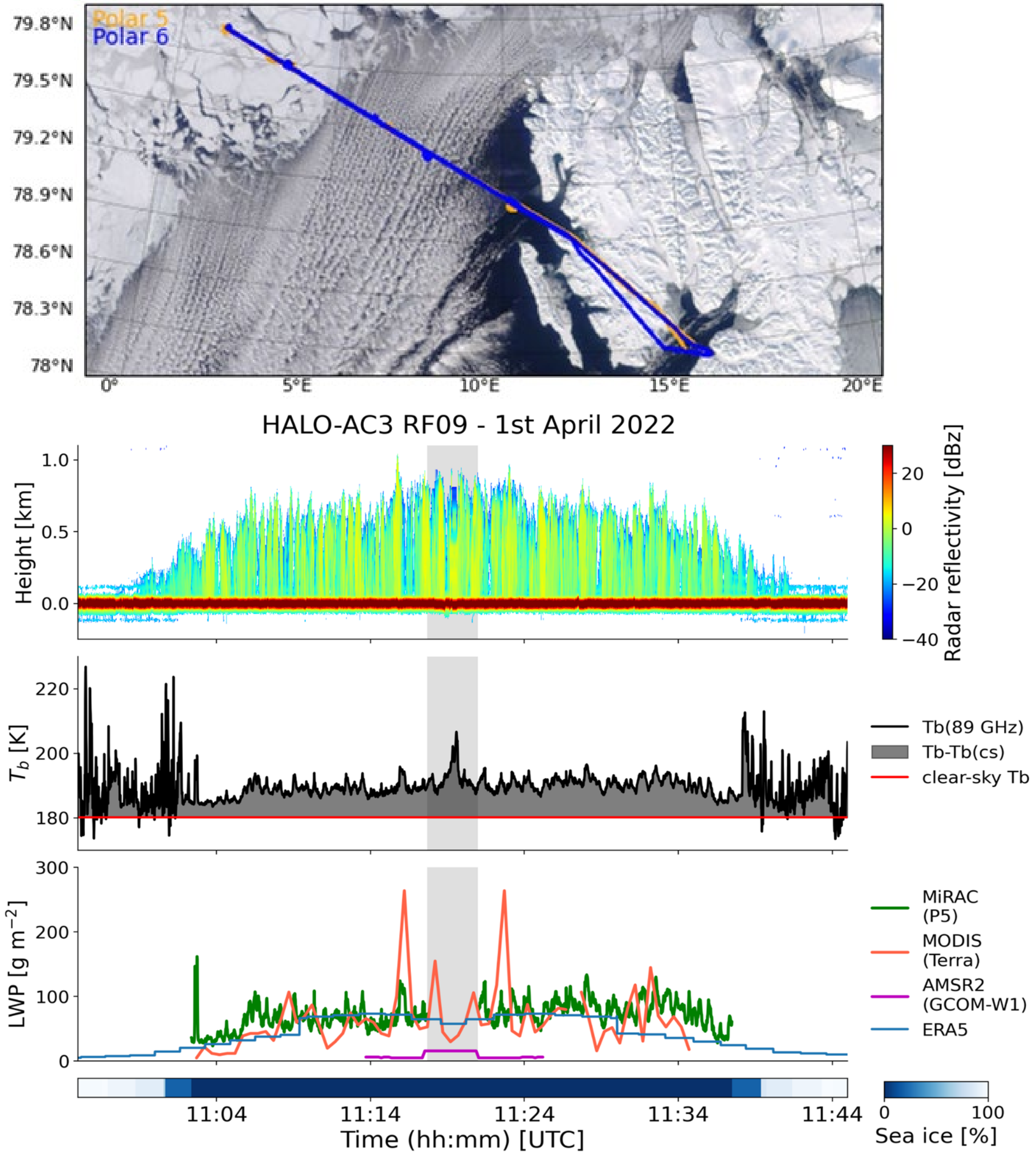
Algorithm ingredients:

- MiRAC-A passive 89 GHz channel on Polar 5
- dropsondes & artificial clouds
- **P**assive and **A**ctive **M**icrowave **TRA**nsfer (PAMTRA; Mech et al., 2020 - GMD)
- ERA5 simulations

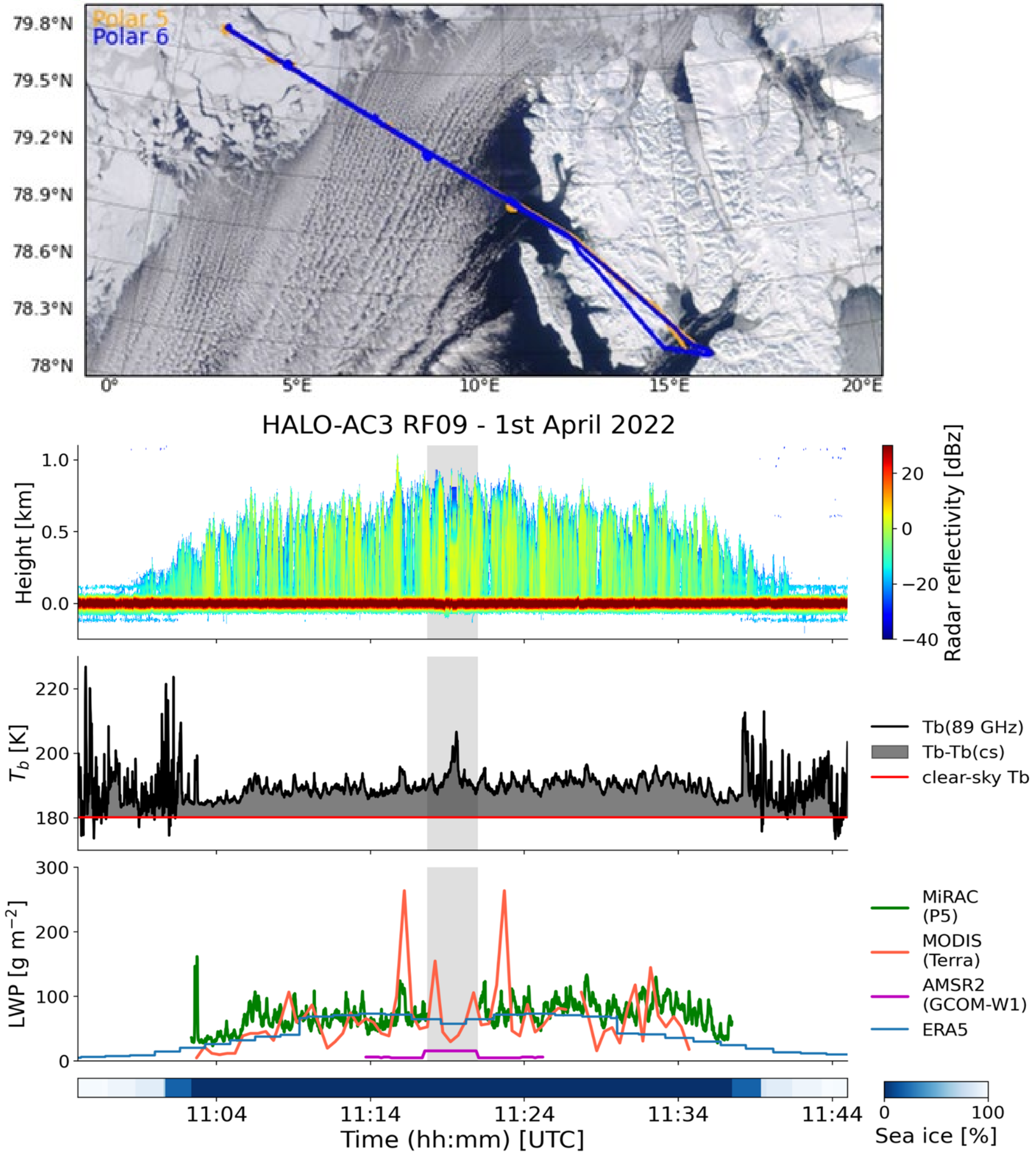
→ statistical retrieval

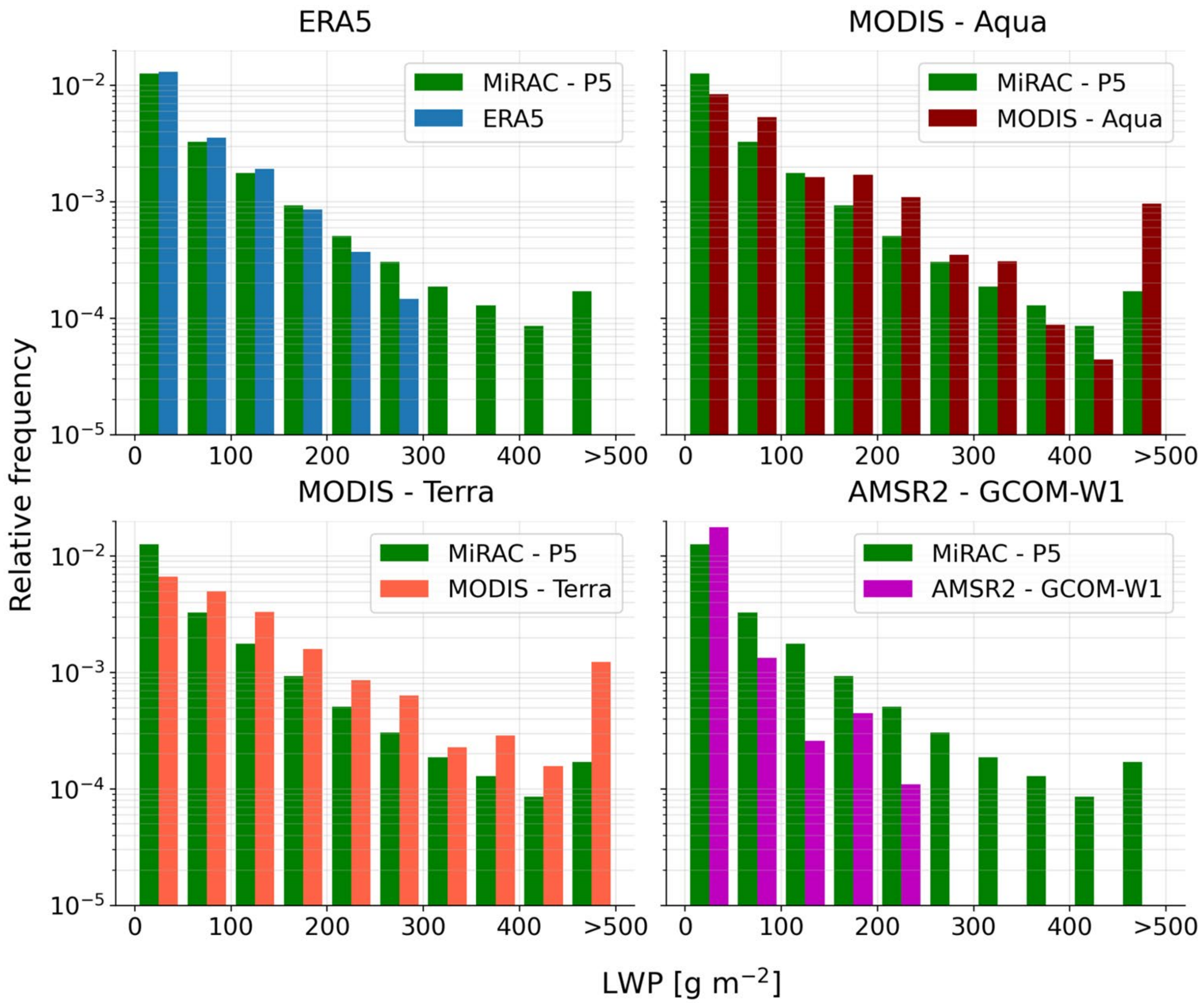
First approach: open ocean only very difficult over (broken) ice due to unknown sea ice emissivity

Liquid water path - aircraft vs reanalyses/satellites



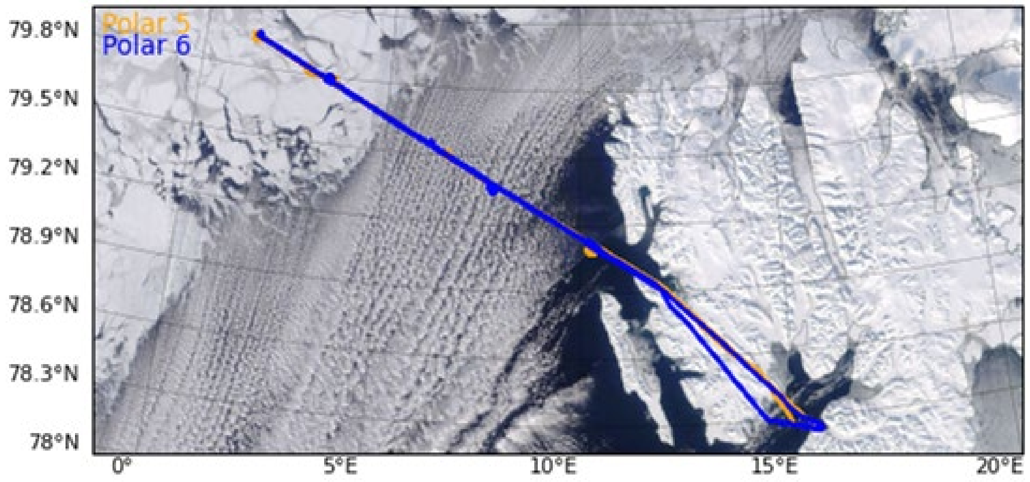
Liquid water path - aircraft vs reanalyses/satellites

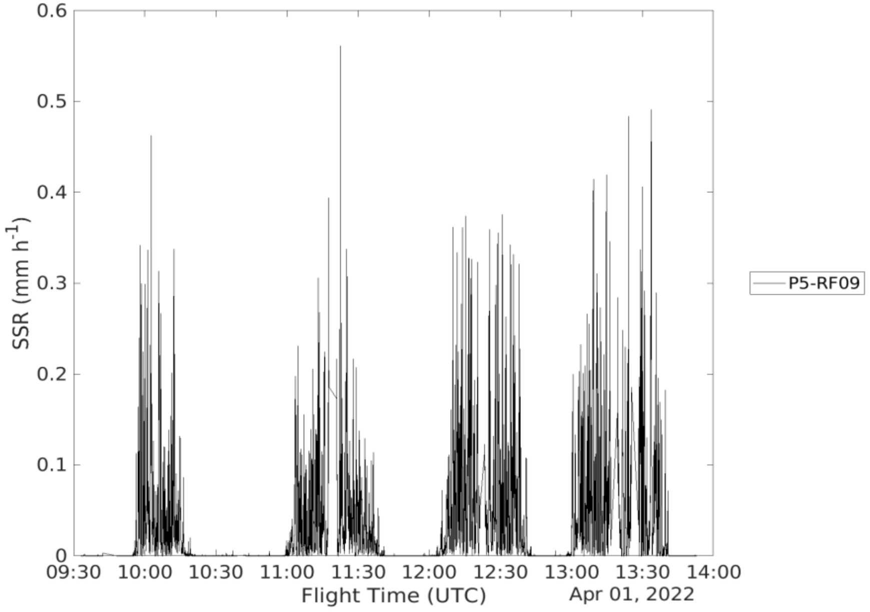




ATMS based snowfall rate retrieval compared to airborne observations

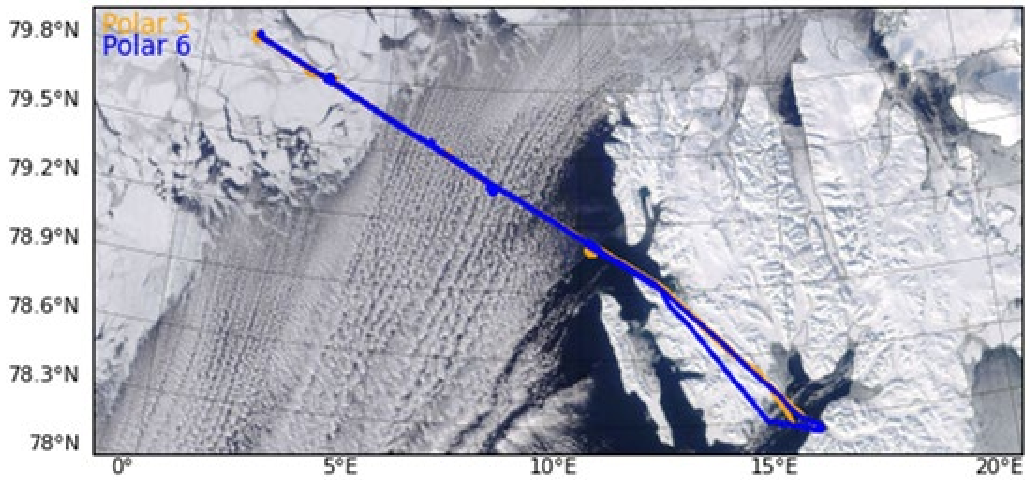
Andrea Camplani et al. - Institute of Atmospheric Sciences and Climate - National Research Council - Rome, Italy

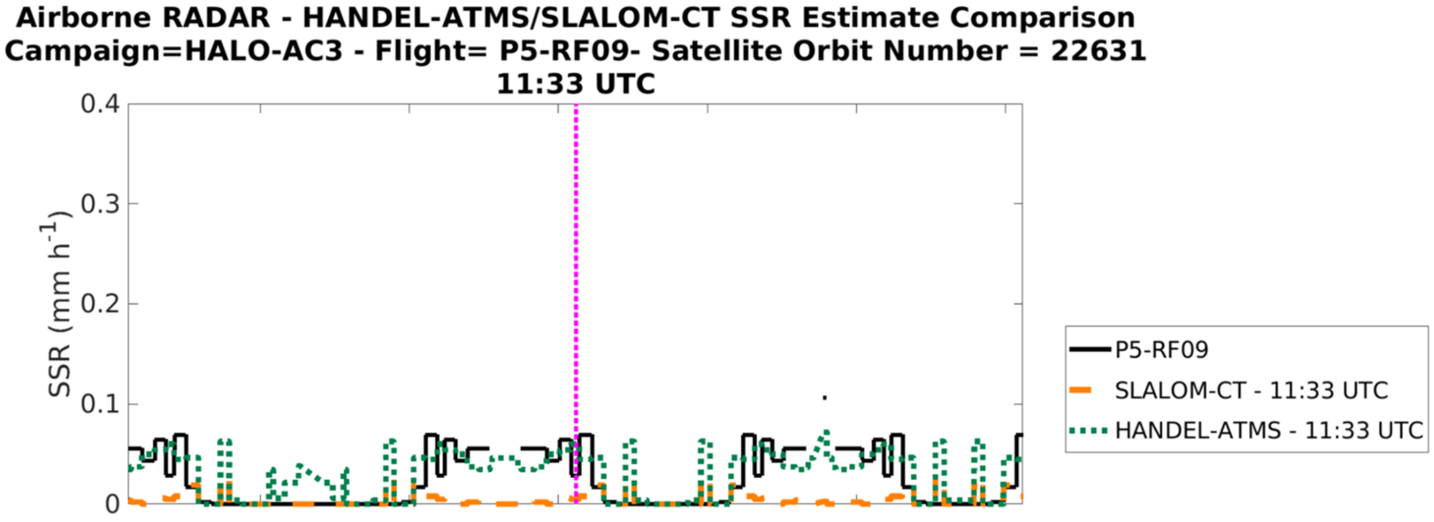


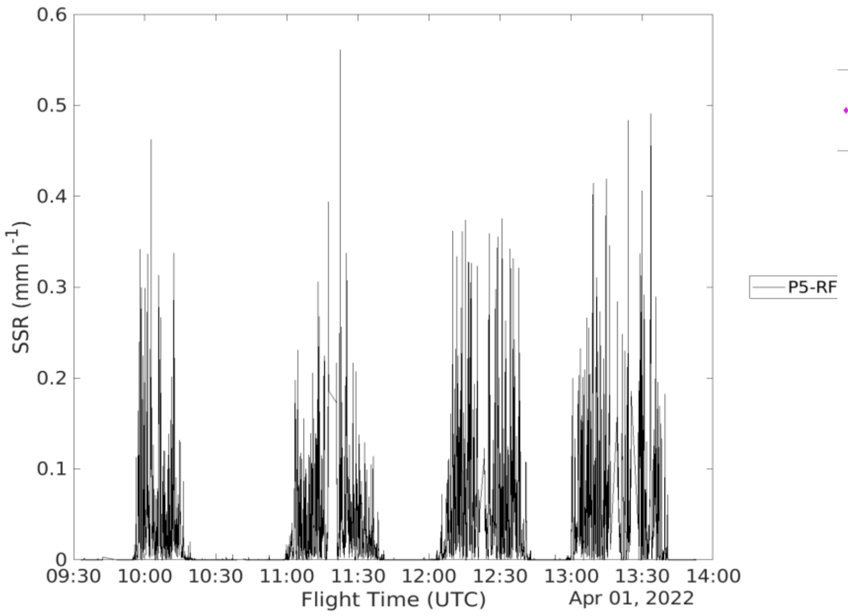


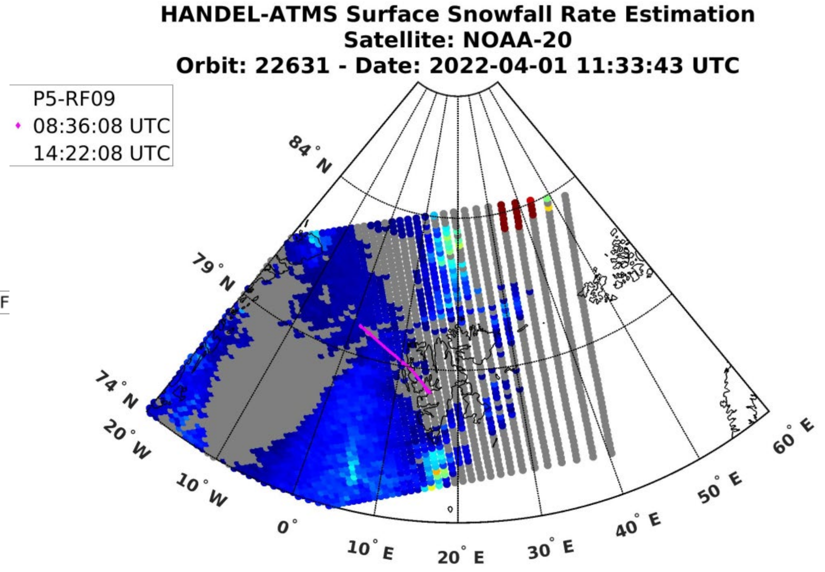
ATMS based snowfall rate retrieval compared to airborne observations

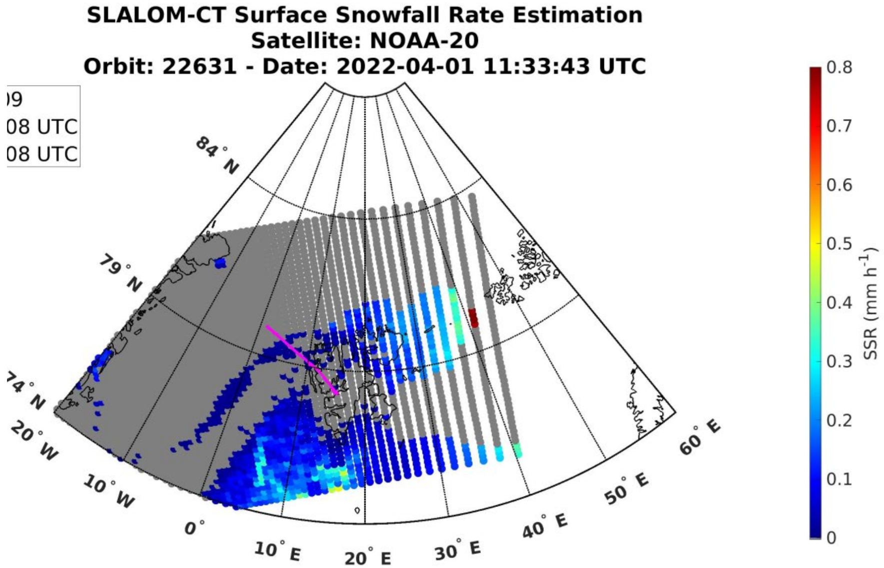
Andrea Camplani et al. - Institute of Atmospheric Sciences and Climate - National Research Council - Rome, Italy



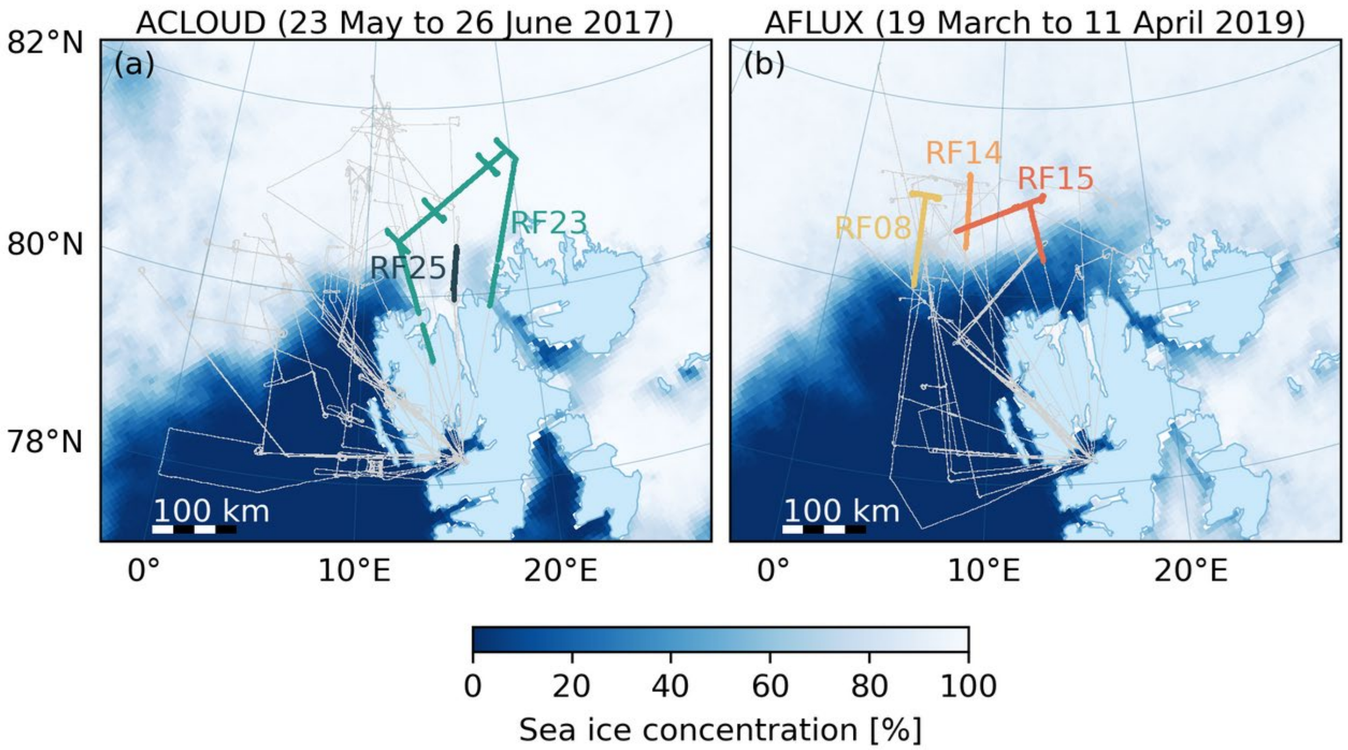








Assessing the sea ice microwave emissivity up to submillimeter waves from airborne and satellite observations (Risse et al., 2024, The Cryosphere)



Flight sections over ice at low levels and clear-sky conditions

Combination with satellites

Satellites: MHS (0-30°): Metop-A/B/C, NOAA-18/19

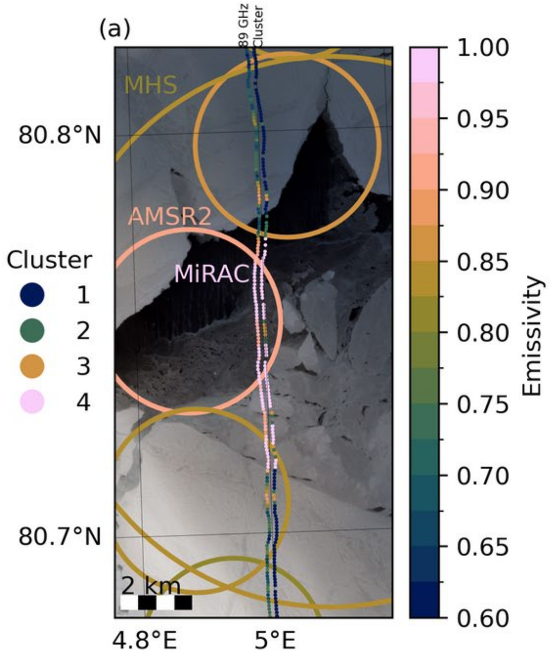
[1] ATMS (0-30°): SNPP, NOAA-20

SSMIS (53°): DMSP-F16/17/18

AMSR2 (55°): GCOM-W1

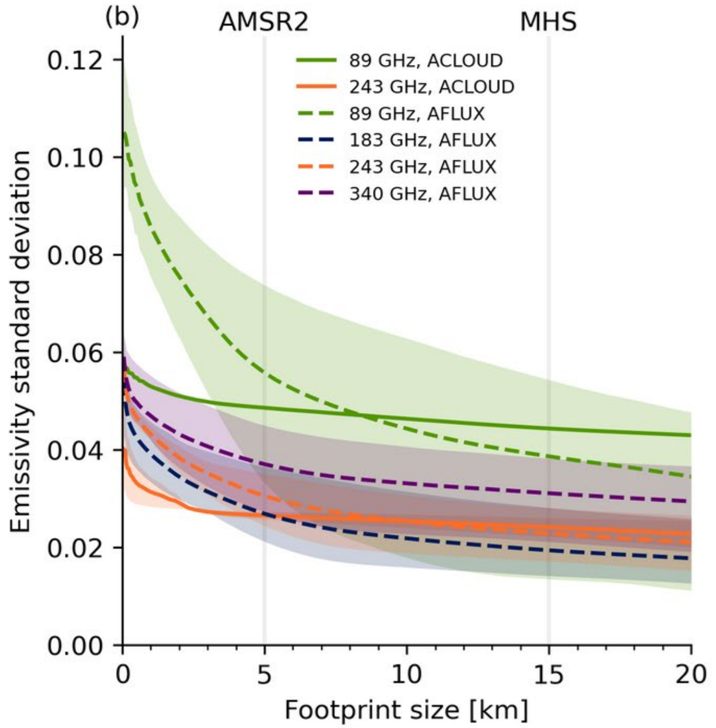
Surface temperature: IR-based reanalysis [2]

Collocation example

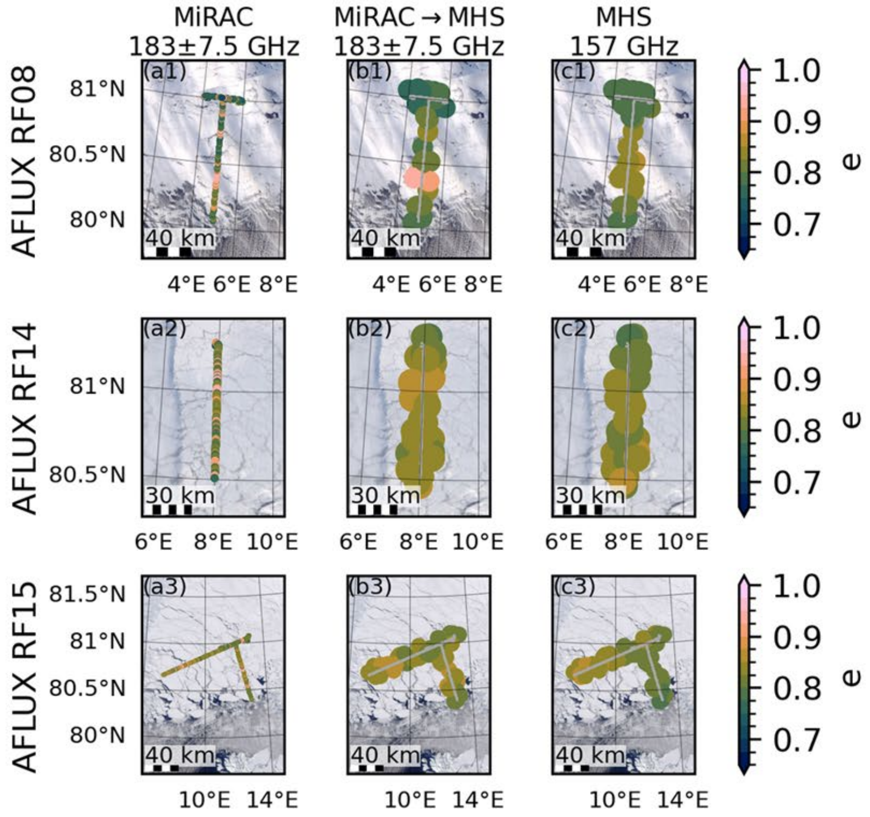


[3]

Variability vs. footprint size



Comparison between MiRAC and MHS



[4]

[1] Berg et al. (2016)

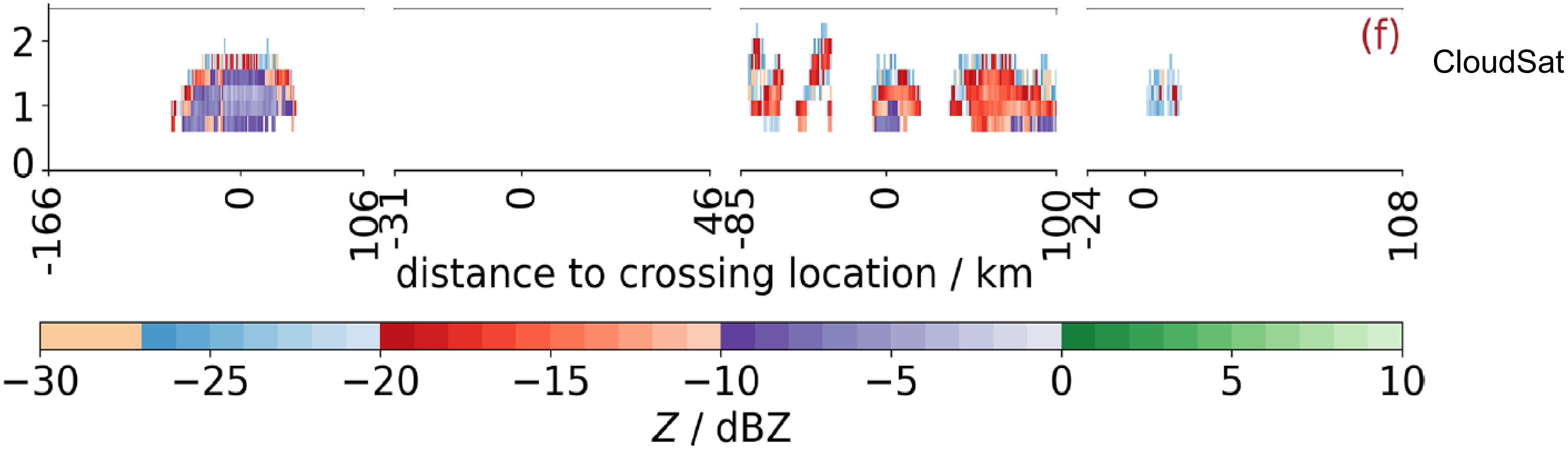
[2] Nielsen-Englyst et al. (2023)

[3] Background: Sentinel-2B from European Space Agency (2021)

[4] Background: MODIS/Terra from NASA Worldview

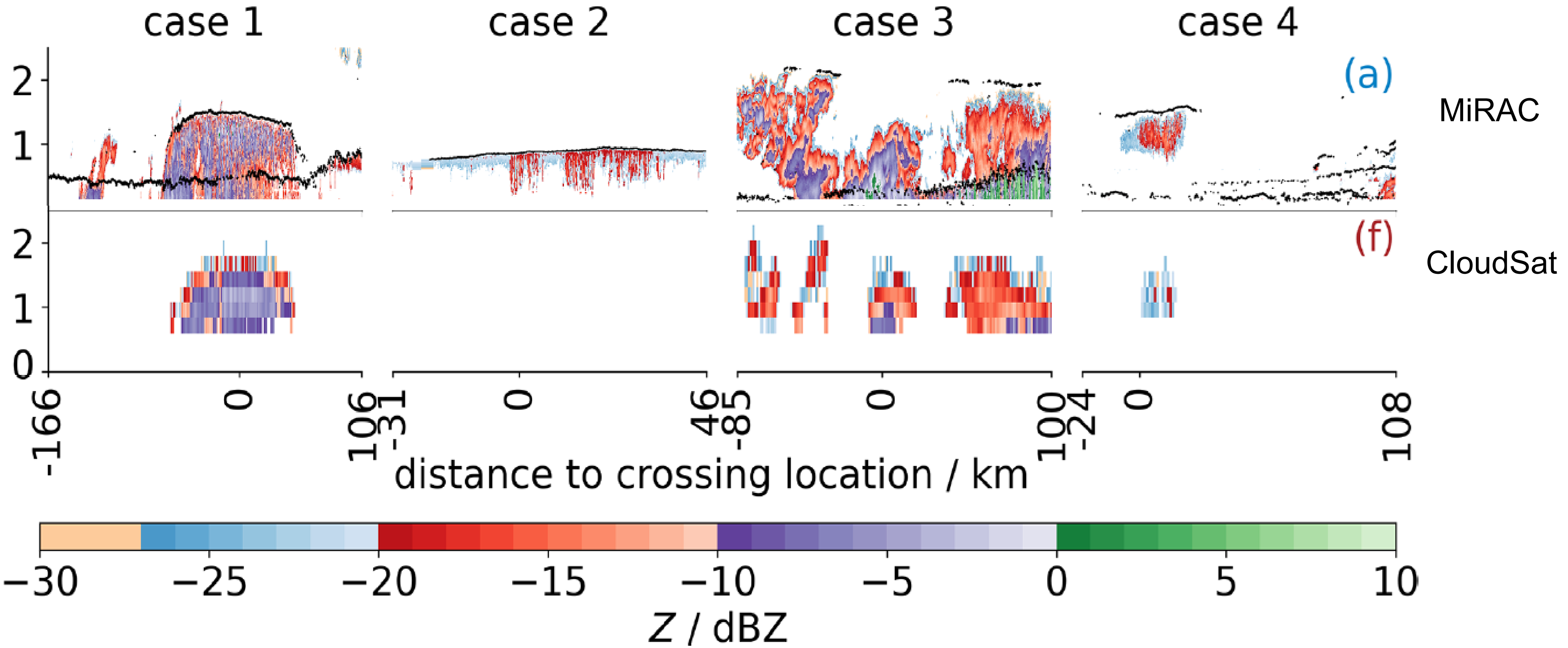
Assessing Arctic low-level clouds and precipitation from above – a radar perspective (Schirmacher et al., 2023, AMT)

- Four research flights coordinated with CloudSat overflights simultaneous measurements of radar reflectivity profile
- Developed and evaluated forward simulator to derive synthetic CloudSat radar reflectivities from MiRAC measurements



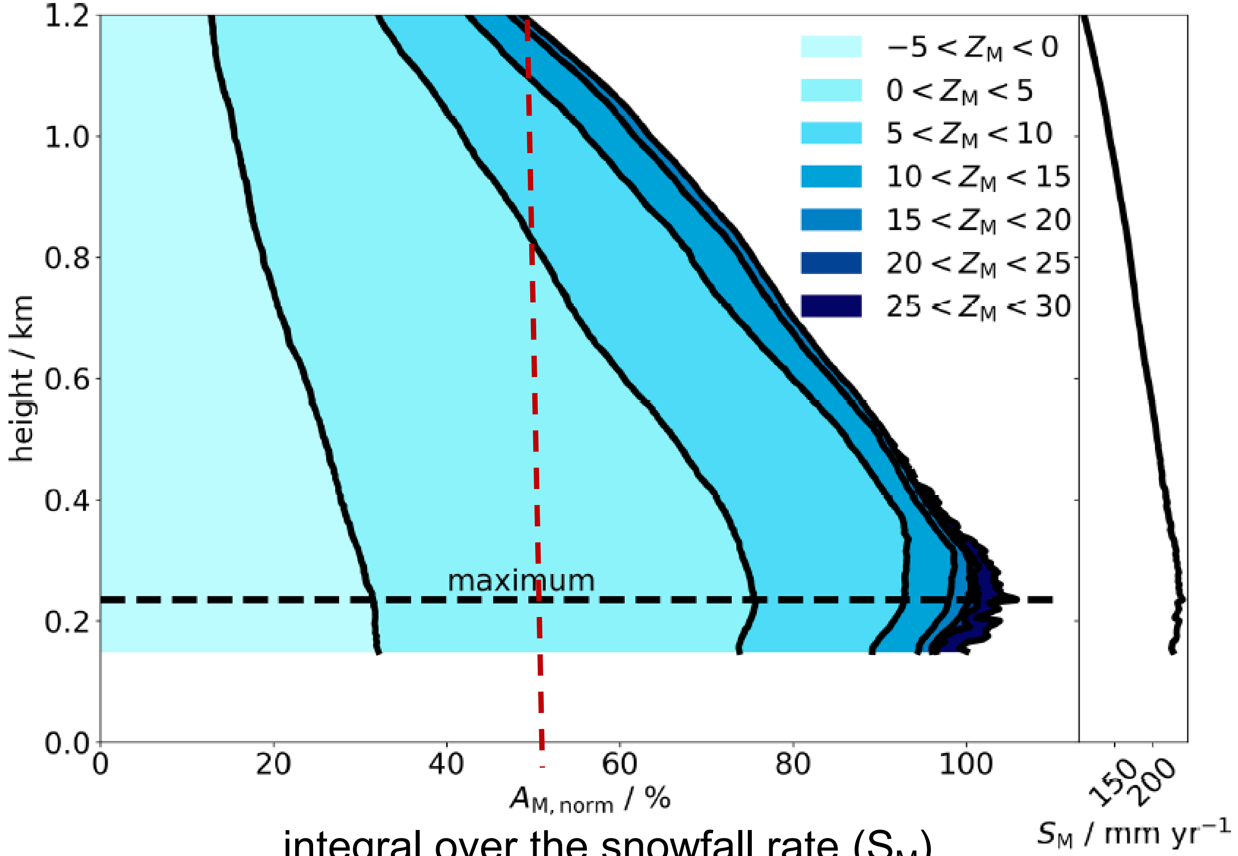
Assessing Arctic low-level clouds and precipitation from above – a radar perspective (Schirmacher et al., 2023, AMT)

- Four research flights coordinated with CloudSat overflights simultaneous measurements of radar reflectivity profile
- Developed and evaluated forward simulator to derive synthetic CloudSat radar reflectivities from MiRAC measurements



Snowfall within blind zone

- Use of standard relation to convert reflectivity to snowfall rate
- Snowfall rate increases within the blind zone towards the ground
  → maximum at about 250 m asl
- At 1.2 km height snowfall rate would be only 50 % of the lowest MiRAC level
- With 90%, light precipitation is more important than at Ny Alesund
  → mainly due to CAOs

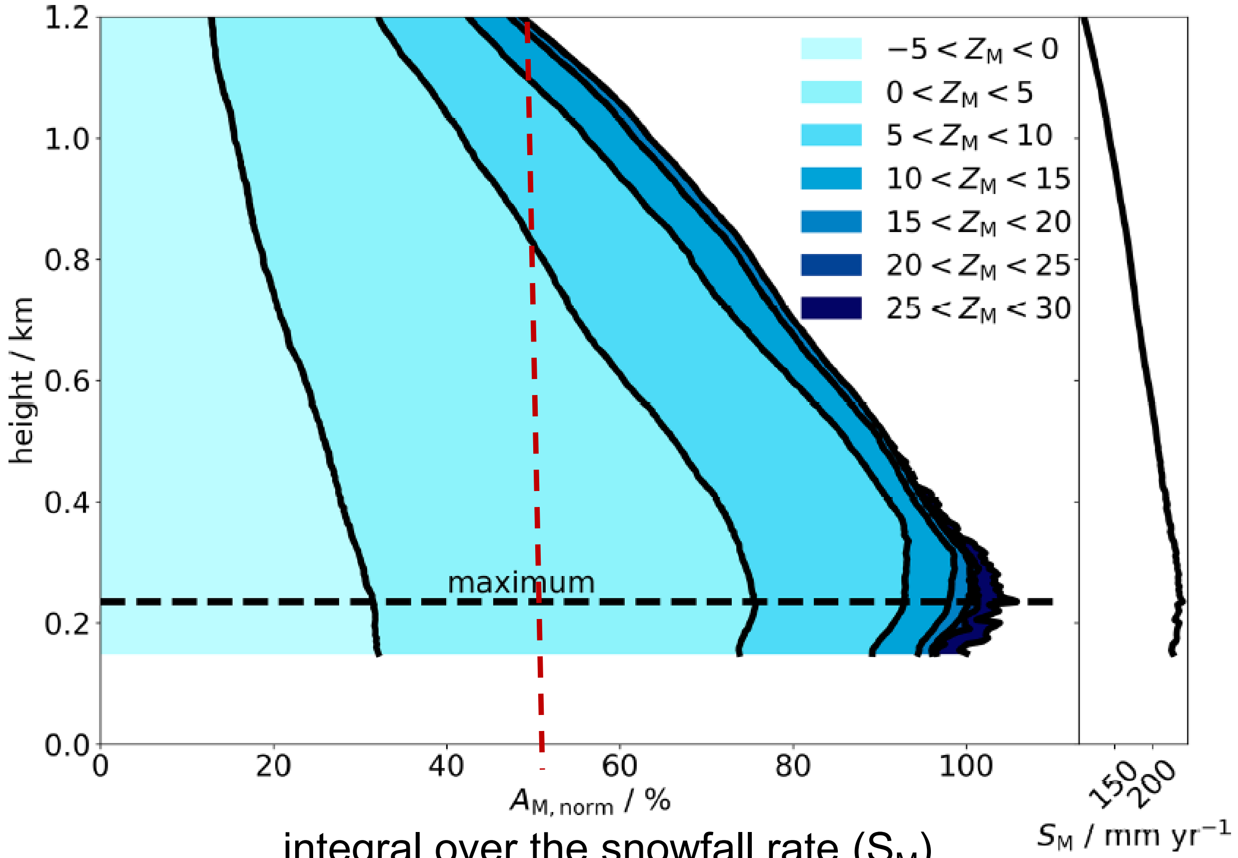


integral over the snowfall rate (S_M) for a specific height

Schirmacher et al., 2023, AMT

Snowfall within blind zone

- Use of standard relation to convert reflectivity to snowfall rate
- Snowfall rate increases within the blind zone towards the ground
  → maximum at about 250 m asl
- At 1.2 km height snowfall rate would be only 50 % of the lowest MiRAC level
- With 90%, light precipitation is more important than at Ny Alesund
  → mainly due to CAOs



integral over the snowfall rate (S_M) for a specific height

CloudSat would see only half of the snowfall

Schirmacher et al., 2023, AMT

GRaWAC: G-band Radar for Water Vapor and Arctic Clouds

Frequency modulated continuous wave (FMCW) radar

Dopplerized, dual-frequency measurements at 167.3 and 174.7 GHz

Versatile deployment from ground, ship, and aircraft under all weather conditions

Frequencies ideal for Differential Absorption Radar: retrieval of water vapor profiles in all-weather conditions [1,2,3]

parameter	specification	
frequency / GHz	167.3 ± 0.1	174.7 ± 0.1
wavelength / mm	1.8	1.7
transmit power / mW	70	90
gain / dB	54.6	
receiver noise / dB	5.5	
receiver intermediate frequency / MHz	4	
dynamic range / dB	58	
antenna diameter / m	0.5	
beam width / $^\circ$	0.36	
power consumption / W	700	
weight / kg	116	
dimension / m^3	115 x 90 x 90	

Radiometer Physics
A Rohde & Schwarz Company

[1] Lebsock et al., 2015; [2] Roy et al., 2020; [3] Millan et al., 2024

Humidity profiles and Arctic Mixed-phase clouds as seen by Airborne G-W-band radars

HAMAG

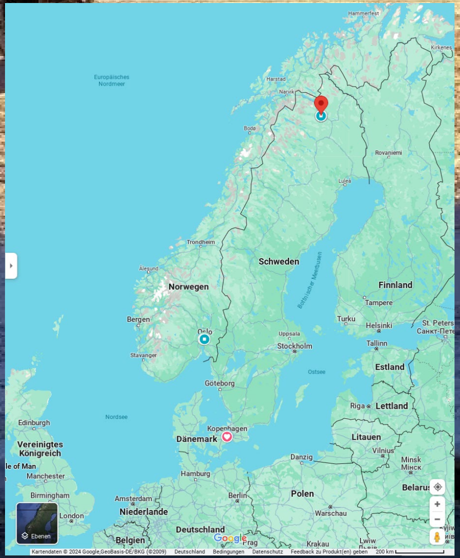
Kiruna (Sweden) - Arena Arctica

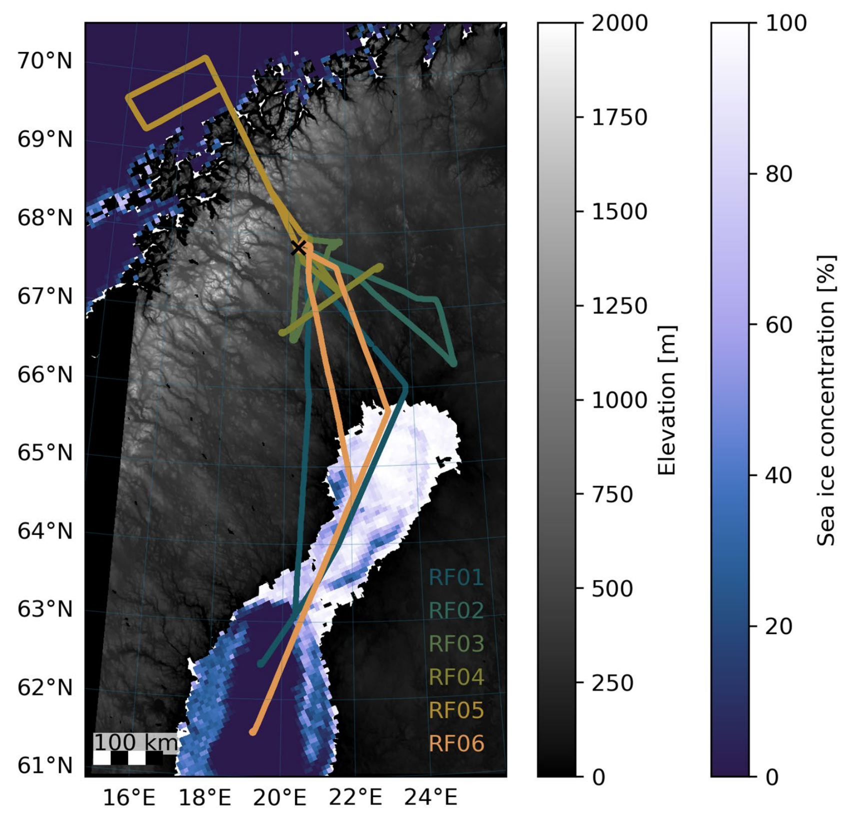
7. to 22. February 2024

Polar 6 research aircraft (BT-67) from AWI

GRaWAC, MiRAC-A, MiRAC-P, KT-19, dropsondes

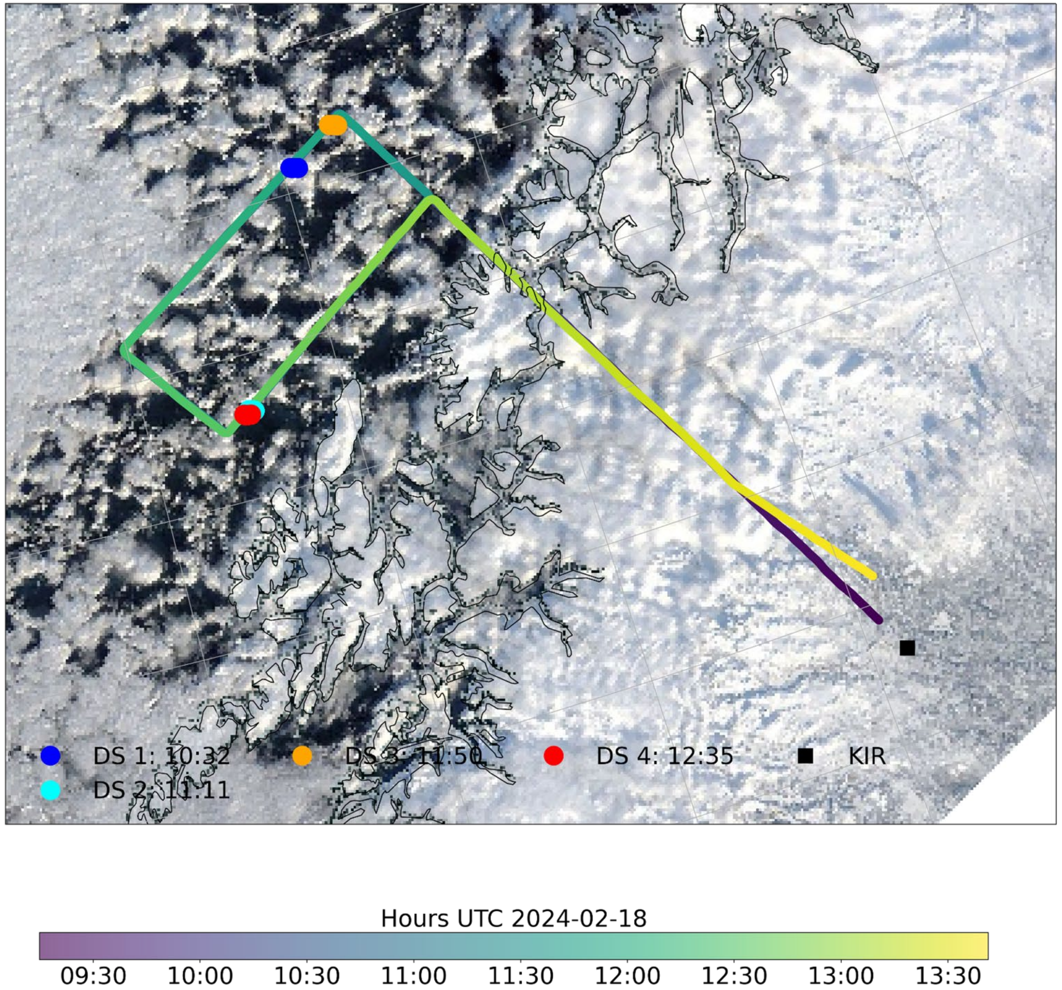
6 research flights over the Gulf of Bothnia and the Norwegian Sea

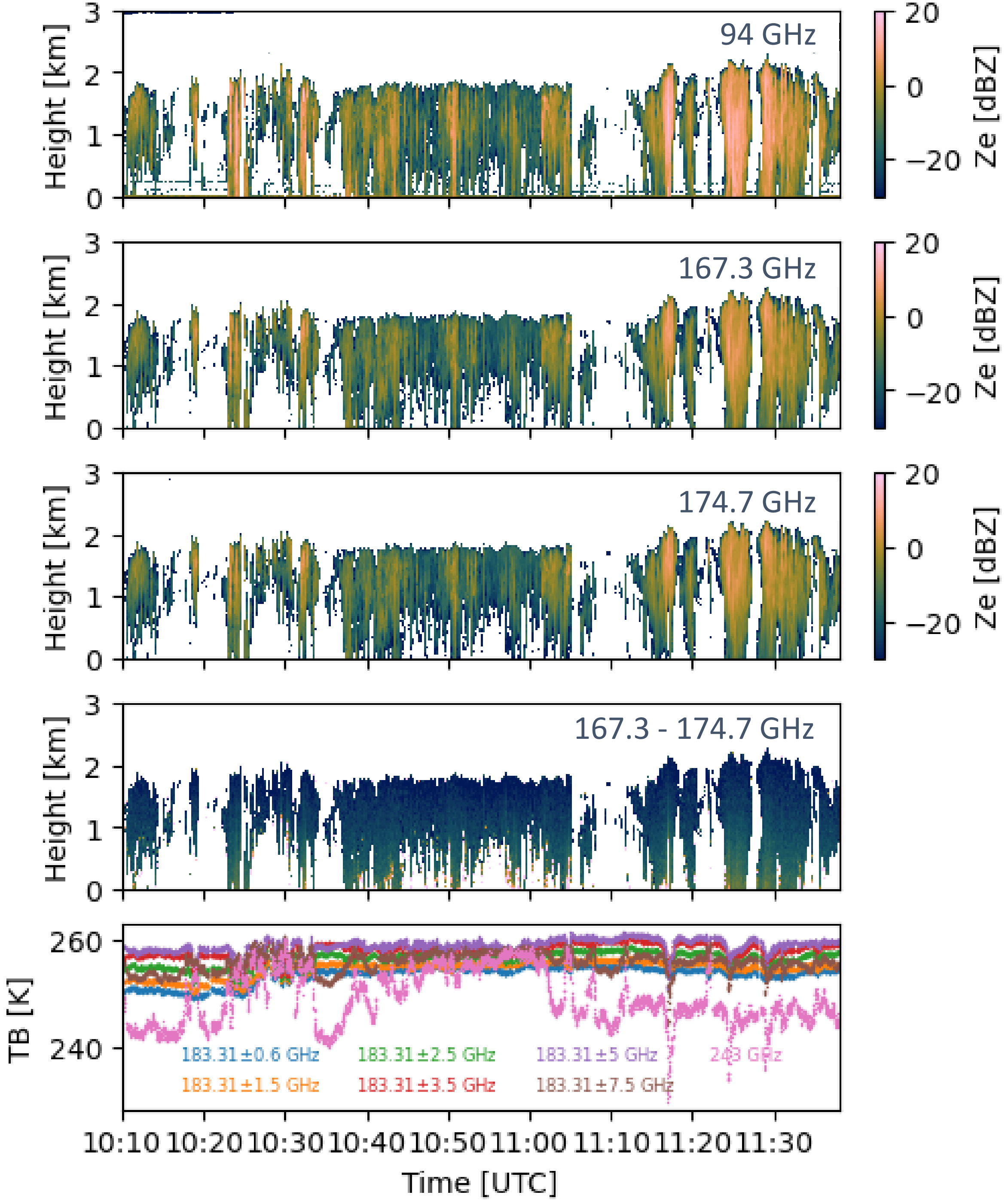




HAMAG RF05 - 18.2.2024

cloud streets with open and closed cells over the Norwegian Sea





EarthCARE CAL/VAL

2 weeks in April 2025 with remote sensing equipment onboard Polar 5 to support

EarthCARE in its early stage

Very likely based from Kiruna (Sweden)

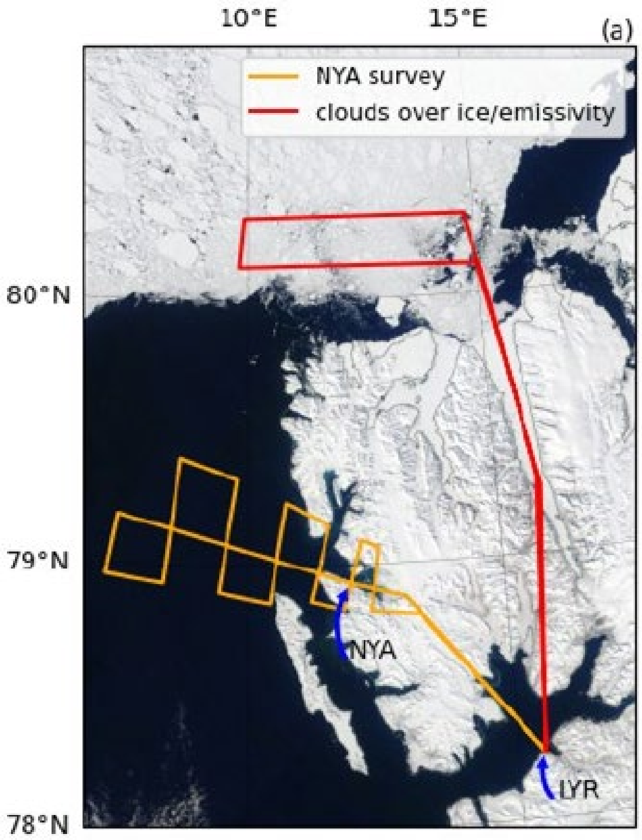
COMPEX - Clouds over cOMPlEX environment

Campaign planed in the framework of **AC3**
(University of Cologne and Leipzig)

Scientific goals:
(i) Spatio-temporal low level cloud variability in the Ny-Ålesund/Kongsfjorden area
(ii) Cloud characteristics over sea ice
(iii) Sea-ice emissivity
(iv) EarthCARE underflights

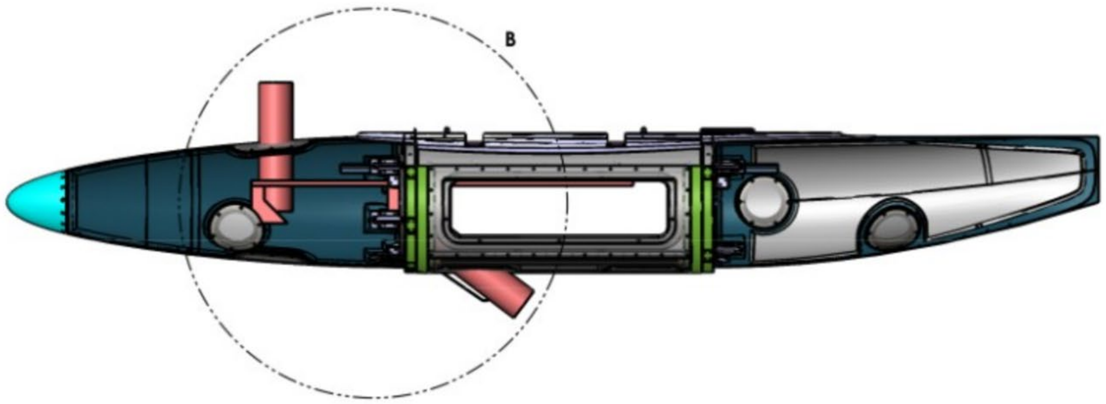
5 weeks granted in Mar/Apr 2026

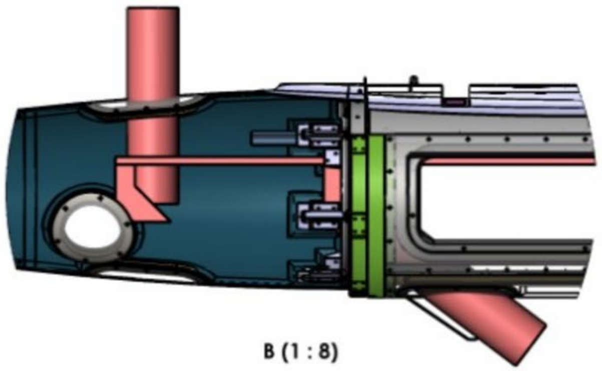
Base in Longyearbyen (Svalbard)



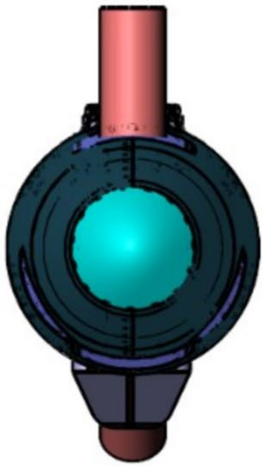
HALO Microwave Package next generation - Sub-Millimeter Radiometer (HAMPng-SMR)

- extend HALO Microwave Package HAMP to higher frequencies
- mimic future satellite sensors in the higher microwave and sub-millimeter range (ICI, AWS)
- sensitivity to ice clouds and their properties and water vapor





B (1 : 8)



Frequency [GHz]	Polarization	Application
183 ± 1.4*, 2.0, 3.4, 4.5*, 7.0	V	humidity, ice water path
243 ± 2.5	V, H	ice water path, ice particle properties
325 ± 1.5, 3.5, 6.6*, 9.5	V	humidity, ice water path
448 ± 1.4, 3.0, 7.2	V	humidity, ice water path

Radiometer Physics
A Rohde & Schwarz Company


ありがとうございます。