Mixed-phase clouds and climate – the importance of airborne measurements

Trude Storelvmo (U of Oslo)

Tim Carlsen, Rob David, Stefan Hofer and Franziska Hellmuth, Britta Schäfer (U of Oslo)

Teams of EU projects IceSAFARI and BRACE-MY

EUFAR Seminar, September 7th, 2022

Outline

INTRODUCTION:

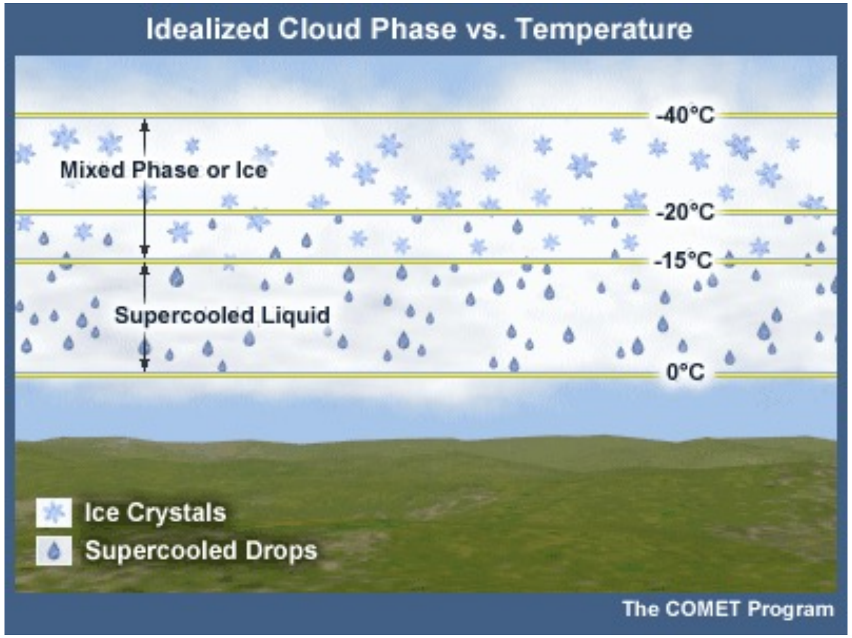
- Mixed-phase clouds
- Cloud feedbacks

PART 1:

- Cloud phase heterogeneity
- Existing observations of mixed-phase clouds

PART 2:

- Our future airborne campaigns
  - Arctic campaign
  - Tropical Pacific campaign



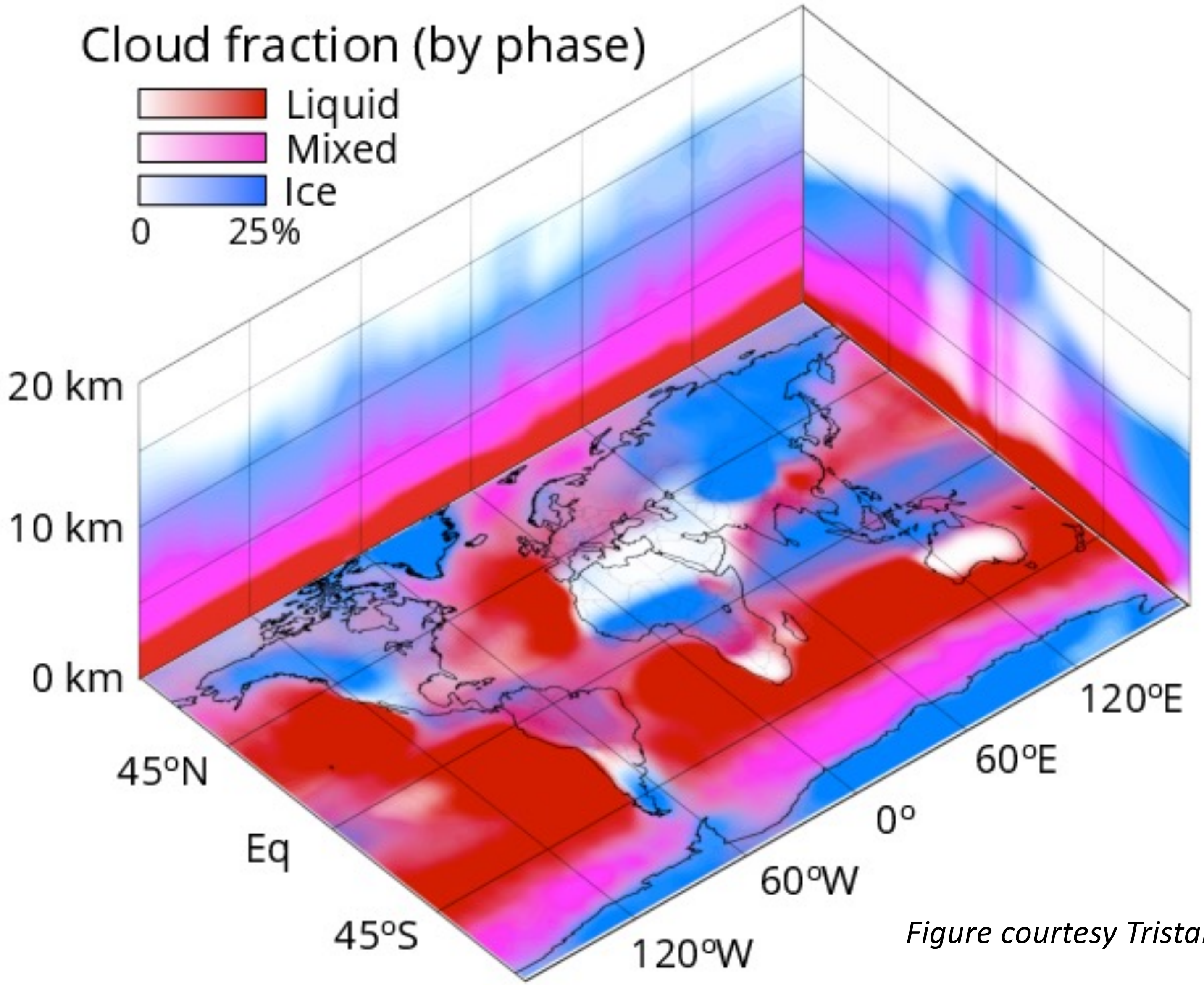
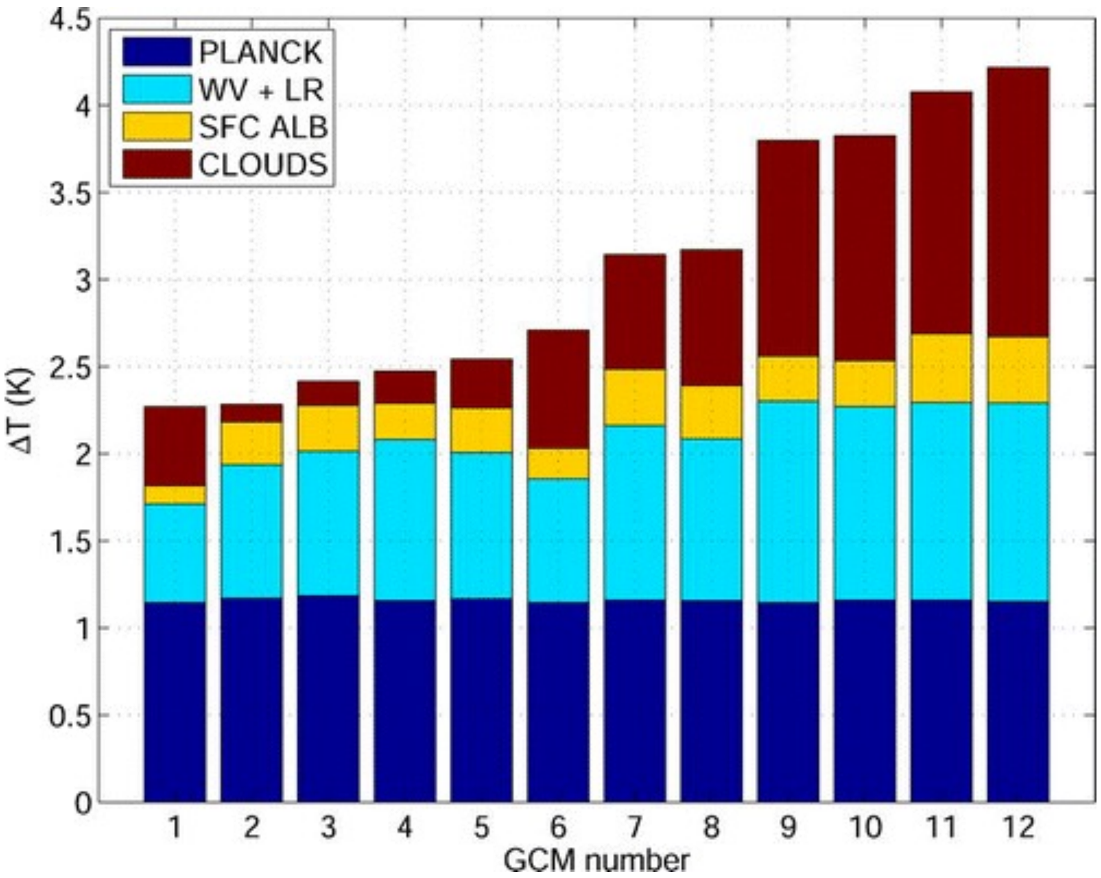


Figure courtesy Tristan L'Ecuyer

Clouds in climate models – why so important?

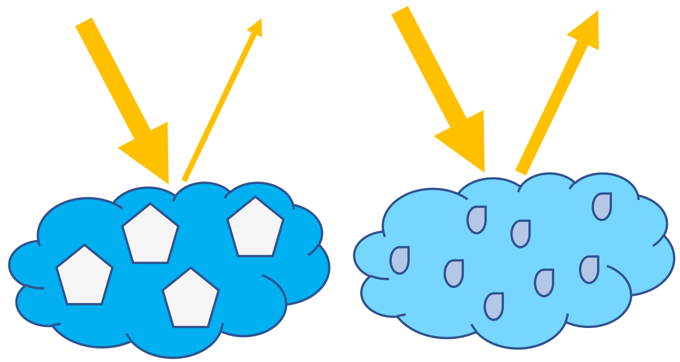
- The magnitude of the ECS is controlled by climate feedbacks
- The cloud feedback is by far the most uncertain one, contributing to a wide range of simulated temperature changes for a given forcing



Temperature change for a doubling of CO_2 *(Dufresne & Bony, Journal of Climate, 2008)*

Cloud feedbacks can be decomposed into contributions from…

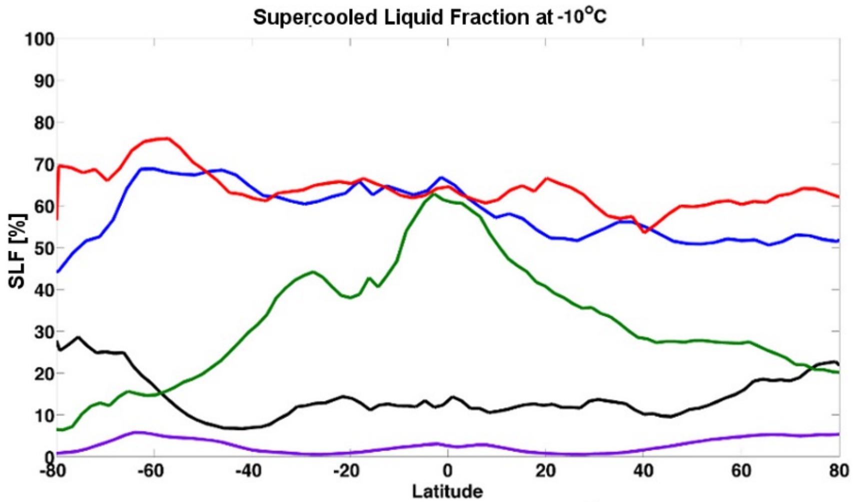
1. Changes in cloud altitude
2. Changes in cloud amount
3. Changes in cloud phase / optical thickness

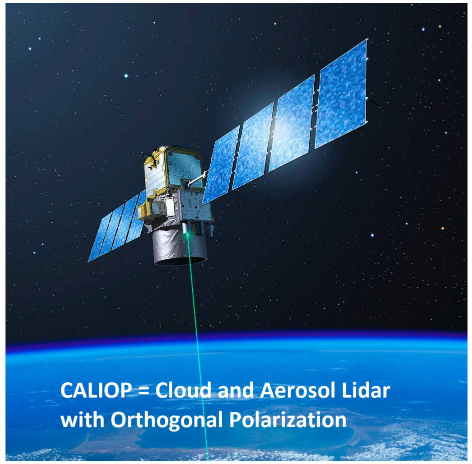


Storelvmo, Tan and Korolev (2015)

For otherwise similar properties, liquid clouds are optically thicker than ice clouds. Tropospheric warming results in fewer ice clouds and more liquid clouds → overall optically thicker clouds → cooling (negative feedback)

Global Climate Models underestimate the amount of supercooled liquid in clouds



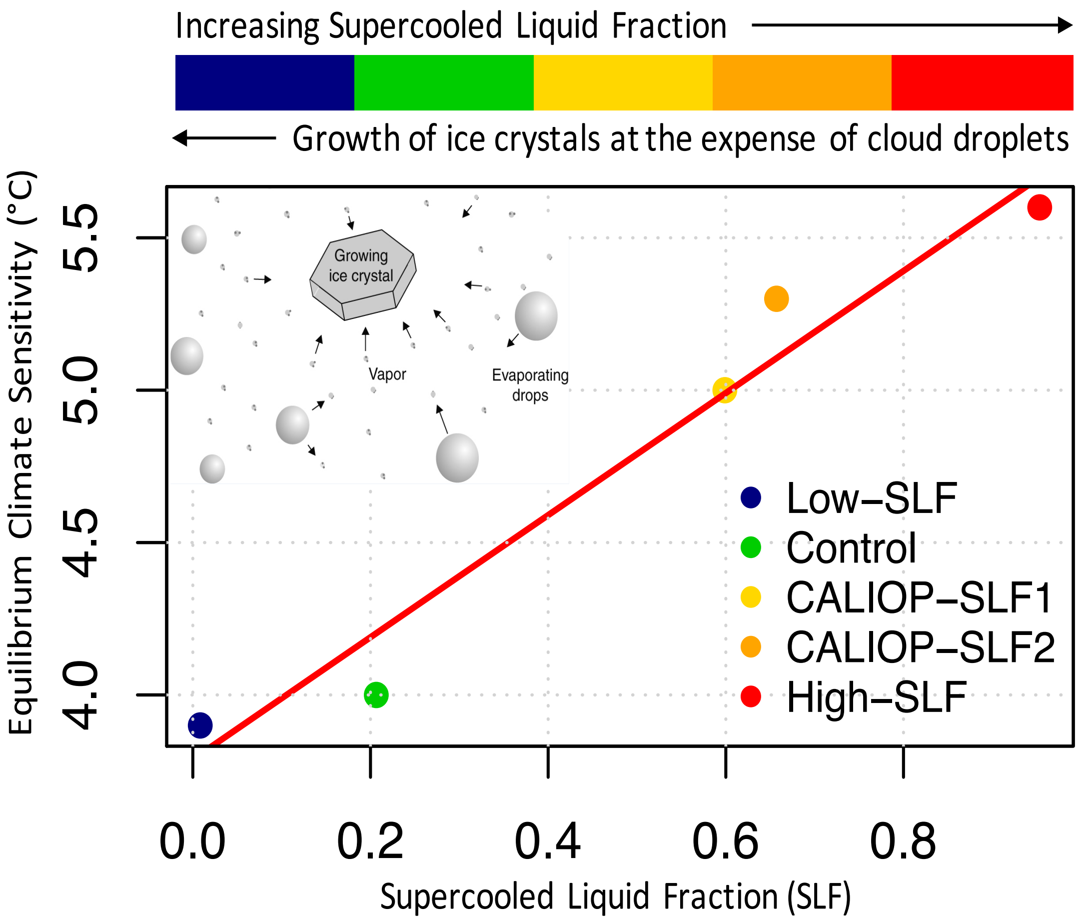


Komurcu et al. (2014)

ECHAM6 CAM-IMPACT CAM-Oslo CAM 5.1 MAM7 CALIOP

These findings have been confirmed by several other studied, for example Cesana et al. (2015) and McCoy et al. (2015)

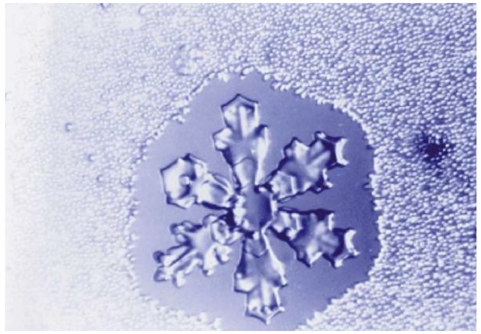
Link between climate sensitivity and cloud phase

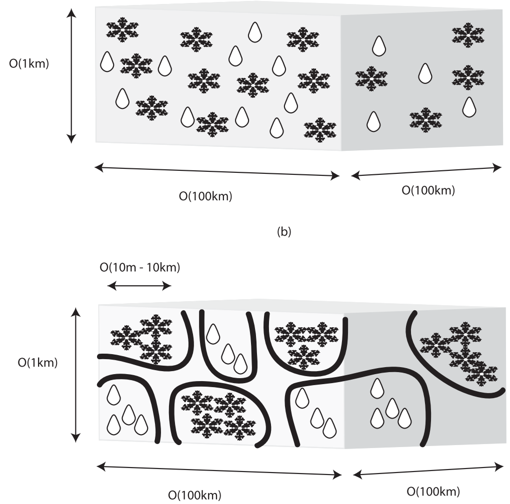


Tan, Storelvmo & Zelinka, Science, 2016

Hypothesis: Phase bias exists because models do not account for cloud subgrid-scale heterogeneity

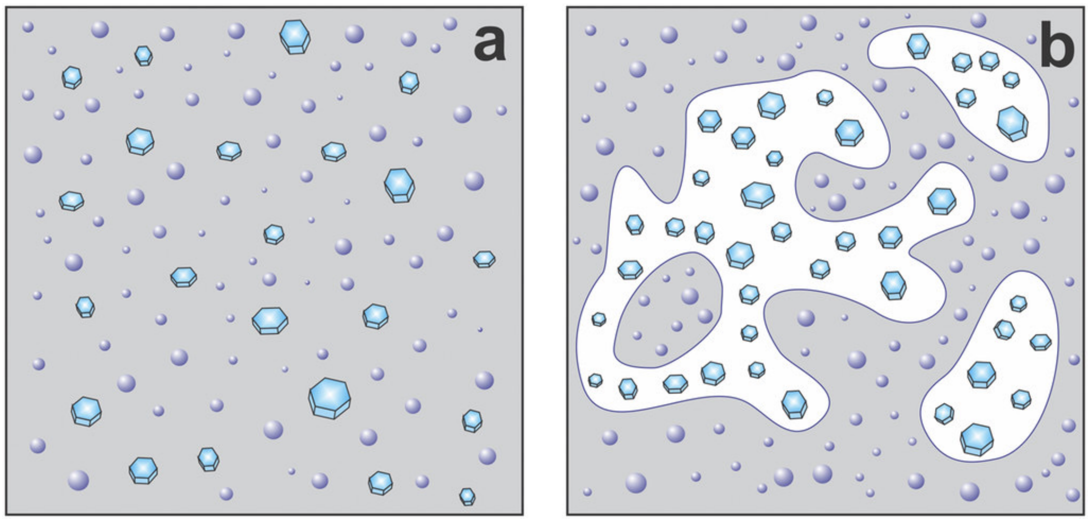
- The Wegener-Bergeron-Findeisen (WBF) process = rapid growth of ice crystals at the expense of surrounding cloud droplets when the two phases co-exist.
- The standard assumption in GCMs is that liquid and ice is uniformly mixed throughout each entire model grid box.
- But in reality, aircraft measurements show that mixed-phase clouds more typically consist of pockets consisting solely of liquid or ice (e.g. Korolev, 2017)
- This has consequences for how the WBF process should be parameterized in large-scale models



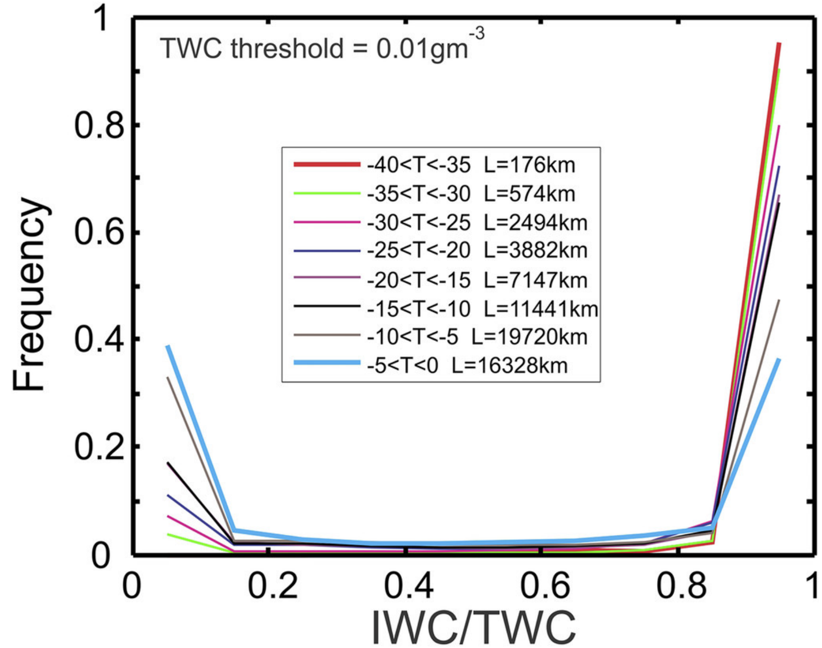


Tan and Storelvmo (JAS, 2015)

Cloud phase heterogeneity

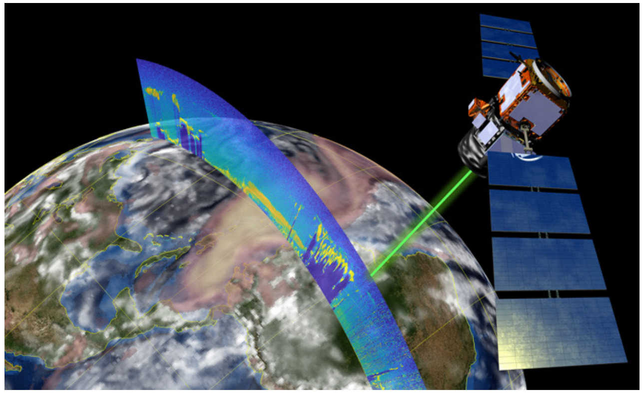


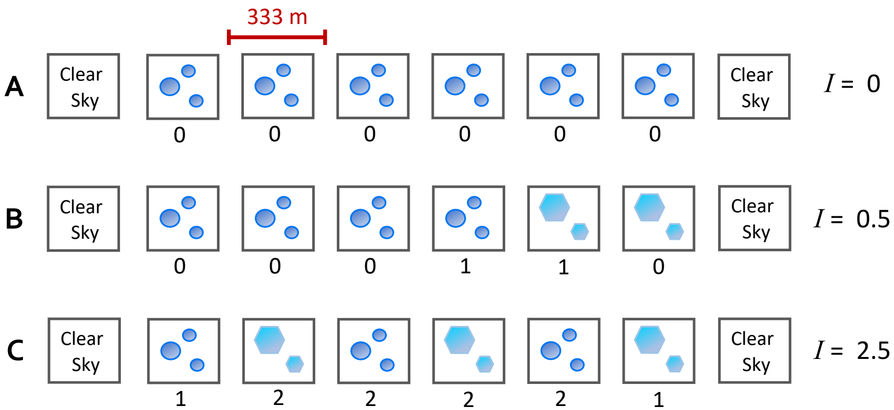
Schematic from Korolev et al. (2017), illustrating the difference between (a) ”genuninely mixed-phase clouds” and (b) “conditionally mixed-phase clouds”

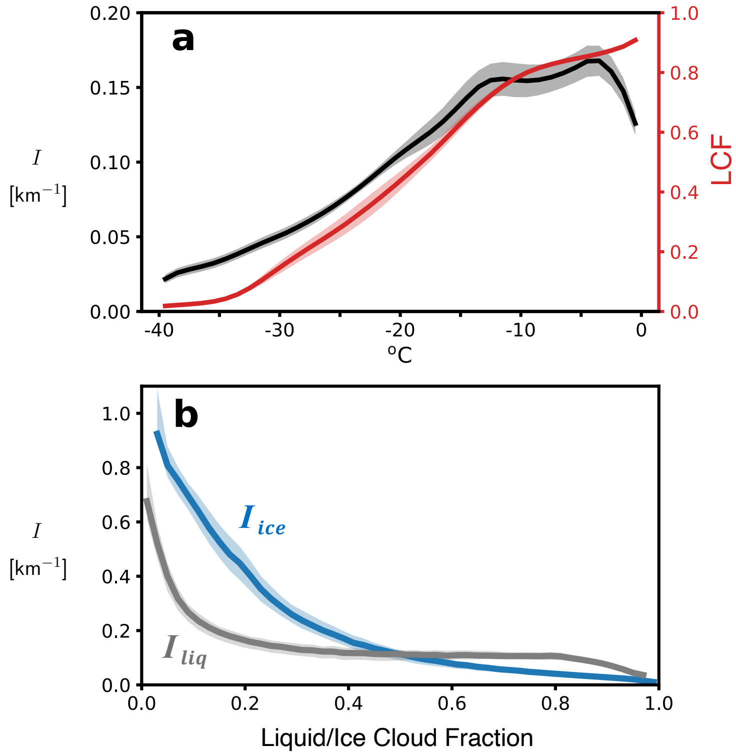


Airborne measurement of mixed-phase clouds with the Nevzorov probe and 100m averaging length (from Korolev et al., 2017)

Cloud phase heterogeneity from Space?

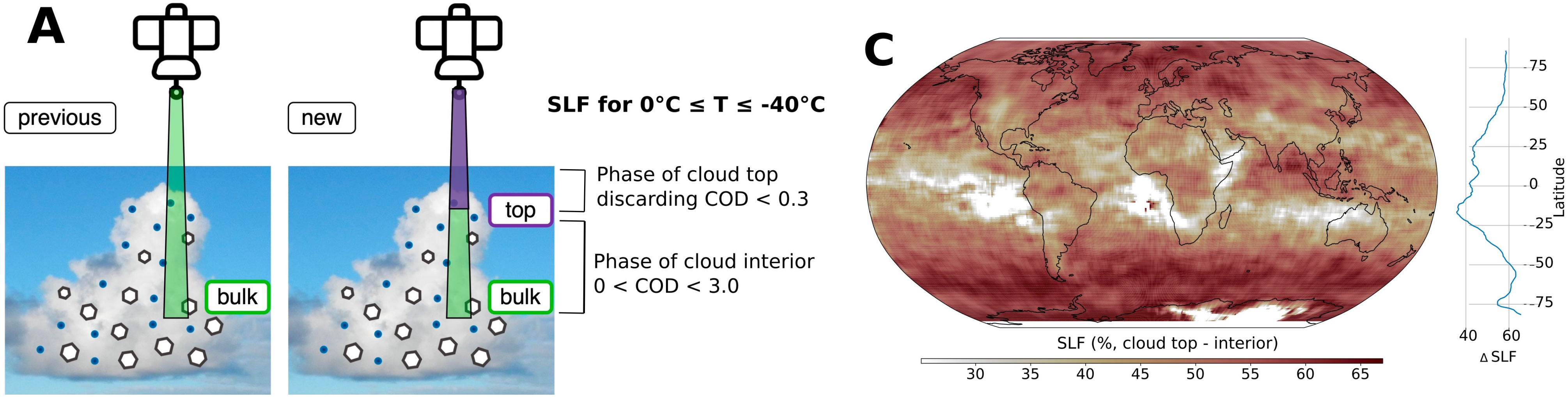






Sokol and Storelvmo (In prep.)

Cloud phase heterogeneity from Space – vertical sorting



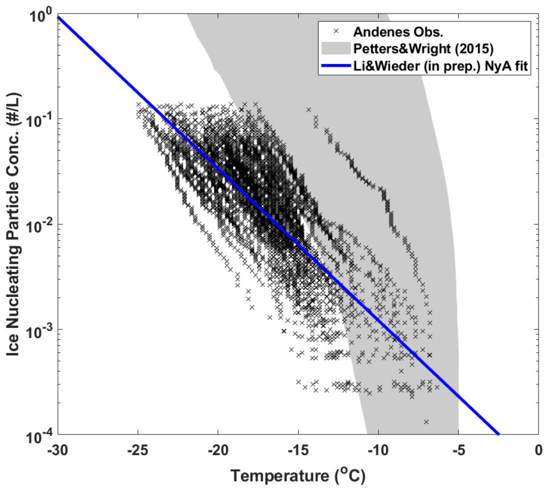
Hofer et al. (In prep)

Alternative hypotheses: phase bias exists because….

……models overestimate INP abundance

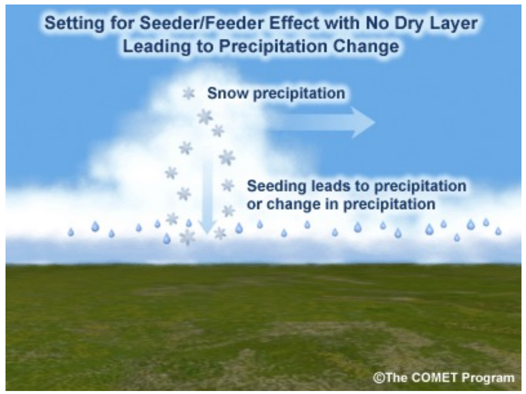
Models often include simplistic treatments of ice nucleation, which are not necessarily a function of the abundance of aerosols that can act as ice-nucleating particles (INPs).

Figure courtesy: Rob David



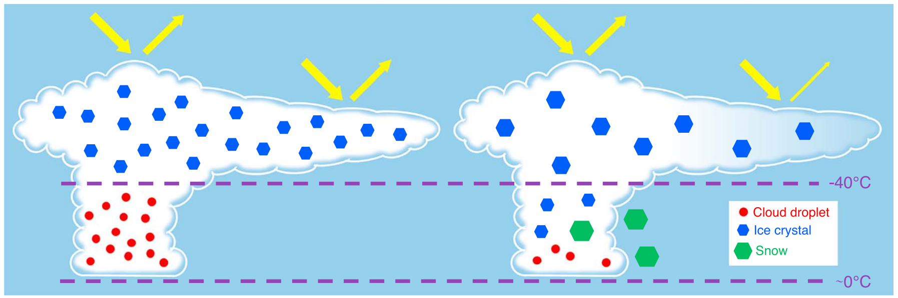
…..the seeder-feeder mechanism is too active in the model

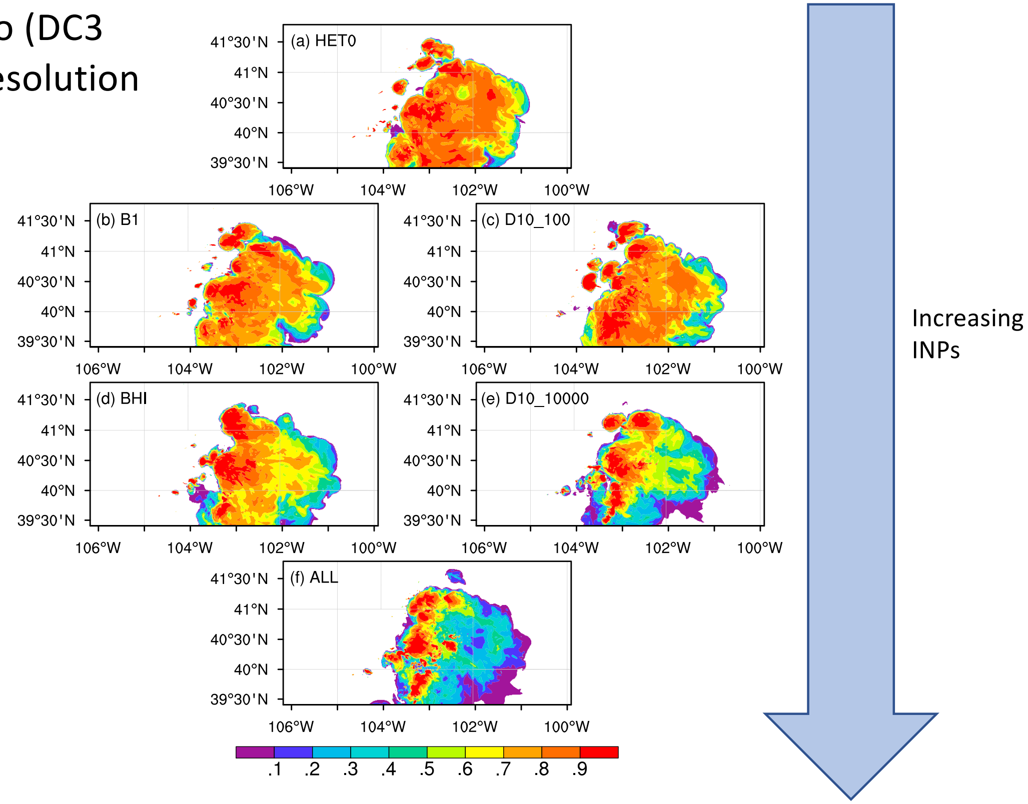
Even if heterogeneous ice nucleation is set to zero in models, there is still plenty of ice at T > -40°C. This can only be due to the seeder-feeder effect – but is it too active?



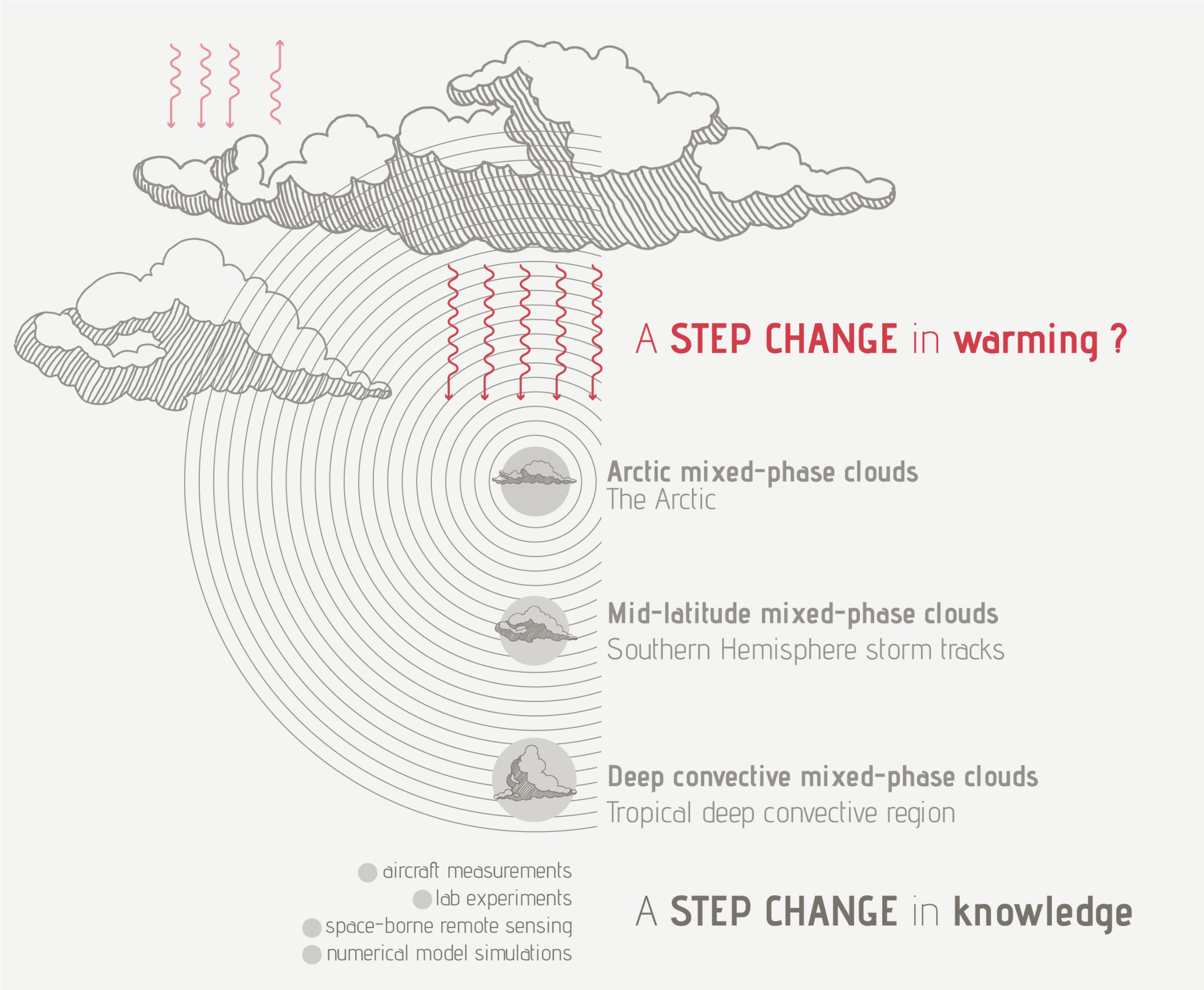
INP perturbations – impacts on deep convection

Convective anvil albedo for deep convection over Colorado (DC3 campaign) simulated with WRF-Chem at 1km horizontal resolution and 100 vertical levels



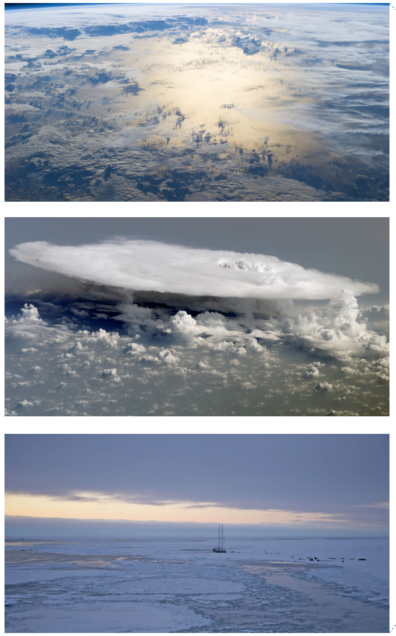


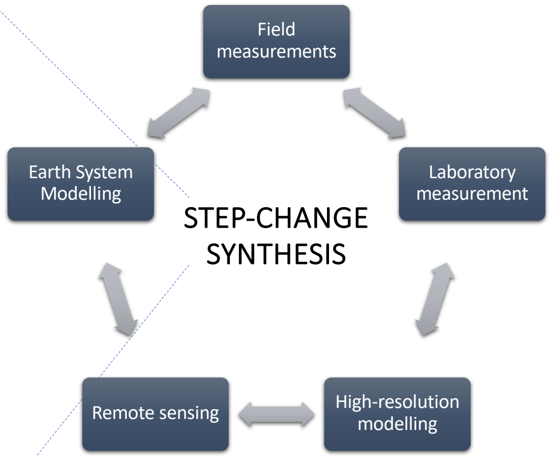
Takeishi & Storelvmo (2019)



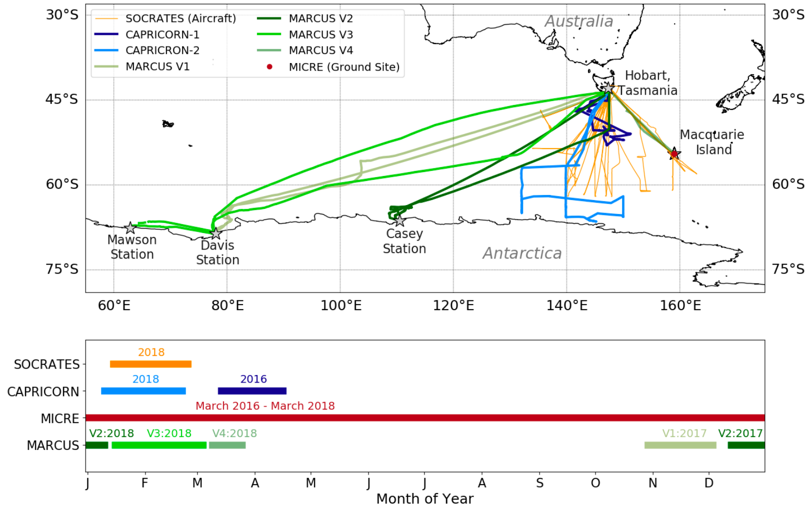
ERC CoG project STEP-CHANGE (2023 – 2028) in a nutshell

Three mixed-phase cloud regimes

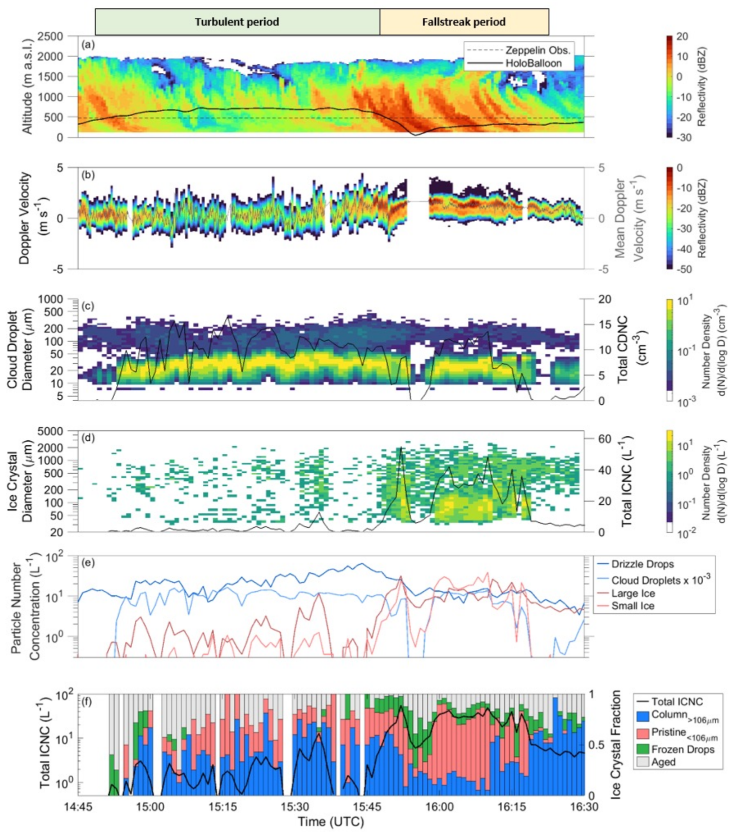




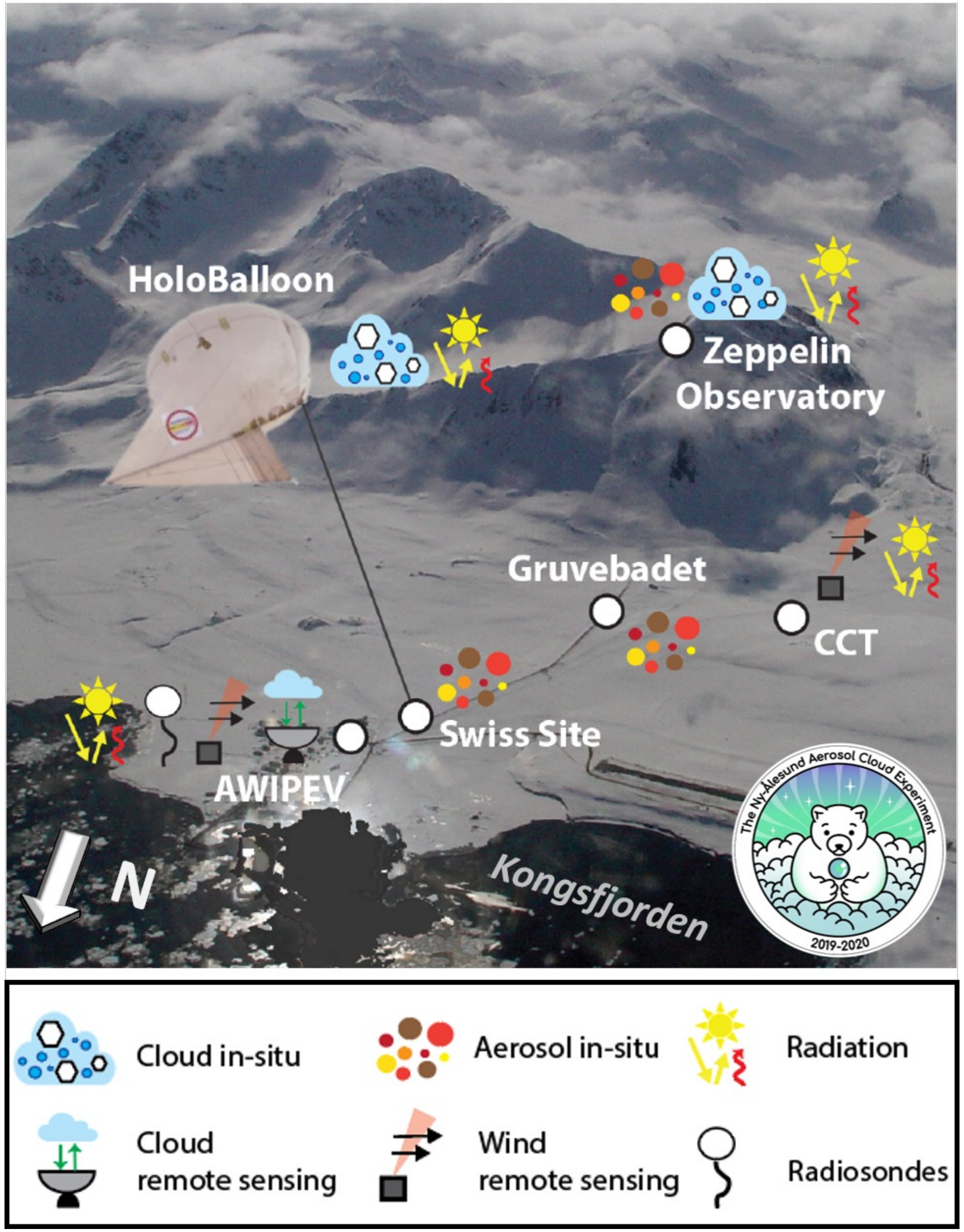
Past campaigns I: Southern mid-latitudes



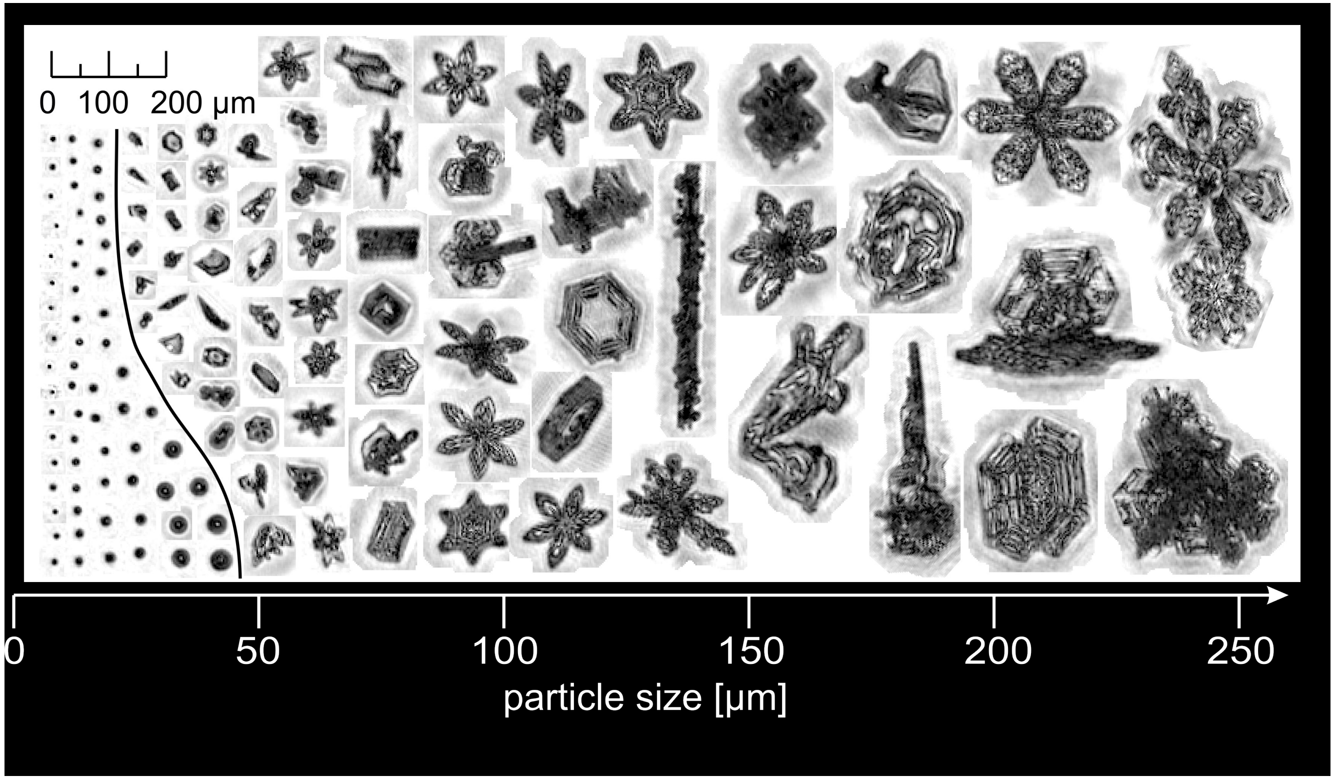
Past campaigns II: Arctic NASCENT campaign



Pasquier et al. (2022)



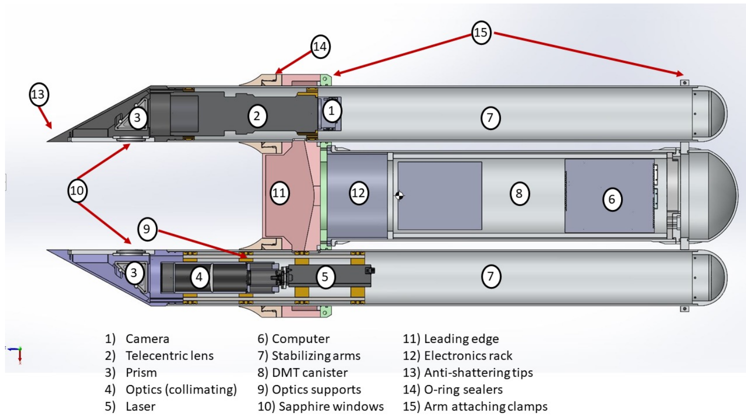
HoloBalloon measurements



Upcoming airborne campaigns

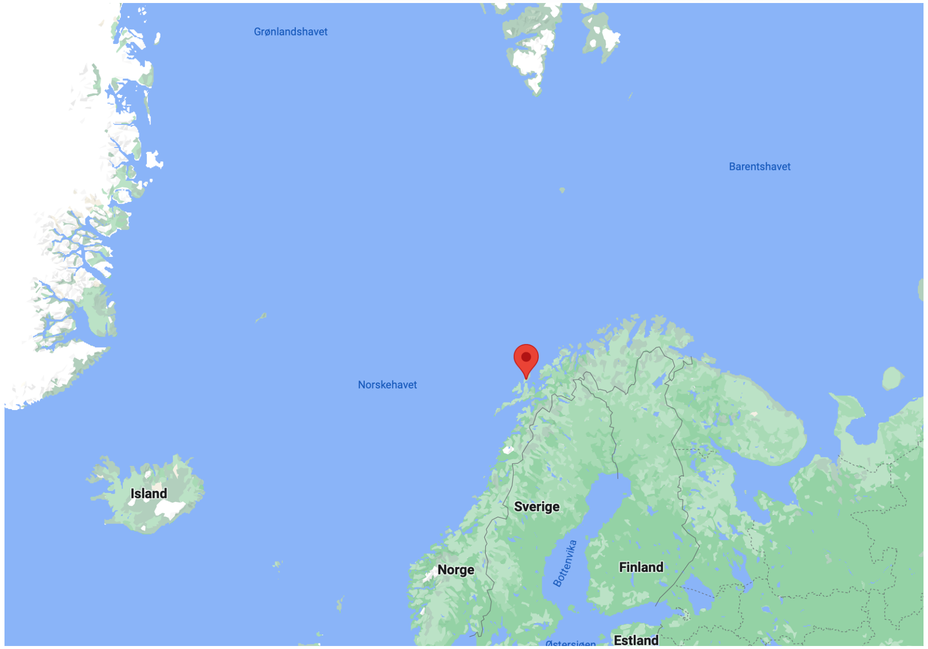
- ATMOSLAB Airborne Laboratory operated by INCAS (Romania)

- HOLOSCENE (HOLOgraphic Sampler for investigating Cloud Evolution from Nucleation to Evaporation)

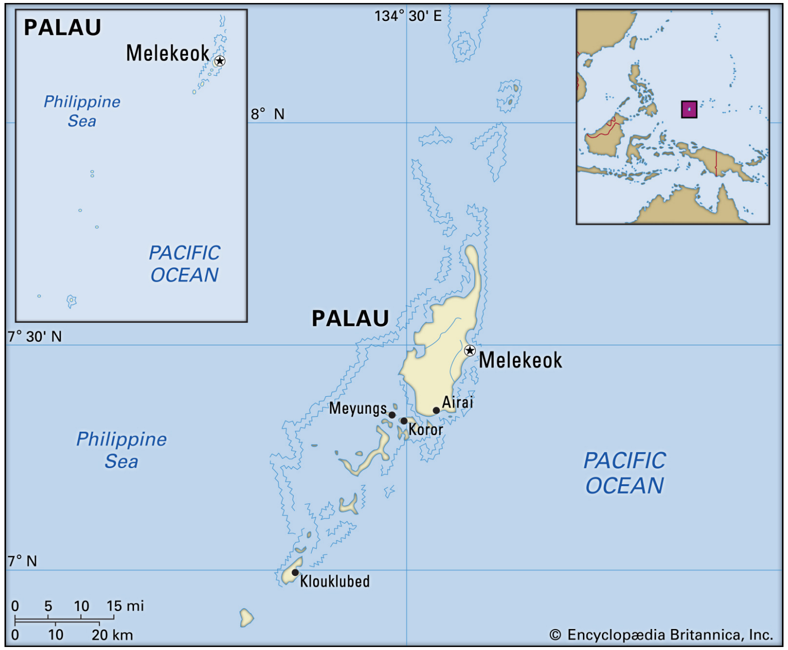


HOLOSCENE is based on the design of Ramelli et al (2020)Additionally, a sideways pointing hyperspectral camera onboard the aircraft will measure cloud phase remotely (following Jäkel et al., 2017)

Spring 2023 – Arctic campaign
Andenes



Fall 2024: Tropical campaign Palau



Summary

- Mixed-phase clouds play a crucial role in Earth's changing climate
- Modeling and satellite observations are essential tools for ivestigations of mixed-phase clouds, but cannot give all the answers
- Airborne measurements of mixed-phase clouds are critical for
  - Observation of small-scale features
  - Process understanding
  - Validation of modeling and remote sensing
- Through recent and upcoming airborne campaigns and new instrumentation, we are hopeful that a step change in understanding of mixed-phase clouds will be possible