Transformation of Arctic mixed–phase clouds in cold air outbreaks characterized by airborne and satellite remote sensing

B03

Susanne Crewell, Hartwig Deneke, André Ehrlich
Marcus Klingebiel, Pavel Krobot, Andreas Macke, Mario Mech,
Stephan Mertes, Imke Schirmacher

1. Summary

B03 aims at quantifying the **evolution of clouds in marine cold air outbreaks** (MCAOs) by airborne and satellite remote sensing to answer the

Research questions

Q1 How and when do transitions of cloud regimes occur in MCAOs, vary regionally, and change with Arctic warming?

Q2 Do clouds over sea ice precondition the development of clouds in MCAOs?

Q3 What are the effects of the air mass transitions on precipitation and cloud radiative forcing?

Contributions to **CCA3** and **CCA4** & **SQ1** and **SQ2**.

2. Achievements phase II

Extended observational data set from airborne campaigns

- MOSAiC-ACA (September 2020), HALO-$(\mathcal{AC})^3$ (March/April 2022)
- Quality controlled retrieval products → public on PANGAEA

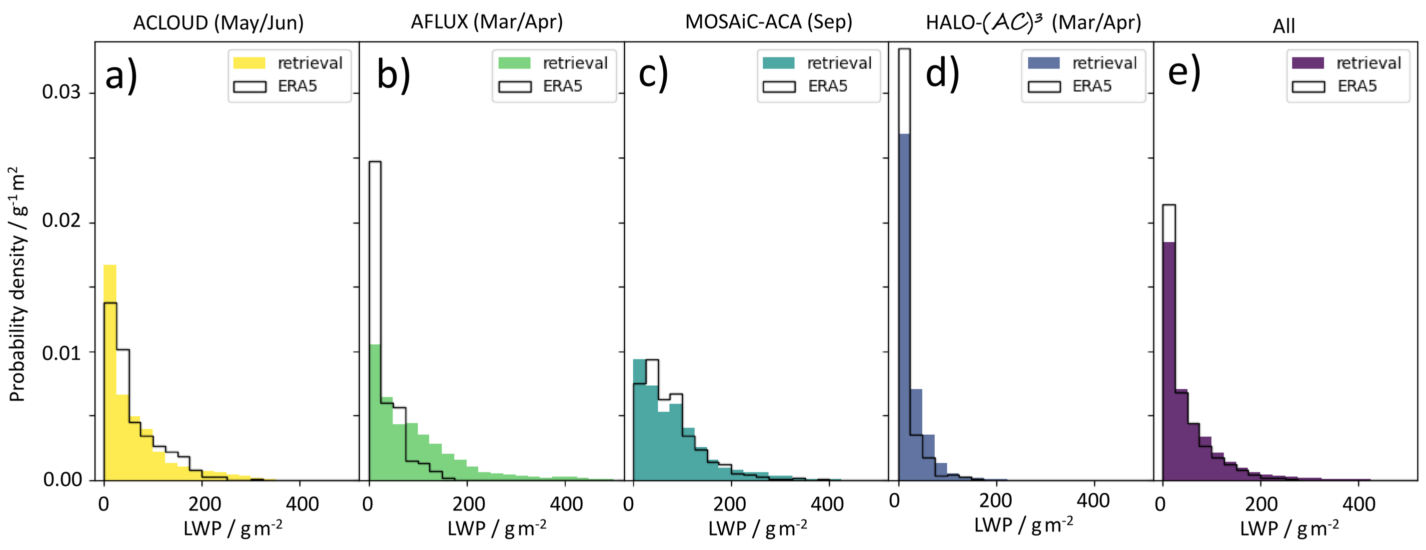


Fig. 1: Retrieved liquid water path (LWP) compared to ERA5.

- Statistical analysis of cloud properties shows dependence on:
  - campaign period (less cloud ice in summer)
  - surface (smaller cloud droplets over sea ice)
  - air mass origin (often dominating)

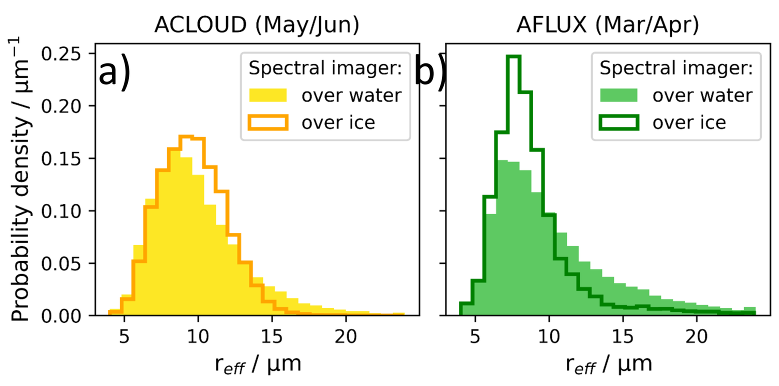


Fig. 2: Retrieved droplet radius.

Assessing satellite limitations

- CloudSat limitations (blind zone, sampling) lead to overestimation of cloud fraction
- CloudSat underestimates the total precipitation amount by 51 p.p

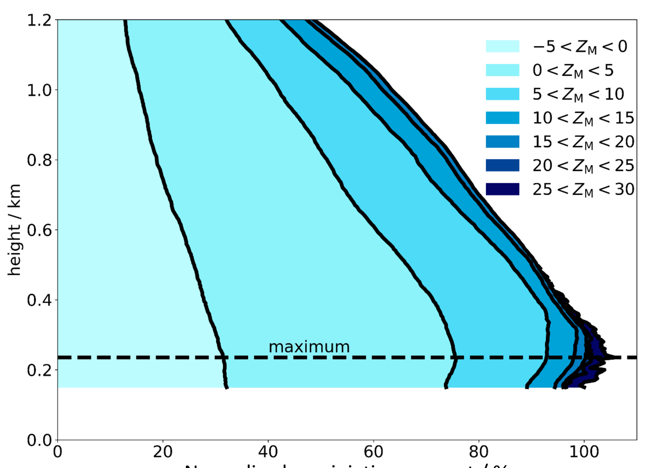


Fig. 3: Vertical profile of the contribution from intervals of MiRAC equivalent radar reflectivity Z_M to the total precipitation amount.

Aerosol and cloud microphysical properties

- Presence of sea ice can influence
  - the source of cloud forming particles
  - the cloud microphysical regime
- Superimposed by air mass origin and season

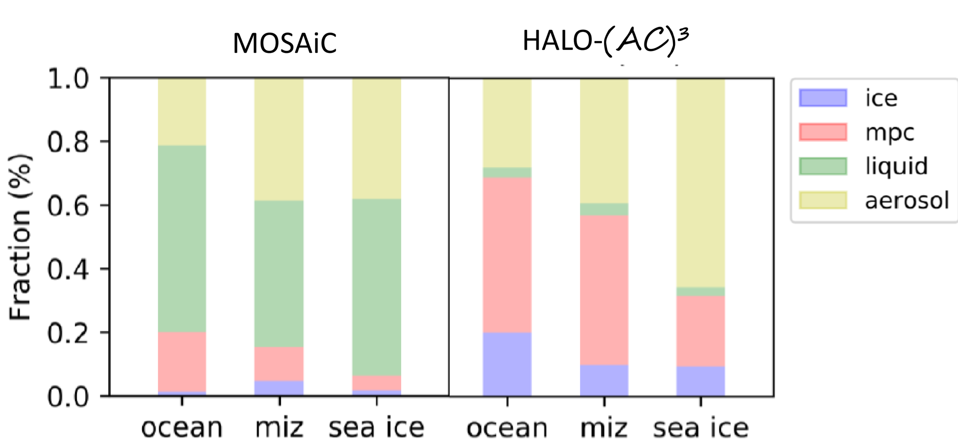


Fig. 4: Occurrence of cloud microphysical regimes.

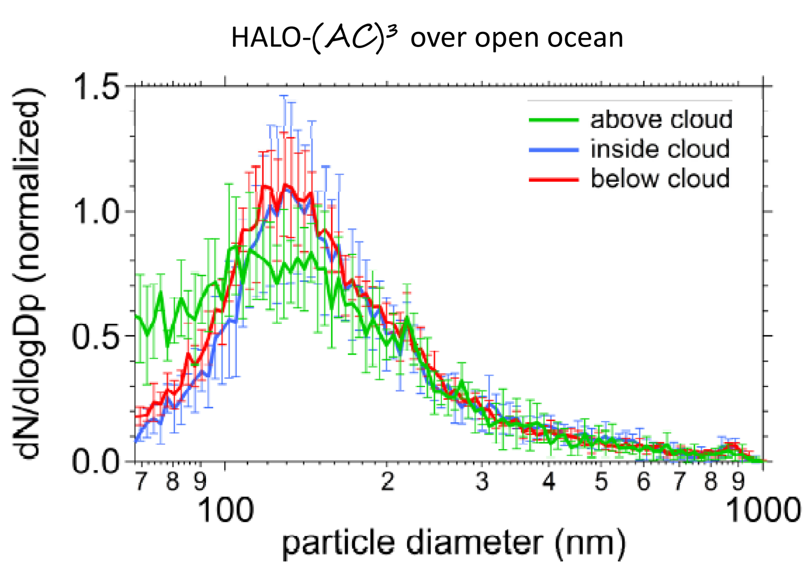
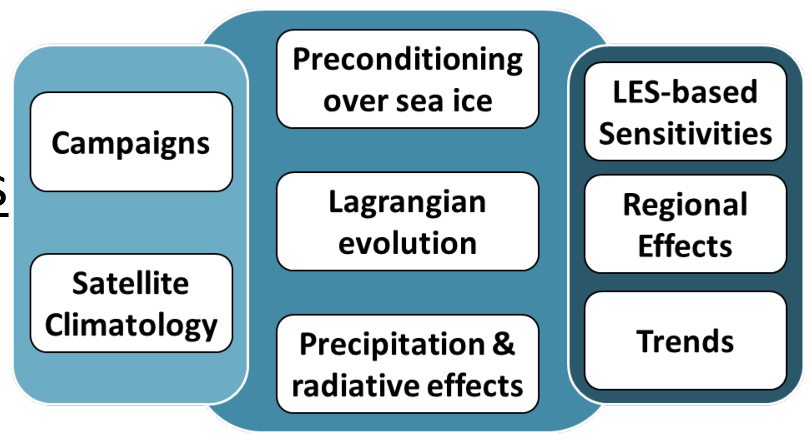


Fig. 5: Size distribution of aerosol particles and cloud droplet residuals.

Hypothesis

The cloud formation in the initial state of MCAOs impacts the downstream evolution of cloud morphology, precipitation, and cloud radiative effects.

3. Research plan phase III



Lagrangian characterization of MCAOs

- Campaign-based airborne remote sensing (HALO-$(\mathcal{AC})^3$ and others)
- Satellite observations:
  - active → vertical structure
  - passive → 2D cloud field
- Evolution of:
  - thermodynamic profiles **CCA4**
  - cloud properties **CCA3**
  - cloud morphology
  - precipitation
  - radiative effects **A03**

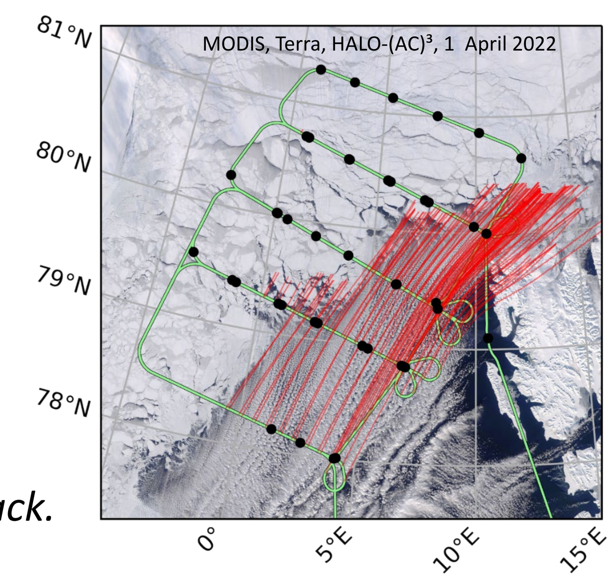


Fig. 6: Trajectories along HALO flight track.

Thin clouds over sea ice and their impact on MCAO

- COMPEX campaign (spring 2025) to study the initial state of clouds forming in MCAOs
- Improved remote sensing for clouds over sea ice (G-band radar GRaWAC, VELOX)
- LES for sensitivity studies **E03** **Z04** **CCA3**
  - e.g., contrasting cases with and without clouds over sea ice **SQ2**

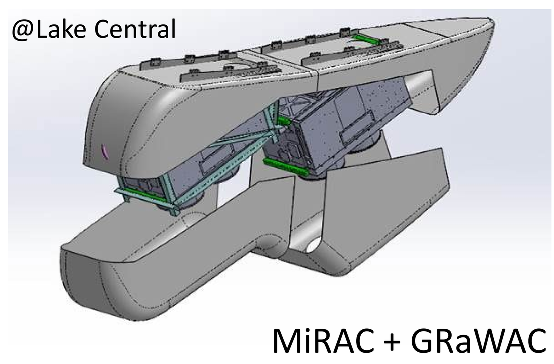


Fig. 7: Technical drawing of new dual radar.

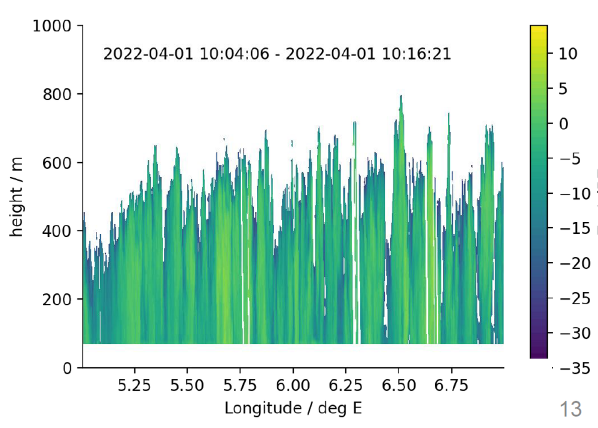


Fig. 8: Example of MiRAC radar reflectivity.

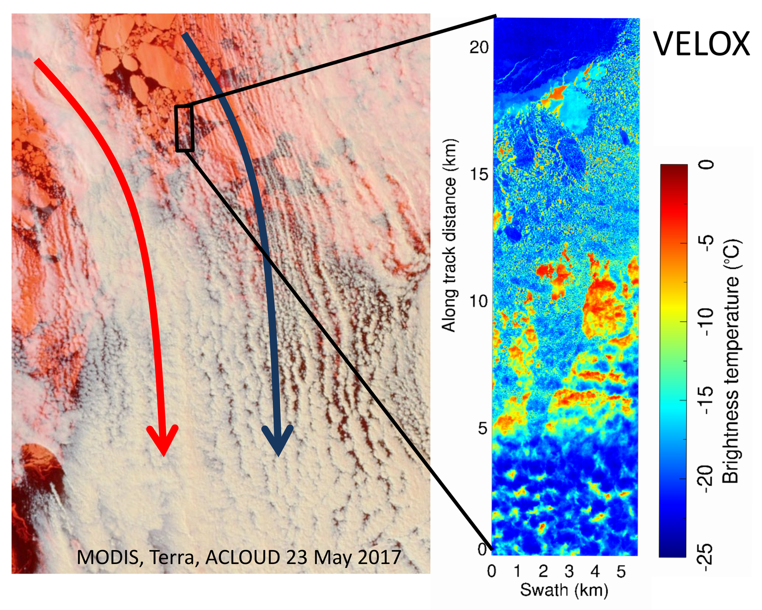


Fig. 9: MCAO with different initial conditions over sea ice and example of VELOX brightness temperature.

Regional contrasts and climatological perspective

- Composites of satellite observations (active and passive)
- Cloud morphology and organization vs. e.g., precipitation and cloud radiative effect (**SQ2**)
- Comparison of Fram Strait and Ny-Ålesund
- Identification of trends **E01**
- Extension to other MCAO hot spots **B01**

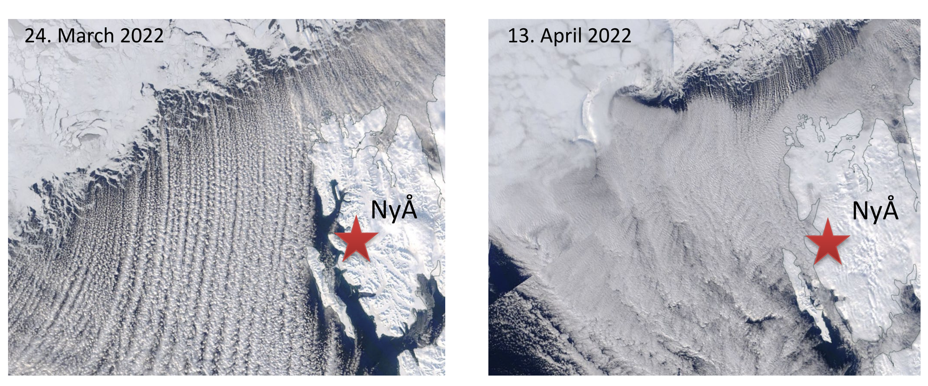


Fig. 10: MODIS images of different cloud regimes.

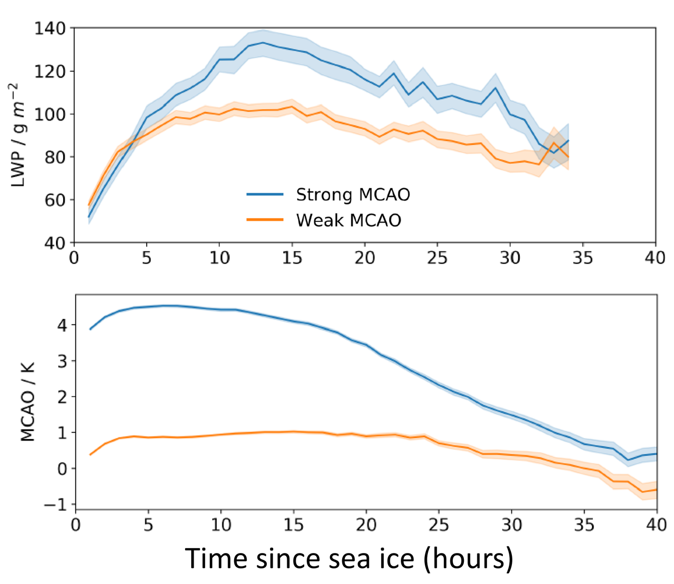


Fig. 11: Evolution of MCAO index and LWP.

4. Major expected results within phase III & Project legacy

- Improved cloud remote sensing by sensor synergy
- Climatological assessment of MCAOs including regional contrasts
- Quantitative impact of MCAOs on Arctic amplification by cloud radiative forcing and precipitation
- Comprehensive reference data sets for model and satellite evaluation, e.g., EarthCARE, MetOp-SG Microwave Imager (MWI), Ice Cloud Imager (ICI)
- Novel instrumentation for assessing polar clouds in future airborne and shipborne campaigns

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