Process-level assessment of Arctic mixed-phase clouds (MPC)

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E03

1. Summary

Research questions:

Q1: What governs the **liquid-ice phase transition** at the top of the MPC and how sensitive is this transition to e.g., CCN/IN, ice particle habit, or number of initial ice particles?

Q2: How relevant are **growth processes** (aggregation, riming) for the evolution of the MPC and are the underlying physical assumptions in current parameterisations sufficient?

Q3: How well are state-of-the-art microphysical schemes able to represent observed **long-term statistics of MPC** at Ny-Ålesund? Is the model performance linked to specific synoptic regimes or coupling states?

Q4: Which are the **relevant microphysical processes** that have to be taken into account by climate models?

2. Achievements phase I

Characterisation of observed MPC

Long-term (2.5 y) observation of MPC at Ny-Ålesund with W Band cloud radar and radiometer

- MPC (>1 h) occur 23% of time
- New method developed to derive coupling state of MPC
- Similar microphysical fingerprints found w.r.t. coupling state (Fig. 1, *Gierens et al., ACPD, 2019*)

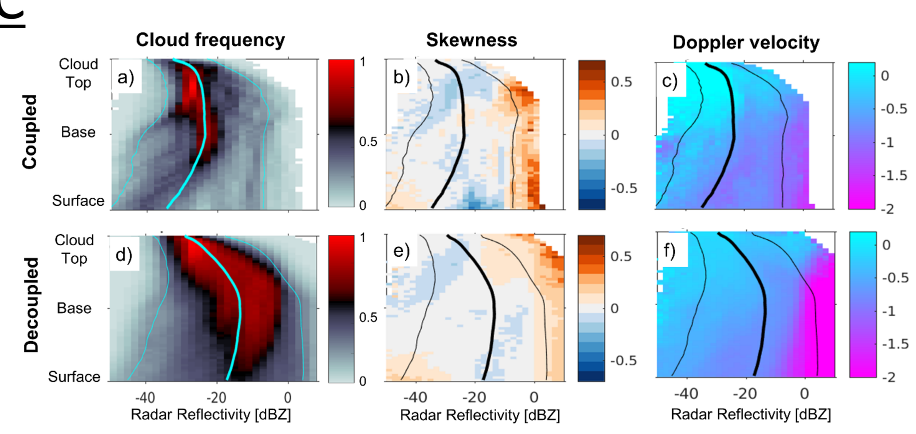

Fig. 1: Histograms of cloud radar moments (W-Band, non-polarimetric) for coupled (upper) and decoupled (lower) MPC observed during 2.5 y at Ny-Ålesund.

LES sensitivity study of MPC

- Improved representation of cloud driving processes with resolutions of O(10 m) in idealized LES simulations
- Differences of only 15% in LWC and IWC due to better resolved entrainment (*Rauterkus and Ansorge, JAS under review*)

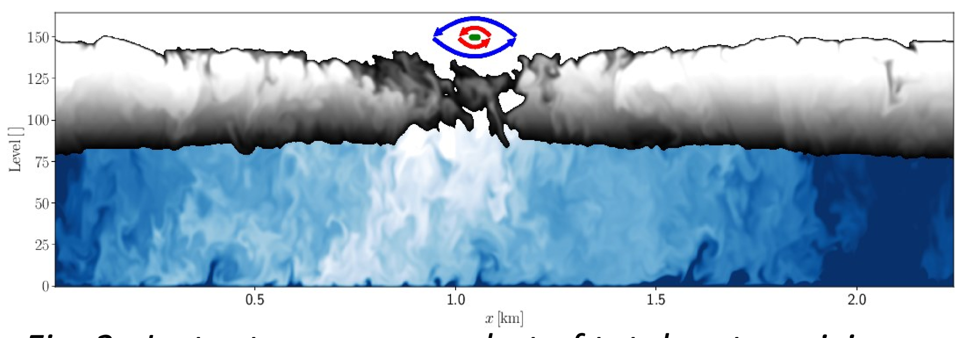

Fig. 2: Instantaneous snapshot of total water mixing ratio (blue) and condensed water mixing ratio (grey).

New modelling tool: ICON-LEM

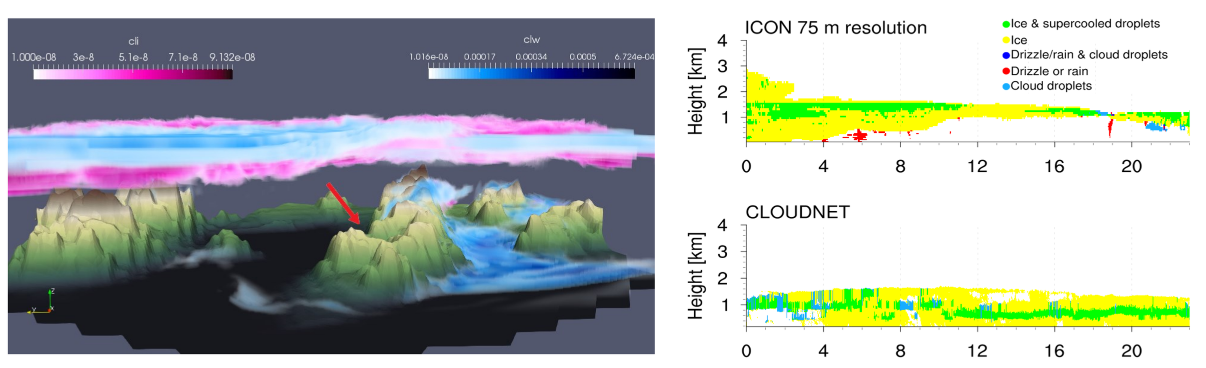

Fig. 3: Snapshot of a MPC simulation (Ny-Ålesund, 16th June 2017, blue: liquid water, purple: ice water) and Cloudnet classification derived from ICON-LEM (upper) and observed (lower).

- Application of new nested LES modelling tool ICON-LEM (100 m scale, complex terrain, lateral boundary conditions (*Schemann and Ebell, ACPD, 2019*))
- Coupling to radar forward operator (PAMTRA)
- ICON model chain enables knowledge transfer from fine to coarse models

Hypothesis

Microphysical cloud processes, such as depositional growth, riming, and aggregation, play a crucial role for the spatio-temporal evolution of Arctic mixed-phase clouds.

3. Research plan phase II

WP1 Statistical assessment of MPC

- Perform long-term simulation of observed MPC (Fig. 1) with nested ICON-LEM
- Statistical assessment of model-observation bias using PAMTRA in order to reveal stable and problematic regimes

WP2 Implementation of new modelling and observational framework

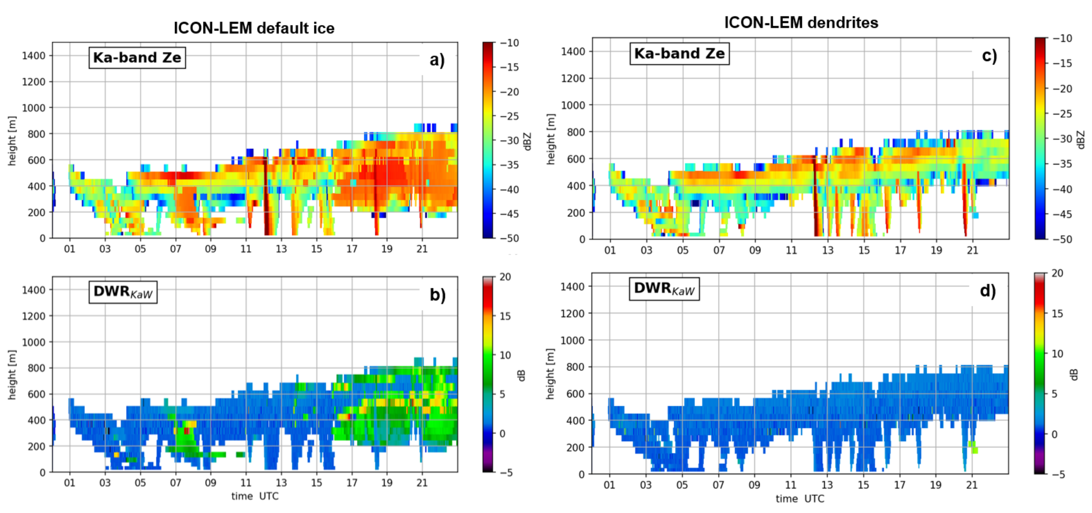

Fig. 4: Example of simulated observations (Upper: Reflectivity, Lower: Reflectivity difference Ka-W) based on ICON-LEM output of a MPC assuming the default ice particle (left) and a slightly different initial ice particle type (dendrites, right).

- Coupling of ICON-LEM and new observations with radar simulator (PAMTRA, Fig. 4)
- Investigation of micro-physical process rates in ICON-LEM
- Collaborative work (D02, E04) on building model hierarchy and improve quality of forcing

Lessons learned from phase I: Need to better characterise initial ice particles and subsequent growth processes.

Proposed approach: New polarimetric Ka Band cloud radar (Fig. 5) in addition to existing W Band

- Dual-frequency retrievals (liquid water, aggregation, riming, width of PSD)
- Shape and concentration of ice particles using high-frequency radar polarimetry
- Identification and characterisation of particle mixtures

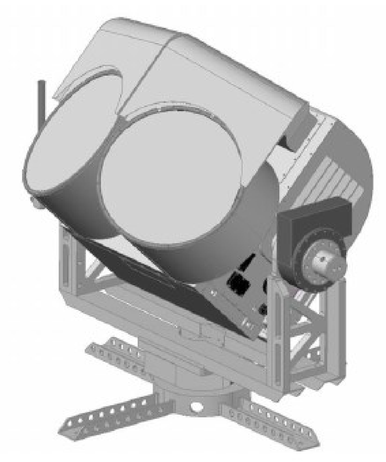

Fig. 5: Proposed vertically scanning, polarimetric, Ka Band (35 GHz) Doppler cloud radar for Ny-Ålesund supersite.

WP3 Achieving consistency between ICON-LEM and new observations

- Detailed case study analysis for problematic MPC regimes
- ICON-LEM sensitivity studies guiding modification of parameterisations
- Test of new parameterisations on a large number of MPC
- Does locally improved microphysics also improve MPC statistics at other locations?

WP4 Coordination of CCA3 (Arctic mixed-phase clouds)

4. Role within (AC)³ & perspectives

Collaborations within (AC)³

- E02 (Extension of Ny-Ålesund column)
- B07 and B03 (MPC processes and life cycle)
- E01, E04 (ICON model hierarchy)
- D02 (aerosol properties)

E03 mixed-phase cloud processes

WP1 MPC statistics	B05 PAMTRA	E01 ICON-LEM setup	E02 Ny-Ålesund	E04 PAMTRA			statistical assessment
WP2 new developments	D02 aerosol input	E04 large-scale forcing	B07 mixed-phase clouds				new capabilities
WP3 application	B04 aerosol	B03 aircraft obs.	C01 radiative forcing				improved parameterizations
WP4 crosscutting activity	A01 Polarstern	A02 Polarstern	B03 aircraft obs.	B07 Utqiagvik	E02 Ny-Ålesund	E04 large-scale forcing	regional differences

Perspectives

Phase II is dedicated to consolidate joined framework of high-resolution modelling and local observations for parameterisation development.

Future directions in phase III are:

- How do microphysical processes change in a warming climate?
- How will these changes affect the life cycle and radiative properties of MPC?

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