Aerosol-Cloud-Turbulence Interaction in Multilayer Clouds Modeled on a Closed Trajectory between MOSAiC and MOSAiC-ACA (EGU22-7185)

Jan Chylik[1] (jchylik@uni-koeln.de), Benjamin Kirbus[2], Niklas Schnierstein[1], Manfred Wendisch[2], and Roel Neggers[1]

24 May 2022, session AS2.13

1: Institute for Geophysics and Meteorology, University of Cologne;

2: University of Leipzig, Leipzig Institute for Meteorology

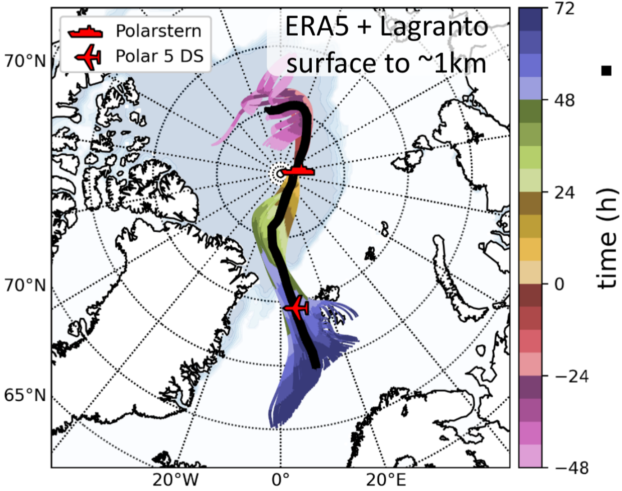
The problem with Arctic clouds

Mixed phase clouds play a key role in the ongoing rapid warming of the Arctic climate, which is not yet fully understood.

Challenges in representation of Arctic Clouds in weather forecast and climate models[1]

- in-situ measurements are typically sparse
- broad range of scales involved
- delicate balance between the liquid and ice phase
- complex interactions of aerosols, clouds, and turbulence
  - For example, turbulent mixing driven by cloud top cooling transforms air masses that travel into and out of the Arctic

MOSAiC-ACA case

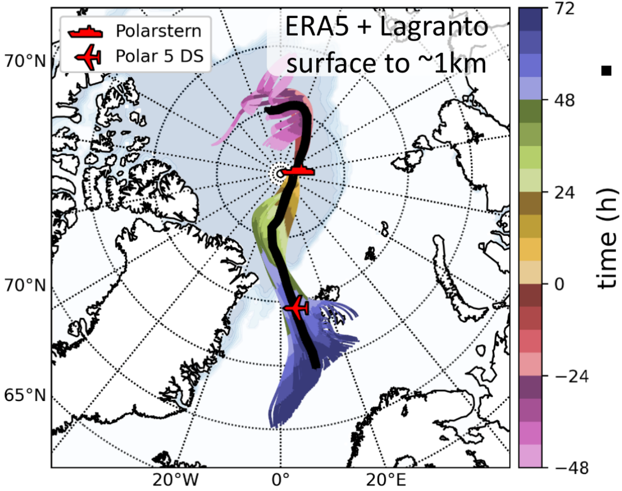


A unique case during MOSAiC-ACA campaign:
The same air-mass was on 11–13 September 2020 sampled twice:

1. Polarstern (over sea-ice)
2. Polar 5 aircraft (over open water, 2 days later)

Multiple cloud layers observed.

MOSAiC-ACA case



A unique case during MOSAiC-ACA campaign:
The same air-mass was on 11–13 September 2020 sampled twice:

1. Polarstern (over sea-ice)
2. Polar 5 aircraft (over open water, 2 days later)

Multiple cloud layers observed.

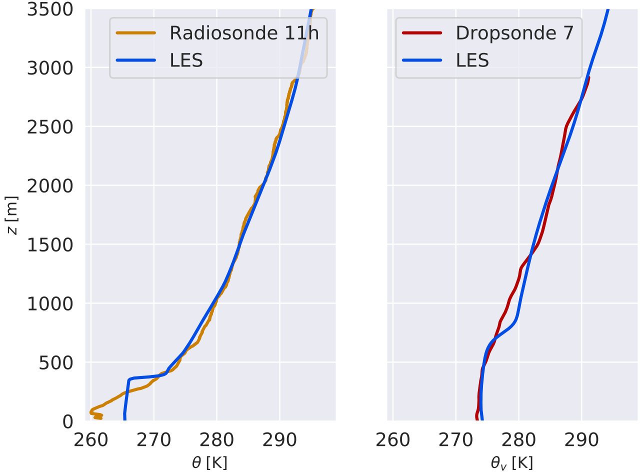
Science objective:
Understand the air mass transformation on this trajectory using Lagrangian LES constrained by local observations

Model Study

We combine high-resolution simulations with observation to better understand the transformation of cloudy air mass. High resolution simulation on a closed trajectory in Large Eddy Simulation (LES)

- Demi-Lagrangian frame of reference following the low-level trajectory [2]
- Initial conditions and large scale forcing based on ERA5
- Dutch Atmospheric Large-Eddy Simulation (DALES), [3]
- Bulk mixed-phase microphysics scheme of Seifert&Beheng [4]
- CCN concentration treated as prognostic variable

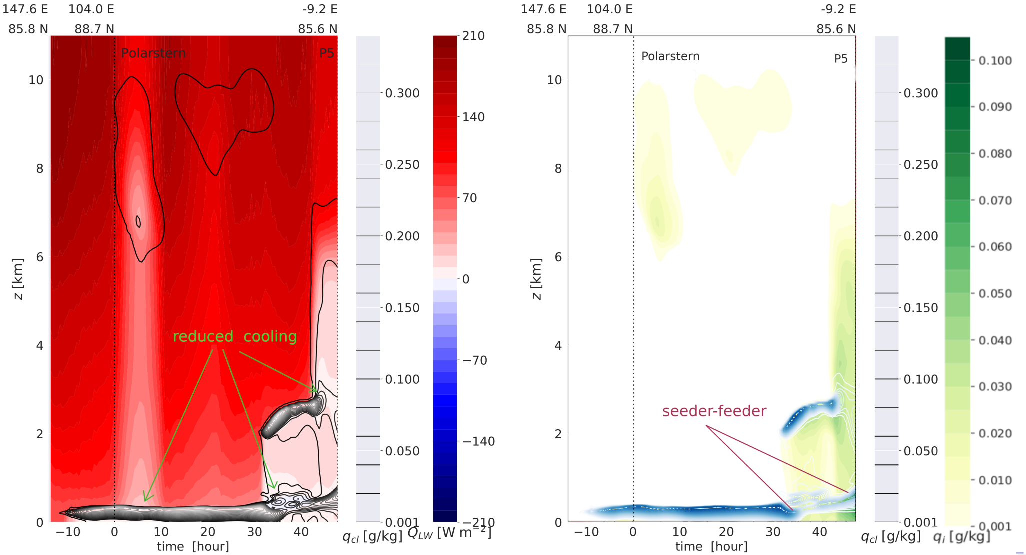
Comparison with Observations



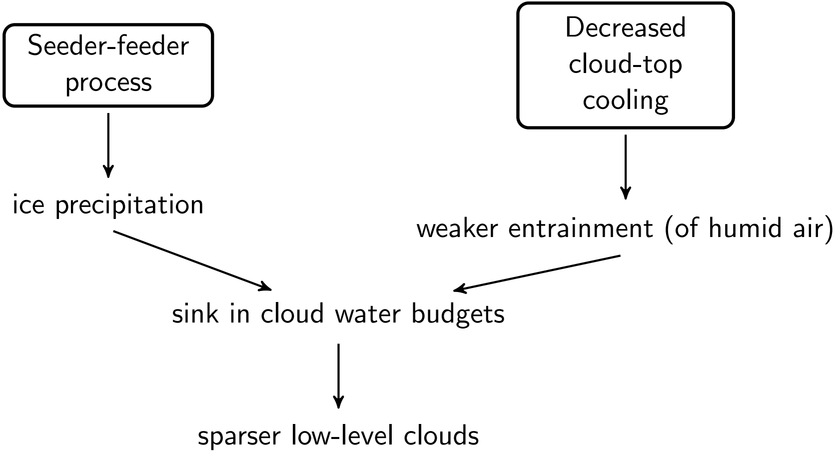
Simulation show reasonably good agreement with soundings at both Polarstern (radisosonde) and in the area of sampled by aircraft (dropsonde).

(note: Difference of sea-ice due to warm bias in ice surface temperature in ERA5.)

Cloud Transformation



Discussion


Seeder-feeder process
Decreased cloud-top cooling
ice precipitation
weaker entrainment (of humid air)
sink in cloud water budgets
sparser low-level clouds

Conclusions & Outlook

- The simulation reproduces the atmospheric structure detected at MOSAiC-ACA
- Importance of interaction of multiple cloud layers
  - Radiative and seeder-feeder mechanisms play a significant role in how clouds modulate the air mass
  - Depletion of low-level clouds

Outlook

- Daily Lagrangian trajectories initialized by Polarstern data will be simulated
- Constraining simulations by in-situ observations, including aerosol and surface properties
- Evaluation against independent observational datasets at Polarstern and MOSAiC-ACA.

Acknowledgements

TR 172 TRANSREGIONAL COLLABORATIVE RESEARCH CENTRE

$(\mathcal{AC})^3$ ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms

Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation

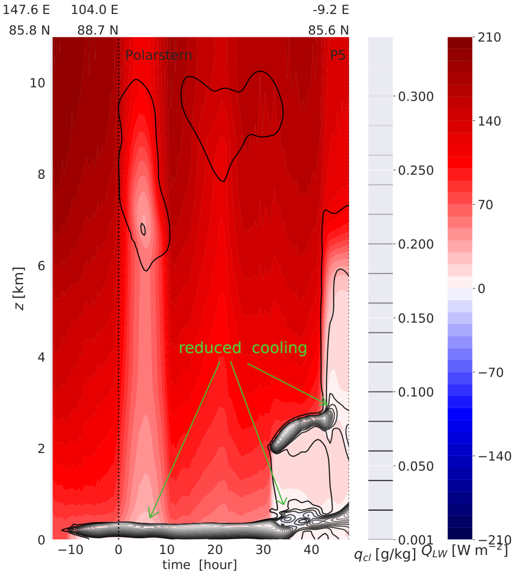
We gratefully acknowledge the funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Projektnummer 268020496 – TRR 172, within the Transregional Collaborative Research Center "ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms $(\mathcal{AC})^3$ ". We thank ECMWF for providing access to the large-scale model analyses and forecasts fields used to drive the LES experiments. We gratefully acknowledge the Regional Computing Centre of the University of Cologne (RRZK) for granting us access to the CHEOPS cluster. The Gauss Centre for Supercomputing e.V. (www.gauss-centre.eu) is acknowledged for providing computing time on the GCS Supercomputer JUWELS at the Jülich Supercomputing Centre (JSC) under projects CHKU28 and VIRTUALLAB.

We further thank the Alfred Wegener Institute (AWI), the PS106/1 crew and the MOSAiC and MOSAiC-ACA science teams for making the field campaign happen and for post-processing the observational data.

References

- Forbes and Ahlgrimm, 2014. doi.org/10.1175/MWR-D-13-00325.1
- Neggers et al., 2019. doi.org/10.1029/2019MS001671
- Heus et al., 2010. doi.org/10.5194/gmd-3-415-2010
- Seifert and Beheng, 2006. doi.org/10.1007/s00703-005-0112-4

Extra: Radiative Impacts



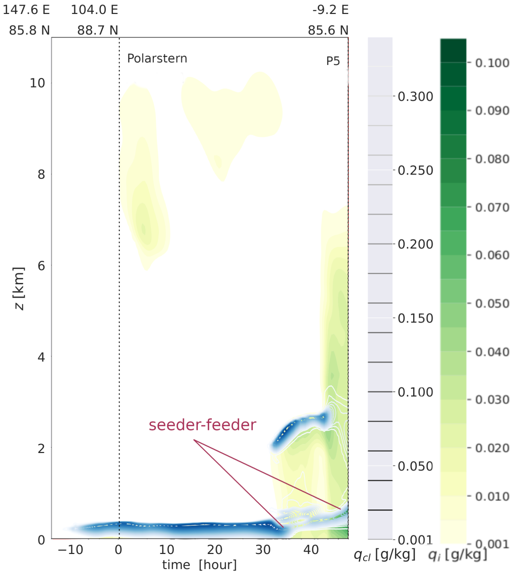
Interaction of multiple cloud layers

- radiative
- seeder-feeder process

The effect of longwave emission form upper-level clouds on the boundary layer clouds:

1. increase in downward radiative flux
2. decreased cloud-top cooling
3. weaker entrainment

Extra: Seeder-Feeder



Mechanism of seeder-feeder

1. descending large ice hydrometeors
2. partial sublimation in cloud-free layer
3. riming in lower-level cloud
4. secondary ice production
5. fading of lower cloud layer

Extra: Sensitivity Studies

Important considerations:

- Rate of processes involved depends on size distribution of droplets and ice particles.
- Decreased entrainment also limits the influx of new CCN into the boundary layer.

This example of the transformation of cloudy air mass bring further implication:

- Advection of upper-tropospheric clouds leads to depletion of boundary clouds below.
- Important to consider long-range transport of aerosols that affect concentration and therefore size of cloud particles.