Arctic aerosol, cloud and radiation from ground-based observations and simulations: The full annual cycle

A01

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1. Summary

- Clouds and aerosol play an important role in Arctic feedback mechanisms
- Clouds dominate the radiative forcing at the sea ice/ocean surface
- It is not clear if clouds and aerosol on average further increase sea-ice melt or not in a changing Arctic and how the forcing depends on location and season
- We propose a **detailed characterisation of Arctic aerosol and cloud properties** as well as of aerosol-cloud interaction by means of state-of-the-art **ground-based remote sensing, surface radiative energy measurements and high resolution modelling during MOSAiC**

Research questions:

Q1 To what extend does **heterogeneous ice formation** of Arctic clouds depend on aerosol types?

Q2 Which processes dominate the **structure of Arctic boundary layer clouds**?

Q3 Can we fully **explain the observed radiation energy fluxes** at the surface with the observed state of the atmosphere?

2. Achievements phase I

(1) Processing of PASCAL observations

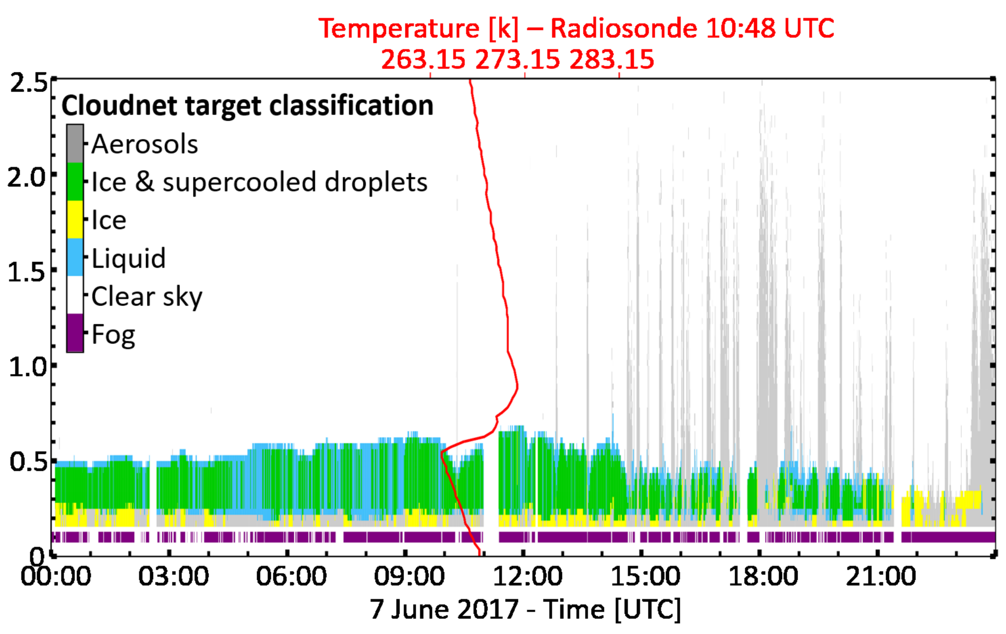


Fig. 1: Cloudnet target classification for 7 June 2017, updated with a new class 'Fog' and temperature profile of the radiosonde launch at 10:48 UTC.

(2) LES evaluation

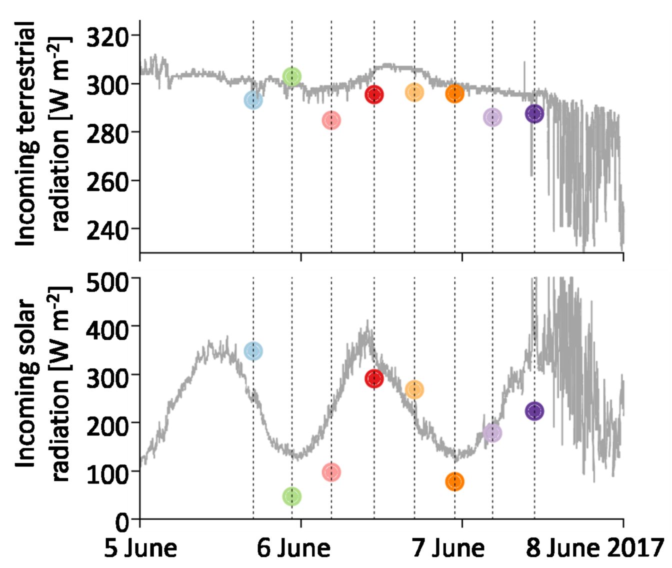


Fig. 2: Comparison of incoming radiation between LES and observations for 5 - 8 June 2017.

(3) Model-observation radiation closure

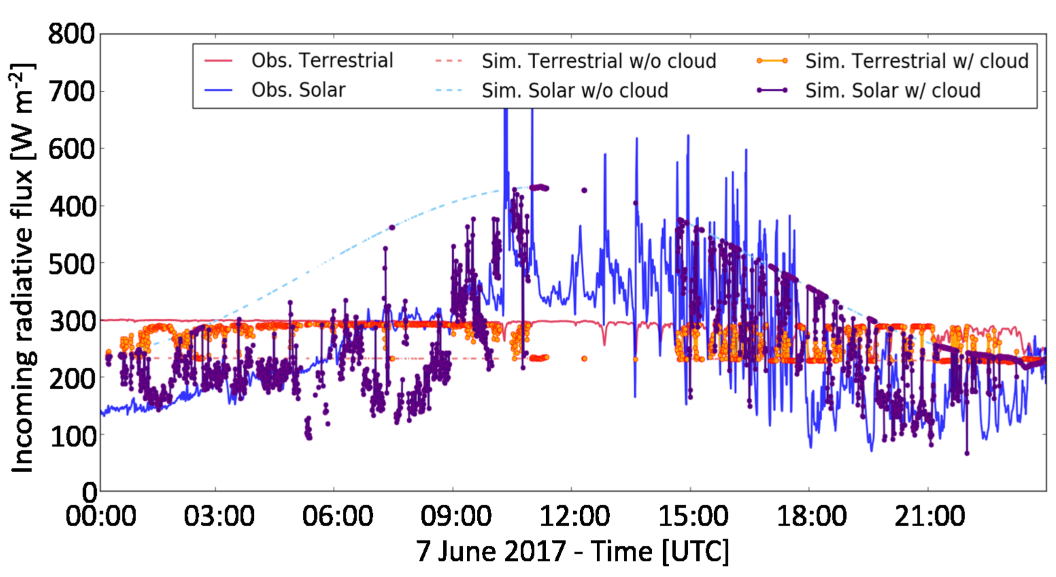


Fig. 3: Closure study of observed and simulated incoming solar and terrestrial radiative fluxes for 7 June 2017 based on Rapid Radiative Transfer Model for GCM(RRTMG) simulations with Cloudnet and radiosonde data as input.

(4) Cloud coupling effects

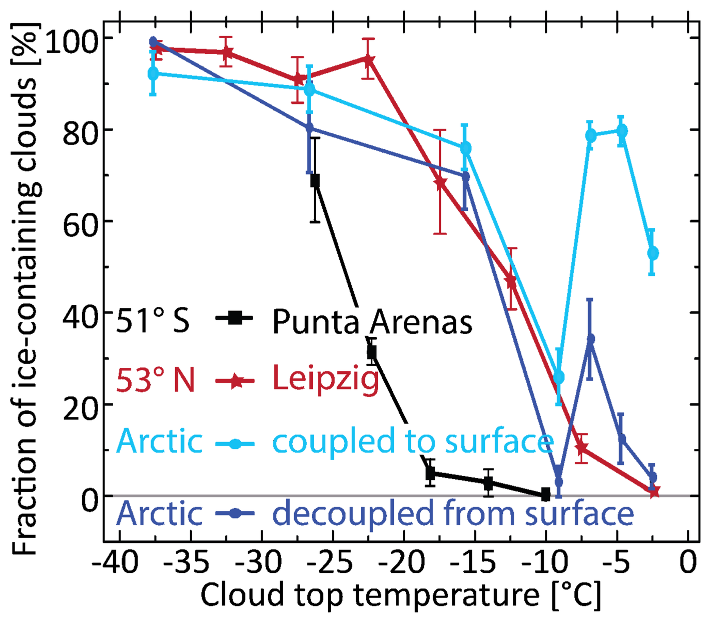


Fig. 4: Fraction of ice-containing clouds vs. cloud-top temperature for surface-coupled and -decoupled Arctic clouds as well as for Leipzig and Punta Arenas.

Hypothesis

Aerosol properties control the microphysical structure of Arctic clouds, while their macrophysical state predominantly reflects thermodynamic conditions

3. Research plan phase II

Heterogeneous ice formation in Arctic clouds

- Retrieval of cloud droplet and ice nuclei **(CCN/INP) from lidar observations**
- Relate the formation and state of clouds to their **microphysical and thermodynamic forcing**
- Characterize the microphysical and thermodynamic forcing under different meteorological regimes from model sensitivity studies

Structure of Arctic boundary layer clouds

- Constrain the factors causing the evolution of Arctic clouds from detailed observation and modelling of microphysical and thermodynamic forcing
- **Multi-day Lagrangian LES** during the MOSAiC drift
- LES budget studies to investigate controls on boundary layer evolution (Fig. 5)
- **Humidity inversions**: formation and impact on low-level clouds

Arctic cloud radiative effect

- Solar and terrestrial downward fluxes from direct **observations and modelling** based on observed cloud microphysical properties and spatial structure

Work packages

- **WP1**: Full-year multi-sensor **remote sensing during MOSAiC** with the OCEANET platform (TROPOS)
- **WP2**: Characterization of aerosol, clouds and heterogeneous ice formation & synopsis of remote sensing and in-situ observations (TROPOS, UNI-K)
- **WP3**: Aerosol, cloud and **radiation closure** (TROPOS, UNI-K)
- **WP4**: **High-resolution simulations** & hypothesis testing (UNI-K, TROPOS)

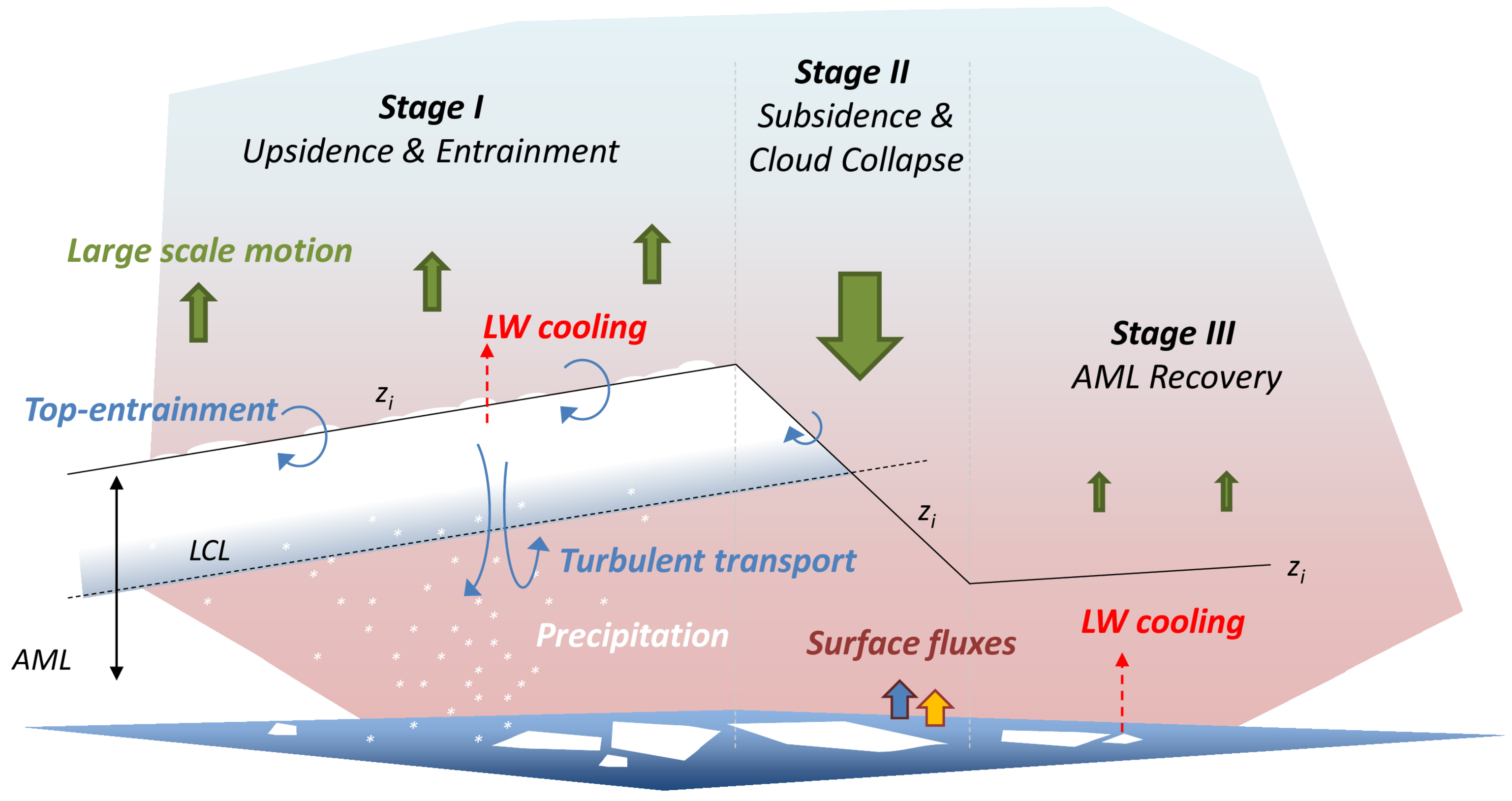


Fig. 5: Illustration of the processes controlling Arctic Mixed Layer (AML) evolution. Stage II depicts a cloud collapse induced by a strong subsidence event, as encountered in LES realizations based on observations from the Physical feedback of Arctic PBL, Sea ice, Cloud And AerosoL (PASCAL) campaign.

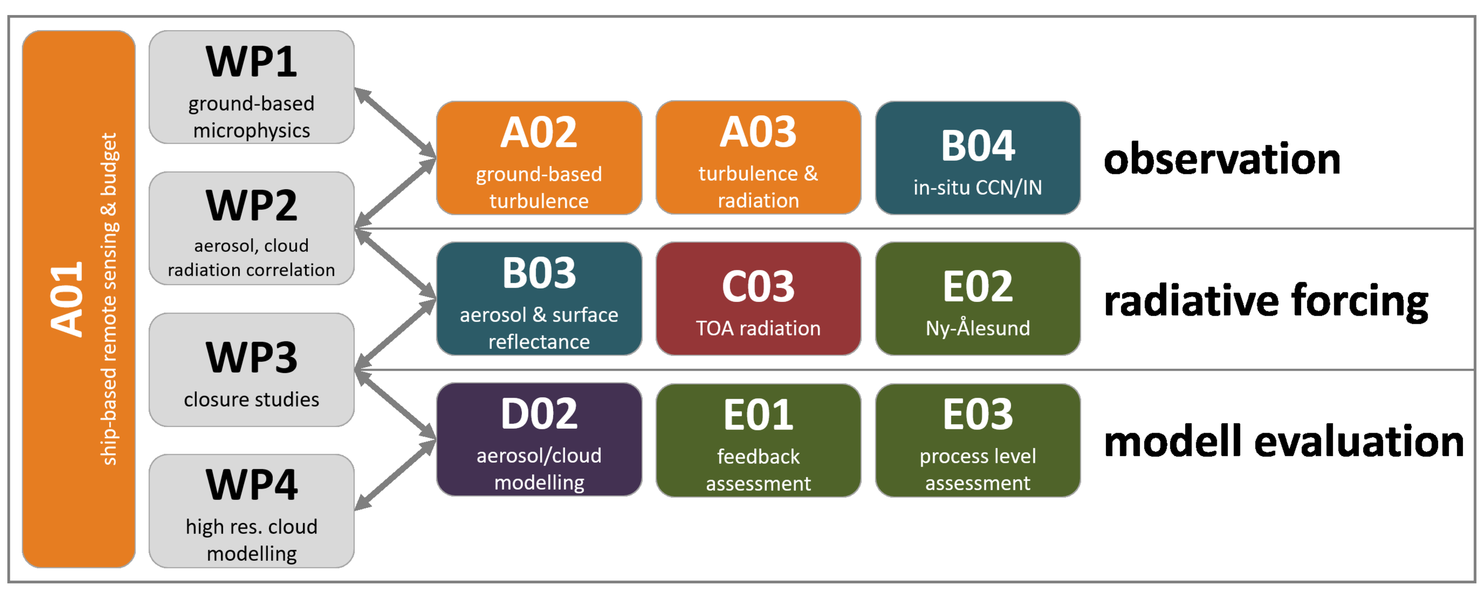
4. Role within (AC)³ & perspectives

Major collaborations within (AC)³

- **A02**: Assessing the role of thermodynamic profiles on cloud formation
- **B04**: Comparing aerosol and cloud in-situ observations and remote sensing
- **E01**: Climate effects of aerosol and clouds and lapse rate feedback

Cross-cutting activities within (AC)³

- **CCA1 - Lapse-rate feedback**: Local and remote causes for temperature inversions
- **CCA2 - Surface processes**: Cloud radiative effects & microphysics for surface de/coupling
- **CCA3 - Mixed-phase clouds**: INP and ice formation
- **CCA4 - Air mass transport & transformation:** Large scale dynamics, Lagrangian LES



Perspectives

- Establish the causal relation between the state of the atmosphere and the **forcing at the sea ice surface**
- Assess the Arctic aerosol/cloud/radiation interaction in more detail based on **EarthCARE**
- More realistic LES modeling of cloud radiative effects using **3D radiative transfer**
- LES studies of **surface heterogeneity** impacts on Arctic boundary layer structure and associated cloud-radiative interactions

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