Impact of low-level clouds and surface conditions on Arctic atmospheric boundary layer turbulence and radiation.

Christof Lüpkes, Michael Schäfer,
Dmitry Chechin, Vladimir M. Gryanik, Johannes Stapf

A03

1. Summary

- Investigating the role of Arctic boundary layer (ABL) clouds in Arctic amplification
  - dependent on sea ice, large-scale forcing, and seasons
  - by airborne observations and theoretical/numerical studies
- Short-term/small-scale view (phase I) → seasonal/large-scale view (phase II)

Therefore, in phase II we aim to answer the following questions:

Q1 Are cloud and surface impacts on turbulent and radiative fluxes **season-dependent**?

Q2 How do ABL and clouds evolve during **air-mass transformations**?

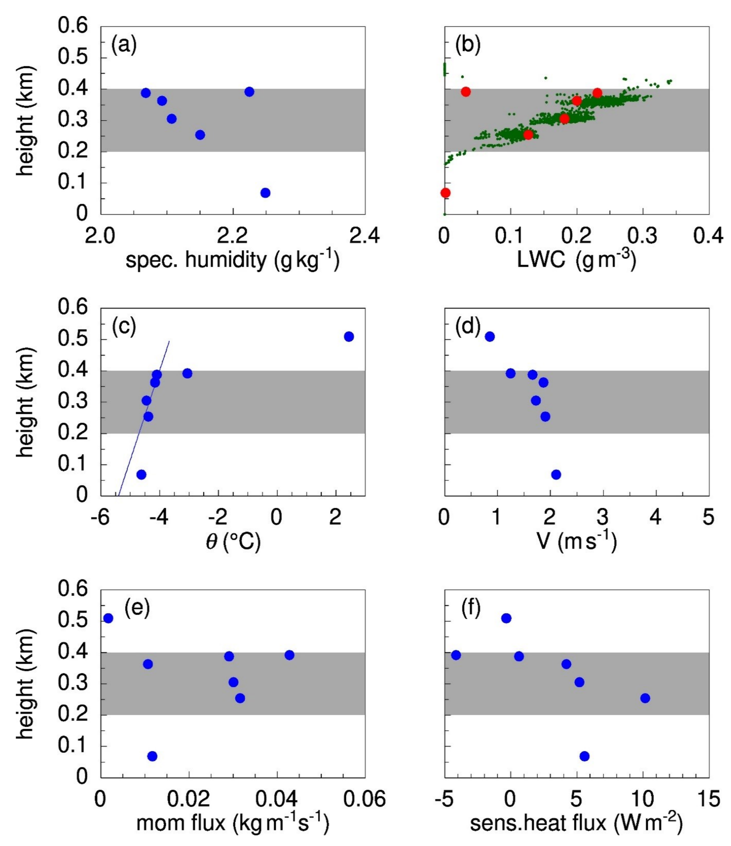
Q3 How does small-scale inhomogeneity in the ABL depend on **surface inhomogeneity**?

Q4 Do parametrisations of turbulent and radiative fluxes **reproduce measurements**?

2. Achievements phase I

Turbulence A01 A02 B03 D03

- Impact of clouds on ABL turbulence over marginal sea-ice zone (MIZ) as large as that of surface roughness and temperature inhomogeneity
- Rolls over MIZ influence turbulence, clouds, and radiative budget at the surface
- Multiple cloud layers: reduced cloud top cooling and turbulence at low cloud



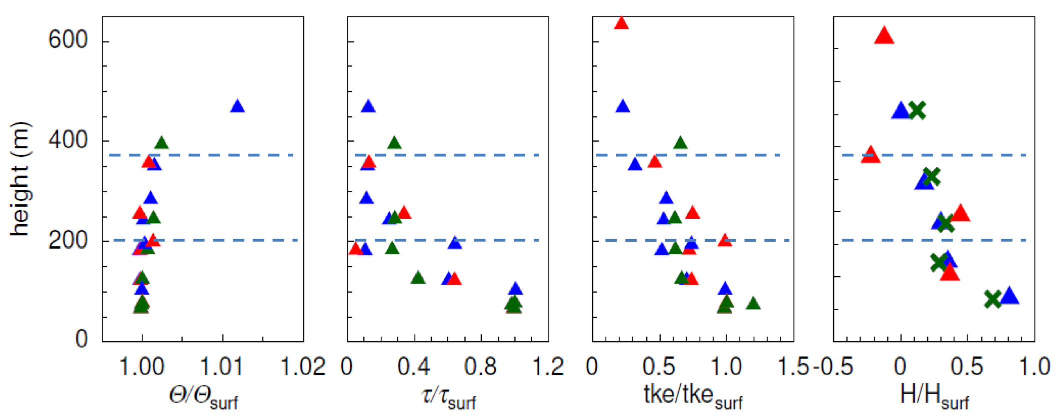


Fig. 1: Aircraft measurements of mean and turbulent quantities for a single (grey shaded) cloud layer case (left) and a case with a second cloud layer (base at 2000 m, right). Radiation (not shown) shows a distinct cloud top cooling for single cloud layer case but almost no cooling at the lower cloud top in the case with two cloud layers (Wendisch et al., 2019, BAMS). Colors: b) red: derived, green: non-averaged Nevzorov, top: different positions

- New surface-flux parametrisation for stable atmospheric conditions (Gryanik and Lüpkes, 2018, BLM)
- Analytical model explaining wind and temperature regimes forced by fluxes over leads (Chechin et al., 2019, JAS)
- Explanation of wind regimes in cold air outbreaks (Chechin and Lüpkes, 2019, BLM)

Radiation A01 A02 B03 C01 D02

The effect of clouds on the surface radiative energy budget (REB) was quantified for different surface conditions (Fig. 2a) and seasons (Fig. 2c and 2d):

- Surface properties modulate warming or cooling effect of clouds (Fig. 2a)
- Surface albedo cloud interaction questions the current understanding of how clouds warm or cool the Arctic (Fig. 2b, Stapf et al., 2019, ACPD)
- Seasonal conditions imprint the REB (Fig. 2c and 2d)
- Validation and improvement of models and parametrisation

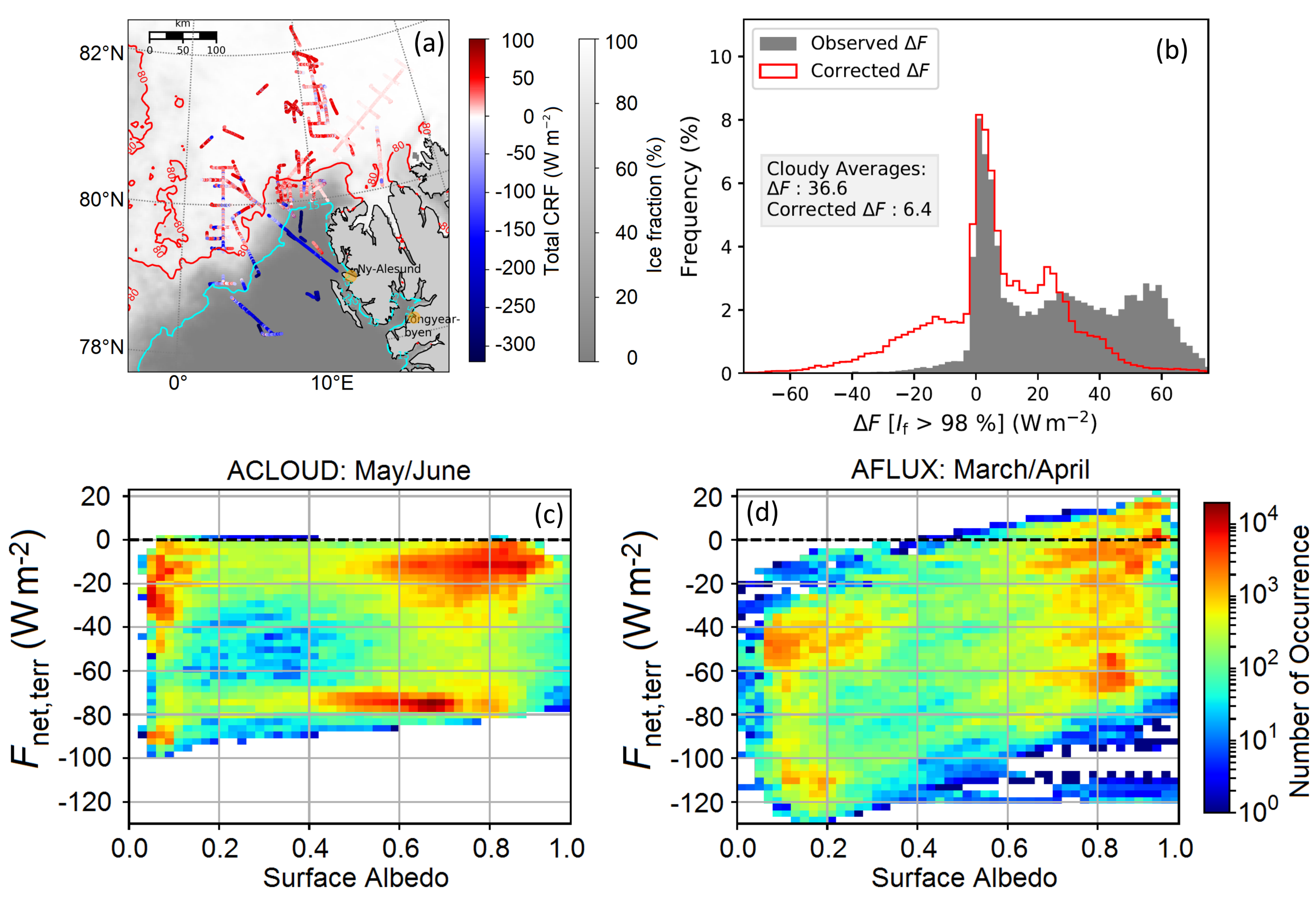


Fig. 2: **(a)** Surface cloud radiative forcing calculated for ACLOUD low-level flights and campaign averaged sea-ice concentration. **(b)** The total cloud radiative forcing (solar plus terrestrial) calculated with two different (cloudy and clear sky) albedo estimates. **(c)** Typical modes of net terrestrial flux densities at the surface during ACLOUD in summer and **(d)** AFLUX in spring.

Hypothesis

The net effect (warming/cooling) of Arctic low-level clouds is mostly driven by sea-ice cover, but also varies on regional and seasonal scales.

3. Research plan phase II

Methods and work programme

- Study **spatial distribution of turbulent and radiative fluxes** along trajectories as a function of **cloud characteristics, flow regime, sea-ice properties, season**.

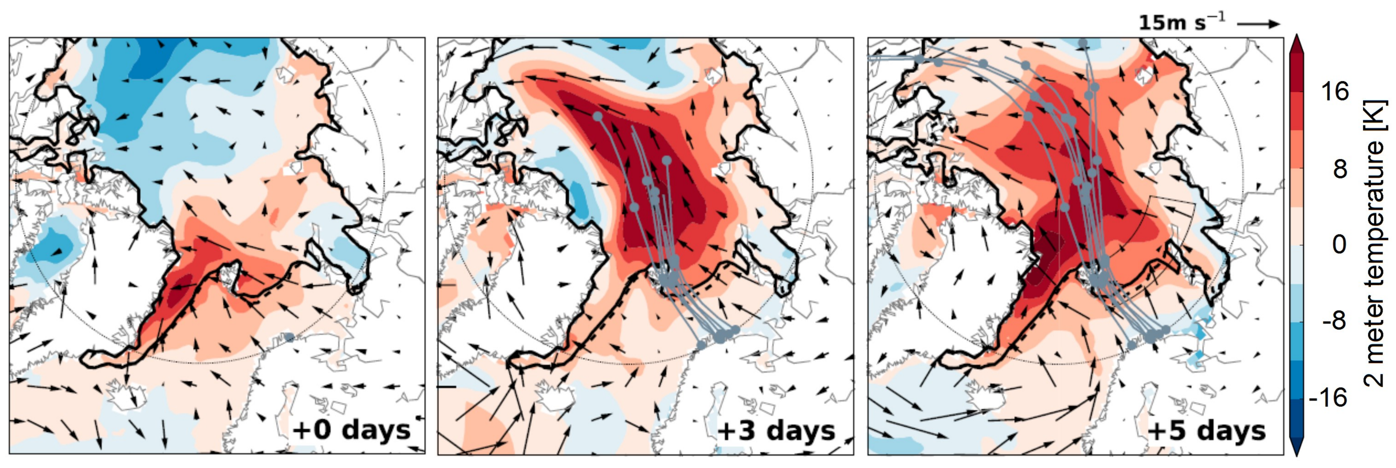


Fig. 3: Typical pattern of a warm air intrusion as seen in the 2 meter temperature at the beginning and after three and five days.

- Quantify the **effects of small-scale surface temperature variability** on ABL
- Our research will be mainly based on previous and new airborne observations
  - Spring and Summer campaign with AWI Polar 5 during MOSAiC in 2020
  - Spring campaign with HALO, Polar 5/6 in 2021
  - Autumn campaign 2022 (P5 combined with RV Polarstern - MIZ Fram Strait)
- Instrumentation as during $(\mathcal{AC})^3$ campaigns ACLOUD, AFLUX
  - Basic meteorology, nose booms with Five-Hole probes, broadband radiation

Further new aspects are:

- Longer distances achievable with HALO
  → **Radiative and turbulent flux properties along Lagrangian air-mass trajectories**
- New Thermal Infra-Red (TIR) imager
  → **Improve flux parametrisation over the marginal sea-ice zone**

Three work packages (WP)

- **WP1** Analysis of previous $(\mathcal{AC})^3$ data
- **WP2** Aircraft activities accompanying the MOSAiC and HALO-$(\mathcal{AC})^3$ expeditions
- **WP3** Investigation of lower ABL processes based on TIR observations and modelling

4. Role within $(\mathcal{AC})^3$ & perspectives

Collaborations within $(\mathcal{AC})^3$

- Project **A02** supports aircraft observations by balloon-borne observations
- Interpreting radiation and turbulence data requires consideration of **B03** cloud physical measurements
- **C01** will provide surface characterisations, needed to discuss surface induced variations of flux profiles
- Data will be delivered to **CCA1 and CCA2**, where the lapse-rate feedback and surface impacts will be synthesised

A03 energy fluxes (aircraft)						
WP1 data analysis, parameterization	A01/A02 combination of data	B03/B07 cloud inhomogeneity and leads	C01 surface inhomogeneity	E01/E02 CCA1, CCA2		data analysis
WP2 aircraft campaigns	A01 cloud observations	A02 turbulence & radiation	D03 parametrization and modelling			observations
WP3 data analysis, modelling	A01/A02 combination of data	B03/B07 cloud inhomogeneity and leads	C01 surface inhomogeneity	D02 validation of simulations	E01/E02 CCA1, CCA2	model evaluation parametrisation

Perspectives

- Lowest flight level limited to 60 m, but many air-ocean interactions occur below 40 m
→ AWI develops tethered turbulence sonde to be flown down to 10 m above ground
→ Simultaneous flux observations at two levels → Determination of flux divergences

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