Tethered balloon-borne energy budget measurements in the cloudy central Arctic

A02

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1. Summary

Research questions

Q1 How do measured profiles of thermodynamic, turbulence, radiation, and aerosol properties evolve during the **transition between cloudy and cloudless conditions and during the formation of Low-Level Jets (LLJs)**, how well can these transformations be modeled by Large Eddy Simulations (LES) and Single Column Models (SCMs)?

Q2 How well does **ICON** in weather forecast mode **represent the transition period from polar night to day**; can possible model deficiencies in this regard be resolved?

Q3 How do stability, temperature lapse rate, inversion height/strength, vertical humidity, and cloud distributions influence the surface warming and the **lapse rate feedback in cloudy and cloudless situations**?

A02 contributes to CCA3 & SQ1

2. Achievements phase II

Ballon-borne in situ profiling

- Case studies (about 200 profiles) analysing turbulence and thermal-infrared irradiance observations during MOSAiC (Fig. 1) and in Ny-Ålesund in different seasons
- More accurate estimates of mixing layer height using turbulence observations
- Vertical turbulent mixing reduced in cloudless conditions
- Radiative cooling at cloud top linked to vertical mixing within and below the cloud layer
- Significant reduction of turbulence by shading effects

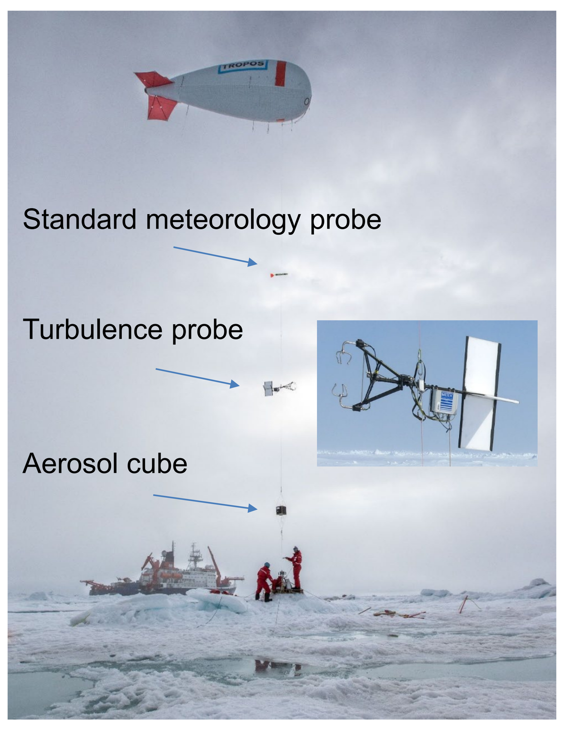

Fig. 1: Tethered balloon setup employed during MOSAiC

Observed changes of ABL properties: Turbulence & Radiation

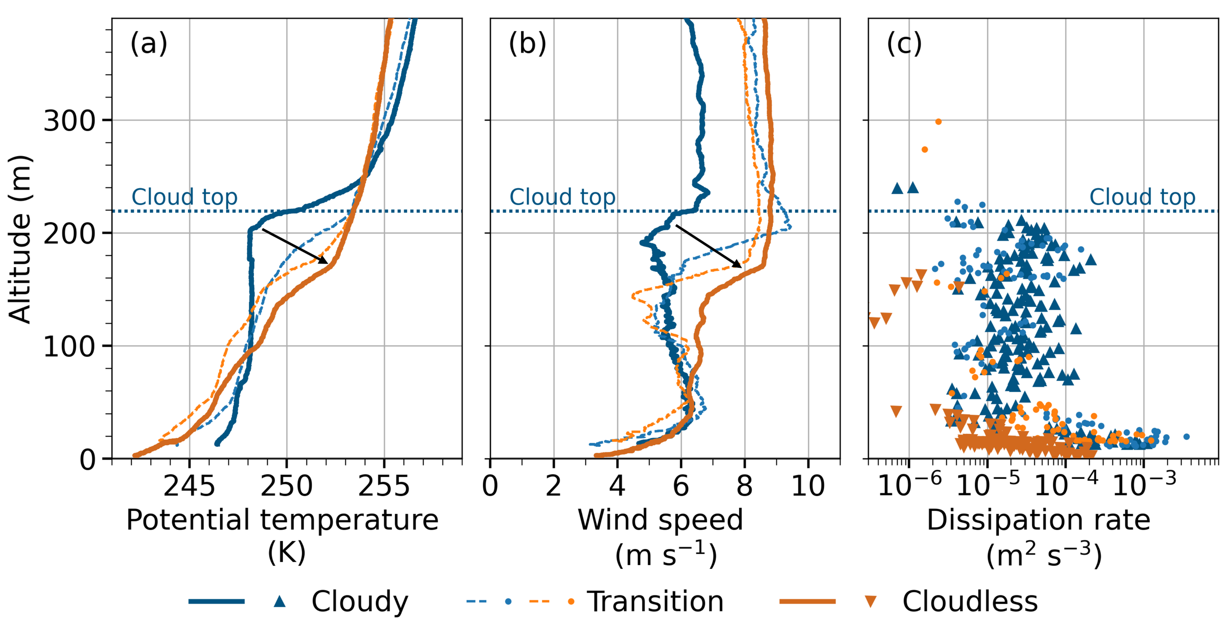

Fig. 2: Vertical profiles of ***thermodynamic, dynamic, and turbulence properties*** *observed during the transition from cloudy (blue) to cloudless conditions (orange) during MOSAiC on 25 January 2020*

- Transition between cloudy and cloudless states
- Increased ABL height for cloudy conditions (Figs. 2a and 2b)
- Reduced turbulence during cloud dissolution (Fig. 2c)

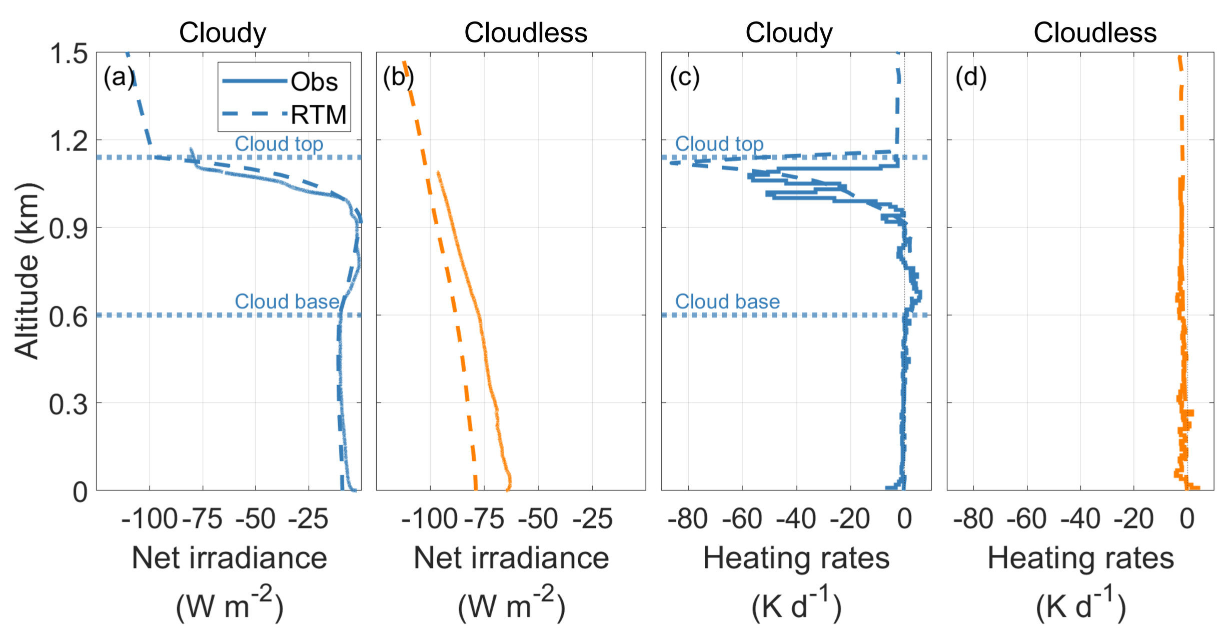

Fig. 3: Vertical profiles of ***radiative properties*** *(thermal-infrared) during the transition from cloudy (blue) to cloudless (orange) conditions observed in Ny-Ålesund on 30 September 2021*

- Strong negative surface radiative energy budget without clouds (Figs. 3a and 3b)
- Radiative cooling at cloud top, warming at base (Fig. 3c)
- Diminished radiative cooling in cloudless conditions (Fig. 3d)

Hypothesis

Highly resolved profile data of the Arctic Atmospheric Boundary Layer (ABL) are needed to realistically simulate typical ABL transition processes and to investigate their effects on the lapse rate.

3. Research plan phase III

ABL during cloudy-cloudless and LLJ transitions — **Q1**

- Extending analysis to entire data set from phases I and II, including planned observations at Station Nord (Greenland, March to April 2024) during phase III
- Applying the Dutch Atmospheric Large Eddy Simulation (DALES) model in cooperation with Roel Neggers (A01) to quantify the model ability to reproduce the processes during the ABL transitions (Figs. 2 to 4)
- Performing SCM simulations in collaboration with Gunilla Svensson (Uni Stockholm) to develop parameterisations and perform sensitivity tests (role of surface albedo versus clouds)

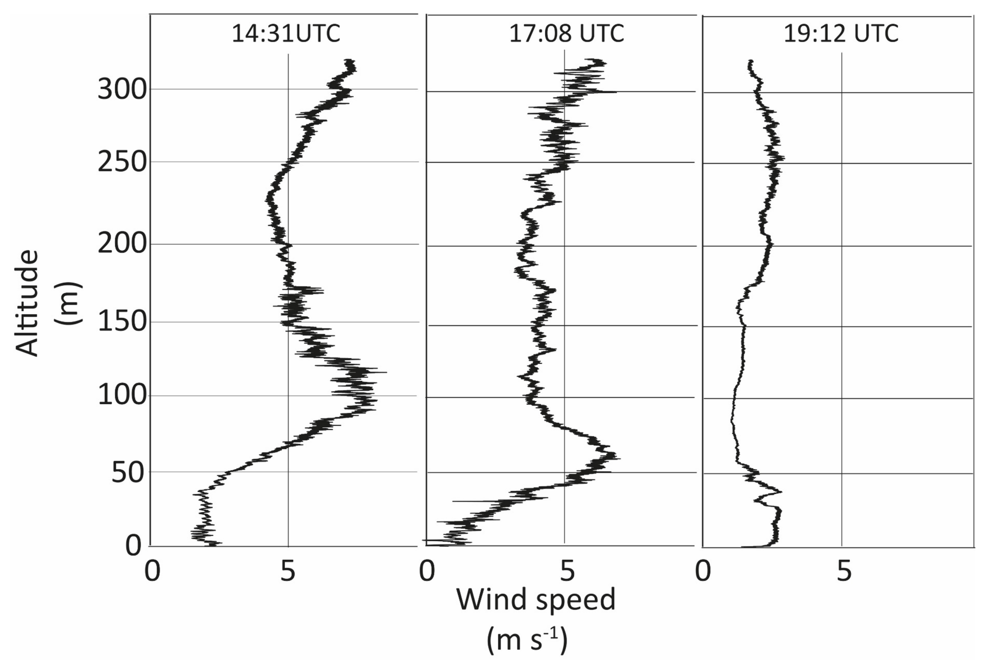

Fig. 4: Transition of a LLJ into an ABL without LLJ observed at Station Nord (Greenland) in 2018

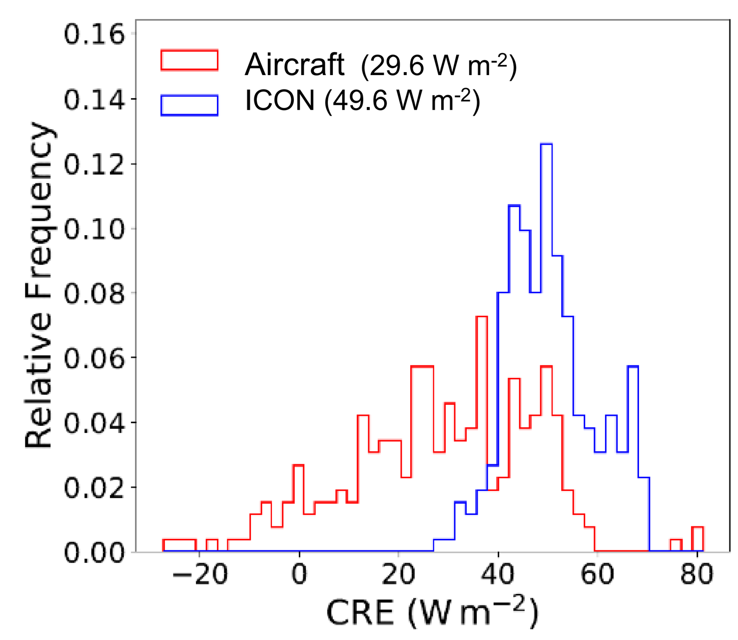

Fig. 5: Relative frequency of the total (solar plus thermal-infrared) cloud radiative effect

Capability of ICON to represent the polar night-day transition — **Q2**

- Comparing observations with ICON output in weather forecast mode for the entire measurement campaign at Station Nord (Fig. 5)
- Utilising ICON results provided by Z04

Quantification of the lapse rate feedback — **Q3**

- Investigating the influence of stratification (lapse rate) on surface warming expressed by:

$$\lambda = \frac{\partial R}{\partial x}\frac{\mathrm{d}x}{\mathrm{d}T_s}$$

$$R = F^{\downarrow} - F^{\uparrow};\ x = \frac{\partial \Theta}{\partial z}$$

with R representing the terrestrial radiative energy budget (Figs. 3a and 3b) at the surface, Θ the potential temperature (Fig. 2a), T_s the near-surface air temperature, and altitude z

- Deriving the feedback parameter λ from time series of measurements during the three types of ABL transitions (cloudy-cloudless, LLJ, polar night-day)
- Simulating λ using SCM results, comparing with observations

4. Legacy & Major expected results

By the end of phase III …

- … a statistical analysis of high-resolution tethered balloon observations throughout the Arctic ABL in different seasons will be available: It includes turbulence, radiation, aerosol, dynamic, and thermodynamic parameters.
- … the accuracy of estimates of mixing layer heights during polar night will be improved.
- … process studies during transitions between main states of the Arctic ABL (cloudy-cloudless conditions, LLJ, polar night-day) based on high resolution profiles will provide new insights into the mechanisms driving the transitions.
- … the ability of LES and SCM to realistically reproduce the transition processes will be quantified.
- … major feedback processes (in particular the lapse rate feedback) and their role in Arctic amplification, based on simulations driven by observations, will be evaluated.
- … the collected data set will be available for further analysis by the international Arctic ABL scientific community.

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