# Assessment of the Arctic lapse-rate feedback using a multi-scale model hierarchy

**E01**

Johannes Quaas, Roel Neggers
Karoline Block, Jan Chylík

## 1. Summary


### Research questions

In order to understand and quantify the lapse-rate feedback in the Arctic
**Q1** Drivers of muted free-tropospheric warming: Changes to components of radiative-advective equilibrium in a warming climate?
**Q2** Temperature inversion and lack of vertical mixing: Role of cloud-top cooling?
**Q3** Strong surface warming: Dependence on changes of the underlying surface?


## Hypothesis

**The lapse-rate feedback plays a key role in Arctic amplification. The impact from clouds, the surface energy budget, and from meridional transports are key to better understand it.**

## 2. Achievements phase I

### Lapse-rate feedback key for Arctic amplification

Analysis of climate models (CMIP5):
- Total feedback *positive* in the Arctic in the multi-model mean
- Lapse-rate feedback flips sign between Tropics and Arctic
- Change in lapse-rate related to control climate inversion strength

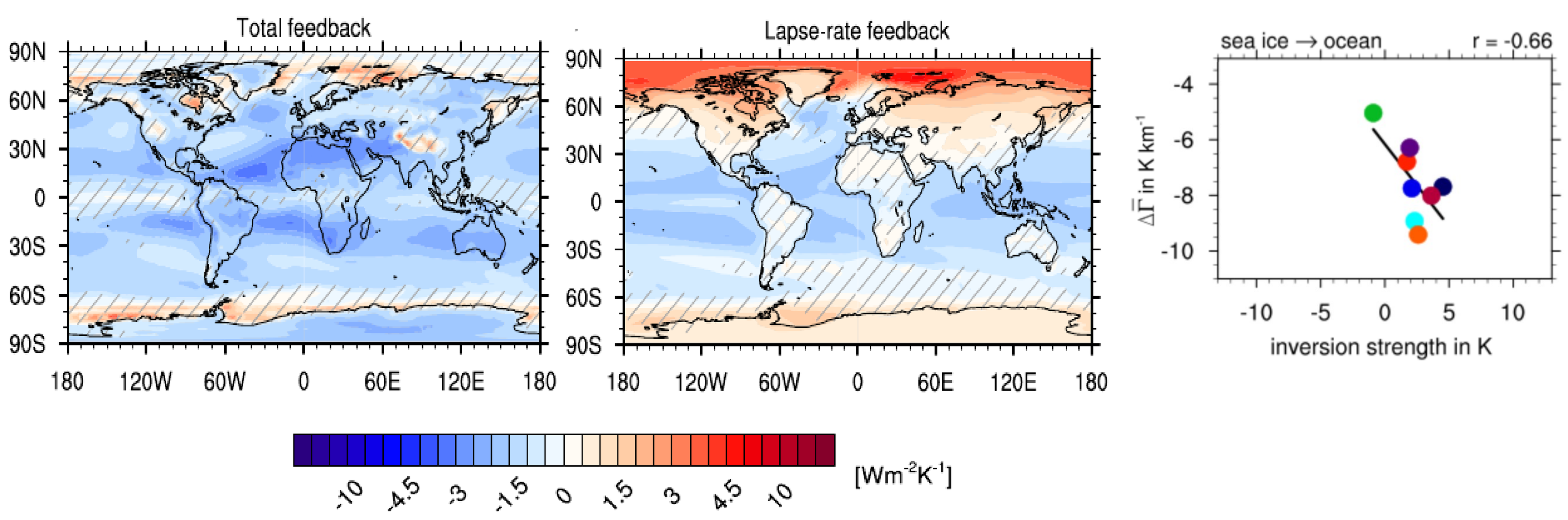


*Fig. 1: (Left/middle) Multi-model time-mean mean feedback strengths (Block et al., Tellus, revised). (Right) change in lapse-rate vs. inversion in control climate (Lauer et al., MetZ, revised).*

### Detailed process analysis using LES and field campaign data

Significant low-level bias over sea ice in GCMs identified, corrected in LES forcings
- Turbulent transport counteracts cloud-top cooling and precipitation
- Subsidence events responsible for cloud collapse
- Importance of cloud ice processes in total water budget

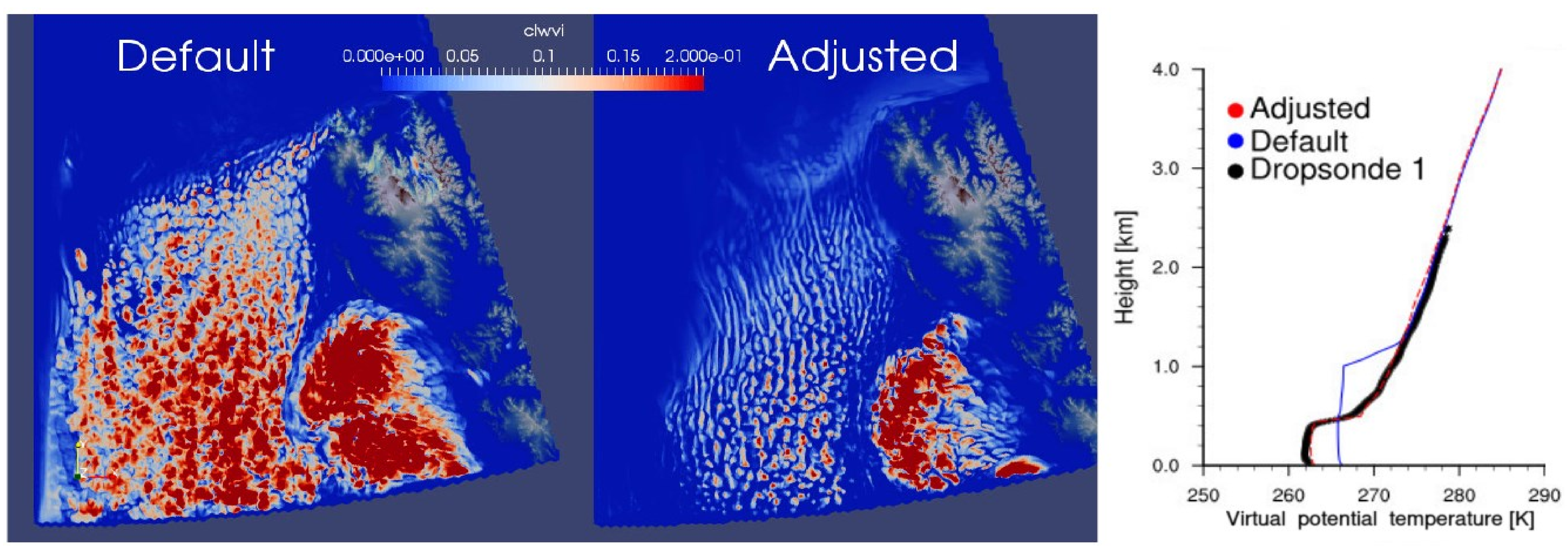


*Fig. 2: ICON-LEM for a Cold Air Outbreak (CAO) case observed during the ACLOUD field campaign. Left: Simulated cloud liquid water path (shaded) using unadjusted (left) and adjusted (right) GCM-derived forcings. Right panel: vertical profile as simulated by the ICON-LEM and in dropsonde data.*

## 3. Research plan phase II

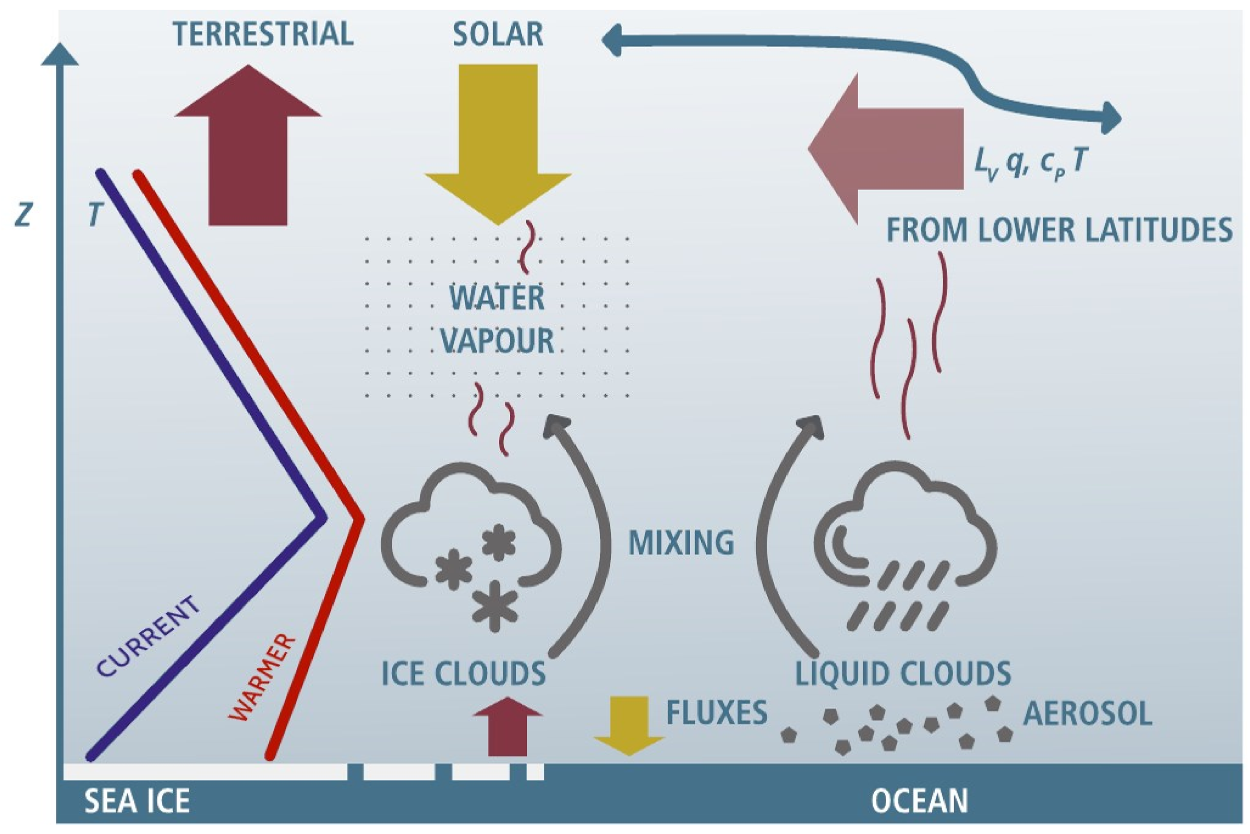


*Fig. 3: Lapse-rate feedback. Low latitudes: moist adiabat → warmer climate implies that surface warms less than free troposphere (reduces the greenhouse effect → negative feedback). Arctic: vertical mixing hampered by stable atmosphere. Surface warms more than free troposphere. Stronger lapse-rate implies a stronger greenhouse effect → positive feedback.*

### WP1 Arctic simulations across scales
- ICON-GCM / CMIP6 multi-model context
- High-resolution ICON-LEM simulations driven by composite forcings based on GCM data for present and future climate
- Four target areas: open ocean, ice margins, high Arctic, land masses
- ICON-LEM and ICON-NWP simulations to accompany field campaigns: MOSAiC, HALO-(𝐴𝐶)³, COMBLE

### WP2 Tropospheric temperature
- Quantify radiative-advective equilibrium in GCMs: radiative cooling, convective and turbulent heating; meridional energy transport
- Observational constraints from top-of-atmosphere radiation and HALO-(𝐴𝐶)³

### WP3 Cloud-top cooling & inversion
- Quantify role of parameterised processes in GCM
- Roles of processes in ICON-LEM

### WP4 Surface energy budget
- Sensitivities in GCM: build on phase I
- Decoupling and turbulence in ICON-LEM
- Differences between sea ice and ocean
- Impacts of an oceanic bulk mixed layer in ICON-LEM

### WP5 Crosscutting activity & synthesis
- Coordinate relevant activities within (𝐴𝐶)³
- Incorporate lessons learned into ICON model family
- Explore relevance for simulated lapse-rate feedback and Arctic amplification

## 4. Role within (𝐴𝐶)³ & perspectives

| | | | |
|---|---|---|---|
| E01 | WP1 Arctic simulations across scales | D02 aerosol-cloud interactions; E03 mixed-phase clouds; E04 precipitation and snowfall | ICON revision and sensitivities |
| | WP2 tropospheric temperature | B01 TOA reflectance space observations; D01 large-scale dynamical impacts; E04 precipitation and snowfall | meridional energy transport: satellites / models |
| | WP3 clouds & inversion | A-cluster energy budget measurements; B01 satellite clouds; B03 mixed-phase clouds; B04 aerosol particles; D02 aerosol-cloud interactions | cloud evaluation and constrains |
| | WP4 surface energy budget | A02 energy budget measurements; B02 surface reflectance; C01 surface heterogeneity; D02 aerosol-cloud interactions; D03 atmosphere / ice / ocean; E04 precipitation and snowfall | surface flux studies |
| | WP5 crosscutting synthesis | A-cluster energy budget measurements; B03 mixed-phase clouds; B05 water vapour; B07 reflectance; C03 atmos.-ocean interactions; D01 dynamics; D02 aerosol-cloud interactions; D03 atmosphere / ice / ocean; E02 Ny-Ålesund; E03 mixed-phase clouds; E04 precipitation and snowfall | synthesis |

### Perspectives

E01 in phase III will serve in (𝐴𝐶)³ to:
- integrate improved process understanding into the climate models across scales;
- demonstrate increased fidelity of models using (𝐴𝐶)³ observations, simulations, process studies, and theoretical developments;
- in particular, climate-oriented evaluation of the observed Arctic climate change in the last decades.

TR 172 TRANSREGIONAL COLLABORATIVE RESEARCH CENTRE
(𝐴𝐶)³ ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms
COORDINATING UNIVERSITY
UNIVERSITÄT LEIPZIG
Universität Bremen
University of Cologne
AWI ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG
TROPOS Leibniz Institute for Tropospheric Research
printed at Universitätsrechenzentrum Leipzig