EXZELLENZCLUSTER
CLIMATE, CLIMATIC CHANGE, AND SOCIETY (CLICCS)

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Tropical free-tropospheric humidity in global storm-resolving models

Theresa Lang[1], Ann Kristin Naumann[1,2], Bjorn Stevens[2], Hauke Schmidt[2], Stefan A. Buehler[1]

1) Universität Hamburg, 2) Max Planck Institute for Meteorology

International Max Planck Research School on Earth System Modelling

theresa.lang@uni-hamburg.de

MOTIVATION

The existing **model spread in tropical relative humidity** (RH) and its change with warming limits our ability to predict Earth's climate sensitivity (e.g. Vial et al., 2013). A recent study showed that, although RH differences are reduced in **global storm-resolving models,** they remain an important source of uncertainty for the clear-sky radiation budget (Lang et al., 2021) and therefore need to be better understood. In this study we address the following research questions:

Which model uncertainties cause the remaining spread in tropical RH across global storm-resolving models?

What are the physical mechanisms behind the RH changes?

METHODS

Test sensitivity of tropical RH in ICON experiments

Control	45 days, 5km grid spacing, 110 vertical levels	
Control 2	As Control, but with perturbed initial conditions to estimate internal variability	
$\Delta x/2$	Halved horizontal grid spacing (2.5 km)	**model resolution**
$2\Delta z$	Doubled vertical grid spacing	
$\Delta z/2$	Halved vertical grid spacing	
$2v_{\mathrm{ice}}$	Increased fall speed of ice particles	**parameterizations**
2-mom	Exchange 1-moment with 2-moment microphysics	
TTE	Exchange 3D Smagorinsky with 1D Total turbulent energy (TTE) turbulence	

Determine last-condensation points from back trajectories

To first order, the humidity of an air parcel is controlled by the temperature at which it was last saturated (Sherwood, 1996).

Are RH changes in the sensitivity experiments explained by the **last-condensation** model?

$$\mathcal{R}_{\mathrm{lc}} = \frac{q^*_{\mathrm{lc}}}{q^*_{\mathrm{t}}} = \frac{e^*(T_{\mathrm{lc}})}{e^*(T_{\mathrm{t}})}\frac{p_{\mathrm{t}}}{p_{\mathrm{lc}}} \quad (1)$$

Or do changes in **parameterized moisture sources and sinks** s after last condensation matter?

$$\mathcal{R}_{\mathrm{lc+s}} = \frac{q^*_{\mathrm{lc}} + s}{q^*_{\mathrm{t}}} \quad (2)$$

RESULTS

RH is most sensitive to parameterizations

- RH changes lie well within the spread in the DYAMOND multi-model ensemble → confirms robust RH in storm-resolving models
- Vertical resolution only matters if it is made too coarse ($2\Delta z$), but changes are small when it is increased ($\Delta z/2$)

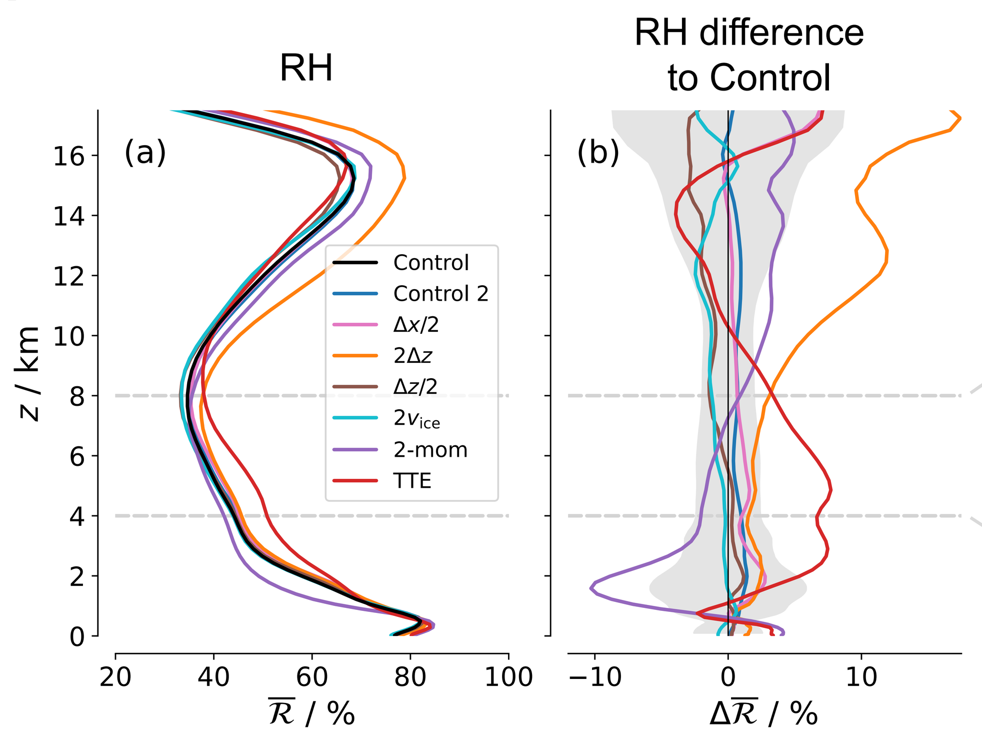
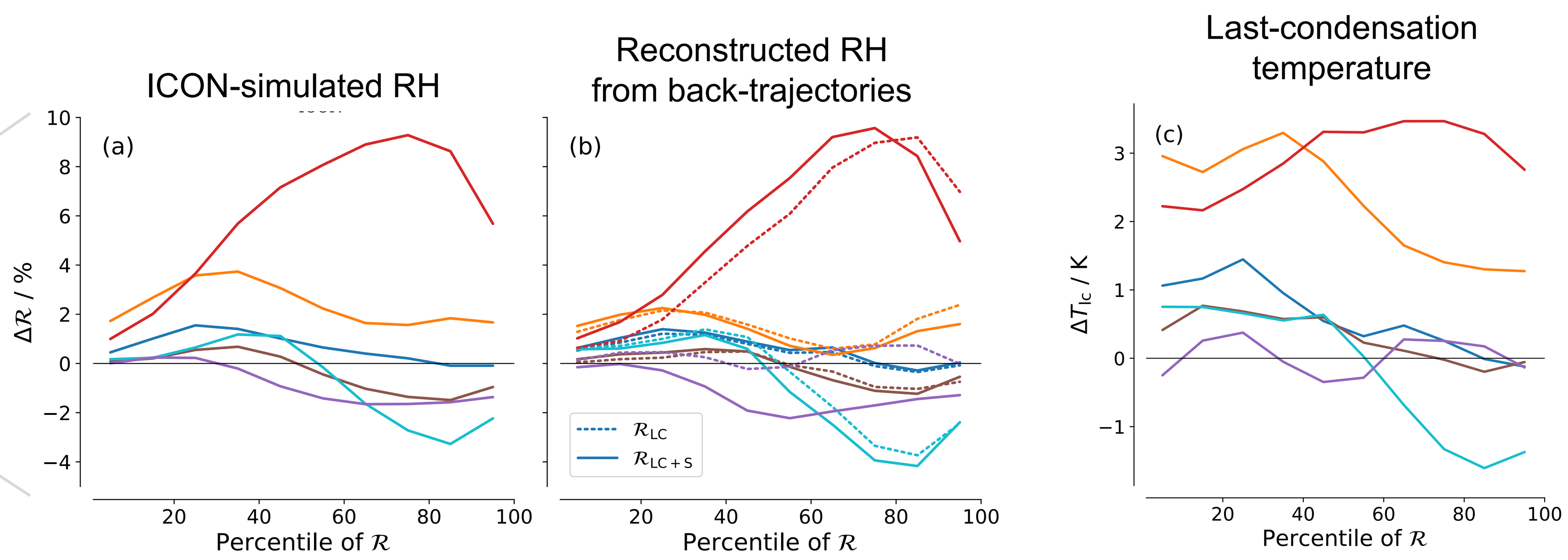


Fig. 1: Tropical mean RH in sensitivity experiments. DYAMOND inter-model standard deviation is indicated by gray shading in (b).

Mid-tropospheric RH changes are largely explained by the last-condensation model



- Except for the 2-mom experiment, RH changes are explained by changes in LC temperature
- A given change in LC temperature translates into a smaller RH change in dry regions due to their cold source temperatures and therefore low water vapor concentrations

Fig. 2: Mid-tropospheric (4-8km average) RH difference to Control experiment in decile-bins of RH – (a) ICON-simulated and (b) reconstructed from Eq. 1 and 2. (c) Difference in last-condensation temperature.

How does the turbulence scheme affect last-condensation temperature?

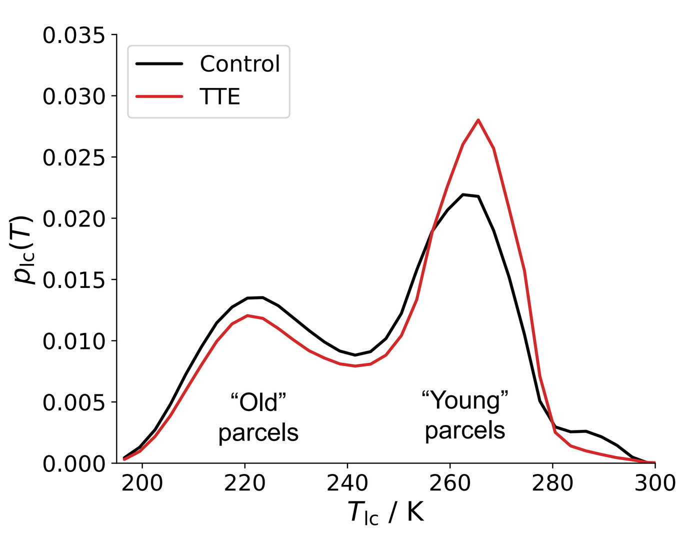


Fig. 3: PDF of last-condensation temperature

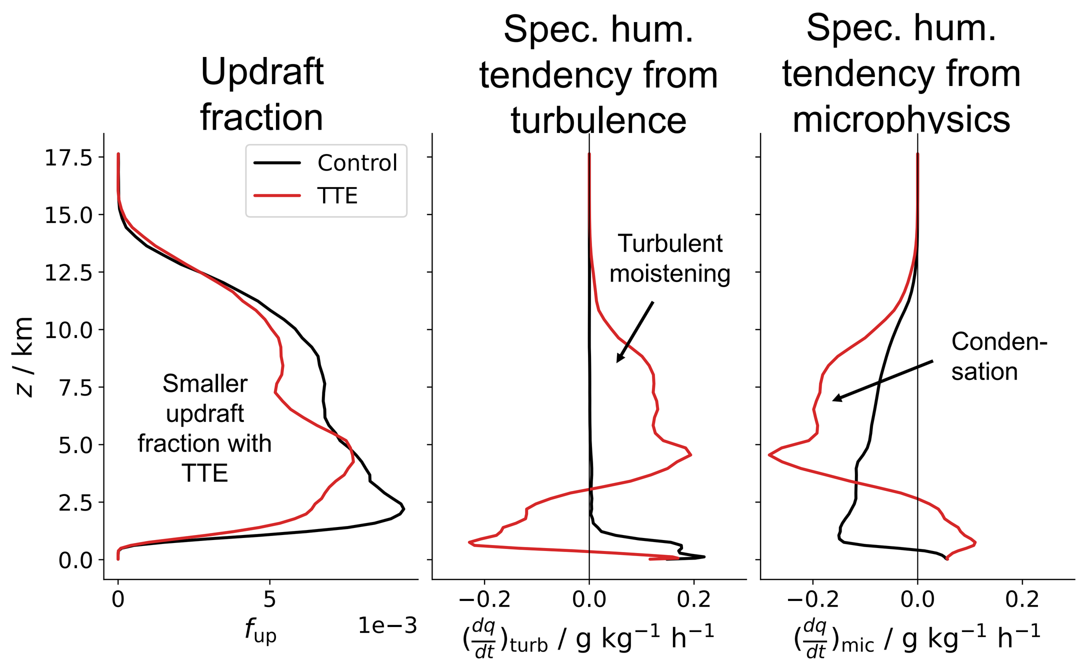


Fig. 5: Updraft fraction and moisture tendencies from parameterizations in top quartile of column relative humidity

Hypothesis: Larger share of "young" parcels in TTE experiment (Fig. 3) results from strong turbulent moistening of the free troposphere, creating a broad moist region with saturation occurring also outside strong updrafts (Fig. 5).

SUMMARY & CONCLUSIONS

- **Parameterized processes** (turbulence and microphysics) are an important remaining source of uncertainty for tropical RH in global storm-resolving models.
- Exchanging the **turbulence** scheme particularly affects RH in the mid troposphere, mainly by **changing the structure of the deep convective regions** and hence the statistics of last condensation points.
- Changes in the **microphysics** result in more localized RH differences, for which changes in **moisture sources** after last condensation also play a role.