Microphysical controls on humidity, radiation and the tropical energy budget in global storm-resolving models

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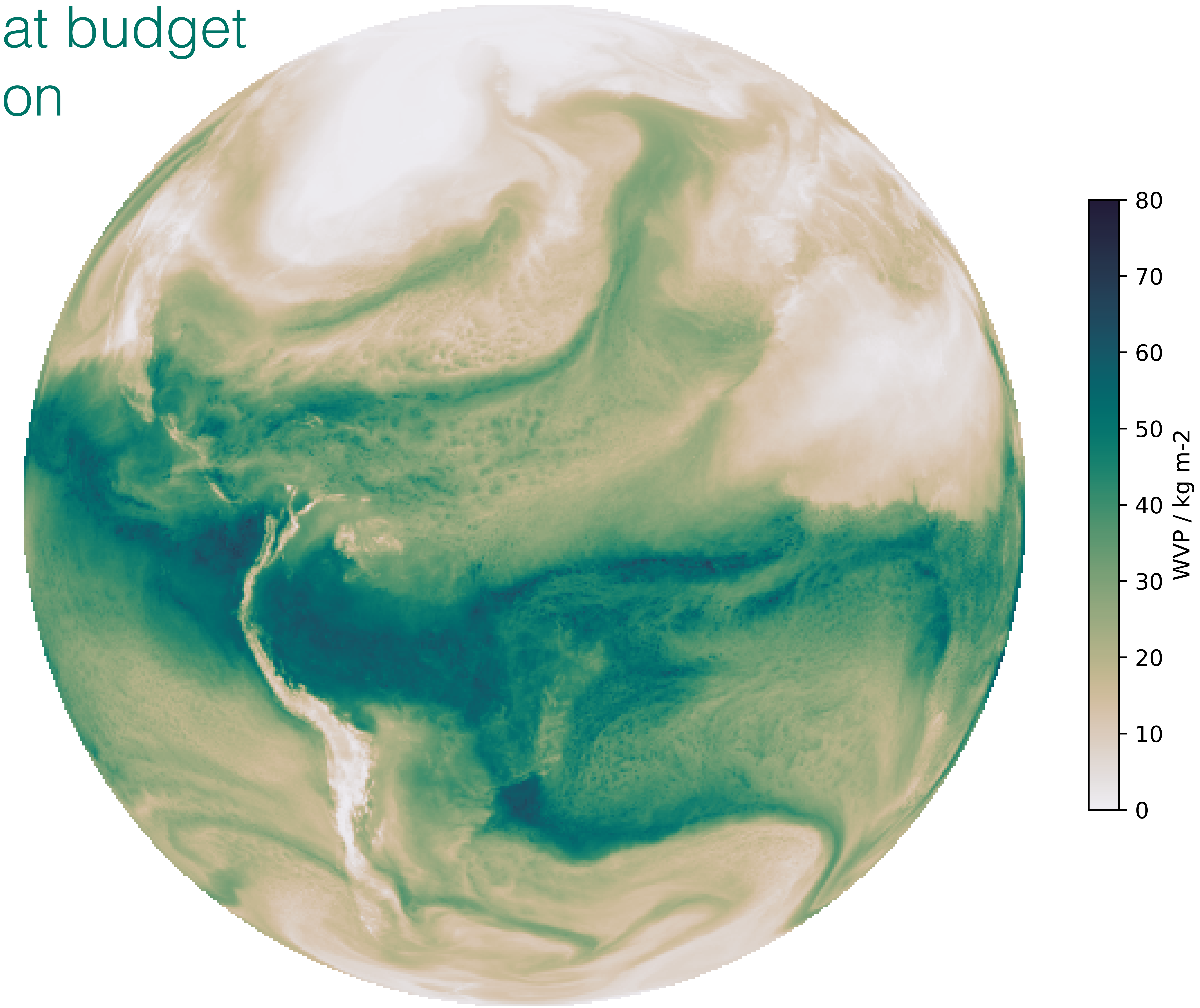
Simulating the tropical heat budget at kilometer-scale resolution

reduced number of poorly constraint processes:

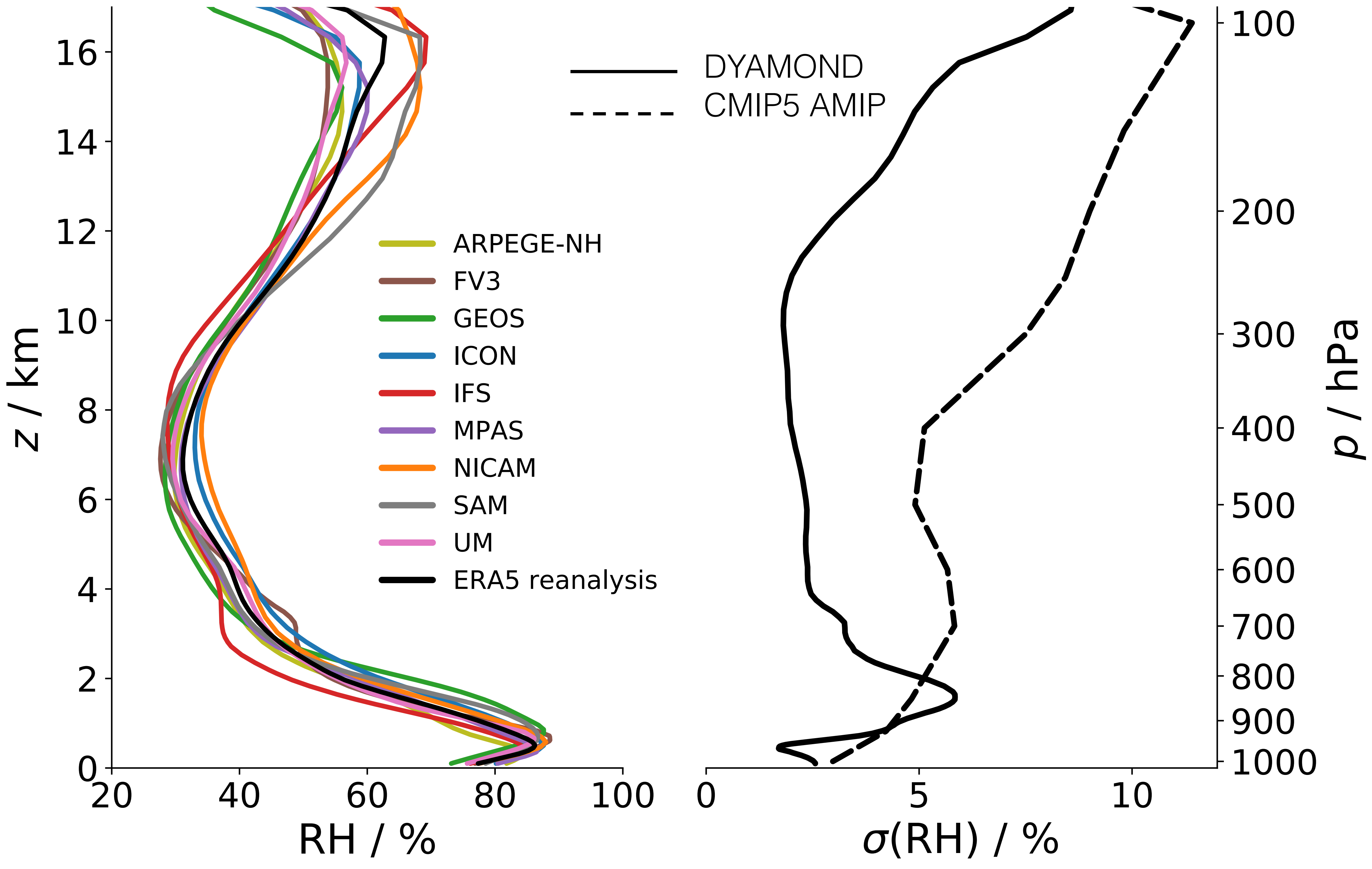
- microphysics
- turbulence

How much of the tropical heat budget is controlled by circulation and dynamics as compared to microphysical processes?

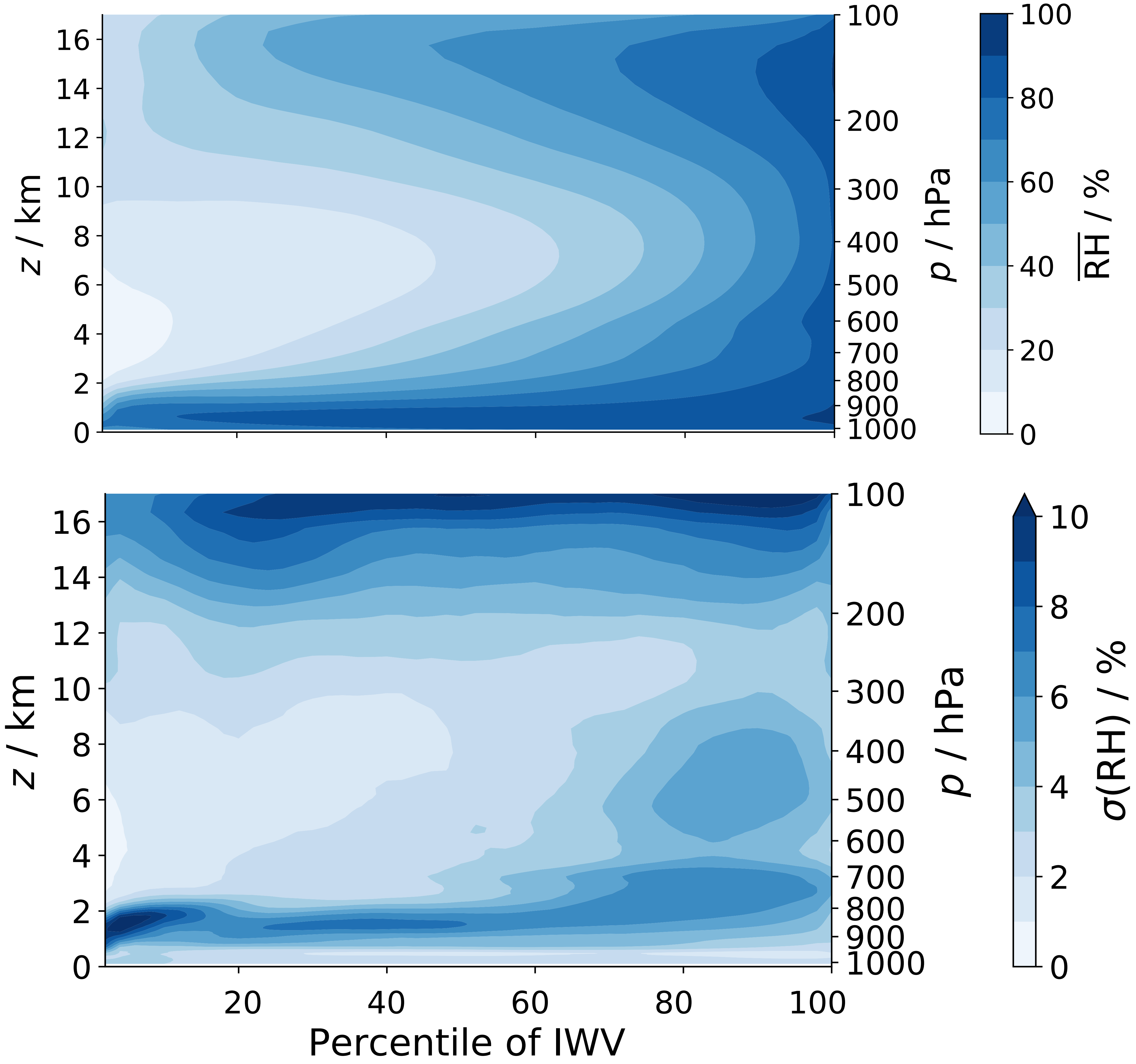


Distribution of free-tropospheric humidity in a multi-model ensemble

(DYAMOND, Satoh et al., 2019, Stevens et al., 2019)

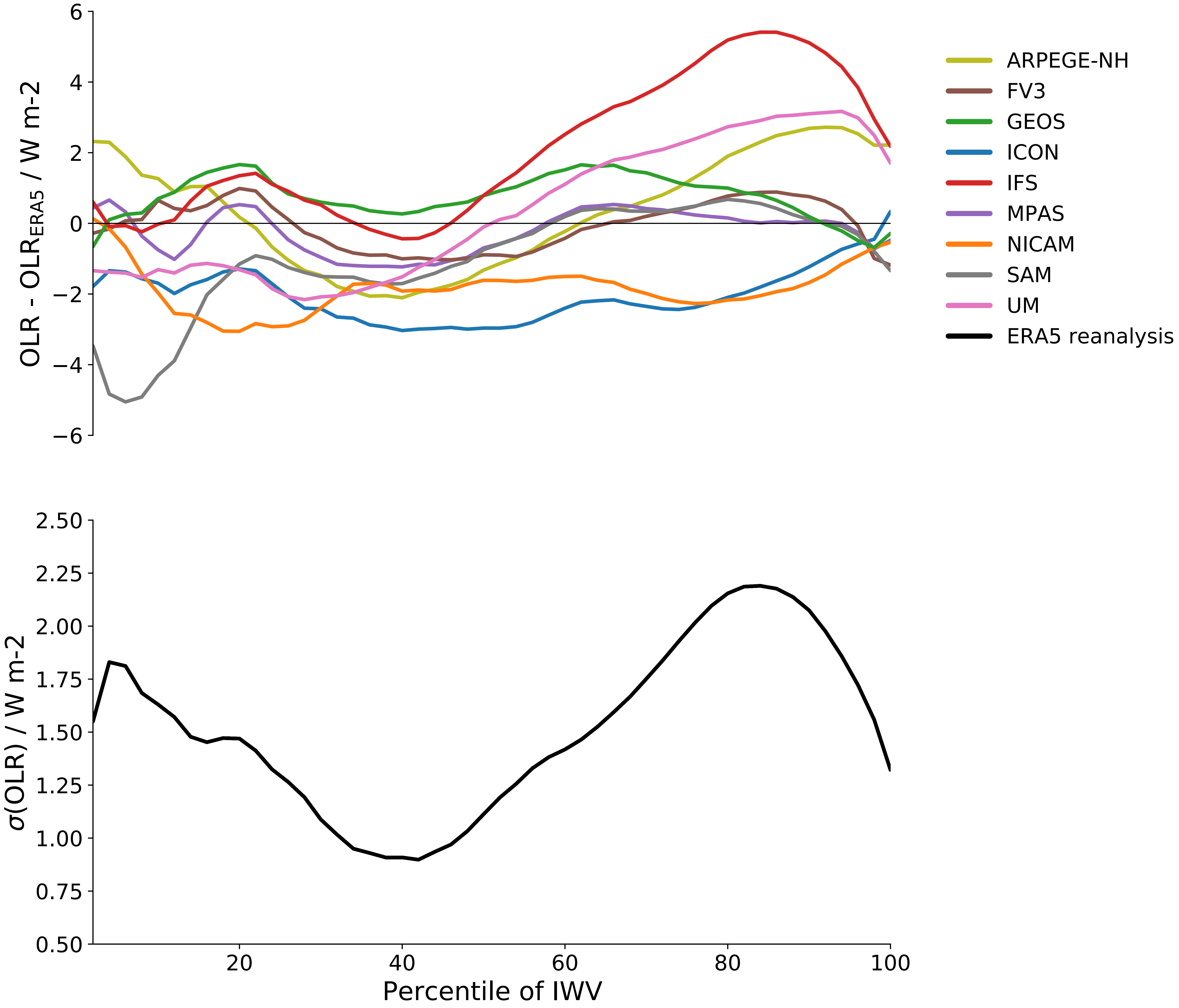


The inter-model spread of RH in GSRMs is about half as large as in the AMIP ensemble.



(Lang et al., 2021)

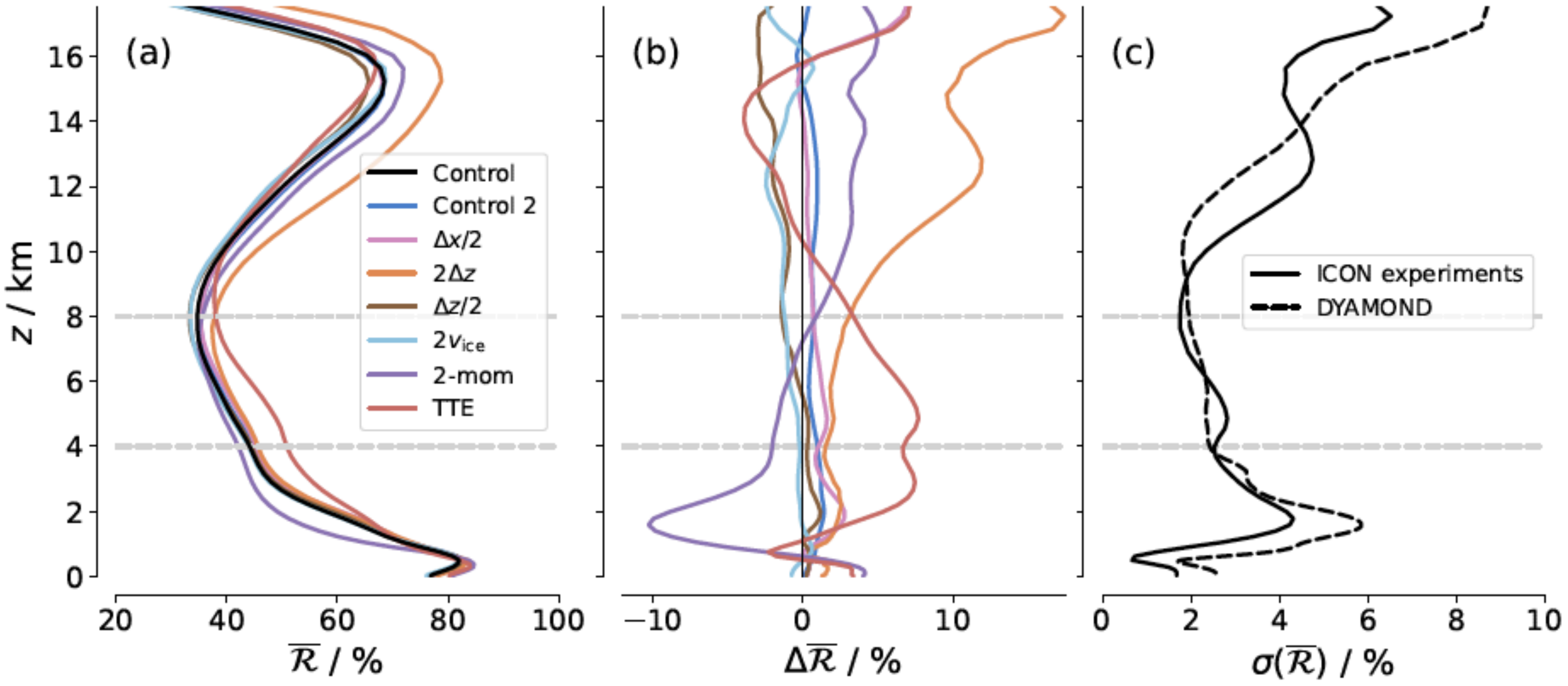
Inter-model differences in clear-sky outgoing longwave radiation (OLR)



Very dry columns and those adjacent to deep convection contribute most to the differences in tropical mean clear-sky OLR.

(Lang et al., 2021)

Tropical relative humidity in a global storm-resolving model is robust to changes in model resolution and parameterizations.



(Lang et al., in prep.)

Which physical processes control the humidity distribution?

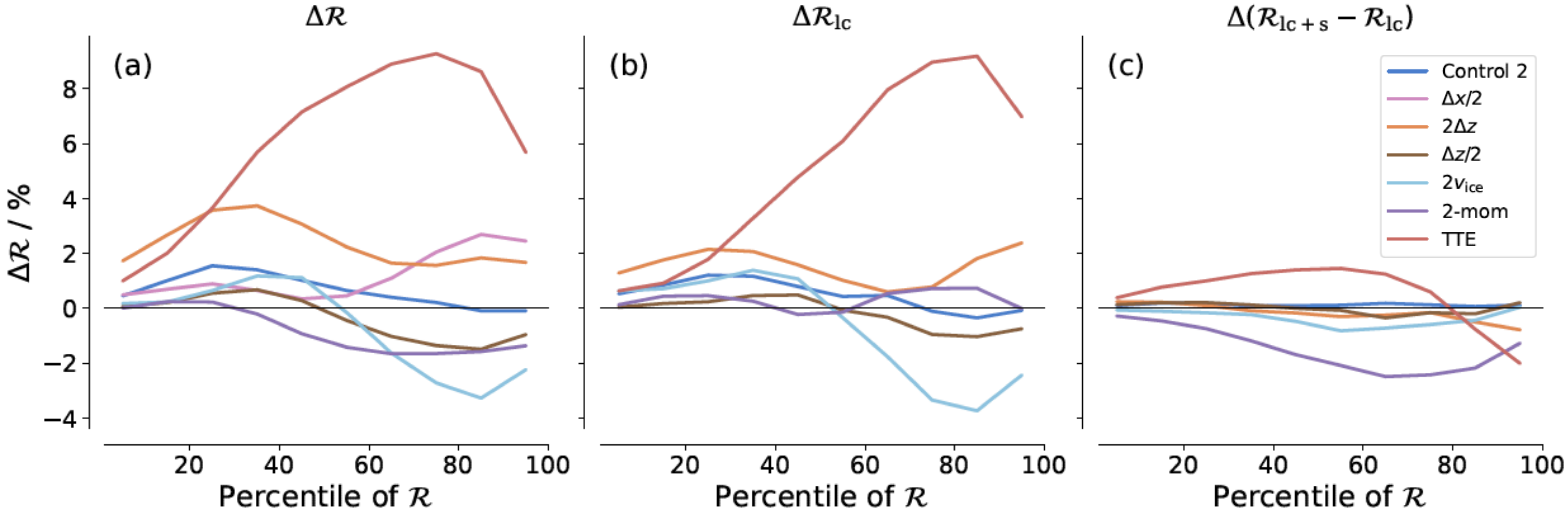
last-saturation model:
(e.g., Pierrehumbert et al., 2006; Sherwood et al., 2010)

$$\mathcal{R} = \frac{q_{\mathrm{lc}}}{q_{\mathrm{t}}^{*}}$$

simulated RH difference

reconstructed RH difference due to last-saturation model

effect of moisture sources and sinks after last saturation



Mid-tropospheric humidity differences are well-explained by differences in their last saturation points, except for a change in the microphysics scheme.

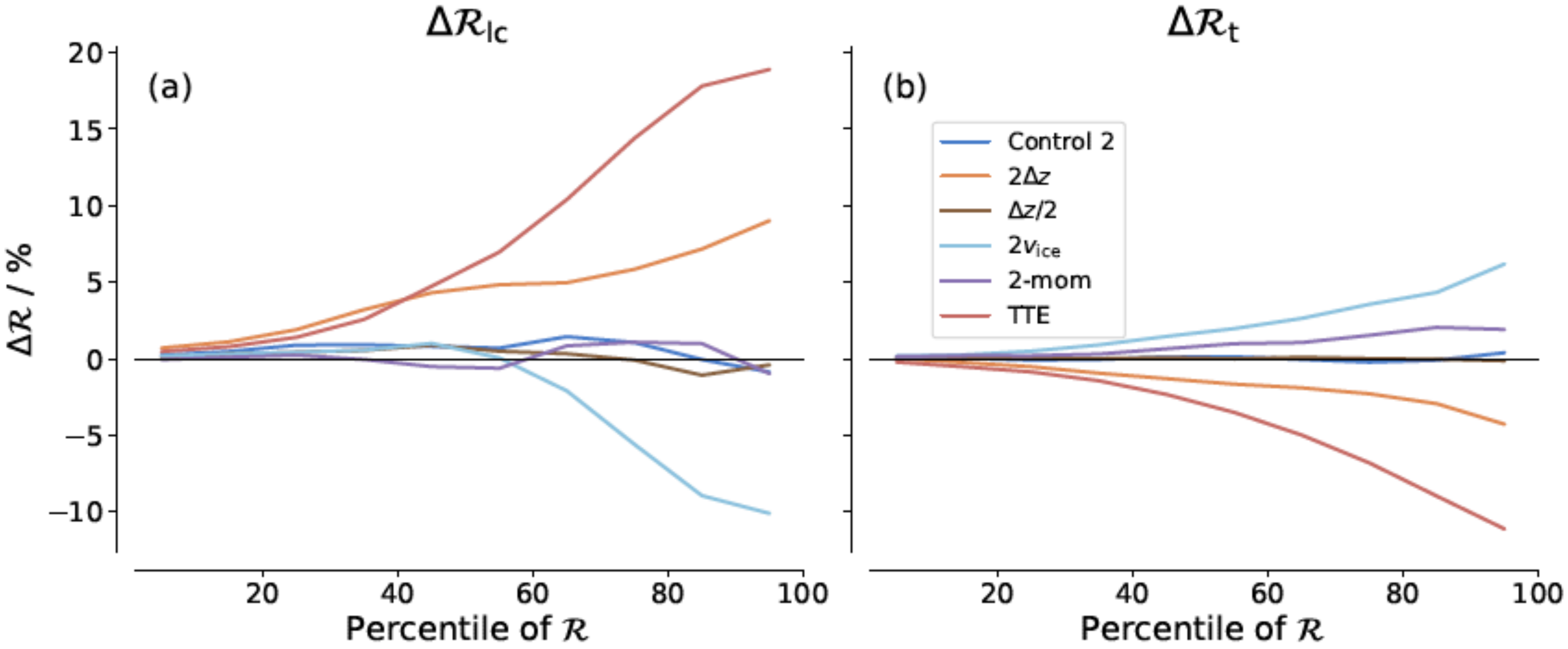
(Lang et al., in prep.)

Humidity differences are largely explained by a change in last-saturation temperature.

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

Contribution from change in last-saturation temperature

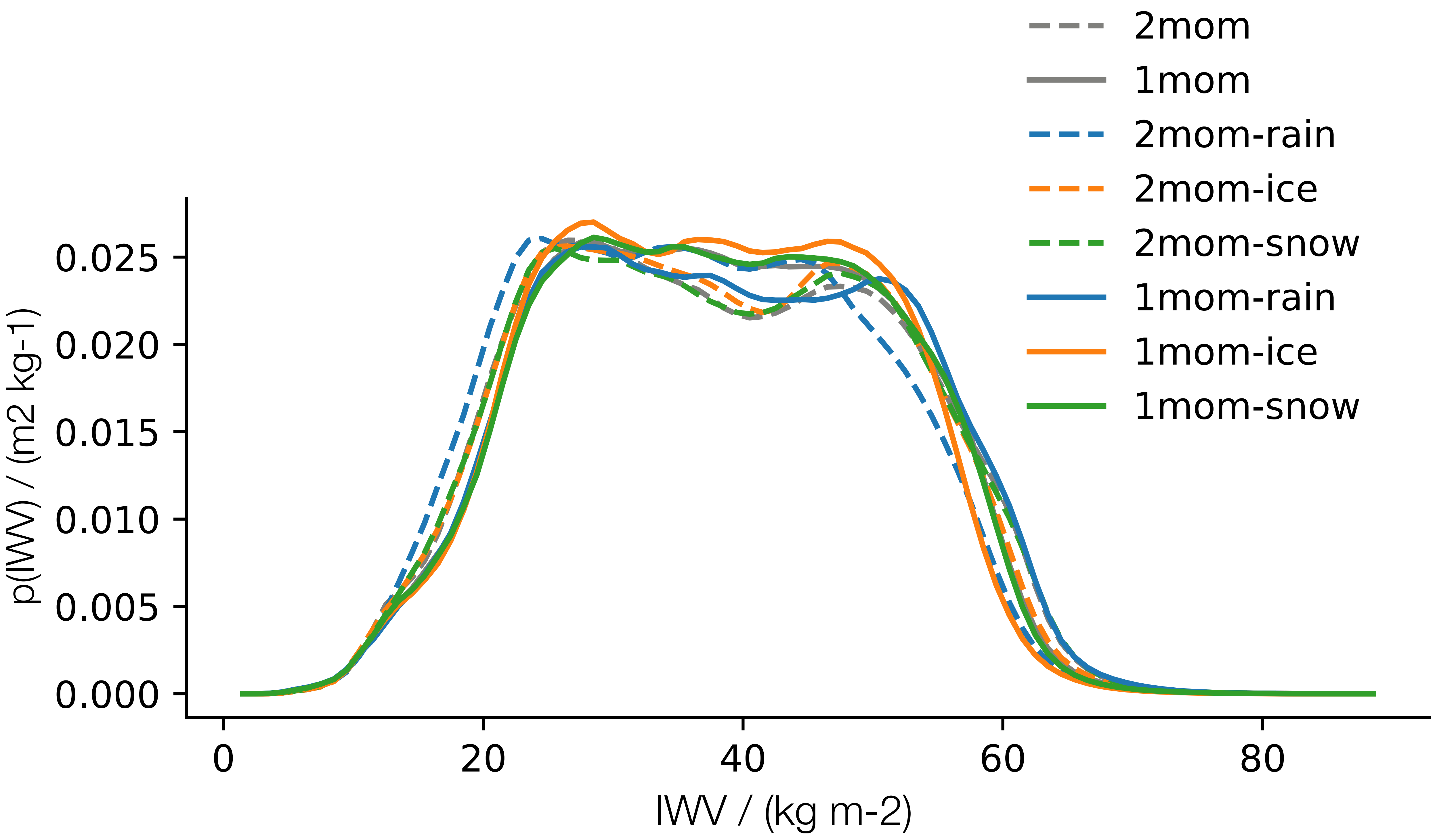
Contribution from change in target temperature



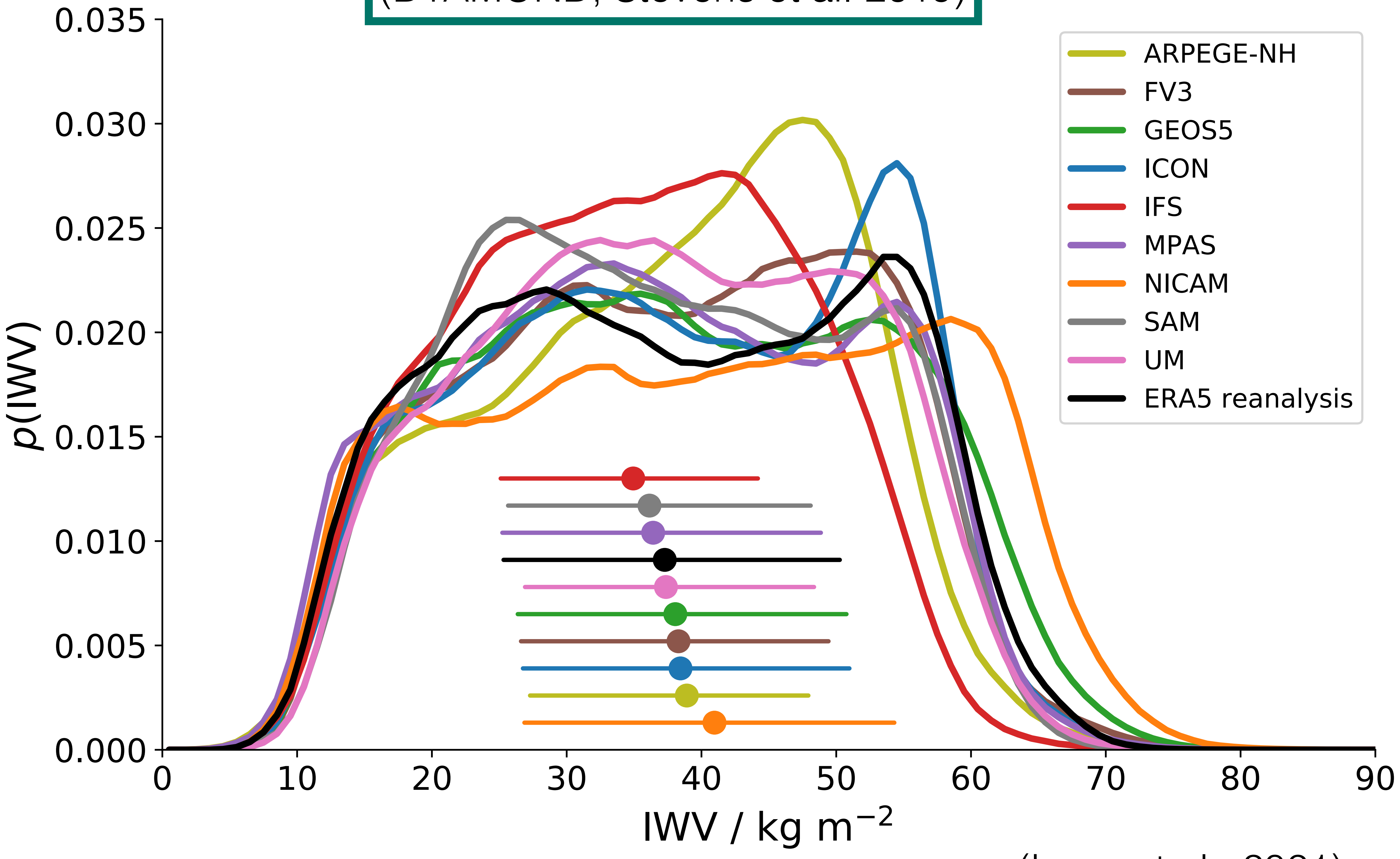
(Lang et al., in prep.)

The humidity spread in a microphysical ensemble is smaller in magnitude than in a multi-model ensemble but shows similar features.

microphysical ensemble

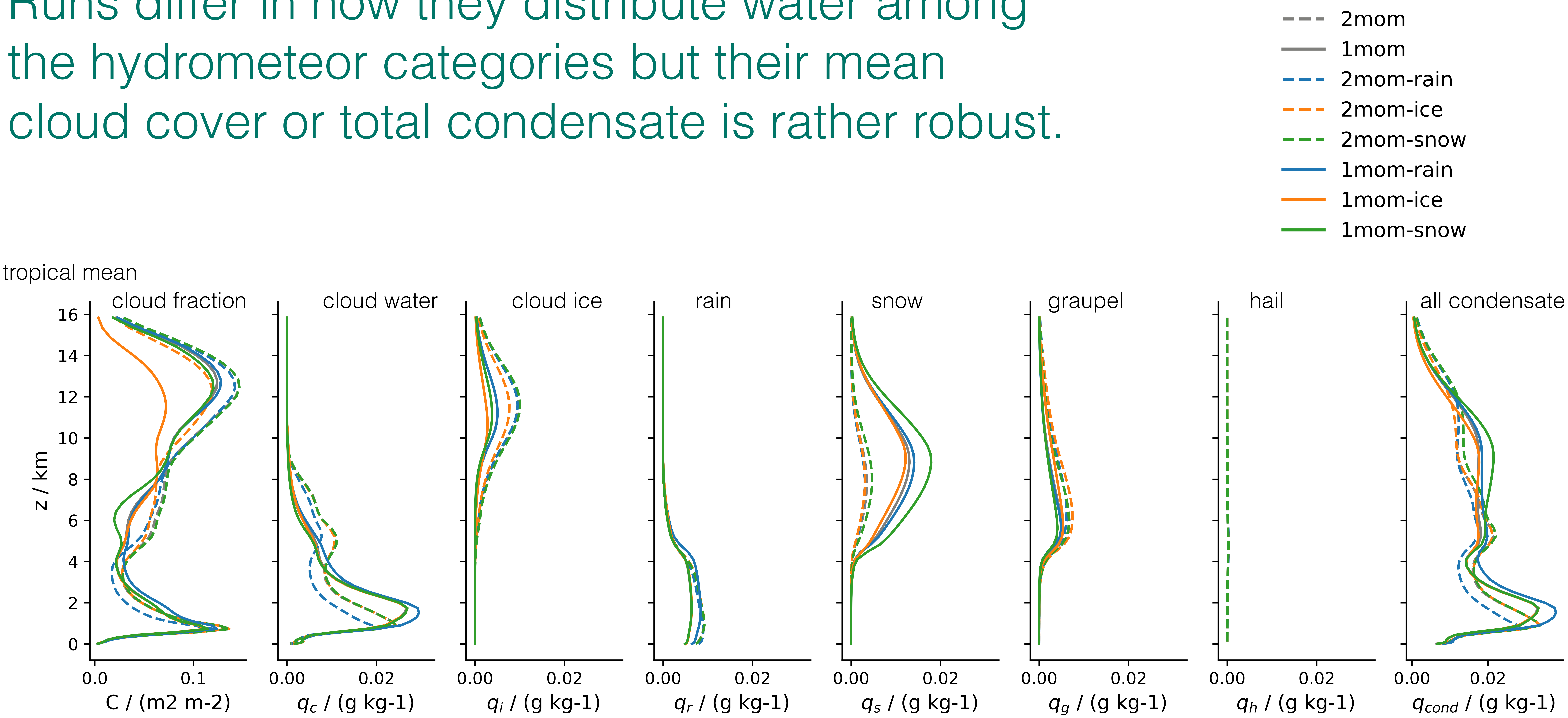


multi-model ensemble
(DYAMOND, Stevens et al. 2019)



(Lang et al., 2021)

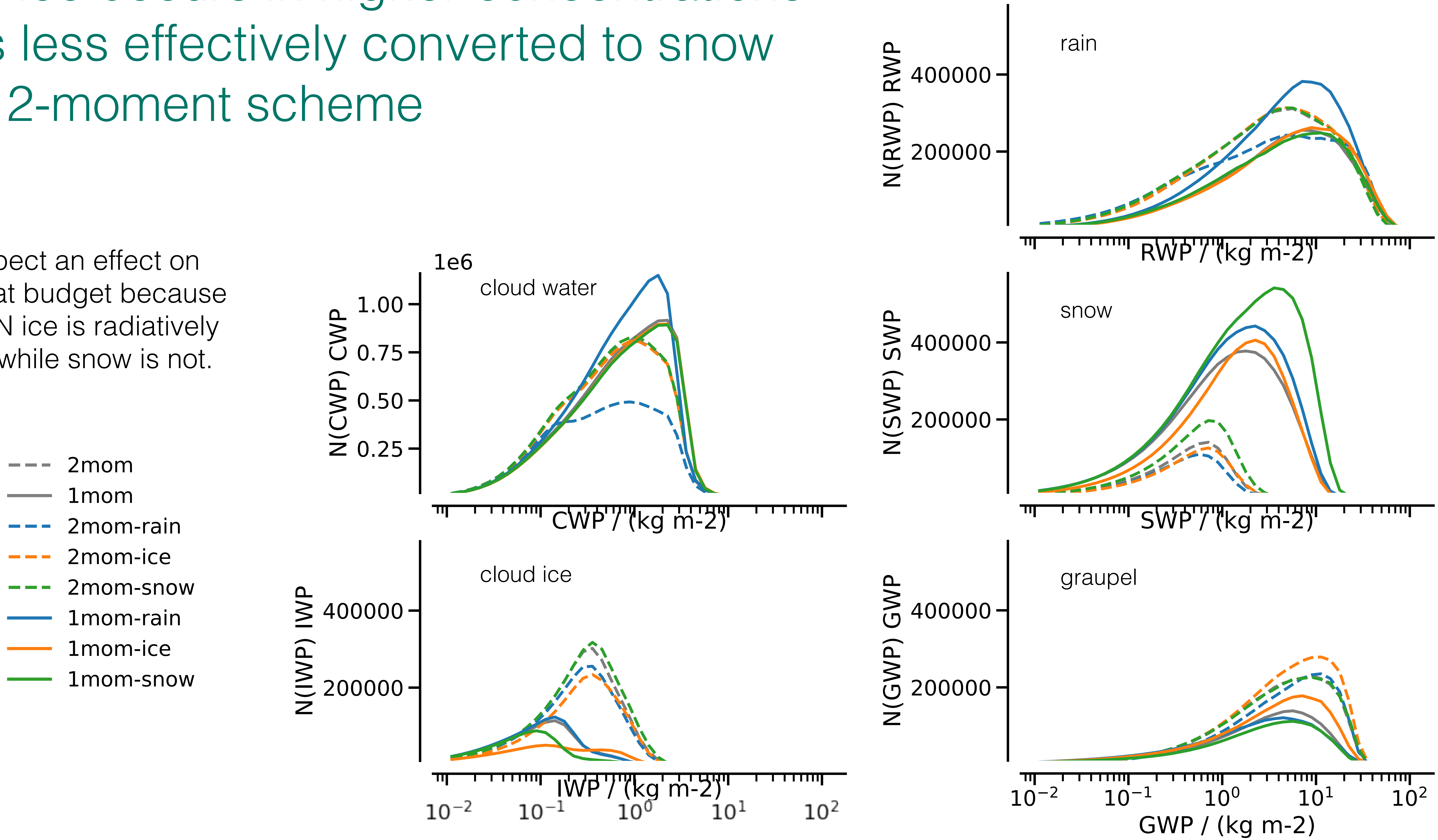
Runs differ in how they distribute water among the hydrometeor categories but their mean cloud cover or total condensate is rather robust.



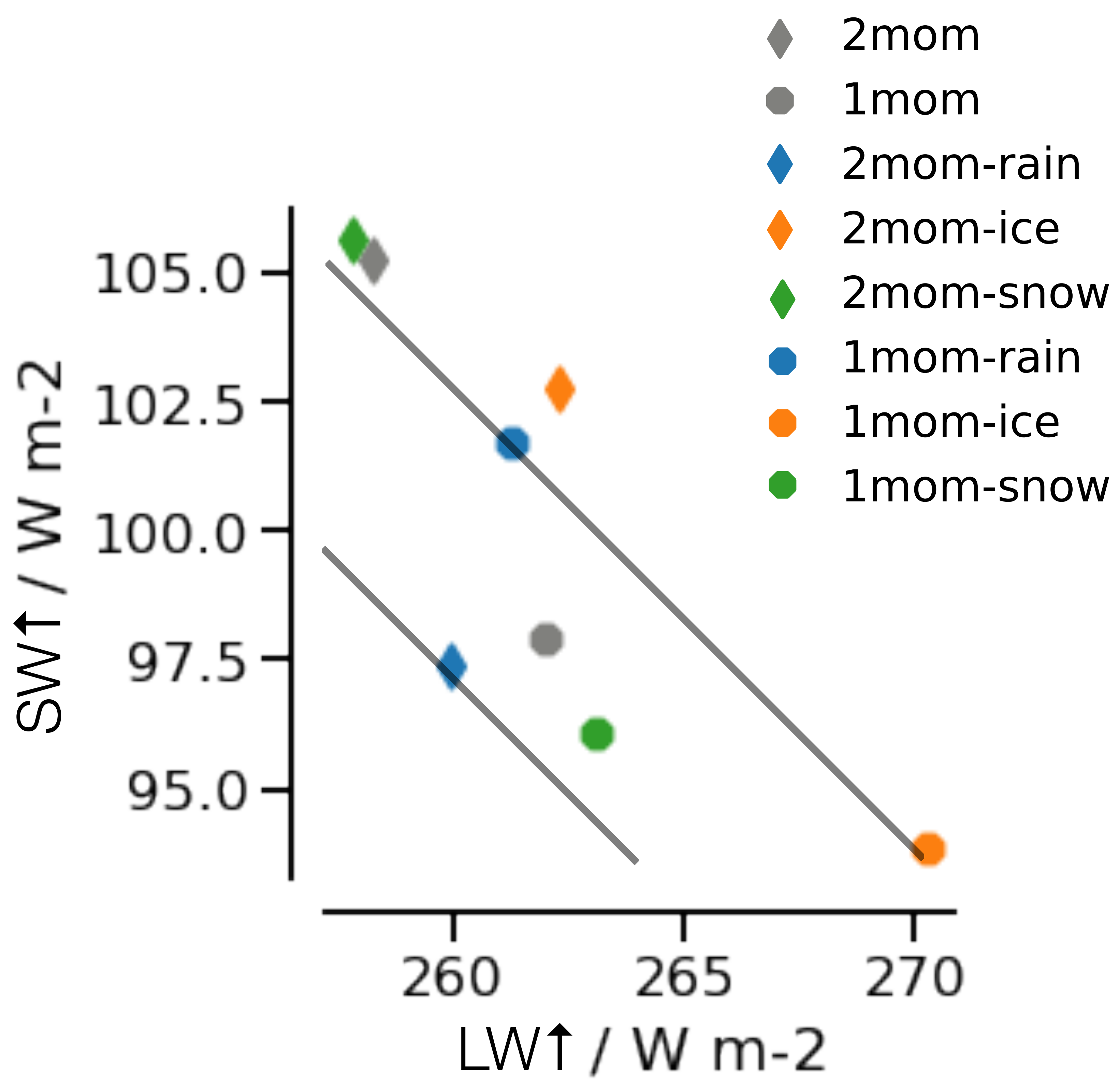
The two-moment scheme less easily converts ice to snow.

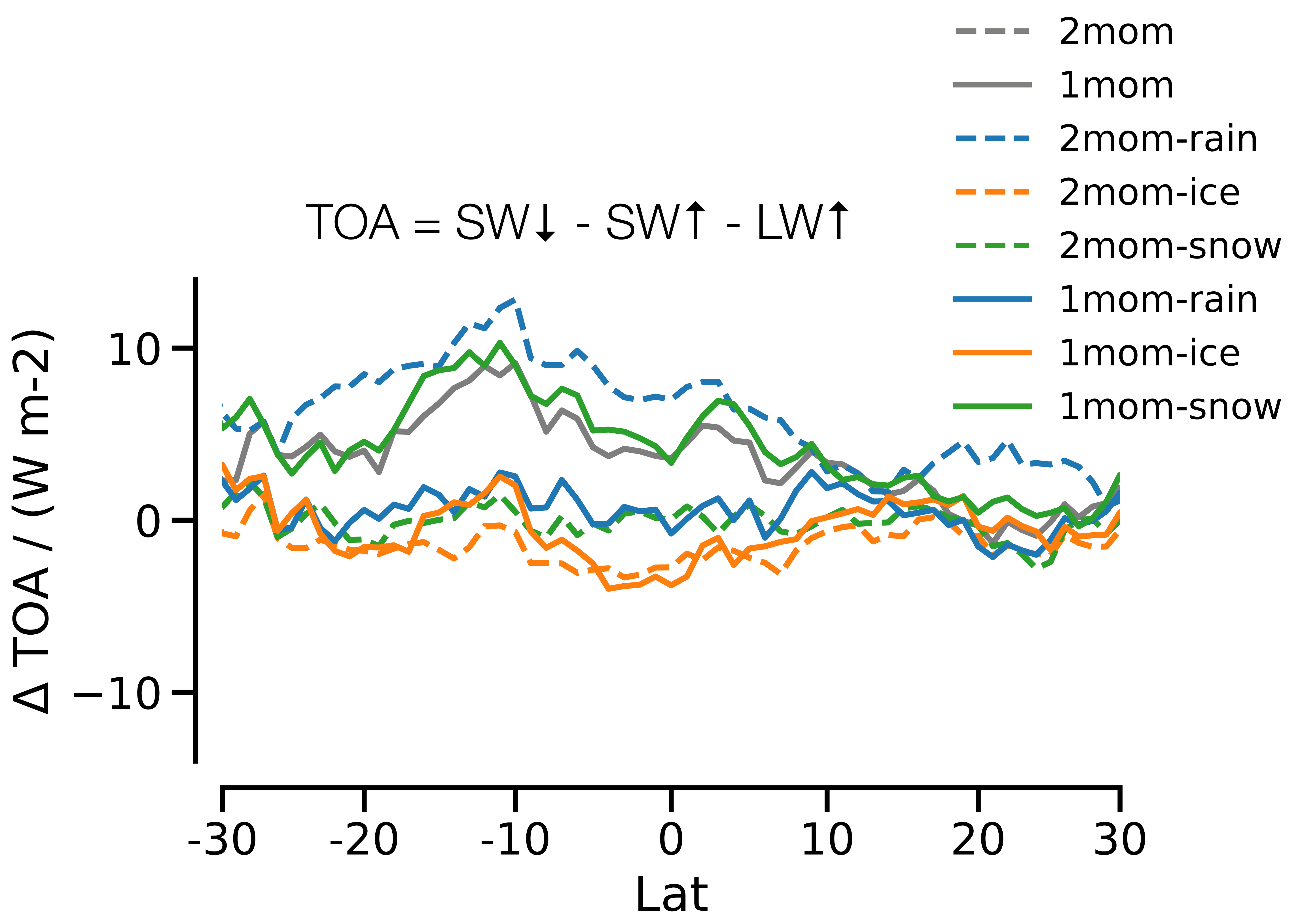
Cloud ice occurs in higher concentrations and is less effectively converted to snow in the 2-moment scheme

We expect an effect on the heat budget because in ICON ice is radiatively active while snow is not.

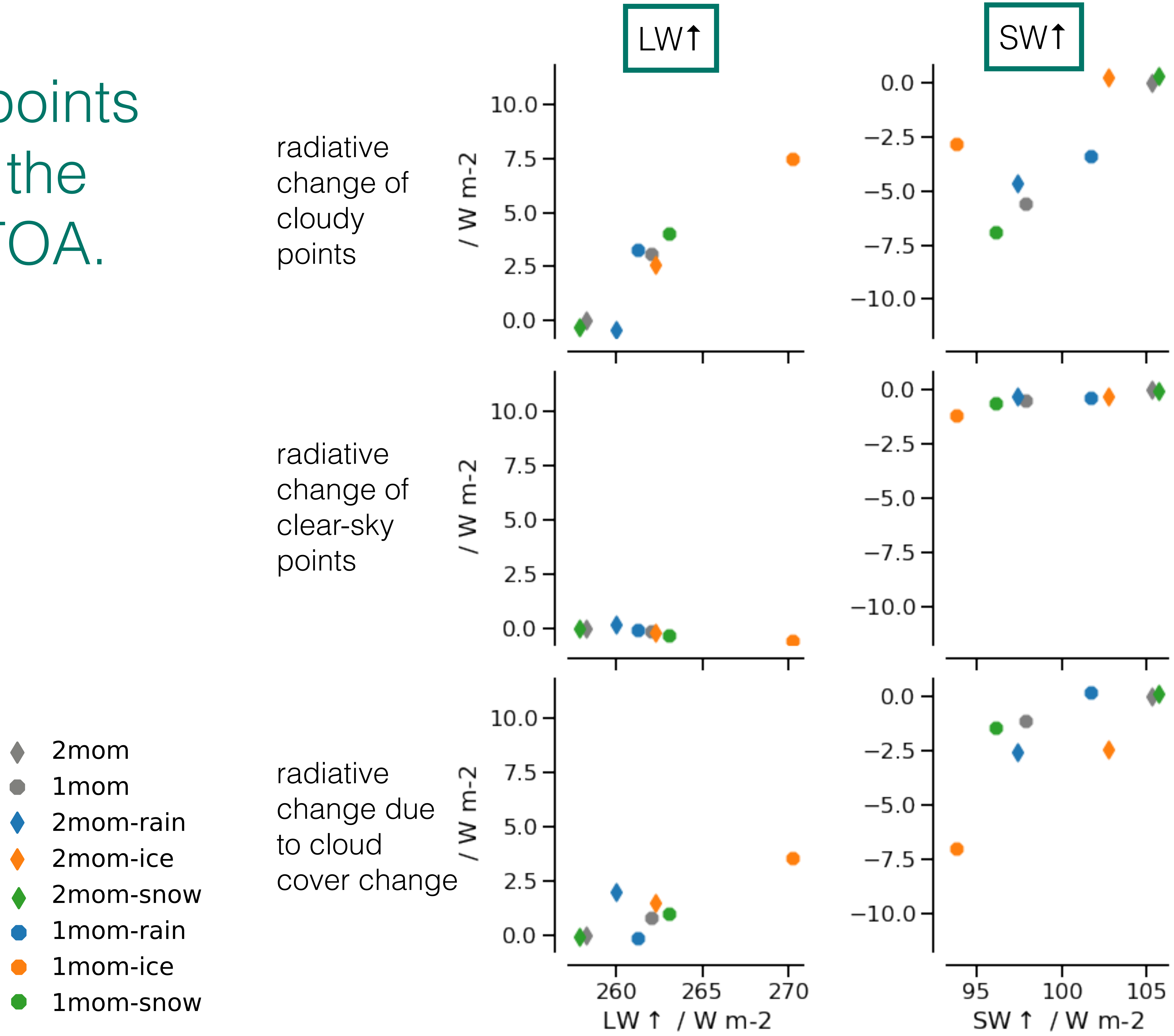


While microphysical effects largely balance for the net top-of-atmosphere (TOA) flux, differences of a few W m^{-2} remain.





Changes in radiative properties of cloudy points dominate changes in the radiative balance at TOA.



Microphysical controls on humidity, radiation and the tropical energy budget in global storm-resolving models

- The inter-model spread in humidity is substantially reduced in GSRMs compared to traditional GCMs. Clear-sky radiative effect of remaining differences are large adjacent to deep convection and in the dry subsidence regions.

- Differences in the mid-tropospheric humidity distribution are mainly related to changes in the temperature at the last point of saturation. Microphysical choices also affect the sources and sinks along a parcel trajectory.

- Tropical cloud cover and total condensate are robust to changes in microphysical parameters but a shift from ice to snow affects the radiative properties of cloudy grid points.