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Control of Tropical Stability and Relative Humidity in Radiative-Convective Equilibrium Simulations

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Radiative-convective equilibrium is the simplest possible way to phrase many questions about a deep-convecting atmosphere and is accessible by a wide range of model types. The radiative-convective equilibrium project (RCEMIP) provides a common configuration, but reveals a large spread in the simulated climate across models, including profiles of temperature and relative humidity. Here we use simple models and theory to understand the intermodel spread in CAPE, relative humidity, and their responses to warming.

Across the RCEMIP ensemble, temperature profiles are systematically cooler than a moist adiabat, consistent with theory that they are set by dilute ascent. As horizontal grid spacing is reduced in models with explicit convection from 1 km to 200 m, CAPE and relative humidity increase. Across all models, CAPE increases with warming at a rate (14-19%/K) greater than that expected from the Clausius-Clapeyron relation. We find that there is higher CAPE (greater instability) in models that are on average moister in the mid-troposphere, which is consistent with the simple plume model of Romps (2016) in which both instability and relative humidity depend on entrainment and precipitation efficiency. The sign of the relationship suggests that differences in entrainment drive the intermodel spread. This relationship is true across both models with explicit and parameterized convection.

To more explicitly evaluate the drivers of the intermodel spread, we use the Romps (2016) model to diagnose theory-implied values of entrainment and precipitation efficiency given the simulated values of CAPE and relative humidity. We then decompose the the variability across models in CAPE and relative humidity (and their responses to warming) into contributions from entrainment, precipitation efficiency, and the depth of the convecting layer. Targeted microphysics parameter perturbation experiments with an individual cloud-resolving model in which precipitation efficiency is varied and explicitly diagnosed provide proof of concept for this decomposition technique.