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Convective aggregation in idealized stochastic models

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Numerical simulations of radiative-convective equilibrium in high-resolution cloud-resolving models (CRMs) revealed the tendency of atmospheric convection to self-aggregate on periods of several weeks when the domain is sufficiently large. Nevertheless, even though CRM simulations manage to identify some of the physical mechanisms driving convective clustering, the occurrence of organization seems to be dependent on the model setup, physics and parameterizations. Robust findings from simpler, idealized models, which may reproduce some of the features of the full-physics systems, are thus beneficial to better understand the differences existing between CRMs.

To this end, we have developed a simplified two dimensional stochastic model able to predict the evolution of column total water relative humidity (CRH) in the tropical free troposphere. The model prognostic equation includes a convective moistening term, diffusive lateral transport and subsidence drying, similar to model of Craig and Mack (2013), but one novelty of the new model is that, instead of the convective moistening term as a smooth deterministic function of the background humidity, we treat convection as a point process and account for stochastic variability in the convective moistening process. Therefore the model allows experiments to use domain sizes and grid resolutions similar to those used for the idealized CRM experiments.

It is found that, depending on the chosen parameter settings, the simple model can reproduce equilibrium states of strong convective aggregation and also randomly distributed states, analogous to the CRM results. A sensitivity of the occurrence of self-organization to the initial conditions, i.e., a modest hysteresis, is also found, which also agrees with the full physics CRMs. Large ensembles of numerical experiments were performed for different values of the subsidence timescale, the moisture diffusion coefficient and the parameter that determines convective sensitivity to background humidity, as well as for a range of domain sizes and horizontal grid spacings. Using dimensional arguments, combined with empirical fits from numerical data, we define a dimensionless parameter whose value indicates whether a clustered state is likely to emerge for a given set of parameter values and experimental configurations. This quantity contains dependencies on all the model processes, while also explicitly including the domain size and resolution in an attempt to explain these latter sensitivities observed in the full-physics CRM experiments.