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Shallow cumuli ensemble statistics for development of a stochastic parameterization

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According to a conventional deterministic approach to the parameterization of moist convection in numerical atmospheric models, a given large scale forcing produces an unique response from the unresolved convective processes. This representation leaves out the small-scale variability of convection, as it is known from the empirical studies of deep and shallow convective cloud ensembles, there is a whole distribution of sub-grid states corresponding to the given large scale forcing. Moreover, this distribution gets broader with the increasing model resolution. This behavior is also consistent with our theoretical understanding of a coarse-grained nonlinear system. We propose an approach to represent the variability of the unresolved shallow-convective states, including the dependence of the sub-grid states distribution spread and shape on the model horizontal resolution.

Starting from the Gibbs canonical ensemble theory, Craig and Cohen (2006) developed a theory for the fluctuations in a deep convective ensemble. The micro-states of a deep convective cloud ensemble are characterized by the cloud-base mass flux, which, according to the theory, is exponentially distributed (Boltzmann distribution). Following their work, we study the shallow cumulus ensemble statistics and the distribution of the cloud-base mass flux. We employ a Large-Eddy Simulation model (LES) and a cloud tracking algorithm, followed by a conditional sampling of clouds at the cloud base level, to retrieve the information about the individual cloud life cycles and the cloud ensemble as a whole. In the case of shallow cumulus cloud ensemble, the distribution of micro-states is a generalized exponential distribution.

Based on the empirical and theoretical findings, a stochastic model has been developed to simulate the shallow convective cloud ensemble and to test the convective ensemble theory. Stochastic model simulates a compound random process, with the number of convective elements drawn from a Poisson distribution, and cloud properties sub-sampled from a generalized ensemble distribution. We study the role of the different cloud subtypes in a shallow convective ensemble and how the diverse cloud properties and cloud lifetimes affect the system macro-state. To what extent does the cloud-base mass flux distribution deviate from the simple Boltzmann distribution and how does it affect the results from the stochastic model? Is the memory, provided by the finite lifetime of individual clouds, of importance for the ensemble statistics? We also test for the minimal information given as an input to the stochastic model, able to reproduce the ensemble mean statistics and the variability in a convective ensemble. An important property of the resulting distribution of the sub-grid convective states is its scale-adaptivity - the smaller the grid-size, the broader the compound distribution of the sub-grid states.