A new bulk model for a boundary layer coupled to convection, the probabilistic bulk convection model (PBCM), is presented. Unlike prior bulk approaches that have relied on top of the mixed layer entrainment rates modeled as a constant fraction β of the surface buoyancy flux, PBCM implements a new closure based on an ensemble of plumes and the corresponding (dry and moist) mass flux of plumes coming from the surface.

Evaluating the model against observed clear-sky reference θ and q-profiles from the Southern Great Plains Atmospheric Radiation Measurement Climate Research Facility shows PBCM performs better than typical constant-β formulations. In particular, the height, state and timing of the boundary layer is improved. Apart from allowing time-dependent entrainment rates and casting the closure in terms of surface properties that can be readily observed in situ, PBCM naturally takes into account the transition to a shallow convection regime. Thus, the model represents an important step towards a unified framework bridging parameterizations of mixed layer entrainment rates in both clear-sky and moist convective boundary layers.

As in the clear-sky case presented previously, the evolution of the shallow convection PBCM is based on the statistical distribution of the plumes' surface thermodynamic state (potential temperature and specific humidity), with the entrainment velocity of the mixed layer directly related to the surface variability. The cloud base mass flux is obtained explicitly by integrating the surface distribution over the uppermost buoyant updrafts, with potential temperature above a threshold value. Significantly, the mass flux reduces the entrainment rate both directly, by reducing the number of updrafts contributing to the growth of the mixed layer, and indirectly, by inducing compensating subsidence on top of the mixed layer. Comparisons of PBCM cloud base, cloud top heights, cloud cover and cloud base mass flux against observations from the Southern Great Plains Atmospheric Radiation Measurement (ARM) Climate Research Facility and large eddy simulations demonstrate favorable agreement.

Given the relative simplicity and transparency of PBCM, we suggest that the model can be a powerful tool for developing process-based understanding and intuition about the physical processes involved in land surface-boundary layer-convection interactions.