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Evaluating shallow-cumulus entrainment retrievals using large-eddy simulation

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A quantitative understanding of cumulus entrainment remains elusive, in part due to the difficulty of directly observing cumulus entrainment rates. To overcome this challenge, multiple retrievals of bulk fractional cumulus entrainment rates have been recently developed, which rely on the unique data available from US Department of Energy Atmospheric Radiation Measurement (ARM) climate research sites. Among these retrievals are the parcel-based method by Jensen and Del Genio (2006), the iterative Entrainment Rate in Cumulus Algorithm (ERICA; Wagner et al. 2013) and a new approach based on turbulent-kinetic-energy (TKE) similarity theory. To provide a first-ever numerical verification of these methods, large-eddy simulations (LES) of a broad range of continental and maritime shallow cumulus convection cases are used as Observing System Simulation Experiments (OSSEs). From these simulations, simulated entrainment retrievals are performed and compared directly to bulk diagnosed entrainment rates. As a first step, we assume that all quantities used in the retrievals are perfectly observable, and evaluate these quantities over the full LES model grid. This evaluation reveals a mean error estimate for the different retrieval methods ranging from 23 to 60%. For the best-performing method, subsequent retrievals are performed that relax the assumption of complete data coverage. To this end, the simulated observations are restricted to fixed vertical profiles within the model domain, to better represent ARM profiling observations (e.g., Lidar and cloud radar). A question of particular interest is the extent to which entrainment rates retrieved from time-height sections at one or more grid points (each representing observations from a profiling Lidar or cloud radar) match the original retrievals over the full LES domain. Even for 10 randomly located profiling sites, which substantially exceed current observational capacity, the uncertainties in the retrievals are of the same order as the entrainment rates themselves. Thus, a major enhancement in observational infrastructure may be required to accurately retrieve bulk entrainment rates for a mesoscale cloud field.