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On Lagrangian stochastic condensation models in turbulent cloud simulations

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Turbulent clouds are challenging to model and simulate due to uncertainties in microphysical processes occurring at unresolved subgrid scales (SGS). These processes include the transport of cloud particles, supersaturation fluctuations, turbulent mixing, and the resulting stochastic droplet activation and growth by condensation. In this work, we apply two different Lagrangian stochastic schemes to model SGS of cloud microphysics. Collision and coalescence of droplets are not considered. Cloud droplets and unactivated cloud condensation nuclei (CCN) are described by Lagrangian particles (superdroplets). The first microphysical scheme directly models the supersaturation fluctuations experienced by each Lagrangian superdroplet as it moves with the air flow. Supersaturation fluctuations are driven by turbulent fluctuations of the droplet vertical velocity through the adiabatic cooling/warming effect. A second more elaborate scheme uses both temperature and vapor mixing ratio as stochastic attributes attached to each superdroplet. It is based on the probability density function formalism that provides a consistent Eulerian-Lagrangian formulation of scalar transport in a turbulent flow. Both stochastic microphysical schemes are tested in a synthetic turbulent-like cloud flow that mimics a stratocumulus topped boundary layer. It is shown that SGS turbulence plays a key role in broadening the droplet-size distribution towards larger sizes. Also, the feedback on water vapor of stochastically activated droplets buffers the variations of the mean supersaturation driven the resolved transport. This extends the distance over which entrained CNN are activated inside the cloud layer and produces multimodal droplet-size distributions. Finally, our simulations suggest that stochastic Lagrangian SGS models may expand the ability of Large Eddy Simulations to represent cloud-top entrainment and associated microphysical details at cloud top.