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Tests of the bulk cloud microphysics parameterizations in the detailed explicit cloud model

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Bulk cloud microphysics parameterizations for autoconversion, accretion and sedimentation processes proposed by Kessler (K, 1969), Beheng (B, 1994) and Khairoutdinov and Kogan (KK, 2000) are presently tested at UHMI against a 1D explicit (bin, drop spectrum resolving) microphysical model. The model includes droplet nucleation on activated CCN, their condensational growth up to the radius which separates droplets from drops (25 μm in this study) that grow further by collision-coalescence with droplets. We consider a geometric sweep-out collection kernel with variable size-dependent collision efficiency based on the experimental and theoretical works of Langmuir and do not account for self-collection neither for droplets nor for drops. Rates of autoconversion (colliding of two droplets to produce a drop), accretion (colliding of a drop with droplets) and sedimentation of drops (their number concentration and LWC) are calculated both with the 1D explicit microphysical model directly and with current bulk cloud parameterizations. Overall, a set of thousands spectra are generated over a typical range of thermodynamic conditions in STBL.

The dynamical forcing of the 1D model is derived from 3D numerical simulations of a marine cloudy boundary layer performed with the Meso-NH model in its LES configuration, by selecting a typical convective cell in the simulation, and averaging over its area. A 1D simulation is then performed with a 10 m vertical resolution, a time step of 0.2 s, 100 size classes for the droplets (class width of 0.25 μm), and 300 classes for the drops (class width of 1 μm). Different number concentrations of cloud droplets are tested from N_c = 1 to 1000 cm^{-3}).

As far as the autoconversion process is concerned the best agreement between the bin and bulk formulations is obtained with N_c in the range 50 – 100 cm^{-3}, LWC

= 0.3 – 0.6 g/m^3 , which correspond to a mean volume radius r_{vc} in the range 11 – 14 μm. At higher number concentrations ($>$ 100 cm^{-3}) and lower LWC ($<$ 0.1 g/m^3) (with corresponding smaller r_{vc}) the bulk autoconversion is more efficient than the bin; while for r_{vc} $>$ 15 μm (N_c $<$ 50 cm^{-3}) the bin autoconversion rate is slightly larger. For low concentration cases the bin rates usually exceed the bulk ones after 20 min of cloud development due to the preexistence of bigger droplets, even at r_{vc} = 11 – 14 μm. Generally, autoconversion rates calculated in the bin model for the above conditions are more close to the Beheng's formulation, probably because we use the same definition of autoconversion process without self-collection for droplets.

Results for the accretion rates show a good agreement between the bin and bulk formulations, particularly the KK one. Exceptions are observed after the first 20 min of cloud development in the low concentration case when a second mode in the drop spectrum appears at radii $>$ 200 μm. In this case the bin accretion rates are larger than the bulk ones.

Sedimentation rates are compared with the KK formulation and generally the best agreement with the bin calculation is obtained for the sedimentation rate of drop number concentration. Fall velocities for LWC in the bin show a larger dispersion. The discrepancies between the bin and KK sedimentation rates can be attributed to the linear approximations proposed in KK for a definitely nonlinear process. Based on the results of our simulations for drizzling Sc we propose a new nonlinear formulation for the bulk sedimentation parameterization.