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Modeling the transition from the aerosol- to the updraft-limited cloud droplet susceptibility regime in large-eddy simulations with bulk microphysics

Matthias Schwarz[1,99], Julien Savre[2], Dipu Sudhakar[3], Johannes Quaas[3], and Annica M. L. Ekman[1]
[1]Stockholm University, Department of Meteorology, Stockholm, Sweden (matthias.schwarz@misu.su.se)
[2]Meteorological institute, Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, German
[3]University of Leipzig, Institute for Meteorology, Leipzig, Germany
[99]now at: Central Institute for Meteorology and Geodynamics (ZAMG), Climate Research, Vienna, Austria

As large-eddy simulations (LES), which explicitly simulate aerosol-cloud interactions, are often considered as benchmark simulations in climate science, it is necessary to critically evaluate if these high-resolution models can skillfully represent expected physical phenomena.

Here, we focus on the first aerosol indirect aerosol effect in a warm stratocumulus cloud. We investigate if the MIMICA LES (Savre et al., 2014) with a widely used bulk two-moment microphysical scheme (Seifert and Beheng, 2006) can reproduce the susceptibility regimes identified by Reutter et al., (2009). Using a parcel model, Reutter et al. (2009) showed that the cloud droplet number (N_d) responds differently to an increase in aerosol number (N_a) depending on ambient updraft strength (w). In the aerosol-limited regime, enough supersaturation can be generated by the updraft motions in the atmosphere so that increasing N_a leads to an increase in N_d. Conversely, in the updraft-limited regime, adding aerosol will not increase as activation is limited by the updraft strength and only increasing w will lead to an increase in N_a.

In the standard setup, the LES cannot simulate the transition from the aerosol- to the updraft-limited regime. Only when implementing a renormalization procedure following Reisin et al., (1996) and, at the same time, increasing the initial droplet radius of newly activated droplets (r_d^i) to values large than r_d^i>1μm, a regime transition emerges. However, a clear recommendation for the choice of r_d^i cannot be made upon physical arguments at this point. Interestingly, the “arbitrarily chosen” droplet mass by Seifert and Beheng (2006) of $1*10^{-12}$kg, which corresponds to r_d^i≈6μm, seems to agree quite well with the expectations from parcel model simulations. The choice is, however, still arbitrary and therefore physically questionable.

A potential way to avoid this problem, which mainly occurs at high aerosol concentrations, would be to run the LES with a small enough temporal resolution (Δt≈0.1s) to explicitly resolve all relevant microphysical processes.

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