Improving the Representation of Aerosol-Cloud-Precipitation Interactions in Numerical Models

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Introduction

Accurately representing aerosol indirect effects in large-scale numerical models requires microphysical parameterizations that treat complex aerosol-cloud-precipitation interactions in a realistic manner.

Here we address two important aspects of these microphysical interactions:

1. Development of a new parameterization of giant cloud condensation nuclei (CCN) for use in bulk microphysical models;

2. Aspects of droplet nucleation revealed by 3D large eddy simulation (LES) results but not captured by nucleation schemes based on simple empirical relations or 1D parcel models

Giant CCN (GCCN) Parameterization

A new GCCN parameterization based on first principles uses precise representations of the condensational growth of aerosol particles in the subcloud layer. Total concentration (*Ng*) and the exponent (α) of a Junge power law distribution constitute specification of the GCCN properties. A source term follows, which can be incorporated into the prognostic rainwater equation of bulk microphysical models,

$$\frac{dq_g}{dt} = 9.82 \times 10^{-7} \frac{\alpha}{\alpha - 2.358} \frac{dN_g}{dt},$$

where *Ng* is expressed in (cm^{-3}) and q_g in (g g^{-1} s^{-1}). Upon saturation, all GCCN are assumed to nucleate droplets.

Preliminary tests use an LES framework under clean and polluted conditions (ASTEX A209 case). GCCN are specified as an initial value problem with domain-uniform concentrations of 30, 300, and

1360 L^{-1} (corresponding to the O'Dowd et al. [1997] "jet" mode at 10 m s^{-1}). The polluted simulations show the greatest sensitivity to GCCN. Compared to the control case, increasing amounts of GCCN produce the expected response of depleted droplet concentrations, reduced liquid water, increased drizzle, and the tendency of the PBL circulation to decouple (Figure 1).

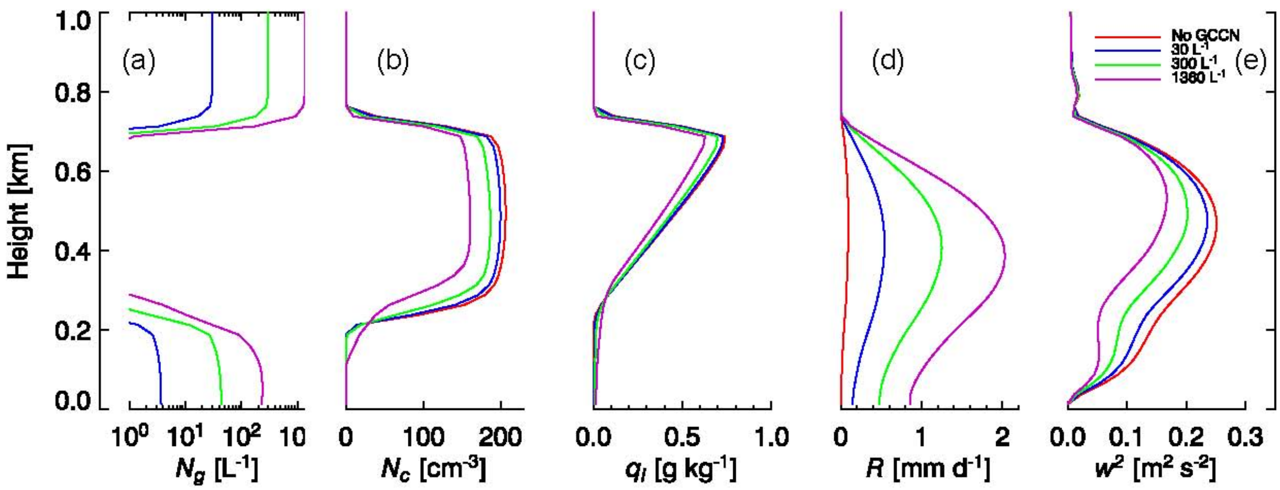

Figure 1. Hourly mean profiles (1-2 h) of LES quantities for the polluted simulation series. Each profile corresponds to a GCCN concentration specified in the initial value problem. (a) GCCN concentration; (b) cloud droplet concentration; (c) liquid water mixing ratio; (d) drizzle rate; (e) vertical velocity variance.

The influence of GCCN on cloud radiative properties (Figure 2) varies with GCCN concentration and the background aerosol load. GCCN has little effect for an already drizzling cloud (clean case) but significantly impacts optical depth and albedo in the polluted cases. Relative susceptibility best illustrates the sensitivity to GCCN in the polluted simulations.

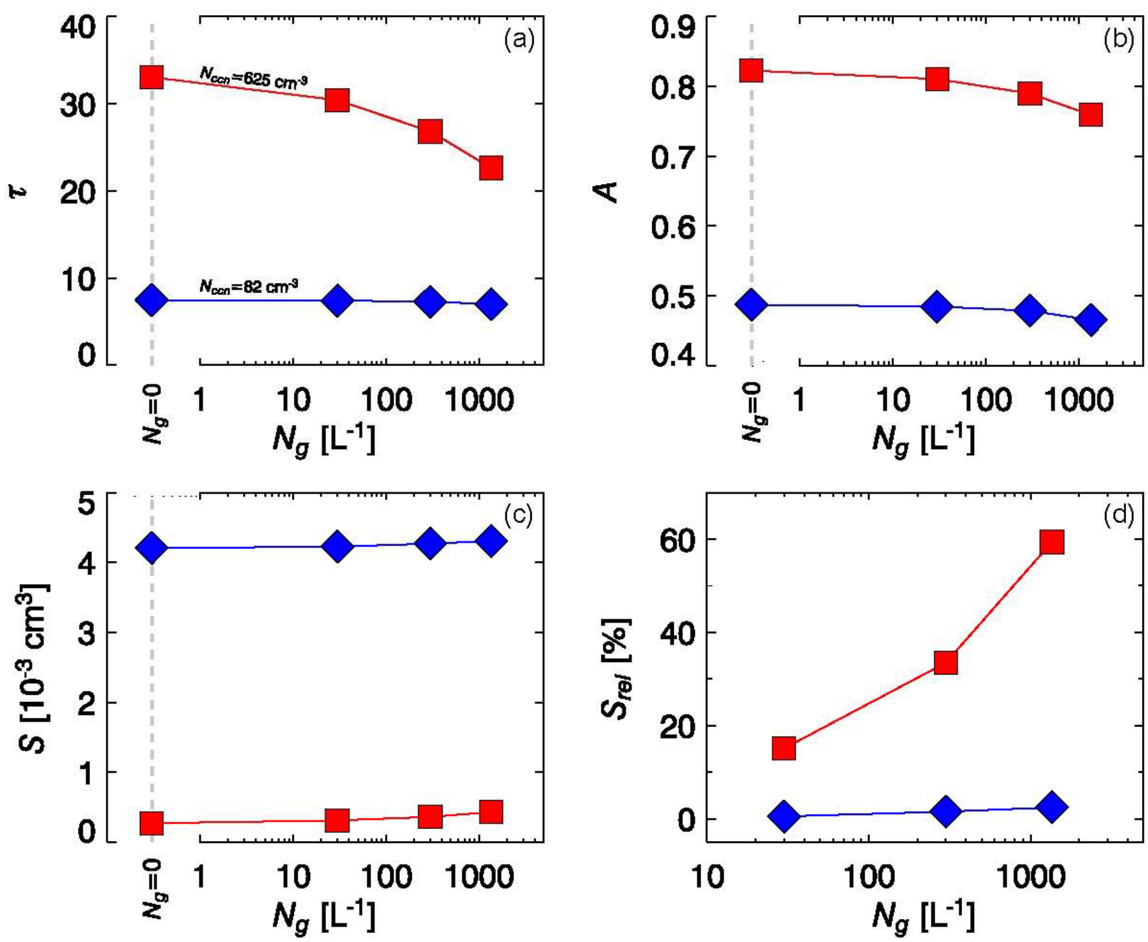

Figure 2. Hourly domain-mean calculations (2-3 h) of radiative quantities for clean (blue) and polluted (red) simulation series. (a) Optical depth; (b) albedo; (c) susceptibly (*A*[*1-A*]/[*3N*]); (d) susceptibility relative to the control runs without GCCN.

Three-Dimensional Aspects of Droplet Nucleation

Classical theory predicts that all aerosol activation occurs at cloud base, where supersaturation is a maximum. LES results employing size-resolved microphysics exhibit deep regions of supersaturation in which droplet nucleation can occur continuously with height. The peak in droplet concentration in Figure 3, for example, is well above cloud base. Regions of in-cloud convergence near updraft boundaries (Figure 3, bottom panel) imply that previously non-activated aerosol are being entrained laterally into updrafts and activated. Entrainment of free tropospheric aerosol appears to be the primary source for these in-cloud CCN. Figure 4 suggests that all regions of supersaturation, not only those at cloud base, are important in droplet nucleation.

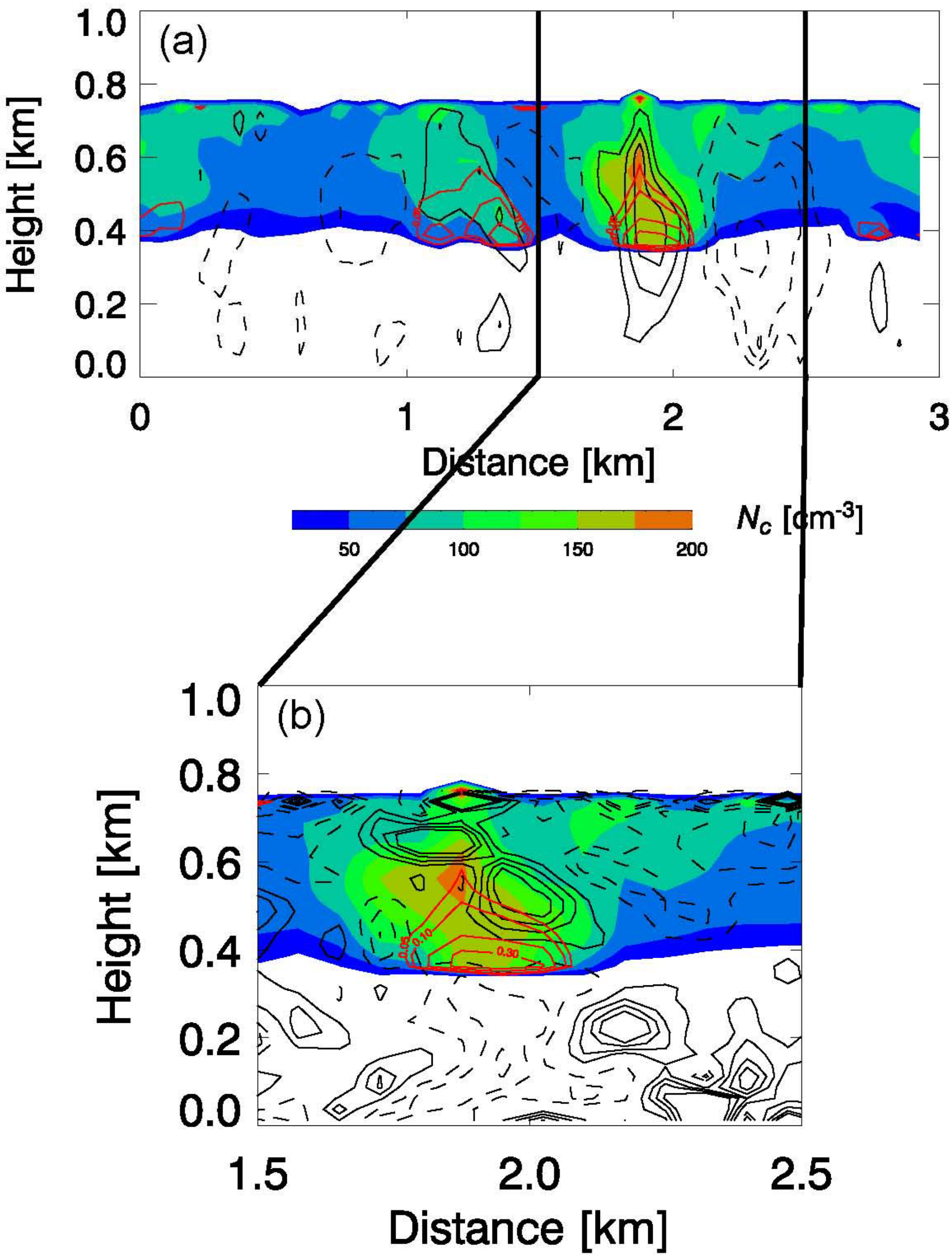

Figure 3. Vertical cross sections of LES results. (a) Droplet concentration (color-filled contours), supersaturation (red contours; values of 0.5, 0.1, 0.2, and 0.3%), and vertical velocity (black contours with an interval of 0.5 m s^{-1}; negative values dashed); (b) droplet concentration and horizontal convergence (black contours with an interval of 2.5 x 10^{-3} s^{-1}; negative vales dashed).

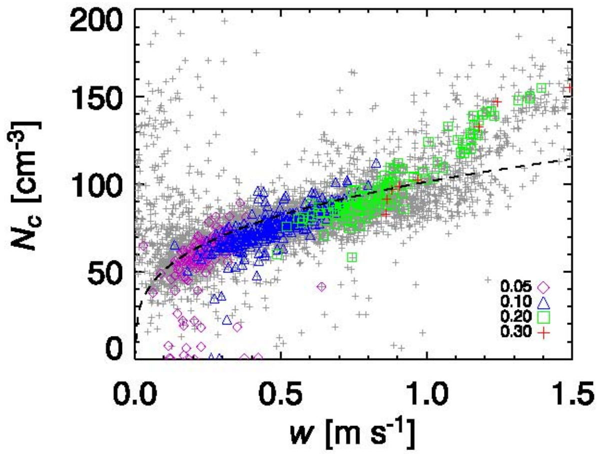

Figure 4. Scatterplot of cloud base droplet concentration as a function of updraft magnitude, stratified by supersaturation (%) according to color and symbol. Gray marks represent all regions of supersaturation. Dashed curve represents a power law fit of $109.9w^{0.459}$.

Conclusions

- The behavior of a new parameterization of GCCN tested in an LES framework is consistent with previous simulations using explicit spectral microphysical methods (e.g. Feingold et al. 1999). Microphysical and cloud optical properties exhibit the greatest sensitivity to the addition of GCCN when the background aerosol concentration is high.

- Removal of GCCN by cloud processing in a few eddy turnover timescales implies the importance of accurately specifying the GCCN source (e.g. flux or concentration of sea salt at the lower boundary). Specifying a constant surface GCCN concentration (boundary value problem) produces similar, though more subtle, results. Longer integrations become necessary to "spin-up" the turbulent transport of GCCN from the surface up to the cloud layer. The source and sink rates are such that the profiles of subcloud GCCN become nearly invariant over time.

- All regions of supersaturation, including those inside the cloud, represent the droplet nucleation zone more completely than simply peak regions of supersaturation at cloud base.

- Since nucleation does not occur uniformly but rather only in supersaturated updrafts, the number of CCN activated should be considered an upper bound on grid-mean droplet concentration.

Acknowledgments

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