Development of a Scheme for Parameterizing the Effects of Cloud Condensation Nuclei on Stratocumulus Cloud Albedo

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Introduction

The goal of this research is to develop a scheme for parameterizing the effects of varying concentrations of cloud condensation nuclei (CCN) on stratocumulus cloud albedo for use in global climate models.

The challenges in achieving this goal are

- CCNs are not a horizontally and vertically uniform species, but vary depending upon differential horizontal advection of differing CCN sources and upon local conditions (e.g., CCN formation by gas-to-particle conversion and cloud removal). CCNs are probably as variable as water vapor.
- The peak supersaturations that determine the activation of CCN and resultant aerosol and cloud droplet distributions are a function of cloud updraft and downdrafts on scales of a few hundred meters with magnitudes of a few meters per second. These scales cannot be represented properly either with large-scale grid-resolvable ascent rates of the order of 0.01 m/s or by eddy diffusion models.
- Cloud albedo is a strong function of the cloud macrostructure (holes, hills, troughs in cloud structure) and of the liquid water paths and aerosol/hydrometeor spectra.
- The aerosol/hydrometeor spectra, in turn, are not only a function of nucleation of cloud droplets at cloud base on resident CCN in the atmospheric boundary layer (ABL), but also the entrainment of CCN from above the capping inversion and the formation of drizzle. (Entrainment is one of the most difficult processes to model in the cloud-topped boundary layer [CTBL]).
- Drizzle formation is a complicated function of the CCN spectra, especially giant and ultra-giant aerosol, cloud liquid water contents, mixing processes, and the time scales of cloud drafts which are determined by the strengths and depths of cloud drafts.

Approach

Our approach is to produce large eddy simulations (LES) or cloud-resolving models (CRMs) of marine stratocumulus clouds including the use of bin-resolving aerosol and cloud microphysics. The model is designed to obtain an internally consistent coupling between stratocumulus cloud dynamics and cloud microphysics.

The simulations are performed for "generically" represented initial conditions for the First ISCCP[(a)] Regional Experiment (FIRE I) stratus case described by Betts and Boers (1990). The credibility of the simulations is evaluated by comparing them with observations performed during the case. Then detailed statistical analyses of model output data, including two-dimensional radiative transfer calculations, are performed. The control simulation is then perturbed to investigate the influence of changing CCN concentrations on cloud microstructure, macrostructure, and cloud albedo.

Model Design

The LES model is based on the nonhydrostatic version of the Regional Atmospheric Modeling System (RAMS) as set up for LES (Hadfield et al. 1991, 1992; Walko et al.

(a) International Satellite Cloud Climatology Project.

1992). The finite difference scheme in the original RAMS was modified to include a hybrid scheme—Leap Frog—for advection of winds and buoyancy terms and forward differencing for scalar terms. A six-order flux-corrected transport algorithm with peak preservers was found to be essential to obtain proper simulations of the transport of CCN and reasonable values of diagnosed supersaturations, particularly near cloud top and cloud base.

Condensation, collection, and evaporation of droplets is based on the two-moment discrete bin model of Tzivion et al. (1987); this model has been shown to have accuracy comparable to that of a single-moment bin model with two to three times the number of bins.

CCNs are simulated in a six-bin sectional model in which each bin is described in terms of the supersaturation activation of the aerosol. This approach avoids the necessity of describing the chemical properties of the CCN, which are generally of internally mixed chemical composition and are chemically heterogeneous across the aerosol spectrum.

Diagnostic radiation calculations are performed with the spherical harmonic spatial grid method of Evans (1993).

RAMS is set up with 25-m grid spacing in the vertical and 55-m grid spacing in the horizontal over a 3.025- by 3.025- by 2.25-km domain with cyclic lateral boundary conditions.

The Chen and Cotton (1983) cloud radiative parameterization is used, and a Smagorinsky-type subgrid turbulence closure is used with surface fluxes determined from similarity theory using Louis' (1979) scheme.

The model is initialized with a horizontally homogeneous aircraft sounding described by Betts and Boers (1990), and since CCN spectra were not observed on this day, CCN spectra from 6/29/87 obtained by Hudson and Frisbie (1991) for another FIRE case were used.

Summary of Results and Conclusions

- The simulated cellular pattern of the cloud field was consistent with satellite observations for the day.
- Cloud liquid water paths and mixing ratios were consistent with the observed properties of those clouds.
- Cloud effective radii ranged from 5-7 microns near cloud base to 12-13 microns near cloud top.
- Droplet concentrations above cloud base in the control simulation were about 100/cc, and no drizzle was simulated
- Introduction of a sixfold enhancement of CCN concentrations above the capping inversion (from large CCN concentrations of 100/cc to over 600/cc) resulted in a linear increase in subcloud CCN concentrations with time.
- One hour after the enhanced CCN had been introduced above the inversion, droplet concentrations increased by 40%, cloud top effective radii decreased by 14%, and albedo increased by 10%.
- Because both the control and the perturbed simulations were drizzle-free, there was no significant change in the dynamic or macroscopic structure of the cloud due to enhanced CCN concentrations.

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