NUMERICAL SIMULATIONS OF THE EFFECTS OF CLOUD CONDENSATION NUCLEI ON THUNDERSTORM INTENSITY AND EVOLUTION

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Introduction

The effect of aerosols on clouds and precipitation has been the subject of many studies, especially recently. Twomey (1977) suggested that an increase in cloud condensation nuclei (CCN) results in more numerous cloud droplets, and Albrecht (1989) showed that such conditions may lead to a suppression of precipitation. An increase in small cloud droplets also tends to narrow the droplet size distribution, which in turn decreases the collision-coalescence efficiency, and can delay or even prevent the formation of precipitation-sized water droplets (e.g., Rosenfeld 1999).

Changes in cloud droplet distributions may have significant effects on the evolution of deep convection. Van den Heever et al. (2006) used the Regional Atmospheric Modeling System (RAMS) to test the sensitivity of convection to changes in CCN, giant CCN (GCCN), and ice forming nuclei (IFN). They found that, in general, updrafts were stronger as the concentrations of these particles were increased. Rainfall decreased with increasing CCN, but was heavier with more GCCN and IFN.
The goal of this study is to perform a very simple sensitivity test with RAMS by varying only initial CCN concentrations within a highly unstable environment. Resulting cloud water and ice concentrations, updraft strength, and rain rate will be compared.

Model Description and Experimental Design

RAMS is a non-hydrostatic 3-D cloud-resolving model, with explicit 2-moment bulk microphysics (Saleeby and Cotton 2004). The domain was set up on a 50-50 km grid, and has 1 km horizontal grid spacing and 100 m vertical grid spacing near the surface, stretching to a maximum of 500 m spacing. This version of RAMS microphysics package predicts the mass mixing ratio and number concentration of 7 hydrometeor types, as well as cloud water and "giant" cloud water. One can specify the initial concentration and distribution of CCN and GCCN (which serve as nuclei for giant cloud water). It is also possible to allow CCN and GCCN to be depleted and/or created by activation and evaporation, but for the current experiment, this source/sink option has been disabled since the goal is to test the model's sensitivity to initial concentrations of CCN.

The initial sounding used throughout the domain is characterized by a deep conditionally unstable layer, and is only slightly capped. Convective available potential energy (CAPE) is approximately 2750 J/kg, and the hodograph shows a linear shear profile from the surface to 10 km, with about 40 m/s of deep-layer shear. Given this environment, one would expect long-lived splitting supercells (Weisman and Klemp 1984). A warm bubble with a temperature perturbation of 2 ˚C was placed in the center of the domain.

GCCN initial concentrations were specified to be 0.001 cm-3 throughout the entire three-dimensional domain. Two experiments were performed, the first having initial CCN concentrations of 800 cm-3 (hereafter referred to as the "dirty" run), and the second having CCN concentrations of 100 cm-3 (hereafter referred to as the "clean" run). No attempt was made to match these values to observations. Instead, the goal was test the model's sensitivity to these initial concentrations, which vary by a factor of 8.

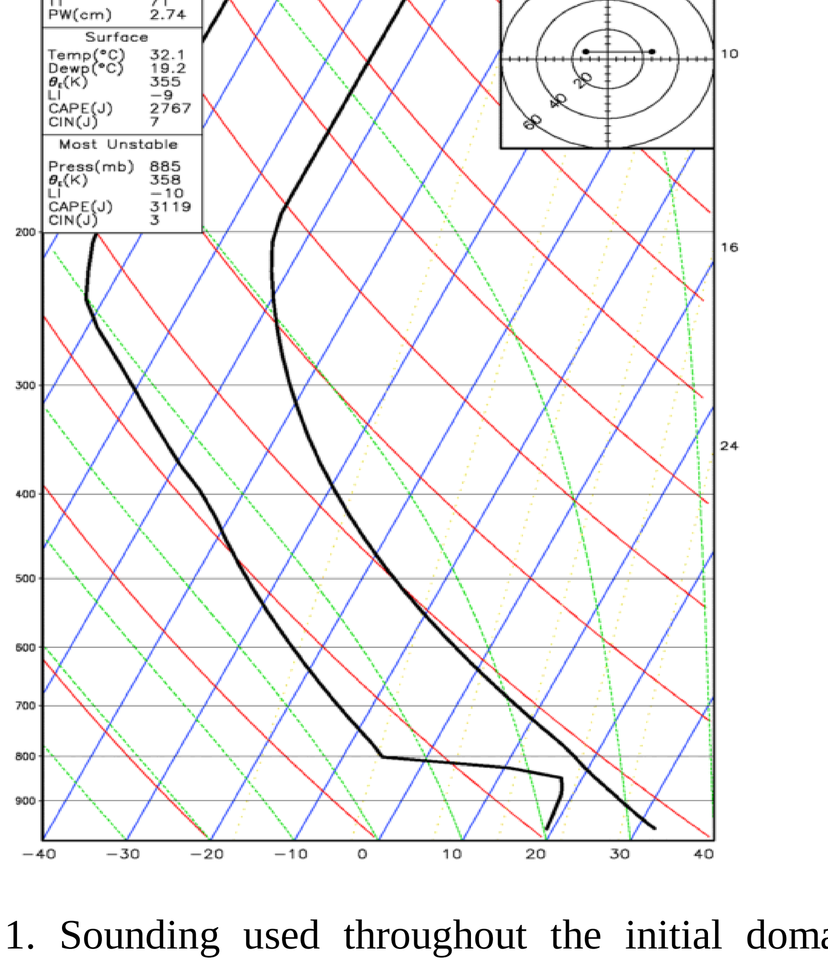

Fig. 1. Sounding used throughout the initial domain. Hodograph in the upper right corner shows the wind profile.

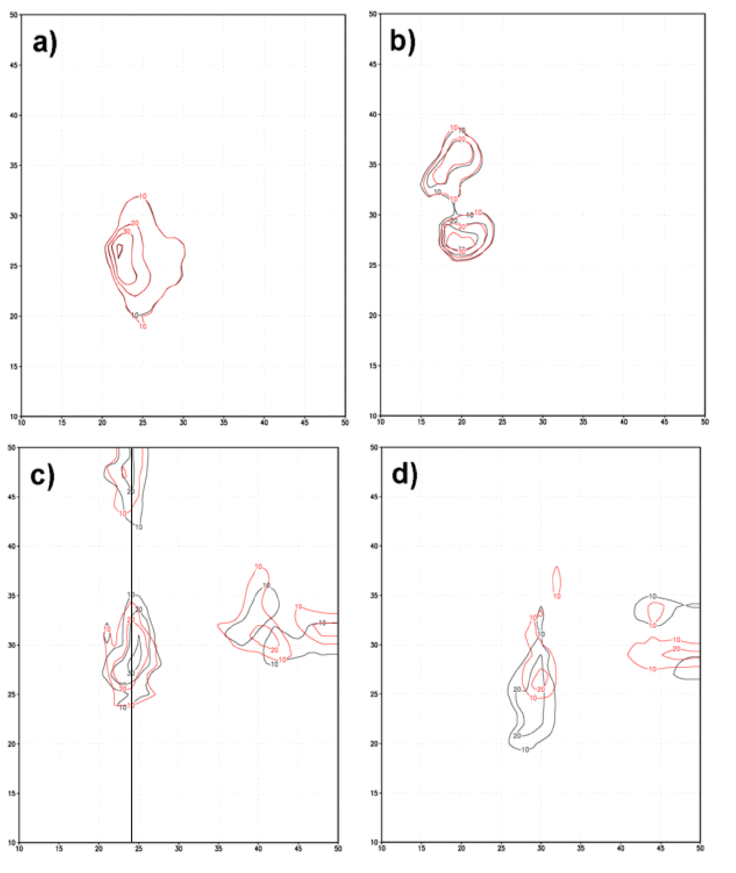

FIG. 2: Horizontal cross section of model updraft velocity (m/s) at z = 5.3 km, at a) t = 20 min, b) t = 45 min, c) t = 70 min, and d) t = 95 min. Horizontal axes have units of km. Black contours correspond to the dirty experiment, red contours to the clean run. The vertical black line in c) is the location of the vertical cross-section in the forthcoming figures.

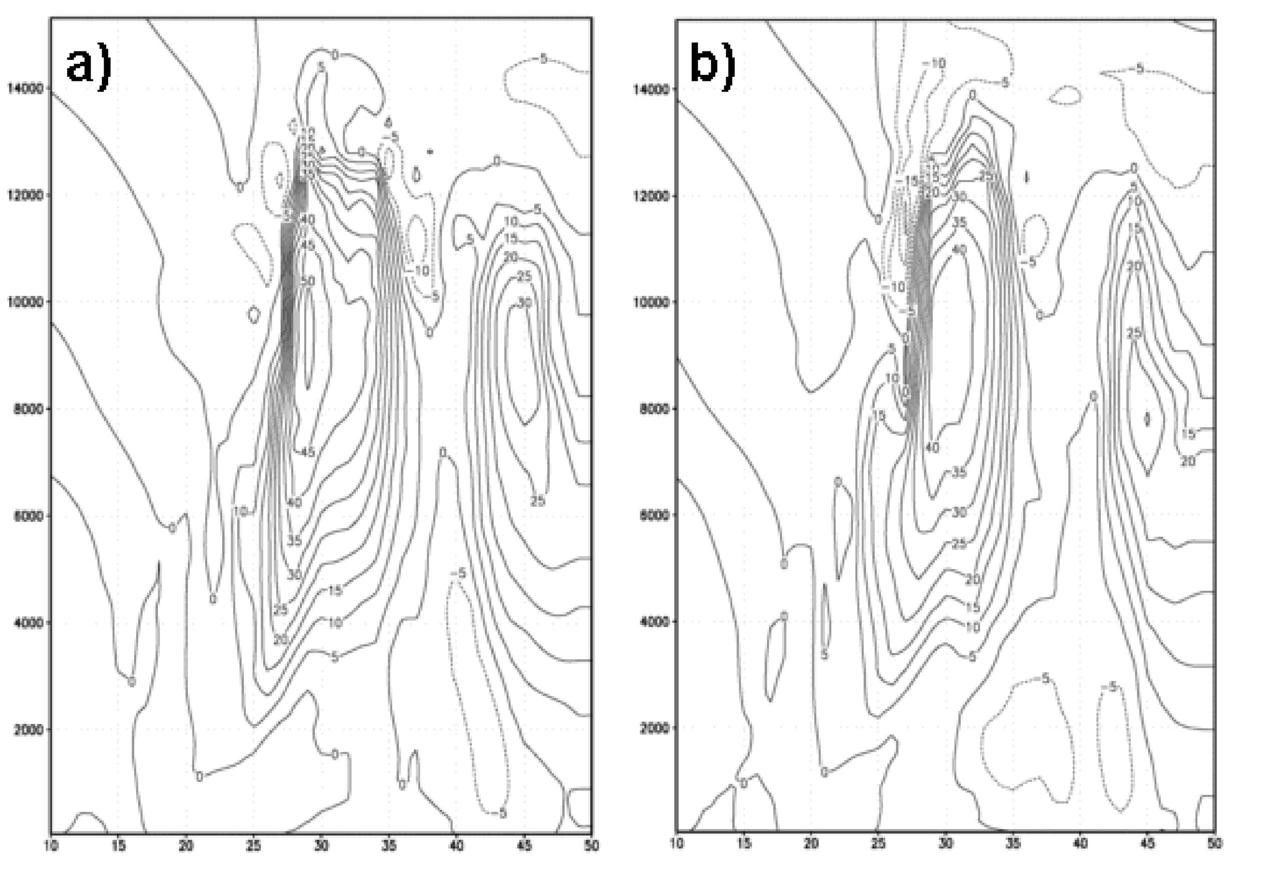

FIG. 3: Vertical cross-section at t = 70 min and Y = 24 km (from Fig. 2c) of vertical velocity (m/s), for a) the dirty run and b) the clean run. Vertical scale has units of meters, and horizontal scale has units of kilometers.

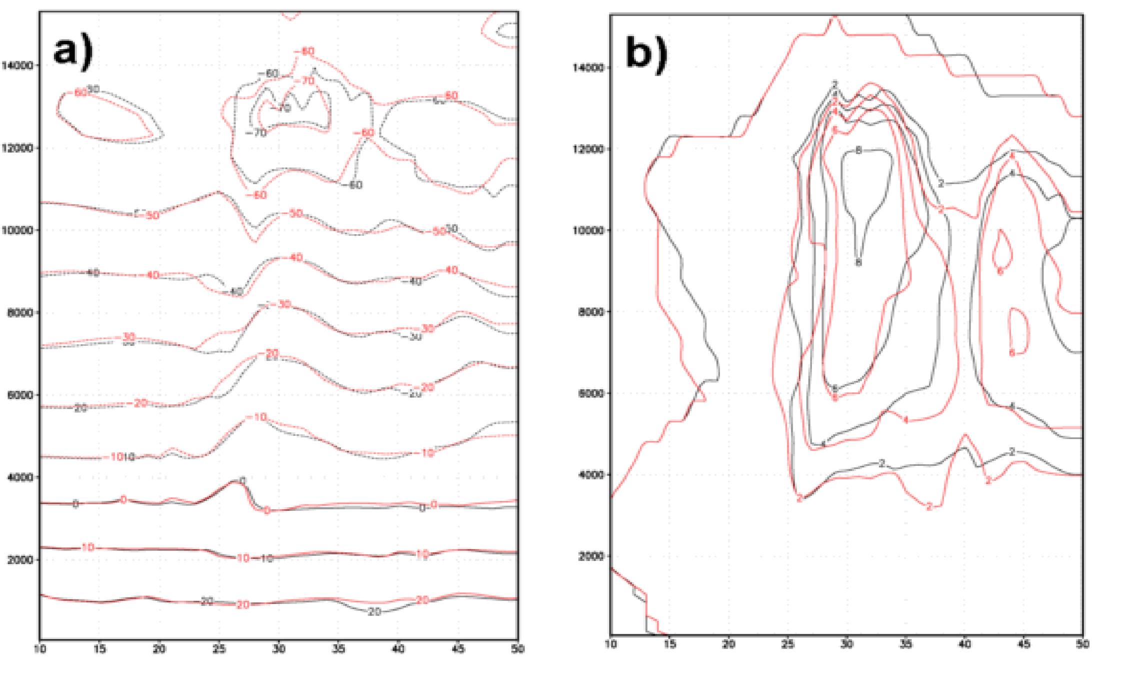

FIG. 4: Vertical cross-section at the same time and location as in Fig. 3. a) temperature (°C), and b) total condensate mass mixing ratio (g/kg). Black lines are for the dirty case and red lines for the clean case.

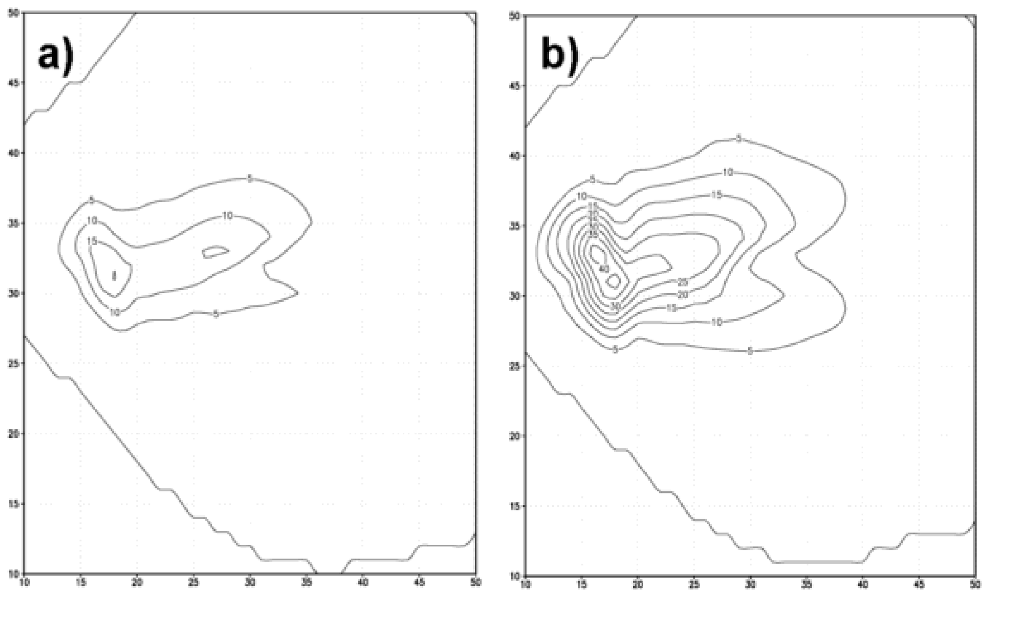

FIG. 5: Horizontal cross-section from t = 45 minutes showing the surface of rain rate (mm/hr) for a) the dirty case, and b) the clean case.

Results

- The temporal evolution of the clean and dirty simulations differs, especially at the later periods (Fig. 2)
- A comparison of the vertical cross sections of *w* show that the dirty run has a slightly stronger updraft core (Fig. 3)
- Reasons for the more intense updraft are not known, but Fig. 4 shows a comparison of the temperature and condensate mass for the clean and dirty runs
- Temperatures within the updraft near the homogeneous freezing level are slighty warmer in the dirty case, possibly due to the additional latent heat of freezing since more water mass is lofted to this level; this may partially explain the slightly stronger updraft
- Fig. 4b shows that the dirty case indeed has more ice mass near 11km – this would tend to weaken the updraft relative to the clean case
- The third term in the updraft tendency equation, vertical gradient in perturbation pressure, is not shown here due to the difficulty involved in extracting it from the results, so it could also be playing a role
- Fig. 5 shows a comparison of the rain rate for the two cases – as expected, the clean storm is raining at a rate about 3 times greater than the dirty storm; this is consistent with previous work

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