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

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I. 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.

II. 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.

III. Results and Conclusions

Fig. 1 shows the time evolution of the vertical velocity (w) at z = 5.3 km. After only 20 minutes (Fig. 1a), w exceeds 40 m/s, and the pattern and magnitude of vertical velocity is almost identical in both the dirty and clean runs. At t = 45 minutes (Fig. 1b), storm splitting has occurred and we begin to see some differences in the maximum updraft horizontal placement, even though the magnitude remains very similar for both cases. These magnitudes have decreased significantly as the effect of the initial warm bubble diminishes. By t = 70 minutes (Fig. 1c), the left mover has nearly exited the northern portion of the domain, while the right mover remains somewhat stationary (by design). New growth has also begun in the eastern portion of the domain, possibly in response to a surface cold pool. We will focus on the right mover. Significant differences in updraft speed can now be seen, with the dirty case having values over 30 m/s compared to 20 m/s in the clean case. At t = 95 minutes (Fig. 1d), the clean storm appears to be dissipating, while the dirty storm persists (at least in terms of midlevel updraft horizontal size).

In order to compare storm characteristics between the dirty and clean experiments, a north-south vertical cross-section was taken at Y = 24 and t = 70 min (see the line in Fig. 1c). Fig. 2 shows the cross-section of vertical velocity. It can now be seen that maximum updraft speeds are even larger at a higher altitude (around 10 km), with the dirty case (Fig. 2a) having values exceeding 50 m/s and the clean case (Fig. 2b) 40 m/s. This is a very intense thunderstorm, and is probably representative of only the *most* vigorous midlatitude convection.

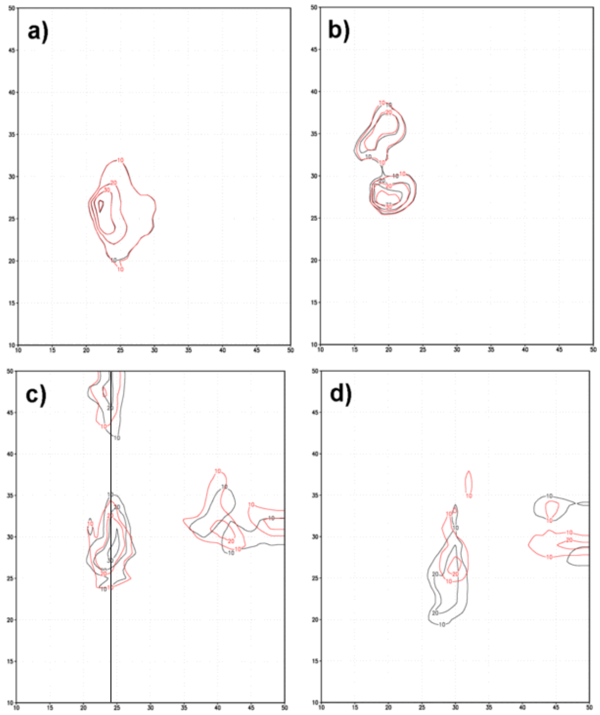

FIG. 1: Horizontal cross section of model updraft velocity (m/s) at z = 5.3 km, at a) t = 20 min, b) t = 45 min, c) t = 70 min, and d) t = 95 min. Horizontal axes have units of km. Black contours correspond to the dirty experiment, red contours to the clean run. The vertical black line in c) is the location of the vertical cross-section in the forthcoming figures.

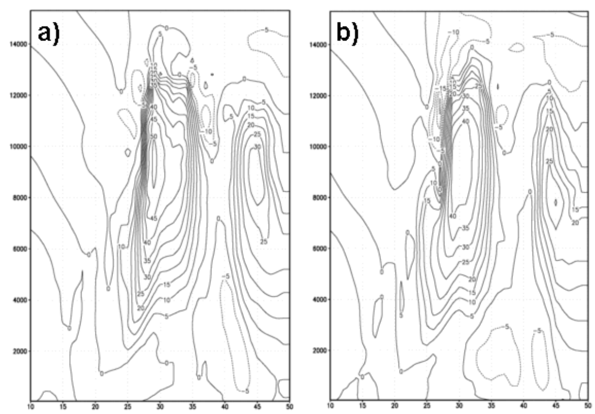

FIG. 2: Vertical cross-section at t = 70 min and Y = 24 km (from Fig. 2c) of vertical velocity (m/s), for a) the dirty run and b) the clean run. Vertical scale has units of meters, and horizontal scale has units of kilometers.

Additional model results will be presented in the full version of this paper. These include the evolution of the microphysics in each storm, such as a comparison of the cloud droplet number concentrations between the dirty and clean runs. We will also show a comparison of the rainrate in each storm to assess whether the model allows for dirtier environments to inhibit the precipitation process. Finally, a discussion will be provided on possible reasons for updraft differences between the dirty and clean experiments.

IV. AKNOWLEDGMENTS

The views, opinions, and findings in this report are those of the authors, and should not be construed as an official NOAA and or U.S. Government position, policy, or decision.

V. REFERENCES

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