2.3 MODELING THE IMPACTS OF URBAN AEROSOL ON CONVECTION AND PRECIPITATION

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1. INTRODUCTION

The relationships that account for the observed anomalies in precipitation and severe weather over and downwind of St Louis, Missouri (Changnon, 1981; Changnon and Huff, 1986) and other urban areas (Westcott, 1995; Orville et al., 2001; Steiger et al., 2002) are still not well understood, in spite of good field studies and data analyses. One of the leading hypotheses explaining these anomalies is the so-called "glaciation" mechanism. This mechanism is related to air pollutants emanating from urban areas which are rich in cloud condensation nuclei (CCN).

It is well known that enhanced CCN concentrations can result in narrower droplet spectra, thereby suppressing warm rain processes (e.g. Warner and Twomey, 1967; Warner, 1968; Rosenfeld, 1999). On the other hand, urban areas like St. Louis can also be sources of giant CCN (GCCN) or ultra-giant particles which can enhance warm rain processes (Johnson, 1976; Hindman et al., 1977a,b; Feingold et al., 1999). The presence of supercooled raindrops greatly increases the rate of glaciation of cumuli as the supercooled droplets readily collect ice crystals and freeze (Cotton 1972a,b; Koenig and Murray, 1976; Scott and Hobbs, 1977), and the Hallett-Mossop, rime-splintering process is also enhanced (Cotton and Pielke, 1995). The goal of the research presented here is to investigate the role of the hypothesized glaciation mechanism on convective storm evolution and precipitation over and downwind of St. Louis, MO using a mesoscale model.

2. METHODS

2.1 *Mesoscale Model*

The Regional Atmospheric Modeling System developed at Colorado State University (RAMS@CSU) was chosen to achieve the goal stated above (Pielke et al., 1992; Cotton et al., 2003). The sophisticated "Town Energy Budget" (TEB) model of the urban land surface (Masson, 2000) has been interfaced and successfully used with RAMS (Rozoff et al., 2003). The TEB model is used to accurately represent the urban surface layer by providing such quantities as sensible heat flux, latent heat flux, momentum co-variances, albedo and emissivity to RAMS. Two-moment microphysics (Meyers et al., 1997), in which both the mixing ratio and number concentration of the hydrometeor species are prognosed is utilized, and all the available species (cloud water, rain, pristine ice, snow, aggregates, graupel and hail) are activated. CCN, GCCN and IFN concentrations are all considered as prognostic variables in RAMS (Saleeby and Cotton, 2004).

Three two-way interactive grids with horizontal grid spacings of 37.5, 7.5 and 1.5 km, respectively, were employed. Forty variable grid levels were used in the vertical, and the model top extends to ~22 km. The fine grid spacing of grid 3 allows for the explicit simulation of convection. The location of these grids is shown in Figure 1.

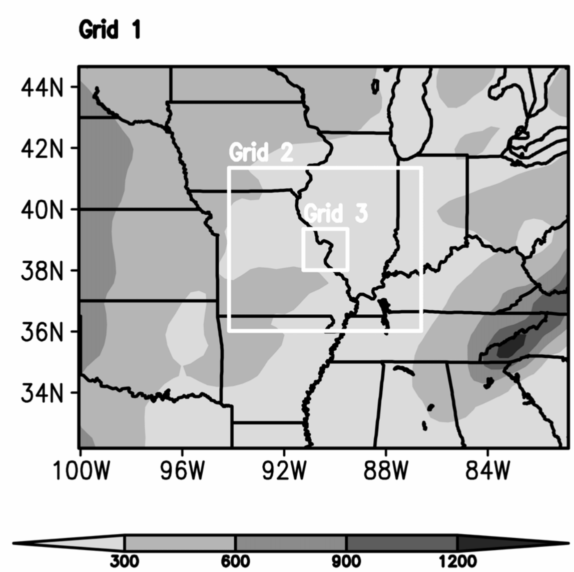

Figure 1: The topography (m) and location of grids 1 through 3 used in the simulations described in the text.

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The atmospheric variables were initialized using ETA data, and the simulations were conducted for 36 hours beginning at 0000 UTC on 8 June 1999. On this day, heavy thunderstorms occurred in the St. Louis area. The storms initiated in the early afternoon and lasted throughout the evening. This case was also simulated by Rozoff et al. (2003) using RAMS to investigate the impact of the urban heat island (UHI) on convective storms. The work presented here is an extension of that study.

2.2 Data and Experiment Design

A series of numerical model simulations using RAMS has been designed to investigate the hypothesized glaciation mechanism on convective storm evolution and precipitation over and downwind of St. Louis, MO. The model is initialized with vertical profiles of CCN and GCCN. These profiles represent the maximum number of CCN and GCCN that can be activated. The number of CCN nucleated to become cloud droplets (with diameters less than 40 microns) is a function of the CCN concentration, temperature and vertical velocity, whereas the number of GCCN nucleated to become cloud droplets (with diameters between 40 and 80 microns) is a function solely of supersaturation. The numbers of CCN and GCCN are model forecast variables, which can be advected and diffused, and which have sources (evaporation of cloud droplets) and sinks (nucleation to form cloud droplets). The CCN and GCCN profiles have been generated based on the data observed during the Metropolitan Meteorological Experiment (METROMEX). Aerosol source functions are employed throughout the simulations to represent the supply of these aerosols over urban and rural regions.

In the CONTROL simulation rural concentrations for both CCN and GCCN are used across the entire model domain. The model setup is otherwise very similar to the TEB control simulation described by Rozoff et al. (2003). Three sensitivity tests have been designed. In these tests, the concentrations of CCN and GCCN over the urban regions are varied both independently and simultaneously, while those over the rural regions are kept at their rural values. The aerosol details of the sensitivity tests are shown in Table 1.

3. RESULTS

An examination of the surface temperature from the CONTROL simulation between 0600 and 1000 UTC (Figure 2) demonstrates the existence of a nocturnal urban heat island (UHI). Around

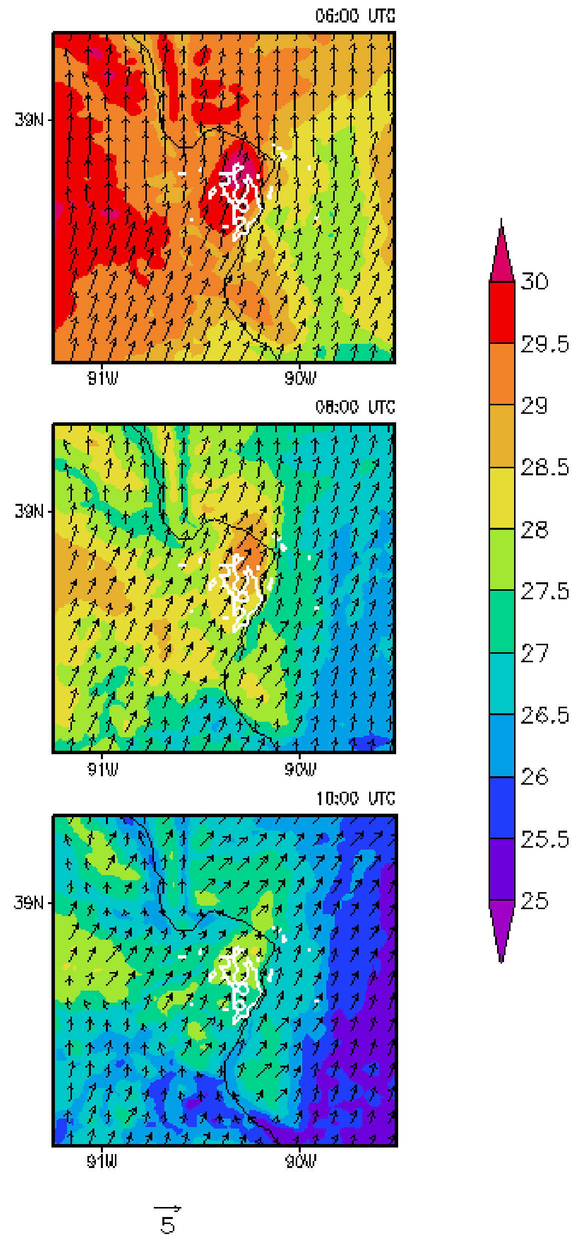

Figure 2: Surface temperature (˚C) and wind vectors for the CONTROL simulation at 2 hour intervals starting at 0600 UTC. The thick white line indicates the location of the urban region.

Table 1: Aerosol profiles used in the sensitivity tests described in the text.

EXP NAME	CCN	GCCN
CONTROL	Rural	Rural
CCN	Urban	Rural
GCCN	Rural	Urban
URBAN	Urban	Urban

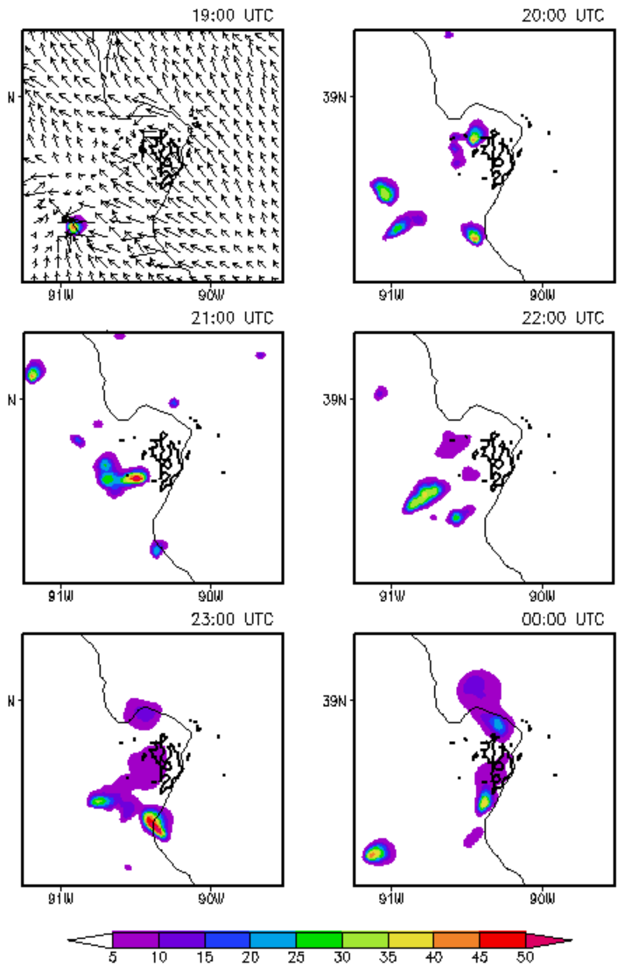

Figure 3: Vertically integrated condensate (mm) on grid 3 for the CONTROL experiment at hourly intervals starting at 1900 UTC. Wind vectors at the lowest model level (48 m) are shown at 1900 UTC. The thick black line indicates the urban region on grid 3.

1000 UTC (5:00 LST) the UHI starts to weaken, however, it does develop again later during the day (~1500 UTC) (not shown). During this time, the winds also switch from southwesterly to southeasterly.

The vertically integrated condensate for the first 6 hours of convective storm development in the CONTROL simulation is shown in Figure 3. It is apparent from this figure that convection initiates downwind of St. Louis by 2000 UTC, and continues to develop to the west and south of the urban region. The similarity between the radar data (not shown) and the CONTROL simulation is fairly good given the problems associated with simulating isolated convection.

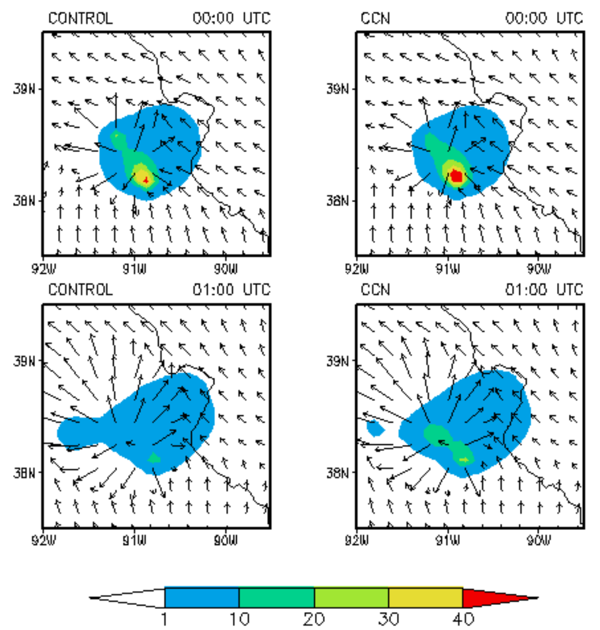

Figure 4: Vertically integrated condensate (mm) on grid 2 for the CONTROL (left column) and CCN (right column) simulations at 0000 (top) and 0100 (bottom) UTC. Wind vectors at the lowest model level (48 m) are also indicated.

Several preliminary CCN sensitivity tests have been conducted. The results from these simulations indicate significant differences between the CONTROL and CCN simulations. It is apparent from Figure 4 that the enhanced aerosol concentrations over the urban region in the CCN simulation increase the vertically integrated condensate. The greater CCN concentrations within this sensitivity test substantially increase the cloud water mixing ratios of the convective storms downwind of the city (not shown). However, while the presence of greater concentrations of CCN over St. Louis enhances the cloud water mixing ratios, it reduces the rain mixing ratios within these storms. The resultant accumulated precipitation at the surface is less in the CCN simulation than in the CONTROL simulation (Figure 5). This is in keeping with previous observations that the warm rain process is suppressed when CCN concentrations are increased (e.g. Warner and Twomey, 1967; Warner, 1968; Rosenfeld, 1999).

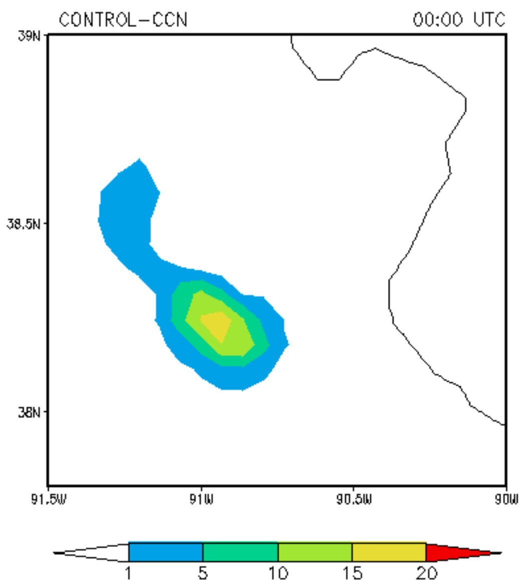

Figure 5: The accumulated surface precipitation difference field on grid 2 between the CONTROL and CCN simulations (mm).

4. CONCLUSIONS

Simulations have been designed and conducted to investigate the impact of enhanced aerosol concentrations associated with urban regions on the convective storm characteristics and precipitation over and downwind of the urban region. The sophisticated TEB model has been used to represent the surface interactions over the urban region, and two-moment microphysics, together with a predictive aerosol scheme has been implemented to simulate the microphysical interactions. The lifecycle of the UHI and the initiation and development of convective storms over and downwind of St. Louis are apparent in the CONTROL simulation. Preliminary sensitivity tests in which the CCN concentrations over the urban region are varied indicate that the cloud water mixing ratios are increased, while the warm rain process is suppressed when CCN concentrations over the city are enhanced. Less accumulated surface precipitation is also associated with these storms when the CCN concentrations are higher. These findings support previous observations.

Simulations are currently underway in which the concentrations of GCCN over the urban region are being varied independently. Following the completion of these sensitivity tests, the concentrations of both the CCN and GCCN will be varied simultaneously. The results of all of these sensitivity tests will be presented.

5. ACKNOWLEDGEMENTS

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