1.2 SIMULATED THUNDERSTORMS OVER ST. LOUIS, MO

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1. INTRODUCTION

The METROpolitan Meteorological EXperiment (METROMEX) results indicate St. Louis enhances convective rainfall in and downwind of the city. Possible mechanisms considered since METROMEX include enhanced convergence from the urban heat island (UHI) and barrier effects of the built-up surface. Microphysical alterations to cloud systems may also play a role over cities. The complex interactions within the urban boundary layer (UBL) have prevented a complete understanding of these phenomena and their role in thunderstorm modification. The current study employs a nonhydrostatic three-dimensional cloud-resolving model with sophisticated a land surface model to investigate some of these hypotheses.

2. MODEL SETUP

The Regional Atmospheric Modeling System (RAMS) Version 4.3 developed at Colorado State University is the nonhydrostatic cloud-resolving model applied to simulation. In the current application, a σ_z vertical coordinate system is utilized. For the modeling domain, three fixed nested grids are centered over St. Louis. Deep, moist convection is explicitly resolved in the fine grid, while the coarser grids simulate general synoptic and mesoscale features. The grid spacing, indicial and physical dimensions, and time step for each grid are listed in Table 1. These grids are initialized and nudged with gridded analyses from the Eta model Data Assimilation System.

2.1 Initialization Of Surface Fields

The Land Ecosystem-Atmosphere Feedback-2 (LEAF-2) (Walko 2000) model is the surface package included in RAMS. LEAF-2 has the ability to represent multiple land use land classes (LULCs) within a grid cell, by subdividing a cell into so-called 'patches'. For each grid cell, the fluxes to the atmosphere are area-weighted by their contributions from each patch. The fluxes are calculated through typical surface layer similarity theory. In the standard form, its urban landuse uses biophysical parameters tuned to a high-density residential environment with vegetation. Typically, the leaf area index and vegetation fractional coverage are minimized and the roughness length is increased to approximate the effects of buildings. Suburban land use is parameterized similarly, allowing for more vegetation than built-up areas.

Table 1: Grid Configuration

Grid	Δx (km)	Grid dimensions	Δt (s)
1	37.5	50 × 40 × 40 (1825 × 1460 × 22 km)	60
2	7.5	92 × 82 × 40 (683 × 608 × 22 km)	15
3	1.5	102 × 102 × 40 (152 × 152 × 22 km)	3.75

The Town Energy Budget (TEB) (Masson 2000) is used to represent high-density residential areas, commercial and industrial land-use in RAMS. TEB follows a generalized urban canyon approach, considering energy budgets separately for roofs, walls, and roads. Fluxes of heat and momentum are calculated considering these energy budgets and canyon geometry. Radiation interactions with the three-dimensional surfaces are included in TEB. Anthropogenic heat release is also incorporated into the TEB.

LULC in RAMS is conventionally obtained from 30 × 30 s resolution U.S. Geological Survey (USGS) data. However, in grid 3, 30-m resolution data from the USGS Landsat-Thematic Mapper database is applied. These data are binned by land-type category into respective patches within each 1.5 × 1.5 km grid cell, retaining more detail than interpolation. Consequently, the current study uses 1 water patch and 3 other patches for the 3 most dominant land-types in each grid cell.

2.2 Experiments

Simulations with and without each of the following factors are performed: urban heat and radiative flux, urban momentum flux, and local topography. When the urban factors are ignored, the respective surface parameters of the dominant surrounding landuse are implemented in place. The simulation without the local topography is really a smoothed topography interpolated from grid 1, which minimizes the effect on larger scale synoptic weather. Small-scale variability in grid 3 topography believed to influence local rainfall anomalies is not present in the simulation with smoothed topography. To accomplish the goal of true factor separation, the technique of Stein and Alpert (1993) is employed. Since three factor variations are used, 8 simulations are carried out. Difference fields enable the thorough review of each factor

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and the interactions between them. An additional simulation allows comparison between the Leaf-2 standard urban parameterization and TEB, which shows modeled thunderstorm events are highly sensitive to the urban parameterization. The TEB is used for the sensitivity tests since validation tests show that it provides improvement in temperature and storm development, compared to the standard Leaf-2 urban parameterization.

3. RESULTS AND CONCLUSIONS

This study investigates an actual convective event over St. Louis. Certain criteria are considered so that the simulations are as generalized as possible. The overarching goal of this project is to produce results comparable to METROMEX. Ordinary, outflow dominant storms, generated in environments devoid of synoptic scale forcing, accounted for a great number of the storms in METROMEX and these storm-types were apparently the most influenced by St. Louis (Changnon 1981). Thus, a similar storm event is chosen for the current study.

The St. Louis area experienced heavy thunderstorms in the afternoon of 8 June 1999. According to Storm Prediction Center Storm Report data, large hail fell within the area and considerable wind damage was reported within the city. The synoptic situation involved a strong anticyclone over the eastern U.S., with its westward grasp over Missouri. The atmosphere was moist and unstable.

The control simulation successfully produces the overall synoptic patterns and the convective situation fairly well. Doppler radar data shows, however, that observed storms initiate almost two hours earlier than the model storms. Nonetheless, the model achieved spatial agreement through time with radar, given the difficulty in timing.

The impact of individual factors on convective initiation as well as the interactions among factors are explored. The control simulation produces a storm downwind of the city in the second hour of convection, located in a region of strong convergence. Downwind convective development never appears when the city is replaced by vegetation representative of the city's surroundings. Contributions by topography, surface roughness, and surface energy fluxes are all important in the outcome of storms.

The urban heat island plays the most significant role in producing convection downwind of St. Louis. A strong mesoscale circulation develops over the heat island. In fact, convective available potential energy increases in the relatively dry urban environment, because strong convergence also converges water vapor near the surface. A simulation including both urban radiative and turbulent heat flux, but neglecting topographic variations and urban momentum flux, actually produces convection downwind of the city earlier than the control simulation. In this experiment, neglecting the impact of the urban scheme on the momentum flux over the city results in locally increased wind speeds. Since sensible heat flux is proportional to wind speed, greater sensible heat flux over the city is promoted. Hence, a stronger heat island ensues. Urban momentum flux impacts both the strength of the heat island and the resulting convective situation.

Although the urban momentum flux decreases the wind by about 1 ms^{-1} over St. Louis, this flux has little effect on convective initiation. In fact, convergence by this mechanism is smaller in magnitude than that driven by thermal differences at the land surface. Later on in the integration however, a storm present over the city in the simulation neglecting urban landcover does not exist when urban momentum fluxes are included.

In reality, the individual contributions by momentum flux and heat flux cannot be separated. When momentum flux changes occur, there are large feedbacks to heat fluxes and resulting heat island. Likewise, changes in heat flux promote dynamical responses. For example, a weakened heat island is associated with a weaker mesoscale circulation and potentially decreased wind over the 'urban barrier'.

In terms of local topographic features, the most significant impacts upon convection are found southwest of St. Louis, over the foothills of the Ozarks. There, convection initiates due to locally elevated heat sources that are associated with topographic variability. In contrast to some of the results in METROMEX (Changnon 1981), bluffs along the Mississippi River have a negligible impact on convective development. More simulations, under various convective regimes, are needed to determine the exact role of local physiography.

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