J2.4 INVESTIGATING THE RELATIONSHIP BETWEEN URBAN LANDUSE AND PRECIPITATING CONVECTIVE SYSTEMS OVER THE ATLANTA REGION

Willis O. Shem * and J.M.Shepherd
University of Georgia, Athens, Georgia

1. Introduction

Several observational and modeling studies have recently focused on the impact of urbanization on the temporal and spatial distribution of precipitation, particularly in the warm season (see Shepherd 2005 for a review). Most of the major research efforts including the extensive study by the Metropolitan Meteorological Experiment (METROMEX) are in agreement that urban effects on precipitation are more pronounced in the summer months (Huff and Changnon 1972a; Changnon et al 1991; Shepherd et al 2002).

Urbanization is accompanied by the replacement of natural land surfaces by artificial surfaces that significantly change the original surface properties. The parameters that are uniquely modified by urbanization include landuse, surface roughness, green vegetation fraction, albedo, volumetric heat capacity and soil thermal characteristics among others.

Recent observational studies (Shepherd et al. 2002; Dixon and Mote 2003; Diem and Mote 2005) have quantified urban-rainfall anomalies around Atlanta, yet there is a lack of modeling studies to explain these findings and possible physical mechanisms.

* Willis O. Shem, Univ. of Georgia in Athens, Dept. of Geography, Athens, GA, 30602; e-mail: willshem@uga.edu

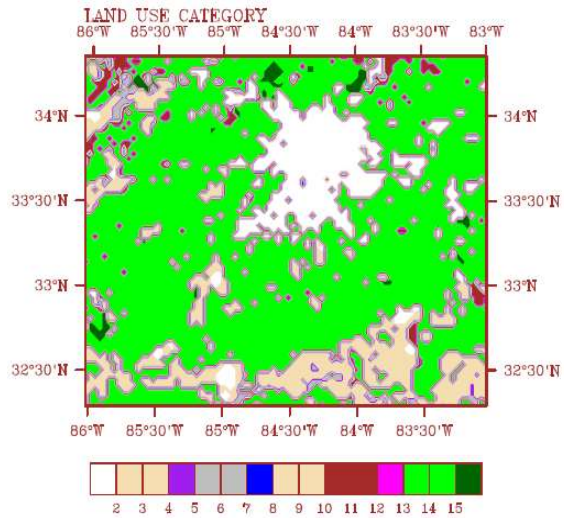
In this preliminary study, the Weather Research and Forecasting (WRF V.2.2) model was used to investigate the effects of urbanization on convective rainfall over the Atlanta region. A case study of the rainfall activity over the region on 17 August 2002 is undertaken with a view to (1) evaluating the ability of the WRF model to simulate the process, (2) investigating the impact of landuse changes on the evolution and characteristics of such convective systems and (3) quantifying how physical size of the urban area affects convective processes. This case date was chosen because there was convection in and around the Atlanta area on that day and yet no major synoptic scale forcing or dynamics was visible from the surface maps.

2. Methodology and experiment design.

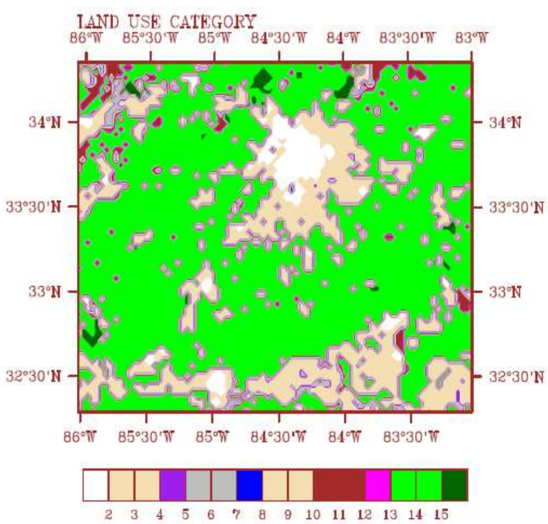
Three distinct landuse scenarios were used as the basis for the experiments. The first scenario, URBAN, represents landuse based on the 30” (seconds) 1994 USGS landuse data set. In this scenario the city of Atlanta is represented by the white region (coded 1) in Figure 1a.

The second scenario, LARGE URBAN (Figure 1b), is characterized by the expansion of the city of Atlanta to a size that is cognizant of the rapid growth of the city (circa 2005) and is closer to that depicted in the map (Figure 2) produced by the Natural Resources Spatial Analysis Laboratory (NARSAL) at the university of Georgia.

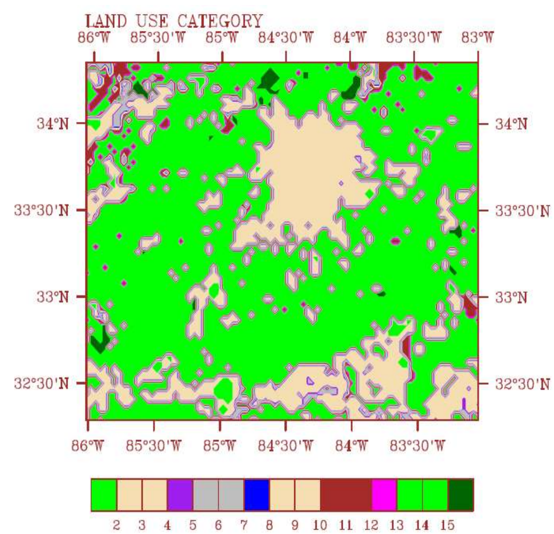
In the third scenario, NOURBAN (Figure 1 c), the city of Atlanta is removed and replaced by the dominant landuse type of the surrounding rural location, i.e., 'dryland, cropland and pasture'.



(b)



(a)



(c)

Figure 1. Land cover for (a) URBAN, (b) LARGE-UBAN and (c) NOURBAN scenarios

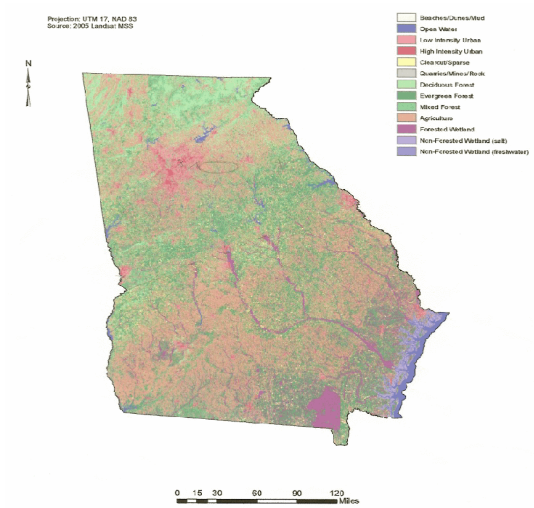


Figure 2. 2005 Georgia Landuse Trends -Land Cover – Courtesy of Natural Resources Spatial Analysis Laboratory (NARSAL) at the University of Georgia.

Initial and boundary conditions were derived from the 40 km ETA analysis data available at 6-hr intervals but interpolated to 3-hr intervals. Three domains DI, D2 and D3 with grid resolutions of 30 km,10 km and 3.3 km respectively, were configured as shown in Figure 3, where domain D1 is bounded by the outer frame of the map. The innermost domain, D3, is the study region.

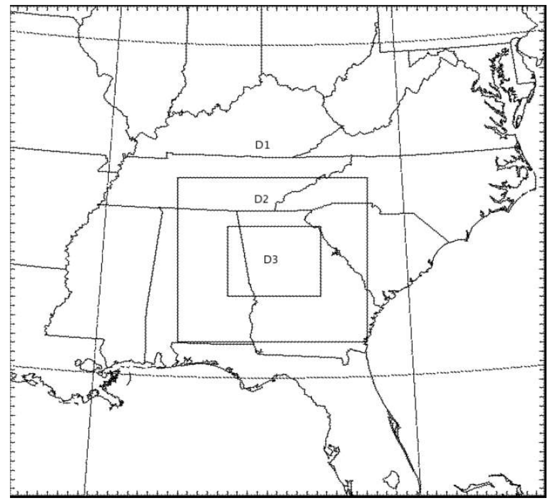


Figure 3. Domain configuration and location of the study area

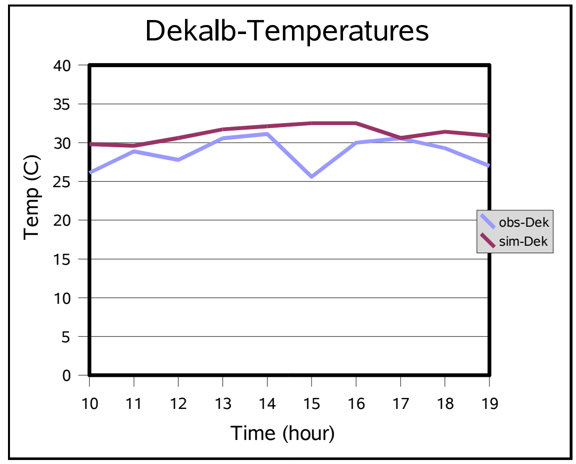
3. Model Validation:

The variation of temperature at Dekalb-Peachtree Airport (PDK) in northeast Atlanta, is compared to the simulated temperature (2-m reference height) for the same location (Figure 4). The model slightly overestimates the surface temperature by about 2^0C on average. Their trends are roughly in agreement although the decrease in observed afternoon temperatures (accompanied by observed rainfall activity) is lagging in time and is less abrupt in the simulated results. The simulated results for Macon (MCN), a station in the southeastern corner of domain 3, mirrors the observed values to a close approximation except for a steeper slope in the morning hours for the observed temperatures (Figure 4b).

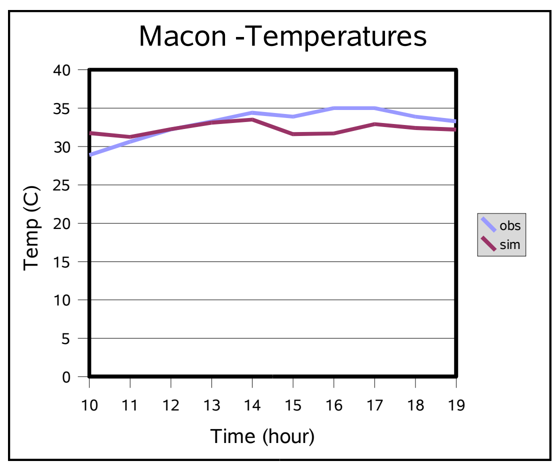
Qualitative validation of the simulation results for rainfall was based on the radar data obtained from the Atlanta-area WSR-88D (KFFC-located at latitude 33.36 N and longitude 84.57 W) on 17 August 2002 starting from around 1400 UTC to 2300 UTC . A comparison of the radar and the model-simulated convective precipitation indicates that the model does capture the major characteristics of the convective system (Figure 5 and Figure 6).

In the initial stages, convective activity is located in the northern mountainous region of the state (not relevant to this study). There was also a weak convection in the southeastern and northwestern suburbs of Atlanta. The model did not capture the convection NW of the city in the early time periods (under further study). However, the early convection SE of the city was mostly captured. Later in the afternoon, more significant convection developed in the northwestern and northeastern suburbs of Atlanta. The model reproduces this spatial pattern of the convection.

Although there are some minor discrepancies in the timing and quantities of the total grid rainfall between the radar data and the simulated results, the model does capture the propagational characteristics of the convective system. The initiation of convective activities in the simulated run lags behind the radar observation in most instances by about 1 hr (Figure 5a and Figure 6a)



(a)



(b)

Figure 4. Variations of observed and simulated temperatures at (a) Dekalb-Peachtree Airport (PDK) in northeast Atlanta and (b) Macon (MCN), a station in the southeastern corner of the study region.

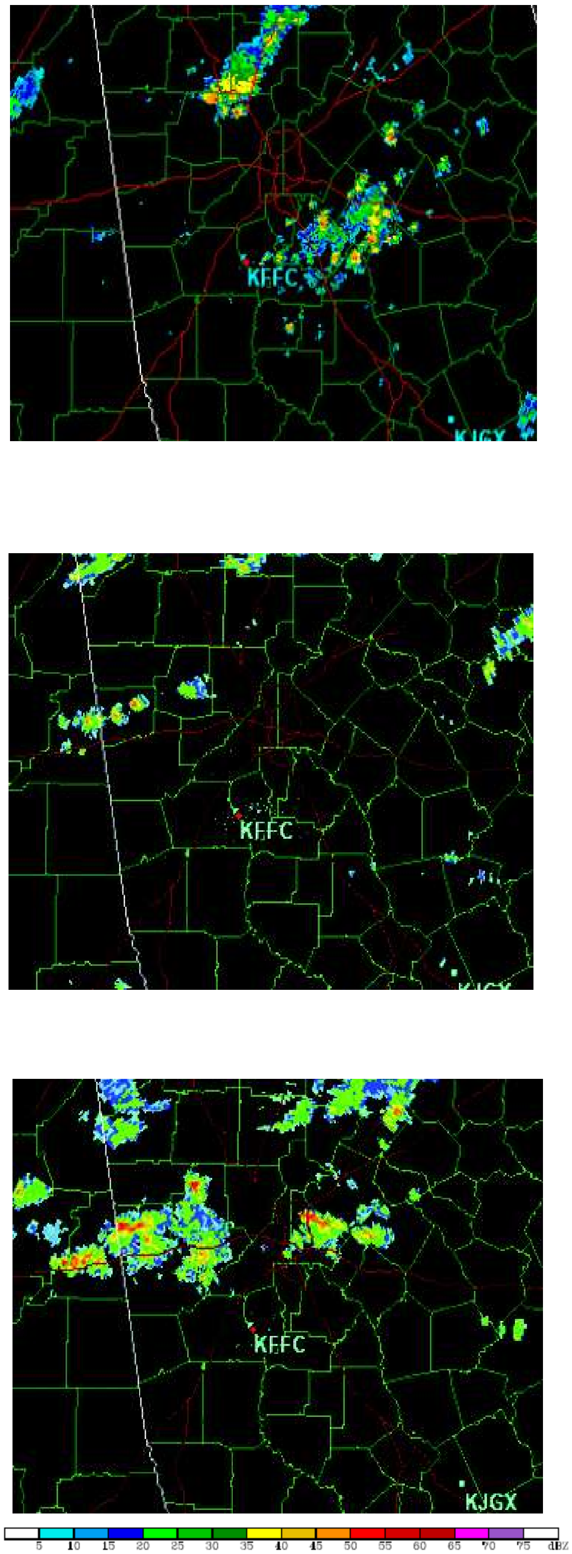


Figure 5. Observed base reflectivity radar data at (a) 18.00 UTC (b) 22.03 UTC and (c) 23.59 UTC -case study day. Observations site is KFFC in map. Units-db Z

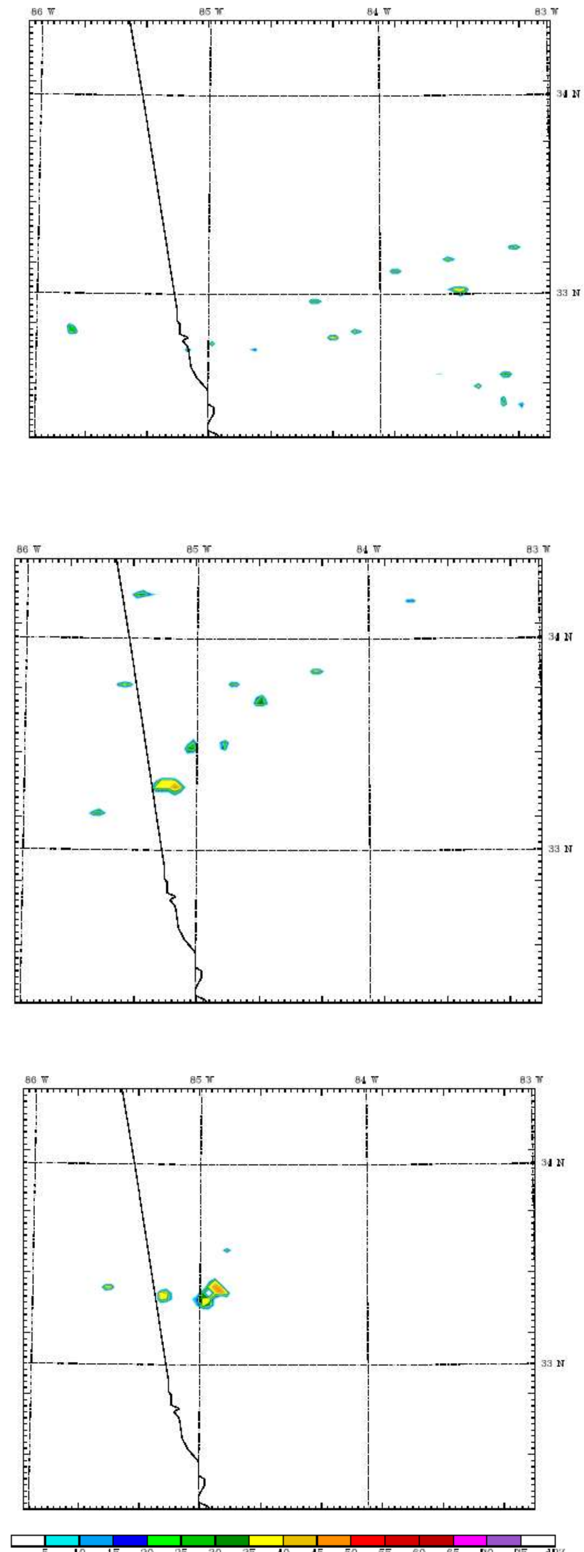


Figure 6. Simulated base reflectivity at (a)1900 UTC. (b) 2200 UTC and (c)2300 UTC -control case (LARGE-URBAN). Units-db Z

4. Results and Analyses

4.1 Cumulative Rainfall

A time series plots of the accumulated grid scale precipitation totals for the URBAN (control -1994 urban size), LARGE ATLANTA (2005 urban size) and the NOURBAN cases for domain 3 depict the temporal evolution of the convective system over the study region from 1500 UTC to 2300 UTC on the case date (Figure 7). Figure 7 does not provide much guidance on physical processes related to urban-induced rainfall. However, it does indicate that modifying the urban land representation can affect the evolution of precipitation. It is interesting to note that early rainfall accumulations are greatest in the URBAN case and not the LARGER-URBAN case. Ultimately, URBAN produces the most cumulative rainfall. More research is required to explain this somewhat surprising result

A comparison of the accumulated rainfall totals for the western section to the eastern section of the region indicates higher values in the URBAN cases and vice versa in the NOURBAN case (Figure 8a and Figure 8b). The western and eastern sections loosely approximate the upwind and downwind locations (respectively) of the domain.

This result is consistent with the findings of Bornstein and Lin (2000) who hypothesized that UHIs tended to create thunderstorms in the downwind quadrants of the city. Additional studies by Shepherd et al. (2002) and Diem and Mote (2005) also found anomalies east of the city, although the location of the anomaly varied from southeast to northeast, respectively. These differences are likely the result of different methodological approaches and data.

Further subdivision of the region into the SE, NE, SW and NW quadrants highlights this phenomena, especially in the SE quadrant. The URBAN and LARGE-URBAN cases seem to enhance convective activities in the SE quadrant where the initial convection around Atlanta originated (Figure 9a). Conversely the SW, quadrant (Figure 9b) demonstrates a decrease in cumulative rainfall in the urbanized cases.

The disparities in cumulative rainfall totals are also visible in the NW and NE quadrants. However, due to the temporal characteristics of these convective activities, their dependence on wind direction can not be easily determined (Figure 9c and Figure 9d).

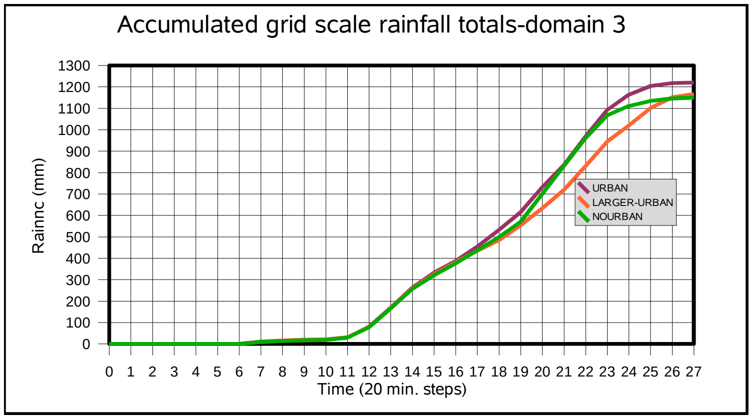


Figure 7. A time series plots of the accumulated grid scale precipitation totals-domain 3.

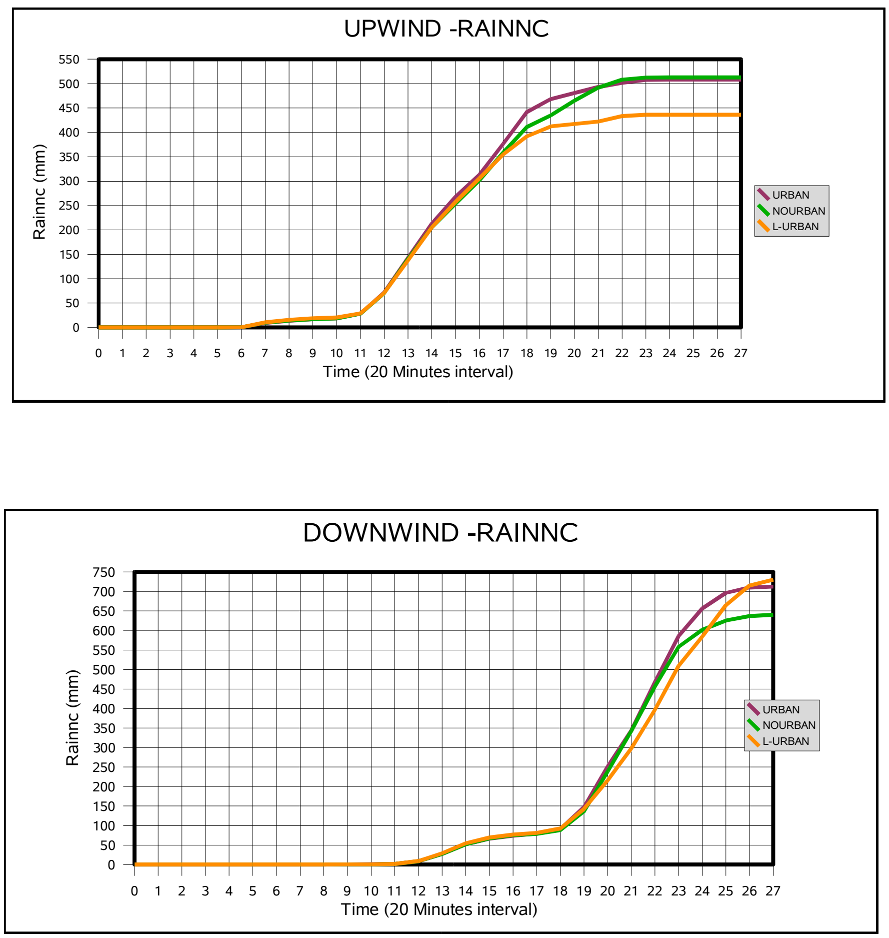
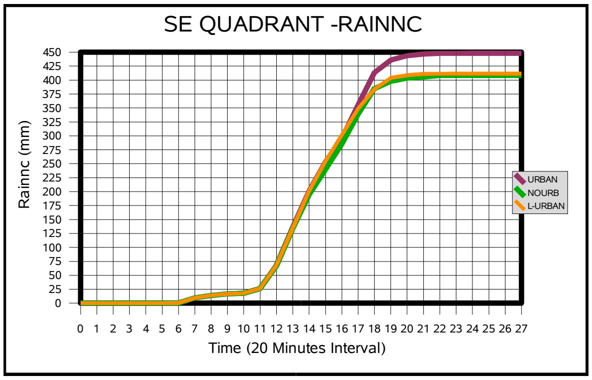
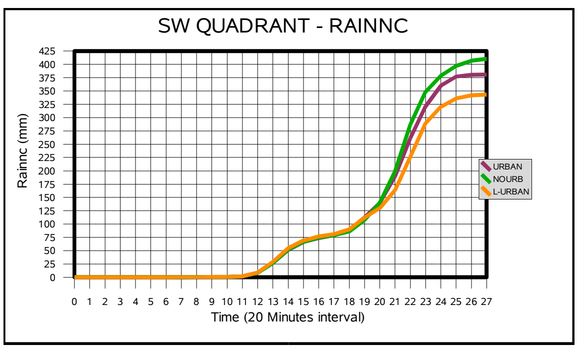


Figure 8. Simulated accumulated rainfall totals for (a) western section and (b) eastern section of domain 3.

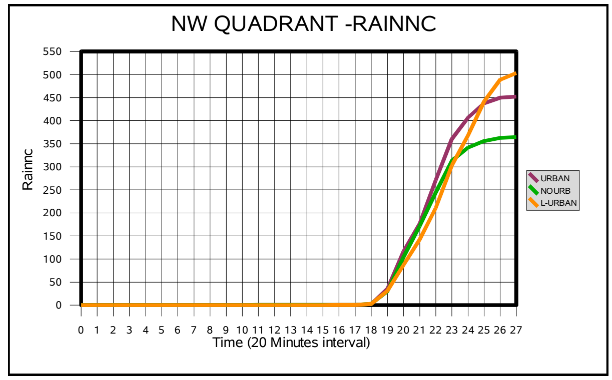


(a)

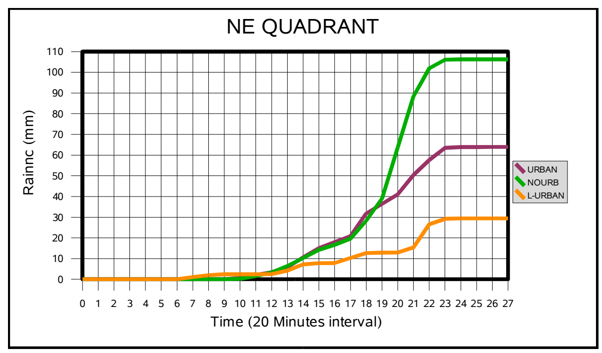


(b)

Figure 9. Simulated accumulated rainfall totals for (a)SE, (b) SW quadrants of the study region.



(c)

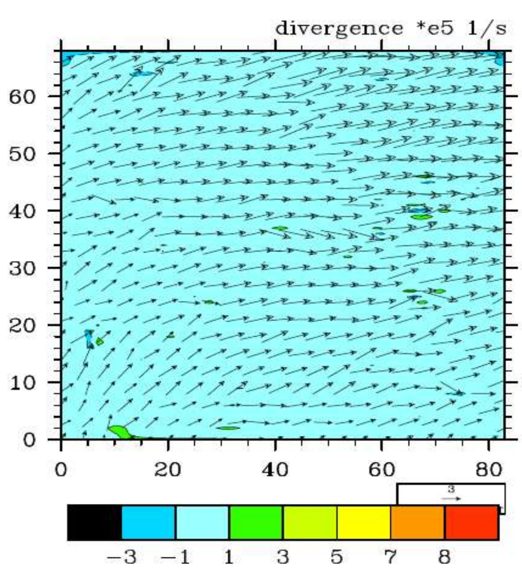


(d)

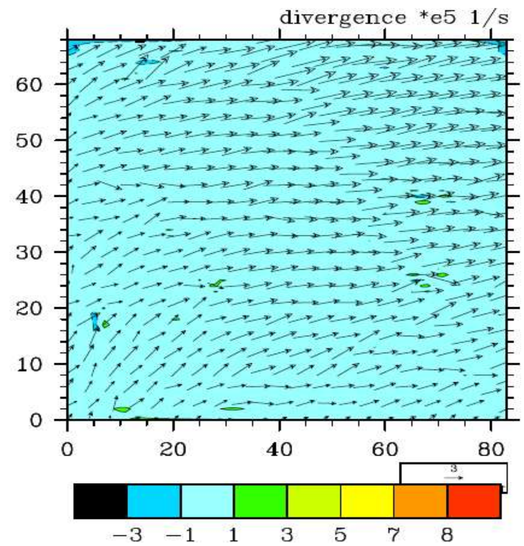
Figure 9. Simulated accumulated rainfall totals for (c) NW and (d) NE quadrants of the study region.

4.2 Surface convergence field.

Further evidence that the urbanized environment enhanced convective activities, especially in the initial stages, can be seen from the divergence (convergence) field (Figure 10a and Figure 10b). Qualitatively the initial convergence fields to the east of Atlanta are more expansive and significant for the LARGE-URBAN scenario as compared with the NOURBAN case. The NOURBAN scenario was modified in this case to include complete removal of urban land use in D3, otherwise the convergence field was not visibly altered. In general the simulated wind field is in close agreement with the observations at this time for both cases.



(a)



(b)

Figure 10. Simulated wind fields and convergence zones for (a) LARGE URBAN (b) NOURBAN at 17.00 UTC

5. Summary

This a preliminary study of the impact of landuse change on the precipitating convective systems over the Atlanta region using WRF (v. 2.2) model. The validation phase of the study demonstrates some weaknesses in the reproduction of the 2-m reference height temperatures and in the timing and placement of the convective thunderstorms over the region on the case date.

The performance of the model in this study can not be considered as optimal due to limitations in some aspects of the input data set. The use of Urban Canopy Model (UCM) coupled to the Noah

Land surface model was not possible due to lack of detailed urban classification for the city of Atlanta. The UCM might have improved the temperature simulation over the city precincts. The influence of topography on the regional Atlanta temperature was not adequately smoothened by the model.

The study, however, does indicate that the temporal and spatial evolution of the convective systems in the Atlanta region is modified by increased urbanization.

A more rigorous treatment of the above issues including further sensitivity studies will be included in our upcoming paper on this topic.

Acknowledgments. This study was supported by a grant from the University of Georgia Research Foundation.

References

Bornstein, R., and Q. Lin,2000: urban heat islands and summertime convective thunderstorms in Atlanta. Three case studies. *Atmos. Envron*., 34 507-516.

Changnon, S.A.,Jr., R.T.Shealy, and R.W.Scott, 1991: Precipitation changes in fall,winter and spring caused by St. Louis. *J. Appl. Meteor*., **30**,126-134 .

Diem, J.E. and T.L. Mote, 2005. Interepochal changes in summer precipitation in the Southeastern United States: Evidence of possible urban effects near Atlanta, Georgia. *J. Appl. Meteor.*, **44,** 717–730.

Dixon, P.G., and Mote, T.L., 2003: Patterns and Causes of Atlanta's Urban Heat Island-Initiated Precipitation. *J. Appl. Meteor.*, vol **42**,Issue 9, 1273-1284

Huff, F.A., and S.A. Changno Jr., 1972: Climatological assessment of urban effects on precipitation at st. Louis. *J. Appl. Meteor.*, **11**, 823-842.

Shepherd, J.M., H.pierce, and A.J. Negri, 2002: Rainfall modification by major urban areas:Observations from spaceborne rain radar on the TRMM satellite. *J. Appl. Meteor*., **41**,689-701.

Shepherd, J.M., 2005: A Review of Current Investigations of Urban-Induced Rainfall and Recommendations for the Future. *Earth Interactions*, **9**, 1–27.