P420

RADAR AND LIGHTNING DELINIATION OF URBAN-ENHANCED THUNDERSTORM FOR ATLANTA, GEORGIA

Walker S. Ashley[+]*, Mace L. Bentley[+], and Tony Stallins^
[+] Meteorology Program, Department of Geography, Northern Illinois University, DeKalb, Illinois
^ Department of Geography, Florida State University, Tallahassee, Florida

1. INTRODUCTION

Changes in land cover can alter climate and meteorological processes (Pielke, 2002; Pielke et al., 2007). Rapid urbanization forms urban heat islands (hereafter, UHIs) which destabilize the boundary layer, enhance thermal circulations and initiate convection (Dixon and Mote, 2003; Shepherd and Burian, 2003; Shepherd, 2005). Aerosols can modify collision coalescence processes to alter precipitation formation and rate (Rosenfeld et al., 2008). The higher surface roughness of cities increases low-level convergence and lift (Bornstein and Lin, 2000; Thielen et al., 2000). UHI-enhanced or initiated convection can increase precipitation and lightning on the periphery or downwind of the urban center (Shepherd, 2005; Mote et al., 2007; Rose et al., 2008).

It is important to document the effects of urbanization on the nature of convection as the amount of impervious surface area for the conterminous U.S. is more than 112,610 km^2 (approximately the area of Ohio; Elvidge et al., 2004). In addition, 80% of the U.S. population now lives in urban areas. These demographic shifts have greatly increased vulnerability to weather hazards in rapidly growing cities such as Atlanta, Georgia, where a prolonged period of migration to the region has lead to low-density development and a general increase in property values.

This investigation examines the distribution of warm season (June through August) thunderstorm activity surrounding Atlanta, Georgia from 1997-2006. Composite reflectivity data obtained from the network of National Weather Service (NWS) WSR-88D radars are utilized to discern thunderstorm prone regions. Our primary objective is to characterize the distribution of deep, moist convection during warm-season, synoptically benign days when the effects of the Atlanta UHI on modulating convective activity is maximized. The research presented is the most comprehensive spatial and temporal analysis of grid averaged composite reflectivity data for urban convection conducted to date. The radar data, at 2km and 5min spatial and temporal resolutions, allows for high resolution analyses of urban convective trends when grid averaged over a ten year period. Corresponding lightning analyses will be presented at the conference.

* Corresponding author address: Dr. Walker Ashley, #118 Davis Hall, Meteorology Program, Dept. of Geography, Northern Illinois University, DeKalb, IL 60115; e-mail: washley@niu.edu

2. BACKGROUND

Within urbanized regions, high population numbers and infrastructure sensitivity are the major impetus for the study of potentially urban-enhanced convective storms. The Studies of Precipitation Anomalies from Widespread Urban Land Use (SPRAWL) project generated an urban-induced thunderstorm database for Atlanta, GA using space-borne precipitation radar (Shepherd et al., 2004). Other UHI-related thunderstorm investigations have focused on large urban areas such as Houston, Atlanta, Phoenix, and New York (Balling and Brazel, 1987; Bornstein and LeRoy, 1990; Selover, 1997; Orville et al., 2001). Recently, thunderstorm climatologies and investigations into precipitation cycles have been conducted using the NWS WSR-88D network of radars (Ahijevych et al., 2003; Parker and Knievel, 2005; Mote et al., 2007; Ntelekos et al., 2008).

The southeastern U.S. experiences frequent diurnally forced thunderstorm convection during the warm season, with occasional synoptic-scale forcing (Court and Griffiths, 1981). The ten most active lightning days within Georgia over a twelve-year period (1992-2003) occurred during the summer months with over half of all reported flashes emanating from air mass storms (Bentley and Stallins, 2005). During the warm season, mesoscale convective systems are less frequent in the southeastern US when compared to the Plains and Midwest (Murphy and Konrad, 2005). Evidence suggests that isolated, air mass thunderstorms are more sensitive to UHI circulations as lightning from weakly-forced events surrounding Atlanta were found to be more tightly coupled to the outline of the central city and outlying hubs of high-density development (Stallins and Bentley, 2006). Therefore, this investigation will focus on warm season (June through August), air mass convective storms from 1997-2006. This time span was chosen as the network of NWS WSR-88Ds surrounding Atlanta were calibrated and fully functional.

2. DATA AND METHODOLOGY

Our analyses incorporate NOWrad™ national composites of WSR-88D reflectivity data produced by WSI Corporation. For this study, we examined the region surrounding the Atlanta, Georgia metropolitan statistical area (Figure 1). To create the composites, raw radar data on a polar grid of 1o x 1o from each radar were converted to Cartesian units with temporal, spatial, and reflectivity intervals of 5min, 2km x 2km, and 5dBZ, respectively. Each grid point's value is the largest reflectivity measured in a 5min interval by any radar in a column above the grid cell, with a qualifier that reflectivity from radars within 230km of the cell are given priority over radars beyond 230km. Automated computer algorithms at WSI filter poor data from individual WSR-88Ds and from the national composites. This preprocessing removes some artifacts such as ground clutter. Radar coverage surrounding Atlanta, Georgia is some of the densest in the country, with some grid cells overlapped by eight radars (Maddox et al., 2002; Parker and Knievel, 2005).

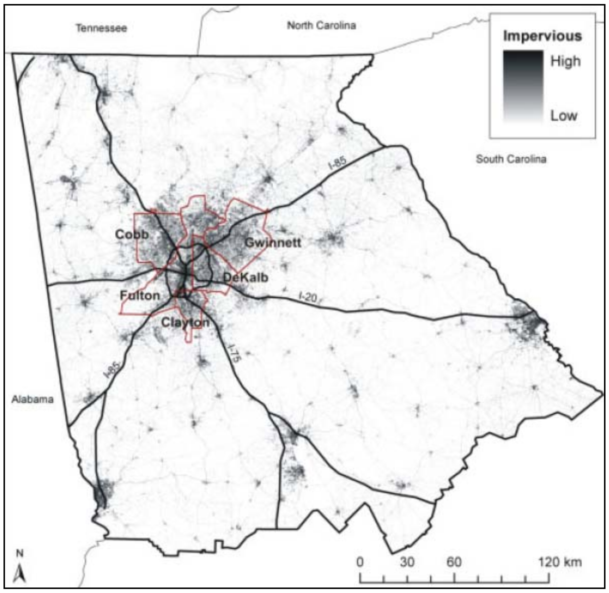

Figure 1. Counties and Per-pixel estimates of percent imperviousness for the study region (USGS 2001; Horner et al. 2004). Pixel size is 30 meters.

The warm season months (June through August) were extracted from the NOWradTM dataset and spatial synoptic classification (SSC) was utilized in order to identify synoptically benign, convectively unstable days (S. C. Sheridan, Spatial synoptic classification data, http://sheridan.geog.kent.edu/ssc.html, 2007). SSC classifies seven different weather types, including transitional days between a specific air mass (Sheridan, 2002). We culled MT (moist tropical), MT+ (moist tropical plus) and MT++ (moist tropical plus-plus) days from the dataset as this is when deep, moist convection is most susceptible to UHI effects (Dixon and Mote, 2005). After extracting for these air masses, 415 days were available for analysis. In order to examine the effects of differing wind regimes, we further stratified the dataset by 700 hPa winds (Rose et al., 2008, Hand and Shepherd, 2009).

The remaining radar data were grid averaged over the study region. In order to remove possible contamination due to miscalibrated or "hot" radars and the effects of an extraordinary convective episode, the radar data were grid averaged in intervals by determining the amount of time that a reflectivity range was met (Ahijevych et al., 2003). Over the study period, this produced a data set with little impact from any one particular reflectivity episode and ensures that infrequent, high-reflectivity outliers do not skew the results. The distribution of medium- and high-reflectivity events (the amount of time a grid cell was between 40-55dBZ and met or exceeded 55dBZ, respectively) will be examined in this investigation. 40dBZ is what we define as a minimum for a convective element or storm. This baseline reflectivity is commonly used as a discriminator between convective and stratiform events using composite reflectivity (Falconer, 1984; Rickenbach and Rutledge, 1998; Parker and Knievel, 2005). The number of days a grid cell registered a medium- and high-reflectivity event (375 and 376 days, respectively) and a summation of the number of 5-minute bins (hereafter, occurrences) reaching these thresholds (54,437,584 and 2,098,682 grid cell occurrences within the domain, respectively) were examined. These reflectivity periods, ranging from moderate to strong and severe thunderstorms, have the potential to produce urban flooding, frequent lightning, and damaging microbursts and downbursts (Roberts and Wilson, 1989).

Minimal processing was conducted to the reflectivity dataset; however, the varying radar densities in the study region and smaller sample size of high-reflectivity occurrences necessitate the application of a normalization scheme. Due to the nature of composite reflectivity, if more radars intersect a grid cell, the greater the probability a higher reflectivity will be detected as the overlying thunderstorm activity will be better sampled. Therefore, we normalized the high-reflectivity data centered on grid cells with three overlapping radars. Three radar coverage was chosen because it encompasses the majority of the grid cells in the study region. Normalization was not necessary for medium-reflectivity data because radar density differences did not counteract the much larger number of reflectivity occurrences (Gorokhovich and Villarini, 2005).

3. RESULTS AND DISCUSSION

Given the high temporal and spatial resolution of the reflectivity data, we were able to discern regions and corridors of enhanced composite reflectivity activity throughout the Atlanta CBD. Eastern Cobb, central Fulton, northern DeKalb, and southern Gwinnett counties exhibit a large number of medium reflectivity occurrences (Figure 2a). The region is over and slightly north of the center of Atlanta and overlays high-density urban land use coinciding with regions of lightning flash enhancement (Stallins and Bentley, 2006). In addition, Central Fulton and DeKalb counties contain grid cells with more than 143 days of medium reflectivity activity (Figure 2b). Since the distributions of medium reflectivity occurrences and days are similar, evidence suggest this is a persistent signal within the temporal span of the dataset.

A similar pattern emerges when examining the occurrences of high reflectivity (Figure 3a). Central and northern Fulton county as well as northern DeKalb county contain regions where high reflectivities were recorded for over 215 minutes. In addition, the Atlanta city-center contains grid cells registering 335 minutes of high-reflectivity. These regions also correspond to maxima in high-reflectivity days (Figure 3b). Portions of Fulton county experienced more than 28 days of high-reflectivity events. The colocation of these grid cells suggests that the sample size is large enough to minimize the effects of a single, high-composite reflectivity episode and that the combined effects of many events are evident.

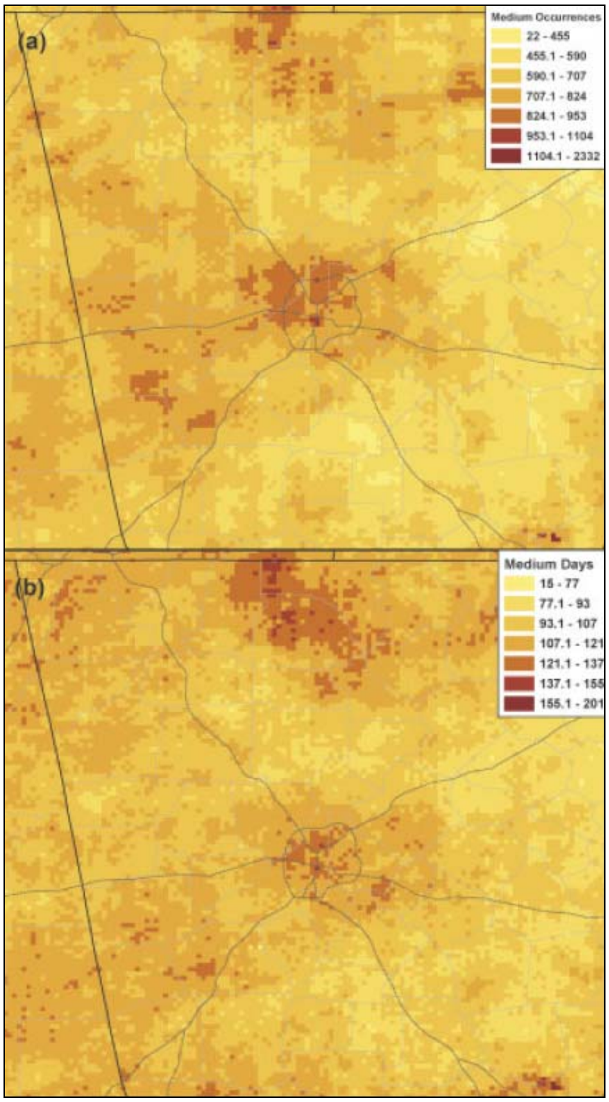

Figure 2. a) The frequency of medium composite reflectivity (40, 45, or 50dBZ) occurrences for each 2km grid cell. b) The frequency of medium composite reflectivity (40, 45, or 50dBZ) days for each 2km grid cell.

The areas of enhanced high-reflectivity correspond to north of downtown Atlanta, downtown Atlanta and immediately east of the primary urban expansion of the CBD. Similar regions are also evident when examining lightning flash densities surrounding the Atlanta area during southwesterly, calm and westerly 700 hPa flow (Rose et al., 2008). Additional enhanced, high-reflectivity zones are found in southern Fulton and Clayton counties, located south of downtown Atlanta (Figures 3a and b). These regions are also collocated with high-density urban expansion south of the Atlanta CBD.

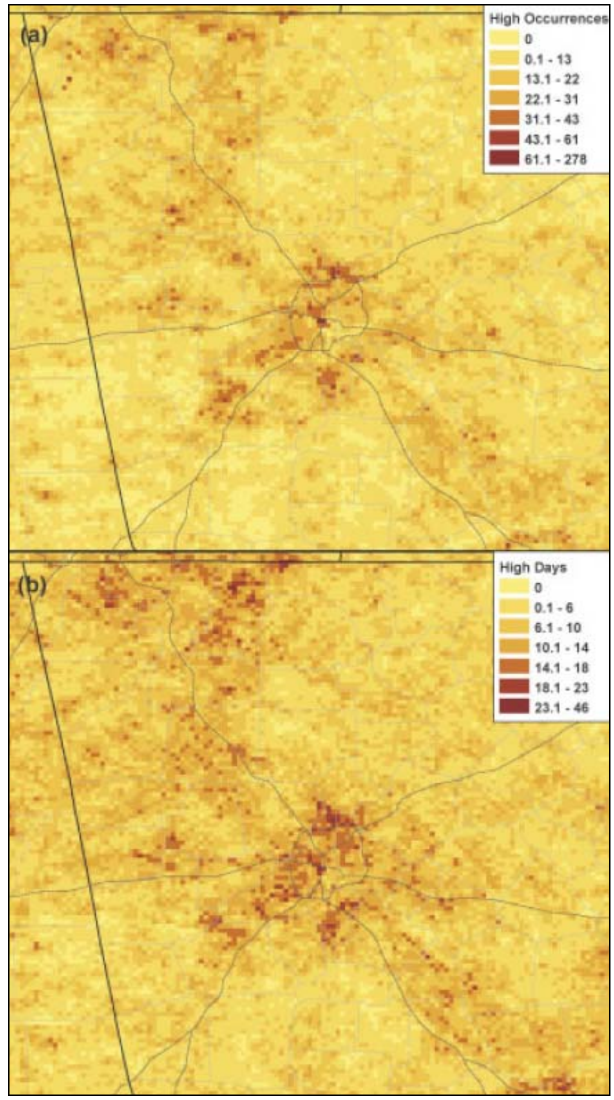

Figure 3. a) The frequency of high composite reflectivity (55dBZ or greater) occurrences for each 2km grid cell. b) The frequency of high composite reflectivity (55dBZ or greater) days for each 2km grid cell.

4. CONCLUSION

Previous observational and modeling investigations have identified areas north and south of Atlanta susceptible to rainfall enhancement (Craig and Bornstein, 2002; Shepherd et al., 2002; Dixon and Mote, 2003; Mote et al., 2007; Diem, 2007; Shem and Shepherd, 2009). Our findings provide further observational support for many of these locations; however, the strongest and most persistent maximum of medium- and high-reflectivities occurs directly over the center of Atlanta. Modeling studies suggest that warm season, synoptically benign time periods allow the UHI to intensify and therefore augment convective activity close to the primary source of heating (Theilen et al., 2000). In addition, urban morphological parameters (building height, roughness length) can significantly alter the dynamic and thermodynamic response in convective processes. Surface roughness, being greater in downtown Atlanta, may also lead to an anomaly of medium- and high-reflectivities over the city center. Evidence suggests, that the UHI and urban morphology may combine to produce the downtown anomaly while thunderstorm bifurcation and the UHI-induced circulations on the fringes of the urban land cover lead to the suburban maxima (Niyogi et al. 2006). Shem and Shepherd (2009) find that the urban-induced convergence starts on the fringe of the land cover and later establishes itself in the main urban core.

Investigations of lightning densities surrounding Atlanta identified activity “hotspots” in eastern Cobb, central Fulton, and central Gwinnett counties (Stallins and Bentley, 2006). We found correlating regions of medium- and high-reflectivity enhancement except within Gwinnett county. In addition, Gwinnett county was also an area of considerable downwind flash augmentation during periods of 700hPa westerly flow (Rose et al., 2008). When stratifying the reflectivity dataset by 700hPa westerly flow, the predominant flow pattern (95 days), there was no reflectivity enhancement evident. Therefore, evidence suggests that mechanisms, in addition to those associated with the UHI, are likely augmenting the lightning activity downwind of Atlanta. These mechanisms may include aerosol size and concentration, as they can exert a strong influence on the strength and timing of updrafts, downdrafts and thunderstorm modulation in urban areas (Van Den Heever and Cotton, 2007; Jin and Shepherd, 2008).

The enhancement of medium- to high-reflectivity episodes during warm season, synoptically benign weather regimes directly over downtown Atlanta coincides with previous research examining urban convective development during light winds (Bornstein and LeRoy, 1990; Bornstein and Lin, 2000). The secondary maxima of enhanced reflectivities found along the periphery of downtown Atlanta would coincide with the focusing of bifurcated thunderstorms around the urban center during stronger regional flows (Bornstein and Lin, 2000; Ntelekos et al., 2008). The downtown and periphery enhancement also coincide with thermally direct lift and convergence from UHI induced circulation cells that develop in response to both high- and low-density development (Shepherd, 2005; Stone and Norman, 2006).

Evidence suggests, that the UHI mechanisms responsible for convective development are related to the scales of analysis and the dynamism of urban areas in general. The longer the time frame, the more widely distributed the expression of urban enhancement. Modeling studies that recreate or parameterize a particular event or set of conditions will not document all the combinations of natural and anthropogenic conditions. Modeling offers a coarse permutation of the range of actual atmospheric and land surface properties. Specific combinations of land use and atmospheric configuration may have been common in the past but are no longer as strongly expressed.

Rather than attempting to summarize conflicting evidence as to the validity of each mechanism, the mechanistic hypotheses should be taken as a rationale for continued urban weather research. Short-term process modeling and longer term climatological visualizations are needed to sew these competing hypotheses together. A pluralistic view is strategic until the data sets and techniques are in place for a robust fusion of the different scalar influences. Future research will focus on analyzing local and regional flow patterns during medium- and high-reflectivity episodes. In addition, a regional examination of the importance of topographic features on initiating/enhancing convection during moist-tropical warm season days in the southeastern U.S. is expected to yield insights into the relative importance of topography versus land use/land cover in modulating moderate to strong thunderstorm activity. Both of these endeavors will utilize the comprehensive radar database developed through this investigation.

Acknowledgements: The authors wish to thank Phil Young and Rick Schwantes of the Advanced Geospatial Laboratory for their technical expertise and equipment. Portions of this research were supported by National Science Foundation Grant #0649343.

5. REFERENCES

Available upon request.