1-1-2010

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Original Citation

Bentley, M.L., W.S. Ashley, and J.A. Stallins, 2010 "Climatological Radar Delineation of Urban Convection for Atlanta, Georgia" International Journal of Climatology, 30, 1589-1594

INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. **30**: 1589–1594 (2010)
Published online 29 September 2009 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/joc.2020

Short Communication

Climatological radar delineation of urban convection for Atlanta, Georgia

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ABSTRACT: The distribution of warm season (June through August) thunderstorm activity surrounding Atlanta, Georgia from 1997 to 2006 was determined utilizing composite reflectivity data obtained from the network of National Weather Service radars. The radar data, at 2 km and 5 min spatial and temporal resolutions, allows for high resolution analyses of urban convective trends when grid averaged over a 10-year period.

Maxima of medium- to high-reflectivity episodes were identified to the north of and within downtown Atlanta and immediately east of the primary urban expansion of the central business district (CBD). Additional enhanced, high-reflectivity areas are found in southern Fulton and Clayton counties, located south of downtown Atlanta. These regions are also collocated with high-density urban expansion south of the Atlanta CBD. The research presented is the most comprehensive spatial and temporal analysis of grid averaged composite reflectivity data for urban convection conducted to date.

KEY WORDS radar; climatology; thunderstorm; urban; Atlanta

Received 13 April 2009; Revised 10 August 2009; Accepted 15 August 2009

1. Introduction

Changes in land cover can alter climate and meteorological processes (Pielke, 2002; Pielke *et al.*, 2007). Rapid urbanization forms urban heat islands (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). The UHI-enhanced or -initiated convection can increase precipitation and lightning on the periphery or downwind of the urban centre (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 US is more than 1 12 610 km^2 (approximately the area of Ohio; Elvidge *et al.*, 2004). In addition, 80% of the US 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 to 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 2 km and 5 min spatial and temporal resolutions, allows for high resolution analyses of urban convective trends when grid averaged over a 10-year period.

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 project generated an urban-induced thunderstorm database for Atlanta, GA using space-borne precipitation radar (Shepherd *et al.*, 2004). Other

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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 US 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 12-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 to 2006. This time span was chosen as the network of NWS WSR-88Ds surrounding Atlanta was calibrated and fully functional.

3. Methods

Our analyses incorporate NOWrad™ national composites of WSR-88D reflectivity data produced by Weather Services, Incorporated (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 $1^\circ \times 1^\circ$ from each radar were converted to Cartesian units with temporal, spatial and reflectivity intervals of 5 min, 2 km $\times$ 2 km and 5 dBZ, respectively. Each grid point's value is the largest reflectivity measured in a 5 min interval by any radar in a column above the grid cell, with a qualifier that reflectivity from radars within 230 km of the cell are given priority over radars beyond 230 km. Automated computer algorithms at WSI filter poor data from individual WSR-88Ds and from the national composites. This pre-processing removes some artefacts 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).

The warm season months (June through August) were extracted from the NOWrad 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). The SSC classifies seven different weather types, including transitional days between a specific air mass (Sheridan, 2002). We culled moist tropical (MT), moist tropical plus

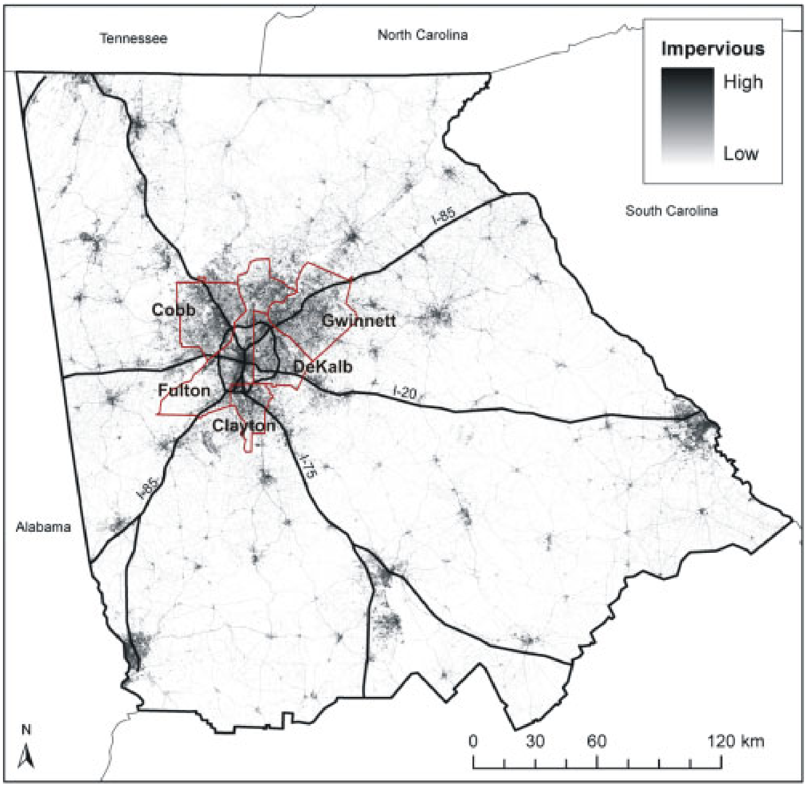

Figure 1. Counties and per-pixel estimates of percent imperviousness for the study region (Homer *et al.*, 2004). Pixel size is 30 m. This figure is available in colour online at wileyonlinelibrary.com/journal/joc

(MT+) and moist tropical plus-plus (MT++) days from the dataset as this is when deep, moist convection is most susceptible to UHI effects (Dixon and Mote, 2003). 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 dataset 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 and 55 dBZ and met or exceeded 55 dBZ, respectively) will be examined in this investigation. We define 40 dBZ 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-min 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, the more radars that 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 centred on grid cells with three overlapping radars. Three radar coverages were chosen as it encompasses the majority of the grid cells in the study region. Normalization was not necessary for medium-reflectivity data as radar density differences did not counteract the much larger number of reflectivity occurrences (Gorokhovich and Villarini, 2005).

4. Results

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 central business district (CBD). Eastern Cobb, central Fulton, northern DeKalb and southern Gwinnett counties exhibit a large number of medium-reflectivity occurrences (Figure 2(a)). The region is over and slightly north of the centre 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 2(b)). 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 3(a)). Central and northern Fulton county as well as northern DeKalb county contain regions where high reflectivities were recorded for over 215 min. In addition, the Atlanta city centre contains grid cells registering 335 min of high-reflectivity. These regions also correspond to maxima

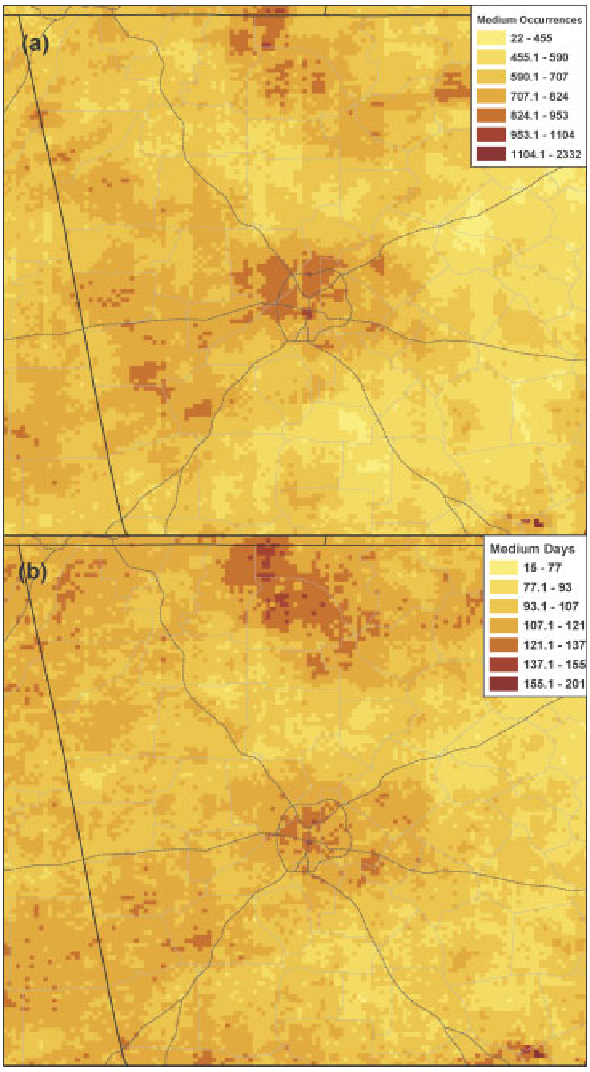

Figure 2. (a) The frequency of medium-composite reflectivity (40, 45, or 50 dBZ) occurrences for each 2 km grid cell. (b) The frequency of medium-composite reflectivity (40, 45, or 50 dBZ) days for each 2 km grid cell. This figure is available in colour online at wileyonlinelibrary.com/journal/joc

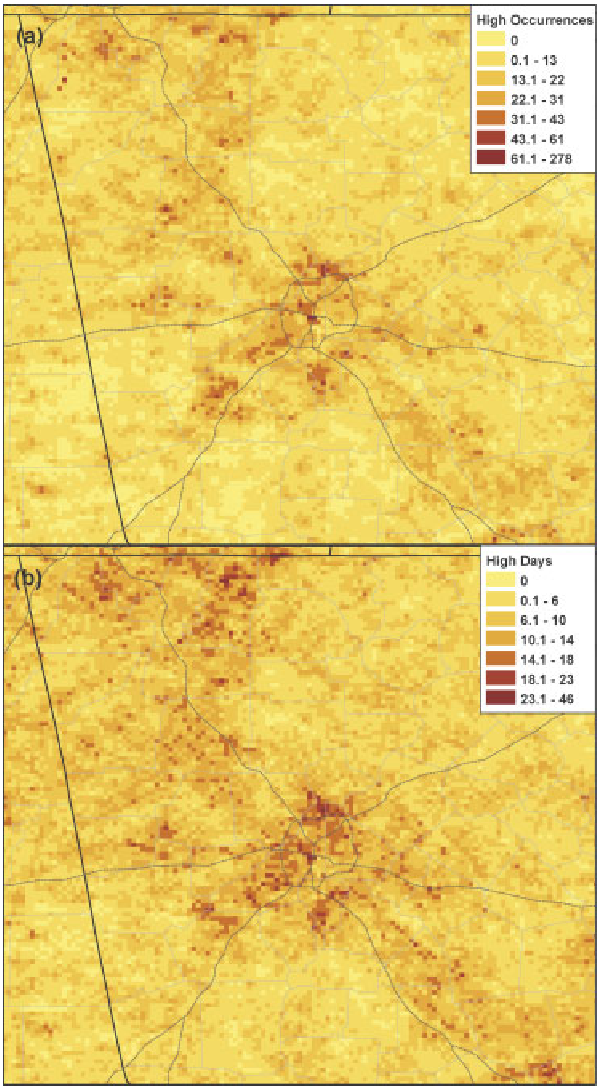

Figure 3. (a) The frequency of high-composite reflectivity (55 dBZ or greater) occurrences for each 2 km grid cell. (b) The frequency of high-composite reflectivity (55 dBZ or greater) days for each 2 km grid cell. This figure is available in colour online at wileyonlinelibrary.com/journal/joc

in high-reflectivity days (Figure 3(b)). Portions of Fulton county experienced more than 28 days of high-reflectivity events. The collocation 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.

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 south westerly, 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 (Figure 3(a) and (b)). These regions are also collocated with high-density urban expansion south of the Atlanta CBD.

5. Conclusions

Previous observational and modelling 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 centre of Atlanta. Modelling 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 (Thielen *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 centre. 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 700 hPa westerly flow (Rose *et al*., 2008). When stratifying the reflectivity dataset by 700 hPa 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 centre 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. Modelling studies that recreate or parameterize a particular event or set of conditions will not document all the combinations of natural and anthropogenic conditions. Modelling 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 modelling and longer term climatological visualizations are needed to sew these competing hypotheses together. A pluralistic view is strategic until the datasets and techniques are in place for a robust fusion of the different scalar influences. Future research will focus on analysing local and regional flow patterns during medium- and high-reflectivity episodes. In addition, a regional examination of the importance of topographic features on initiating or enhancing convection during moist-tropical warm season days in the southeastern US is expected to yield insights into the relative importance of topography *versus* land use or land cover in modulating moderate to strong thunderstorm activity. Both of these endeavours 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 No. 0649343.

References

Ahijevych DA, Carbone RE, Davis CA. 2003. Regional-scale aspects of the diurnal precipitation cycle. Preprints. *31st International Conference on Radar Meteorology*, American Meteorological Society: Seattle, CD-ROM, 5B.3.

Balling R, Brazel S. 1987. Recent changes in Phoenix summertime diurnal precipitation patterns. *Theoretical and Applied Climatology* **38**: 50–54.

Bentley ML, Stallins JA. 2005. Climatology of cloud-to-ground lightning in Georgia, USA, 1992–2003. *International Journal of Climatology* **25**: 1979–1996.

Bornstein R, LeRoy M. 1990. Urban barrier effects on convective and frontal thunderstorms. Preprints. *Conference on Mesoscale Processes*. American Meteorological Society: Boulder; 25–29.

Bornstein R, Lin Q. 2000. Urban heat islands and summertime convective thunderstorms in Atlanta: three cases studies. *Atmospheric Environment* **34**: 507–516.

Court A, Griffiths JF. 1981. Thunderstorm climatology. In *Thunderstorm Morphology and Dynamics*, Kessler E (ed.) University of Oklahoma Press; 9–39.

Craig K, Bornstein R. American Meteorological Society 2002. MM5 simulation of urban induced convective precipitation over Atlanta. Preprints. *Fourth Conference on the Urban Environment*, Norfolk, Virginia, 5–6.

Diem J. 2007. Detecting summer rainfall enhancement within metropolitan Atlanta, Georgia USA. *International Journal of Climatology* **28**(1): 129–133.

Dixon PG, Mote TL. 2003. Patterns and causes of Atlanta's urban heat island-initiated precipitation. *Journal of Applied Meteorology* **42**: 1273–1284.

Elvidge CD, Milesi C, Dietz JB, Tuttle BT, Sutton PC, Nemani R, Vogelmann JE. 2004. U.S. constructed area approaches the size of Ohio. *Eos Transactions* AGU, **85**: 233.

Falconer PD. 1984. A radar-based climatology of thunderstorm days across New York state. *Journal of Climate and Applied Meteorology* **23**: 1115–1120.

Gorokhovich Y, Villarini G. 2005. Application of geographic information system for processing and establishing correlation between weather radar reflectivity and precipitation data. *Meteorological Applications* **12**(1): 91–99.

Hand L, Shepherd JM. 2009. An investigation of warm season spatial rainfall variability in Oklahoma City: possible linkages to urbanization and prevailing wind. *Journal of Applied Meteorological Climatology* **48**(2): 251–269.

Homer C, Huang CQ, Yang LM, Wylie B, Coan M. 2004. Development of a 2001 national land-cover database for the United States. *Photogrammetric Engineering and Remote Sensing* **70**: 829–840.

Jin M, Shepherd JM. 2008. Aerosol relationships to warm season clouds and rainfall at monthly scales over east China: urban land versus ocean. *Journal of Geophysical Research* **113**: D24S90, 12.

Maddox RA, Zhang J, Gourley JJ, Howard KW. 2002. Weather radar coverage over the contiguous United States. *Weather Forecasting* **17**: 927–934.

Murphy MS, Konrad CE II. 2005. Spatial and temporal patterns of thunderstorm events that produce cloud-to-ground lightning in the interior Southeastern United States. *Monthly Weather Review* **133**: 1417–1430.

Mote TL, Lacke MC, Shepherd JM. 2007. Radar signatures of the urban effect on precipitation distribution: a case study for Atlanta, Georgia. *Geophysical Research Letters* **34**: L20710.

Niyogi D, Pielke RA Sr, Adegoke J, Chang HI, Chase T, Douglas E, Gupte M, Marshall C, Matsui T, Pyle PC, Shepherd M. 2006. Considering the role of aerosols and land-atmosphere interactions related to agriculture and urbanization in climate studies. *Annual Meeting of American Association of Geographers*, Chicago, March 2006.

Ntelekos AA, Smith JA, Krajewski WF. 2008. Climatological analyses of thunderstorms and flash floods in the Baltimore metropolitan region. *Journal of Hydrometeorology* **8**: 88–101.

Orville RE, Huffines G, Nielsen-Gammon J, Zhang RY, Ely B, Steiger S, Phillips S, Allen S, Read W. 2001. Enhancement of cloud-to-ground lightning over Houston, Texas. *Geophysical Research Letters* **28**: 2597–2600.

Parker MD, Knievel JC. 2005. Do meteorologists suppress thunderstorms? Radar-derived statistics and the behavior of moist convection. *Bulletin of the American Meteorological Society* **86**: 341–358.

Pielke RA Sr. 2002. *Mesoscale Meteorological Modeling*. Academic Press: New York, 676.

Pielke RA Sr, Nielsen-Gammon J, Davey C, Angel J, Bliss O, Doesken N, Cai M, Fall S, Niyogi D, Gallo K, Hale R, Hubbard K, Lin X, Li H, Raman S. 2007. Documentation of uncertainties and biases associated with surface temperature measurement sites for climate change assessment. *Bulletin of the American Meteorological Society* **88**: 913–928.

Rickenbach TM, Rutledge SA. 1998. Convection in TOGA COARE: horizontal scale, morphology, and rainfall production. *Journal of Atmospheric Sciences* **55**: 2715–2729.

Roberts RD, Wilson JW. 1989. A proposed microburst nowcasting procedure using single-Doppler radar. *Journal of Applied Meteorology* **28**: 285–303.

Rose LS, Stallins JA, Bentley ML. 2008. Concurrent cloud-to-ground lightning and precipitation enhancement in the Atlanta, Georgia (USA) urban region. *Earth International* **12**: 1–30.

Rosenfeld D, Lohmann U, Raga GB, O'Dowd CD, Kulmala M, Fuzzi S, Reissell A, Andreae MO. 2008. Flood or drought: how do aerosols affect precipitation? *Science* **321**(5894): 1309–1313.

Selover N. 1997. Precipitation patterns around an urban desert environment topographic or urban influences? *Proceedings of the Association of American Geographers Conference*. Association of the American Geographers: Fort Worth.

Shem W, Shepherd JM. 2009. On the impact of urbanization on summertime thunderstorms in Atlanta: two numerical model case studies. *Atmospheric Environment* **43**(28): 4359–4373.

Shepherd JM. 2005. A review of current investigations of urban-induced rainfall and recommendations for the future. *Earth International* **9**: 1–27.

Shepherd JM, Burian SJ. 2003. Detection of urban-induced rainfall anomalies in a major coastal city. *Earth International* **7**: 1–17.

Shepherd JM, Pierce H, Negri AJ. 2002. Rainfall modification by major urban areas: observations from spaceborne rain radar on the TRMM satellite. *Journal of Applied Meteorology* **41**: 689–701.

Shepherd JM, Taylor L, Garza C. 2004. A dynamic multi-criteria technique for siting NASA-Clark Atlanta rain gauge network. *Journal of the Atmospheric Oceanic Technology* **21**: 1346–1363.

Sheridan SC. 2002. Redevelopment of a weather-type classification scheme for North America. *International Journal of Climatology* **22**: 51–68.

Stallins JA, Bentley ML. 2006. Urban lightning climatology and GIS: an analytical framework from the case study of Atlanta, Georgia. *Applied Geography* **26**: 242–259.

Stone B, Norman JM. 2006. Land use planning and surface heat island formation: a parcel-based radiation flux approach. *Atmospheric Environment* **40**: 3561–3573.

Thielen J, Wobrock W, Gadian A, Mestayer PG, Creutin JD. 2000. The possible influence of urban surfaces on rainfall development: a sensitivity study in 2D in the mesogamma scale. *Atmospheric Research* **54**: 15–39.

Van Den Heever SC, Cotton WR. 2007. Urban aerosol impacts on downwind convective storms. *Journal of Applied Meteorology and Climatology* **46**: 828–850.

