Urban Modification of Thunderstorms: An Observational Storm Climatology and Model Case Study for the Indianapolis Urban Region*

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ABSTRACT

A radar-based climatology of 91 unique summertime (May 2000–August 2009) thunderstorm cases was examined over the Indianapolis, Indiana, urban area. The study hypothesis is that urban regions alter the intensity and composition/structure of approaching thunderstorms because of land surface heterogeneity. Storm characteristics were studied over the Indianapolis region and four peripheral rural counties approximately 120 km away from the urban center. Using radar imagery, the time of event, changes in storm structure (splitting, initiation, intensification, and dissipation), synoptic setting, orientation, and motion were studied. It was found that more than 60% of storms changed structure over the Indianapolis area as compared with only 25% over the rural regions. Furthermore, daytime convection was most likely to be affected, with 71% of storms changing structure as compared with only 42% at night. Analysis of radar imagery indicated that storms split closer to the upwind urban region and merge again downwind. Thus, a larger portion of small storms (50–200 km^2) and large storms (>1500 km^2) were found downwind of the urban region, whereas midsized storms (200–1500 km) dominated the upwind region. A case study of a typical storm on 13 June 2005 was examined using available observations and the fifth-generation Pennsylvania State University–NCAR Mesoscale Model (MM5), version 3.7.2. Two simulations were performed with and without the urban land use/Indianapolis region in the fourth domain (1.33-km resolution). The storm of interest could not be simulated without the urban area. Results indicate that removing the Indianapolis urban region caused distinct differences in the regional convergence and convection as well as in simulated base reflectivity, surface energy balance (through sensible heat flux, latent heat flux, and virtual potential temperature changes), and boundary layer structure. Study results indicate that the urban area has a strong climatological influence on regional thunderstorms.

1. Introduction

Land use/land cover (LULC) change and resulting urbanization can affect regional weather and climate (Pielke and Niyogi 2009). Heterogeneities in land surface characteristics such as urban–rural interfaces tend to form mesoscale boundaries that can often be conducive to convective initiation or enhancement of preconvection (Changnon 1981; Holt et al. 2006). The change in natural landscape in urban areas can cause changes in temperature (Hafner and Kidder 1999; Zhou and Shepherd 2009), mesoscale convection (Niyogi et al. 2006; Thompson et al. 2007; Miao and Chen 2008), and precipitation amounts (Jauregui and Romales 1996; Bornstein and Lin 2000; Shepherd and Burian 2003; Mote et al. 2007; Rose et al. 2008; Shem and Shepherd 2009; Hand and Shepherd 2009; Bentley et al. 2010; Zhang et al. 2009; Shepherd et al. 2010; M. Lei and D. Niyogi 2010, unpublished manuscript) and can alter regional climate (Oke 1988) by changing regional temperatures (Zhou et al. 2004; Fall et al. 2009) as well as heavy-rainfall trends (Kishtawal et al. 2010).

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