FACTOR SEPARATION ANALYSIS OF URBAN IMPACTS ON A SIMULATED SUPERCELL

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EXECUTIVE SUMMARY

The effect of urban areas on weakly forced precipitation events is well documented and the mechanisms by which this happens are generally understood. However, the effects of urban areas on precipitation systems in synoptically active regimes, particularly severe convection, are relatively unstudied. This investigation used the ARW–WRF model to simulate an isolated supercell interacting with a large Great Plains urban area. We used a factor separation approach to determine the relative importance of roughness and thermal characteristics of urban areas on storm modification. Results generally suggest that surface roughness and its interactions with thermodynamic properties are the dominant contributors to urban-induced effects on storm strength and evolution. Additionally, the amplitude of interactions between shear and thermodynamic modifications is often similar in magnitude to either effect individually.

RESEARCH CHALLENGE

Earth's population is increasingly concentrated in urban areas, with nearly two-thirds of the world's population expected to live in urban areas by 2050. As the number of people within cities grows, it is becoming more important to understand, and to be able to correctly predict, the interactions between urban environments and the atmosphere. As such, many studies have investigated the effect of urban areas on weakly forced precipitation systems. However, interactions between urban areas and synoptically-active convection, such as supercells, remain relatively unexamined. In order to truly understand the nature of these interactions, and thus provide city planning recommendations for the future, it is important to ascertain whether the urban heat island or slower winds induced by increased urban surface roughness result in greater storm modifications.

METHODS & CODES

Using the Weather Research and Forecasting (WRF) [1] model, a community mesoscale numerical weather prediction model, we conducted a total of 334 simulations of a supercell thunderstorm to quantify the impacts of a large Great Plains urban area on the evolution and strength of a supercell thunderstorm. In order to properly resolve complex urban structure, all simulations were run on a 500-m horizontal grid over a 250-km x 250-km grid. In addition, to well resolve the atmospheric boundary layer, we used 120 vertical grid points, with 20 of those points in the lowest 1.5 km above ground. In all, we integrated more than 29.7 million points over 75,600 timesteps for each simulation. Ten of the simulations contained homogeneous land use (CTRLE) to serve as a comparison point for simulations with urban areas. An urban area simulated to have both increased surface roughness and thermal properties characteristic of man-made surfaces (i.e., full physics; ORIG) was placed in 108 gridded locations throughout the domain to determine effects of the city-relative path of the storm. We performed two additional simulations for each urban location: one with only increased surface roughness over the city (ROUG), and one with only the different thermal properties of the urban area represented (THER).

RESULTS & IMPACT

Full- and single-physics urban simulations were compared to CTRLE, with the aid of hierarchical clustering analysis (HCA) to form statistically similar groups of simulations. In this analysis, we investigated the effects of the storm having various city-relative paths, as well as the storm lifecycle stage during urban interactions. These comparisons concentrate on differences in boundary layer characteristics prior to storm formation to establish how the urban effects on the prestorm environment are being represented, as well as changes in supercell structure, dynamics, and evolution. Analyses of the data are still underway, but early results suggest that groups of simulations (each with an urban area in a unique location) that are significantly similar have cities that are more geographically co-located (and more similar to the ORIG groupings) when the urban area is only represented as a roughness element than when it is only parameterized by its thermal properties. This result suggests that urban surface roughness may play a greater role in modifying supercell characteristics than the better-known urban heat island effect.

WHY BLUE WATERS

While HCA has been used previously for attribution of variations in synoptic and mesoscale fields to various factors, this is one of the first times it has been used to analyze storm-scale modifications. Given their large scale of motion, synoptic [O(1,000 km)] and mesoscale[O(100 km)] phenomena are generally quite predictable; thus, few simulations are required to attribute variations in fields of these scales to modifications in boundary conditions and parameterization options. However, due to their inherently unpredictable nature, to attribute deviations in storm-scale [O(10 km)] phenomena to various factors in a real data (i.e., nonidealized) simulation, many simulations are required to ensure that the simulated changes are significant. The general hindrance to such an analysis is the large computational requirement; hence, the resources made available on Blue Waters were vital to this work. While each simulation was relatively small, the quantity of simulations needed to produce significant results required the large computational and data storage capacities of Blue Waters.

PUBLICATIONS & DATA SETS

Reames, L.J., and D.J. Stensrud, Influence of a Great Plains urban environment on a simulated supercell. *Monthly Weather Review*, 146 (2018), pp. 1437-1462.

Larissa Reames graduated from the University of Oklahoma in May 2017 with a PhD in meteorology. There, her work was directed by David Stensrud at Pennsylvania State University.