# The Effect of Urban Environments on Storm Evolution Through a Radar-Based Climatology of the Central United States

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"Storms, Forms, and Complexity of the Urban Canopy: How Land Use, Settlement Patterns, and the Shapes of Cities Influence Severe Weather"

# Motivation


**Objective:** Observe and explore the modification of supercell storms by urban environments in multiple cities and years.

- Supercells: 97% of fatalities, 92% of damage
- Automated multi-year, multi-radar analysis
- Four cities of varying size/shape in the Central USA
  - Central city corridor with surrounding agriculture
    - Dallas-Fort Worth, TX
    - Minneapolis, MN
    - Oklahoma City, OK
    - Omaha, NE

# Case & Storm Selection

- United States storm-typing database (Smith et al. 2012)
- Over 25K "significant severe" events
  - > 5cm hail, > 65kt wind, tornado
- 200x200km study domain
  - +/- one convective day (12z – 12z)
  - 2006 - 2013

| Urban Domain | Number of Case Dates |
|---|---|
| **Minneapolis, MN** | **215** |
| **Omaha, NE** | **304** |
| **Oklahoma City, OK** | **392** |
| **Dallas-Fort Worth, TX** | **365** |

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**Convective Modes for Significant Severe Thunderstorms in the Contiguous United States. Part I: Storm Classification and Climatology**

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ABSTRACT

Radar-based convective modes were assigned to a sample of tornadoes and significant severe thunderstorms reported in the contiguous United States (CONUS) during 2003–11. The significant hail (≥2-in. diameter), significant wind (≥65-kt thunderstorm gusts), and tornadoes were filtered by the maximum event magnitude per hour on a 40-km Rapid Update Cycle model horizontal grid. The filtering process produced 22 901 tornado and significant severe thunderstorm events, representing 78.5% of all such reports in the CONUS during the sample period. The convective mode scheme presented herein begins with three radar-based storm categories: 1) discrete cells, 2) clusters of cells, and 3) quasi-linear convective systems (QLCSs). Volumetric radar data were examined for right-moving supercell (RM) and left-moving supercell characteristics within the three radar reflectivity designations. Additional categories included storms with marginal supercell characteristics and linear hybrids with a mix of supercell and QLCS structures. Smoothed kernel density estimates of events per decade revealed clear geographic and seasonal patterns of convective modes with tornadoes. Discrete and cluster RMs are the favored convective mode with southern Great Plains tornadoes during the spring, while the Deep South displayed the greatest variability in tornadic convective modes in the fall, winter, and spring. The Ohio Valley favored a higher frequency of QLCS tornadoes and a lower frequency of RM compared to the Deep South and the Great Plains. Tornadoes with non-supercellular/non-QLCS storms were more common across Florida and the high plains in the summer. Significant hail events were dominated by Great Plains supercells, while variations in convective modes were largest for significant wind events.

**1. Introduction**

Our understanding of the convective mode has increased considerably in the past few decades, beginning with the pioneering work by Browning (1964) documenting conventional radar observations and inferred airflow within supercell thunderstorms, continuing with descriptions of organized bow echoes (Fujita 1978), and a host of more recent studies (e.g., Weisman and Trapp 2003; Trapp and Weisman 2003) examining quasi-linear convective systems (QLCSs). Convective mode is widely recognized as an important contributor to the likelihood and type of severe convective weather (e.g., tornadoes, large hail, damaging wind gusts). Prior work by Trapp et al. (2005, hereafter T05) considered a relatively simple designation of the convective mode for 3828 tornadoes in the contiguous United States (CONUS) from 1999 to 2001. They used regional radar mosaics of base-elevation reflectivity, and did not attempt to specify convective mode beyond a QLCS, cell, or "other" classification scheme. Grams et al. (2012) followed a similar scheme in classifying convective mode for 448 significant tornado events in the CONUS from 2000 to 2008. Gallus et al. (2008, hereafter G08) employed a more detailed radar reflectivity classification scheme (nine distinct convective morphologies). Like T05, G08 examined regional radar reflectivity mosaics every 30 min for 949 cases of documented convective mode, and associated all severe reports with a storm type over the Great Plains and Upper Midwest during the 2002 warm season. More recent work by Duda and Gallus (2010) considered the

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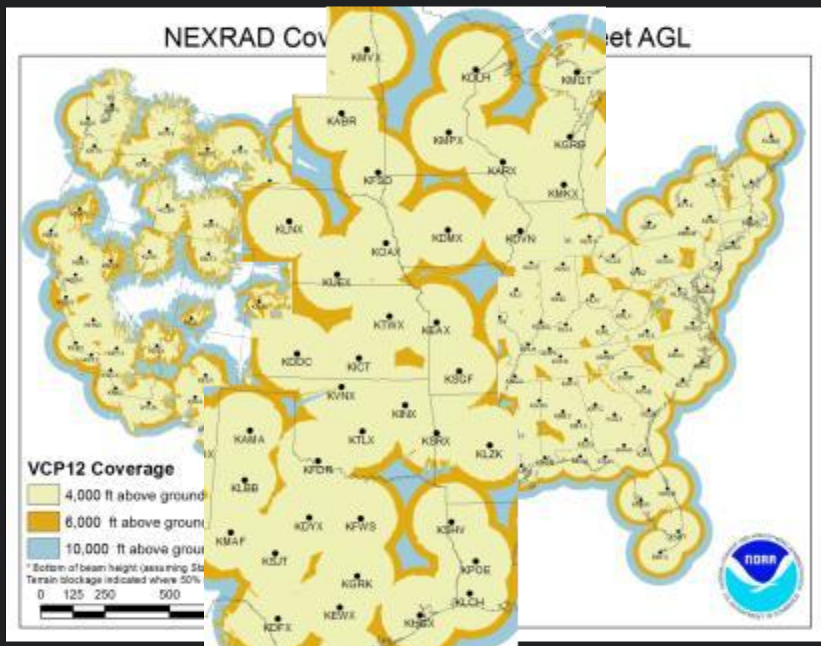
# Data

## NEXRAD Radar Network




| Urban Domain | Number of Radars |
|---|---|
| Minneapolis, MN | 12 |
| Omaha, NE | 12 |
| Oklahoma City, OK | 15 |
| Dallas-Fort Worth, TX | 17 |

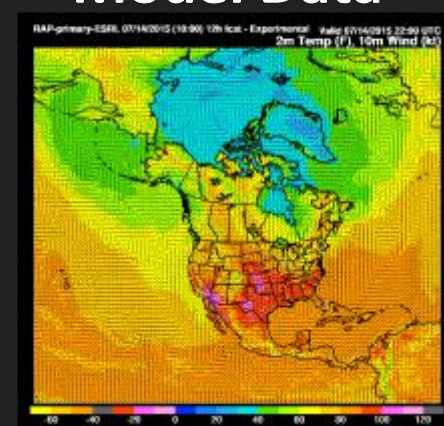
2,424,252 volumes of radar data

20.7 years of processing time

## National Lightning Detection Network (NLDN)


1,850,886 minutes of lightning data

## Model Data



31,653 hours of model data

# Methods

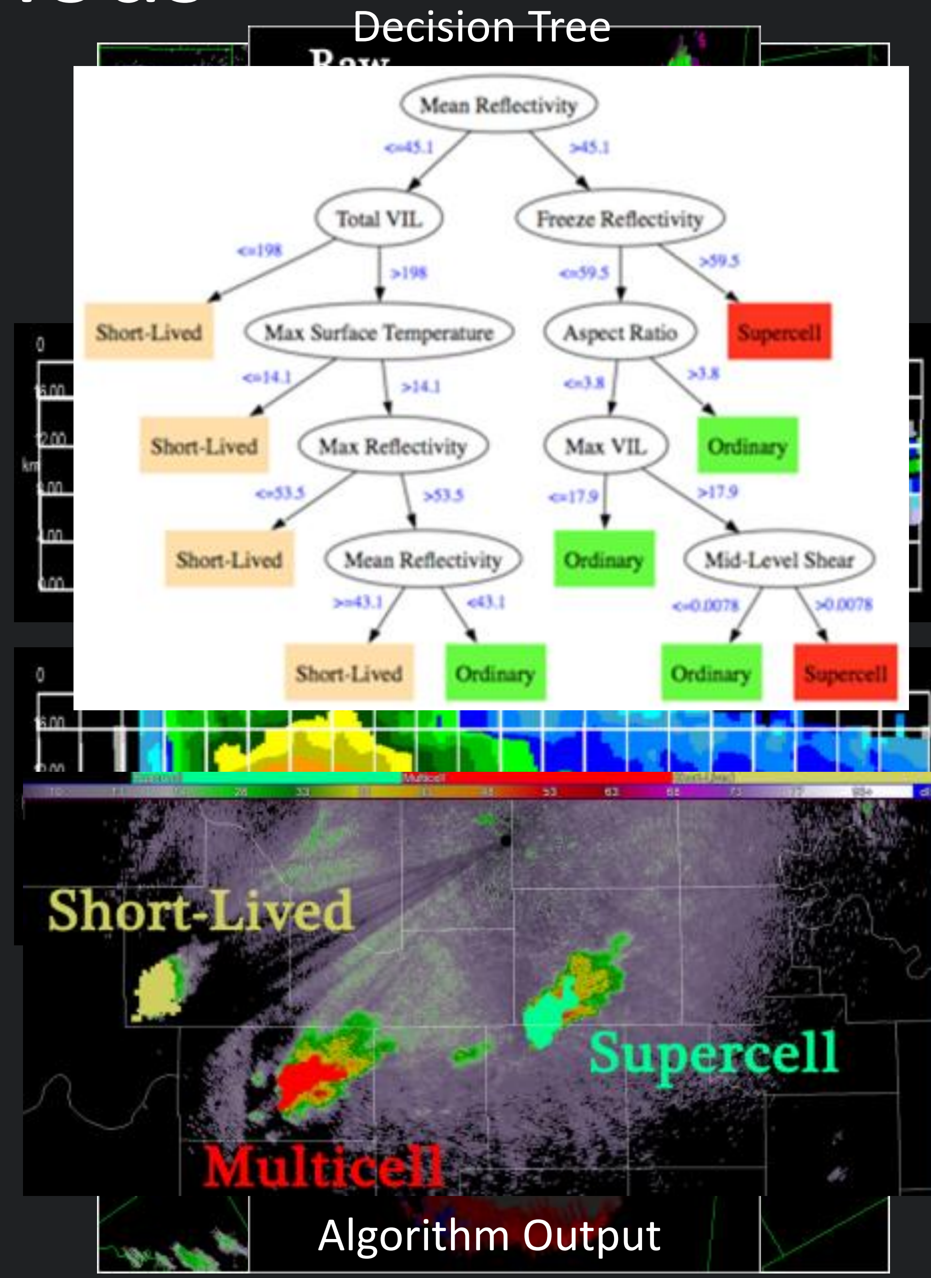
- Warning Decision Support System – Integrated Information (WDSS-II)

**Procedure**

1. Ingest & quality control single radar moments
   - Reflectivity – Neural Network
   - Velocity – Dealias & AzShear

2. Merge single-radar fields into 3D Cartesian cube
   - At least 1km/1 min. spatiotemporal resolution
   - 33 vertical levels

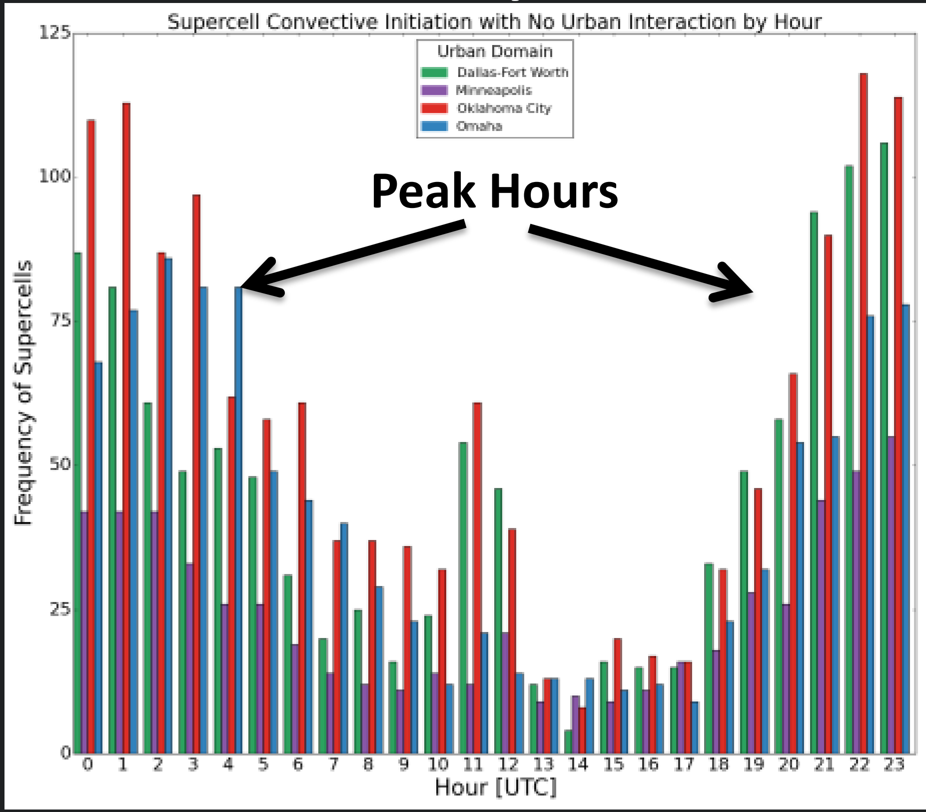
3. Automated storm-typing and tracking  track storm objects/attributes
   - Did supercell interact with urban environment?



# Spatiotemporal Frequency of Supercells (2006 – 2013)

| Urban Domain | # of Supercells | # (%) of City Interactions |
|---|---|---|
| Dallas-Fort Worth, TX (6006 km$^2$) | 1516 | 417 (27.5%) |
| Minneapolis, MN (2997 km$^2$) | 840 | 251 (29.9%) |
| Oklahoma City, OK (1284 km$^2$) | 1656 | 286 (17.3%) |
| Omaha, NE (810 km$^2$) | 1218 | 217 (17.8%) |
| Total: | 5230 | 1171 |

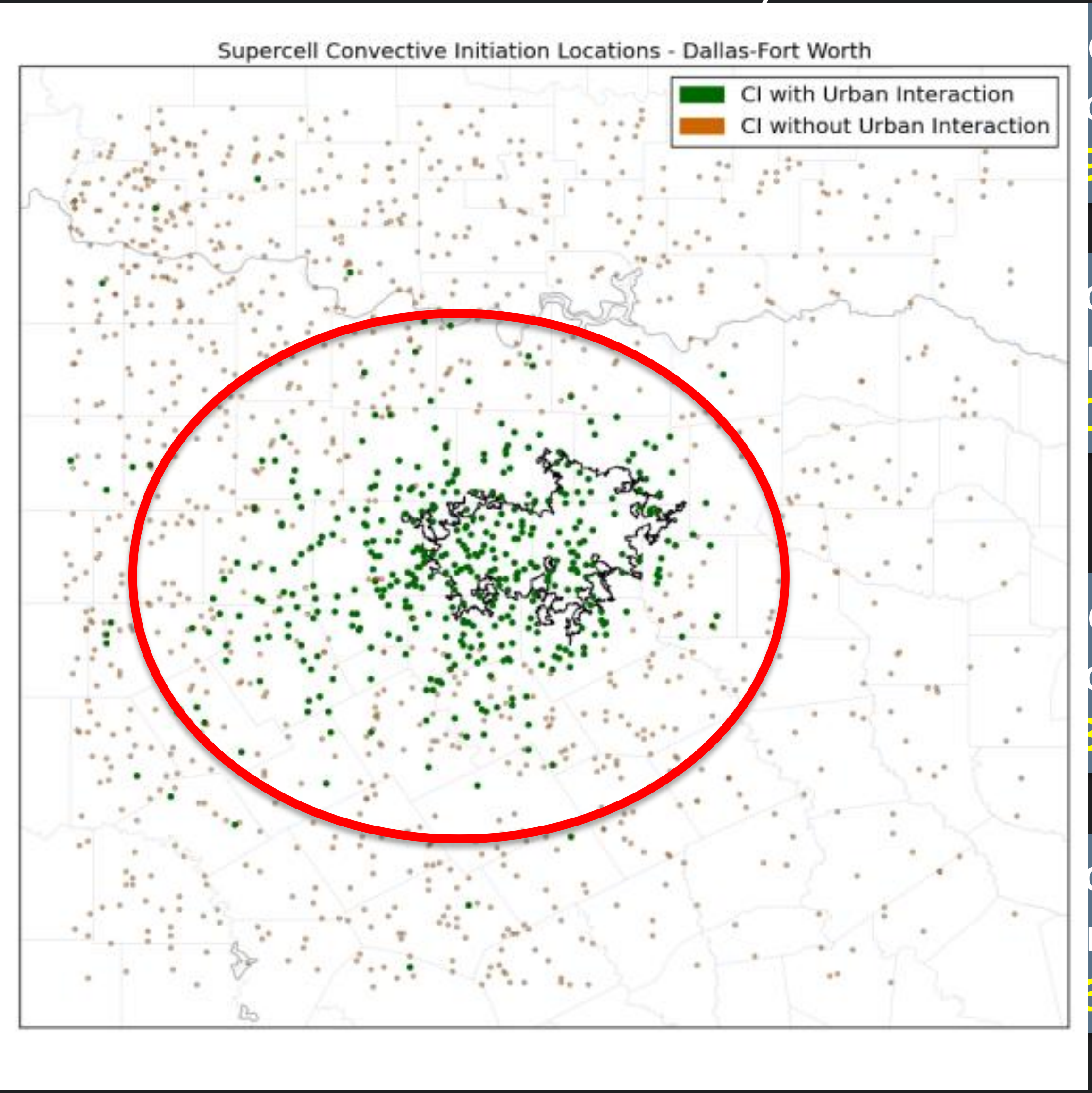
- 22.4% of all storms interacted with urban environment




- Supercells most prevalent in late afternoon/evening hours (20 – 05 UTC)

# Supercell Initiation Locations

## Dallas-Fort Worth, TX




d in urban
ome
9.1%)

d outside
n dome
0.9%)

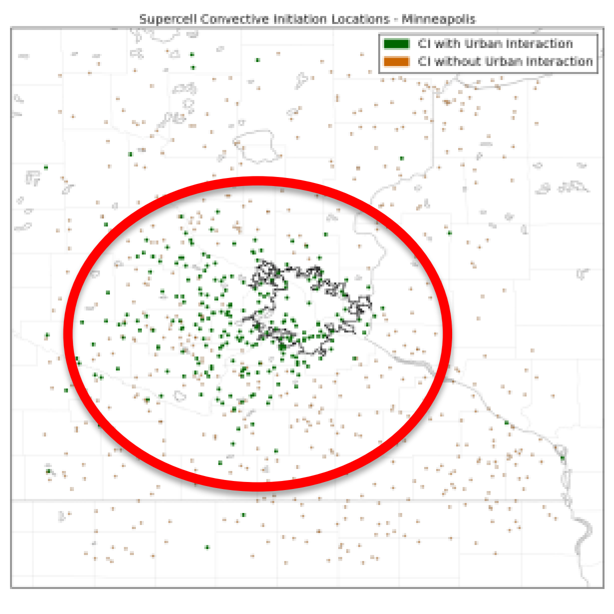
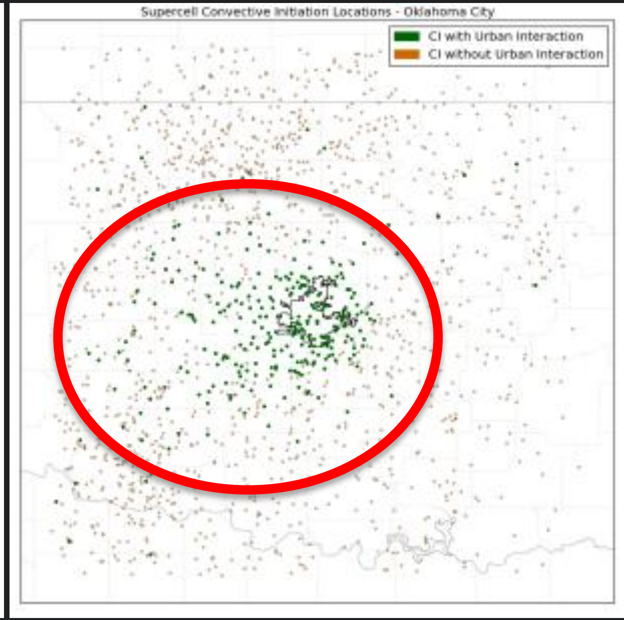
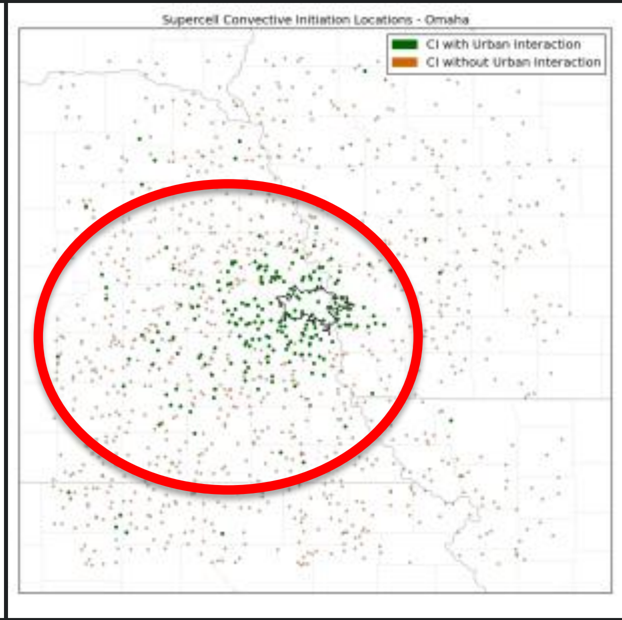
**417** Urba
Interactio

d in urban
ome
3.9%)

d outside
n dome
6.1%)

- 61.3% of
within the

# Other City Initiation Statistics

| Minneapolis, MN | Oklahoma City, OK | Omaha, NE |
|---|---|---|
|  |  |  |
| **251** Urban Interactions | **286** Urban Interactions | **217** Urban Interactions |
| **37.8%** Urban Dome Initiation | **41.3%** Urban Dome Initiation | **34.5%** Urban Dome Initiation |
| **59.7%** Killed in Urban Dome | **44.4%** Killed in Urban Dome | **47.9%** Killed in Urban Dome |

# Supercell Lifetime

| Domain | No Urban Dome Interaction | Urban Dome Interaction | Two-Sample Permutation Test | e |
|---|---|---|---|---|
| **Minneapolis, MN** | 70.7 min. | 83.6 min. | P = 0.006<br>Reject null at 99% CI | |
| **Omaha, NE** | 69.8 min. | 71.2 min. | P = 0.68; Fail to reject null | |
| **Oklahoma City, OK** | 81.3 min. | 96.7 min. | P < 0.001<br>Reject null at 99% CI | |
| **Dallas-Fort Worth, TX** | 87.6 min. | 103.9 min. | P < 0.001<br>Reject null at 99% CI | |

- Mean storm lifetime for supercells interacting with the urban dome is higher. Statistically significant at 99% CI except Omaha
- However, where a supercell forms is critical
- Supercells forming within the urban dome had lower mean lifetimes over supercells forming outside the urban dome

# Radar-Derived Metrics for Storm Intensity

- 34 radar-derived/other storm attributes tracked each minute
- Storms were sampled every 10 min. to mitigate correlation between successive observations
- Three metrics shown:
  - Maximum Expected Size of Hail (MESH)
    - Thermally weighted integration of reflectivity (> 40 dBZ) from the melting level to storm top
  - Composite Reflectivity Size > 40 dBZ
    - Total area [$km^2$] of the 40 dBZ pixels in the tracked feature
  - Cloud-to-Ground (CG) Lightning Density
    - Density of CG strikes in a 1km x 1km spatial by 1 min. temporal domain

# Storm Intensity Metric: MESH

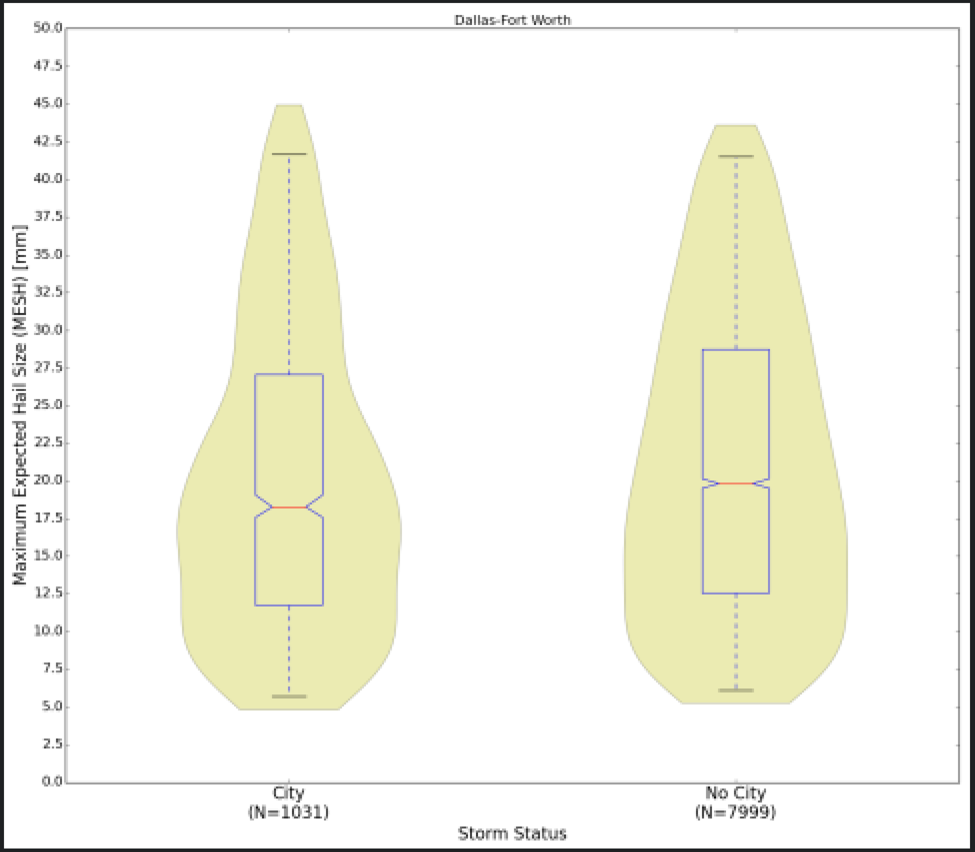
## Dallas-Fort Worth, TX & Omaha, NE

- Decline in MESH on city interacting trajectories ~ 1 mm
    - Omaha differences statistically significant at 95% CI

## Minneapolis, MN & Oklahoma City, OK

- Slight increase in mean MESH; 0.1 mm

**Dallas-Fort Worth, TX**




**City** **No City**

| Dallas-Fort Worth, TX | Minneapolis, MN | Oklahoma City, OK | Omaha, NE |
|---|---|---|---|
| -0.94 mm | +0.1 mm | +0.11 mm | -1.17 mm |

# Storm Intensity Metric: Area of Composite Reflectivity > 40 dBZ

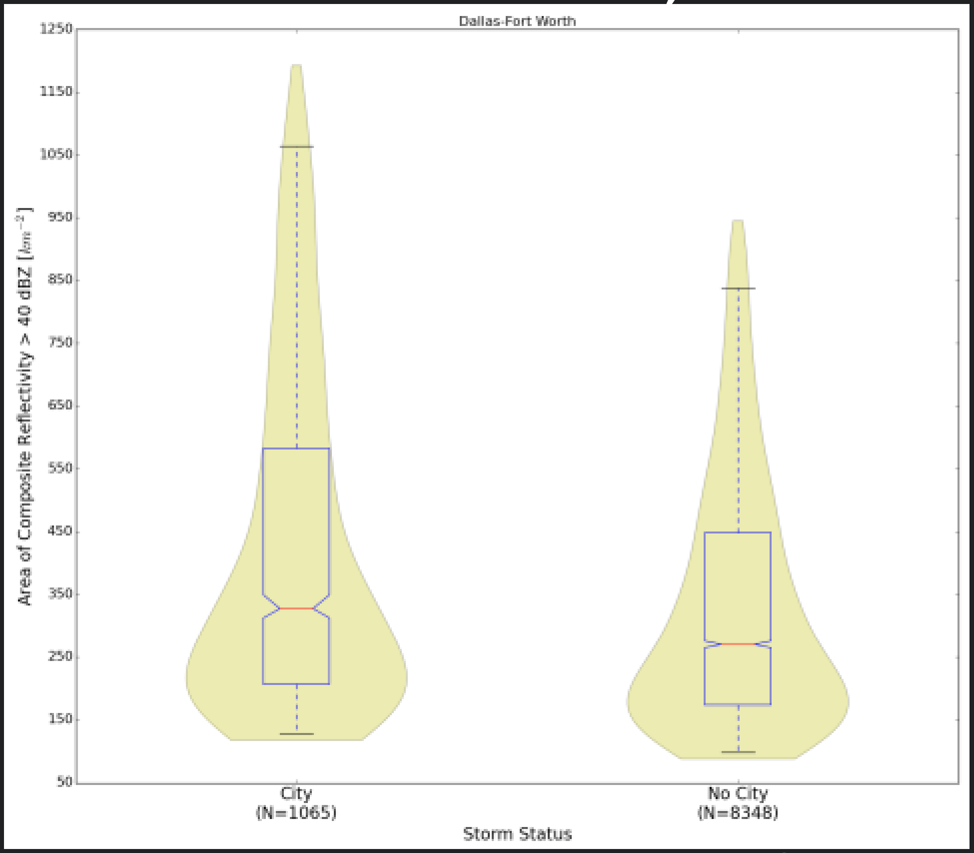
## Dallas-Fort Worth, TX, Omaha, NE, Minneapolis, MN

- City interacting trajectories had a higher overall area > 40 dBZ

## Oklahoma City, OK

- Opposite effect
- Dryline forcing, early CI?

**Dallas-Fort Worth, TX**




**City** **No City**

| Dallas-Fort Worth, TX | Minneapolis, MN | Oklahoma City, OK | Omaha, NE |
|---|---|---|---|
| +132.5 km$^2$ | +102.2 km$^2$ | -38.9 km$^2$ | +82.3 km$^2$ |

# Storm Intensity Metric: CG Lightning Density

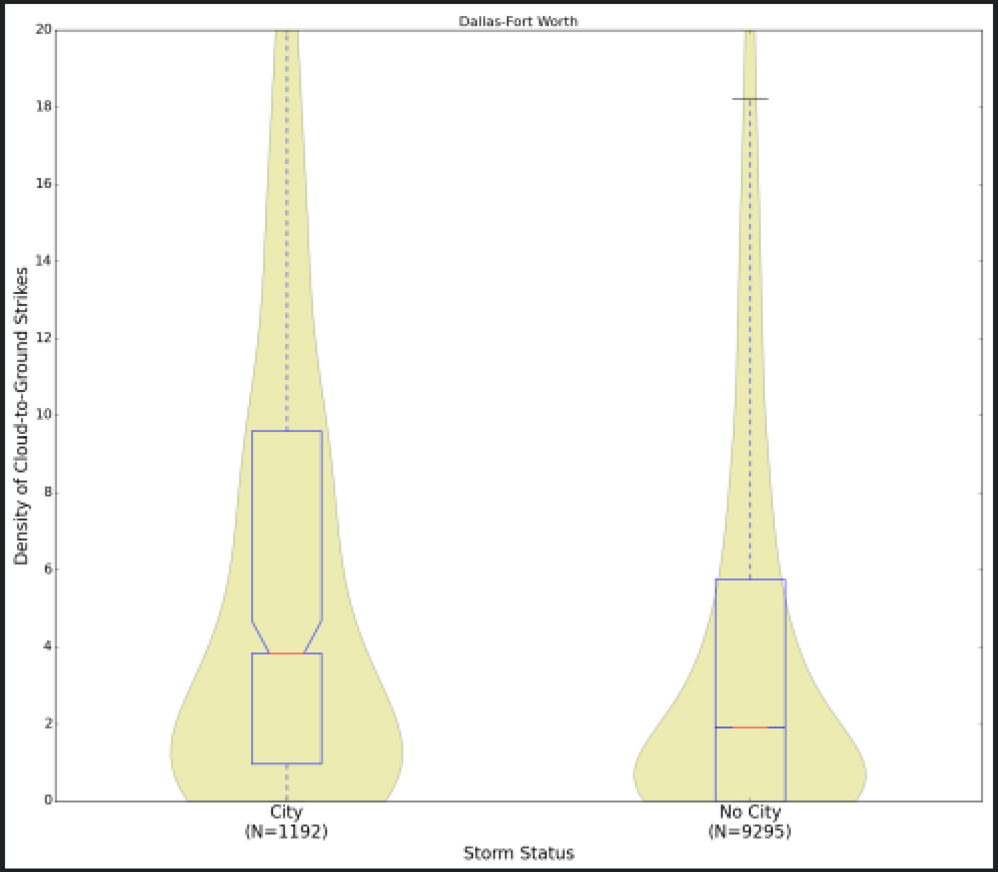
Dallas-Fort Worth, TX, Omaha, NE, Minneapolis, MN

- Higher mean CG density in storms that interact with the city

Oklahoma City, OK

- Lower mean CG density in storms that interact with the city
  - Lack of tall structures?

**Dallas-Fort Worth, TX**




**City** **No City**

| Dallas-Fort Worth, TX | Oklahoma City, OK | Omaha, NE | Minneapolis, MN |
|---|---|---|---|
| +2.8 $min^{-1}km^2$ | -0.9 $min^{-1}km^2$ | +1.0 $min^{-1}km^2$ | +0.9 $min^{-1}km^2$ |

# Summary

- **5,230 supercells tracked across 1,276 convective days from 2006-2013**
- **Storm Lifetime Analysis**
  - At least 33% of storms initiated within the urban dome
    - Larger cities had more in-dome initiations and subsequent deaths
  - At least 50% of storms formed outside urban dome end within urban dome
    - The remainder of these storms had the longest lead times
- **Radar-derived Metrics**
  - Variable magnitude of difference depending on the metric chosen
  - Largest & smallest cities showed similar trends in MESH, composite area, and CG densities
  - No single metric showed significant trend across all cities

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