An Observational Study of Urban-Modified Thunderstorms Across the Nashville Metro Area 2003-2012

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Purpose

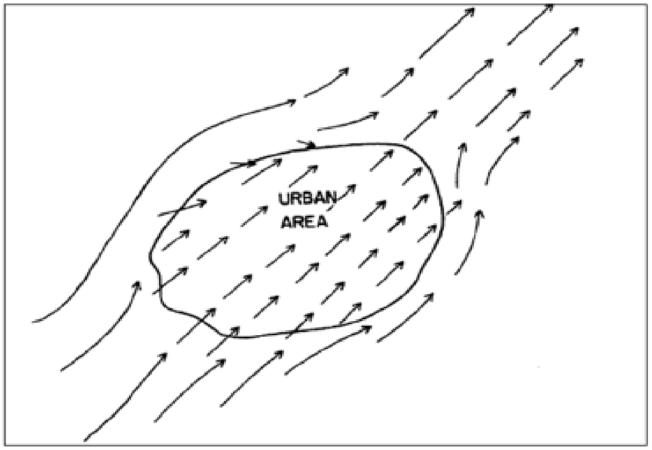
1. Identify city-storm modification events for database integration
2. Find typical atmospheric conditions for the occurrence of the phenomenon and temporal patterns of events
   - For numerical modeling purposes
3. Detect urban-storm modification identification locations within a different urban study area (ATL, IND, NYC, STL, CHI)
   - A slightly elevated terrain area is needed for research
4. Develop an objective term to identify unclassified phenomenon
   - City-thunderstorm initiation? Storm-urban modification?

Brief Background on Past Research

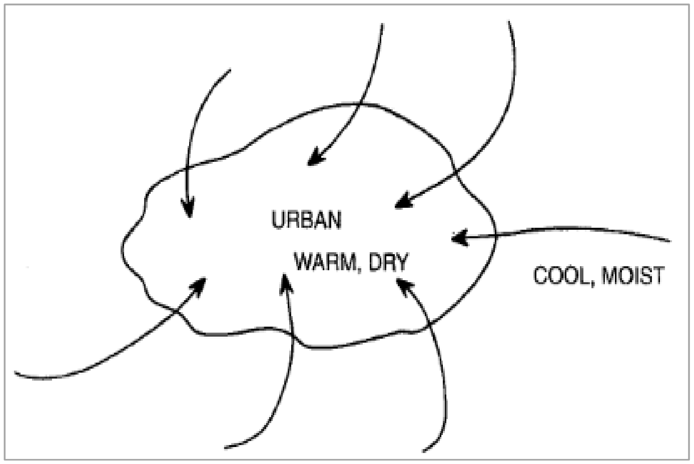
- **<u>Bornstein et al. 1990 & 2000:</u>** NYC urban barrier effect on convective & frontal storms
  - 1st to noticed storms slowed ahead & diverged around NYC-1990
  - 1st to identify urban areas form convergence regions overhead and downwind in ATL-2000
- **<u>Dixon and Mote 2003:</u>** Patterns & causes of ATL's UHI-initiated precipitation
  - Studied spatial and temporal patterns of thunderstorms in relation to land-cover around Atlanta for 5 years and found moisture played a huge role in development
- **<u>Niyogi et al. 2011:</u>** Urban Modification of Thunderstorms in Indianapolis
  - Suggested land-use and fluxes from the surface heterogeneity affect storms and movement
- **<u>Bentley et al. 2012:</u>** Synoptic environments favorable for urban convection
  - Moderate instability with excess aerosols are needed for urban-storm development in ATL.

Defining Urban-Storm Modification

- **Splitting-** divergence upwind of the city convergence downwind of city (slight flow)
- Theories:
  - Different surface fluxes (UHI)? (Niyogi et al. 2011)
  - Roughness length variations? (Rozoff et al. 2003)



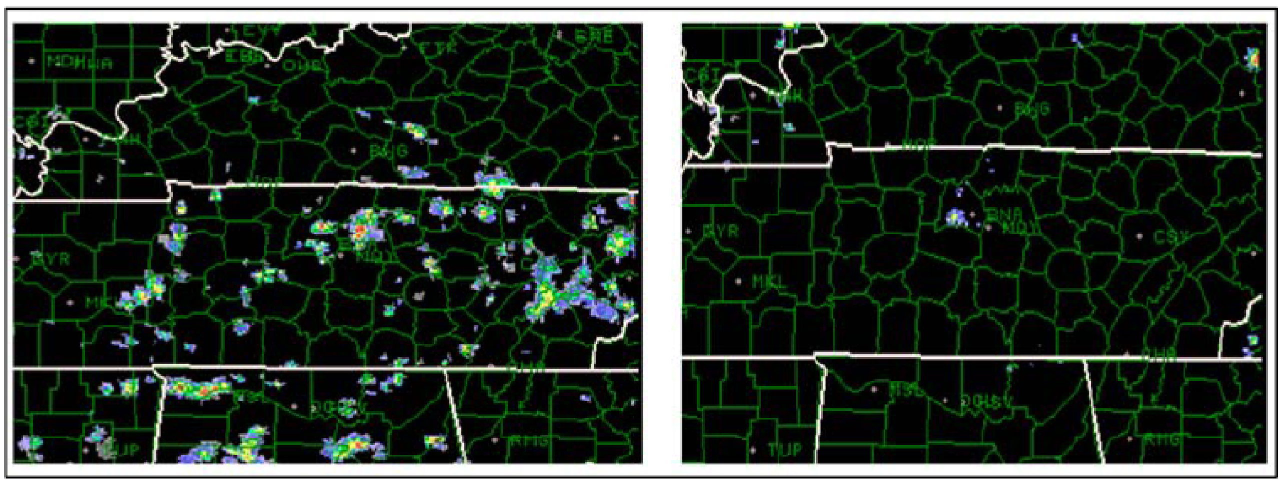
- **Initiation**- convergence overhead and on the peripherally of the city (no flow)
- Theories:
  - Convergence regions (UHI)? (Bornstein et al. 2000)
  - Increased size & concentration of CCN? (van den Heever et al. 2007)



Images from Cotton et al. 2007

Defining an urban thunderstorm

- **<u>Urban thunderstorm</u>** is a meso-gamma convective process identified by weather radar that develops over urban land-cover in weak synoptic flow and must not be initiated by any visible surface forcing features lasting for 1 to 4 hrs.
  - Weak synoptic-flow environments within 500 km of Nashville (Brown and Arnold 1998)
  - Thunderst erstorms, squall lines, and stratif ntley et al. 2012)
  - Widesprea
  - Radar spec pling the atmosphere in areas be
  - *NOTE: An
    - Niyogi et a ne Nashville analysis

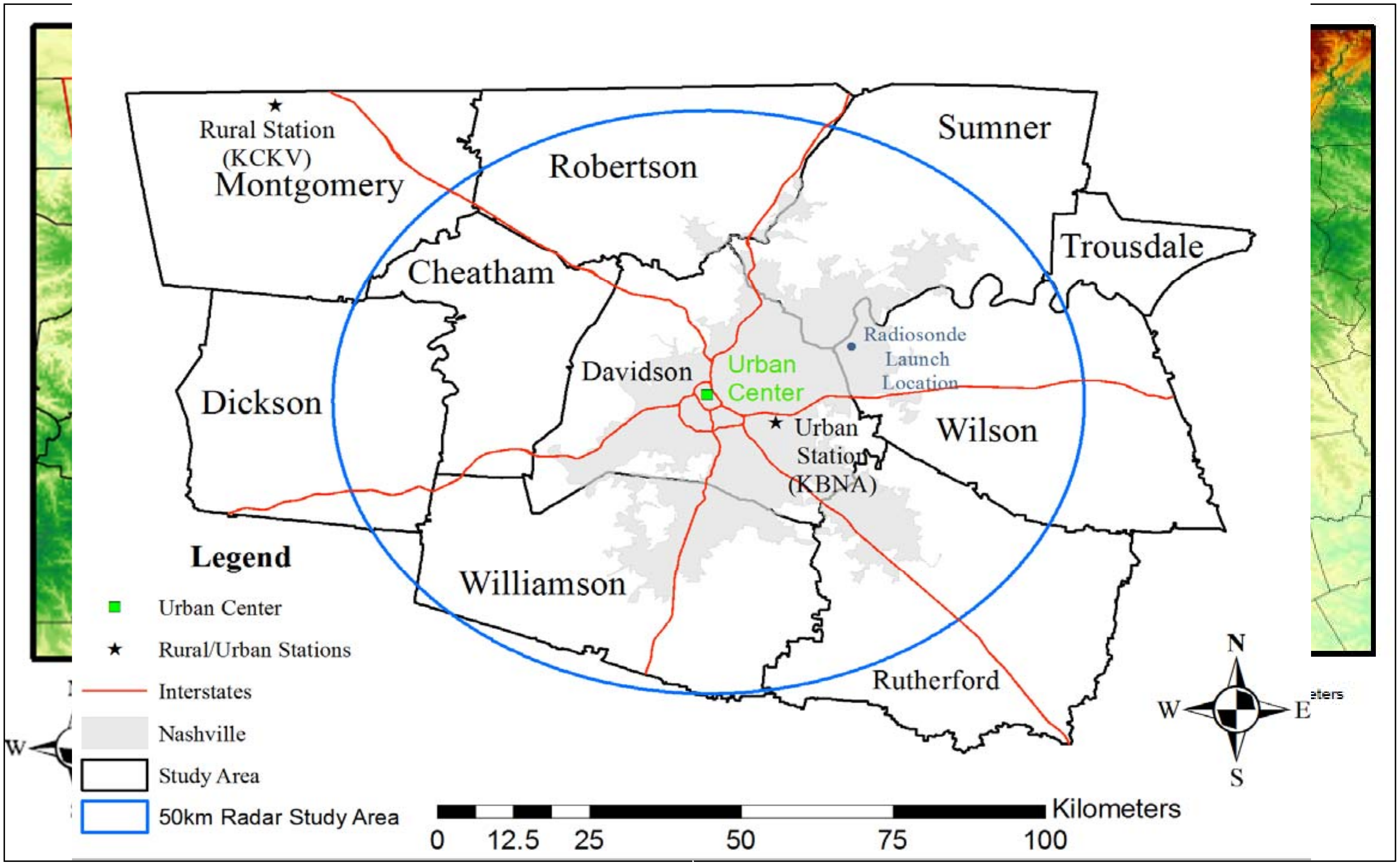


Methods

- **Partially adopting the Dixon and Mote 2003 methodology:**

1. Study Period: 2003-2012, Warm Seasons (May 1-Sept. 30)
2. Identify weak synoptic-flow days using archived upper-air charts from UCAR datasets
3. Examine days for thunderstorm modification (splitting or initiation), meeting the "urban thunderstorm" criteria using KOHX radar imagery from the NCDC
4. Once identified, temporal data of initiation and splitting were gathered (day/time/month/year).
5. Measured UHI intensity using urban (KBNA) and rural (KCKV) surface observing data 24 hours ahead of the event were collected and compared to average study days
6. KOHX sounding data were also collected before and after the storm events. Average temperature, dew point, geopotential and thermodynamic indices were calculated
7. Difference-of-means t-tests were conducted on all urban-thunderstorm days and compared to average weak synoptic flow study days. Statistically significant results were reported

Study Area

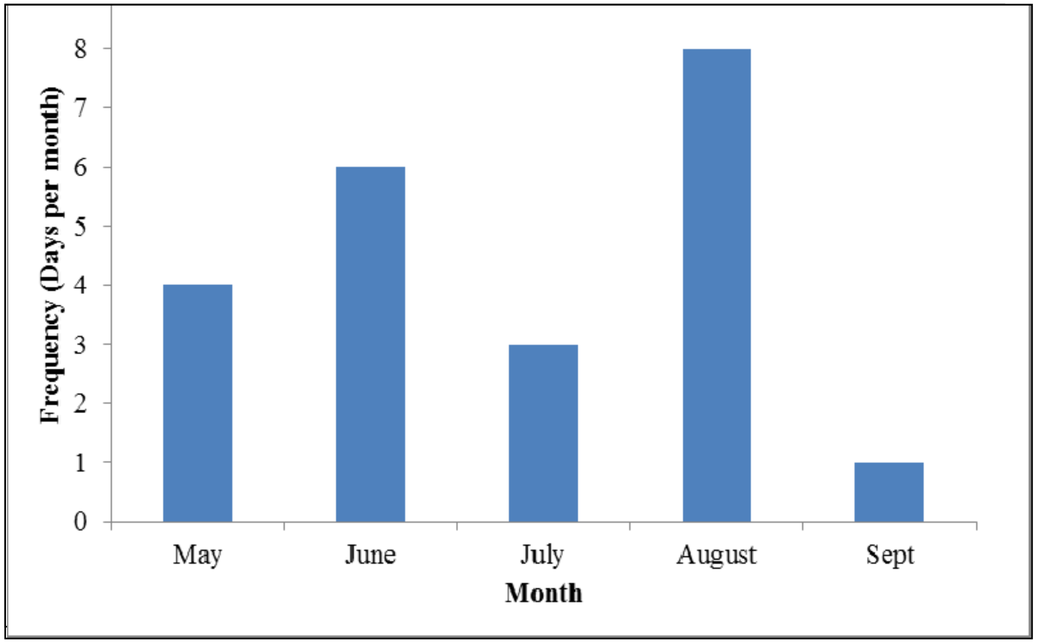


Rural Station (KCKV)
Montgomery
Robertson
Sumner
Trousdale
Cheatham
Davidson
Urban Center
Radiosonde Launch Location
Dickson
Urban Station (KBNA)
Wilson
Williamson
Rutherford
Legend
Urban Center
Rural/Urban Stations
Interstates
Nashville
Study Area
50km Radar Study Area
0 12.5 25 50 75 100 Kilometers
N
W
E
S

Temporal Results

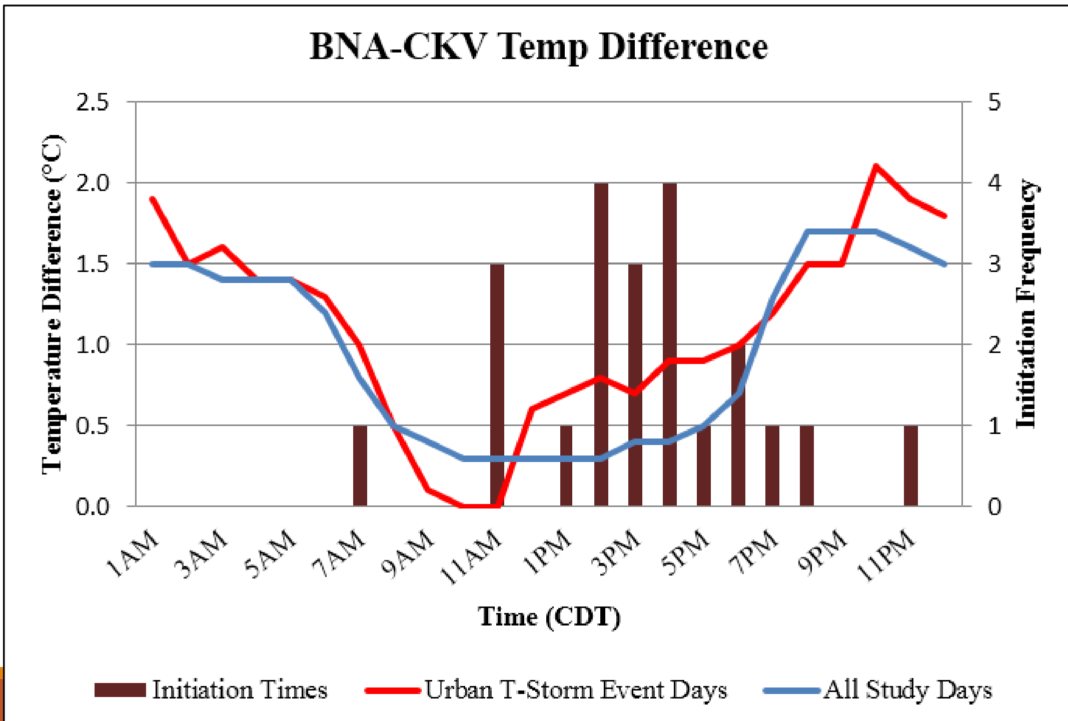
- 1,530 days (10 years) were examined
  - 528 days exhibited weak synoptic flow
  - 175 days had precipitation
- 156 days had convection
  - 22 (1.5%) of days met study definitions
    - 18 urban thunderstorm days
    - 4 bifurcation days
  - 31 initiation & splitting storm centers were found
- 2005 & 2010 had the greatest events
  - 2004, 2007, & 2011 had no events
- Every month had “events”
  - August had the most of both types of modification

Urban Modified Thunderstorm Event Days



Surface Results

- Temperature differences may not be significant for storm development based on results



Station Time (CDT)	Urban T-Storm Event Days ($\bar{X}$)	All Study Days (μ)	Difference	T-Score	p-value*
1AM	1.9°C	1.5°C	0.4°C	1.676	0.109
2AM	1.5°C	1.5°C	0.0°C	-0.072	0.943
3AM	1.6°C	1.4°C	0.2°C	0.459	0.651
4AM	1.4°C	1.4°C	0.0°C	0.017	0.986
5AM	1.4°C	1.4°C	0.0°C	0.048	0.962
6AM	1.3°C	1.2°C	0.1°C	0.593	0.559
7AM	1.0°C	0.8°C	0.2°C	0.966	0.345
8AM	0.5°C	0.5°C	0.0°C	0.125	0.901
9AM	0.1°C	0.4°C	-0.3°C	-1.359	0.189
10AM	0.0°C	0.3°C	-0.3°C	-1.287	0.212
11AM	0.0°C	0.3°C	-0.3°C	-1.449	0.102
12PM	0.6°C	0.3°C	0.3°C	1.618	0.121
*1PM	0.7°C	0.3°C	0.4°C	2.561	0.018
*2PM	0.8°C	0.3°C	0.5°C	3.348	0.003
*3PM	0.7°C	0.4°C	0.3°C	2.771	0.011
*4PM	0.9°C	0.4°C	0.5°C	2.279	0.033
*5PM	0.9°C	0.5°C	0.4°C	2.503	0.021
6PM	1.0°C	0.7°C	0.3°C	1.059	0.302
7PM	1.2°C	1.3°C	-0.1°C	-0.030	0.976
8PM	1.5°C	1.7°C	-0.2°C	-0.426	0.674
9PM	1.5°C	1.7°C	-0.2°C	-0.367	0.717
10PM	2.1°C	1.7°C	0.4°C	1.012	0.323
11PM	1.9°C	1.6°C	0.3°C	1.166	0.257
12AM	1.8°C	1.5°C	0.3°C	1.044	0.308

Sounding Results

- Most sounding results showed statistically significant differences between event & average study days (α=0.05)
  - Possible sampling of the UHI?
- Minimal convective instability and slightly elevated lapse rates were present

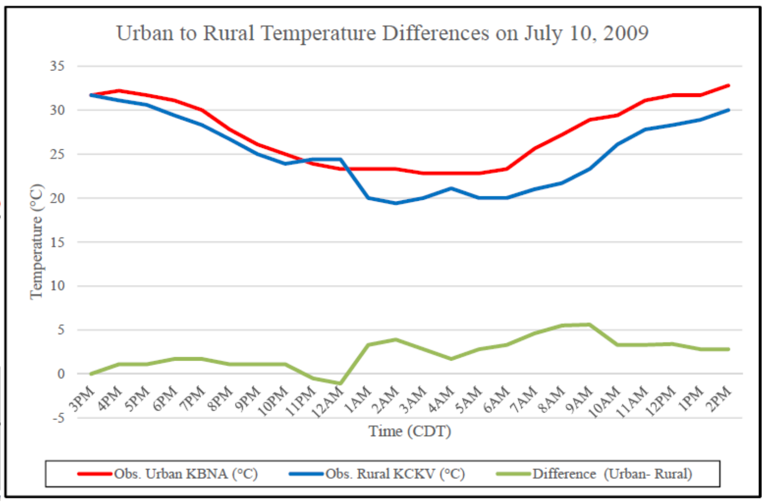
Parameters	Urban Thunderstorm Events	All Study Days	Difference	t-score	p-value*
*MML-MR	14.5 g/kg	12.0 g/kg	2.5 g/kg	5.888	0.000
*PWAT	40.0 mm	34 mm	6 mm	4.256	0.000
LCL Height	880 hPa	877 hPa	3 hPa	0.439	0.665
*LCL Temp.	17°C	14°C	3°C	6.169	0.000

Index	Urban Thunderstorm Events	All Study Days	Difference
CAPE	970 J/kg	443 J/kg	527 J/kg
CIN	68 J/kg	56 J/kg	12 J/kg
KI	31	22	9
LI	-2	0.9	-2.9

Parameter	Urban Thunderstorm Events (X̄)	All Study Days (μ)	Difference	t-score	p-value*
*925 hPa Height	842 gpm	811 gpm	31 gpm	5.327	0.000
*925 hPa Temp.	23.3°C	20.0°C	3.3° C	8.226	0.000
*925 hPa Dew Point	16.3°C	13.6°C	2.7° C	5.047	0.000
*925 hPa Mix Ratio	13.0 g/kg	11.2 g/kg	1.8 g/kg	4.175	0.000
*925 hPa Theta E	342 K	333 K	9 K	5.711	0.000
*850 hPa Height	1572 gpm	1535 gpm	37 gpm	7.572	0.000
*850 hPa Temp.	17.6°C	15.2°C	2.4° C	6.263	0.000
*850 hPa Dew Point	13.0°C	9.4°C	3.6° C	7.227	0.000
*850 hPa Mix Ratio	11.3 g/kg	9.5 g/kg	1.8 g/kg	5.018	0.000
*850 hPa Theta E	339 K	330 K	9 K	6.518	0.000
*700 hPa Height	3200 gpm	3154 gpm	46 gpm	8.024	0.000
700 hPa Temp.	6.8°C	6.3°C	0.5°C	1.278	0.215
*700 hPa Dew Point	-0.9°C	-4.8°C	3.9°C	3.611	0.002
*700 hPa Mix Ratio	5.6 g/kg	4.6 g/kg	1.0 g/kg	3.111	0.005
*700 hPa Theta E	327 K	324 K	3 K	2.998	0.007

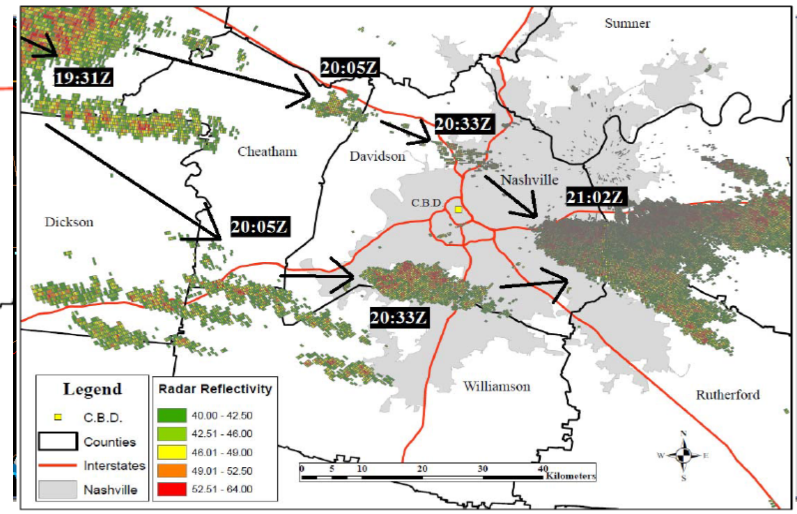
Case Studies

Initiation Event: 07/10/2009 @ 19Z to 22Z



- Impressive urban to rural temp differences
- Surface dew points 20°C (S winds @ 5 knots)
- Very low instability (KI: 9; CAPE ~500 J/kg)
- High 925–850-hPa temperatures & dew points

Bifurcation Event: 06/13/2010 @ 18Z to 21Z



- Hodographs show weak wind shear for splitting
- Only +1.1°C UHI intensity (30°C @ KBNA)
- High theta-e and dew points (weak surface winds)
- Somewhat dry 3 days before event

Conclusion

- Convergence regions due to UHI temperature differences may exist often in urban areas, but without substantial moisture flow, urban modified convection is muted (similar findings from Dixon and Mote 2003)
- The position of the Bermuda high system off the Atlantic Coast may be a large factor
- Higher sensible heat fluxes from the UHI may bifurcate storms
  - Days ahead of splitting were "dry" in the area on average
- The spatial size and layout of the city may play a role in the episode of events
- Similar upper-air results were similar as Bentley et al. (2012) found with KFFC
- Modeling of the case studies are needed (bifurcation and initiation)

Sources and Questions?

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