Investigating Climate Impacts of Urbanization and the Potential for Cool Roofs to Mitigate Future Climate Change in Kansas City

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Goals of this study

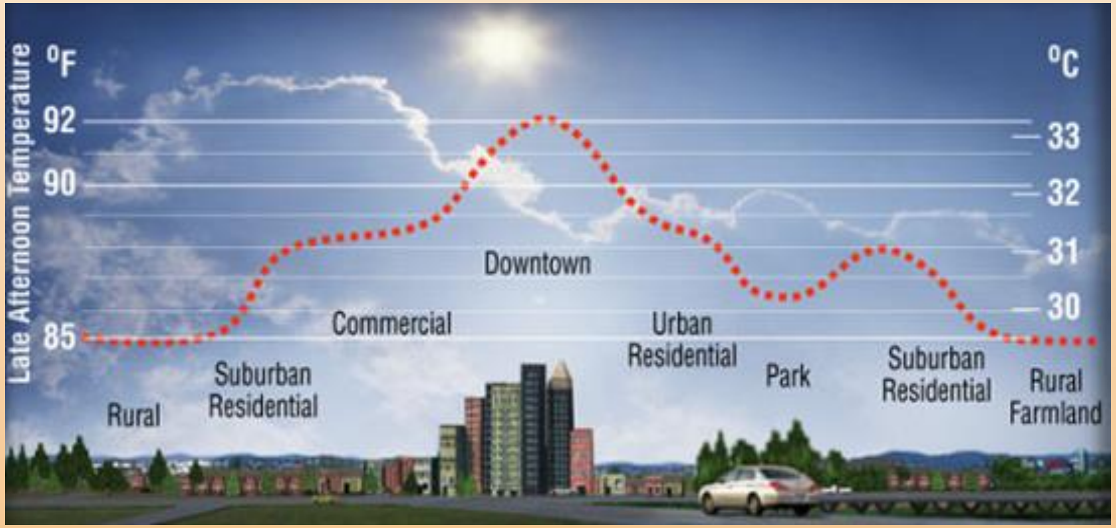
- *To understand the **impacts land cover change** on regional climate by numerical simulations;*
- *To provide evidence for the **mitigation of urban heat island** through the implementation of cool roofs, which will benefit the local community by improving city's resilience to climate change.*

Presentation Outline

- **What is an urban heat island (UHI)?**
- Urban growth and the Kansas City metropolitan area
- Cool roofs
- High-resolution climate modeling to analyze Kansas City's UHI and its mitigation
- Summary

What is an Urban Heat Island?

- Phenomenon where the air temperature within a city is warmer than that of surrounding rural areas, especially at night
- Difference can be up to 12^{o}C in the evening
- Most intense in the urban core due to density of infrastructure



What Causes UHIs?

- Multiple causes (UCAR 2017):
  - Less absorption of moisture by urban surfaces
  - Human activities
  - Buildings prevent mixing of air
  - Albedo of urban surfaces

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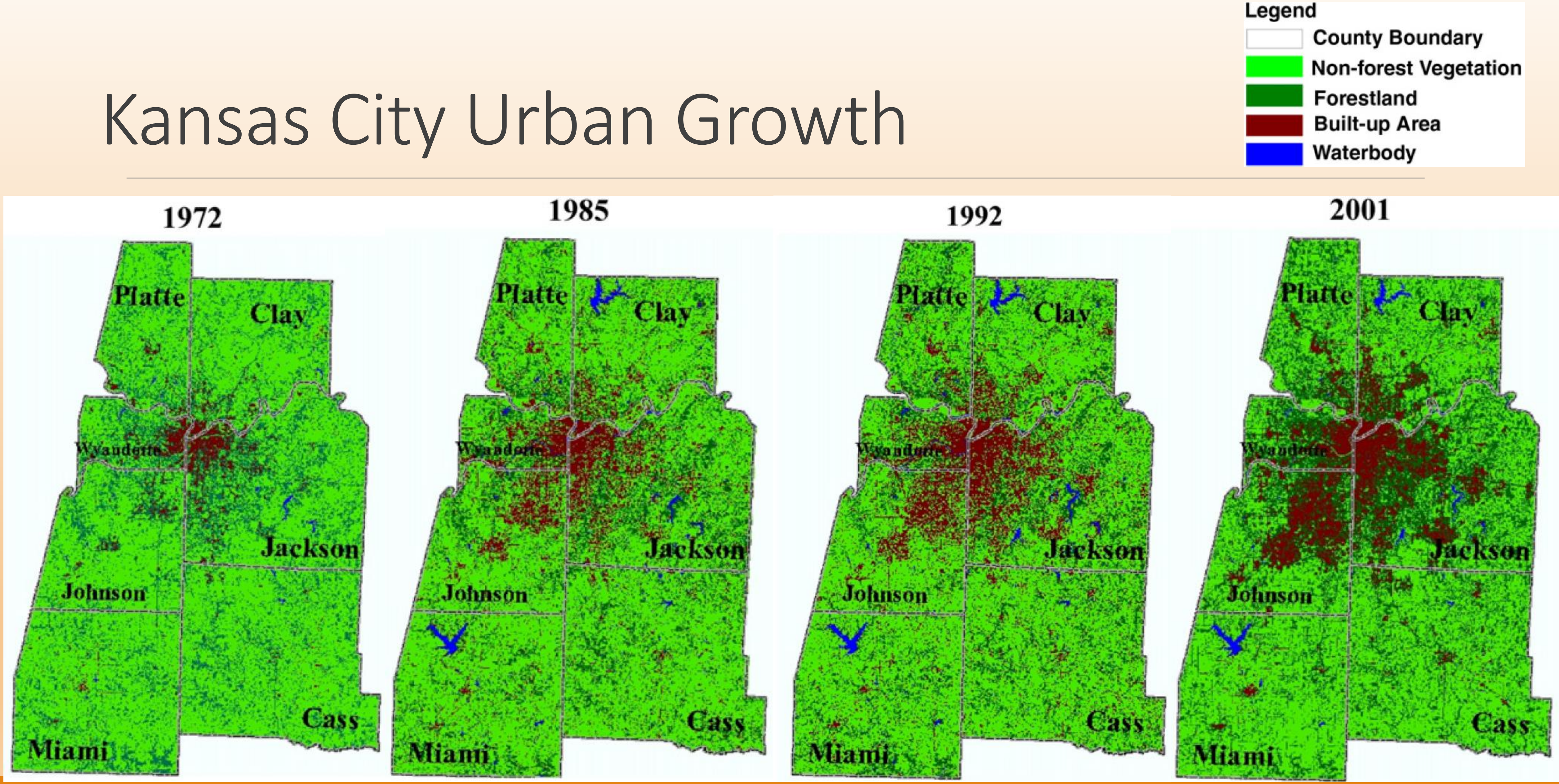
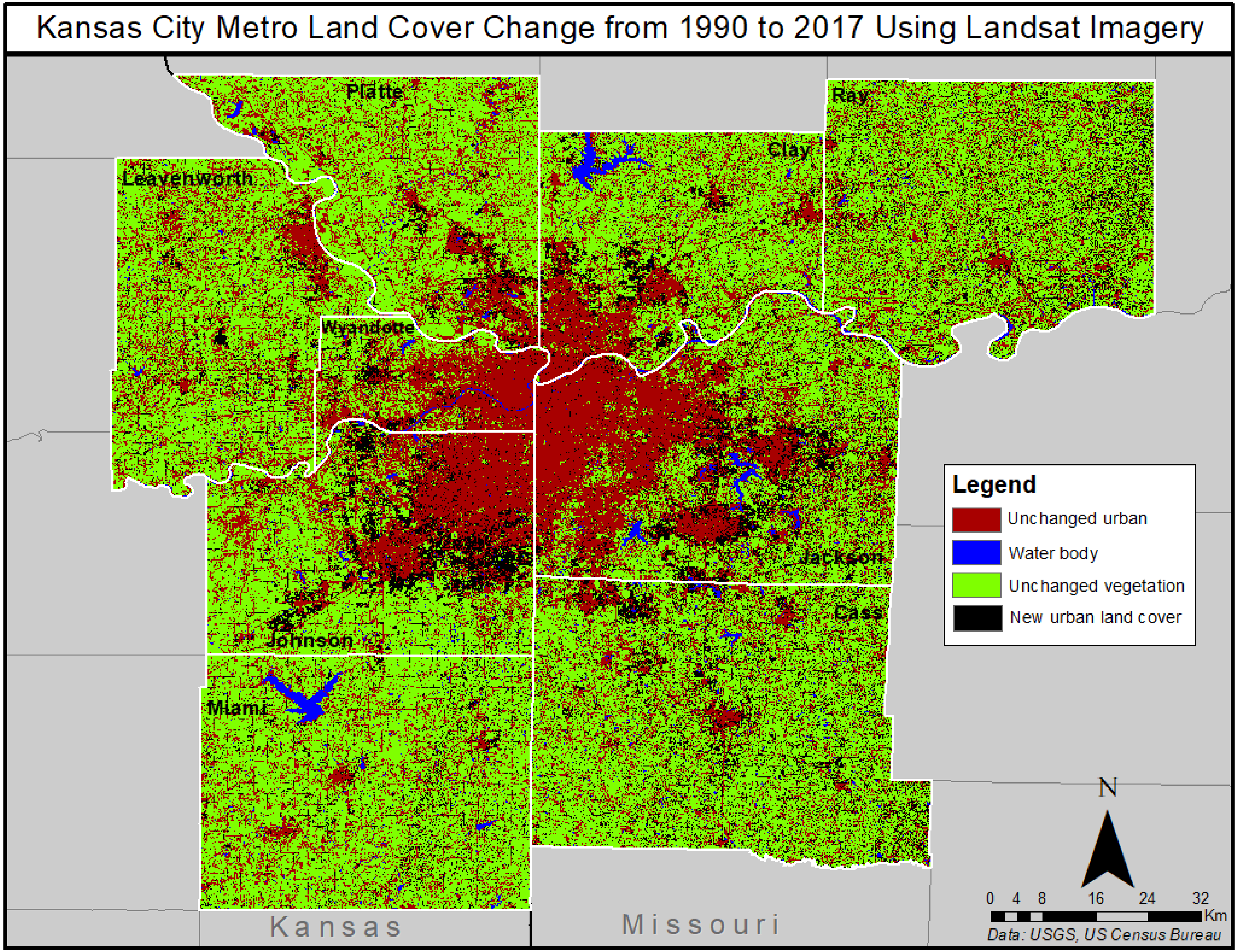
Kansas City Urban Growth



(Ji et al. 2006)


Kansas City Metro Land Cover Change from 1990 to 2017 Using Landsat Imagery
Platte
Clay
Ray
Leavenworth
Wyandotte
Jackson
Cass
Johnson
Miami
Kansas
Missouri
Legend
Unchanged urban
Water body
Unchanged vegetation
New urban land cover
N
0 4 8 16 24 32
Km
Data: USGS, US Census Bureau

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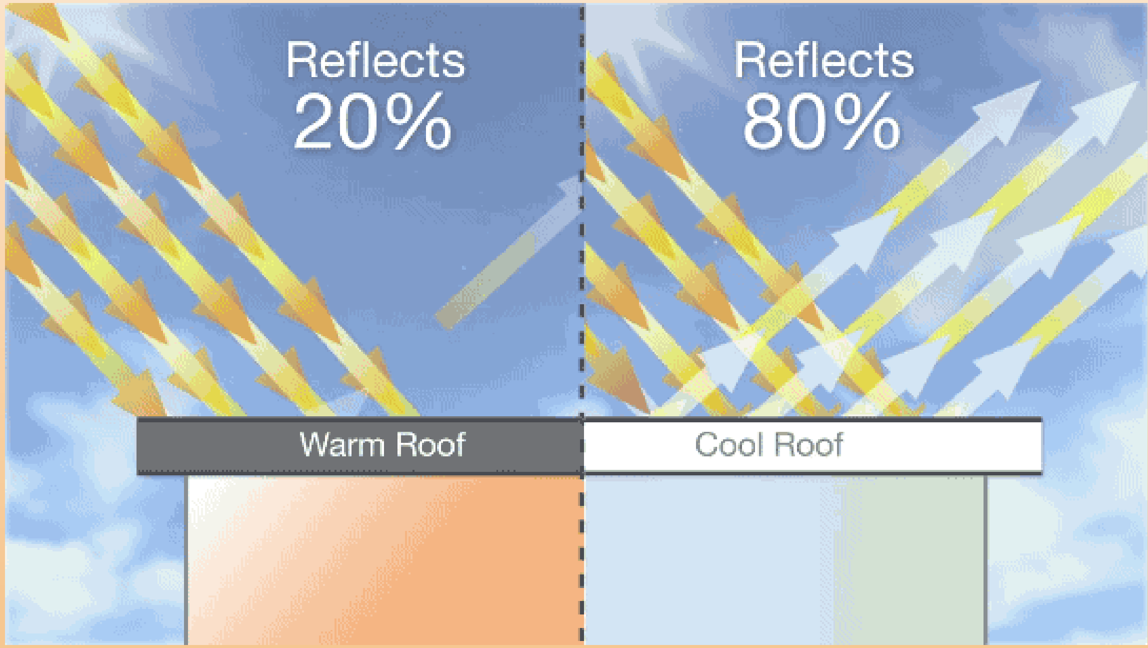
Cool Roofs

- Replaces conventional roofing materials with lighter-colored materials
- Greater reflection of solar radiation
- Advantages vs green roofs
  - Less costly
  - Less upkeep
  - Doesn’t require additional structural support
- Disadvantage
  - Albedo decreases with debris
    - Can be restored with cleaning



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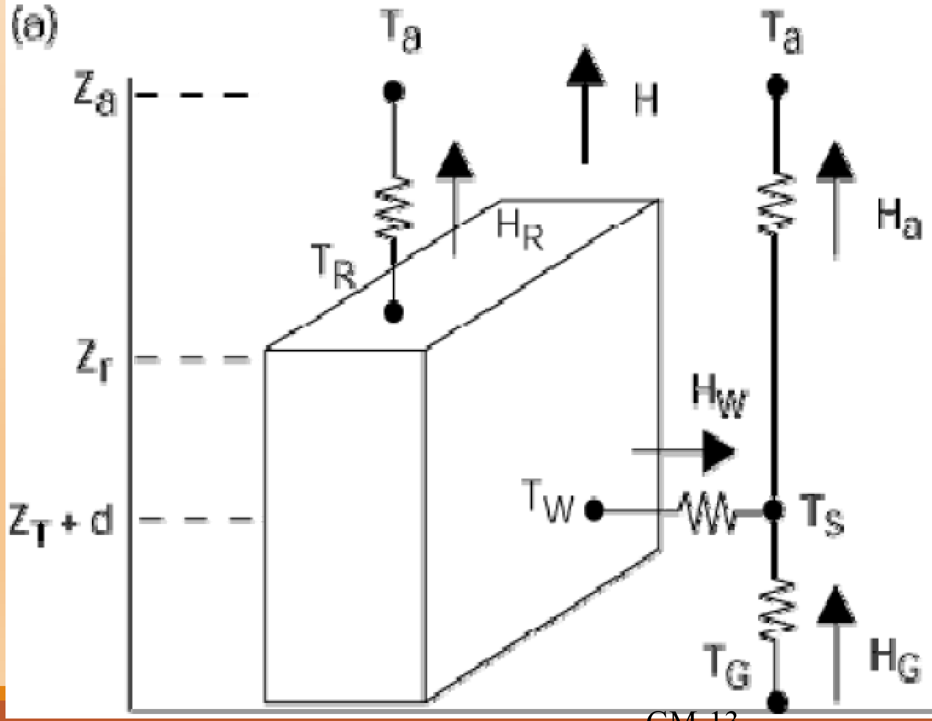
High-Resolution (1-km) Climate Model

- Weather Research and Forecasting (WRF) model
- Mesoscale numerical weather prediction system
- Coupled to an urban canopy model (UCM)
- Commonly used for researching UHI effect and cool roofs (Vahmani 2016, Sharma 2016, Li 2014, Jandaghian 2018)



(Tewari 2007)

Part 1 – Sensitivity Simulations

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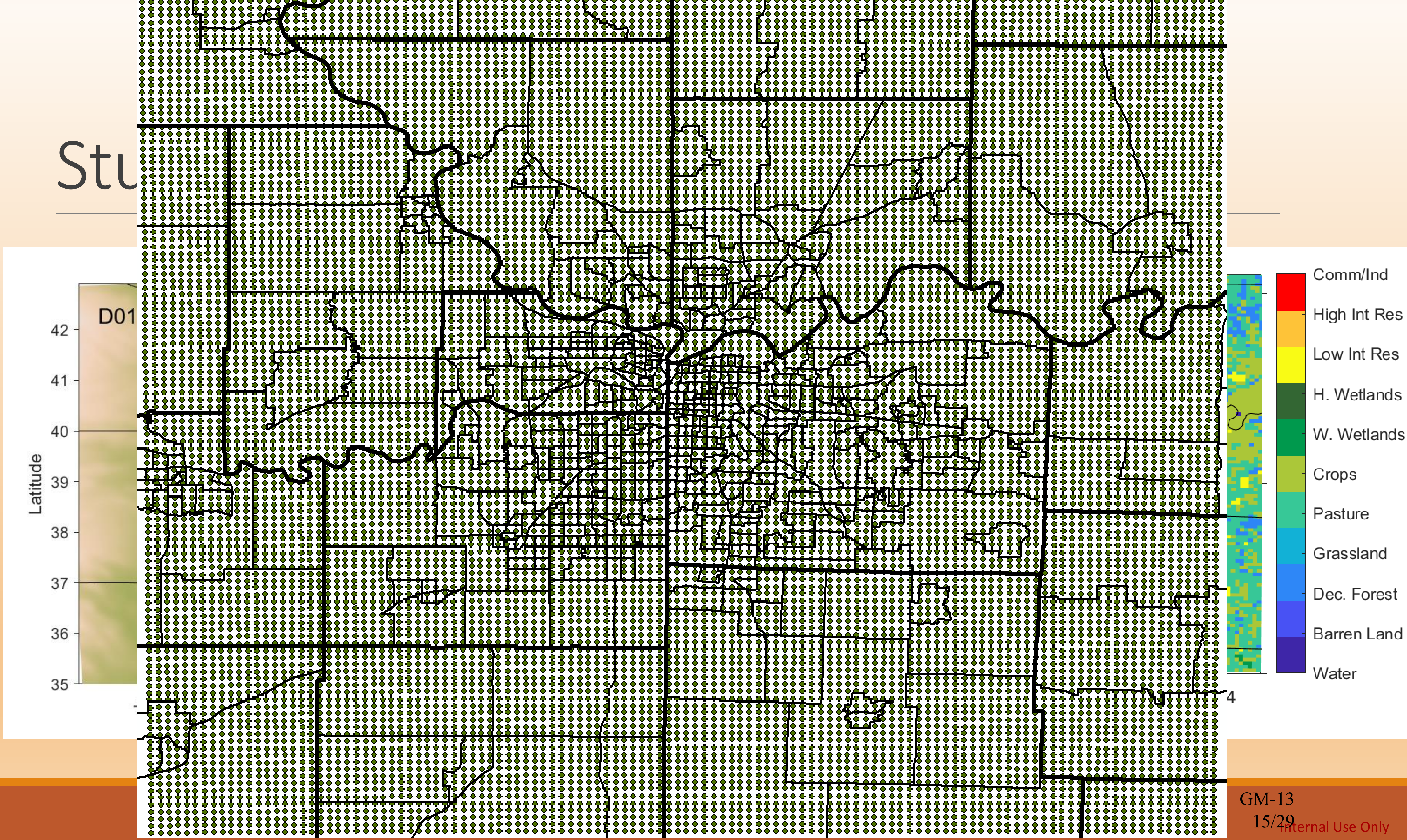
- Area of interest: Kansas City metropolitan area
- Time frame: July 17th – 26th, 2012
  - Maximum observed temperature: 40^{o}C (104^{o}F)
  - Average observed temperature: 31^{o}C (88^{o}F)
- Initial and boundary conditions
  - North American Regional Reanalysis (NARR)
- Land cover
  - Urban pixels: National Land Cover Database (NLCD) 2011

Stu


D01
42
41
40
39
38
37
36
35
Latitude
4
Comm/Ind
High Int Res
Low Int Res
H. Wetlands
W. Wetlands
Crops
Pasture
Grassland
Dec. Forest
Barren Land
Water

Part 1 - Results

- Model performance assessed using root mean squared error, mean bias, and mean absolute error
  - Lower values = better performance
  - Combination of measurements is more accepted (Chai 2014)
- Compared to observation data from Charles B. Wheeler Downtown Airport

Parameterizations			Statistics		
PBL/Surface Layer	LW	SW	RMSE (°C)	MB (°C)	MAE (°C)
MYJ/Eta					
	RRTMG	RRTMG	2.29	0.88	1.78
	RRTM	Dudhia	2.19	0.60	1.74
	RRTM	Goddard	2.26	1.08	1.81
BouLac/MM5					
	RRTMG	RRTMG	2.49	1.86	2.07
	RRTM	Dudhia	2.39	1.67	1.95
	RRTM	Goddard	2.69	2.11	2.26
	RRTM	RRTMG	2.68	2.05	2.22
	CAM	RRTMG	2.10	1.04	1.66
	CAM	Dudhia	1.91	0.66	1.50
	GFDL	GFDL	2.91	2.34	2.43
ACM2/MM5					
	RRTMG	RRTMG	2.18	1.44	1.72
	RRTM	Dudhia	2.01	1.10	1.61
	CAM	CAM	2.07	0.66	1.65
MYNN2/MM5					
	RRTMG	RRTMG	1.96	0.94	1.53
→	RRTM	Dudhia	1.74	0.45	1.39
	CAM	RRTMG	2.05	0.05	1.69

Part 2 - Short-Term Cool Surfaces Sensitivity Simulations

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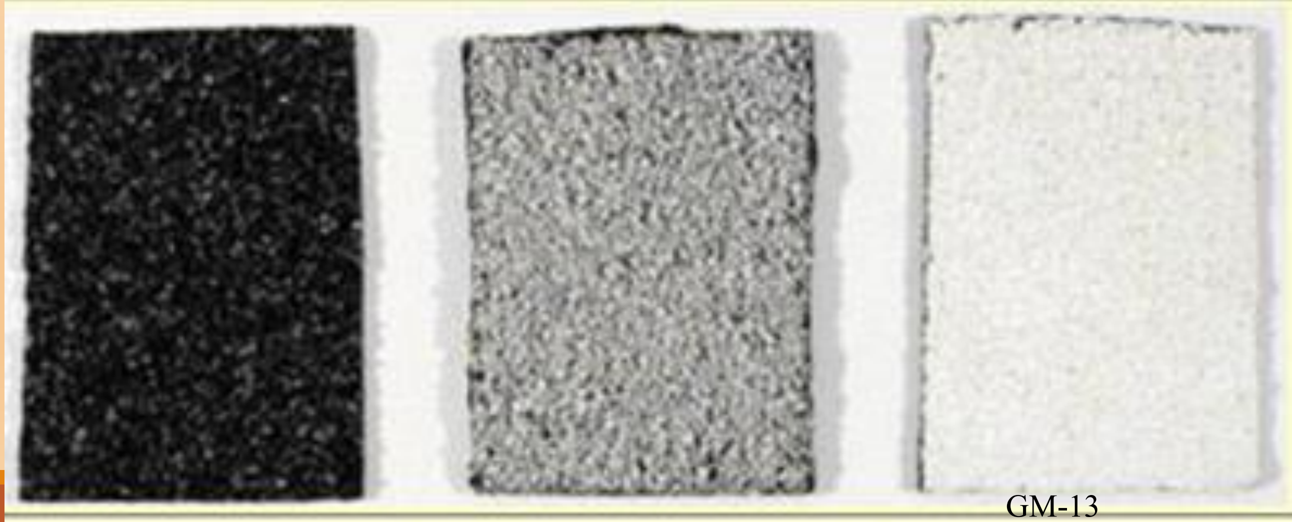
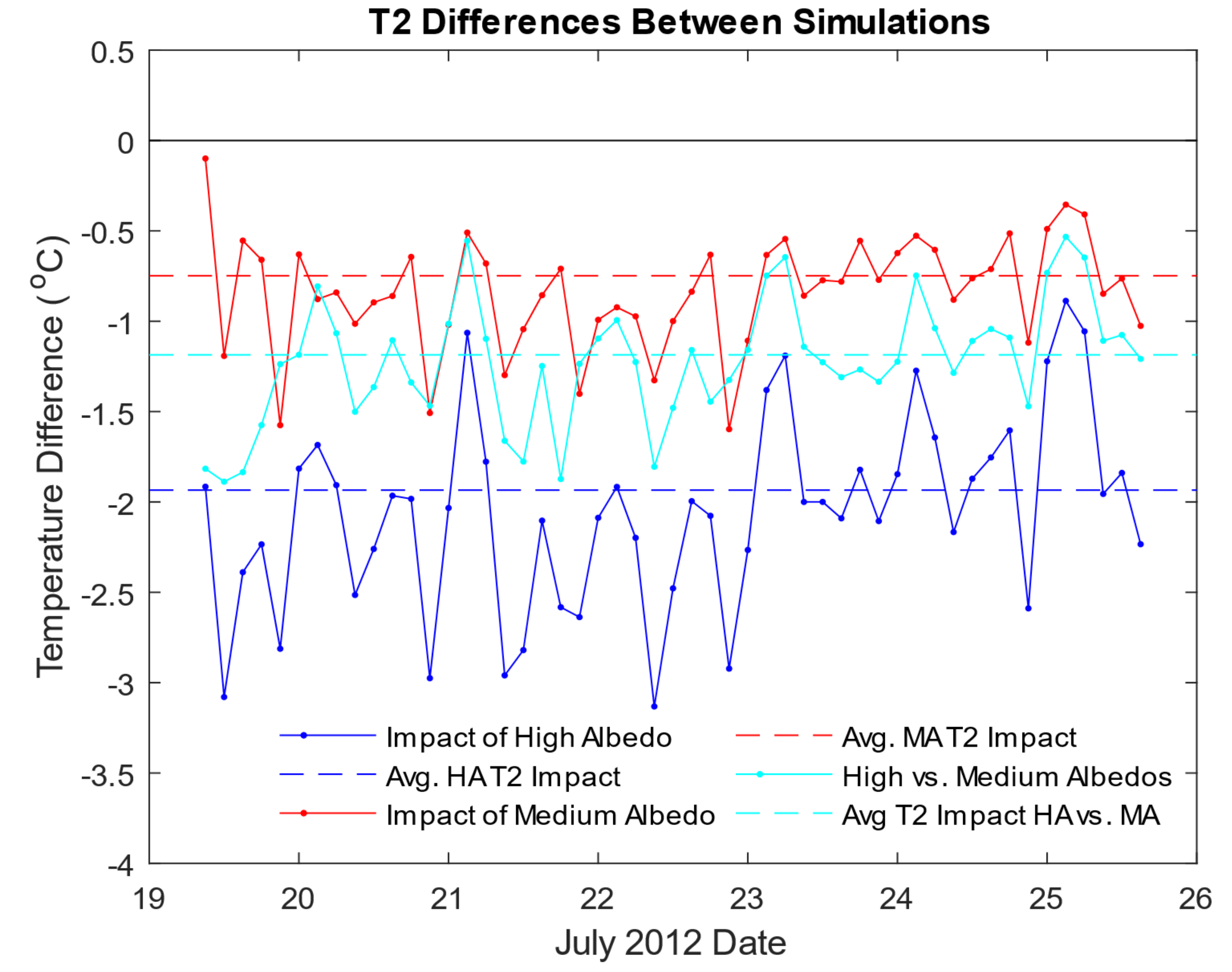
- Cool surfaces simulations were ran in addition to the normal albedo (0.2) simulations
  - Medium albedo (0.5)
  - High albedo (0.8)
- All simulations included the same 3 domains, land cover data, parameterizations, and forcing data
- Results were then compared

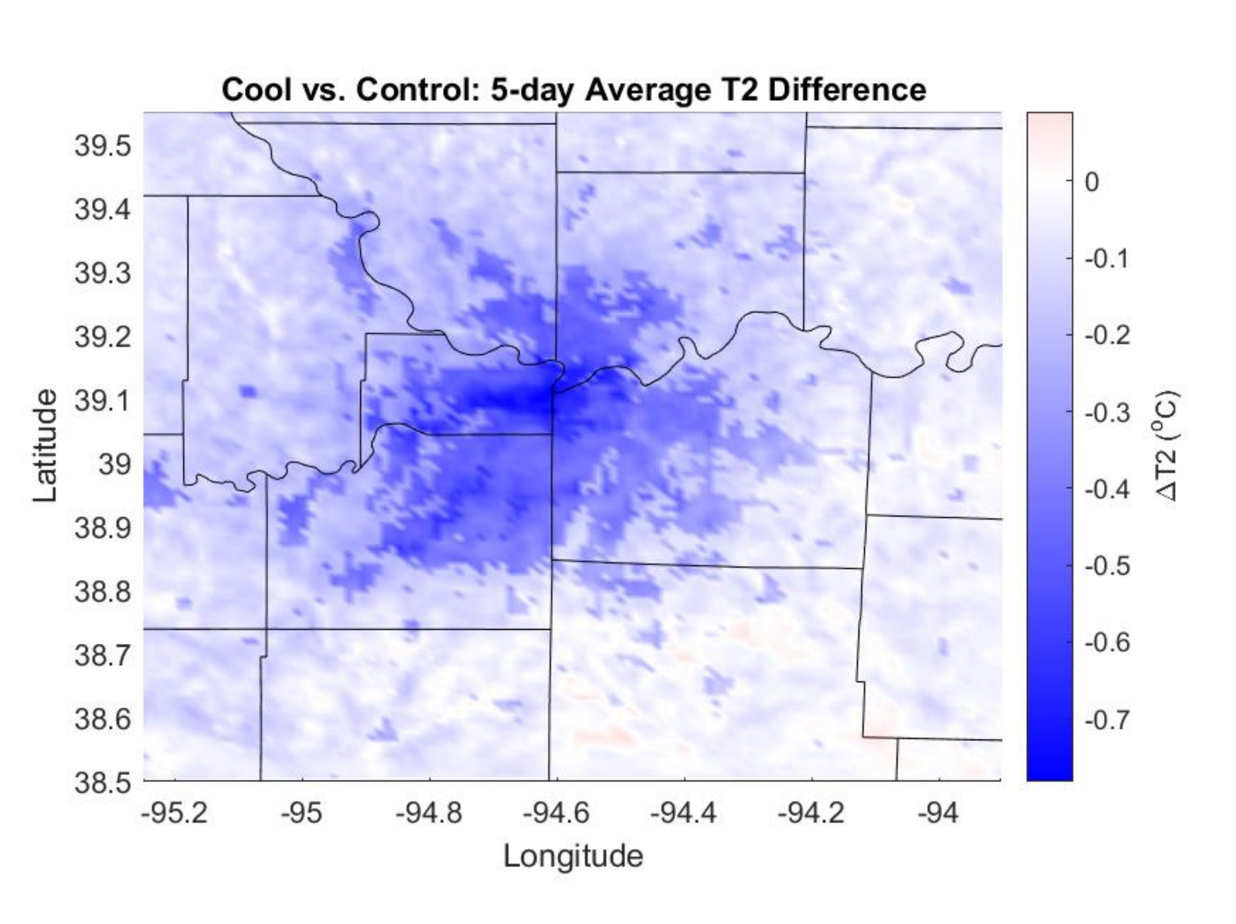


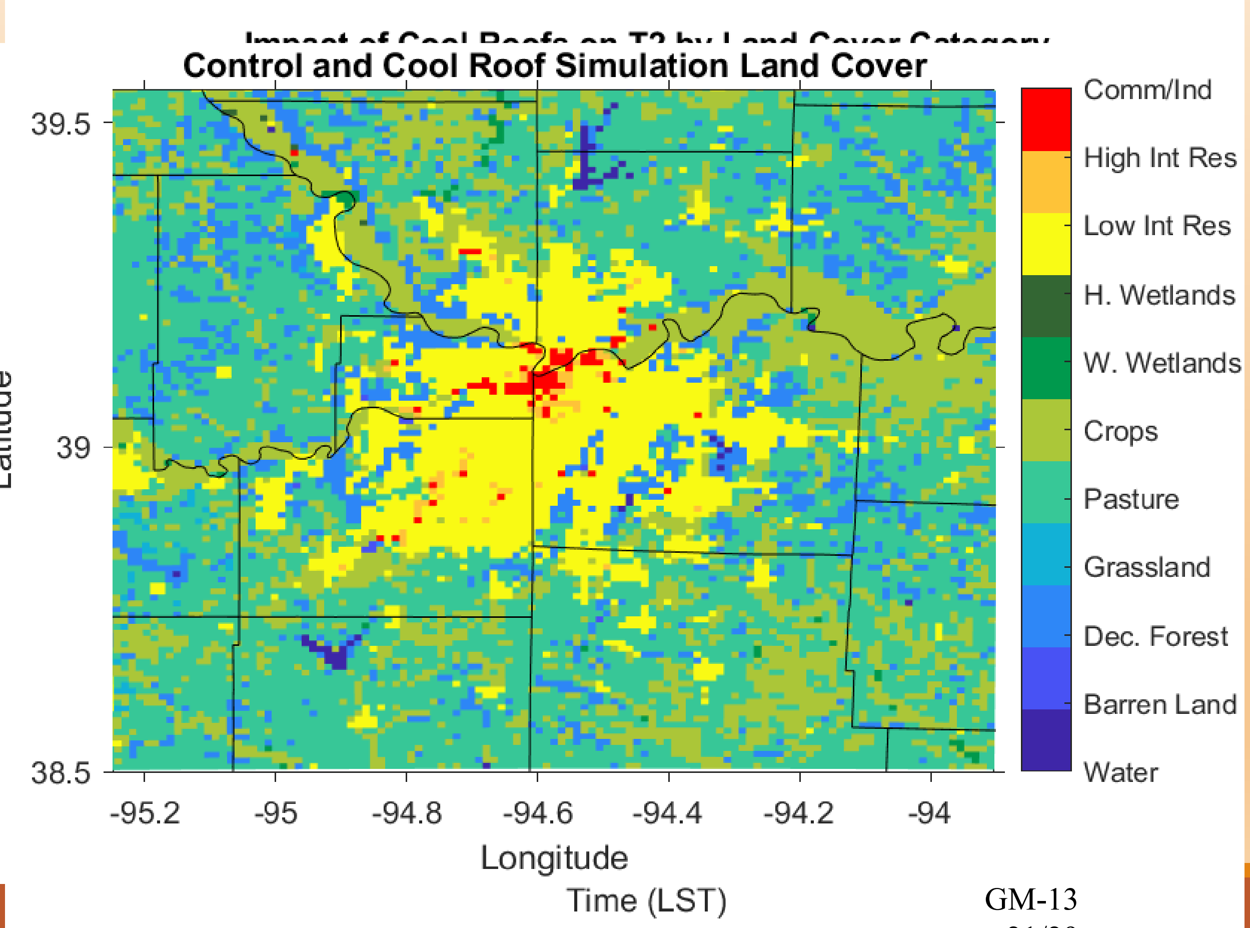
Part 2 - Results

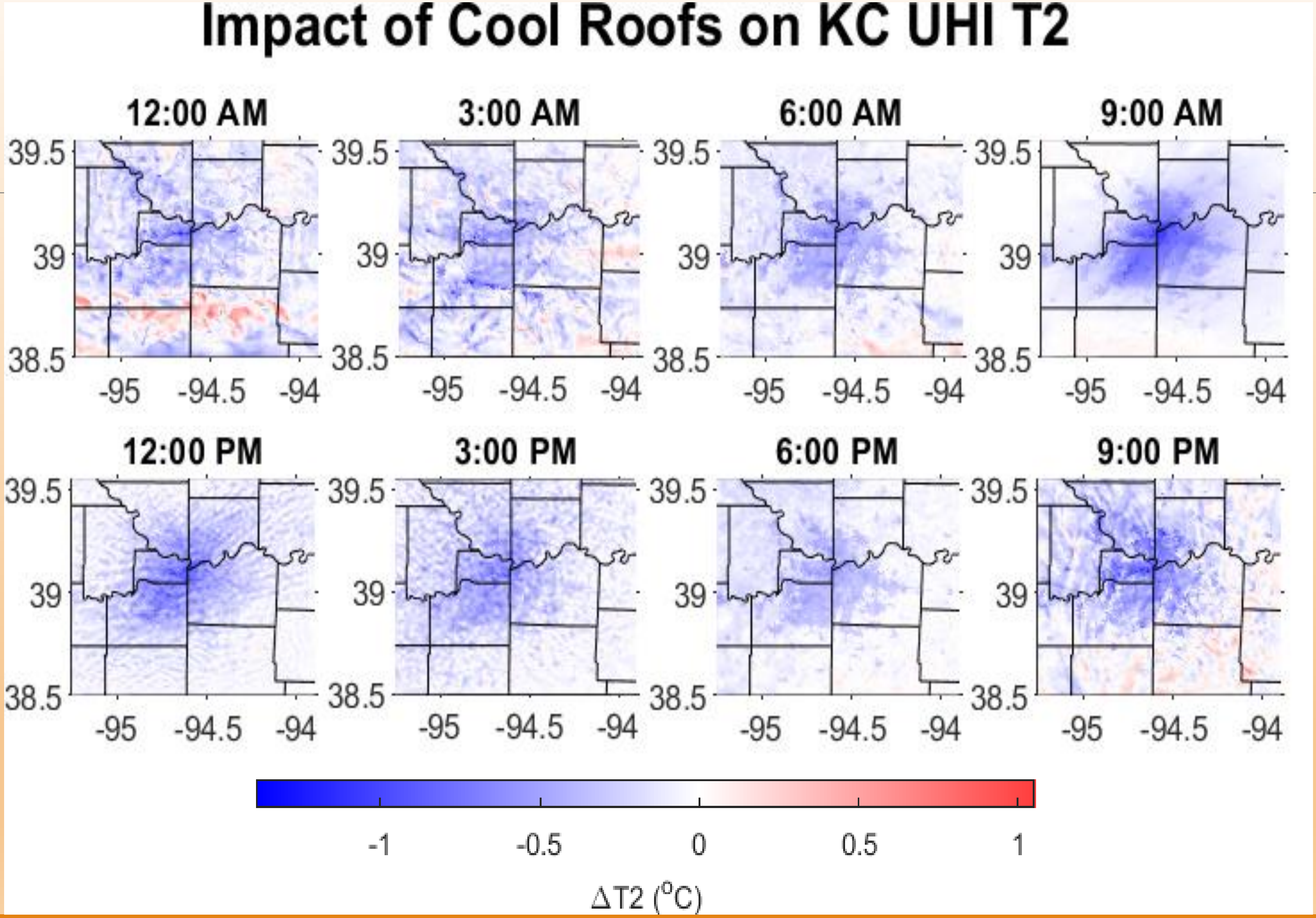


Part 3 – Cool Roof Simulation

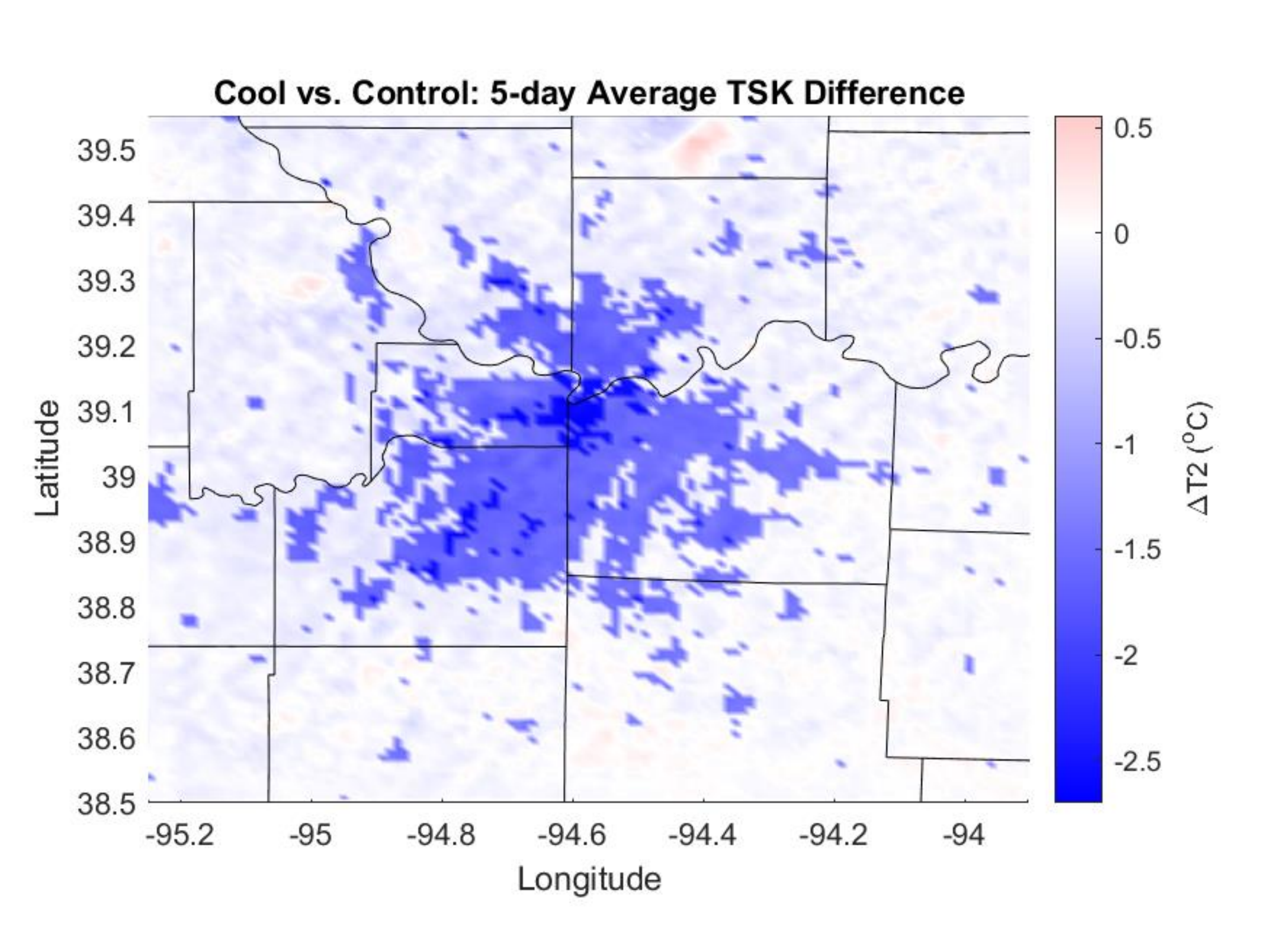
Part 3 Results: 2-meter Air Temperature (T2)

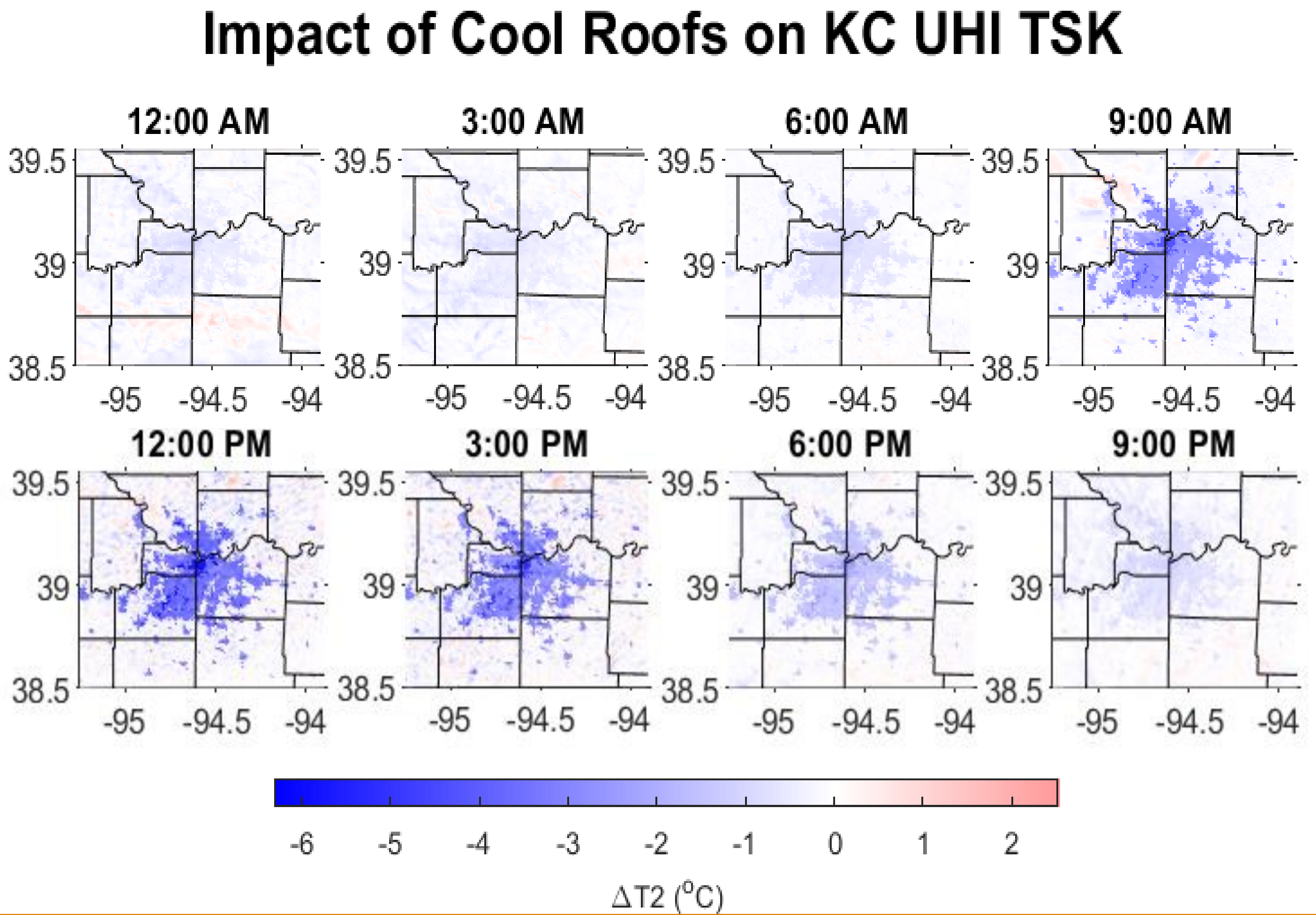





Impact of Cool Roofs on KC UHI T2
12:00 AM
3:00 AM
6:00 AM
9:00 AM
12:00 PM
3:00 PM
6:00 PM
9:00 PM
39.5
39
38.5
-95
-94.5
-94
-1
-0.5
0
0.5
1
ΔT2 (°C)

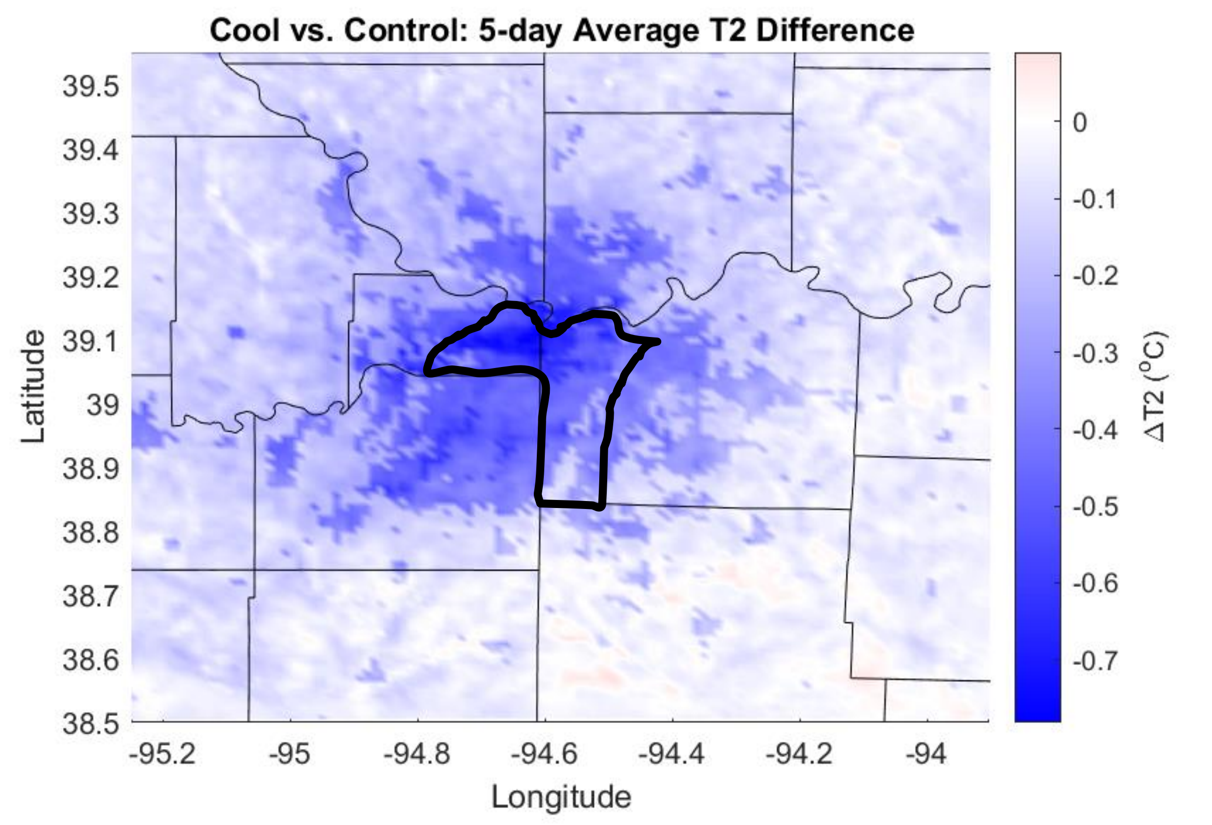
Part 3 Results: Skin Temperature

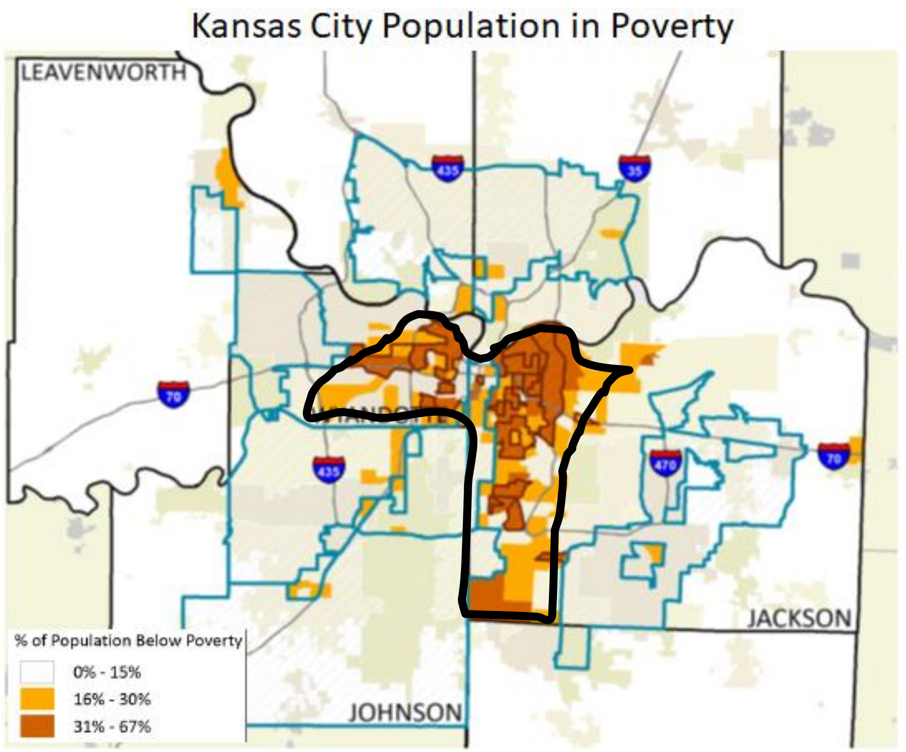



Impact of Cool Roofs on KC UHI TSK
12:00 AM
3:00 AM
6:00 AM
9:00 AM
12:00 PM
3:00 PM
6:00 PM
9:00 PM
39.5
39
38.5
-95
-94.5
-94
-6
-5
-4
-3
-2
-1
0
1
2
ΔT2 (°C)

Part 4 – Implications for socio-economic impacts

UHI Mitigation vs Poverty in Kansas City





(MARC 2014b)

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Summary

- WRF was shown to reasonably simulate the diurnal 2-m air temperatures during the July 2012 heat wave in the Kansas City metro
- Impact of cool roofs on T2 was found to be -0.45°C (-0.81°F), averaged over the entire heat wave for all urban land cover
  - TSK reduced by -1.66°C (2.99°F)
- The highest intensity urban built-up area experienced the greatest reduction in T2

Next steps

- Short-Term
  - Look at socioeconomic impacts of cool roofs by collaborating with other researchers
  - Look at effect of green roofs on the UHI effect
  - Investigate the effect of UHI mitigation on human thermal comfort using a biometeorological index
- Long-Term
  - Compare the present-day and end-of-century UHI effect and the impact of cool roofs