The Effects of Urban Heat Islands on Racial and Income Distribution: A Case Study in Houston

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1. INTRODUCTION

- In 2010, more than half of the world's population lives in urban area. The US is projected to have an over 40 percent increase of urban population, i.e. from 255 million to 358 million, between 2010 and 2050 (United Nations 2011).
- Urban planners are facing challenges of accommodating the needs for jobs, housing, energy and infrastructure and at the same time mitigating the negative impacts related to urbanization, such as the effects of urban heat island (UHI).
- UHI is observed as notably higher temperature in urban built-up areas than the surrounding rural areas due to human activities in urban areas.

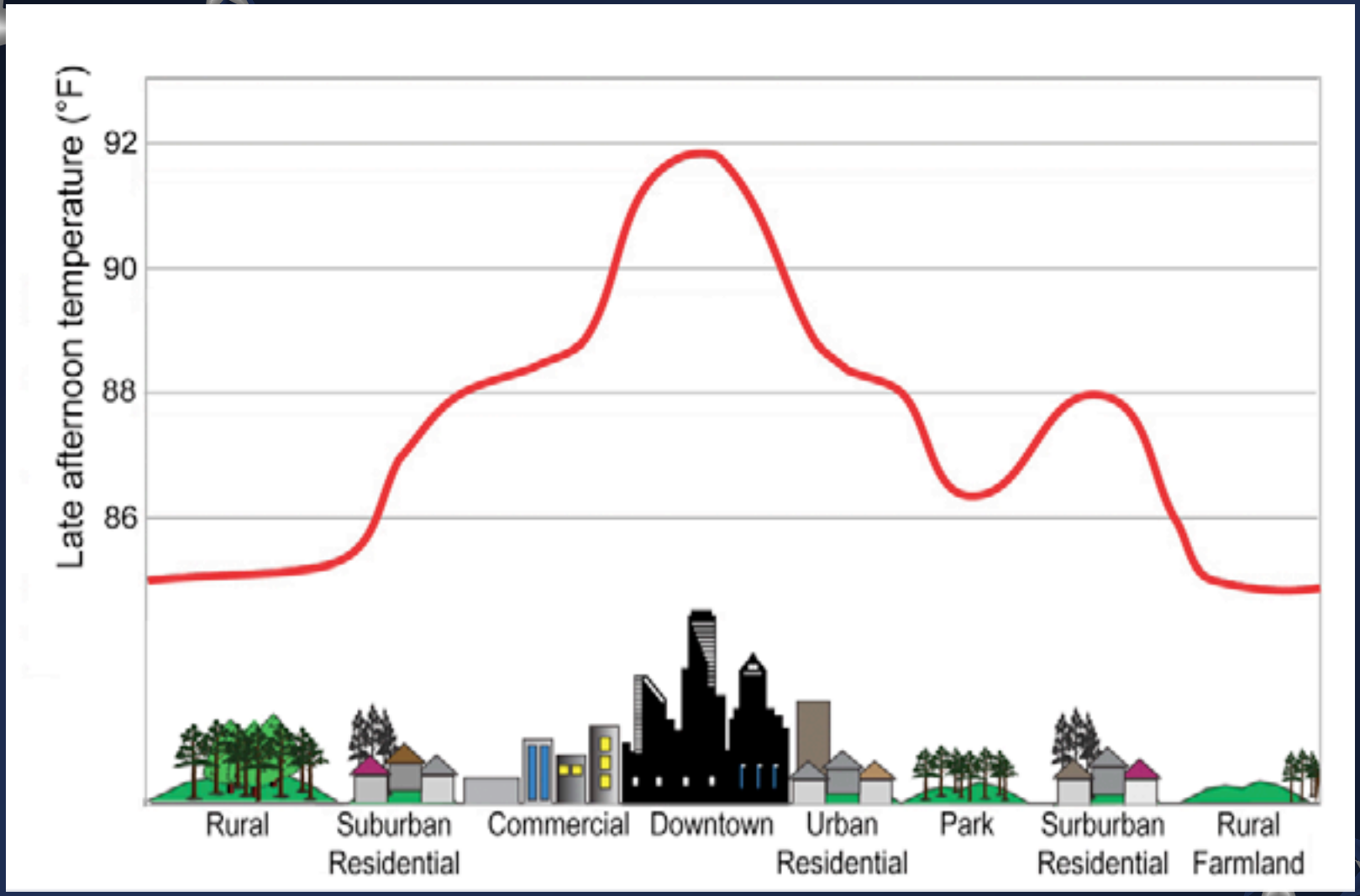

Figure 1. Illustration of the UHI effects (Source: Lemmen and Warren, 2004)

- UHI tends to have disproportional impact on the vulnerable urban populations, such as the minority, elderly, and poor, who lack of necessary socio-economic means to get around the undesirable health effects of UHI or extreme heat events (Klinenberg 2002).
- This study intends to measure the UHI using data from weather monitoring stations and satellite images.
- It employs Houston as an empirical case to examine the effects of UHIs on racial and income distribution.

2. Methodology

- Most of the relevant studies measured the UHI in air temperature or in land surface temperature.
- It is straightforward to measure the UHI in air temperature for an urban area through the interpolation of temperatures recorded at individual weather stations.
- It requires multiple steps to calculate the UHI in land surface temperature using radiative temperature maps from the infrared bands of satellite images.

Step 1. Convert digital number to radiance

$$R = \frac{L_{\max} - L_{\min}}{Q_{\max} - Q_{\min}} \cdot (Q - Q_{\min}) + L_{\min}$$

Where,

R	is radiance value
Q	is digital value
$L_{\min}$	is spectral radiance scales to
$L_{\max}$	is spectral radiance scales to
$Q_{\min}$	is the minimum digital value, which is typically 1
$Q_{\max}$	is the maximum digital value, which istypically 255

Step 2. Apply atmospheric correction

$$R_{ac} = \frac{R - L_{up}}{e \times t} - \frac{1 - e}{e} L_{down}$$

Where,

- R_{ac} is radiance value with atmospheric correction
- R is the radiance value calculated in equation 1
- L_{up} is upwelling radiance
- L_{down} is downwelling radiance
- t is transmittance
- e is emissivity

Step 3. convert radiance to degrees Kevin using the inverse of Planck's equation

$$T = \frac{K_2}{\ln(\frac{K_1}{R_{ac}} + 1)}$$

Where,

- T is degrees Kevin
- R_{ac} is the radiance value with atmospheric correction from Step 2
- K_1 and K_2 are thermal constants

Note: Degrees Kelvin can be further converted to brightness temperature in Calsius degree or Fahrenheit degree.

3. Data and Data Analysis

- Urban heat island in Houston can be measured by air temperatures or land surface temperature.
- Air or outdoor temperatures are obtained from 43 Continuous Ambient Monitoring Stations (CAMS) located in the Houston-Galveston-Brazoria area.
- Land surface temperature (LST) can be derived from radiation data in the thermal infrared bands of newly available Landsat 8 satellite images.
- Socioeconomic characteristics for urban residents come from 2007-2011 American Community Survey (ACS) 5-Year Estimate at census block group level.

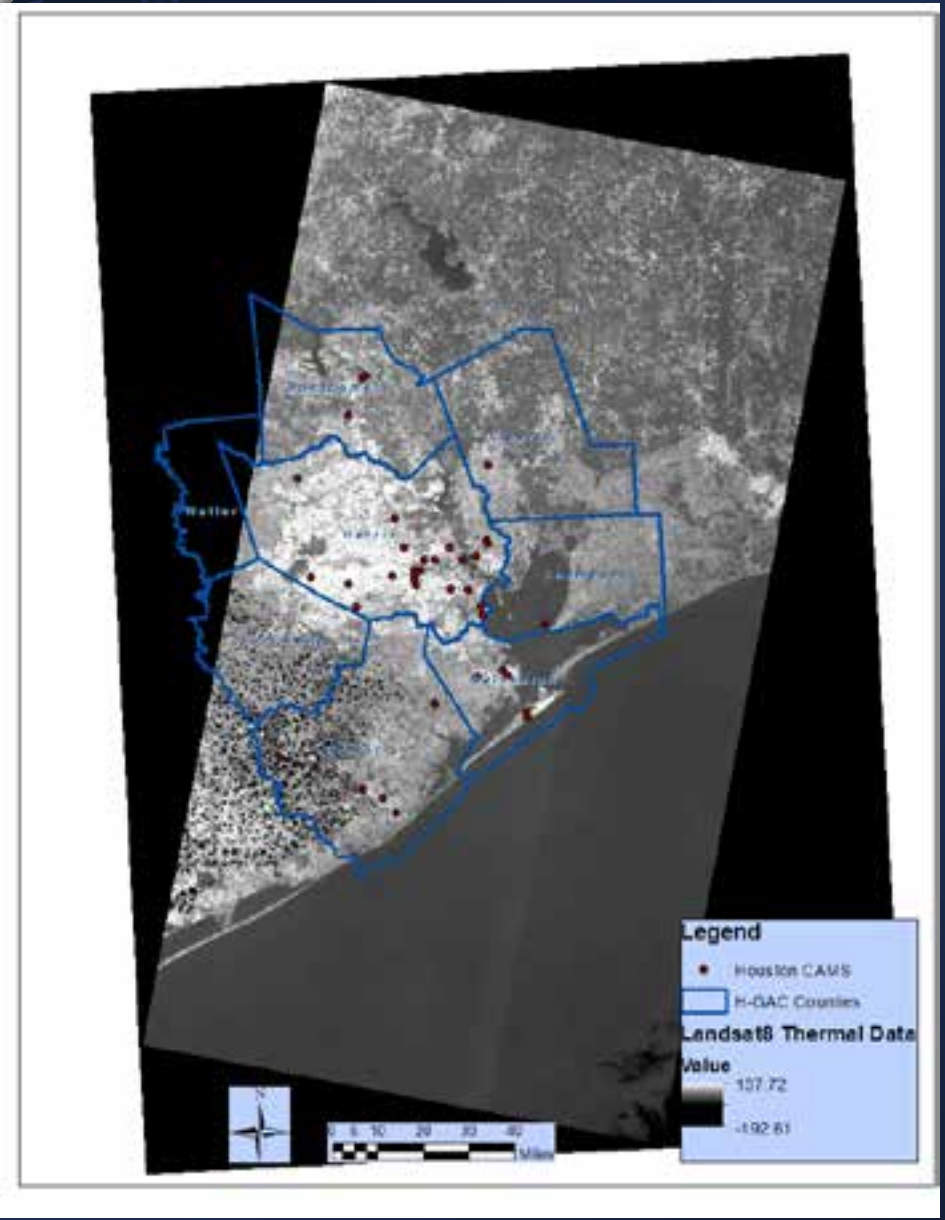

Figure 2. Data Collected for the Study Area

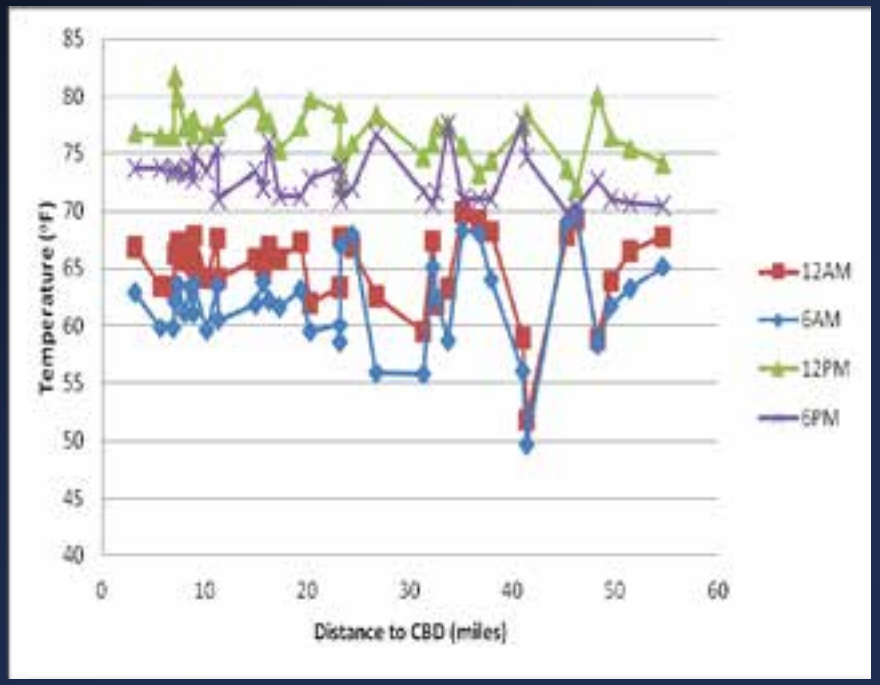

Figure 3. Outdoor temperature at Houston CAMS, May 13

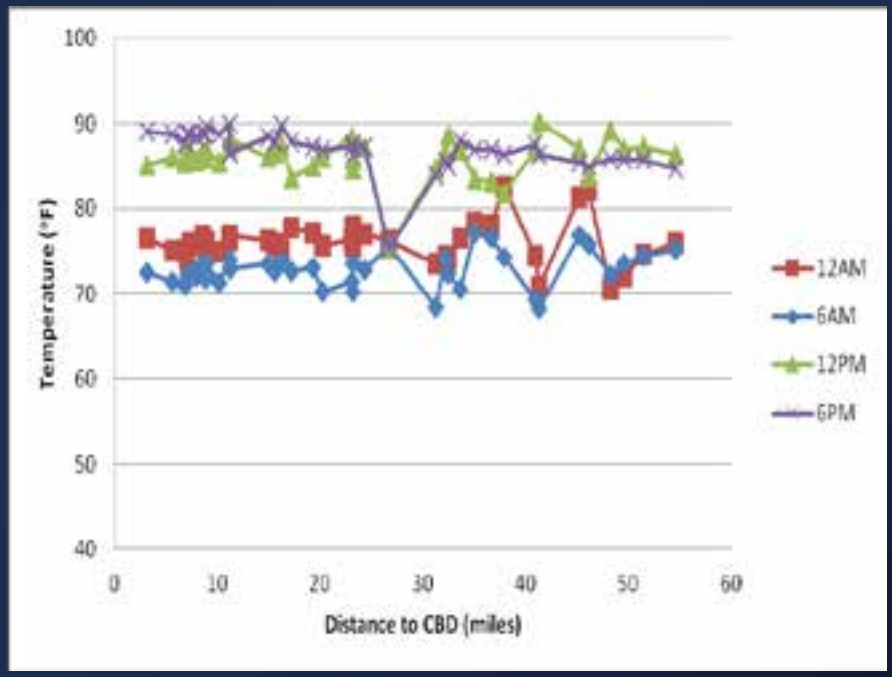

Figure 4. Outdoor temperature at Houston CAMS, Aug. 17

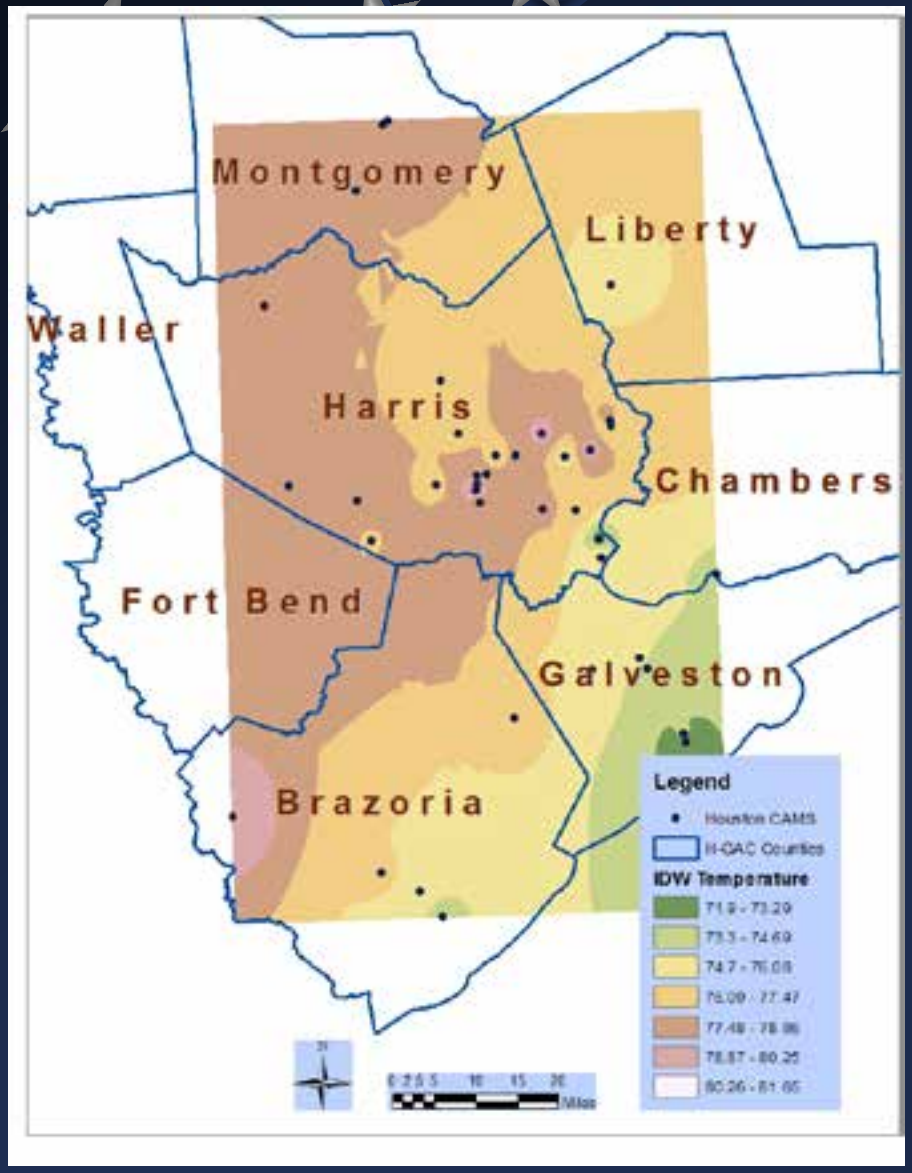

Figure 5. IDW temperature at noon in Houston, Texas on May 13, 2013

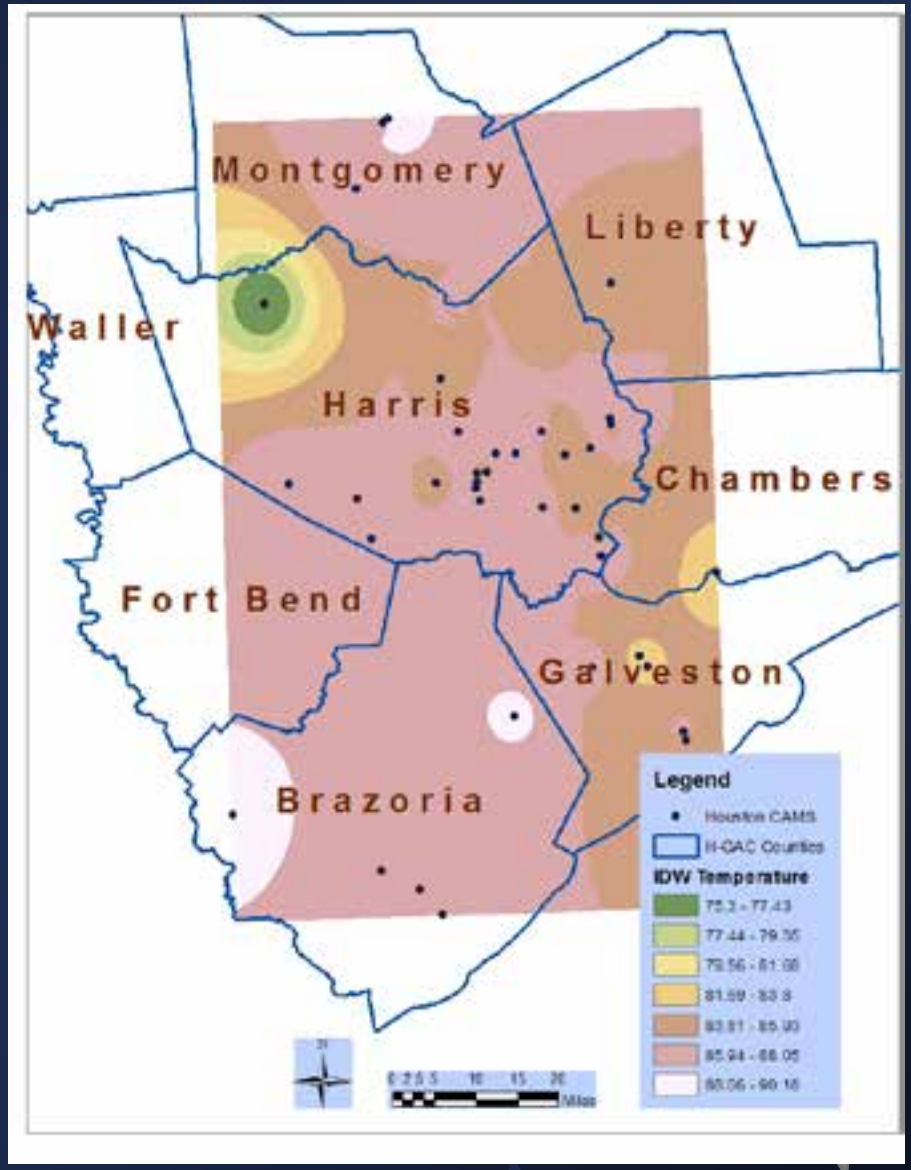

Figure 6. IDW temperature at noon in Houston, Texas on August 17, 2013

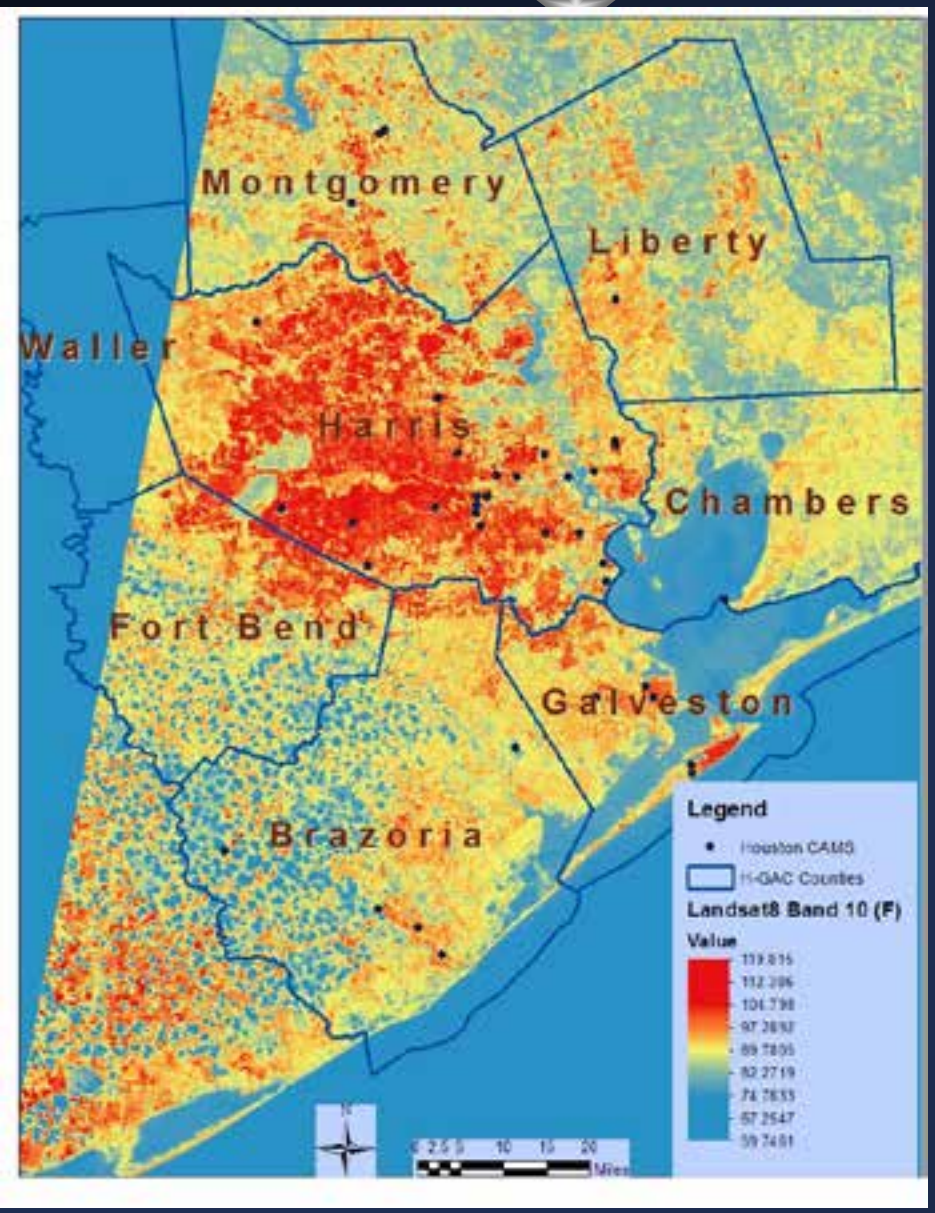

Figure 7. Brightness temperatures at noon on May 13, 2013

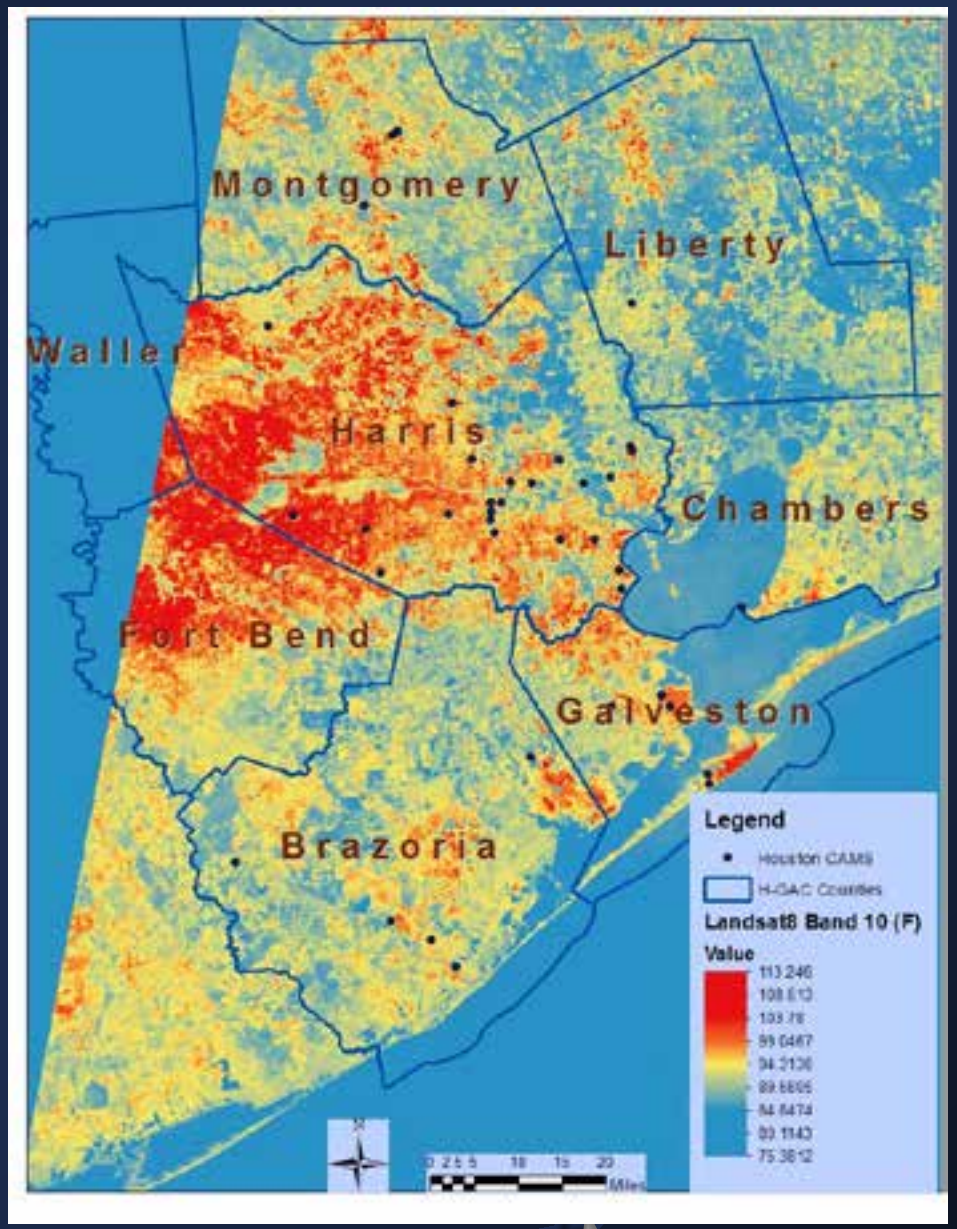

Figure 8. Brightness temperatures at noon on August 17, 2013

Table 2. The effects of UHI on the distribution of urban residents by race/ethnicity, poverty, and income in Harris County, Texas

Characteristics	Population ([n(%)]	Average Temperature Exposed on May 13 (^{o}F)	Relationship with Temperature on May 13 (t-statistic value)	Average Temperature Exposed on August 17 (^{o}F)	Relationship with Temperature on August 17 (t-statistic value)
Total population	4,025,409 (100%)	98.89		97.40	
Race/ethnicity					
Hispanic	1,621,065 (40.27%)	99.40	3.46 (***)	97.57	1.09
Non-Hispanic					
White	1,353,868 (33.63%)	98.00	-5.39 (***)	96.87	-3.34 (***)
African American	747,398 (18.57%)	99.06	0.89	97.58	0.91
Asian	246,924 (6.13%)	99.91	4.37 (***)	98.66	5.13 (***)
Poverty					
Below poverty	607,564 (15.09%)	99.76	4.15 (***)	97.77	1.99 (**)
Above poverty	3,417,845 (84.91%)	98.73	-	97.33	-
Median household income ($)	52,675		-3.53 (***)		-1.80 (*)

4. Conclusions

- The relationship between temperature and racial distribution is found significant in Harris County.
- It also finds significant relationship between temperature and income.
- Minority and poor population are more likely to expose to high temperature and suffer more from the UHI effects.
- The physical planning strategies adopted for warming mitigation can be incorporated into an environmental justice framework.

Thank You !

Questions and Comments?

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