High Resolution Simulation of Heat Waves in New York City using Weather Research and Forecast Model to Identify Challenges to Potential Mitigation Strategies

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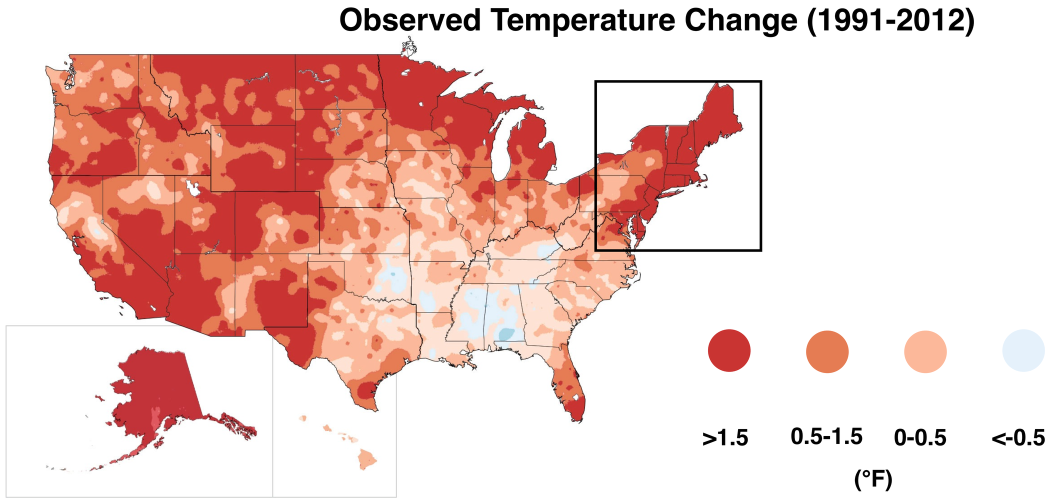
Motivation

Observed Temperature Change (1991-2012)



".. the frequency, intensity and duration of heat waves is expected to increase, with larger increases under higher emission scenarios. Much of the North-Eastern region is projected by mid-century to experience more than **60 additional days per year above 90°F** under continued emission scenarios. This will affect the region's **vulnerable populations, infrastructure, agriculture and ecosystems.**"

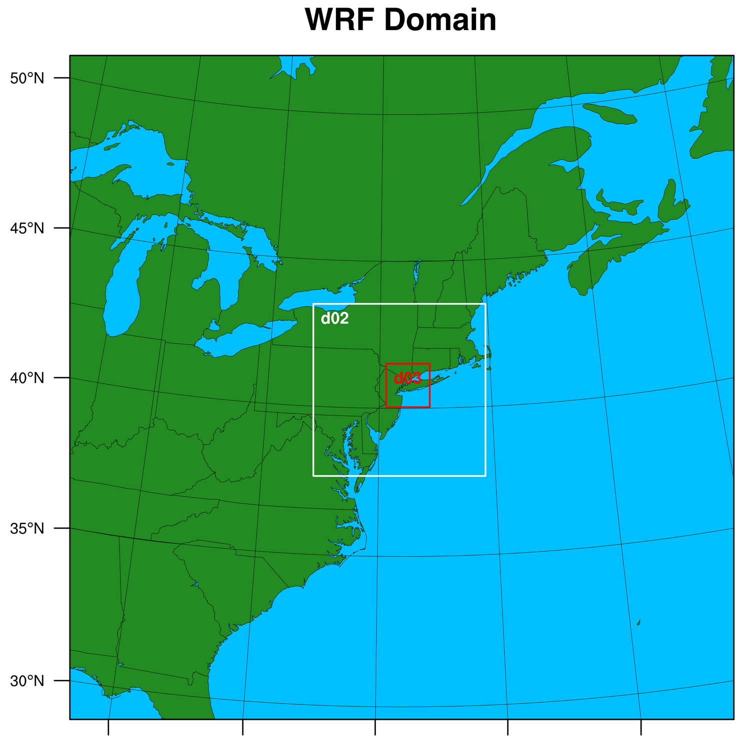
The Third National Climate Assessment. U.S. Global Change Research Program, 2014

With large swathe of the North-Eastern U.S. population residing in dense urban centers, it is germane to address the impact of Heat Waves on cities. Urban areas, dominated by built surfaces which act as reservoirs for heat and with low moisture retention capacity tend to experience high near-surface air temperature compared to the surrounding rural areas. This phenomenon is widely known as the **Urban Heat Island** effect. The primary goal of this study is to investigate the interaction between the local city-scale UHI with the meso-scale Heat Waves in the densely populated New York City. The study also examines the challenges to potential mitigation strategies.

Approach

The **W**eather **R**esearch and **F**orecast model is used to simulate two heat wave episodes in July-August 2006 centered around NYC. The WRF model is modified in two major ways to improve its performance over urban areas; the **Princeton Urban Canopy Model** which includes sub-facet level representation for fluxes replaces the regular urban canopy model, a **mosaic approach** which includes fractional representation of multiple land surface categories at each grid is implemented instead of the dominant land use category approach.

WRF Domain



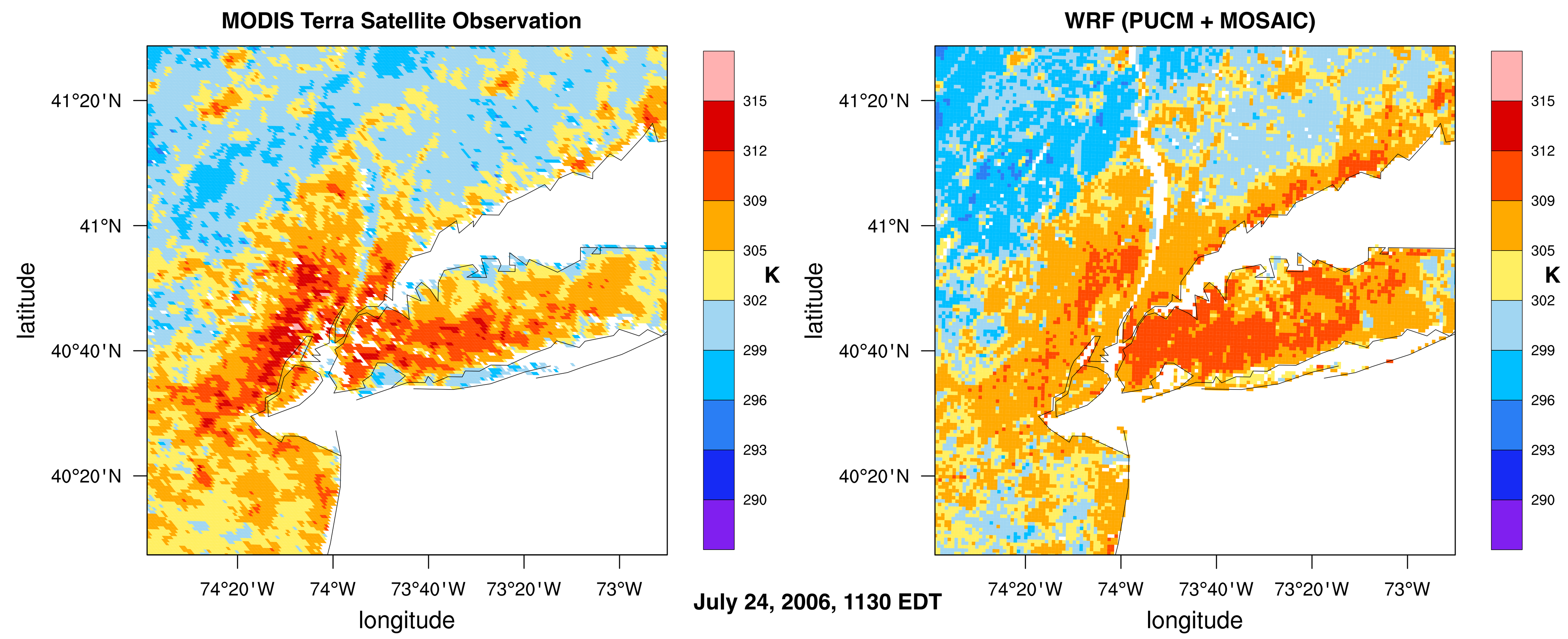
Time Period
Jul 13-31, 2006
Jul 29-Aug 9, 2006

Input Data
NARR (3-hourly)
NLCD 2006, 33 Categories

Domain
9 km x 3 km x 1 km
60 Vertical levels

Physics Option
RA_LW - RRTM
RA_SW - MM5 Dhudia
PBL - YSU PBL
SF_SURFACE - NOAH LSM
SF_URBAN - PUCM (8 Tiles)

Validation



The modifications significantly improve the prediction of land surface temperature (LST) as shown in the figure above. In the inner most domain, not only the surface temperatures are comparable at each grid cell, the smooth transition in LST along the urban - suburban - rural transect is very well reproduced. LST is the most significant factor that characterizes the surface to atmosphere exchanges and hence accurately predicting LST is crucial to understanding the dynamics of the surface energy budget.

Urban-Rural Difference

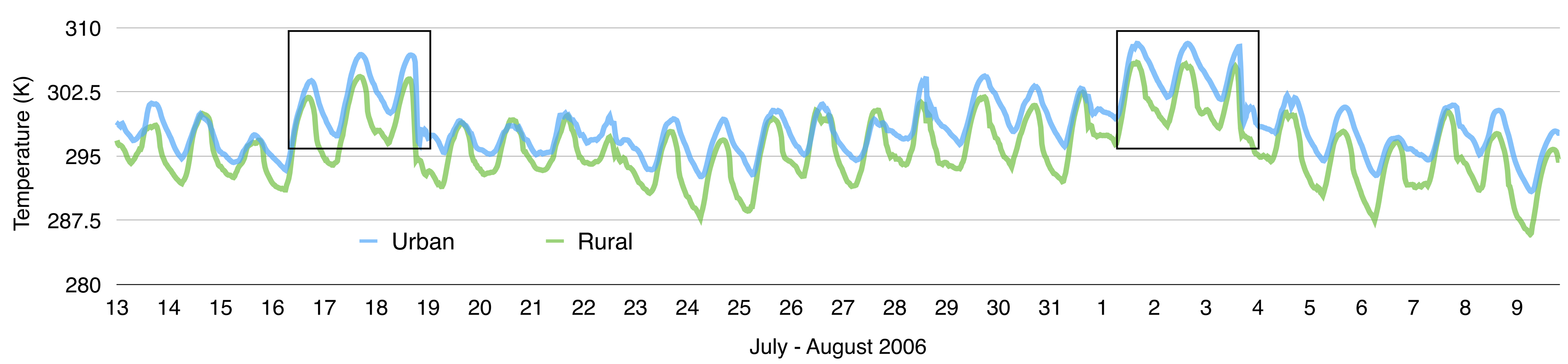
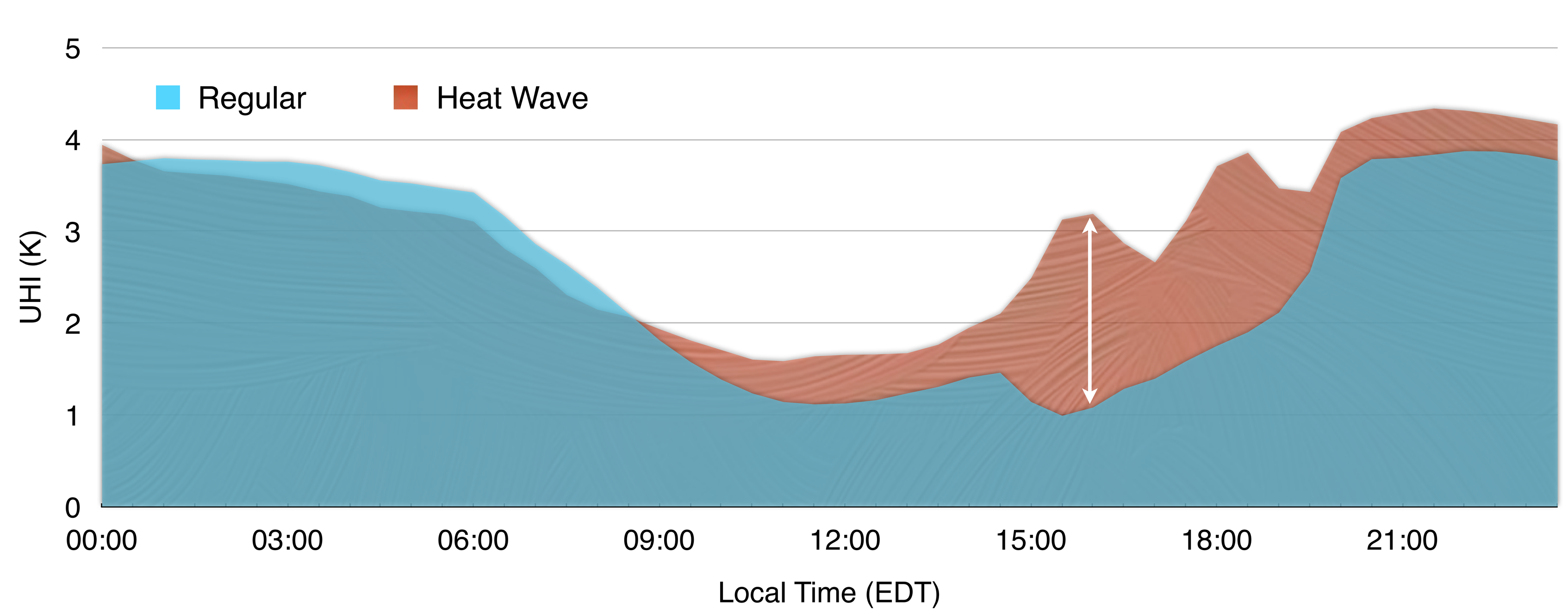
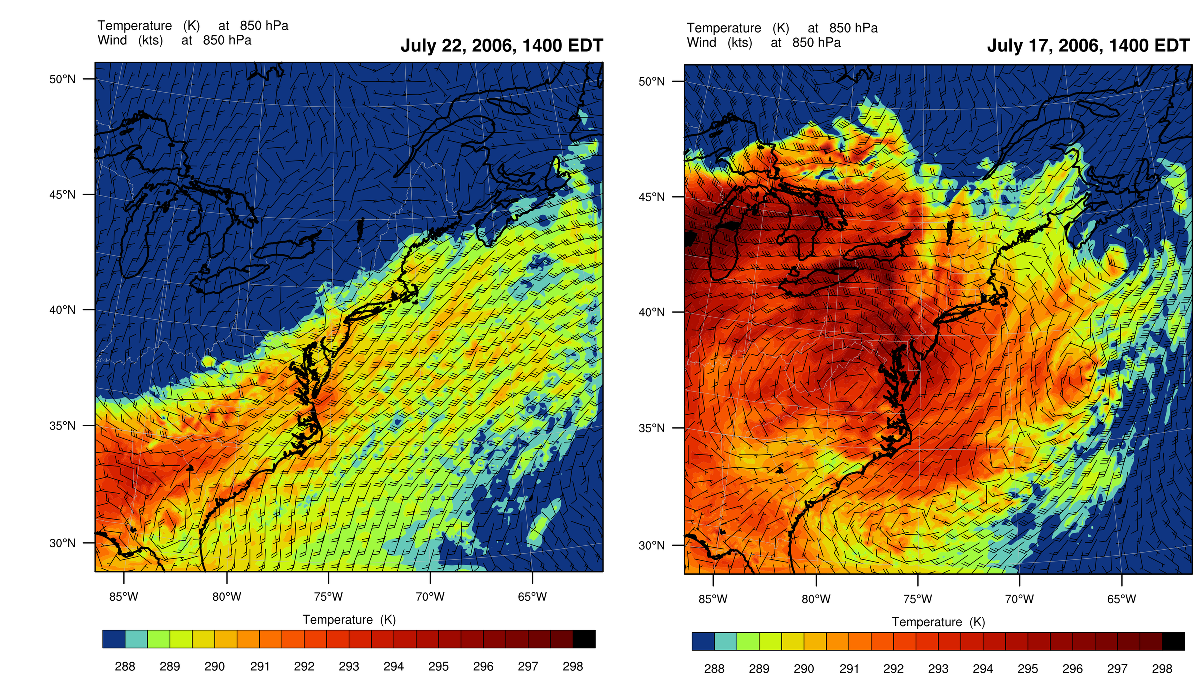


Figure above shows the 2m air temperature for NYC and the surrounding rural area. The black boxes indicate the elevated temperatures at both rural and urban areas during the Heat Wave period. Overall the urban core is on average 2.5 K hotter than the surrounding rural area.

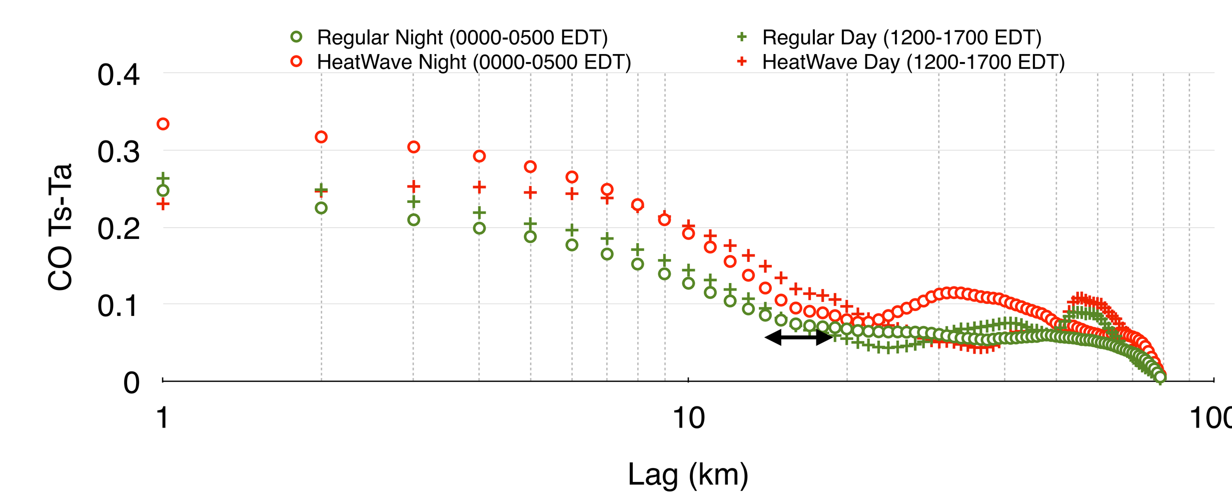


Ensemble averaged diurnal variation of Urban Heat Island intensity shows large differences in UHI pattern over a day between regular and Heat Wave periods. Particularly, high UHI is observed during mid afternoon period (1500 Local Time) when the near surface air temperatures peak.

Coastal Influence



Contours of air temperature and wind barbs from 850 hPa shows significant shift in wind patterns in the North East during the heat wave. The high pressure ridge attracts warm air from the west and restricts the influence of sea. The region to the west of NYC is also highly industrialized.



The ensemble averaged cross correlation between the land surface temperature and vertically averaged air temperature indicates extended Ts-Ta correlation during the heat wave periods. During the regular day the averaged correlation between Ts and Ta stretches to 11 and 12 Km for night and day times, for heat wave periods this extends to 19 and 20 km respectively.

Conclusion

Our analysis indicates that UHI intensity is significantly changed by its interaction with the heat wave. Particularly during the midday and the late afternoon period the UHI intensity is 0.5 - 2K higher compared to regular days. **This could be attributed to greater coupling between Ts and Ta and significant shifts in wind pattern.**

The stronger coupling between Ts and Ta shows that land cover modifications can have a pronounced effect on UHI intensity. In terms of mitigation strategies to combat Heat Wave episodes, programs like the Cool Roof initiative and the million tree initiative will help, however **since the footprint of influence is doubled during the intense Heat Wave episodes, the urban cover positively modified should also be significantly increased.**

Finally, it is imperative that Legislators and Policy makers from neighboring Cities/States work together on UHI and Heat wave mitigation. Our analysis shows that the vast industrial core to the west of NYC in New Jersey affects the microclimate of the City. And hence any UHI/Heat Wave initiatives undertaken by neighboring cities will have a positive impact on NYC's microclimate.