Statistical Modeling of the Urban Heat Island: High School through Graduate School

Brian Vant-Hull, Maryam Karimi, Awalou Sossa,
Louis Waxman, Estatio Guiterrez,
Sarah Johnson*, Reza Khanbilvardi

NOAA-CREST, City University of New York
* New York City Department of Health and Mental Hygiene
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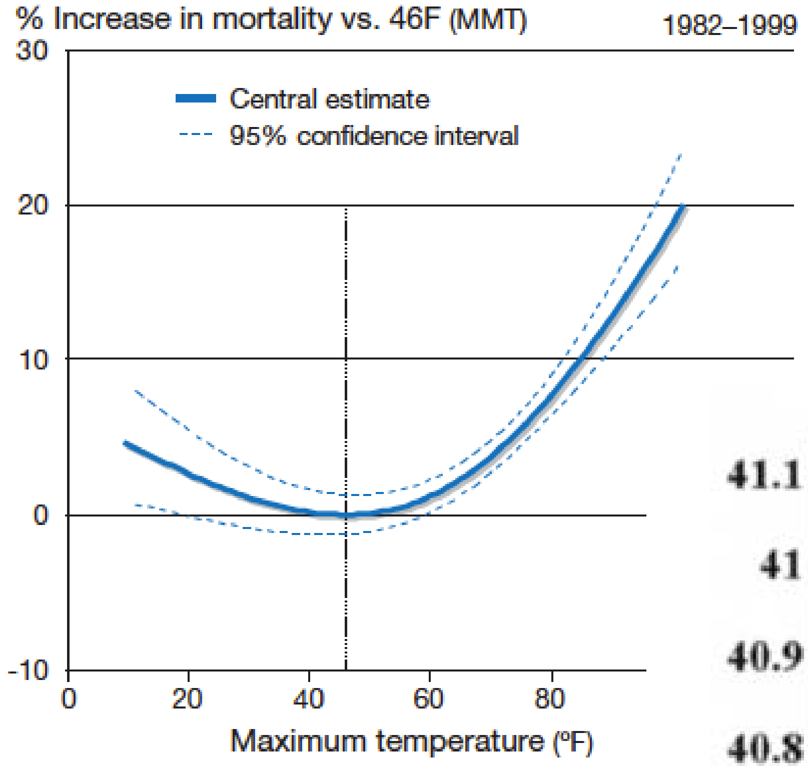
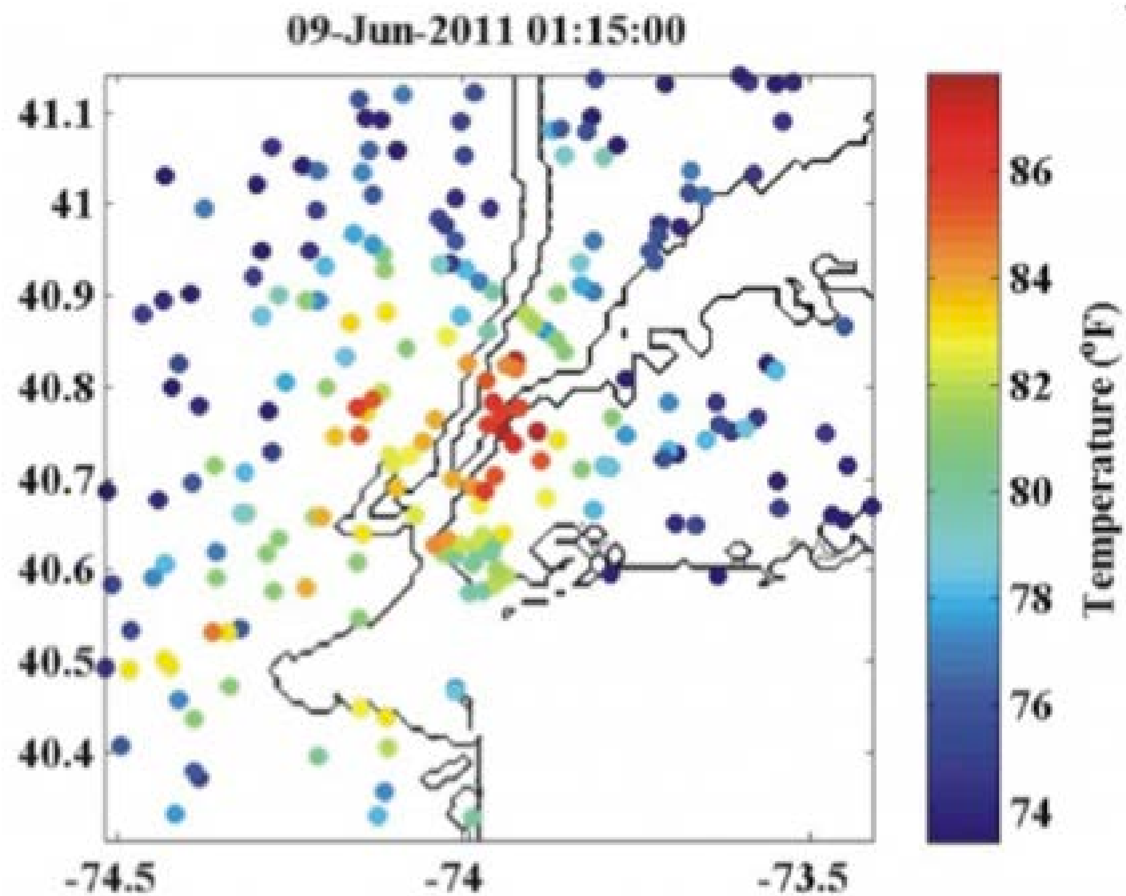
Urban Temperatures and Mortality



Patrick Kinney, NYC ClimAID Report 2013

NYC MetNet data



from "Forecasting the New York City urban heat island and sea breeze during extreme heat events". Meir, Orton, Pullen, Holt, Thompson and Arend in *Weather and Forecasting, 2013*


3.5 M
1.5 M
WEDDING
& PARTY
SPECIALIST

Field Campaigns

Temps, RH => dewpoint, Light

designed by grad student, implemented by undergrads

High spatial resolution measurements:

2 pm, ~ 40 minutes, 1.5 m AGL

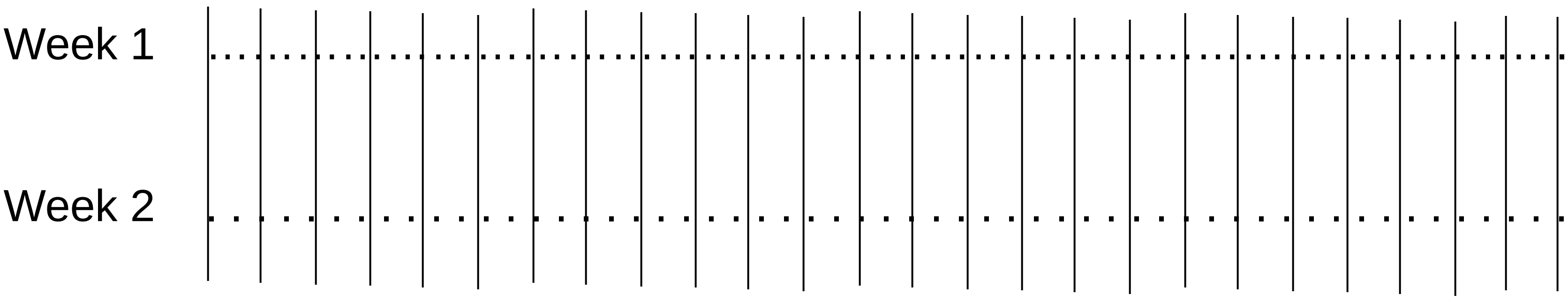
- 19 Simultaneous street walks (mainly in shade)
- 13 Simultaneous avenue walks (mainly in sun)
- Every 6 seconds, averaged to ~ 2 minutes; ~ 150 m

High time resolution measurements:

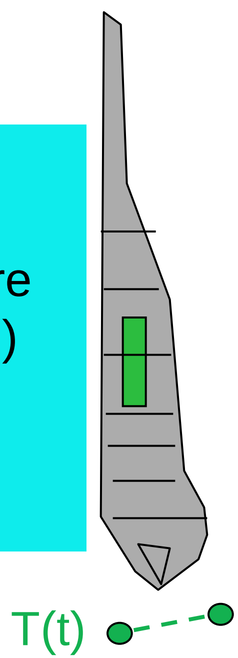
- Fixed Instruments, 10 locations
- 3 minute increments, 3 months
- ~ 3.5 m agl

Walking Campaign Data Reduction

Step 1: all walks divided into equal number of bins for spatial averaging



Step 2:
detrend
Temperature trend (fixed) subtracted from bin averages



Step 3: *group statistics*
For each day, Manhattan average and standard deviation calculated ('daily avg' & 'daily SD') from detrended data

Step 4: *Anomalies, scaling*

'Differences' =
bin avgs - daily avg

'Deviations' =
Differences/(daily SD)

Color Scheme for all Measurement Units

Black	< -1.75 units
Blue	-1.25 to -1.75 units
Light blue	-0.75 to -1.25 units
Green	-0.25 to -0.75 units
Yellow	+/- 0.25 units; average
Orange	+0.25 to +0.75 units
Red	+0.75 to +1.25 units
Purple	+1.25 to +1.75 units
White	> + 1.75 units

Bluer is lower: Yellow is Average: Redder is higher

Temp Avgs

< In the shaded street data, low buildings are warmer, vegetation and higher elevations are cooler.

Student T-test values > Purple or dark blue is significant at 90% confidence level

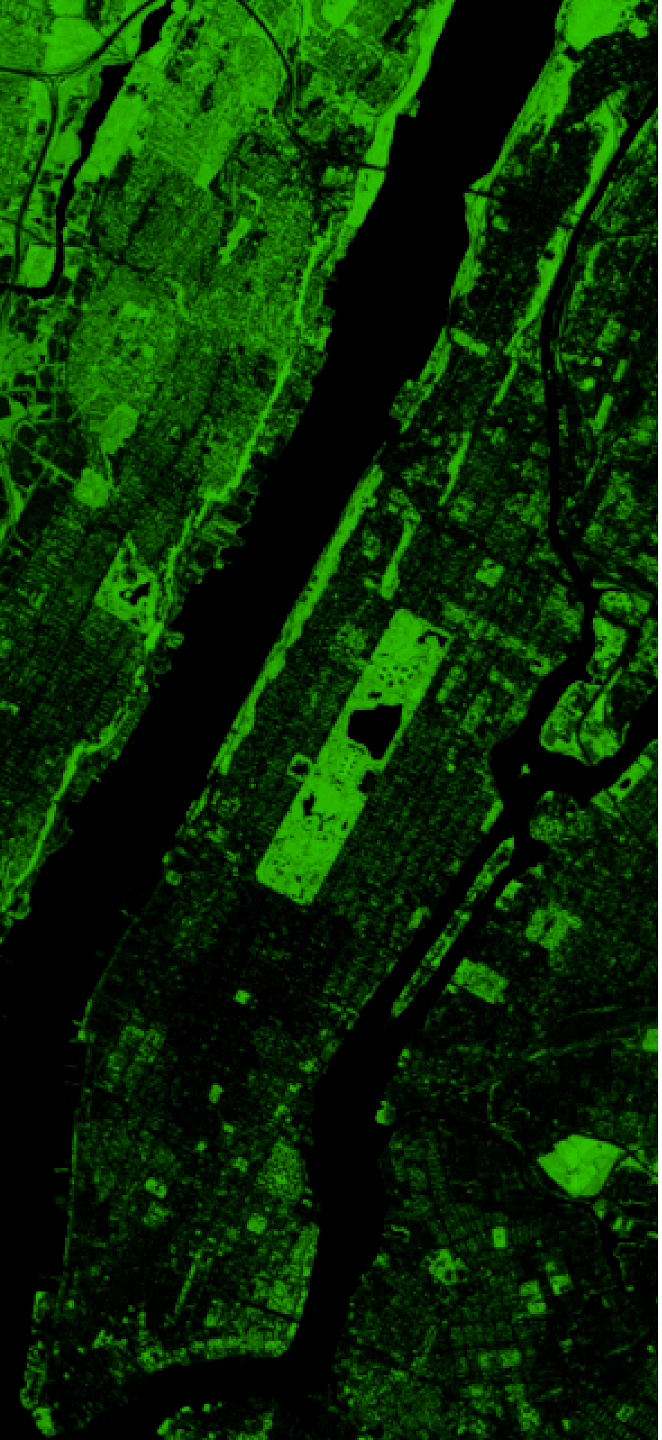
Bluer is lower: Yellow is Average: Redder is higher

Surface Data Sets

USGS survey - 30 m resolution
- elevation
- water (elevation < 0.15 m)
- 1km^2 water fraction

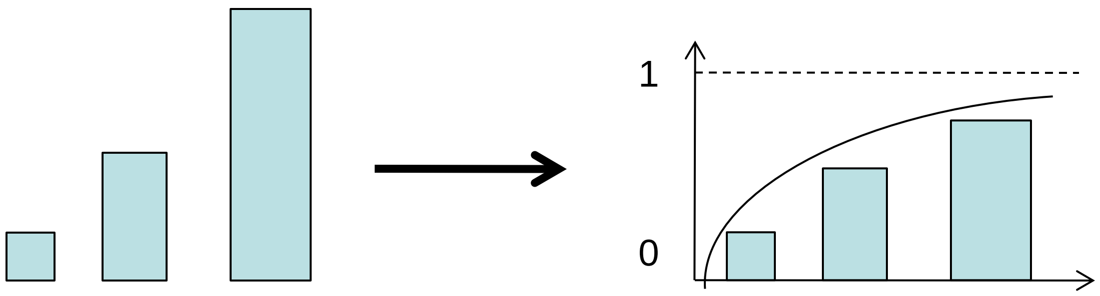
LandSat - 30 m resolution (processed by undergrad
- Vegetation (NDVI)
- Albedo (narrow to broadband conversion)

NYC mapPluto - aggregated to 100 m resolution
(processed by graduate students)
- Building height
- Building area fraction



Viewing Vegetation/Albedo in Cities

Variable Modifications

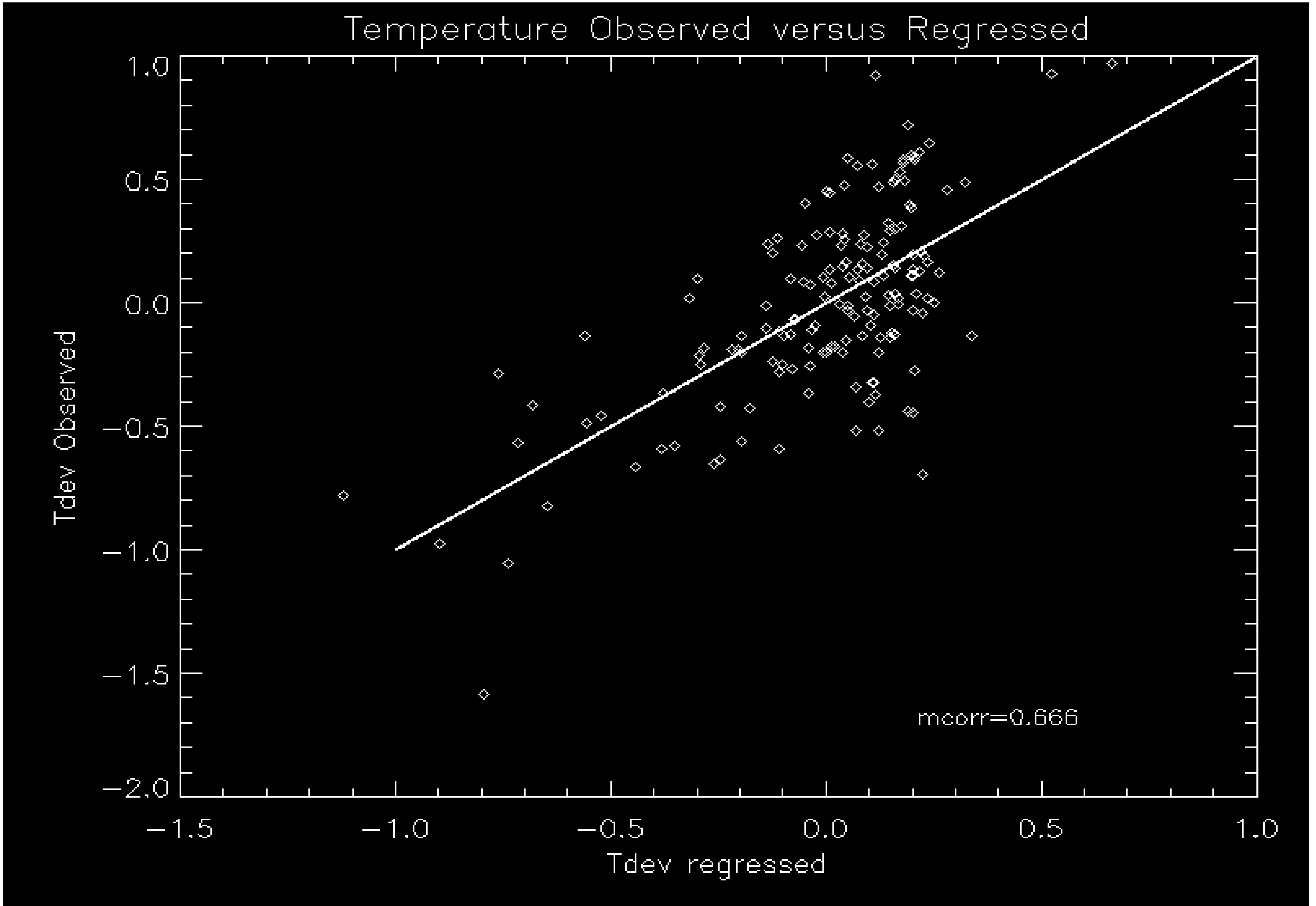


Scaled Building Height => 1 - exp(-H/Ho)
Ho = 7.5 m *(0 < SBH < 1)*

Scaled Building Volume = SBH x Building Area Fraction

note that 1 - SBV ~= Sky View Fraction

Regression of local Temperature Anomalies to Surface Characteristics



Correlations and Coefficients
Temperature anomalies to Surface Variables

0

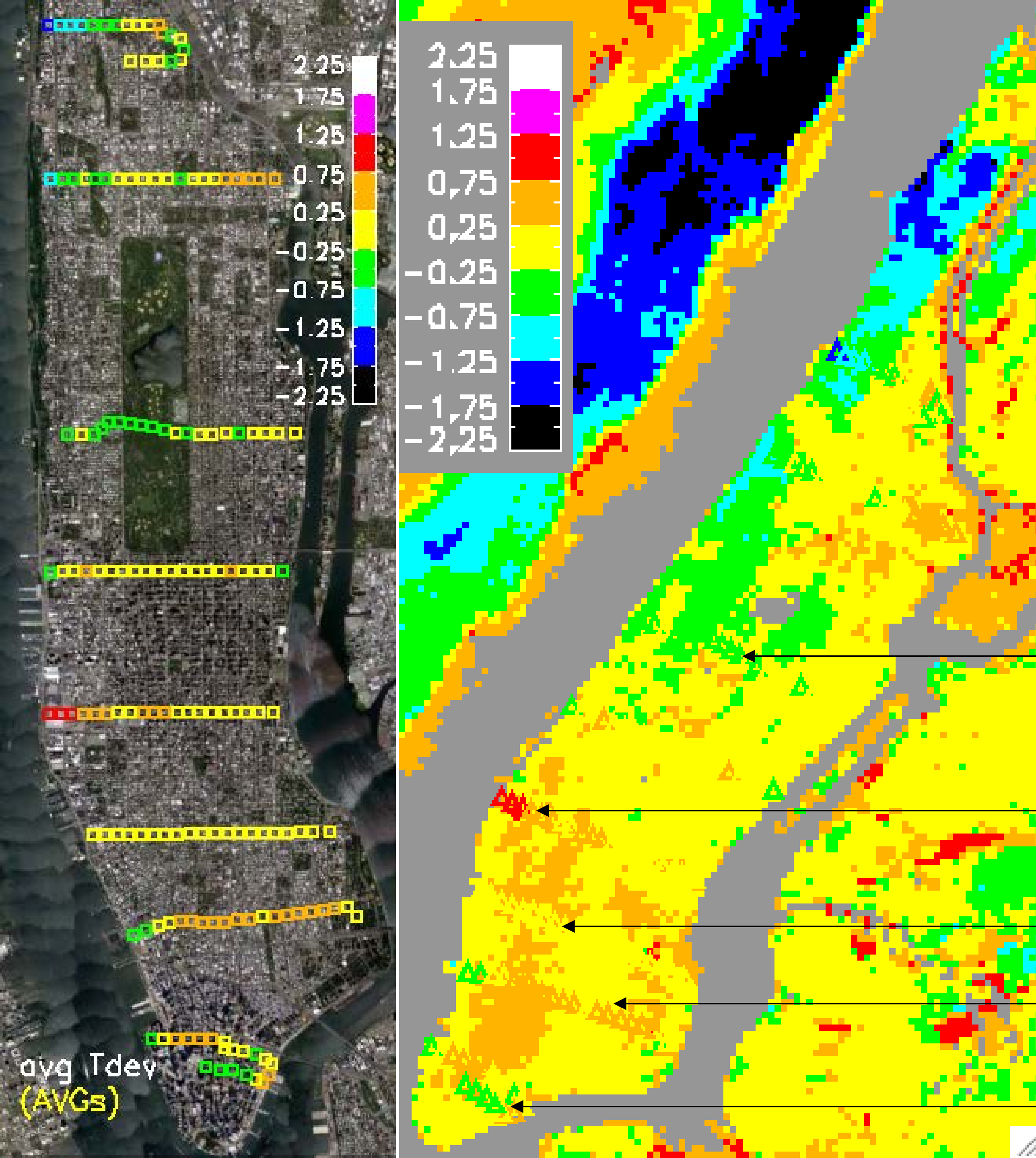
to

1

Variable	Correlation	Coefficient
Elevation	- 0.52	- 0.03 /m
NDVI	- 0.39	- 0.59
Build Volume	0.087	2.5
Build Area %	0.08	- 2.1
Albedo	0.06	- 0.70
Water %	0.02	- 0.81
Build Height	- 0.01	- 0.76

1 std dev ~ 1 degree C

When observations differ from the model predictions (1.5 m agl)



Cool in the Park

Hot spot at piers

Unpredicted average

Warm in villages

Cool in downtown

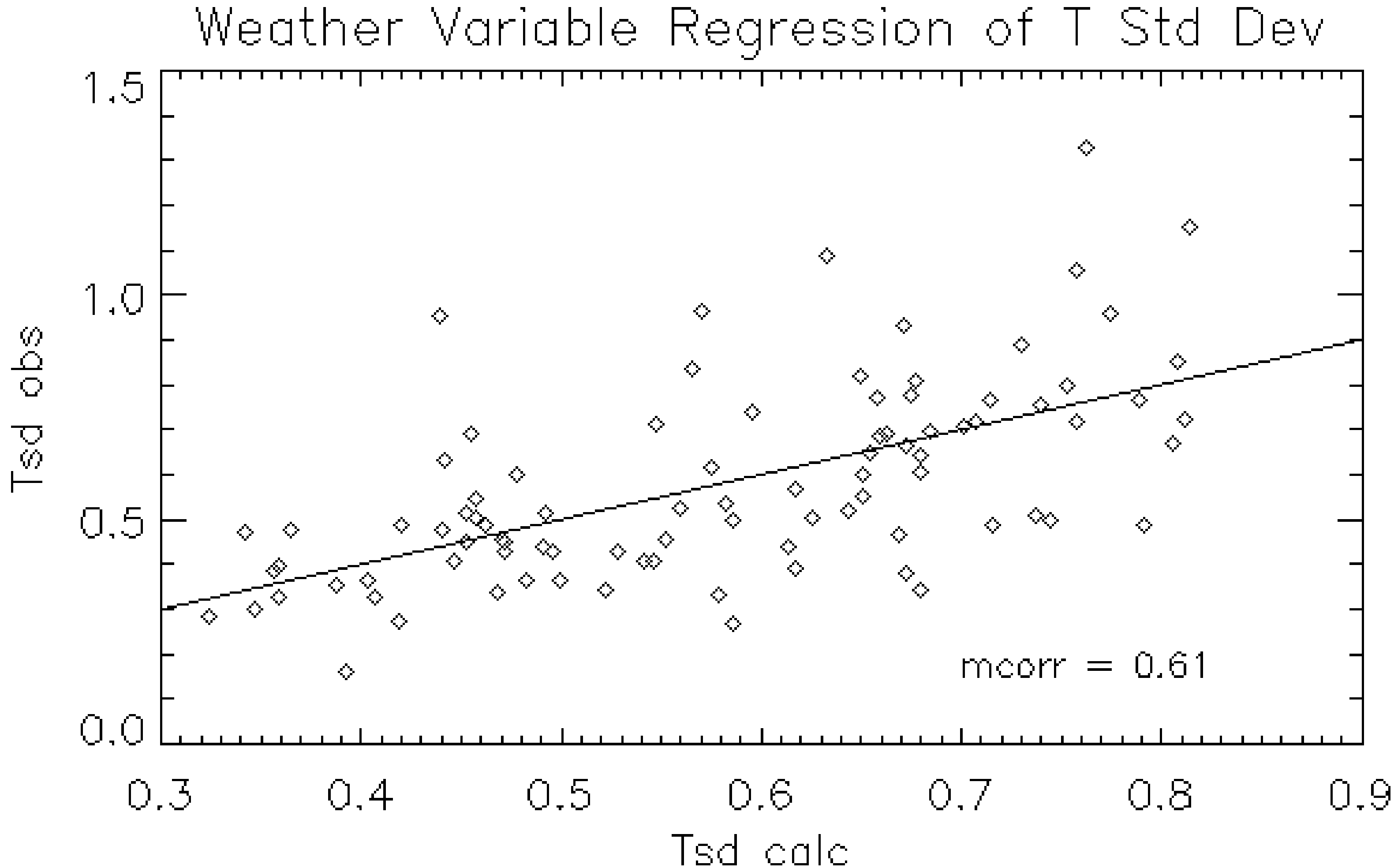
During 3 months the fixed instruments sample a wide range of meteorological conditions, reflected in the spread of temperatures between locations. The standard deviation is a measure of spatial variability.

Since our field campaigns are scaled to standard deviation, we can relate weather to the amplitude of temperature variation within the city.

(3.5 m agl)

Weather and Temperature Anomaly Amplitudes

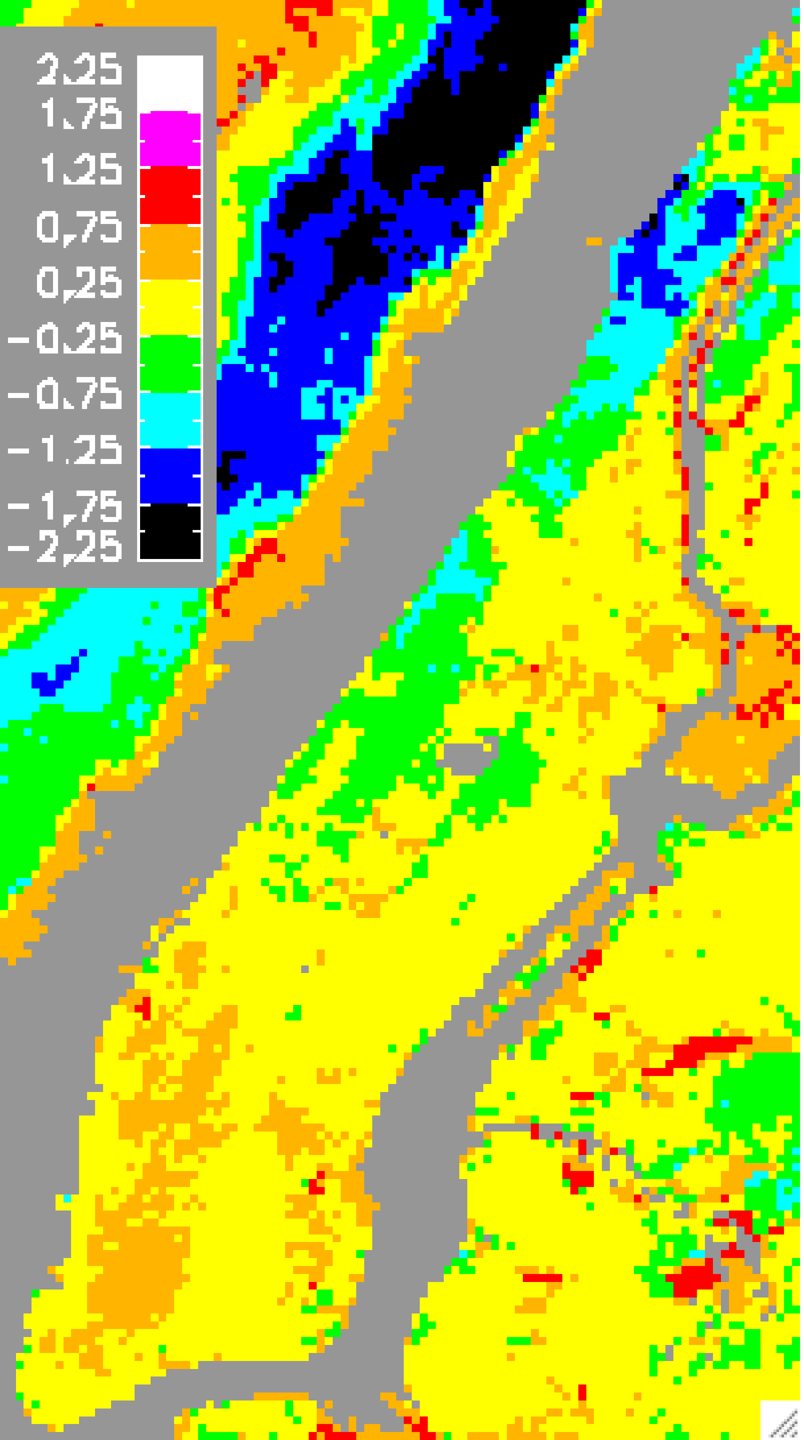
A windy overcast day is expected to have less temperature variation within the city than a calm clear day.



Temperature Difference between Highest and Lowest Elevation Stations

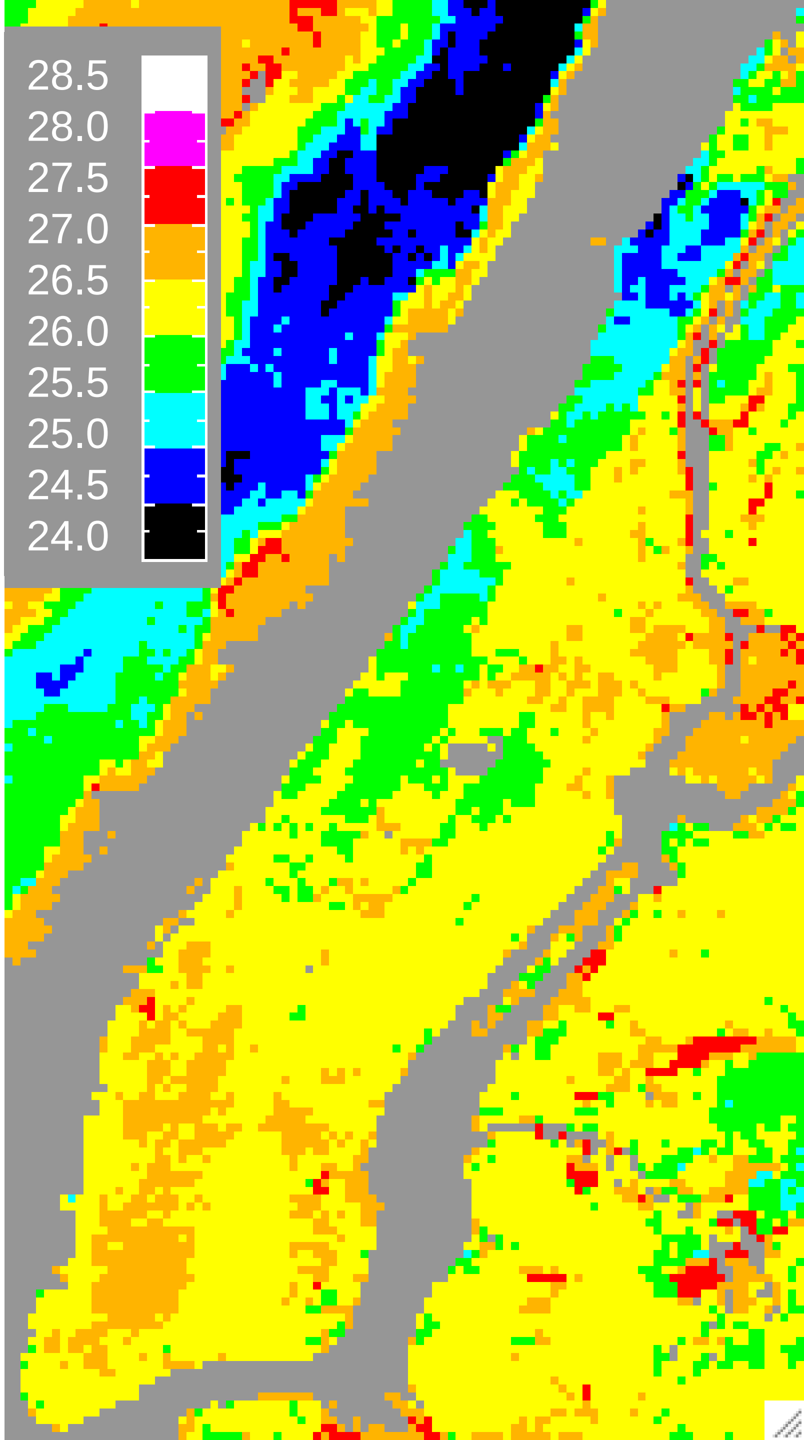
Variable	Correlation	Coefficient
Temp	0.471	0.067
RH	-0.134	0.011
Northward Wind	0.186	0.012
Eastward Wind	0.278	0.025
CF	-0.047	-0.003
Mid Level LR	-0.106	-15.315
Low Level LR	-0.216	-41.859
V Total	0.018	-0.001
Evaporation Rate	0.076	0.024

Temperature (sunlight?) and wind more important than the change of air temperature with altitude (lapse rate)



Actual degrees

Weather forecast



Critique: is the anomaly function Separable?

Temperature Anomalies = F(surface, weather)

?= G(surface) * K(weather)

(Anomaly map * Amplitude)

Not rigorous; and yet…

…simple approximate tools get more use.

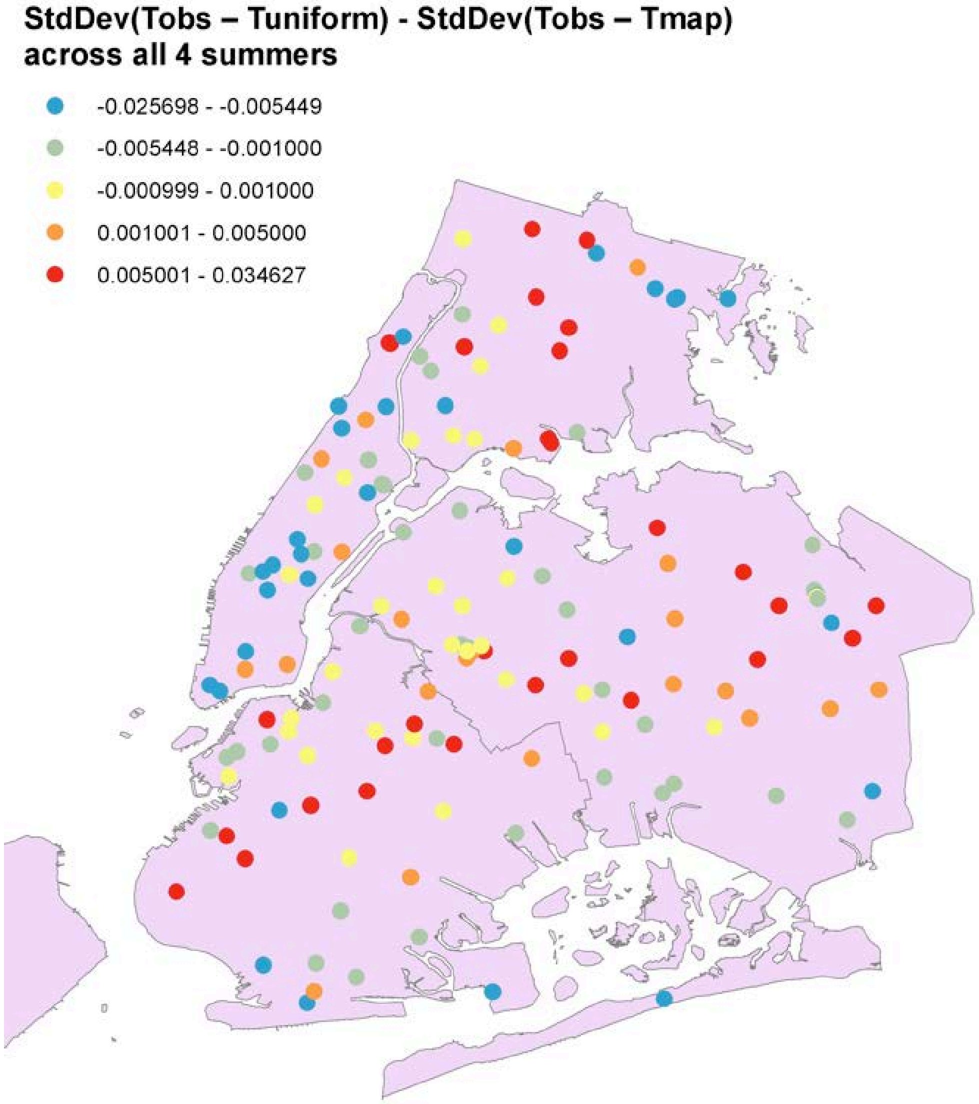
Testing the Model

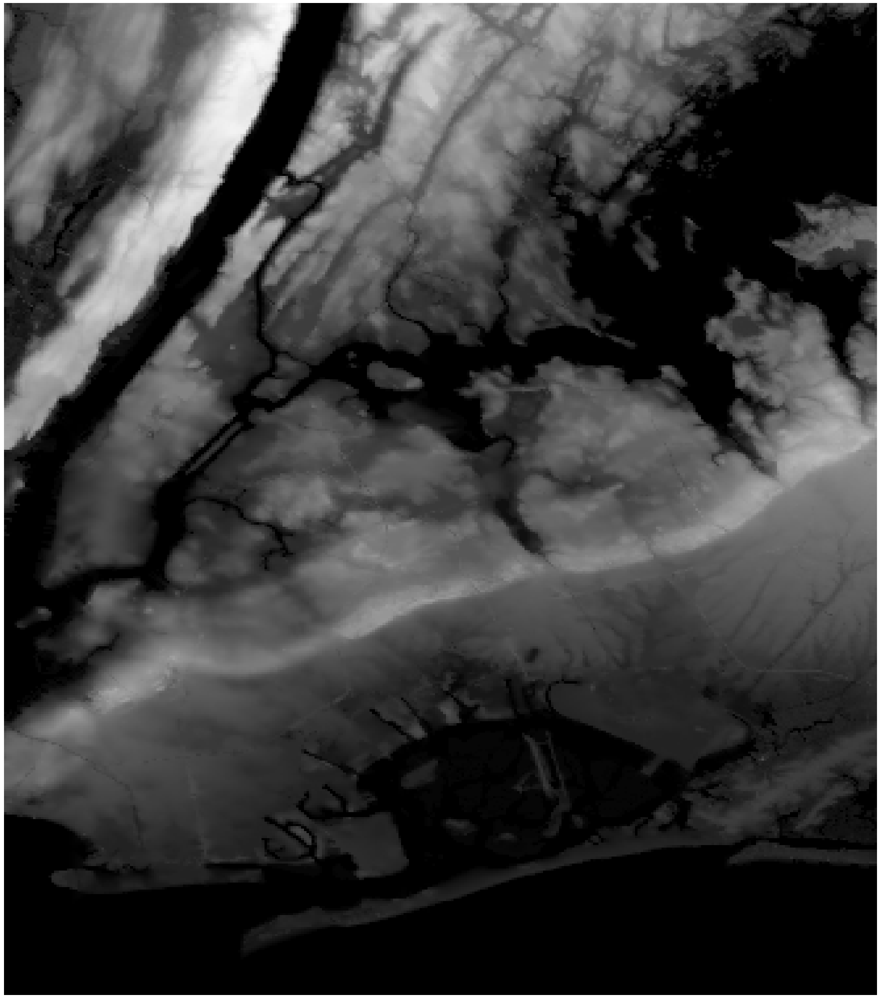
If the model is correct, then for a set of observations:

$$StdDev(T_{observed} – T_{uniform}) > StdDev(T_{observed} – T_{model})$$

3 months of observations with our 10 stations on Manhattan
calculating spatial variability each day (Tsd ~ 0.6 C)
show an average reduction of 4% in standard deviation.
(work done by undergraduate)

Department of Health Comparison





elevation

Manhattan UHI Website

The site explains methods, provides images and data for download, and the paper describing the dataset. It hosts real time forecasts and nowcasts of the Manhattan UHI.

http://glasslab.engr.ccny.cuny.edu/u/brianvh/UHI

This data has been used by the urban WRF team at CCNY, testing output of a high resolution dynamical model with urban surface parameterizations (Guiterrez, Gonzalez, Arend).http://air.ccny.cuny.edu/ws/wrfn/anibmaster.wrfmetnet.php

Summary

- A multivariable linear regression is used to model afternoon urban temperature anomalies from surface characteristics: buildings, vegetation, and elevation.
- The amplitude of the anomalies are predicted via regression of weather variables.
- Temperature dependence on elevation is super-adiabatic, perhaps linked to wind.
- This simple model is imperfect but easy to apply using data available to any municipality.

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