



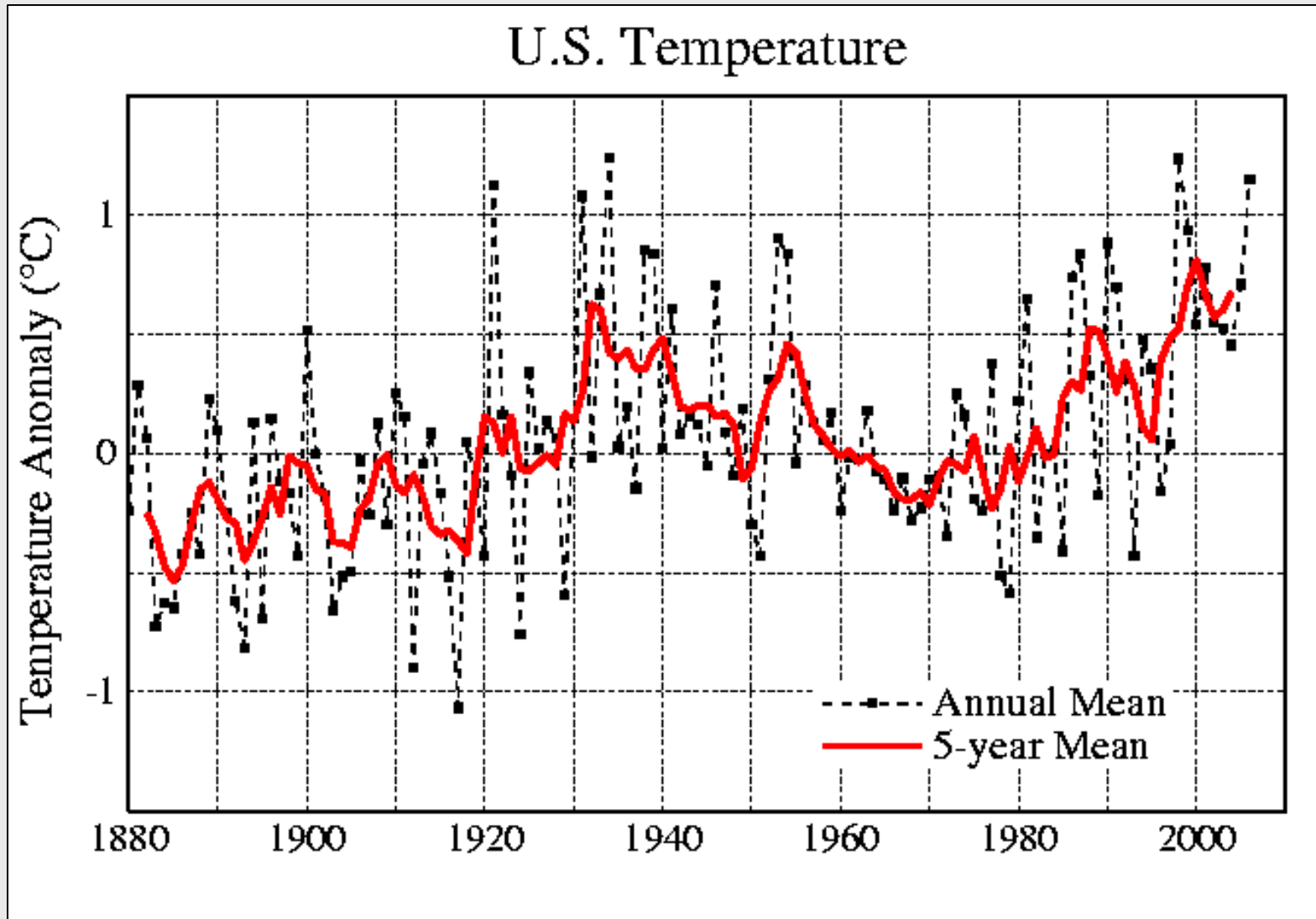
# Are Cities Warming Faster than the Planet as a Whole?

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## Overview

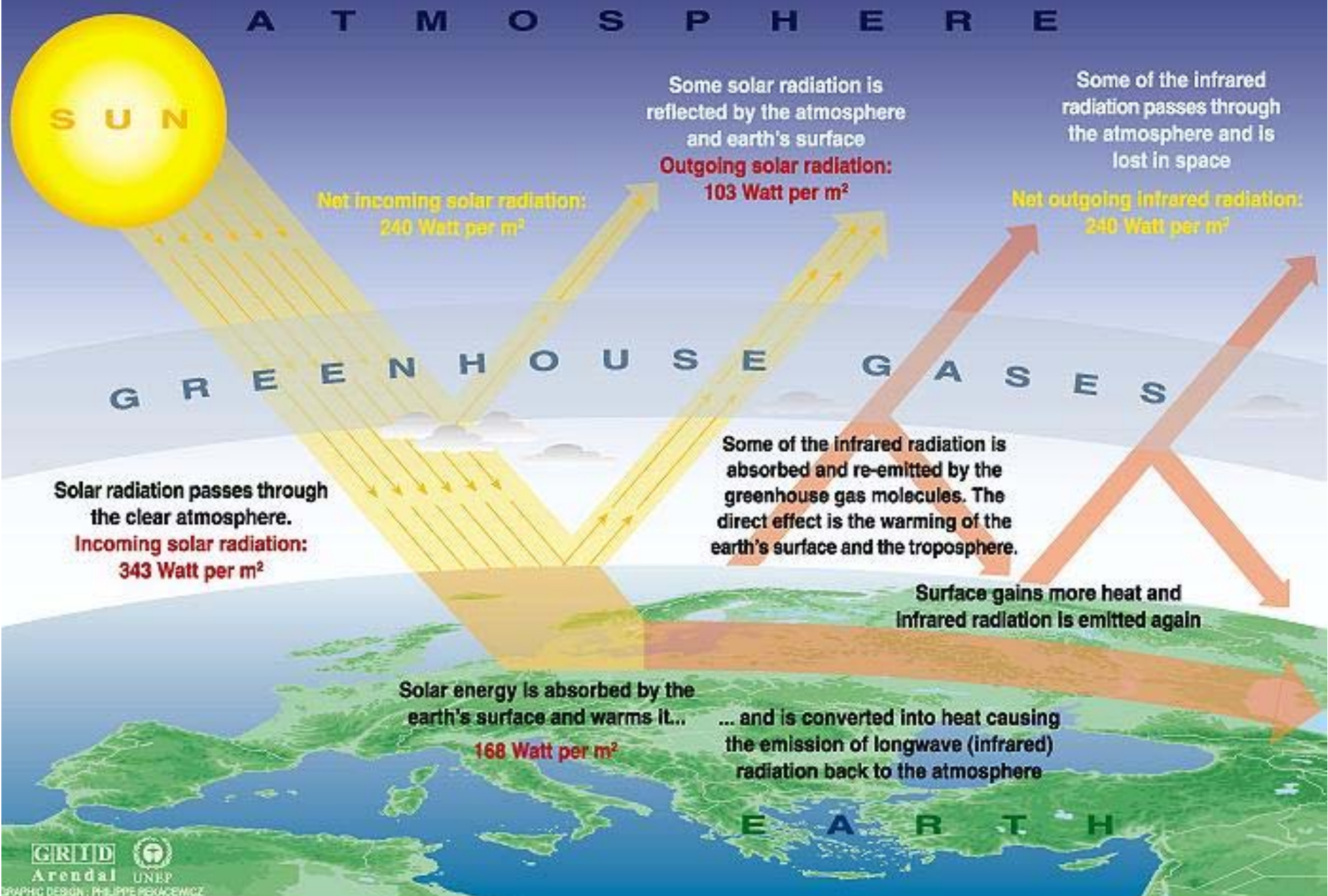
- ❖ Mechanisms of climate change
- ❖ Urban warming trends in large U.S. cities
- ❖ Threats of urban warming
- ❖ Planning responses to climate change



Source: NASA Goddard Institute for Space Studies

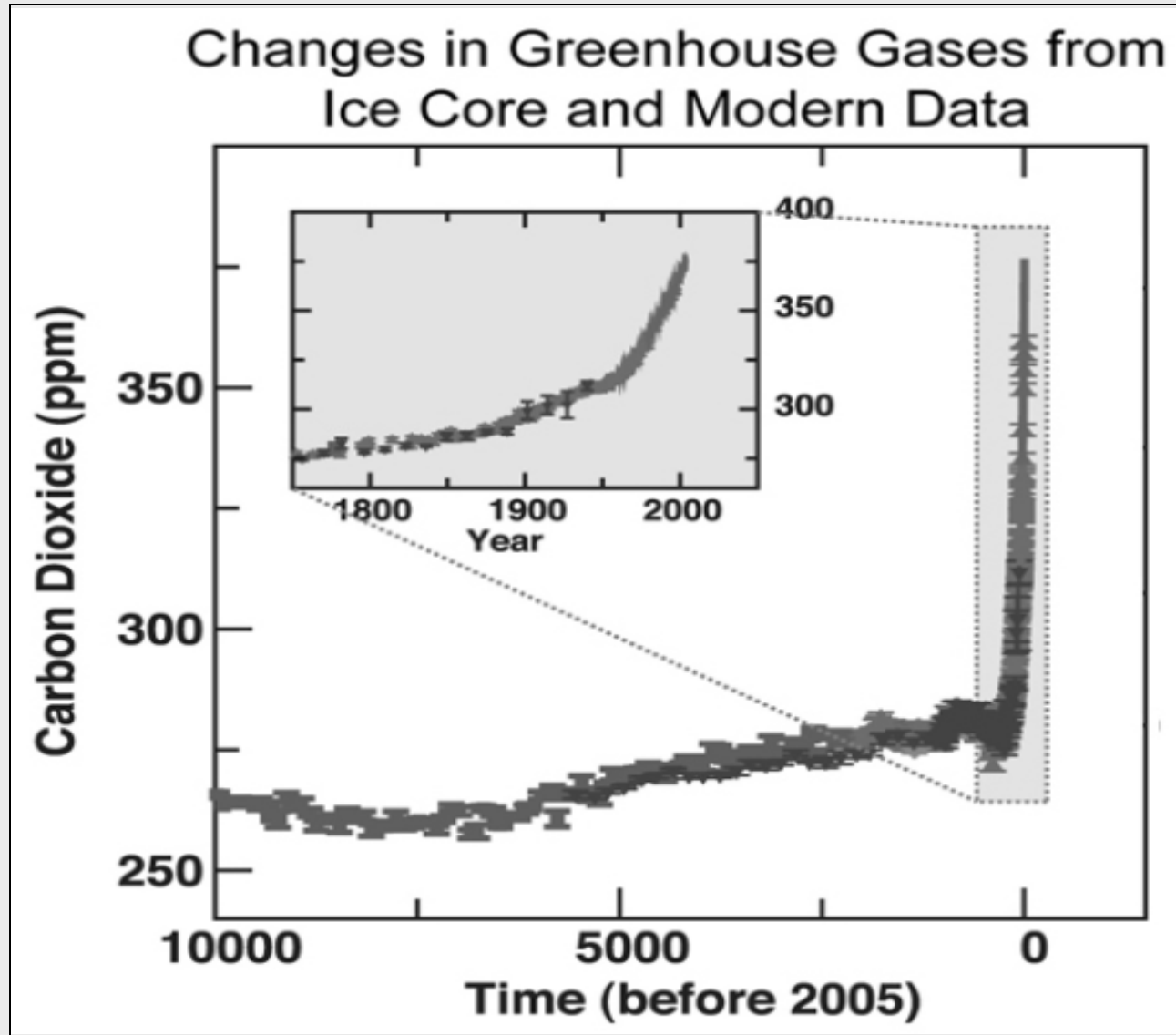
B. Stone, City and Regional Planning, April 2008

# The Greenhouse effect





B. Stone, City and Regional Planning, April 2008





## Land Surface Change





Approximately 50% of the rise in near surface air temperatures since the 1960s is attributable to land use change.

## Impact of urbanization and land-use change on climate

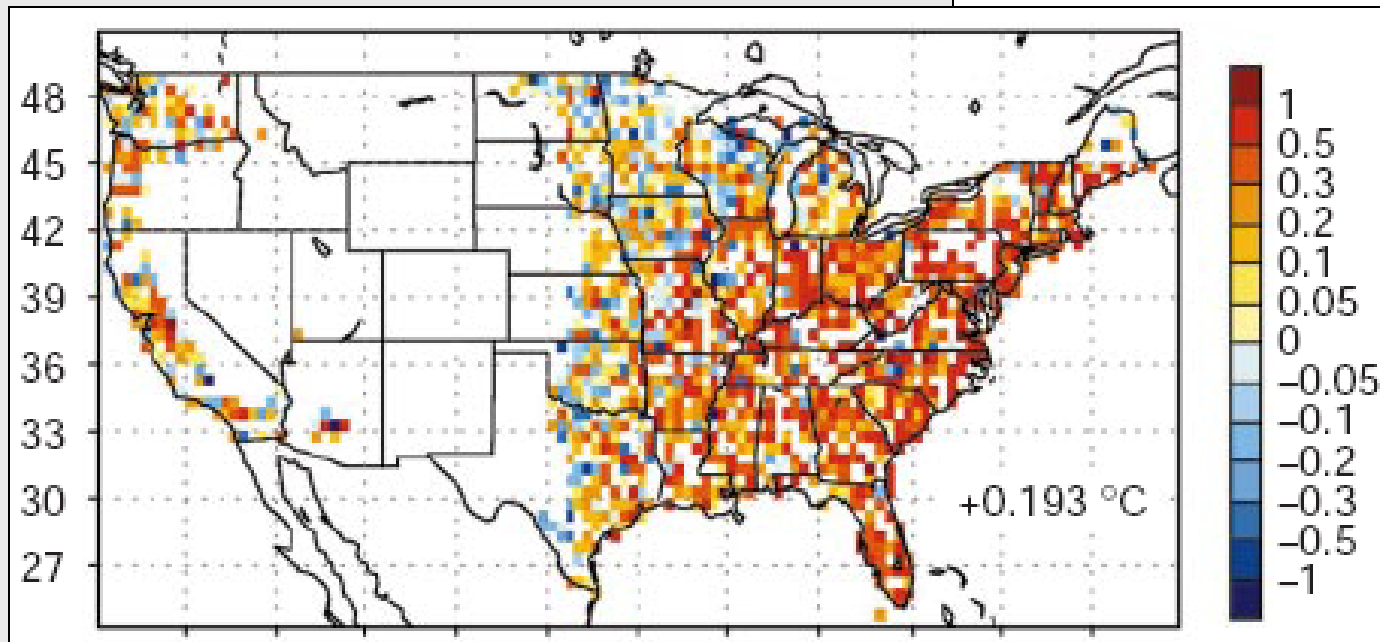
Eugenia Kalnay & Ming Cai

University of Maryland, College Park, Maryland 20770-2425, USA

The most important anthropogenic influences on climate are the emission of greenhouse gases<sup>1</sup> and changes in land use, such as urbanization and agriculture<sup>2</sup>. But it has been difficult to separate these two influences because both tend to increase the daily mean surface temperature<sup>3,4</sup>. The impact of urbanization has been estimated by comparing observations in cities with those in surrounding rural areas, but the results differ significantly depending on whether population data<sup>5</sup> or satellite measurements of night light<sup>6-8</sup> are used to classify urban and rural areas<sup>7,8</sup>. Here we use the difference between trends in observed

mental United States and the  
 ction of surface temperatures  
 obal weather over the past 50  
 observations, to estimate the  
 urface warming. Our results  
 crease in diurnal temperature  
 d-use changes. Moreover, our  
 warming per century due to

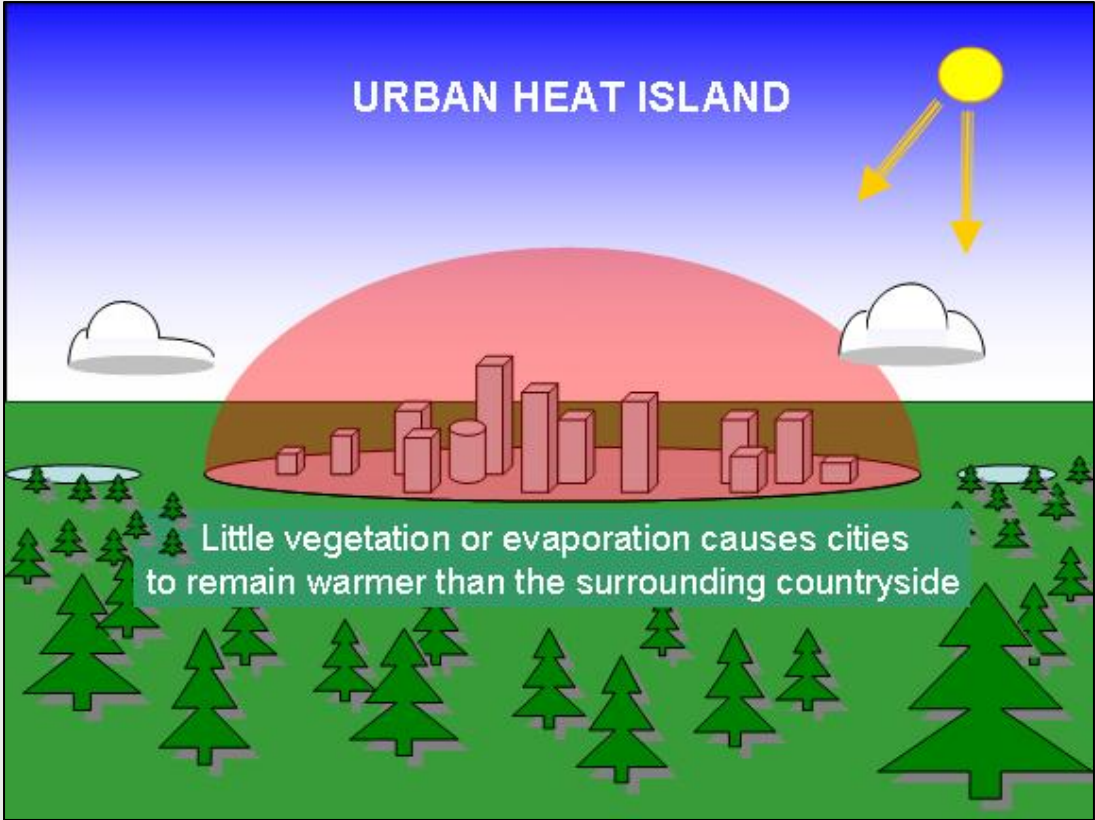
23 | 29 MAY 2003 | www.nature.com/nature



Source: Kalnay & Kai, 2003



# Urban Heat Island Effect



Source: Weatherstreet.com, 2008

UHI increases near surface air temperatures by  
 1 - 6 °C (2 - 10 °F)

B. Stone, City and Regional Planning, April 2008



Source: gunsmoke.com, n.d.



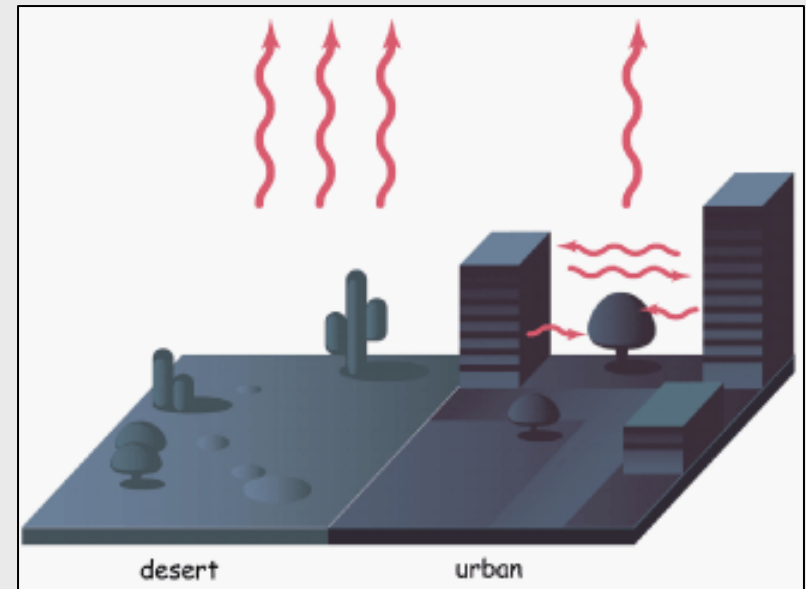
Source: Lonely Planet, com, n.d.



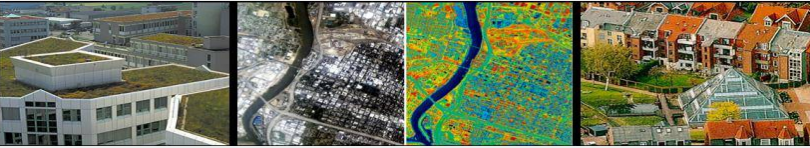
Source: uwee-foto, n.d.



## Thermal Properties of Urban Surfaces



Source: ASUSMART, 2006

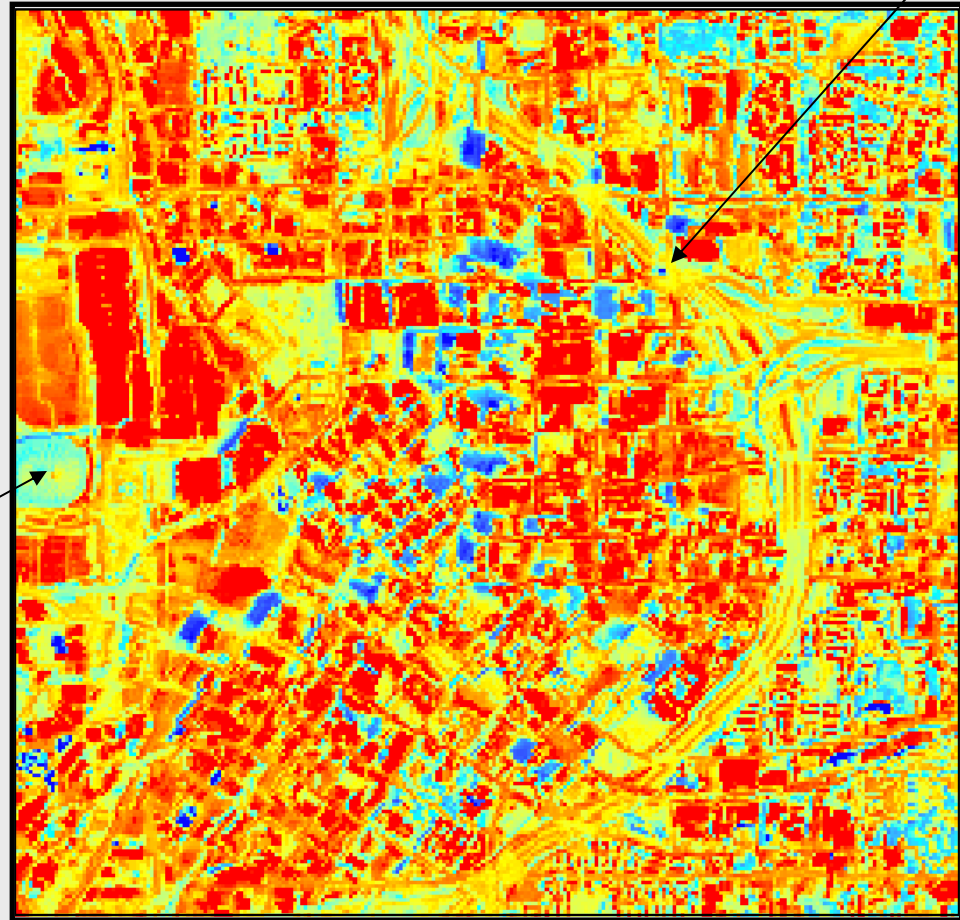


# Research Question

Are large U.S. cities warming more rapidly than the planet as a whole?

Georgia Dome

I-75/85

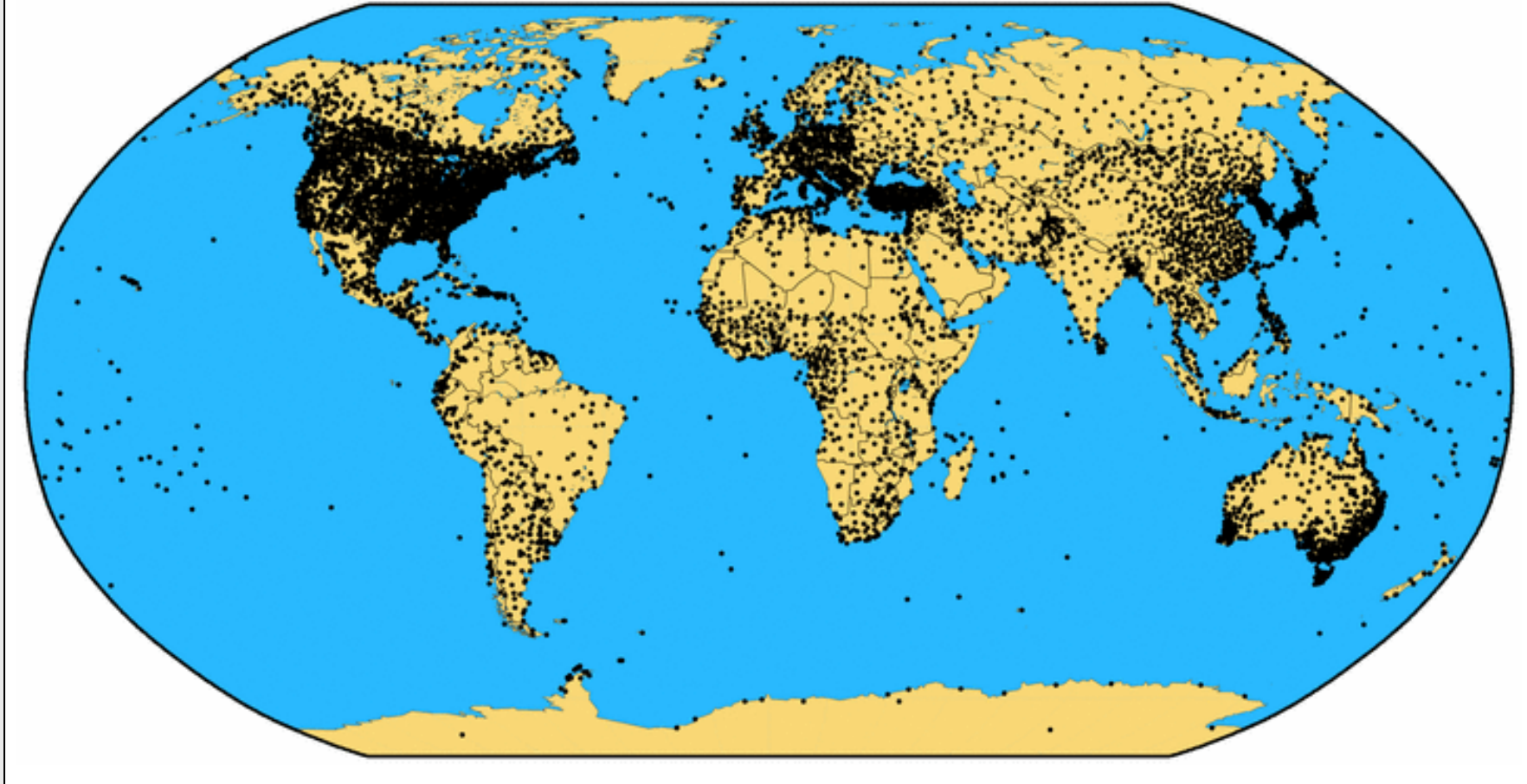


Intensity of surface heat in Atlanta's CBD, 1997



# Global Historical Climatology Network

Figure 1: GHCN-Monthly Coverage Map for Mean Temperature



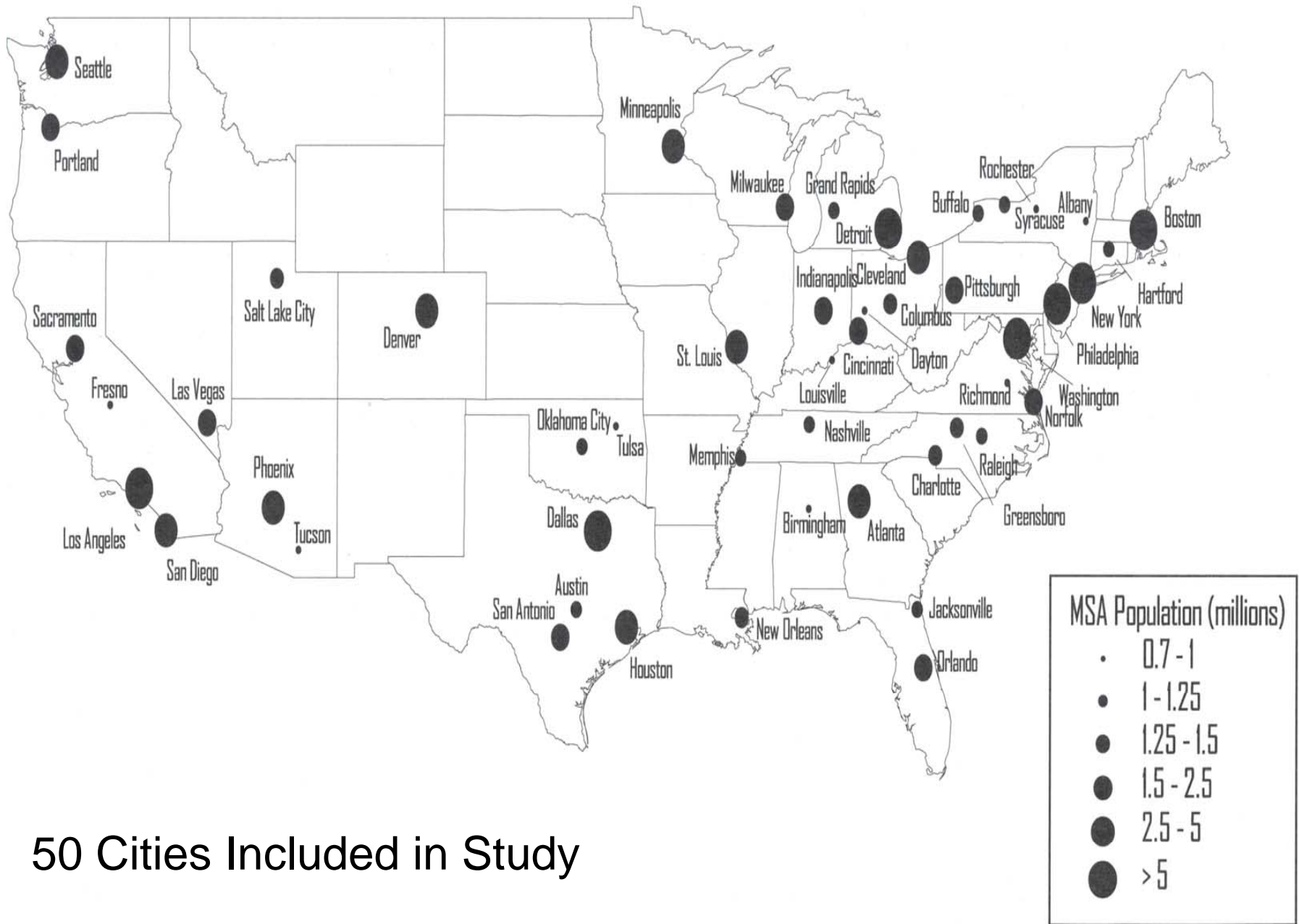
Source: GISS, 2007.



## Sources of “Inhomogeneity” in Temperature Record

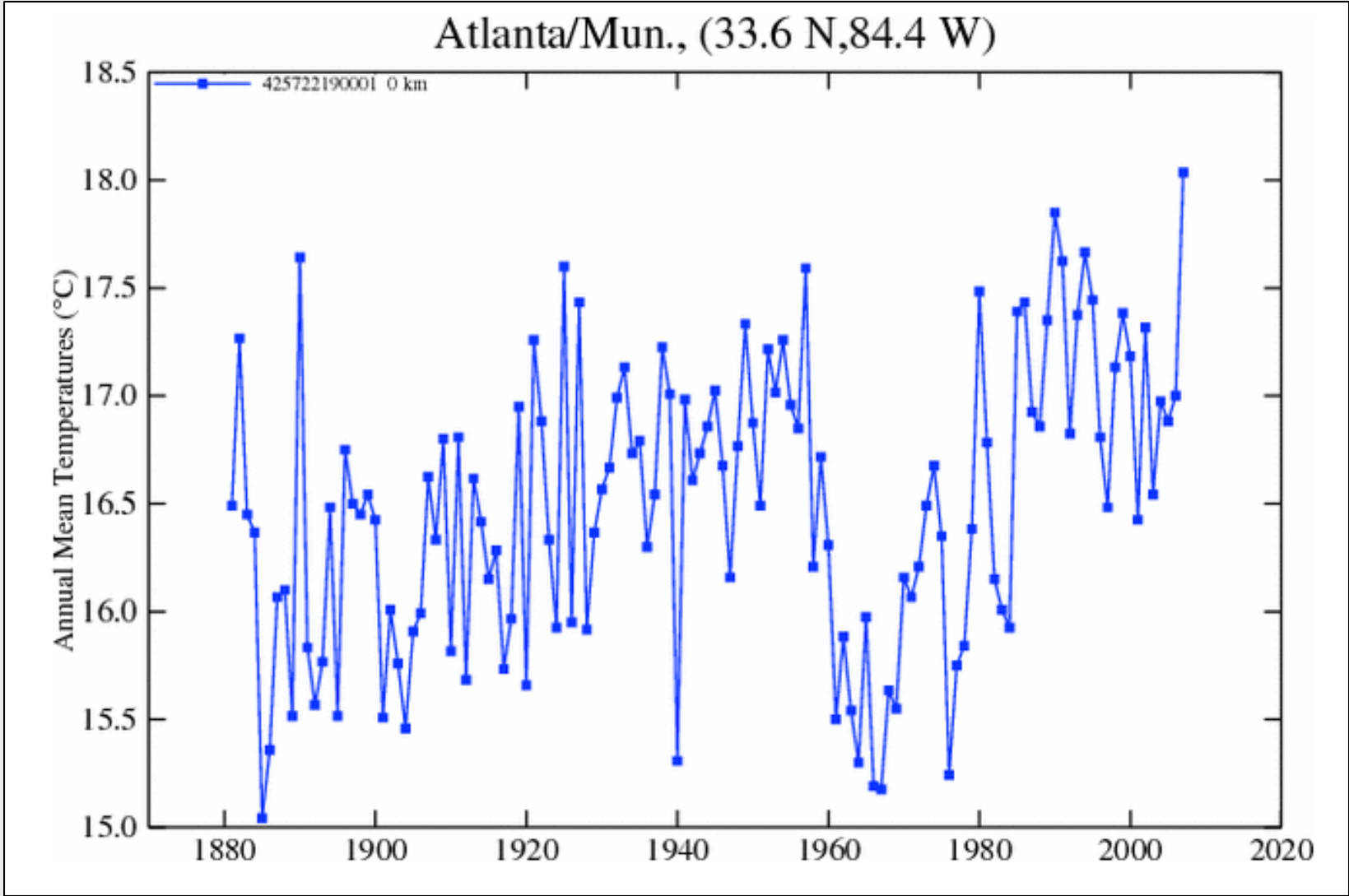
1. Change in location of instrument
2. Change in instrumentation
3. Change in time of observation
4. Contamination by urbanization







# Hartsfield-Jackson Observations





## Station Selection

### URBAN

- Airport as single “first-order” meteorological station for each urban center
- Night light ranking of C (bright)

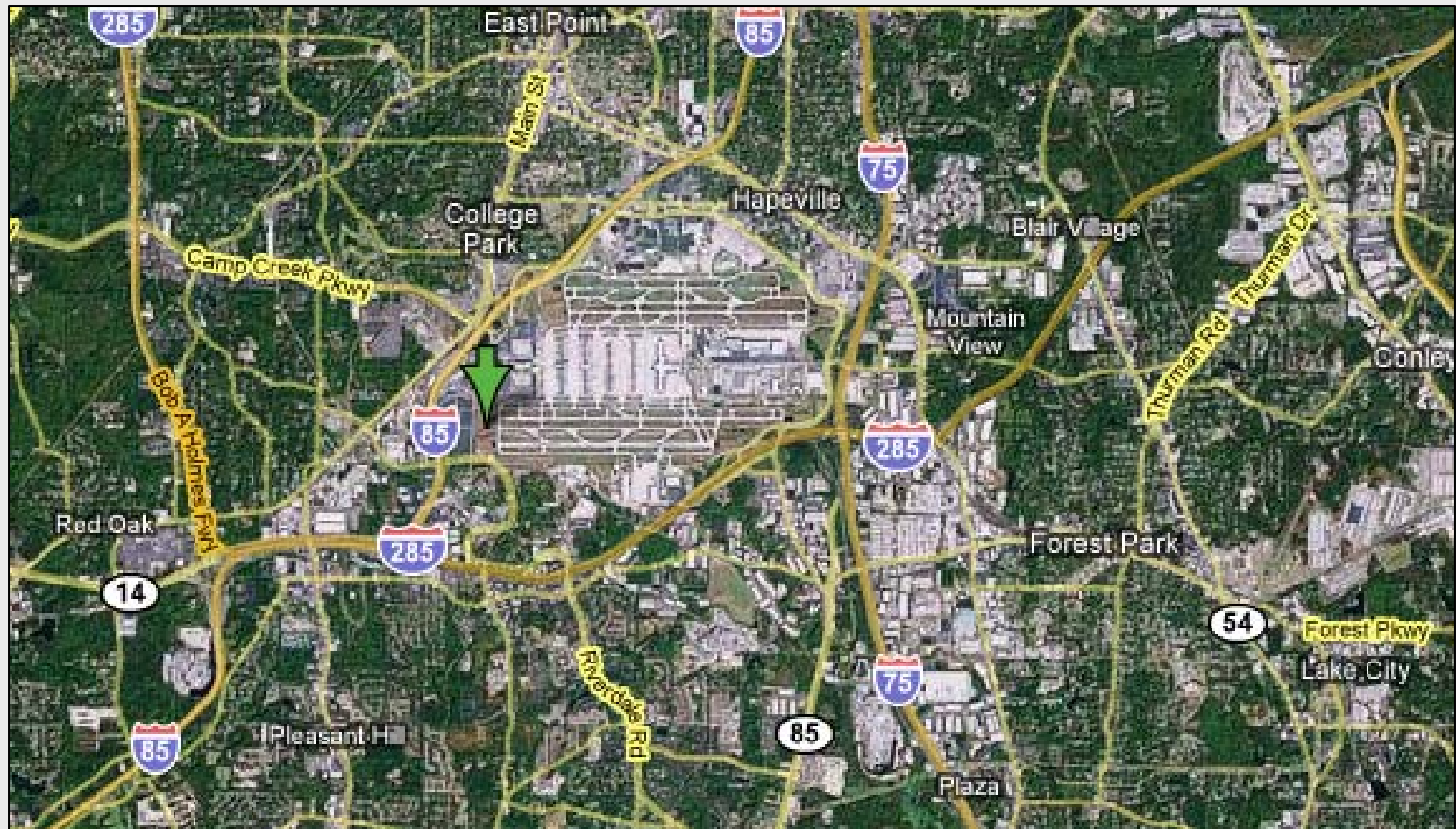
### RURAL

- Three stations selected for each city based on:
  1. Night light ranking of A (dark) or B (dim)
  2. Population < 4,000 per square kilometer
  3. Located within 50 to 250 km of urban station





# Hartsfield Meteorological Station





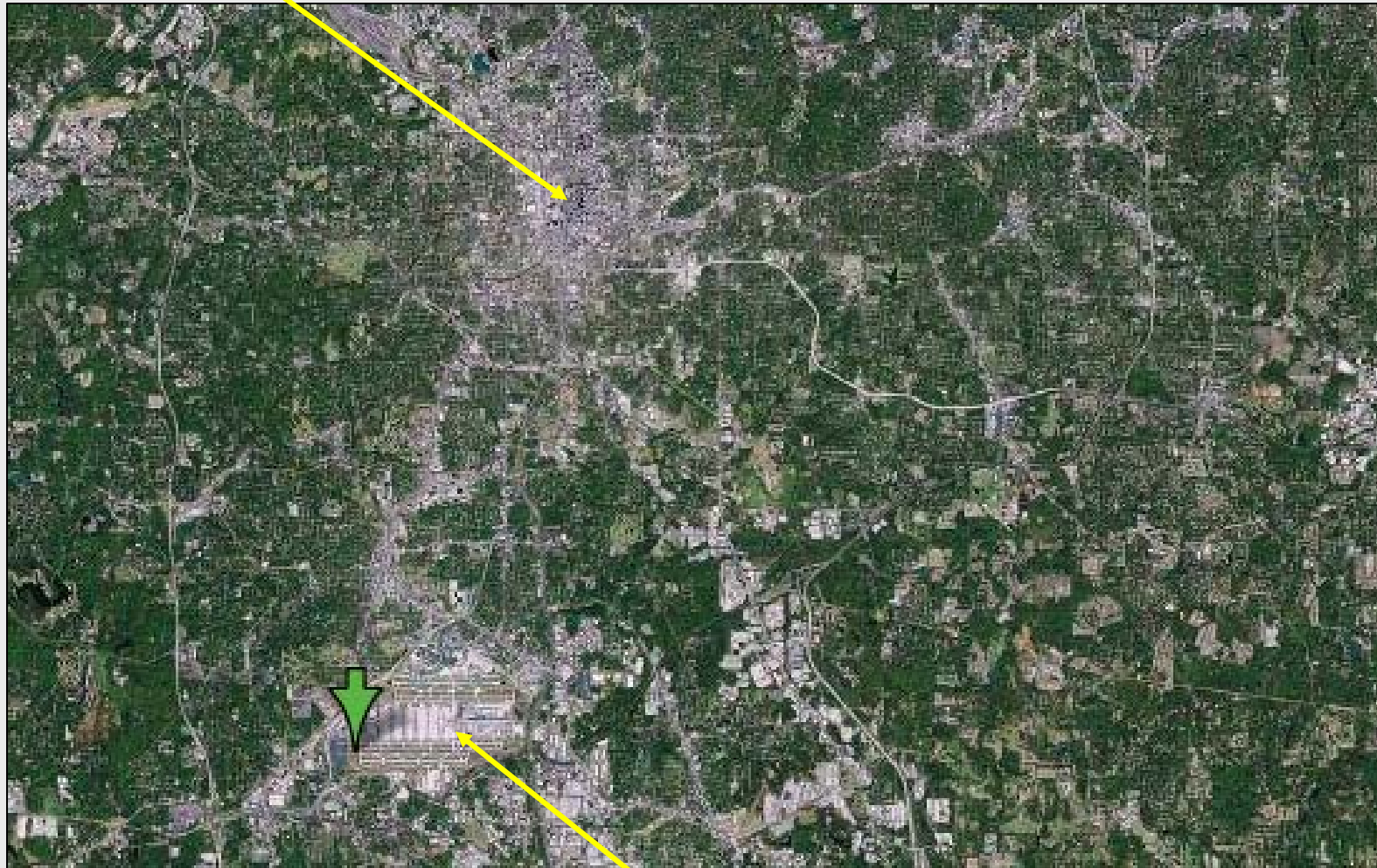
# Hartsfield Meteorological Station





# Hartsfield Meteorological Station

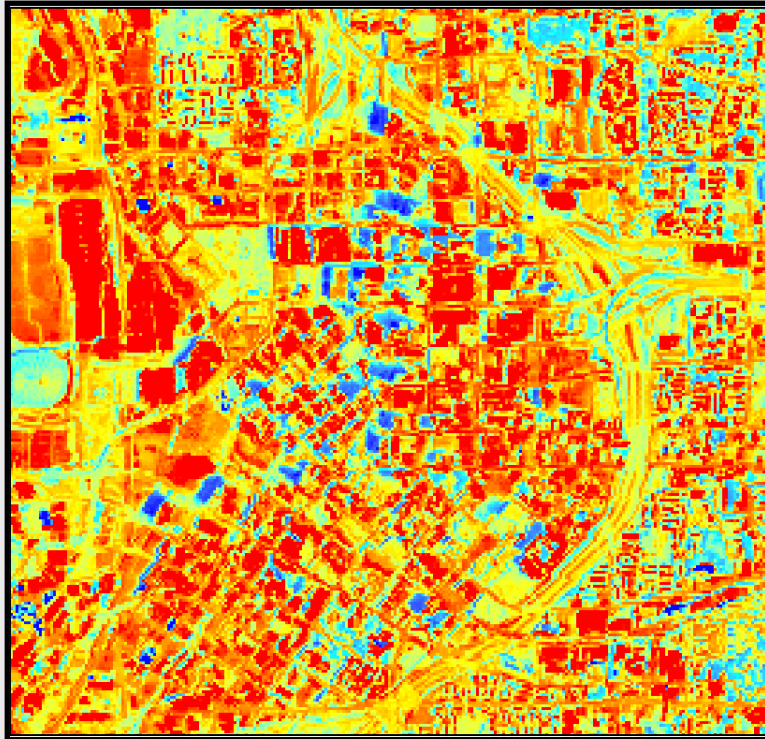
Atlanta CBD



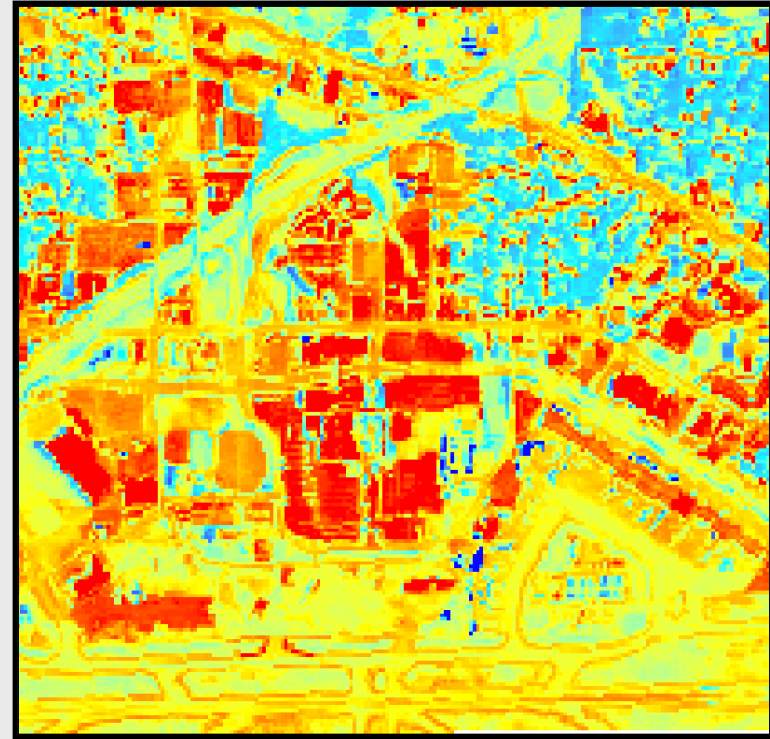
Hartsfield-Jackson International Airport



## Surface Temperatures

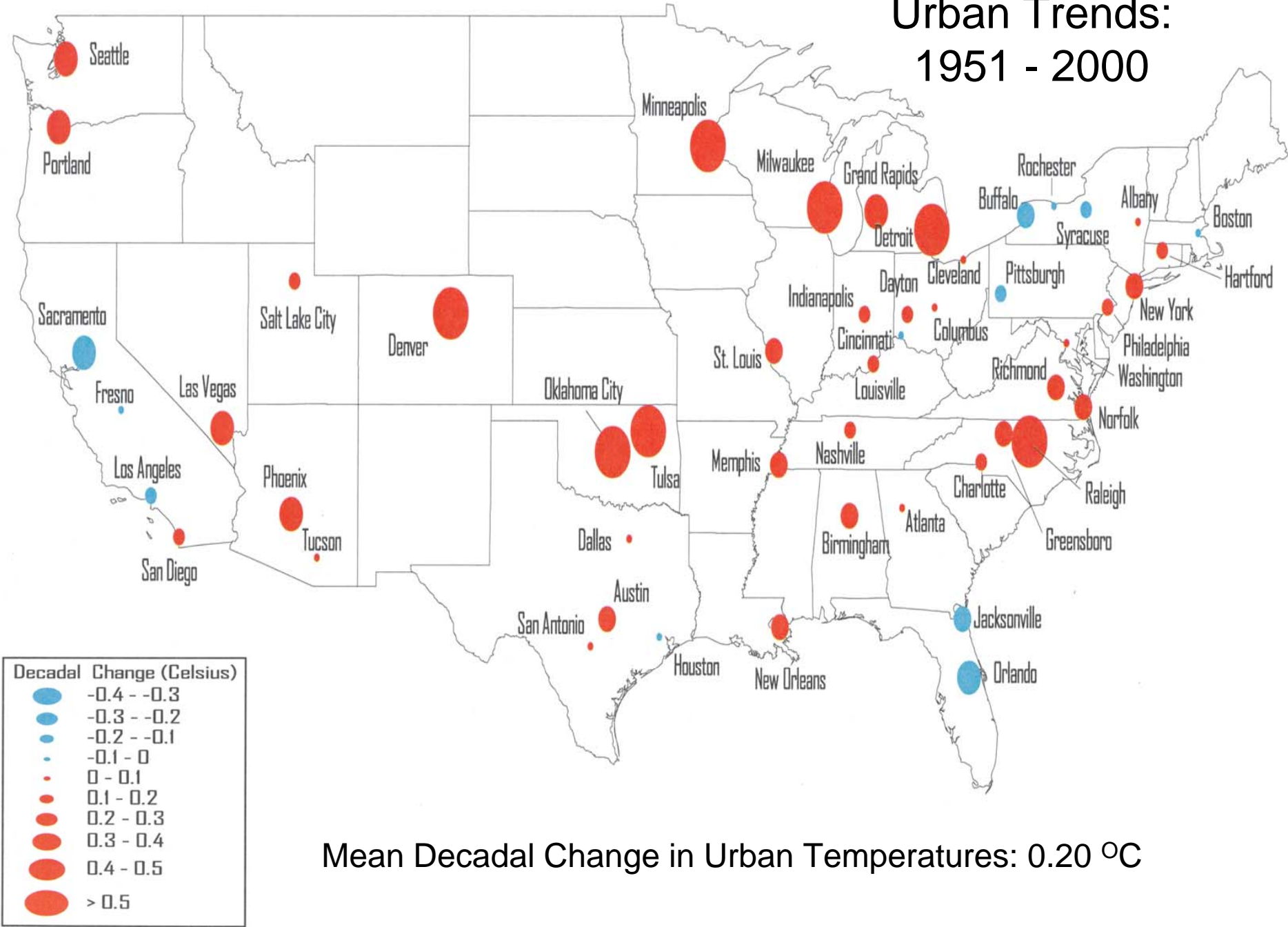


CBD

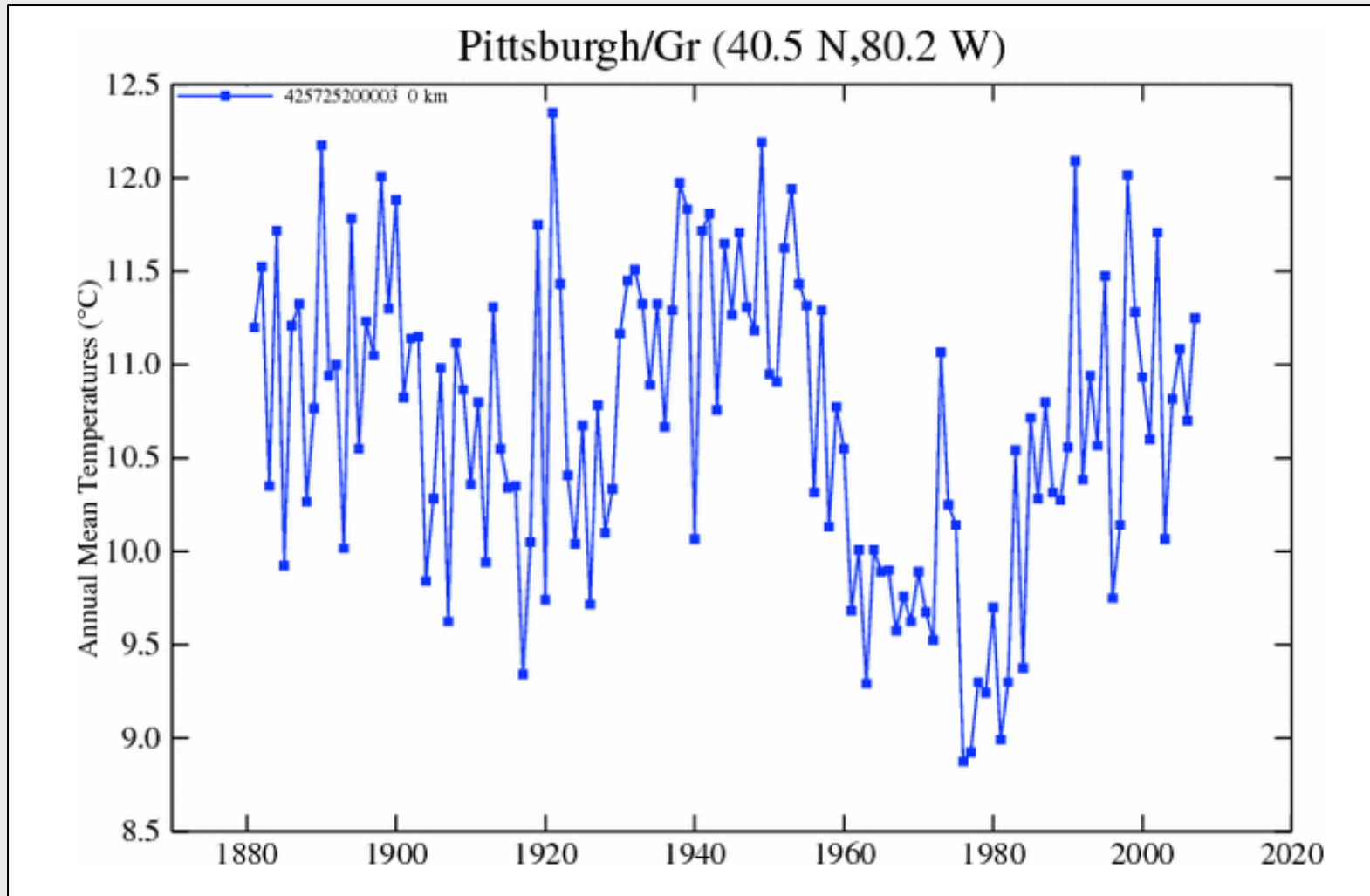


Hartsfield-Jackson

# Urban Trends: 1951 - 2000

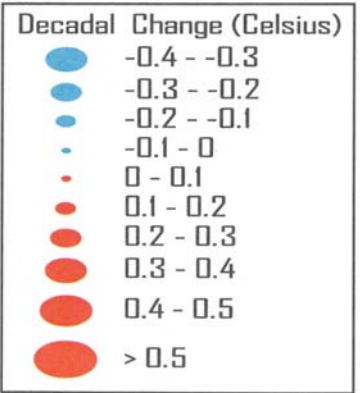
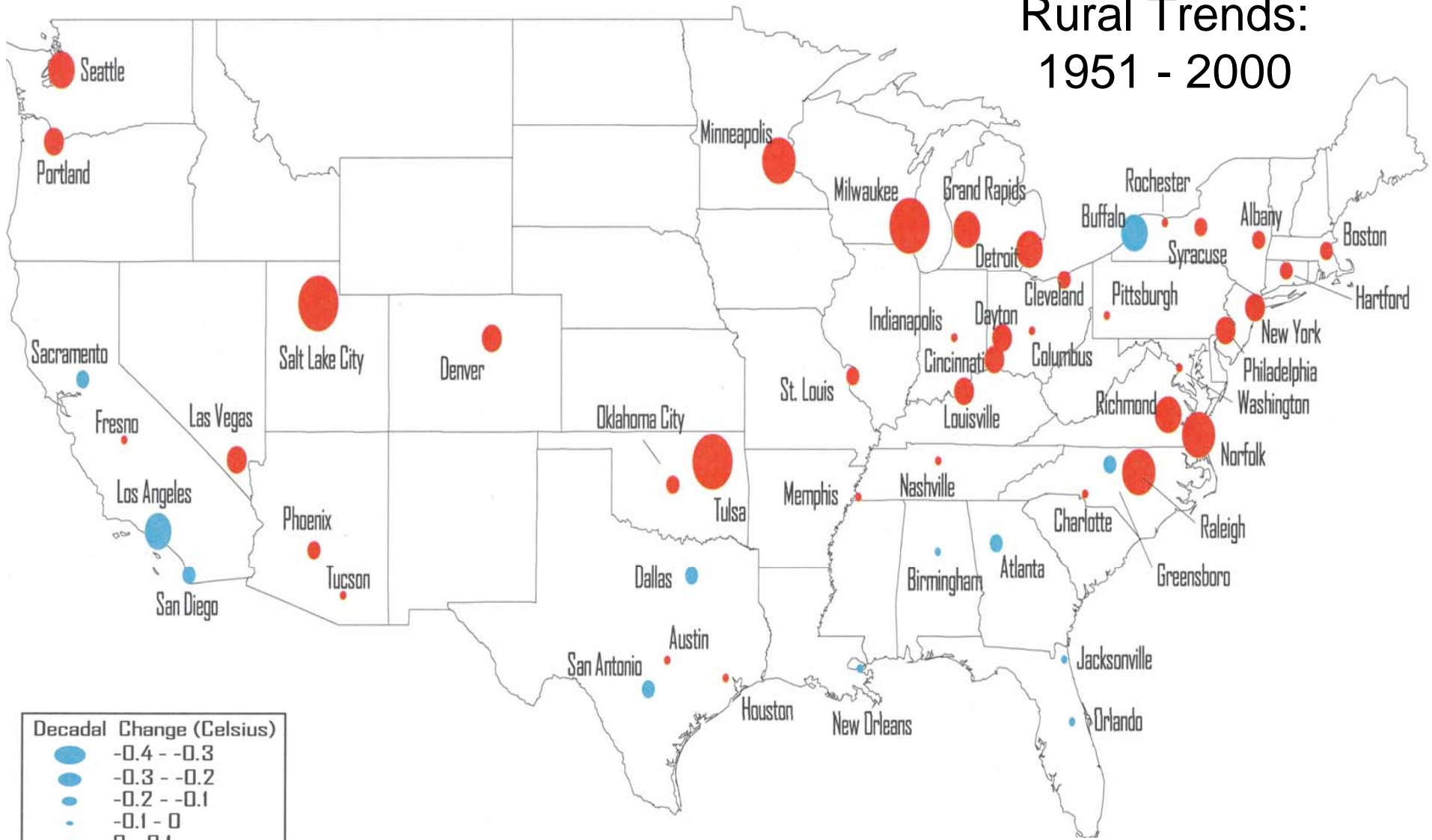


Mean Decadal Change in Urban Temperatures: 0.20 °C



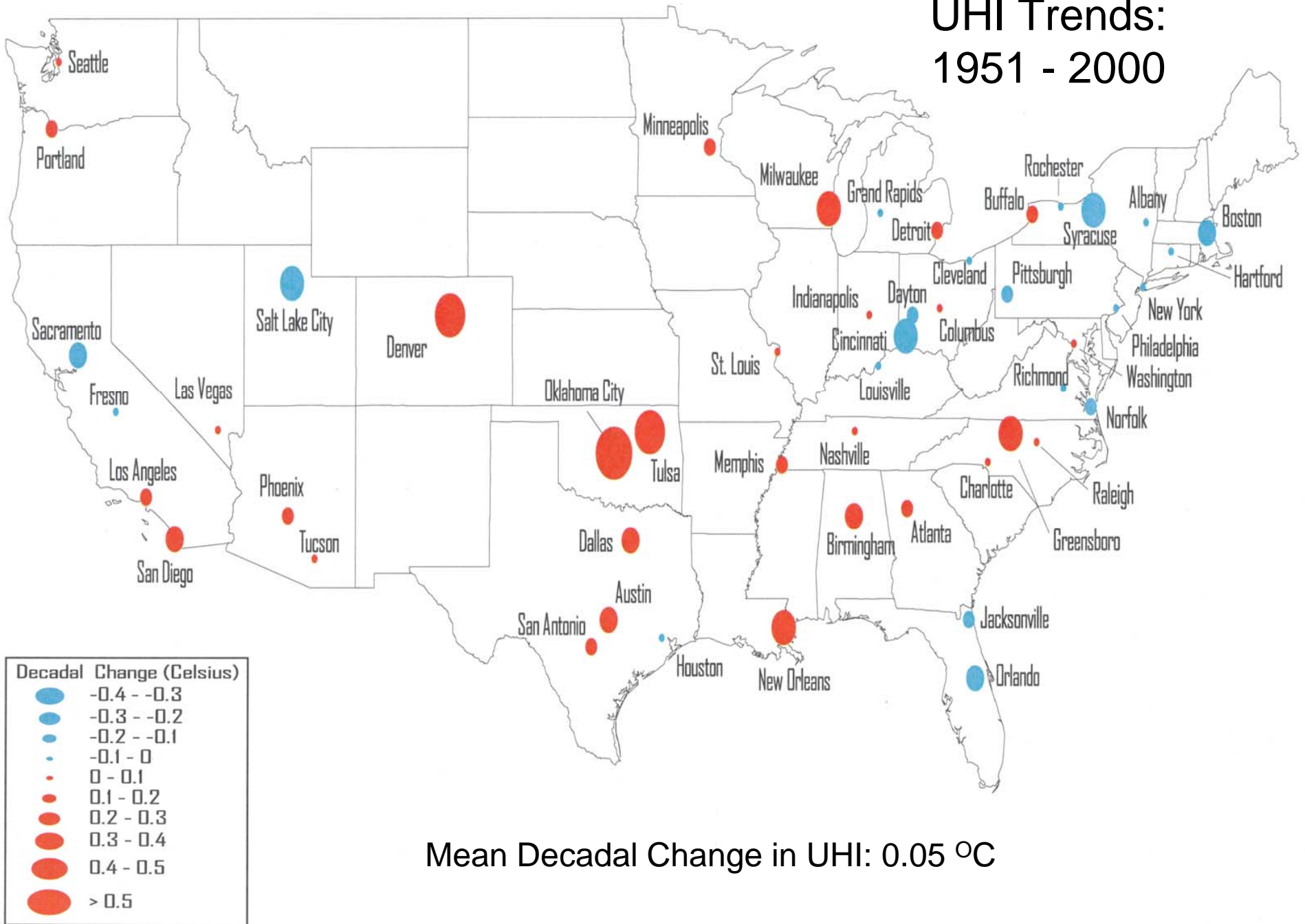
Source: NASA Goddard Institute for Space Studies, GHCN

# Rural Trends: 1951 - 2000

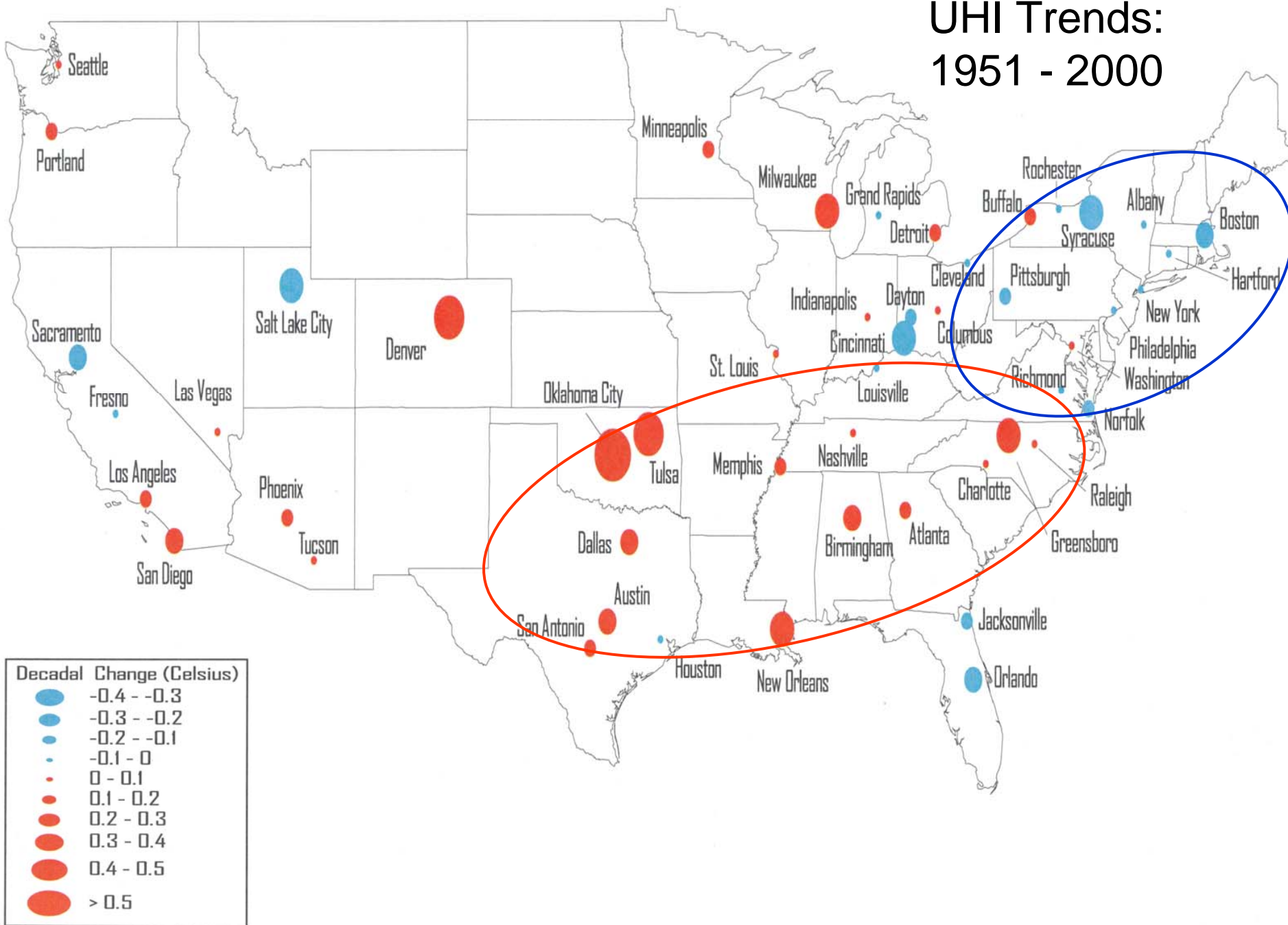


Mean Decadal Change in Rural Temperatures: 0.15 °C

# UHI Trends: 1951 - 2000

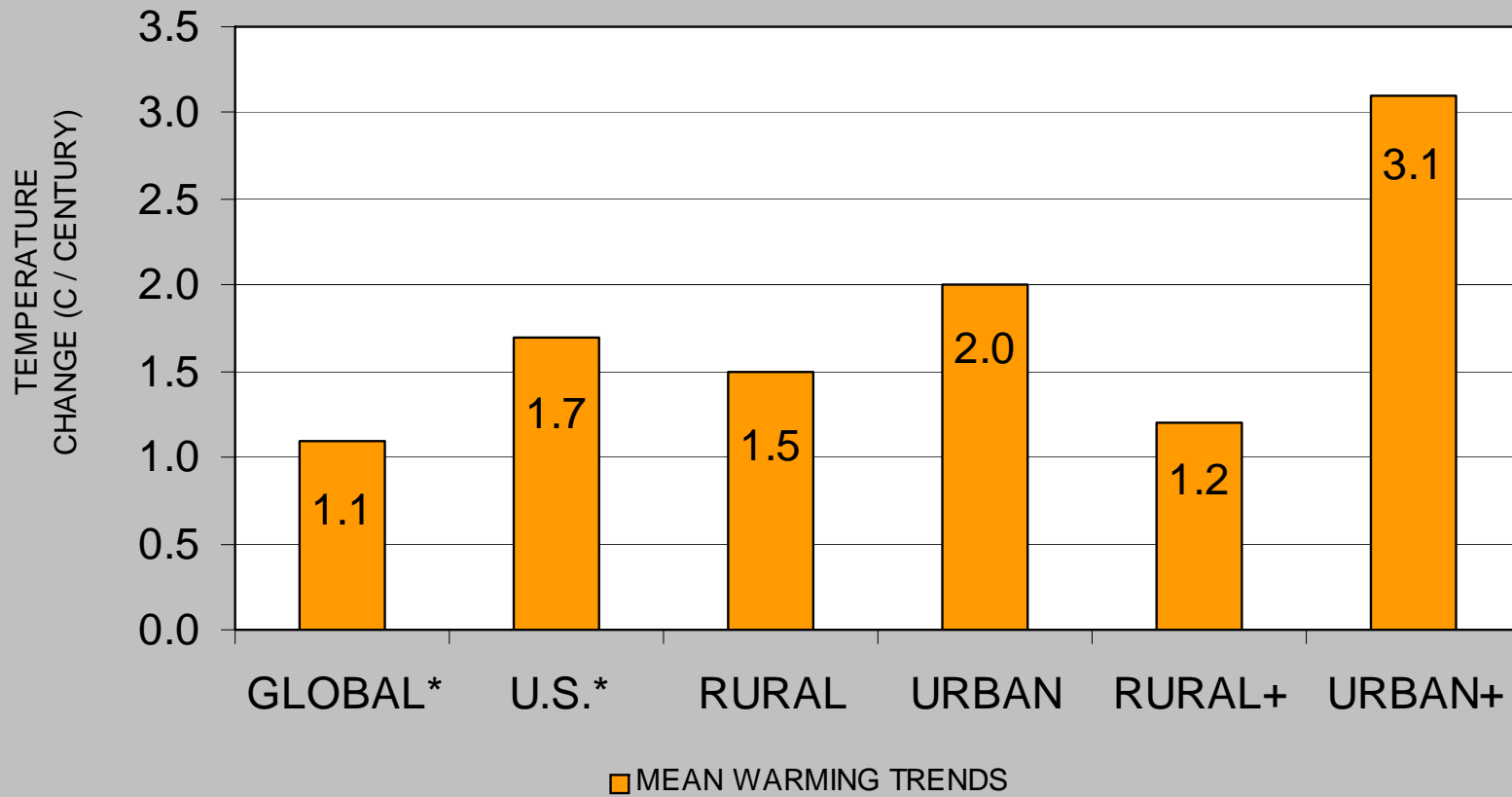


# UHI Trends: 1951 - 2000





## RATE OF TEMPERATURE CHANGE 1951-2000

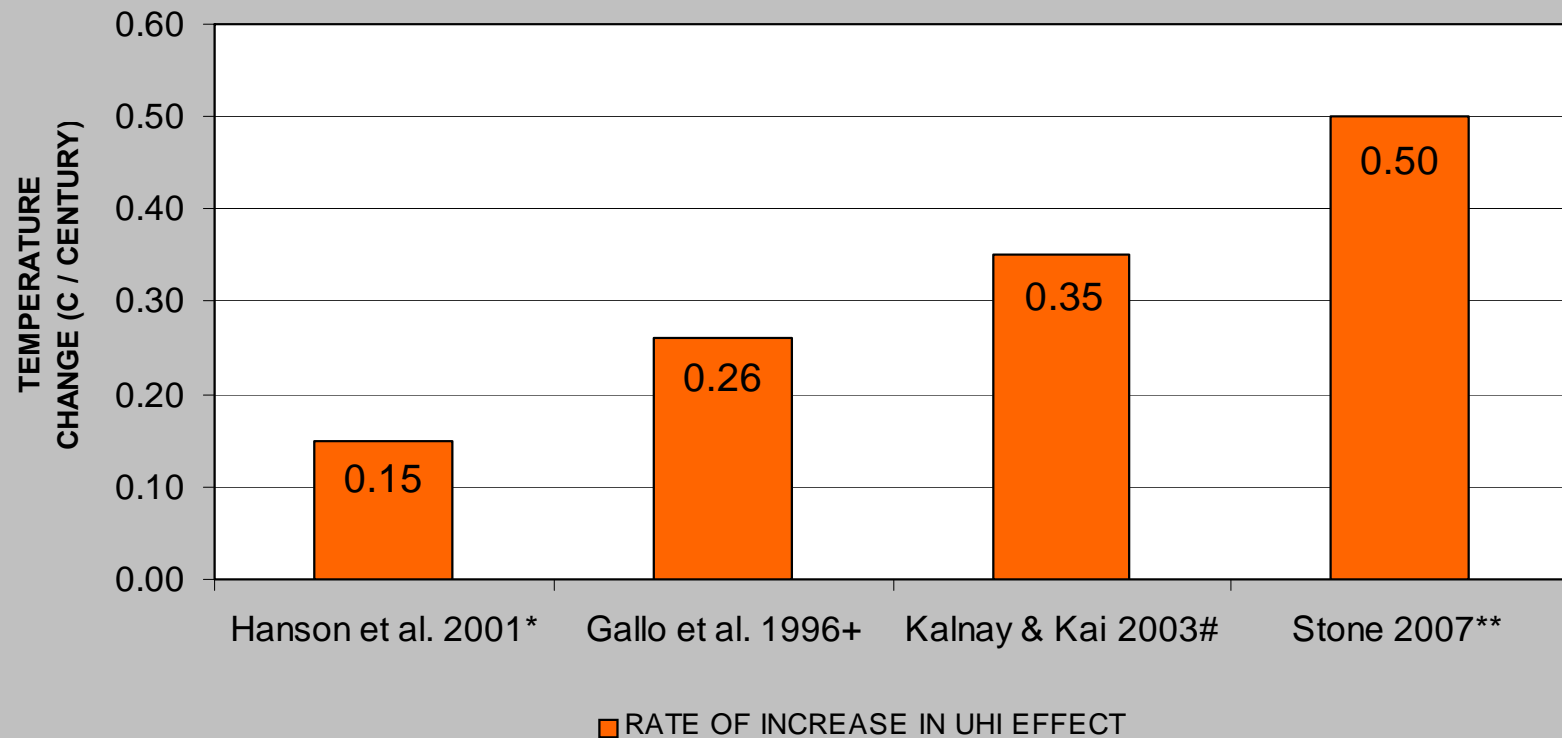


\* NASA Goddard Institute of Space Studies

+ Cities in which UHI increased between 1951 and 2000



## AMPLIFICATION OF WARMING ATTRIBUTED TO URBANIZATION IN U.S.



\* Mean rate over 1900-1999

+ Mean rate over 1950-1996 (results not significant)

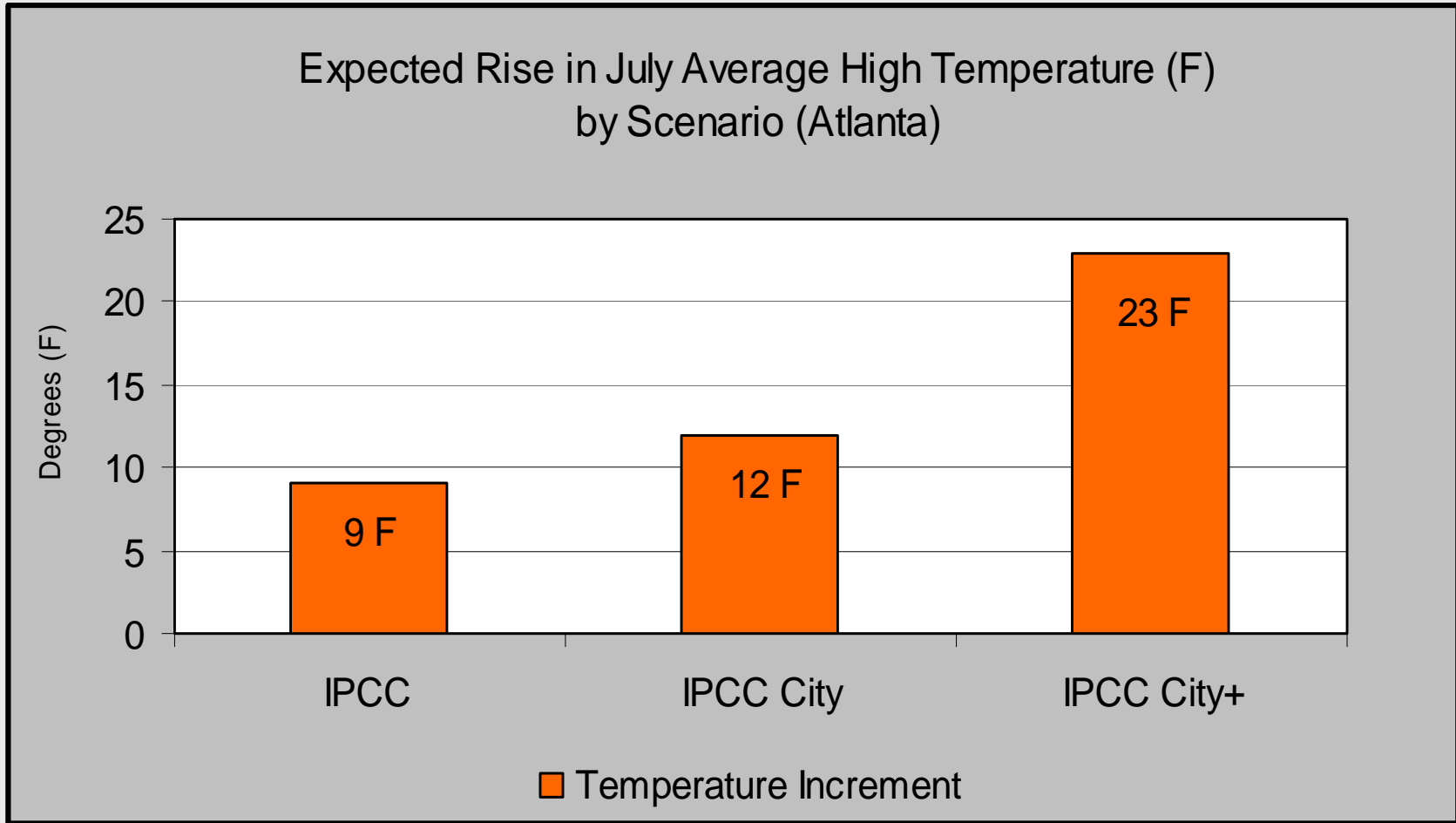
# Mean rate over 1951-2000; reflects impacts of urbanization and agriculture

\*\* Mean rate over 1951-2000



## Study Findings

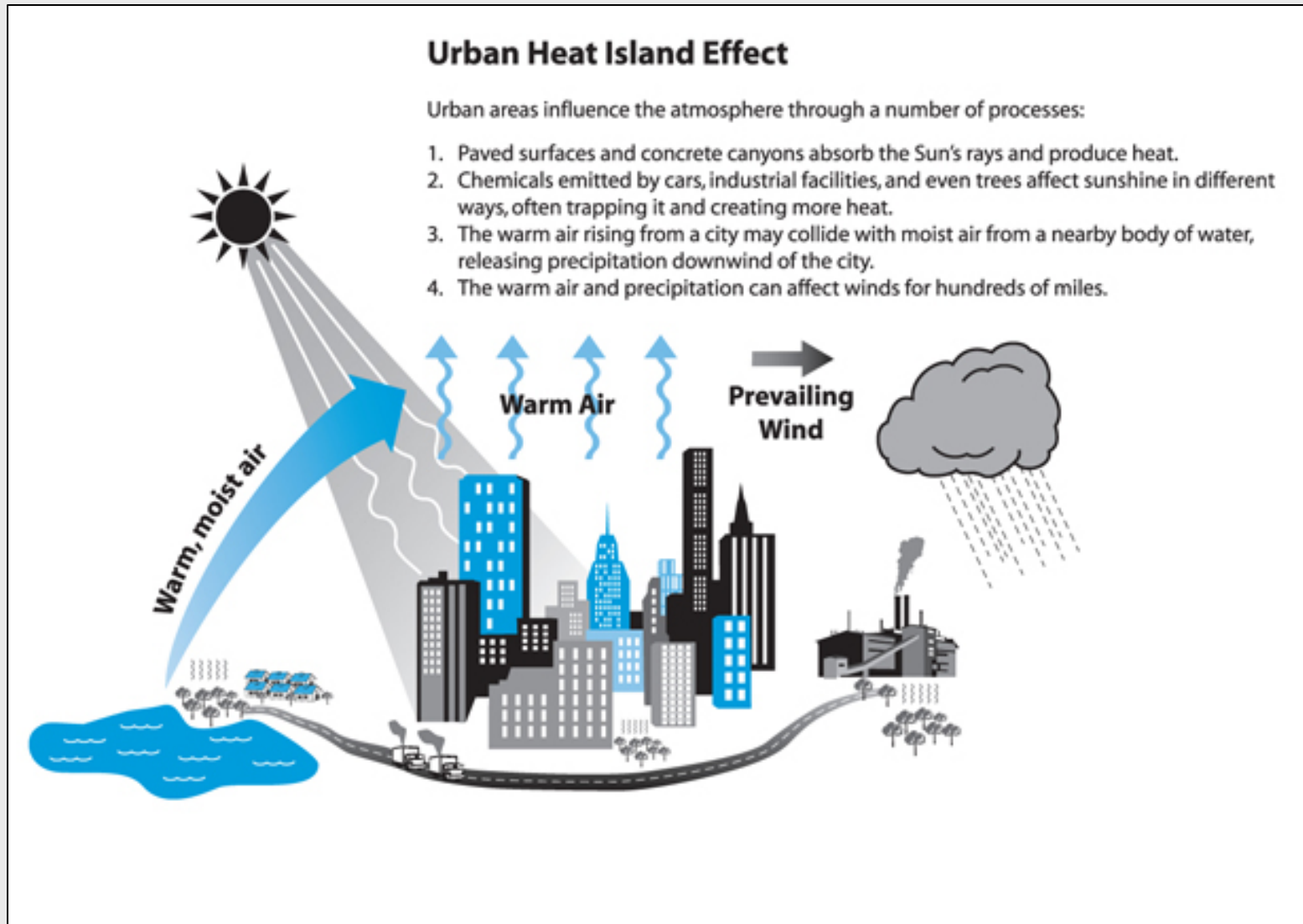
- On average, the decadal rate of warming in large U.S. cities was 30% greater than that of proximate rural areas taken to represent “background” warming trends
- For cities in which the urban heat island effect intensified during this period (60%), the decadal rate of warming was 150% greater than that of proximate rural areas
- As warming scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) are based on background global rates of warming, these scenarios (1.4 to 5.8 °C by 2100) are likely to significantly underestimate the rate of warming in large cities over time



\*Assumes 5 °C (9 °F) rise in temperature by 2100. Historical average high temperature for Atlanta in July: 89 °F

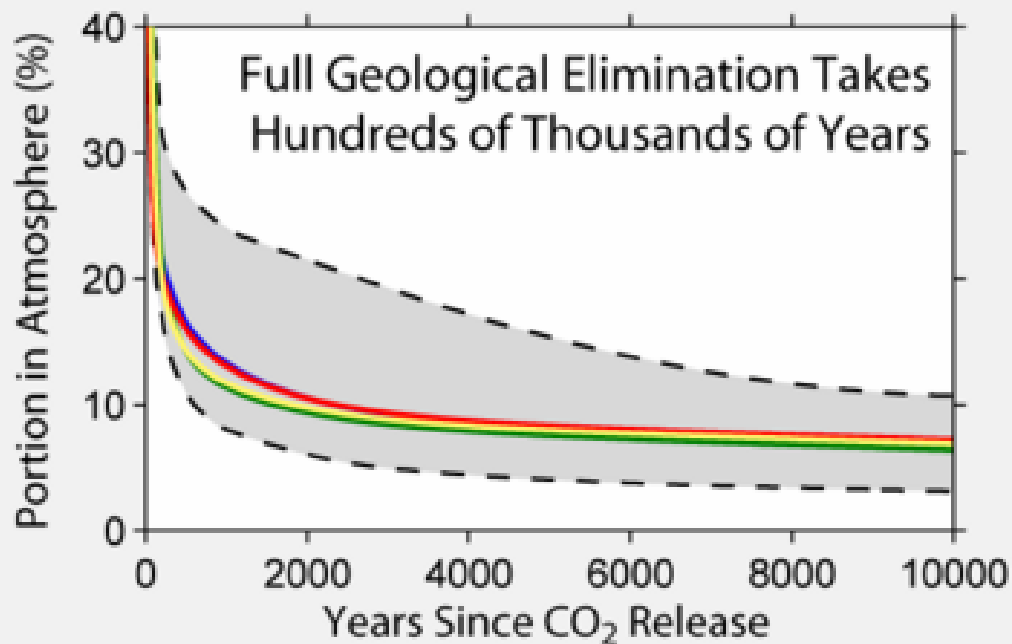
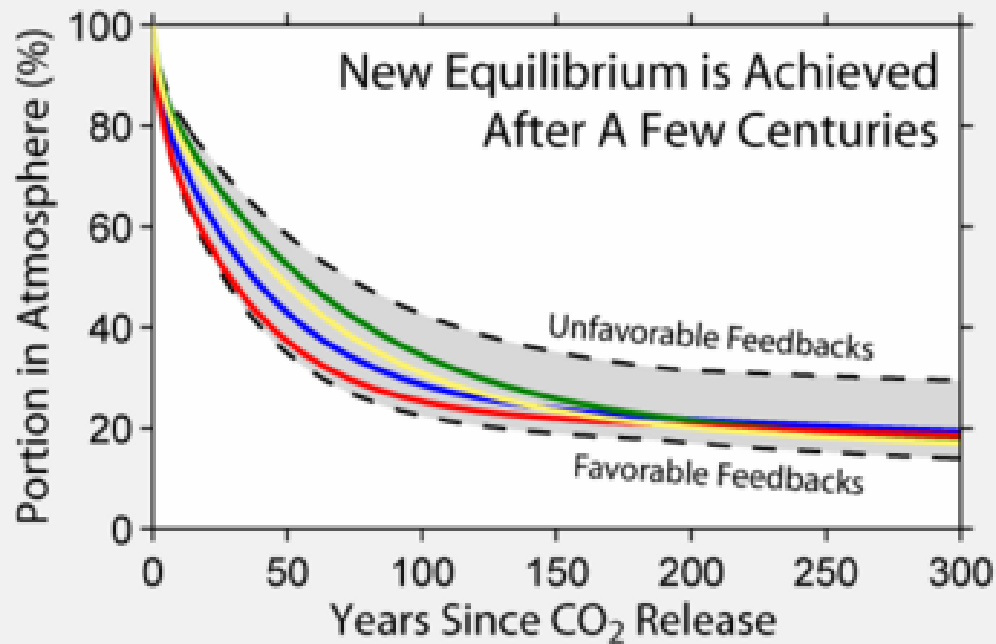


# Negative Feedbacks on UHI



Source: NCAR, 2006

# Carbon Dioxide Residence Time



## Climate Change Management

Over the near-to-medium term, local adaptation strategies such as heat island management are likely to yield greater cooling benefits in cities than mitigation strategies focused on greenhouse gas controls.



## Threats of Climate Change



Source: An Inconvenient Truth, 2006

## 2003 Heat Wave in Europe

Estimated Dead

France	15,000
Netherlands	1,400
Portugal	13,000
Italy	20,000
UK	900
Spain	100



Source: An Inconvenient Truth, 2006

Chicago heat wave of 1995:  
~500 deaths over six days

B. Stone, City and Regional Planning, April 2008

Source: Klinenberg, 2002

# Weather Related Fatalities



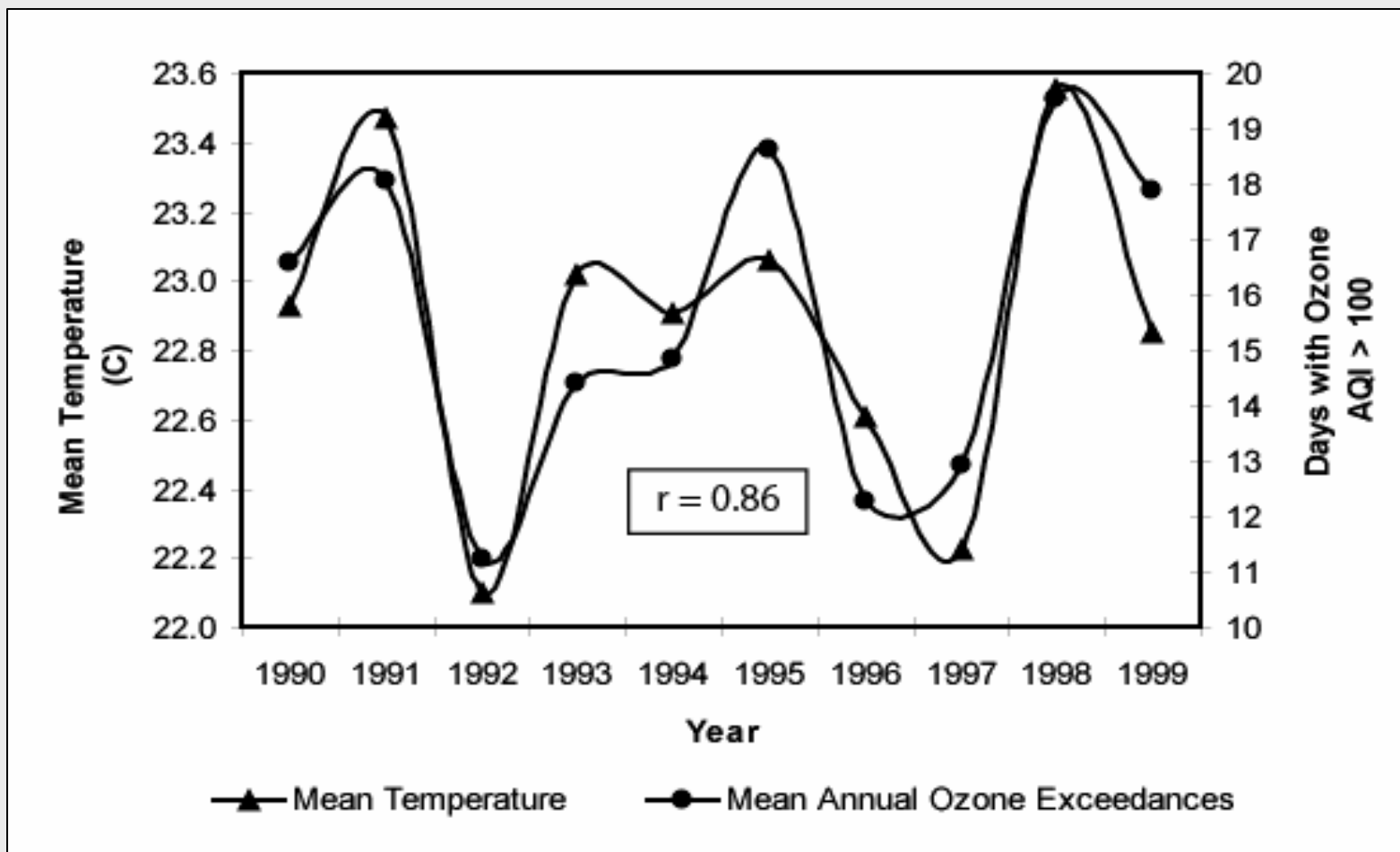
TABLE 1. Number of deaths attributed to weather in the United States.

Condition	Annual average	Maximum events <sup>1</sup>	Date
Tornadoes	82 <sup>2</sup> -130 <sup>3</sup>	739	3/25
		322	4/74
Heavy rains/floods	100 <sup>3</sup> -160 <sup>4</sup>	2200	5/99
		732	3/13
Hurricanes	38 <sup>12</sup> -63 <sup>3</sup>	6000	9/00
		1836 <sup>8</sup>	9/28
Hail	1 <sup>5</sup>	22	5/81
Wind storms	60 <sup>6</sup> -115 <sup>3</sup>	105 <sup>6</sup>	12/72
Lightning	100 <sup>3</sup> -156 <sup>12</sup>	unknown	
Winter storms and cold	130 <sup>3</sup> -200 <sup>7</sup>	500	12/83
		270 <sup>7</sup>	3/92
Heat waves	1000 <sup>9</sup>	> 10 000 <sup>10</sup>	1980
		> 9500 <sup>11</sup>	1901

Source: Changnon et al. 1996



# Temperature and Air Quality



Note: Significant at the  $p < .05$  level

Sources: EPA, Air Trends Report: 1990-1999

NOAA, National Climatic Data Center: 1990-1999



### ANNEX 3-1 Potential Climate Changes and Impacts on Transportation

Potential Climate Change	Impacts on Land Transportation (highways, rail, pipeline)		Impacts on Marine Transportation		Impacts on Air Transportation	
	<i>Operations and Interruptions</i>	<i>Infrastructure</i>	<i>Operations and Interruptions</i>	<i>Infrastructure</i>	<i>Operations and Interruptions</i>	<i>Infrastructure</i>
<b>Temperature:</b> Increases in very hot days and heat waves	<ul style="list-style-type: none"> <li>• Limitations on periods of construction activity due to health and safety concerns; restrictions typically begin at 29.5°C (85°F); heat exhaustion possible at 40.5°C (105°F)</li> </ul>	<ul style="list-style-type: none"> <li>• Impacts on pavement and concrete construction practices</li> <li>• Thermal expansion on bridge expansion joints and paved surfaces</li> <li>• Impacts on landscaping in highway and street rights-of-way</li> <li>• Concerns regarding pavement integrity, e.g., softening, traffic-related rutting, migration of liquid asphalt; sustained air</li> </ul>	<ul style="list-style-type: none"> <li>• Impacts on shipping due to warmer water in rivers and lakes</li> </ul>	<p>temperature over 32°C (90°F) is a significant threshold</p> <ul style="list-style-type: none"> <li>• Rail-track deformities; air temperature above 43°C (110°F) can lead to equipment failure</li> </ul>	<ul style="list-style-type: none"> <li>• Delays due to excessive heat</li> <li>• Impact on lift-off load limits at high-altitude or hot-weather climate airports with insufficient runway lengths, resulting in flight cancellations and/or limits on payload (i.e., weight restrictions)</li> <li>• More energy consumption on the ground</li> </ul>	<ul style="list-style-type: none"> <li>• Heat-related weathering and buckling of pavements and concrete facilities</li> <li>• Heat-related weathering of vehicle stock</li> </ul>



# Temperature and Infrastructure

## Buckling in the heat



By Tom Symonds  
BBC Transport Correspondent

**Last month a freight train carrying a cargo of Guinness came off the tracks near Lichfield in the Midlands.**

The driver walked away shocked, he was the only person on board and the crash closed the West Coast Main Line.

Investigators would only have had to look up at the sun beating down on the rails to have worked out what went wrong. The track had buckled in the heat.

That is why Network Rail is being so cautious, and why thousands of rail passengers across Britain have been so disrupted.

Last month's freight train could easily have been a high-speed passenger train.

The problem that is making Network Rail sweat is relatively simple to explain - track is made of steel, and it expands in the heat. More modern track is welded together into continuous runs, making it much smoother but more susceptible to warping.



## Commuters face more heatwave delays

**Rail passengers are being warned they face a week of delays because of speed limits imposed in response to soaring UK temperatures.**



Temperature records ready to fall

Many trains ran slower than usual for the second day on Tuesday, amid concern tracks could buckle in temperatures of 30C plus.

The limits were lifted from 1900 BST as temperatures cooled, but Network Rail said they would be imposed again at noon every day until temperatures drop below 30C.

Tuesday was the hottest day of the year so far, the BBC Weather Centre said - with 34.6C (94.3F) being recorded at Jersey Airport. Wednesday is forecast to be even hotter.

Passengers were trapped on a train in sweltering heat in Cumbria for four hours.

Source: BBC News, August 2003



Interstate 80 in Illinois, July 2006

## Road Buckling and Melting

New Delhi, India  
June 2007

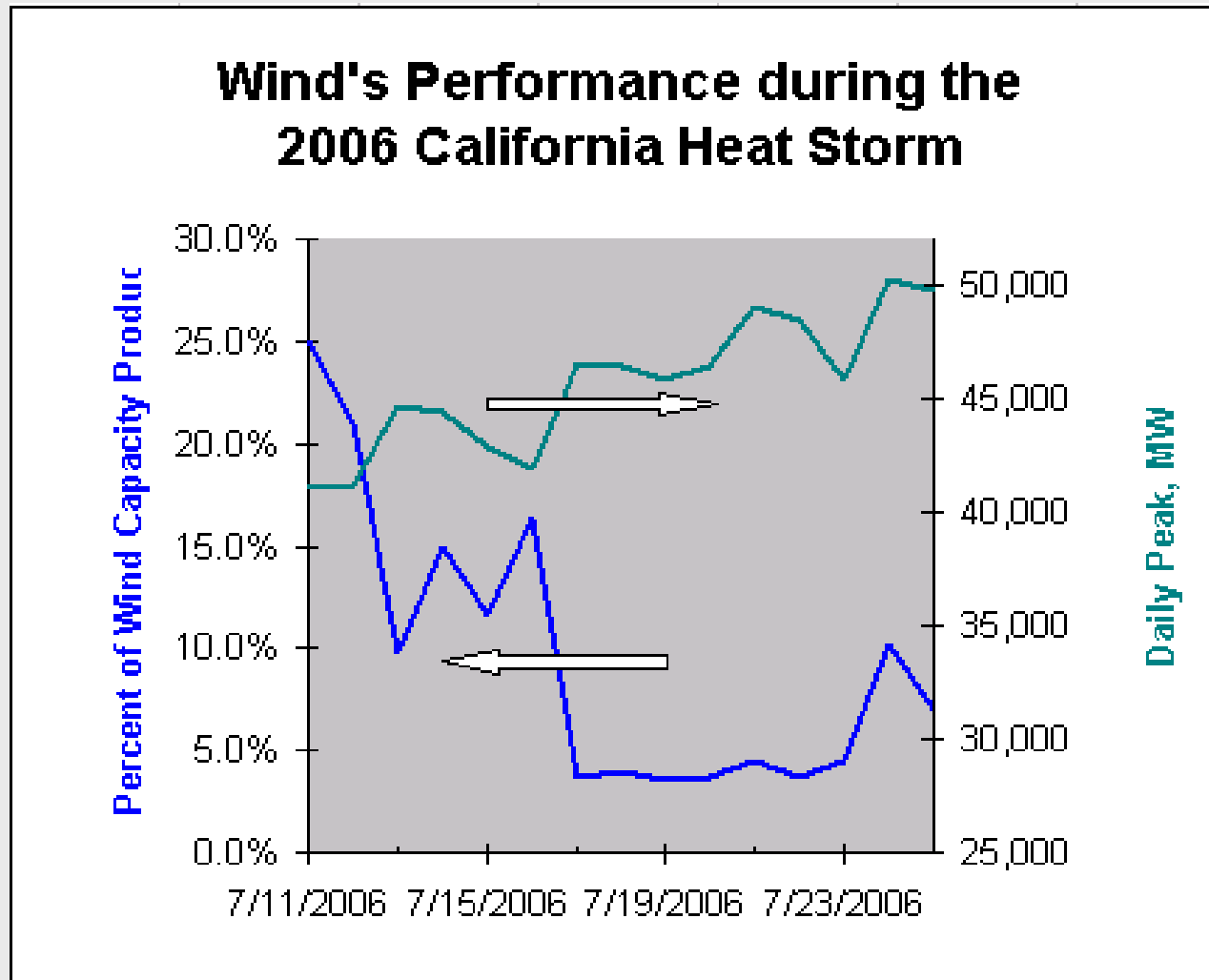


B. Stone, City and Regional Planning, April 2008

Source: Anonymous



## Temperature and Infrastructure



Source: NEI, 2006

B. Stone, City and Regional Planning, April 2008



# Heat and Water Consumption

Table 2. Results of regression models predicting the natural log of tract mean water use by single-family units, June 1998 (gallons).

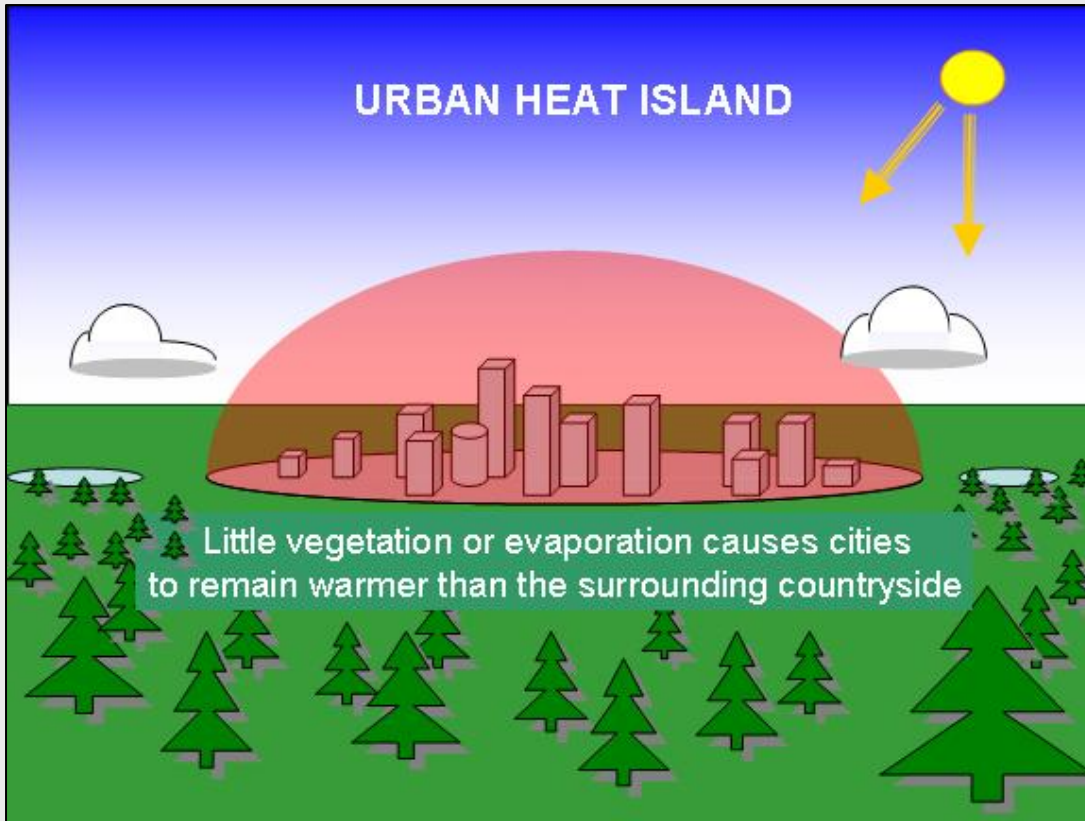
	Model 1			Model 2		
	<i>B</i>	Beta	<i>t</i>	<i>B</i>	Beta	<i>t</i>
Constant	7.348*		11.18	8.958*		28.242
Median household income (\$)	.00000384*	.297	2.80	.00000154	.119	1.058
Median persons per unit	.026	.110	.98	.048 <sup>ψ</sup>	.203	1.668
Mean lot size (square feet)	.0000179*	.425	6.54	.0000140*	.331	4.549
Mean age of single-family units (years)	.009*	.377	6.37	.001*	.219	3.493
% of single-family units with pool	.002*	.148	2.17	.003*	.180	2.397
Mean pool surface area (square feet)	.001*	.171	3.72	.001*	.228	4.346
% of single-family units with evaporative coolers	.159*	.153	2.48	.339*	.326	5.186
Vegetation index (NDVI)	.203	.018	0.41	.810	.073	1.498
% housing units owner occupied	.049	.041	0.56	.143	.121	1.527
Water supply from SRP (0 = no, 1 = yes)	.013	.021	0.46	.049 <sup>ψ</sup>	.083	1.665
Mean land parcel price, single-family residences (\$)	.000000268	.020	0.22	.000001420	.100	1.013
Daily low temperature (°F)	.017*	.110	2.07			
Difference between high and low temperatures (°F)				-.040*	-.166	-3.901
<i>R</i> <sup>2</sup>		0.68			0.62	
<i>N</i>		287			287	

<sup>ψ</sup>*p* < .10    \**p* < .05

5 °F increase in low temperatures would result in an almost 10% increase in water usage (Guhathakurta & Gober, 2007).



# Urban Climate Change Adaptation



Source: Weatherstreet.com, 2008

UHI increases near surface air temperatures by  
 1 - 6 °C (2 - 10 °F)

B. Stone, City and Regional Planning, April 2008



Source: gunsmoke.com, n.d.



Source: Lonely Planet, com, n.d.



Source: uwee-foto, n.d.



# Cooling through Tree Planting

**million treesLA**

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[Million Trees LA Initiative](#)

[How Can the Public Get Involved?](#)

[Why Get Involved?](#)

[A Greener LA](#)

[Tree Canopy Analysis](#)

[Donate](#)

[Get Involved!](#)

**Welcome to the Million Trees LA website!**

I love this amazing city, and I know you do too. As part of a larger effort to make Los Angeles greener, cleaner, healthier and more beautiful for us all to enjoy, I have launched the Million Trees LA initiative; the plan is to plant one million trees over the next several years. This is a partnership between the City of Los Angeles, community groups, businesses and individuals like you, working together to plant and provide long-term stewardship of one million trees, planted all over the city with a focus on areas that need it most.

The trees will provide shade and save on energy costs, clean the air and help reduce the greenhouse gases that cause global warming, capture polluted urban runoff, improve water quality, and add beauty to our neighborhoods.

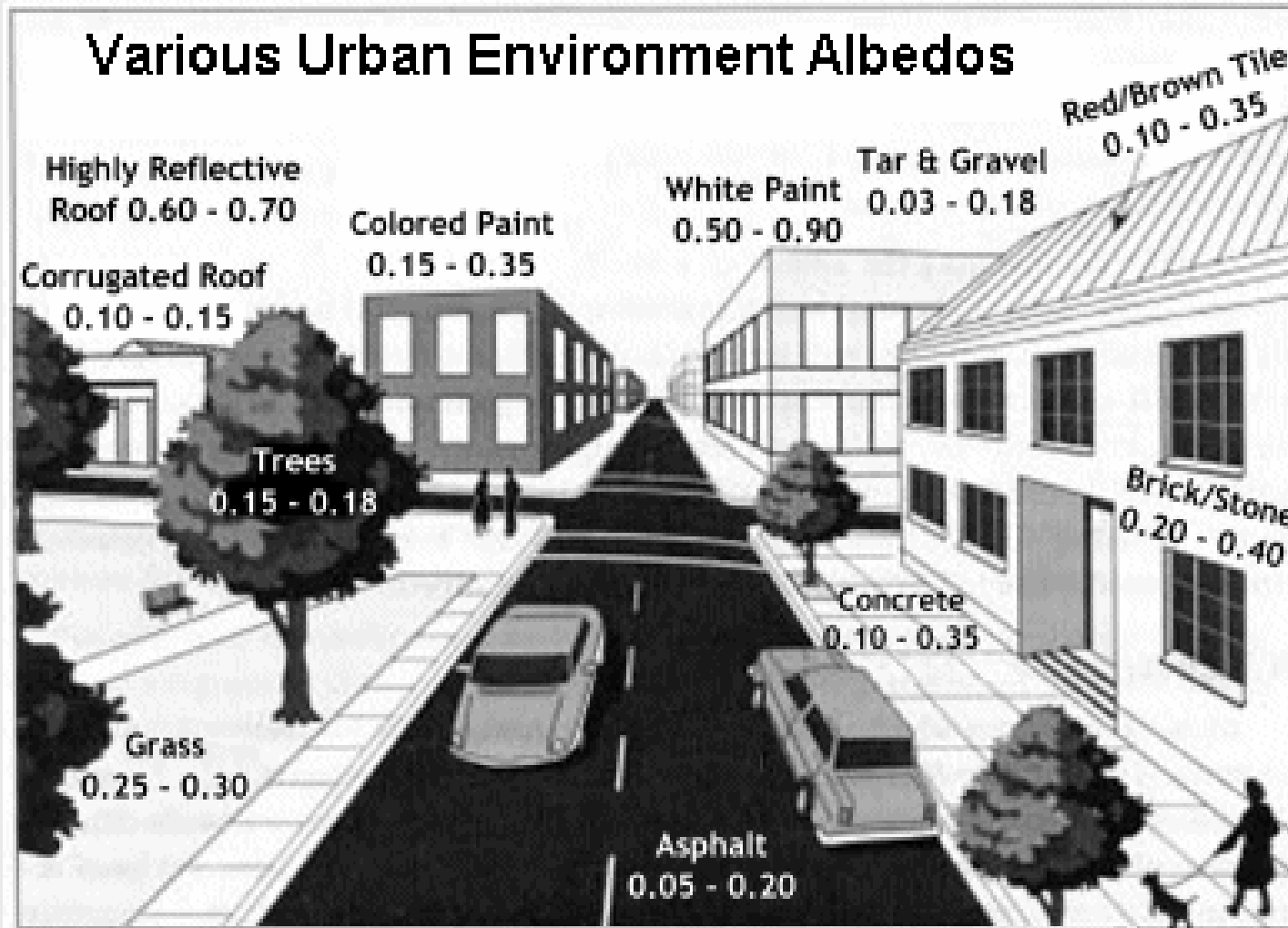
**“ Each tree planted needs water and care for its entire life. It’s worth the work. Over its lifetime, that tree will pay you back in lower energy bills, higher property values, cleaner air and water. ”**

*Mayor Antonio Villaraigosa, May 2006*

Cost per tree: \$70



# Cooling through Surface Reflectivity

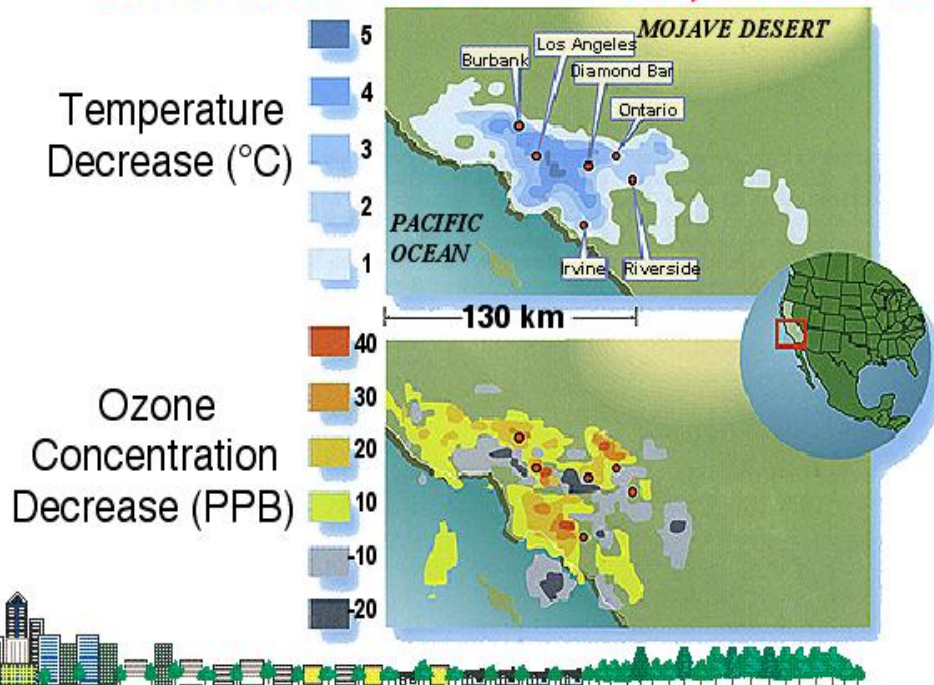


Source: HIRI, 2003



## Heat Island Reduction Simulation in Los Angeles

### Meteorology and Air-Quality Simulations — $\Delta\alpha$ , $\Delta T_{\text{Trees}}$



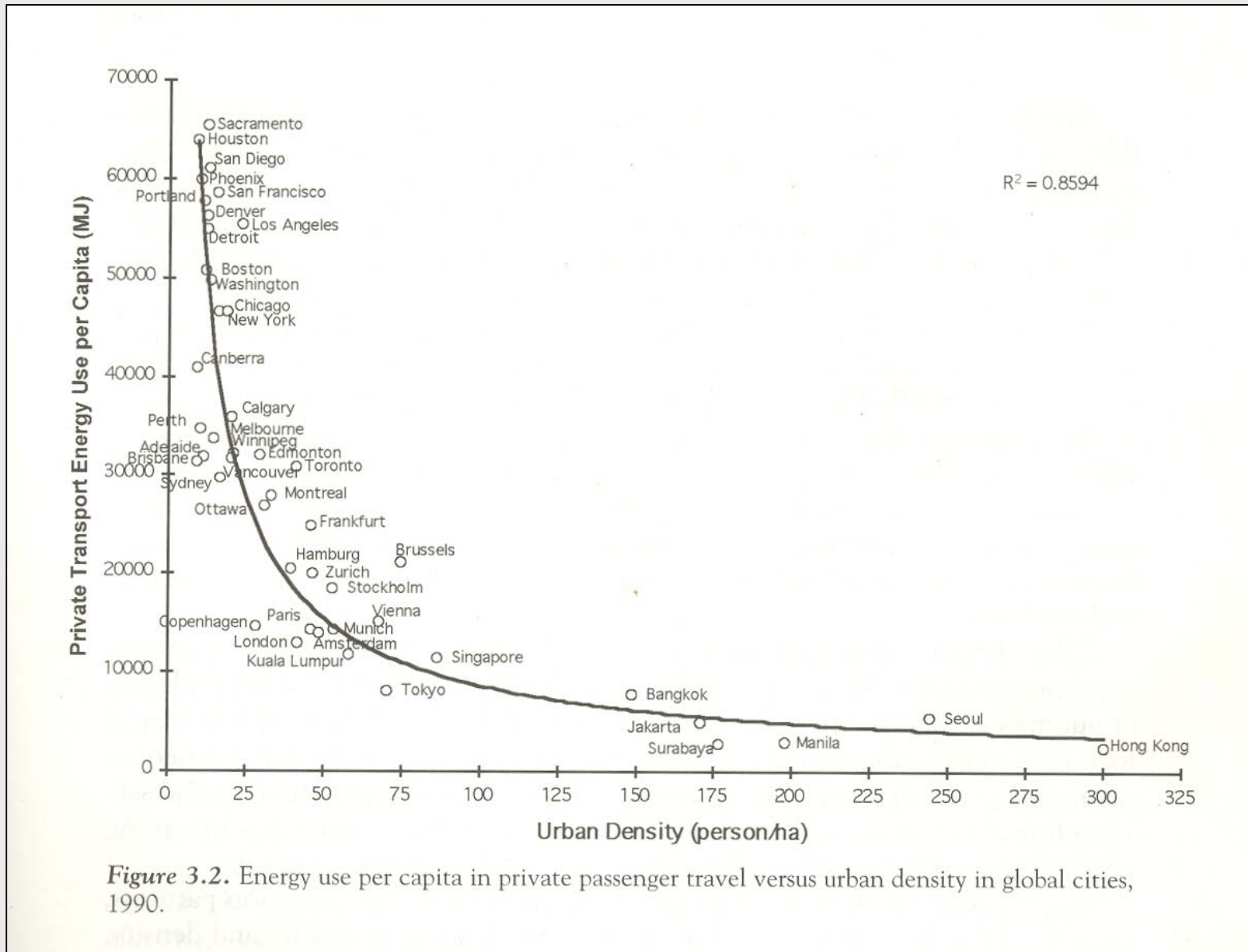
Planting of 11 Million  
Trees = 1.5 °C Reduction

Use of Highly Reflective  
Roofing and Paving  
Materials = 1.5 °C Reduction

IPCC by 2100: 1.4 – 5.8 °C

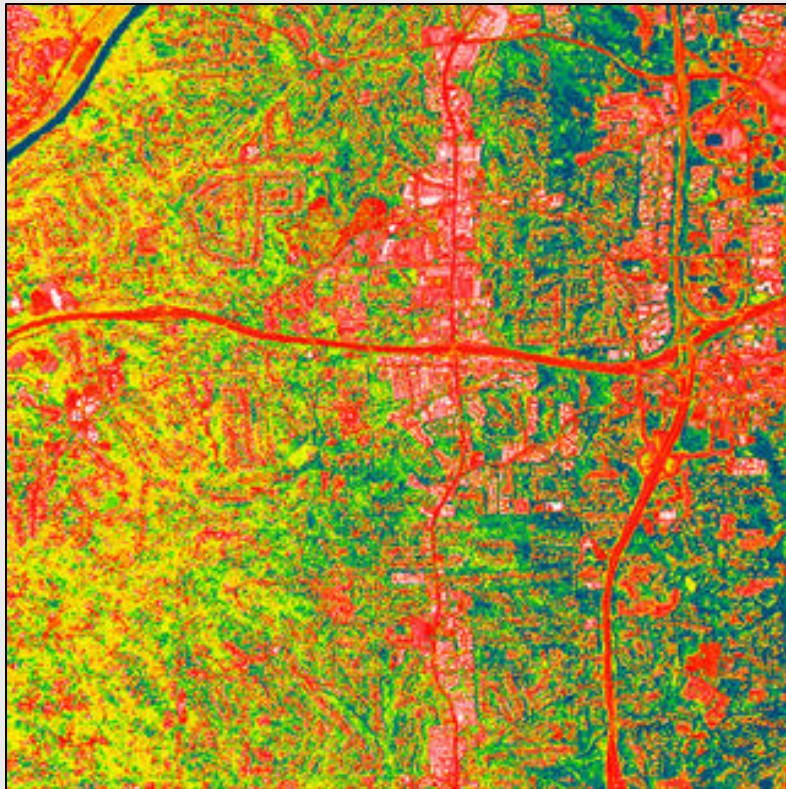


# Planning and Energy Consumption





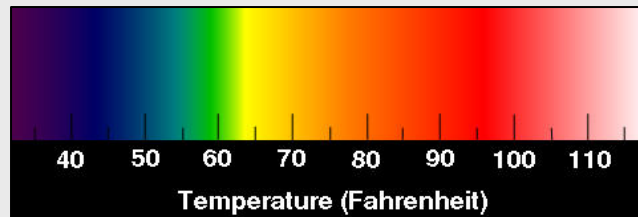
## What Model of Metropolitan Development Minimizes UHI?



Suburban Atlanta

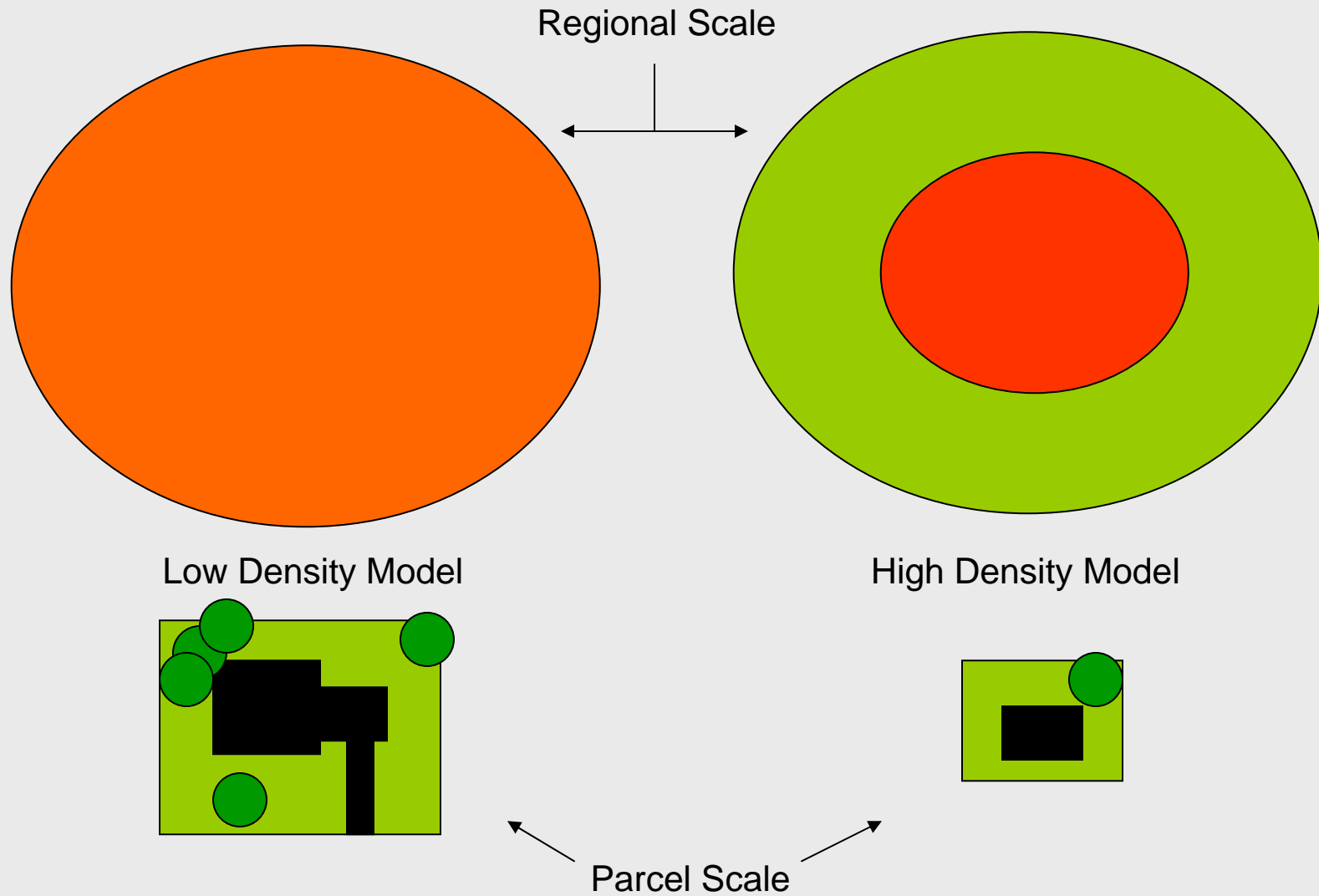


Downtown Atlanta





# What Model of Metropolitan Development Minimizes UHI?





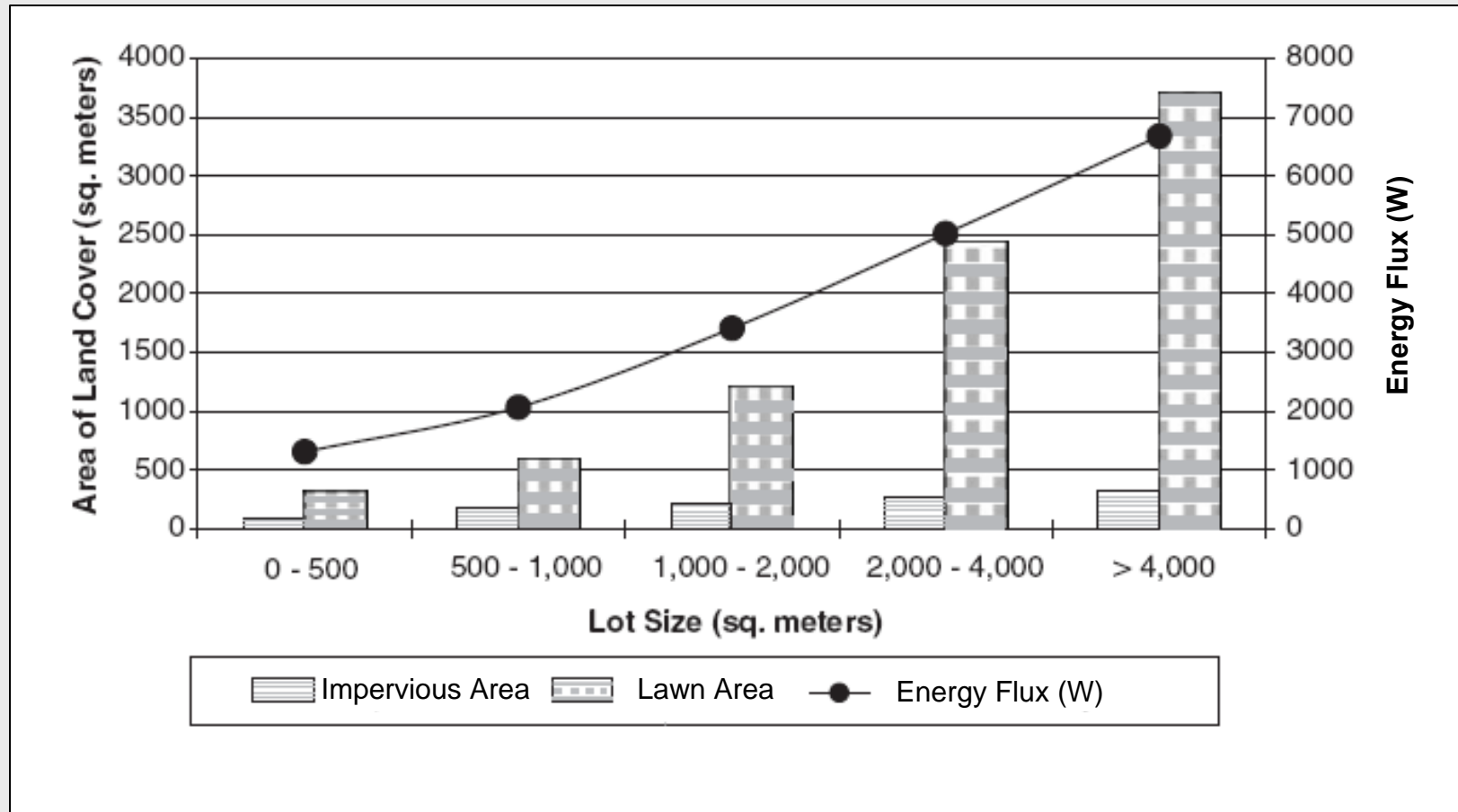
# Calculating Development-Induced Heat Production



How much additional surface heat is emitted following the conversion of a natural land cover to a single family residence?



## Planning for Climate Change: Density and Heat Island Formation



Stone & Norman, 2006

Increasing lot size was found to be associated with increasing levels of parcel heat emissions.



## Study Results

- Impervious cover and lawn area were found to have a positive association with parcel heat emissions; tree canopy cover shown to have a negative association
- Lawn area was found to have the greatest standardized effect on parcel heat emissions

Table 4

Linear regression results for parcel net black body flux (W)

Variable	<i>B</i> -coefficient	Standardized coefficient	Significance
Impervious area (m <sup>2</sup> )	0.083	0.290	< 0.001
Lawn area (m <sup>2</sup> )	0.012	0.512	< 0.001
Tree canopy cover (%)	-24.42	-0.432	< 0.001
Number of bedrooms	0.440	0.020	< 0.001
Summary statistics	Adj. <i>R</i> <sup>2</sup>	<i>F</i> -statistic	<i>F</i> significance
	0.55	31,866	< 0.001

*Note:* the square root of the net black body flux was used in this model as a variance stabilization transformation.

Stone & Norman, 2006



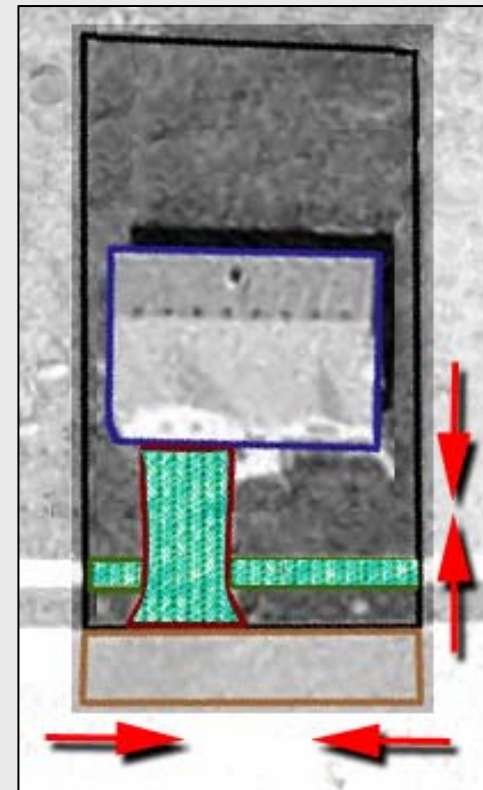
## Study Results

- ❖ A 25% reduction in the area of lawn for the average residential parcel would reduce heat emissions by 13%
- ❖ A 25% reduction in the area of impervious cover for the average residential parcel would reduce heat emissions by 16%
- ❖ A 25% reduction in the area of lawn and impervious cover would reduce heat emissions by 28%
- ❖ The combination of the above strategies with an increase in average parcel canopy cover from 45 – 60% would reduce heat emissions by 40%



## Effect of Zoning on Impervious Cover

Projected to grow by approximately 25,000 residents by the year 2020, the Madison, WI region can expect to add at least 350 acres of additional residential impervious surface area over the next fifteen years. If the average lot frontage and front yard setback were reduced by 25%, the growth in impervious cover would be reduced by about 130 acres, or by 38%.



- Frontage & Setback Reductions





“More than half of the built environment of the United States we will see in 2025 did not exist in 2000, giving planners an unprecedented opportunity to reshape the landscape.” (Nelson, 2006)



## Concluding Thoughts

- ❖ The phenomenon of global climate change is driven by both atmospheric and surface warming mechanisms
- ❖ A study of warming trends in large U.S. cities between 1950 and 2000 finds the average rate of urban warming to be 1.3 times greater than planetary, background rates. For those cities in which heat islands are intensifying over time, the rate of warming is 2.5 times that of background rates.
- ❖ Cities can offset the rate of warming over the near-to-medium term through restoration of natural land covers (e.g., tree planting), the enhancement of surface reflectivity through routine maintenance, a reduction in energy consumption, and preservation of existing greenspace.