Evaluating Governmental Efforts to Combat the Chicago Urban Heat Island

Chris Mackey, Ron Smith, Xuhui Lee

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Questions:

1) Have policies produced impacts large enough be detected in coarse-grained satellite images such as LANDSAT?
2) If so, have the reflective or vegetative strategies been generally more effective?
3) Which specific methods seem to be the most effective in the study period?

Intro: Overview of Efforts

The Methods

1) Reflective Roofs
2) Reflective Pavement
3) Green Roofs
4) Street/Yard Trees
5) Greenspace (Parks/Reserves/Schoolyards)

1) Reflective Roofs

- The city first passed reflective roof policies as part of an energy efficiency code in 2003, declaring that all new low-sloped roofs had to have a minimum reflectance of 0.25.
- In 2004, they authorized an addition to the code that required all new medium-sloped roofs had to have a minimum reflectance of 0.15.
- In 2008, they passed an amendment requiring all new low-sloped roofs to have a minimum 3-year reflectance of 0.5 (or initial reflectance greater than 0.72).

2) Reflective Pavement

- In 2006, the city started the Green Alleys pilot project, which as of 2008, had changed more than 80 alleys to reflective, semi-permeable pavement.

- Starting in 2006 and ending on October 26, 2007, the Illinois Department of Transportation reconstructed the entire length of the Dan Ryan Expressway and used a much more reflective pavement in their reconstruction.

3) Green Roofs

- In April 2005, the city started an expedited Green Permits Program that makes the application for green roof renovations faster.
- 2005 to 2007, the city had a Green Roof Grants Program, which awarded grants of up to $5,000 to projects installing green roofs.
- The city installed a green roof on its city hall in 2001 and completed the 24.5 acre (1,067,220 sq ft.) Millennium Park over parking garages and commuter lines in 2004.

3) Green Roofs (cont.)

The city currently has over 400 green roofs, which is over 4 million sqft or over 0.092% of the city’s area.

4) Street/Yard Trees

- The city provides a tree-planting service.

- In 1991, the city passed the Chicago Land Ordinance and revised it to be stricter in 1999. It requires new or renovated buildings to plant or maintain street trees, shrubs, etc. or new parking lots to be encircled with trees or have tree islands.

4) Street/Yard Trees (cont.)

From 1993 to 2008, Chicago recorded the planting of more than 500,000 new trees bringing its total tree count over 4 million.

(many of these trees cannot be directly linked to government policies but the policies likely had an indirect impact)

5) Greenspace
(Parks/Reserves/Schoolyards)

- In 1998, the city adopted an Open Space Impact Fee Ordinance that requires new residential development to contribute a proportionate amount of open space or to pay fees that can be used to purchase new community green space.

- In 1993, the city created an organization called CitySpace to develop a comprehensive plan for creating and preserving open space in Chicago. The organization incorporates over 100 agencies including the school district, which joined in 1996.

5) Greenspace

Agencies Under CitySpace

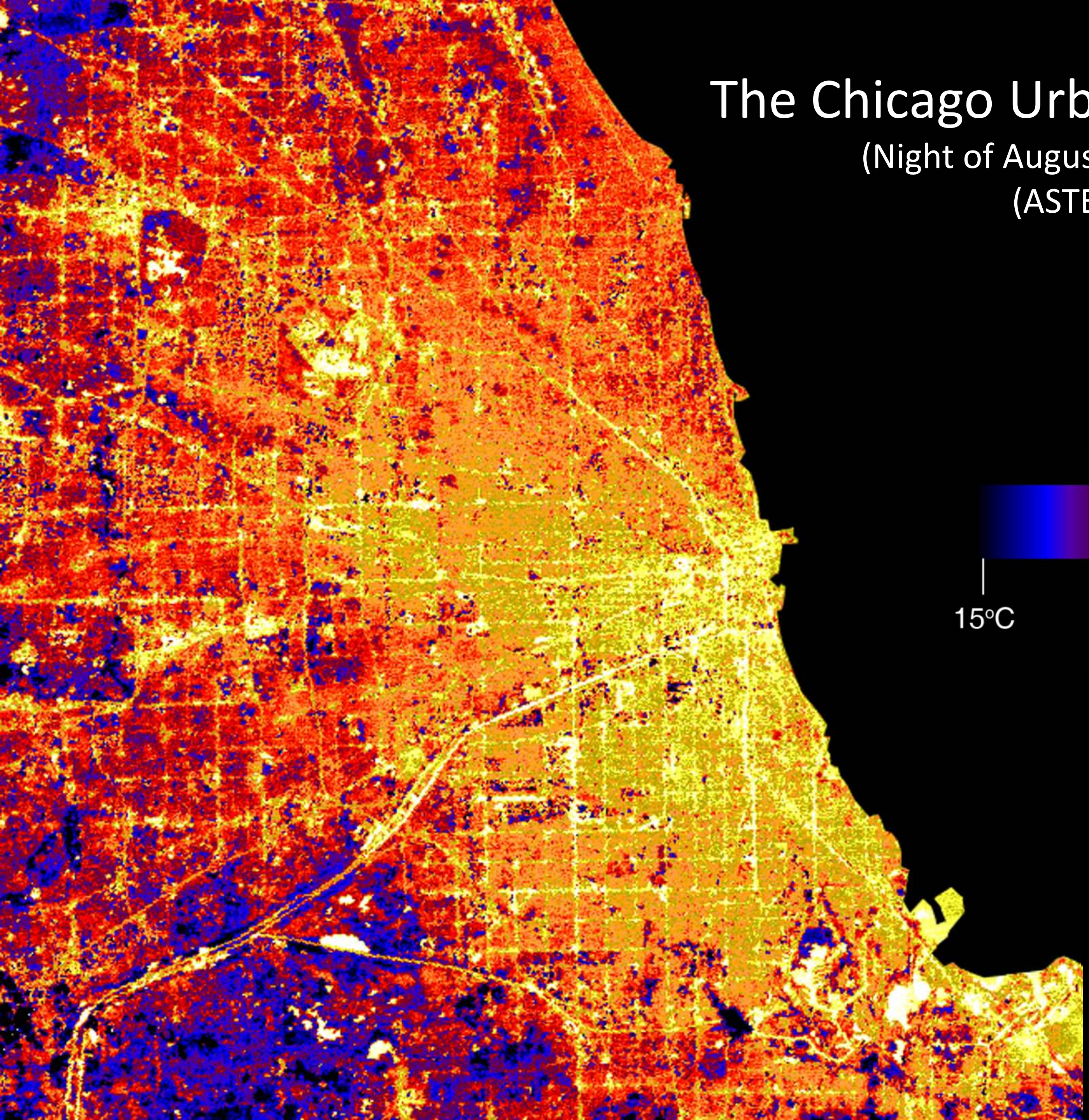
- In 1996, CitySpace initiated a nonprofit organization called NeighborSpace that allows members of a community to purchase land for community gardens.
- The city started acquiring small lots along the Chicago river to zone as parks and has required all new developments along the waterway to step back 30 feet.
- In 1996, it announced the Campus Parks Program to change asphalt schoolyards to lawns and public greenspace (over 100 parks were made by 2001)
- In 2002, the city began acquiring properties to make the Calumet Open Space Reserve.

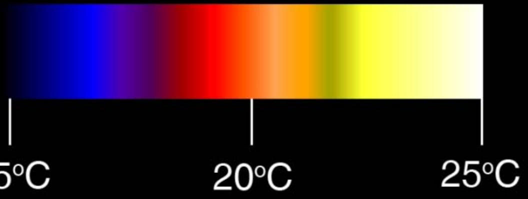
Intro: Overview of Study Area/Period

The Chicago Urban Heat Island

(Night of August 13th, 2007)

(ASTER)



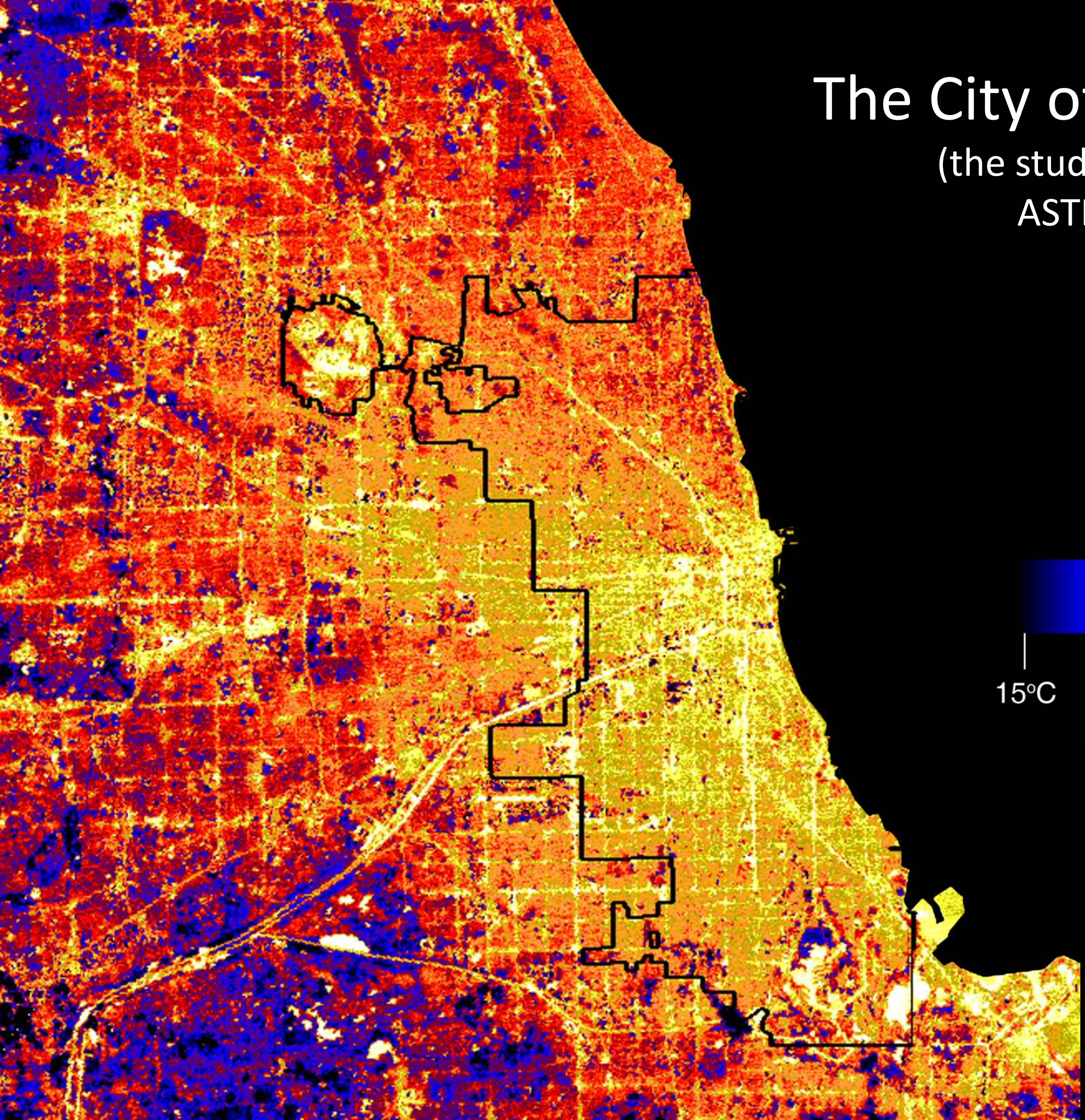


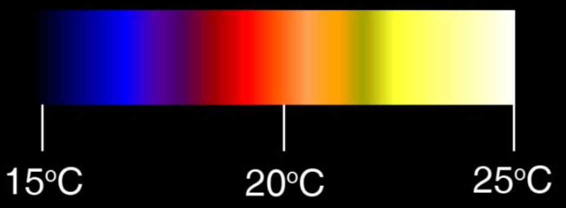
Chris Mackey

The City of Chicago

(the study area)

ASTER

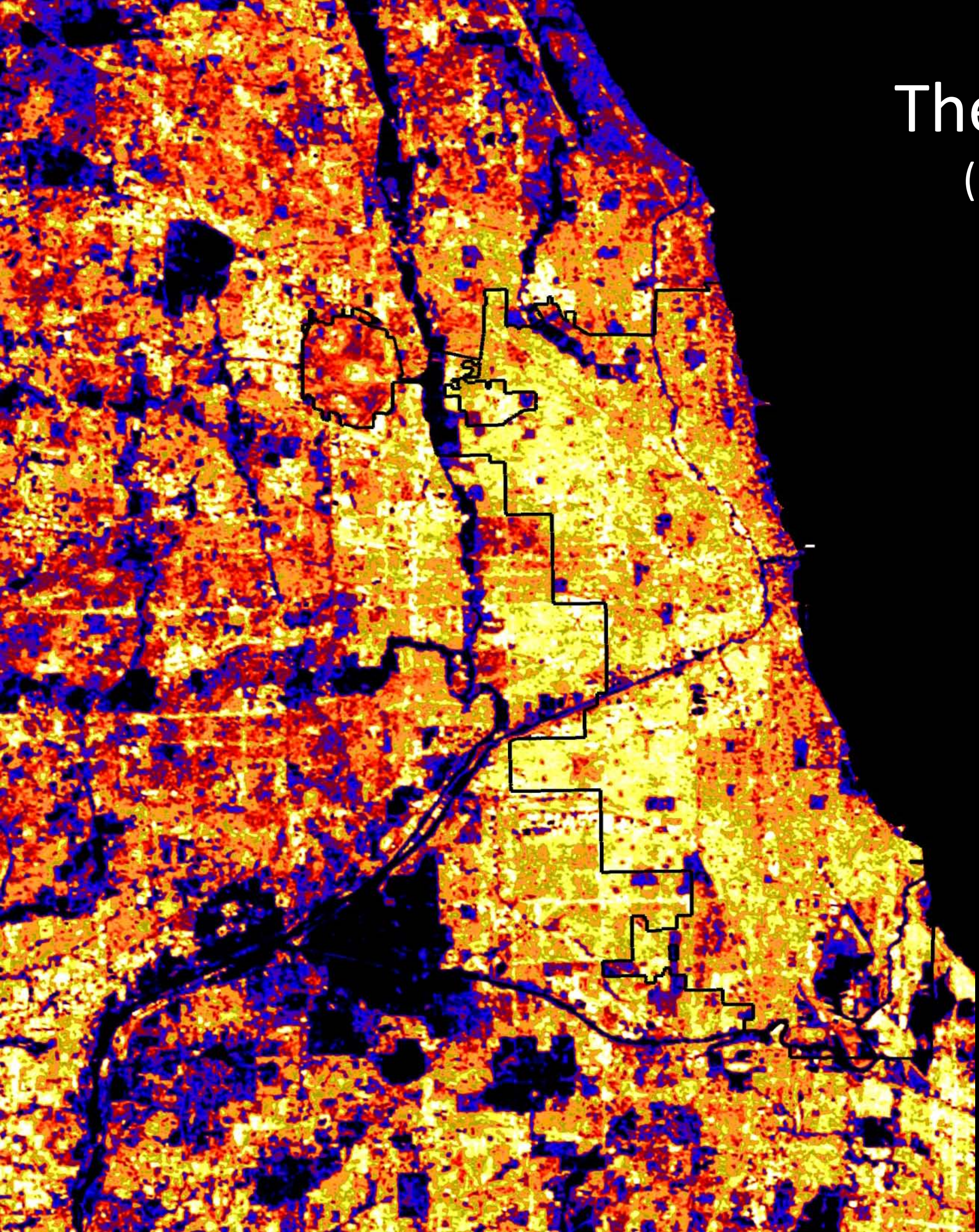


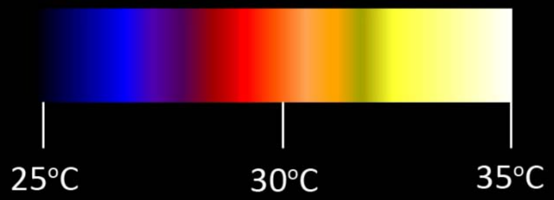


The City of Chicago

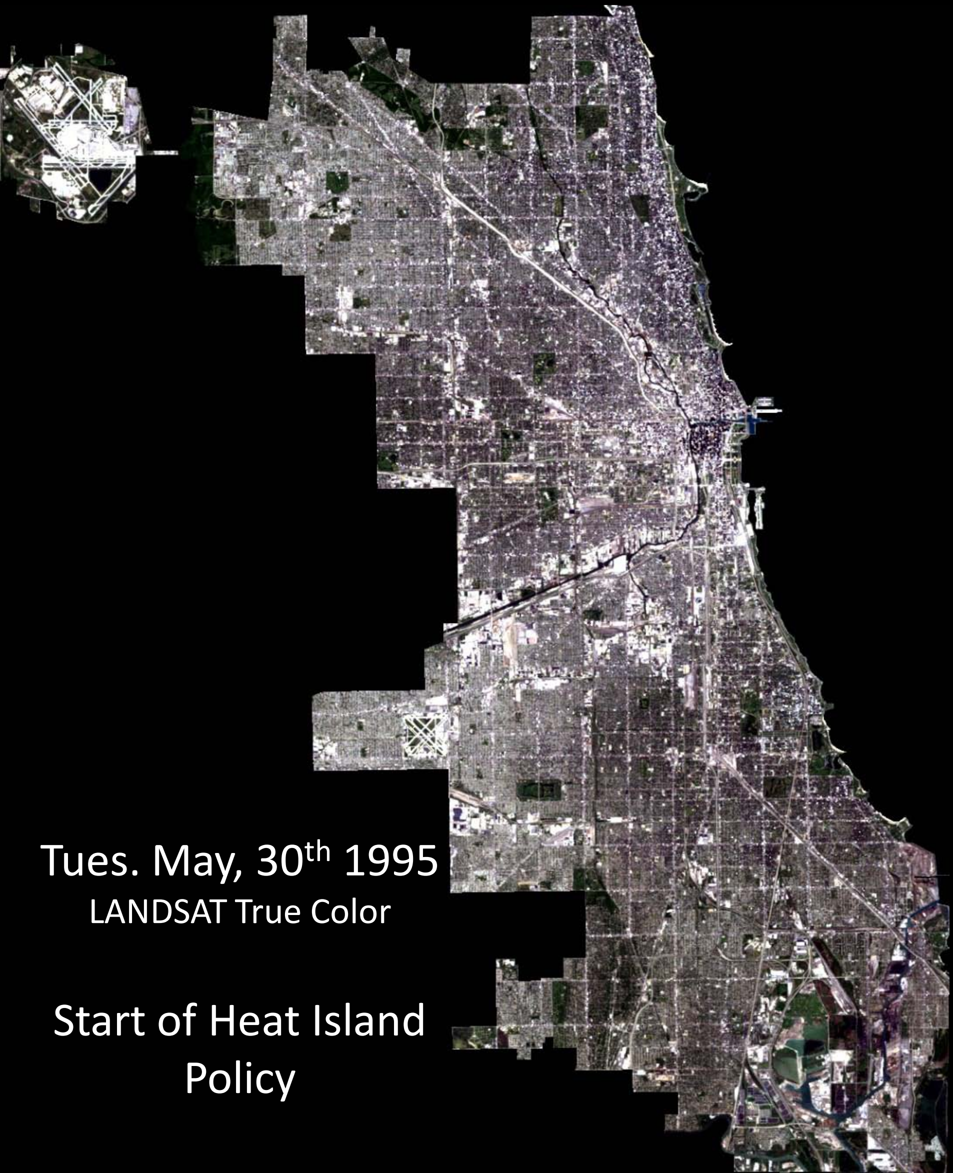
(Day of June 5th, 2009)

(LANDSAT)





Early June Image Pair



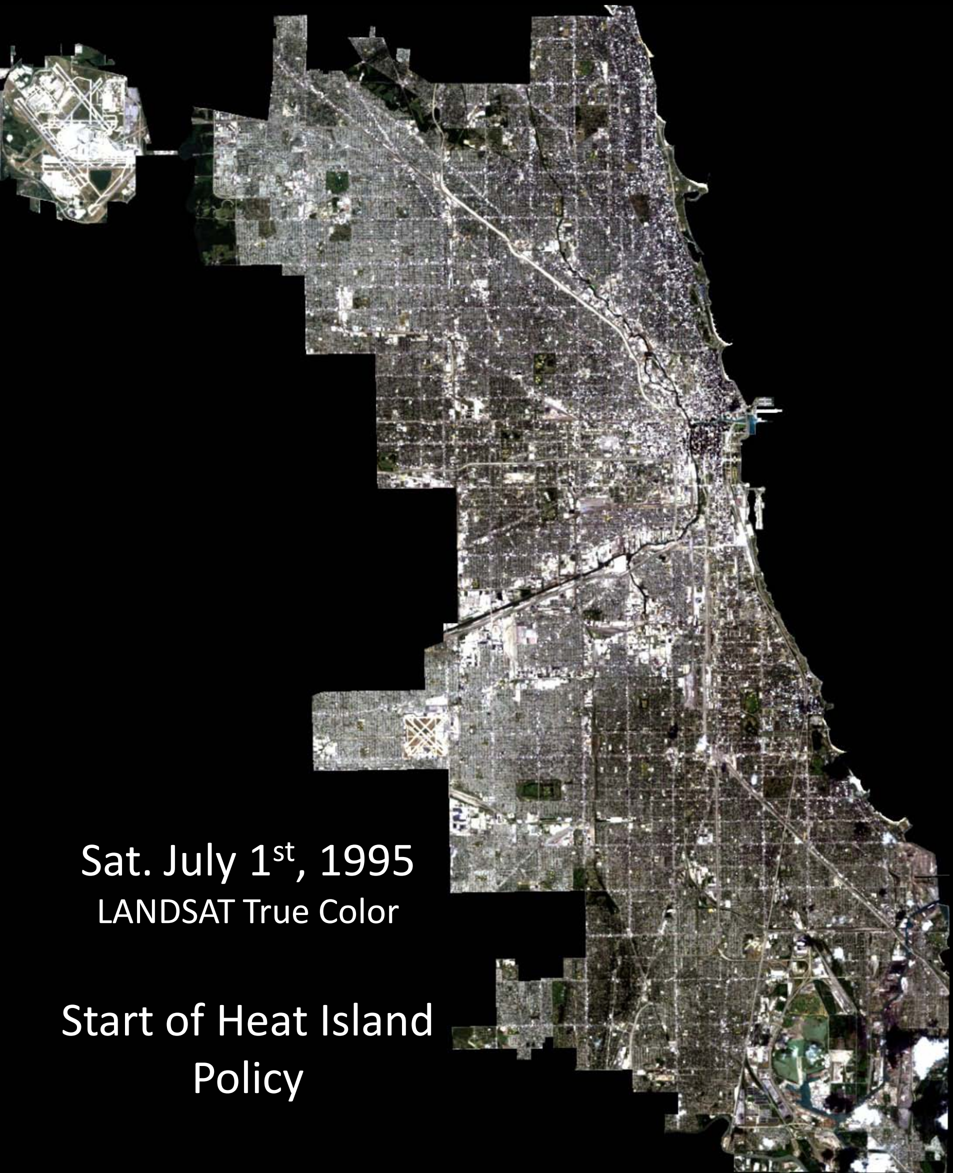
Tues. May, 30th 1995
LANDSAT True Color

Start of Heat Island Policy

Fri. June, 5th 2009
LANDSAT True Color

Present

Early July Image Pair



Sat. July 1st, 1995
LANDSAT True Color

Start of Heat Island Policy

Mon. July, 2nd 2007
LANDSAT True Color

Present

Heat Wave Image

Fri. August 3rd, 2007

LANDSAT True Color

Present

Atmospheric Conditions

Date	Avg LANDSAT Srf Temp (^oC)	Midway Air Temp (^oC)	O'Hare Air Temp (^oC)	Balloon Air Temp (^oC)*
Early June				
May 30th 1995	29.8	19.4	20.0	15.0
June 5th 2009	30.9	18.3	16.7	13.4
Difference	+1.1	-1.1	-3.3	-1.6
Early July				
July 1st 1995	29.8	16.7	18.3	12.2
July 2nd 2007	30.2	20.0	18.9	17.6
Difference	+0.4	+3.3	+0.6	+5.4
Heat Wave				
August 3rd 2007	37.6	23.3	26.7	23.8

Date	Wind Speed (knots)*	Wind Direction (^{o})*	Humidity (%)*	Cloud Cover (%)	Prev. Month's Rainfall (in)
Early June					
May 30th 1995	10	325	51	0	4.47
June 5th 2009	20	40	67	0	3.63
Difference	+10	75	+16	0	-0.84
Early July					
July 1st 1995	15	355	67	2.3	1.4
July 2nd 2007	8	125	52	0	2.29
Difference	-7	130	-15	-2.3	+0.89
Heat Wave					
August 3rd 2007	9	310	65	0	3.86

* reading taken from a weather balloon sounding in Lincoln IL at a pressure/height of 925 hpa

PART I: Change Detection of Policies

Question:

1) Have policies produced impacts large enough be detected in coarse-grained satellite images such as LANDSAT?

Chicago Vegetation Change

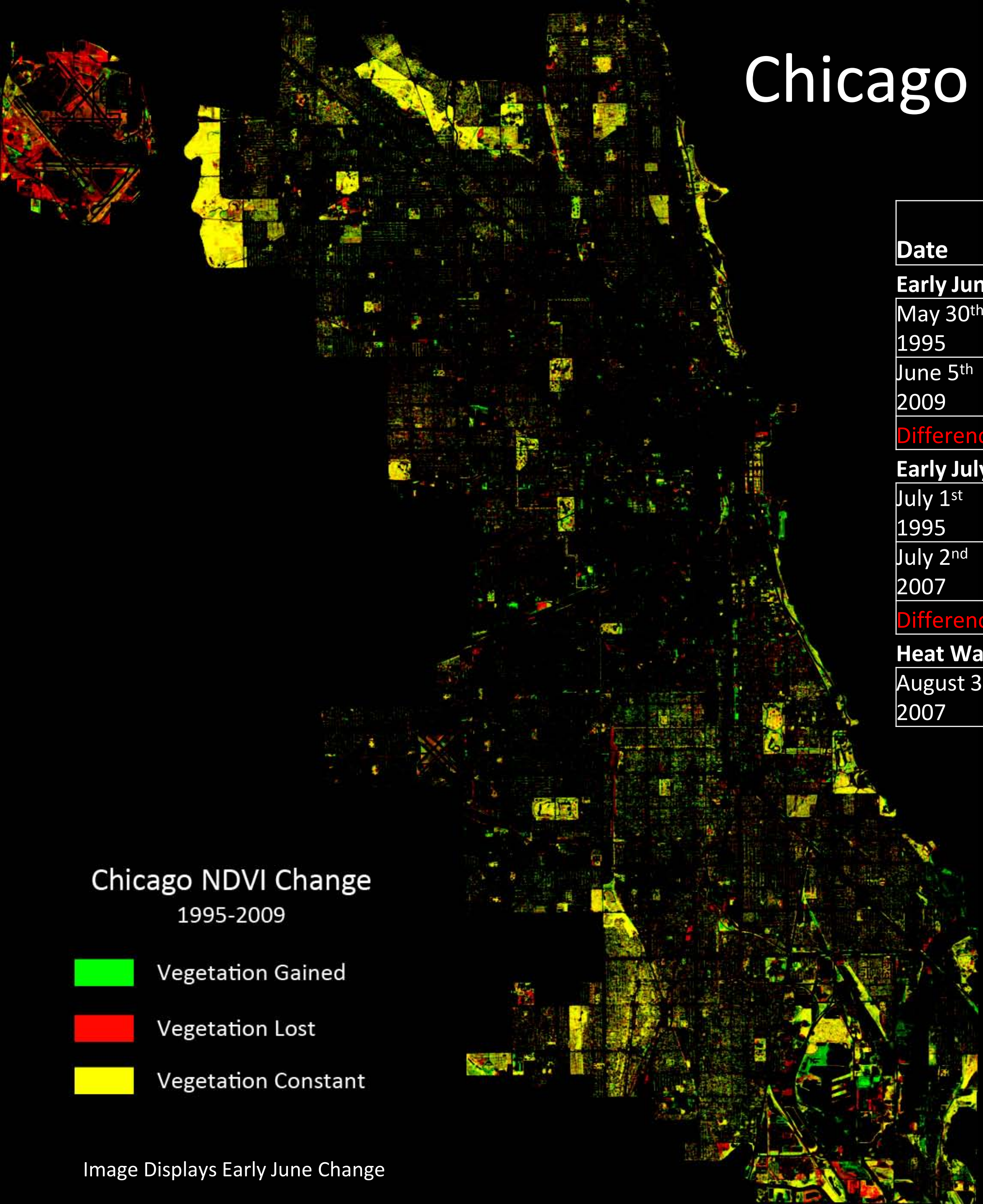


Image Displays Early June Change

Date	Number of Vegetated Pixels	% Vegetation in Scene	Prev. Month's Rainfall (in)
Early June			
May 30th 1995	187,458	27.2	4.47
June 5th 2009	177,773	26.3	3.63
Difference	-9,685	-1.4	-0.84
Early July			
July 1st 1995	178,127	27	1.4
July 2nd 2007	282,262	42.8	2.29
Difference	+104,135	+15.8	+0.89
Heat Wave			
August 3rd 2007	325,195	48.2	3.86

Chicago Vegetation Change

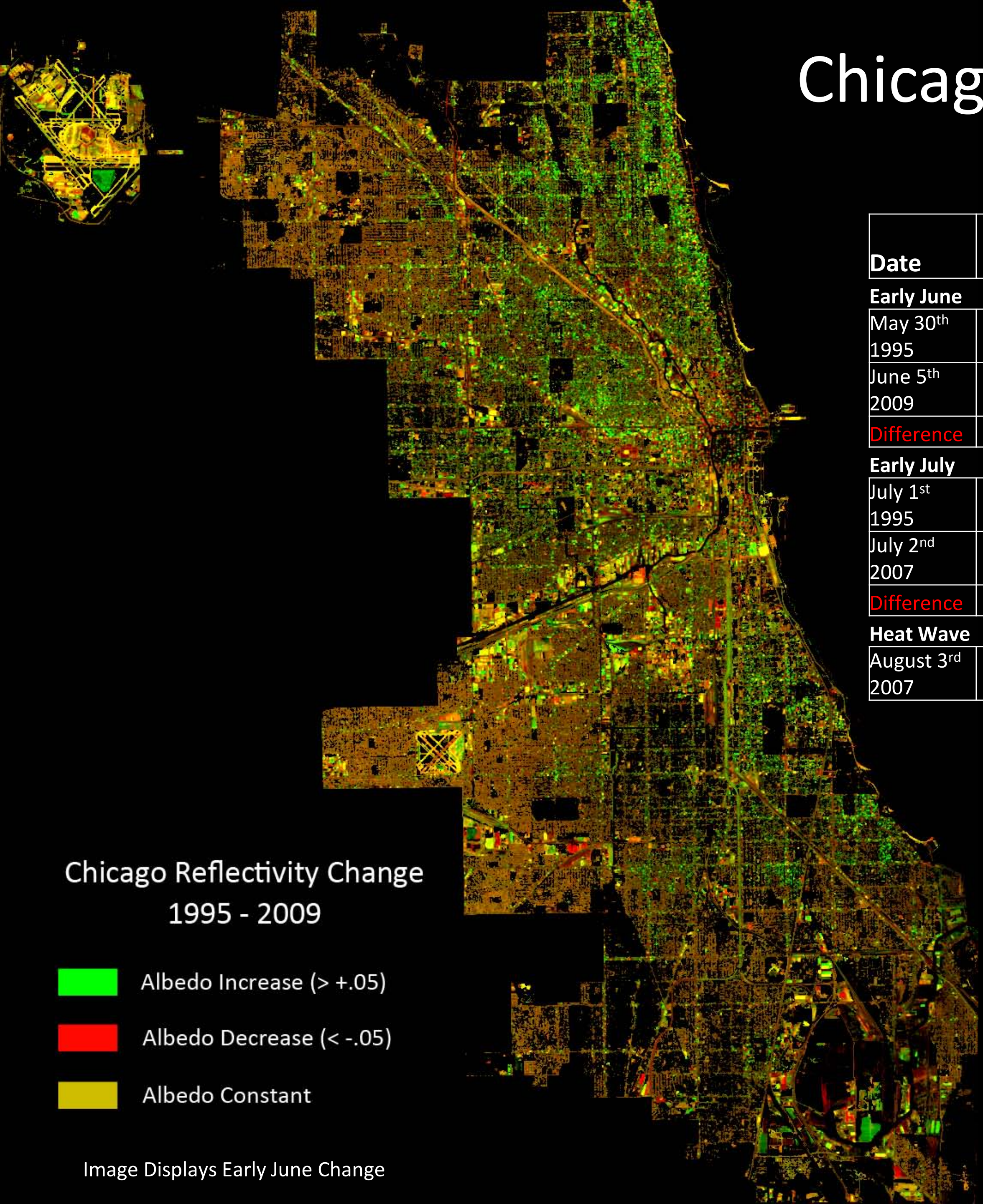
It is uncertain whether the total vegetation of Chicago increased or decreased in the test period since the detectability of vegetation varies greatly from year to year and even month to month.

This is probably because precipitation varies widely.

Chicago Albedo Change

Date	Entire City Albedo	Non-Vegetated Non-Water Albedo	Prev. Month's Rainfall (in)
Early June			
May 30th 1995	0.11665	0.117019	4.47
June 5th 2009	0.135543	0.140415	3.63
Difference	+0.018893	+0.023396	-0.84
Early July			
July 1st 1995	0.11895	0.119802	1.4
July 2nd 2007	0.125028	0.132466	2.29
Difference	+0.006078	+0.012664	+0.89
Heat Wave			
August 3rd 2007	0.132388	0.141301	3.86

Note: Albedo Values are taken after a dark object subtraction and thus are probably all lower than true albedo values.



Chicago Albedo Change

Chicago's albedo, like its vegetation, seems to display some variation with precipitation. The variance may also be the result of a reflective policy passed in 2008 that might have generated significant albedo changes between 2007 and 2009.

Unlike vegetation, it is fairly certain that the overall albedo of the city increased in the test period.

Part I Conclusions

-It is uncertain whether the total vegetation of Chicago changed in the test period. However, both areas that clearly gained vegetation and areas that clearly lost vegetation are visible in fairly similar quantities over the city (policies are noticeable).

- It is certain that the total albedo of the city increased in the test period and it is estimated that this was by 0.0125 .

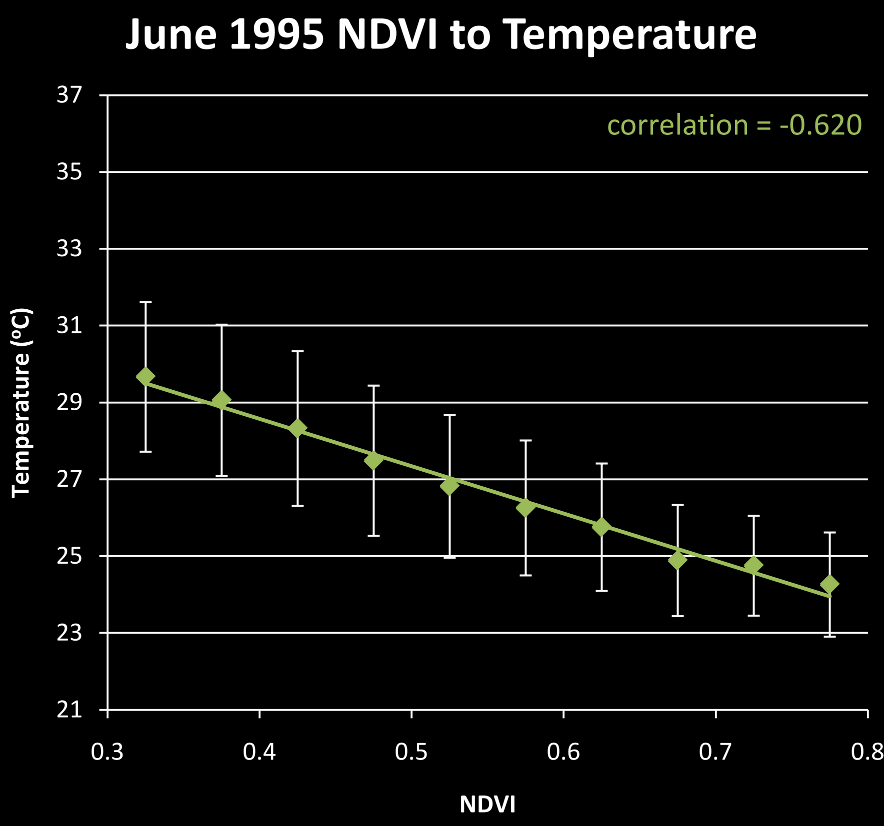
- The fact that the reflectivity increases in Chicago between 1995 and the present are more noticeable than vegetation changes suggests that reflective policies and efforts may have had a more significant impact on the whole city than vegetation policies.

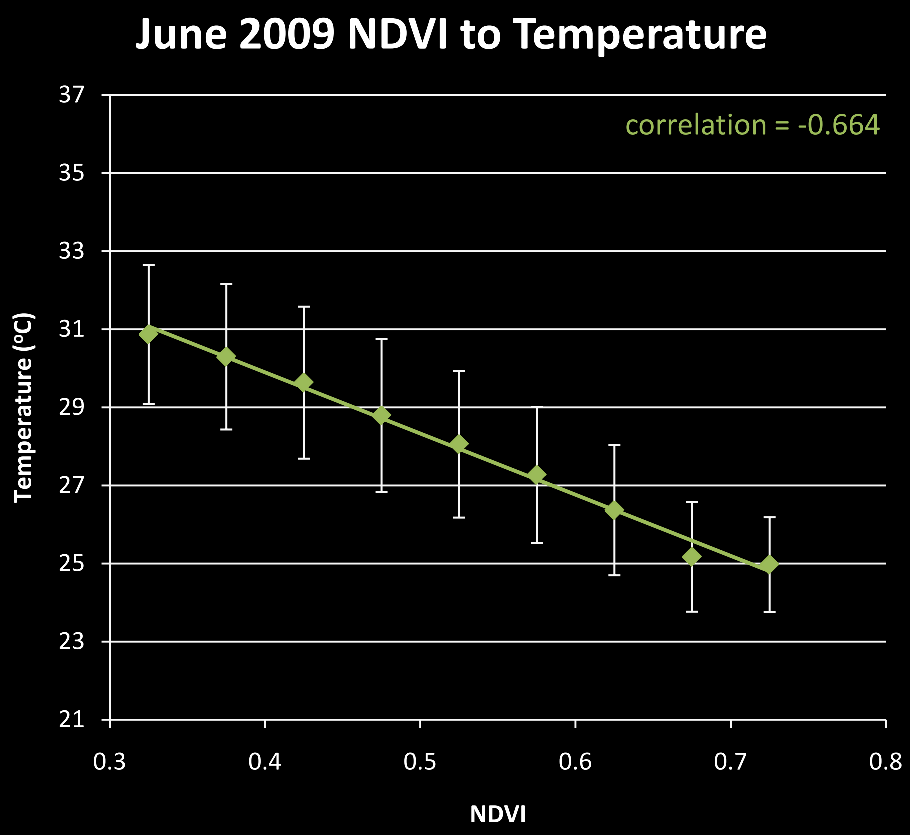
PART II: Correlations in Single Images

Question:

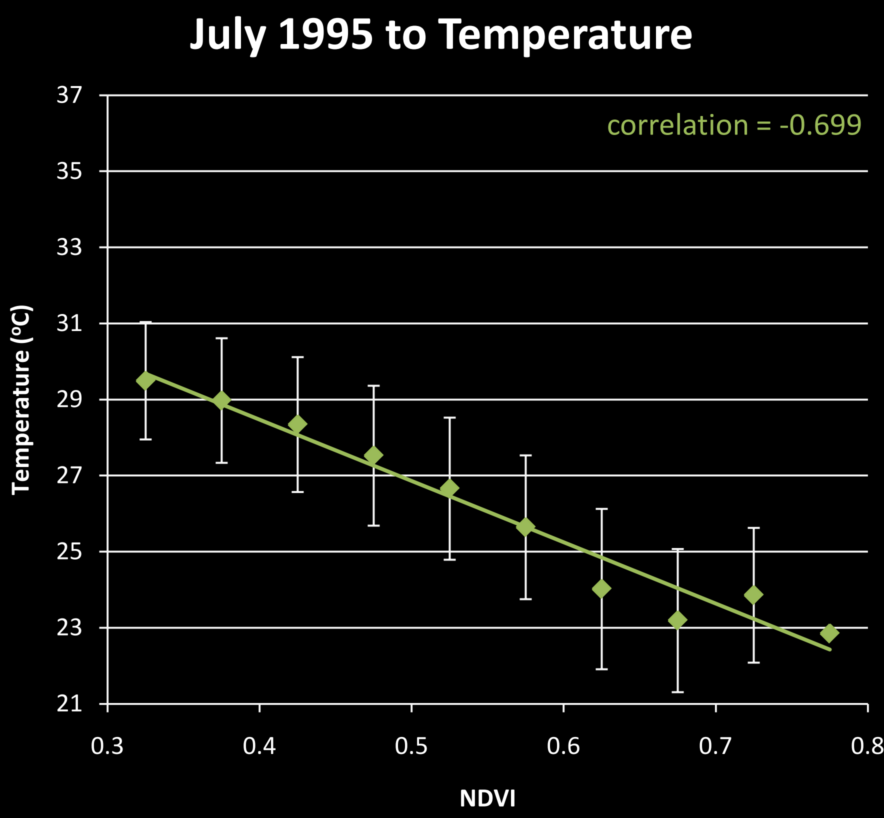
2) Have the reflective or vegetation strategies been generally more effective?

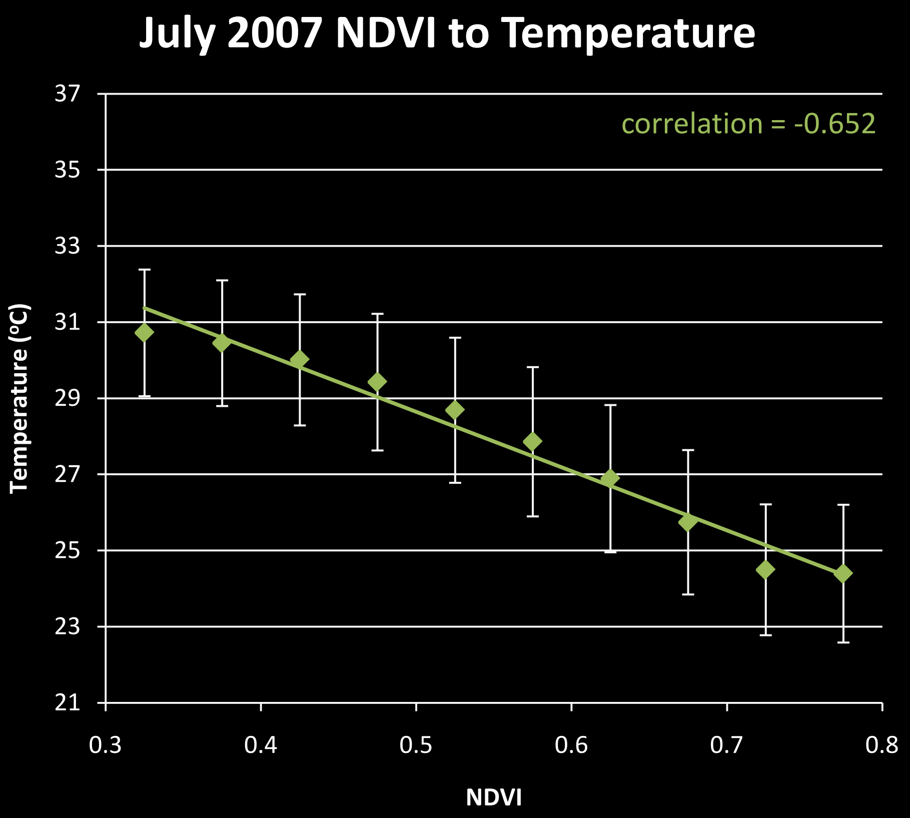
NDVI to Temperature (Early June)



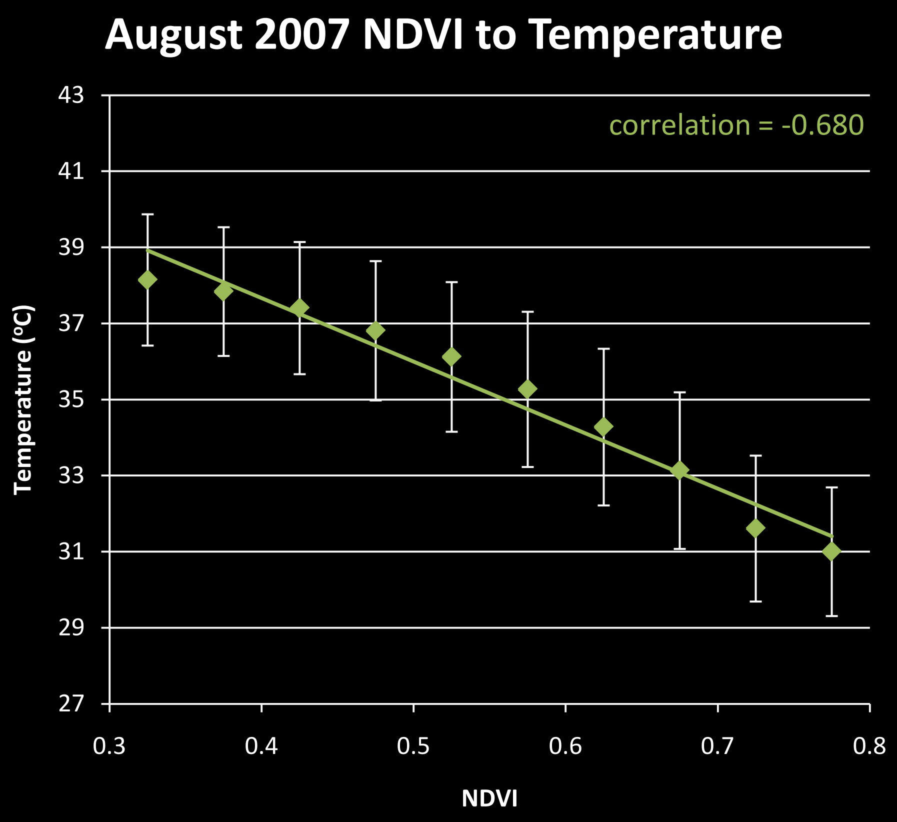


NDVI to Temperature (Early July)

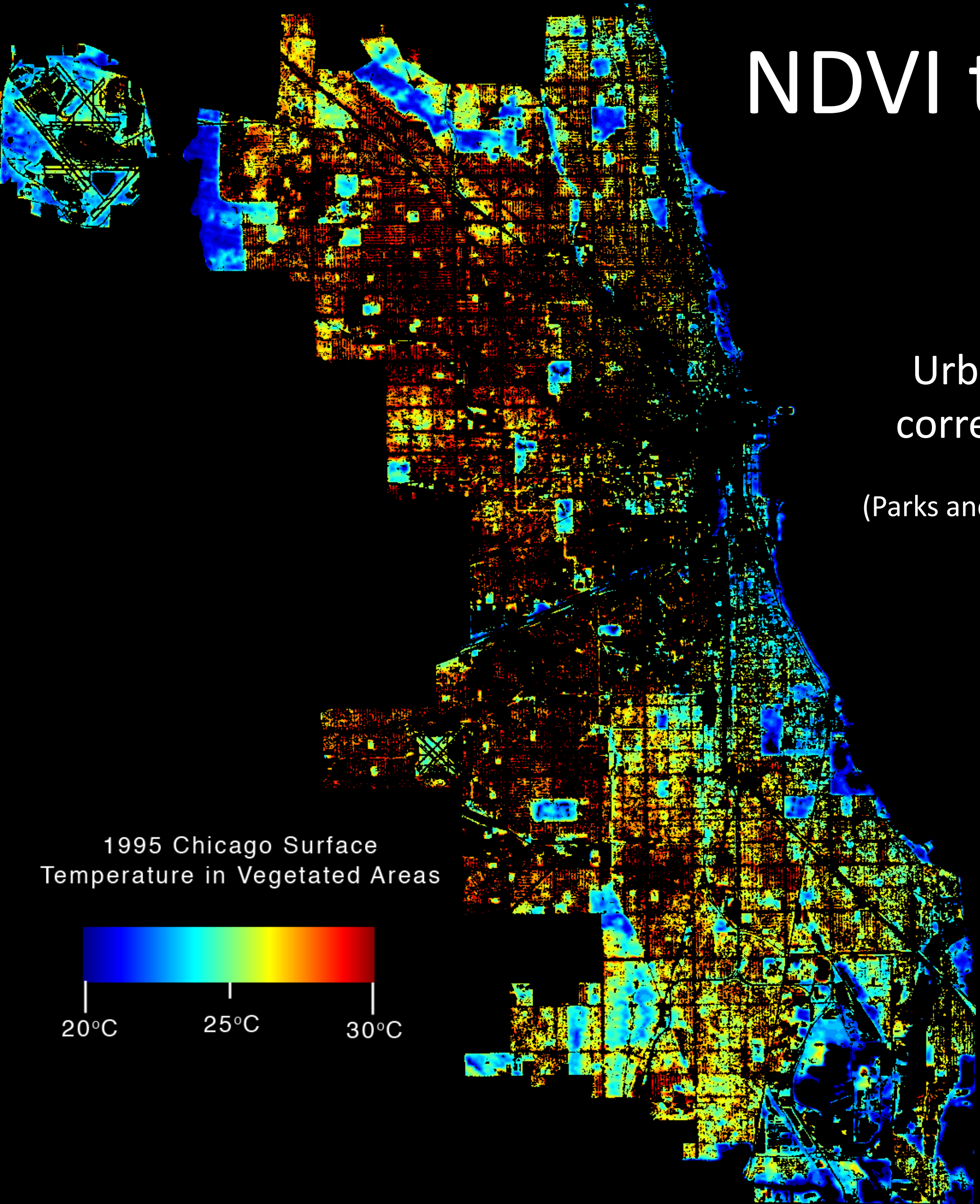




NDVI to Temperature (Heat Wave)



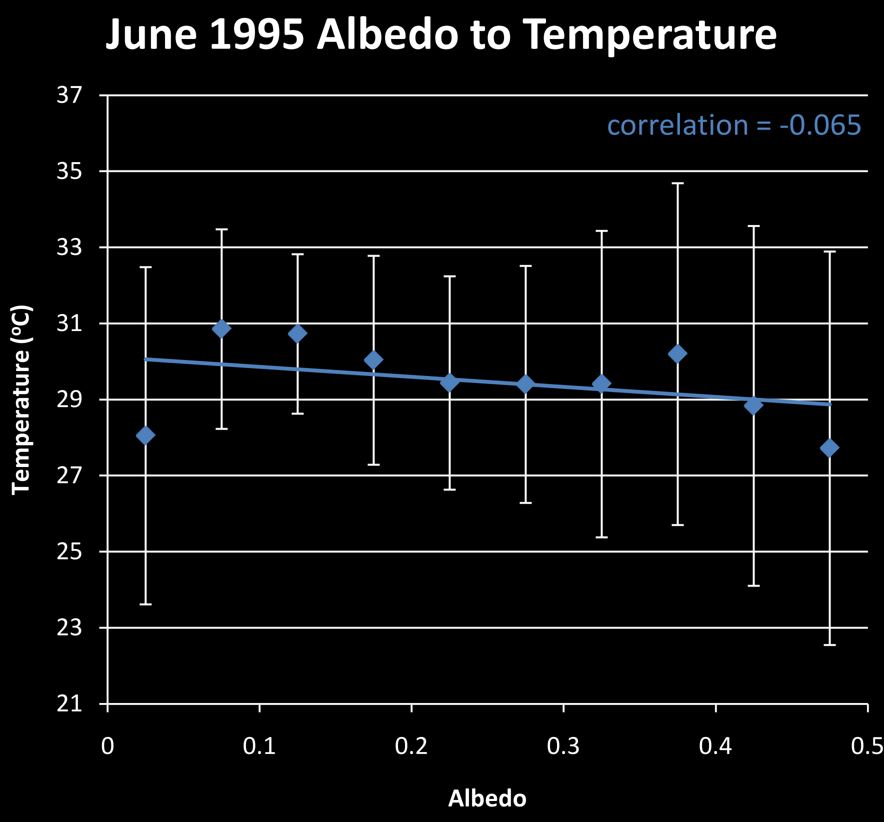
NDVI to Temperature

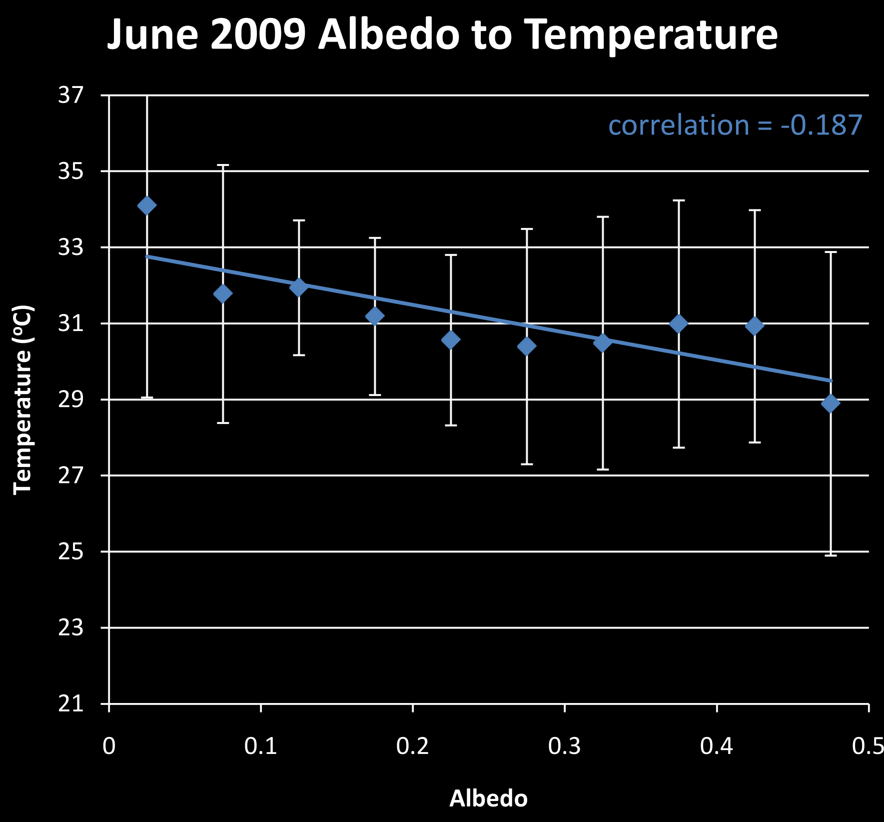


Urban NDVI above .3 is strongly correlated to lower temperatures

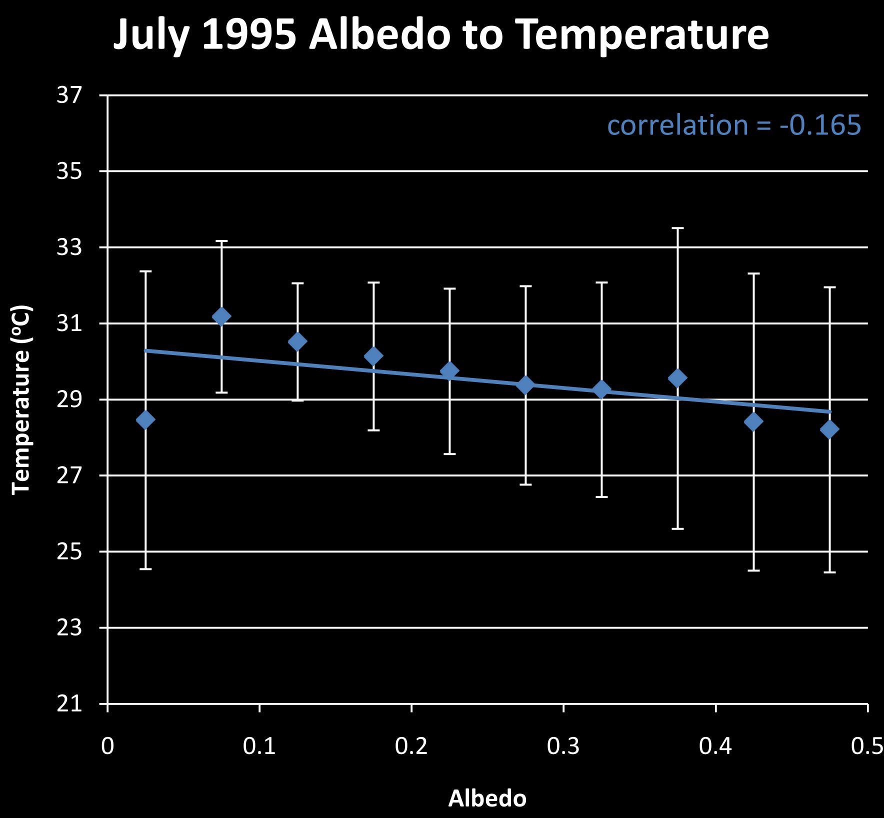
(Parks and areas of dense vegetation are the coolest)

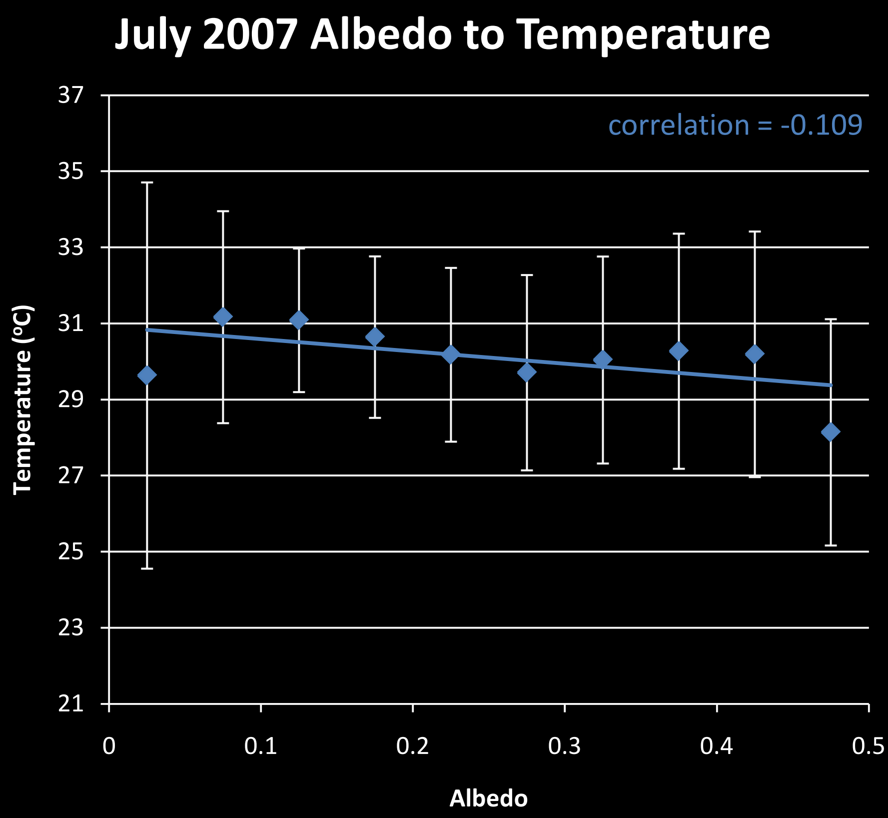
Albedo to Temperature (Early June)



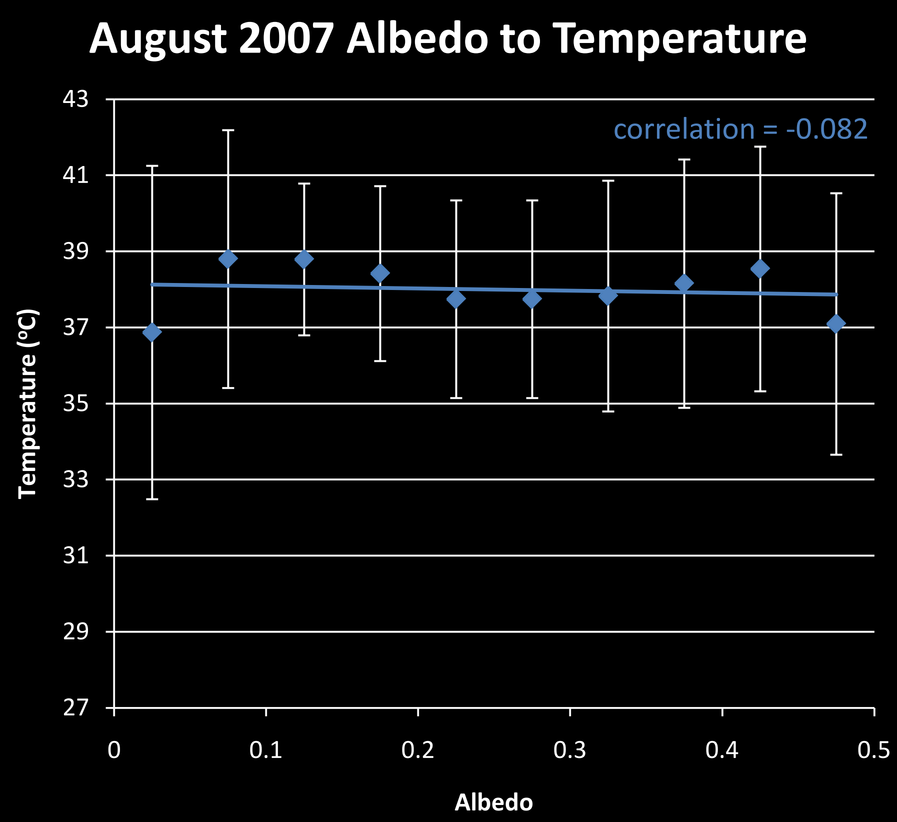


Albedo to Temperature (Early July)





Albedo to Temperature (Heat Wave)



Albedo to Temperature

Urban albedo is very weakly
correlated to lower temperatures

(More reflective surfaces are not necessarily cooler)

Part II Conclusions

-This method supports the scientific agreement that urban heat island is primarily caused by a removal of vegetation (as opposed to decreases in albedo of some surfaces).

-It is consistent with observations that large parks and areas with abundant vegetation are often the coolest parts of a city in Summer.

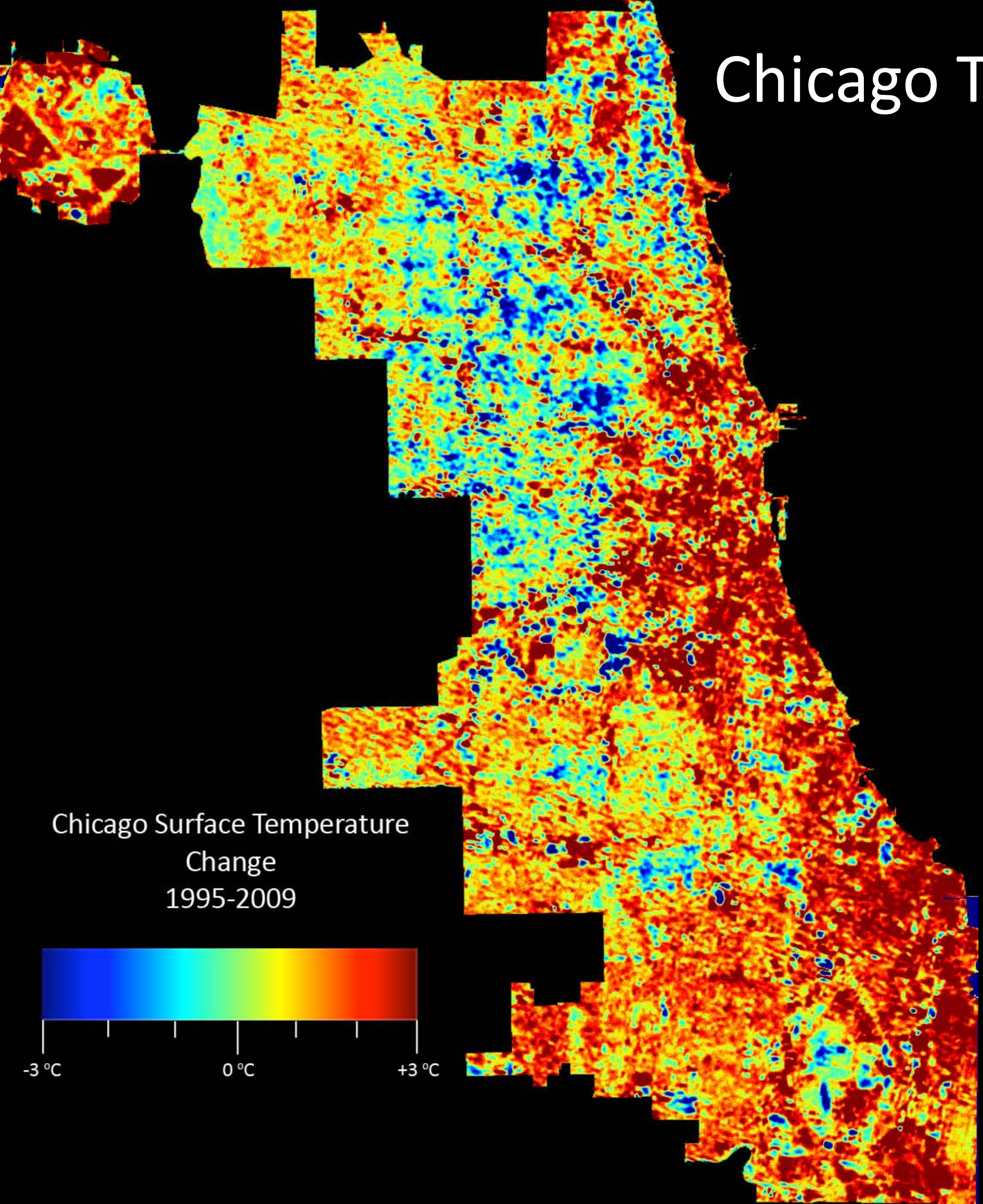
-It suggests that the ideal method of dealing with urban heat island is to have abundant vegetation to the level of an urban park throughout the city.

PART III: Correlations of Policy Changes to Temperature Change

Question:

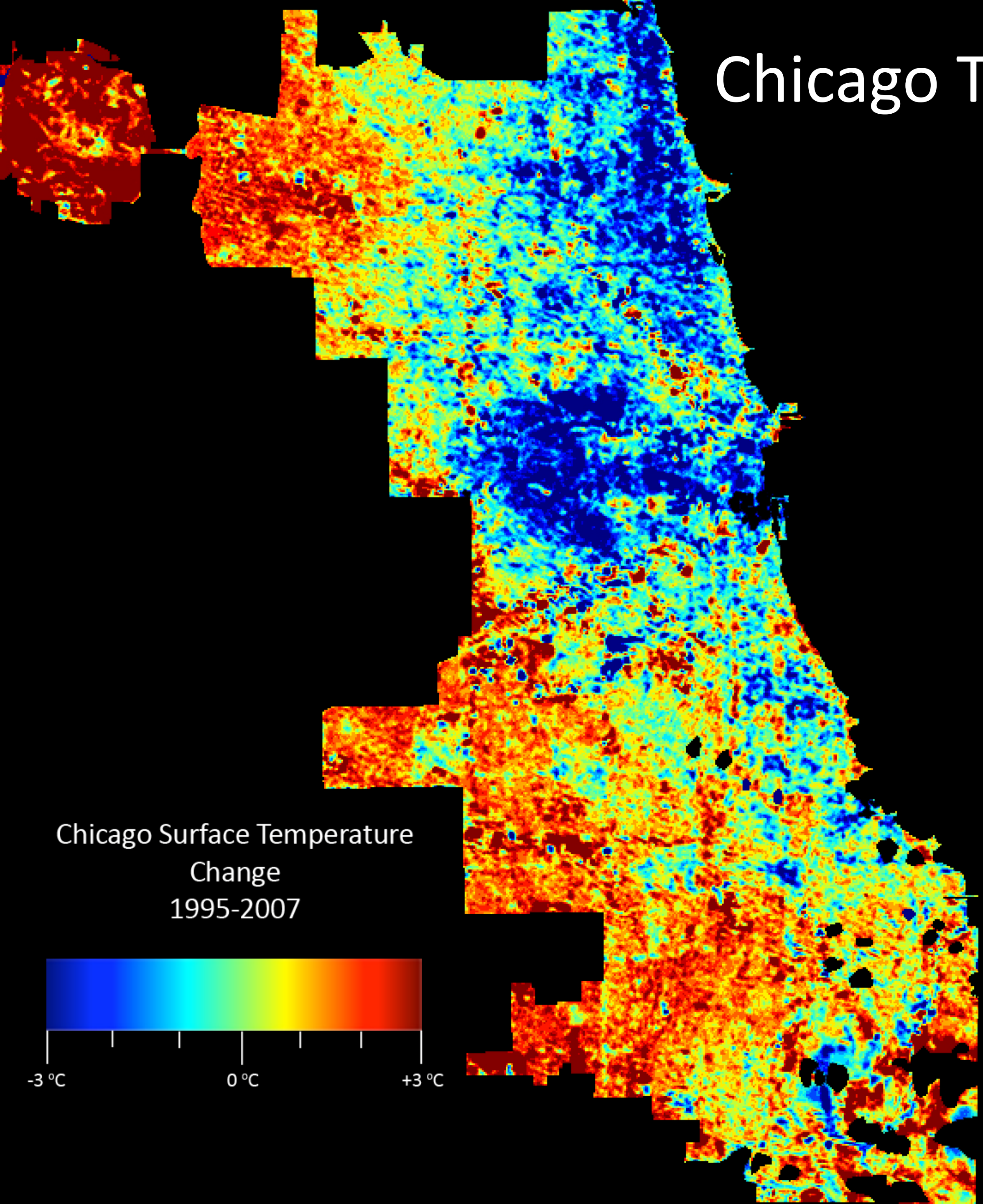
2) Have the reflective or vegetation strategies been generally more effective?

Chicago Temperature Change



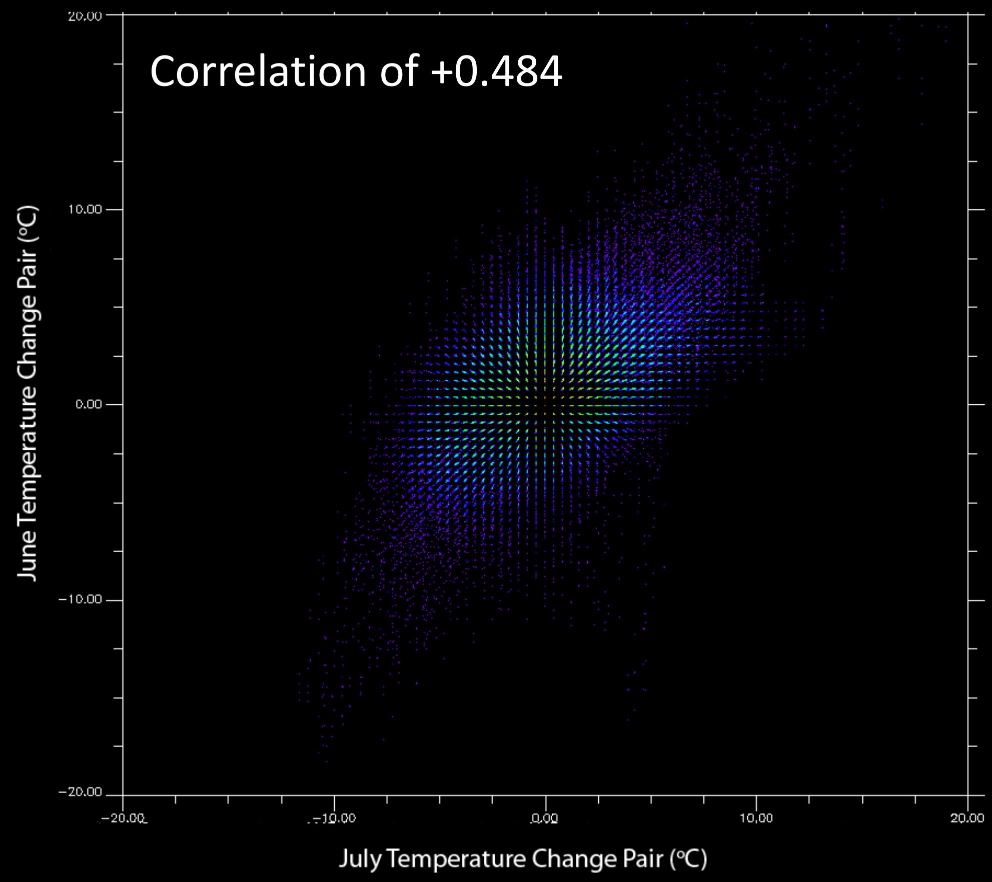
Early June Image Pair Temperature Change

Chicago Temperature Change



Early July Image Pair
Temperature Change

Chicago Temperature Change



Temperature Change Comparison

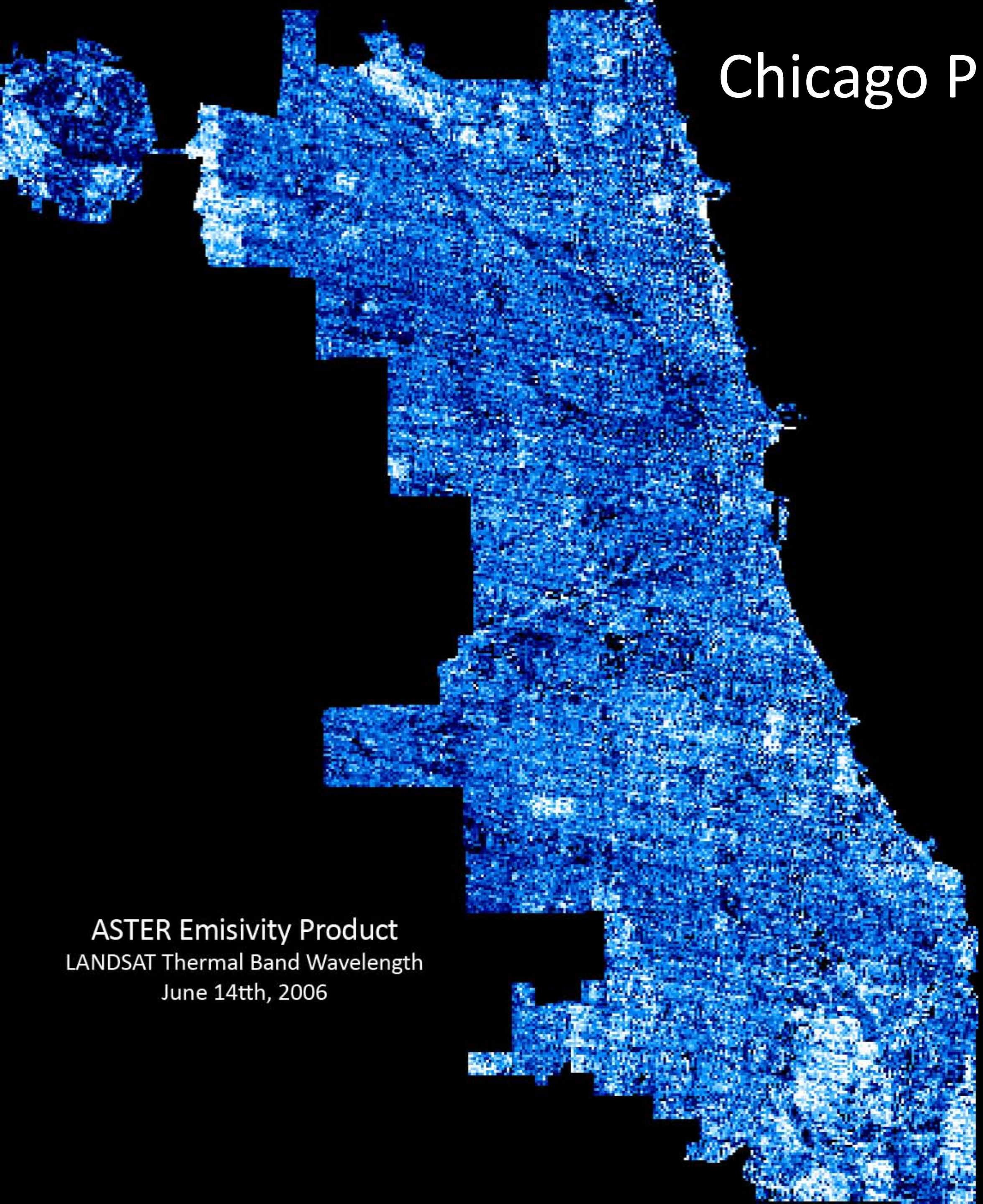
Image Pair	Avg. Srf. Temp. Change (°C)	Temp. Change Standard Deviation (°C)
June	+1.10	1.65
July	+0.41	1.92

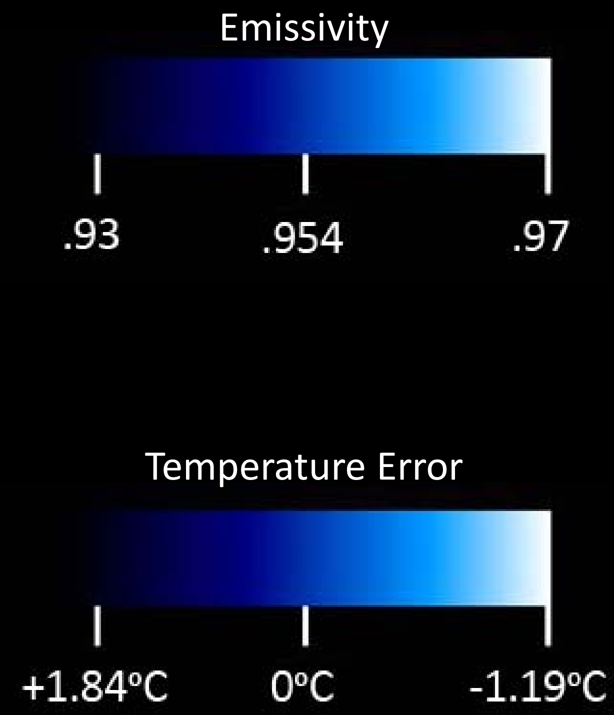
Correlation of +0.484

The method is not perfectly consistent but at least there is a mildly-strong correlation that is positive.

Errors can probably be explained by changes in water levels or infrastructure changes between 2007 and 2009.

Chicago Present-Day Emissivity

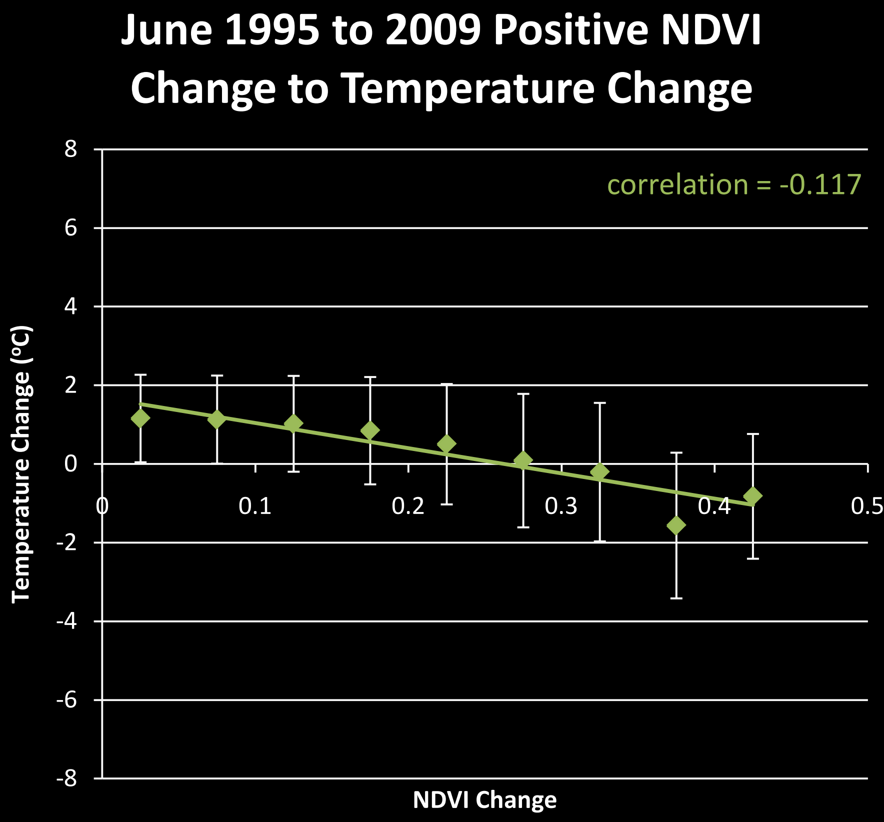


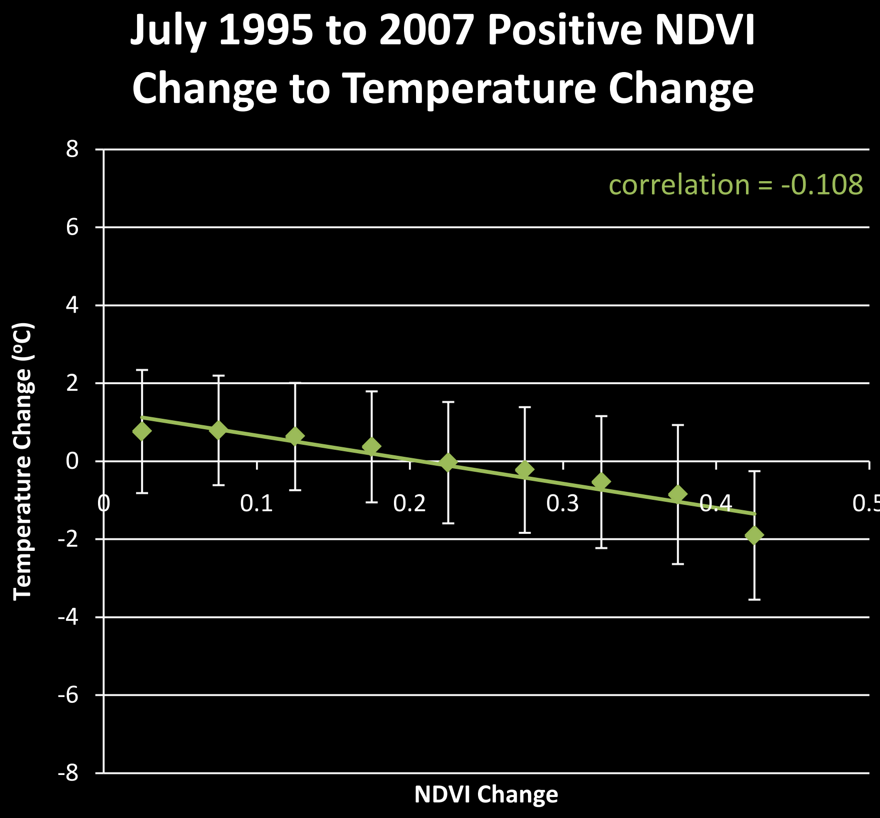


ASTER Emisivity Product
LANDSAT Thermal Band Wavelength
June 14tth, 2006

Avg Emissivity of Whole Scene = 0.954
Avg Emissivity of Vegetated Pixels = : 0.956
Avg Emissivity of Non-Vegetated Pixels = 0.951

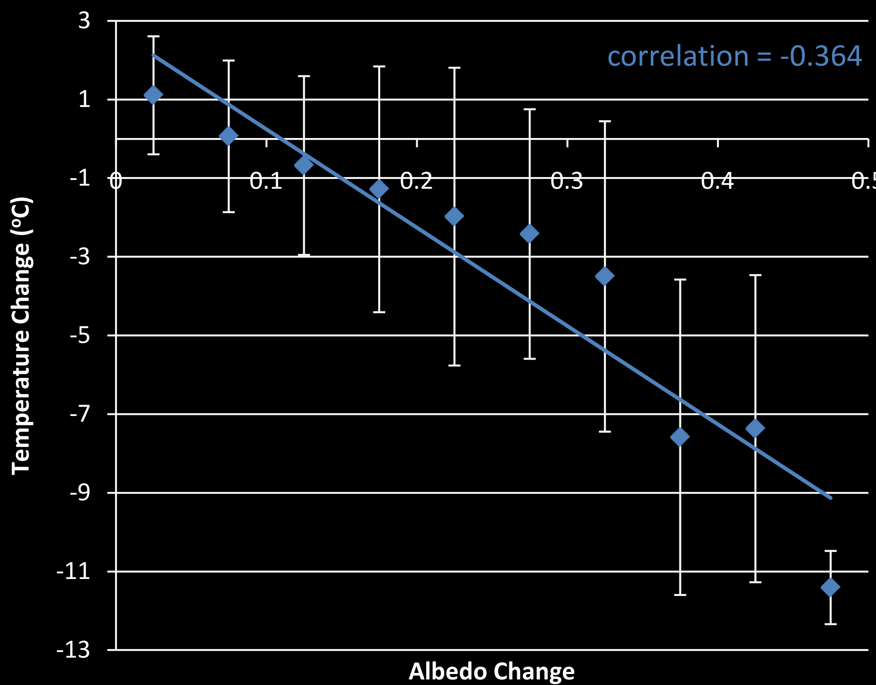
NDVI Change to Temperature Change



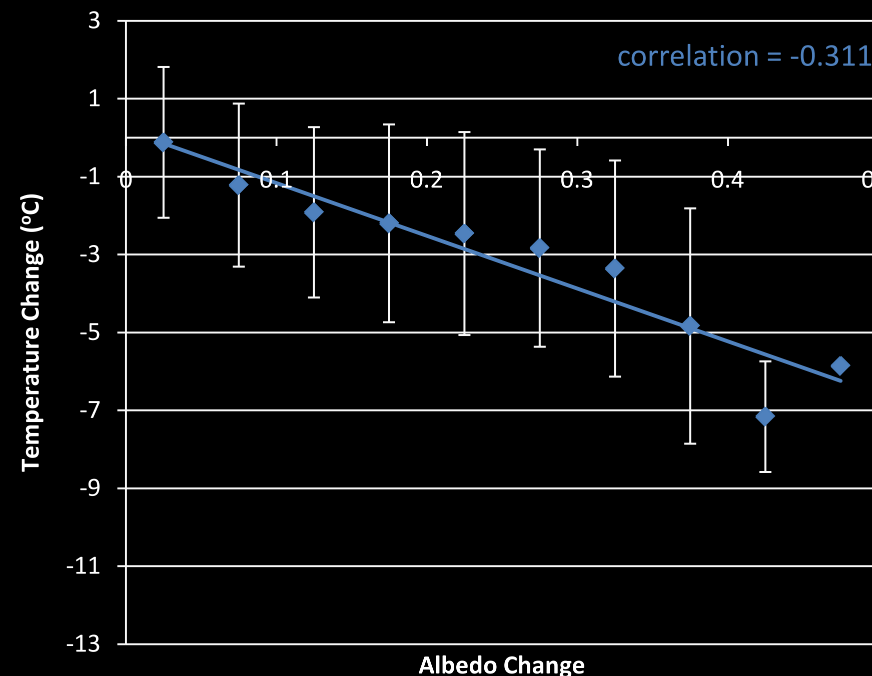


Albedo Change to Temperature Change

June 1995 to 2009 Positive Albedo Change to Temperature Change



July 1995 to 2007 Positive Albedo Change to Temperature Change



Part III Conclusions

-The positive changes in NDVI above .3 between 1995 and the present are weakly correlated to a temperature decreases (-0.113) while positive changes in albedo are fairly strongly correlated (-0.338).

-The higher correlation of albedo increase to temperature decrease suggests that the reflective policies and efforts in the test period were more effective at cooling the city than the vegetation efforts.

PART IV: Aerial Image Confirmation

Question:

3) Which specific methods seem to be the most effective and most promising?

Aerial Image Sources

Illinois Natural Resources Geospatial Data Clearinghouse

1998
Single visible band
1 meter resolution

Google maps

2010
True color visible bands
1 meter resolution

The Methods

1) Reflective Roofs

2) Reflective Pavement

3) Green Roofs

4) Street/Yard Trees

5) Greenspace (Parks/Reserves/Schoolyards)

1) Reflective Roofs

1) Reflective Roof Neighborhood

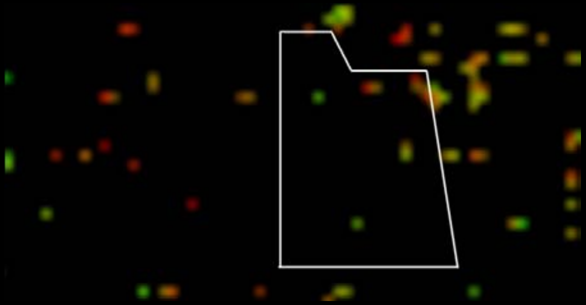
1998

2010

Ndvi Change

June: -0.014 (7px)

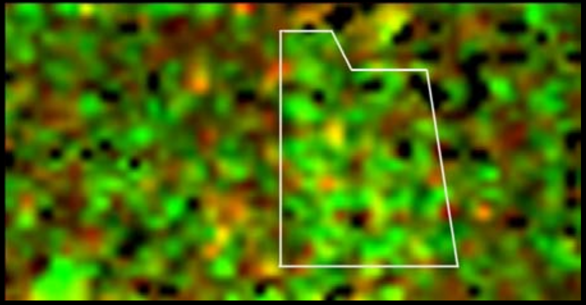
July: +0.015 (20px)



Albedo Change

June: +0.078

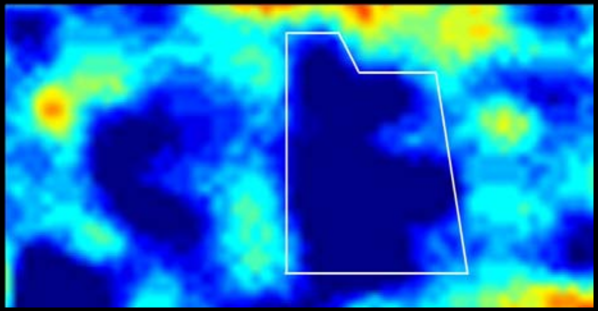
July: +0.051



Temp. Change

June: -3.52 ^{o}C

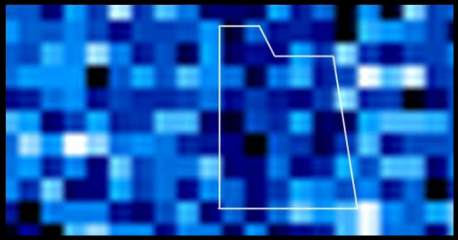
July: -3.46 ^{o}C



Present Emissivity

Emissivity: 0.948

Error from Mean: +0.48 ^{o}C

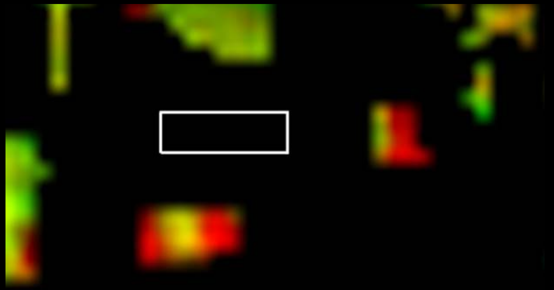


1) Reflective Roof Industrial Area

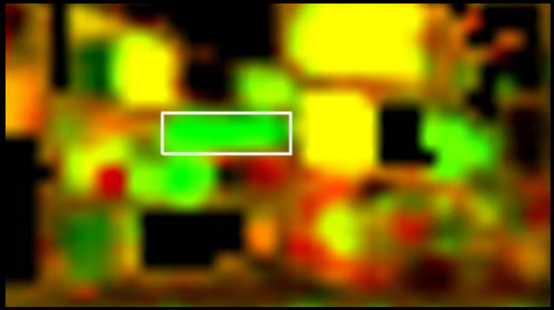
(Existing Building)

1998

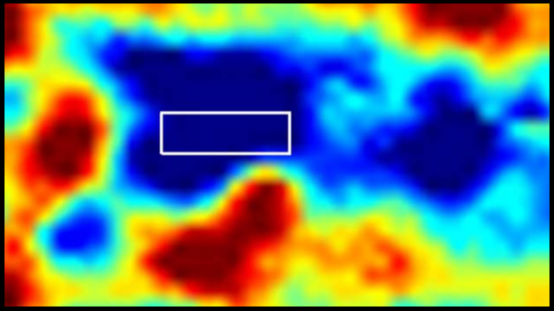
2010



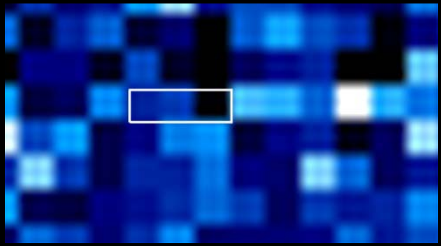
NDVI Change
June: 0 px
July: 0 px



Albedo Change
June: + 0.207
July: + 0.180



Temp. Change
June: -5.45 °C
July: -4.64 °C

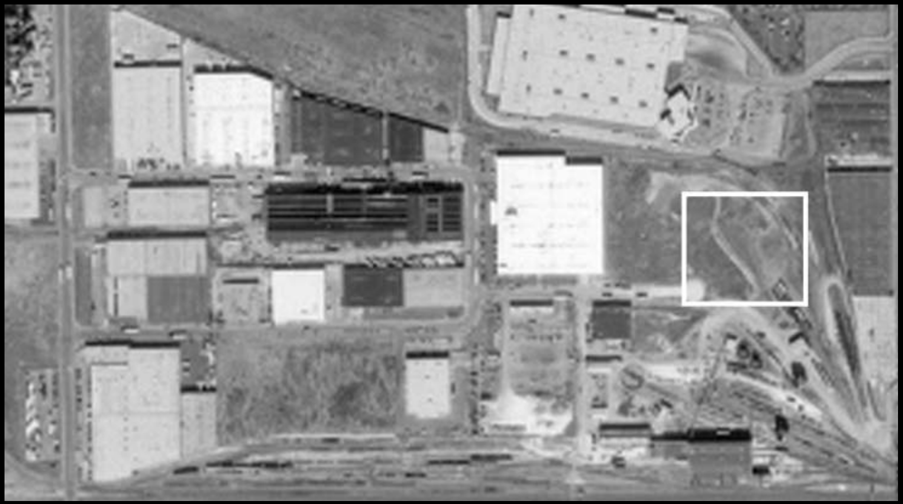


Present Emissivity
Emissivity: 0.948
Error from Mean: +0.47 °C

1) Reflective Roof Industrial Area

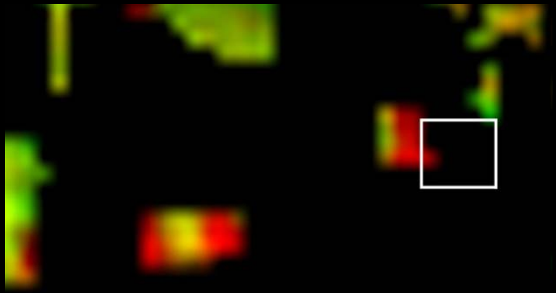
(New Building Over Soil)

1998

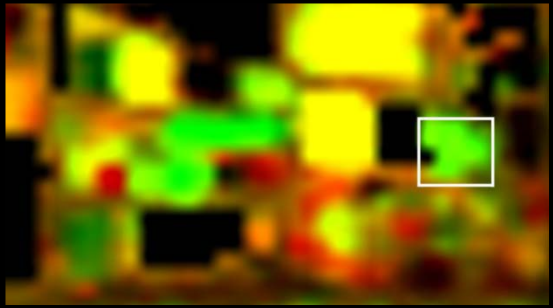


2010

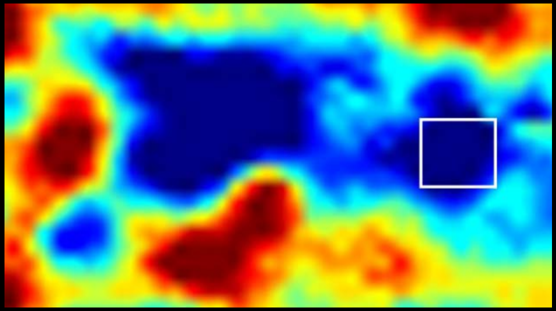
NDVI Change
June: 0 px
July: 0 px



Albedo Change
June: +0.166
July: +0.163



Temp. Change
June: -4.48 °C
July: -5.25 °C

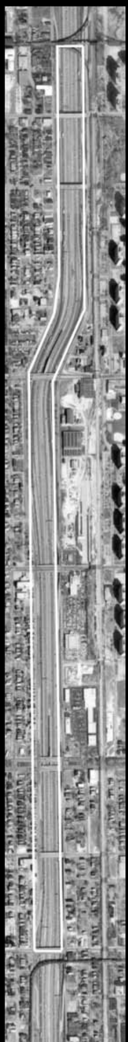


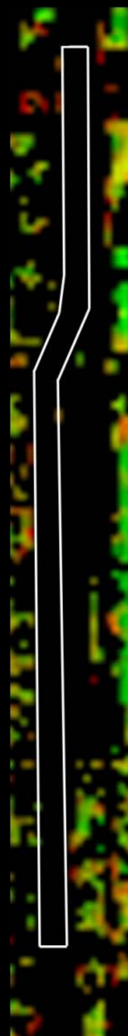
Present Emissivity
Emissivity: 0.953
Error from Mean: +0.09 °C

2) Reflective Pavement

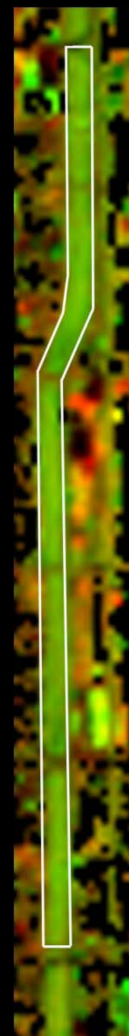
2) Road Reflectivity Increase

1998 2010

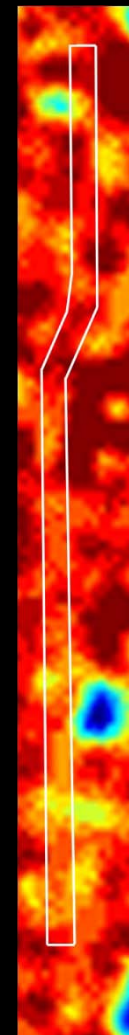




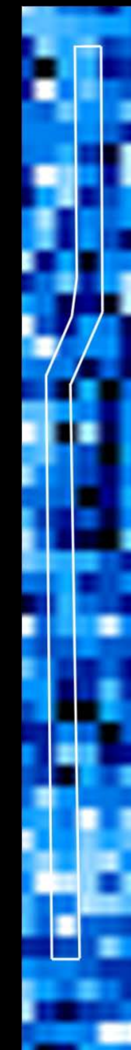
NDVI Change
June: 0 px
July: 0 px



Albedo Change
June: +0.068
July: +0.064



Temp. Change
June: +1.86 ^{o}C*
July: -0.34 ^{o}C*



Present Emissivity
Emissivity: 0.956
Error from Mean: +0.18 ^{o}C

* The large temperature difference probably has to do with the fact that the road was still under construction in 2007, which ended in October 2007. Thus, there had been no cars driving on the road in the July image pair but there were cars in the June image pair, which must have heated it up.

3) Greenroofs

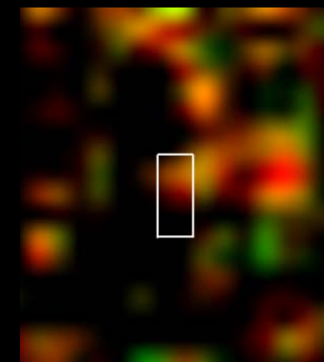
3) New City Hall Greenroof

1998

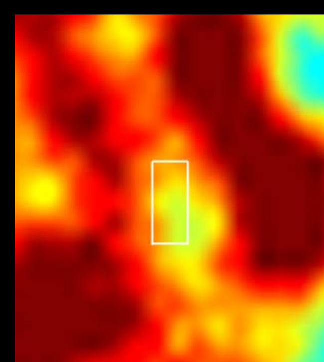
2010

NDVI Change
Undetectable

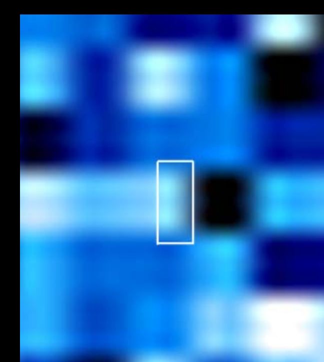
Albedo Change
Undectable



Temp. Change
Undetectable



Present-day Emissivity
Undetectable

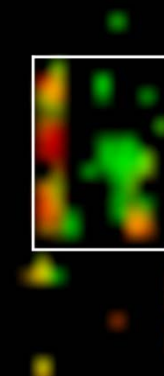


3) Millennium Park (New Greenroof?)

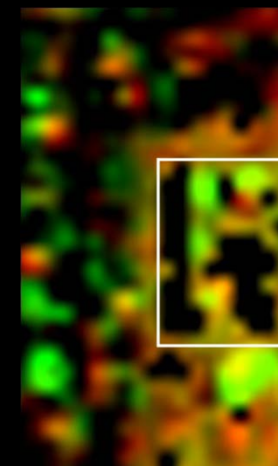
1998

2010

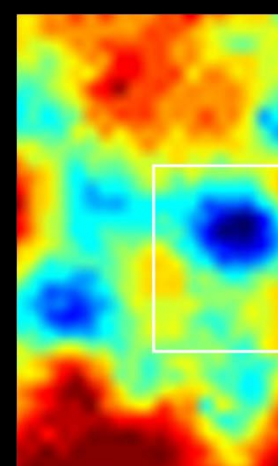
NDVI Change
June: +0.013 (39 px)
July: +0.091 (58 px)



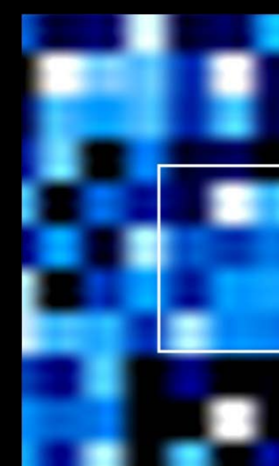
Albedo Change
June: +0.033
July: +0.010



Temp. Change
June: -0.73 ^{o}C*
July: -4.63 ^{o}C*



Present Emissivity
Emissivity: 0.954
Error from Mean: +0.02 ^{o}C



* The large temperature difference probably has to do with the fact that there was a breeze blowing off of the lake in the 2007 July image and the site is only a block away from the lake..

4) Street/Yard Trees

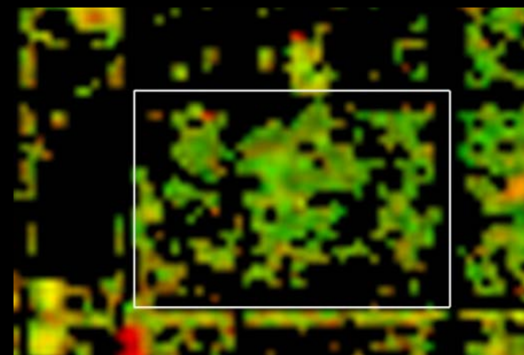
4) Street Tree Neighborhood

1998

NDVI Change

June: +0.044 (492 px)

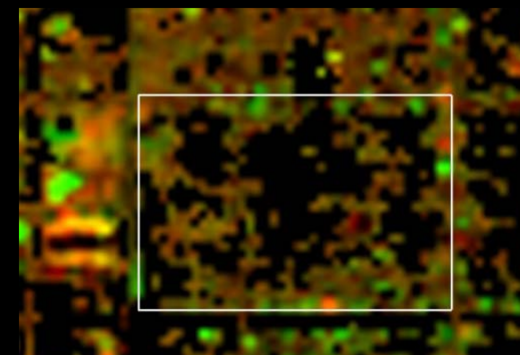
July: +0.080 (752px)



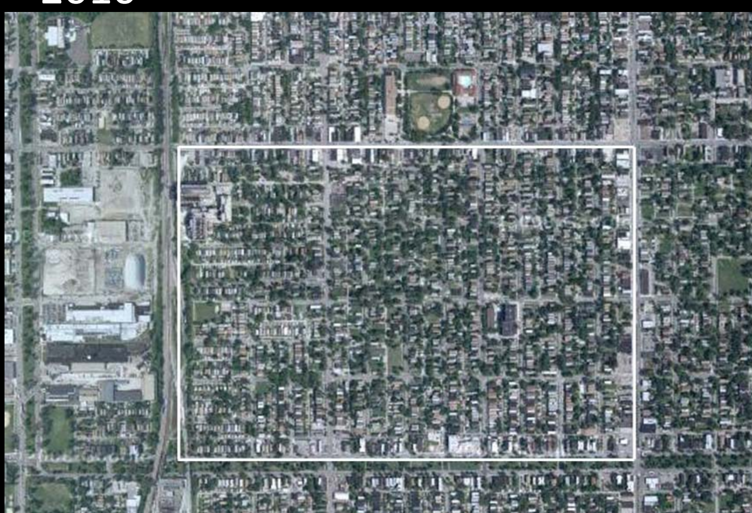
Albedo Change

June: +0.019

July: +0.004



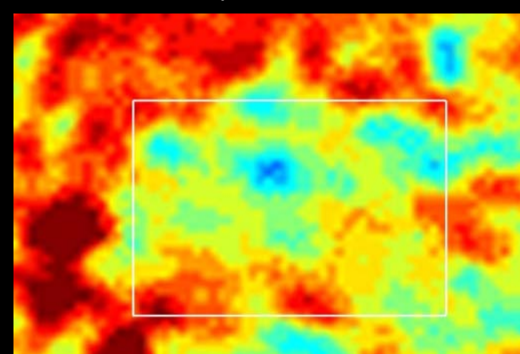
2010



Temp. Change

June: + 0.48 ^{o}C

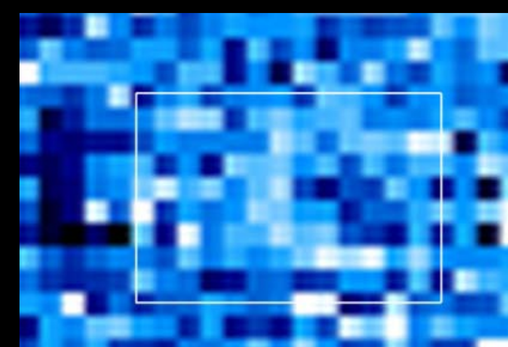
July: +0.30 ^{o}C



Present Emissivity

Emissivity: 0.958

Error from Mean: -0.34 ^{o}C



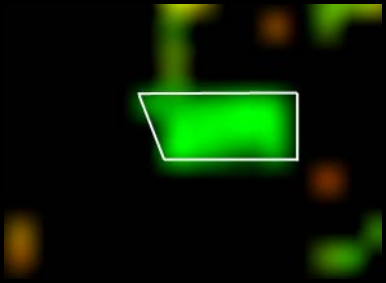
5) Greenspace ((Parks/Reserves/Schoolyards)

5) Grass Replacing Asphalt Schoolyard

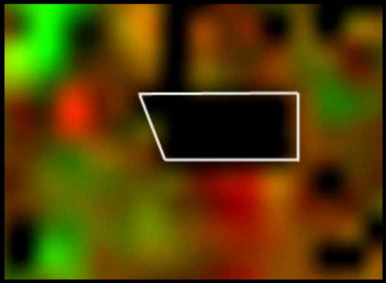
1998

2010

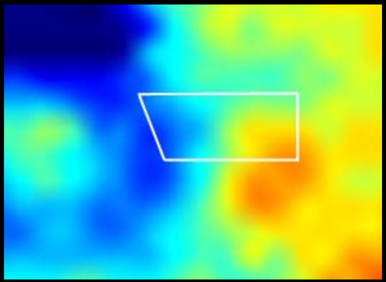
NDVI Change
June: +0.193
July: +0.120



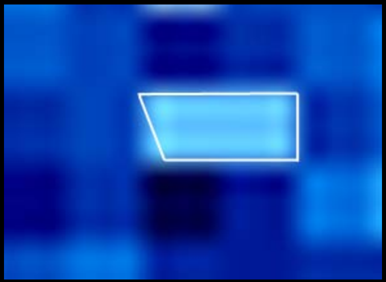
Albedo Change
June: +0.008
July: -0.017



Temp. Change
June: -0.37 ^{o}C
July: -0.47 ^{o}C



Present Emissivity
Emissivity: .963
Error from Mean: -0.67 ^{o}C

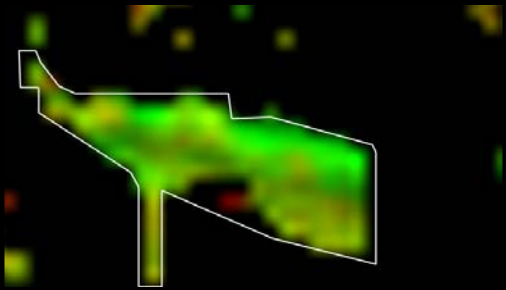


5) New Park From Old Rail Yard

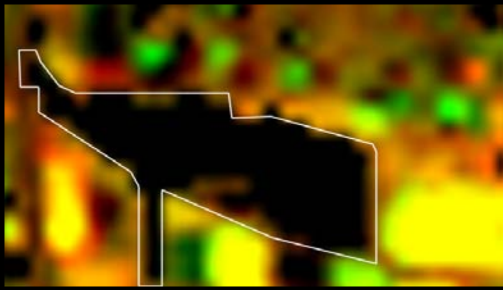
1998

2010

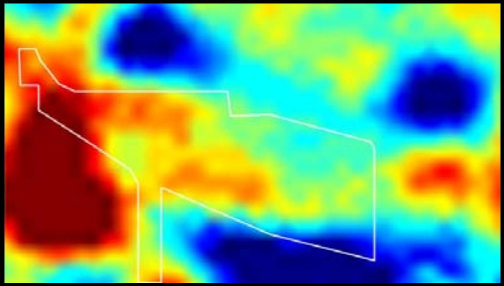
NDVI Change
June: +0.117 (125 px)
July: +0.106 (126px)



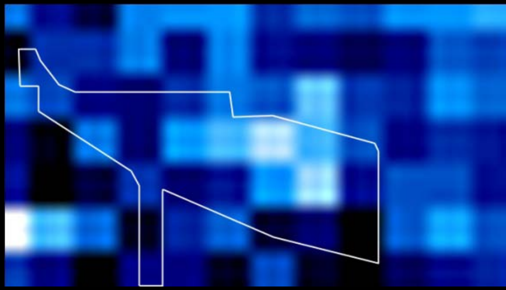
Albedo Change
June: +0.013
July: : -0.006



Temp. Change
June: +0.46 ^{o}C
July: -0.83 ^{o}C



Present Emissivity
Emissivity: 0.951
Error from Mean: +0.23 ^{o}C



5) Park from Demolished Apartments

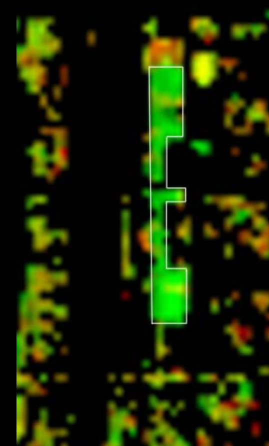
1998

2010

NDVI Change

June: + 0.178

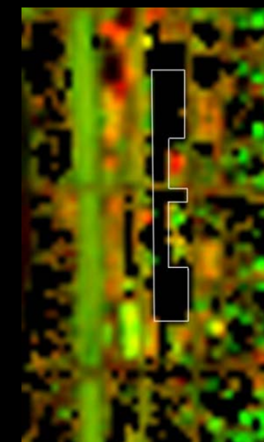
July: still apartments



Albedo Change

June: +0.039

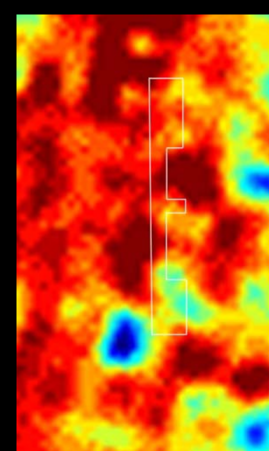
July: still apartments



Temp. Change

June: +1.48 ^{o}C*

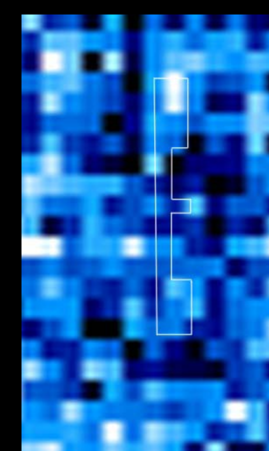
July: still apartments



Present Emissivity

Emissivity: 0.956

Error from Mean: +0.18 ^{o}C



* Likely the result of better air coupling of buildings

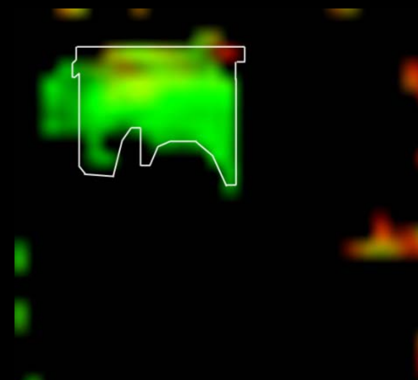
5) Greening a Part of a Power Plant

(Possibly an Effort of the City's to Clean-Up Brownfield Sites)

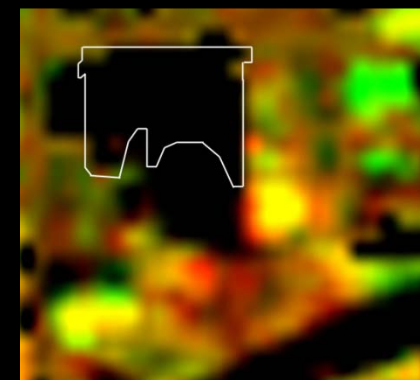
1998

July 2010

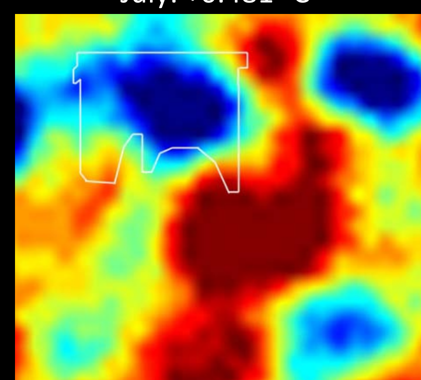
NDVI Change
June: +0.213 (68 px)
July: +0.091 (59 px)*



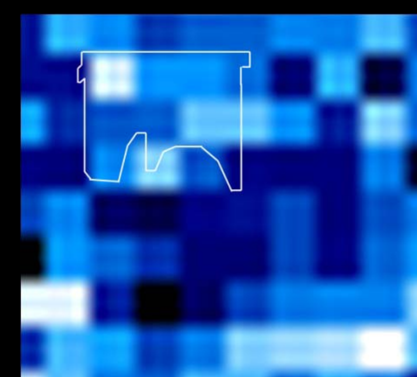
Albedo Change
June: +0.058
July: +0.016*



Temp. Change
June: -2.05 ^{o}C
July: +0.481 ^{o}C*



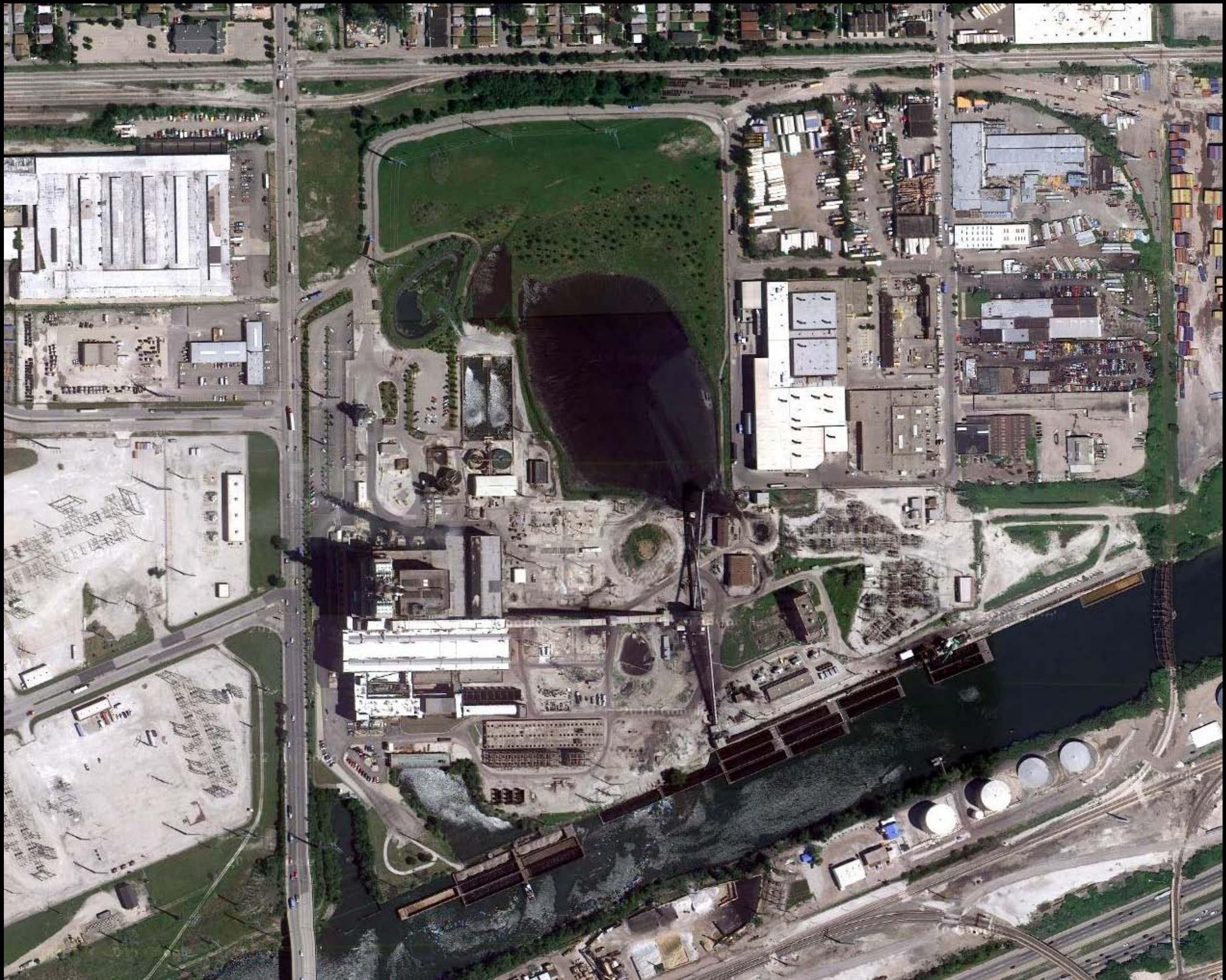
Present Emissivity
Emissivity: 0.958
Error from Mean: -0.27 ^{o}C



* Clearly, massive improvements must have been made between 2007 and 2009

5) Greening a Part of a Power Plant

(Early September Image Showing Improvement)

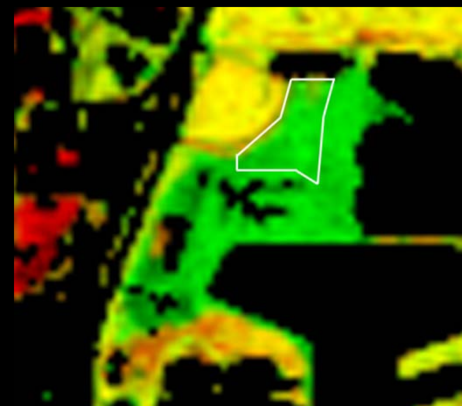


5) Creation of the Calumet Open Space Reserve

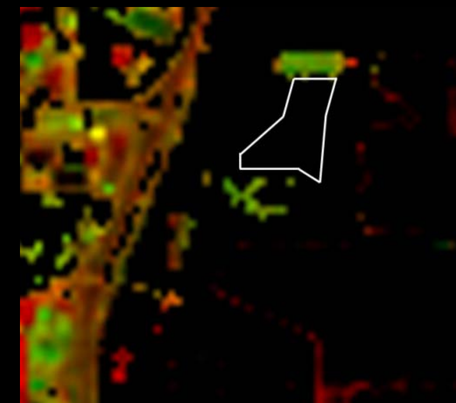
(Lake Calumet Unit, Owned by Illinois International Port District)

1998

NDVI Change
June: +0.248
July: cloud-covered

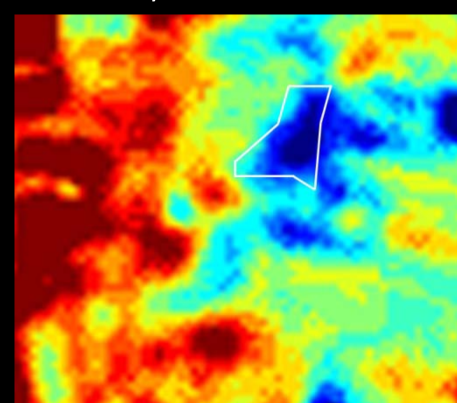


Albedo Change
June: +0.022
July: cloud-covered

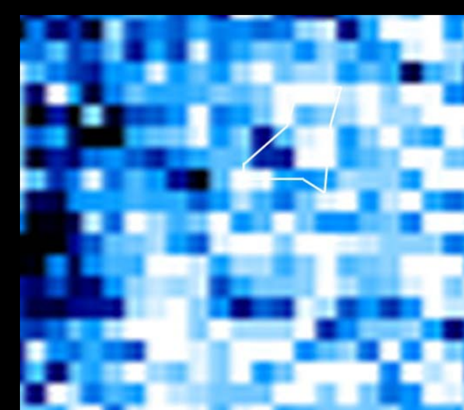


2010

Temp. Change
June: -2.28 ^{o}C
July: cloud-covered



Present Emissivity
Emissivity: 0.966
Error from Mean: -0.91 ^{o}C



Part IV Conclusions

-Most of the reflectivity increases in Chicago that decreased temperatures seem to be the result of new reflective roofs that were likely brought about by new energy efficiency zoning codes. Over the test period, this method appears to have been the most successful.

-Greenroofs and reflective pavements seem to have been the least effective methods of cooling urban temperatures at least in the way the government implemented them.

-Street/Yard Trees present a promising approach as exhibited by certain city blocks but larger-scale efforts will be necessary to cool entire neighborhoods.

-Cooling the city with greenspace is possible but it requires more than putting in grass or a few trees. Simply adding small amounts of vegetation as per many of Chicago's efforts does not significantly cool the area and much more abundant vegetation is necessary to produce the desired effects.

Final Suggestions

-While increasing vegetation to abundance may be the ideal method of addressing the issue of urban heat island as suggested by the stronger correlation of NDVI to low temperatures in single images of the city, a reflective strategy might be much more effective at least over a short period.

-Since reflective roof codes have proven themselves an effective way to address urban heat island over the test period of this study, Chicago might consider intensifying its current policies in this area. Also, other cities combating urban heat island might consider implementing similar policies.