Impacts of the Urban Heat Island on Temperatures in Madison, Wisconsin USA: How can we best use these data?

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Water Sustainability and Climate (Category 2)

Topics to cover today

Research on Madison's urban heat island

Methodology and observations

Impacts on extreme heat and linkages to human health

Impacts on energy demands

Future directions and ideas

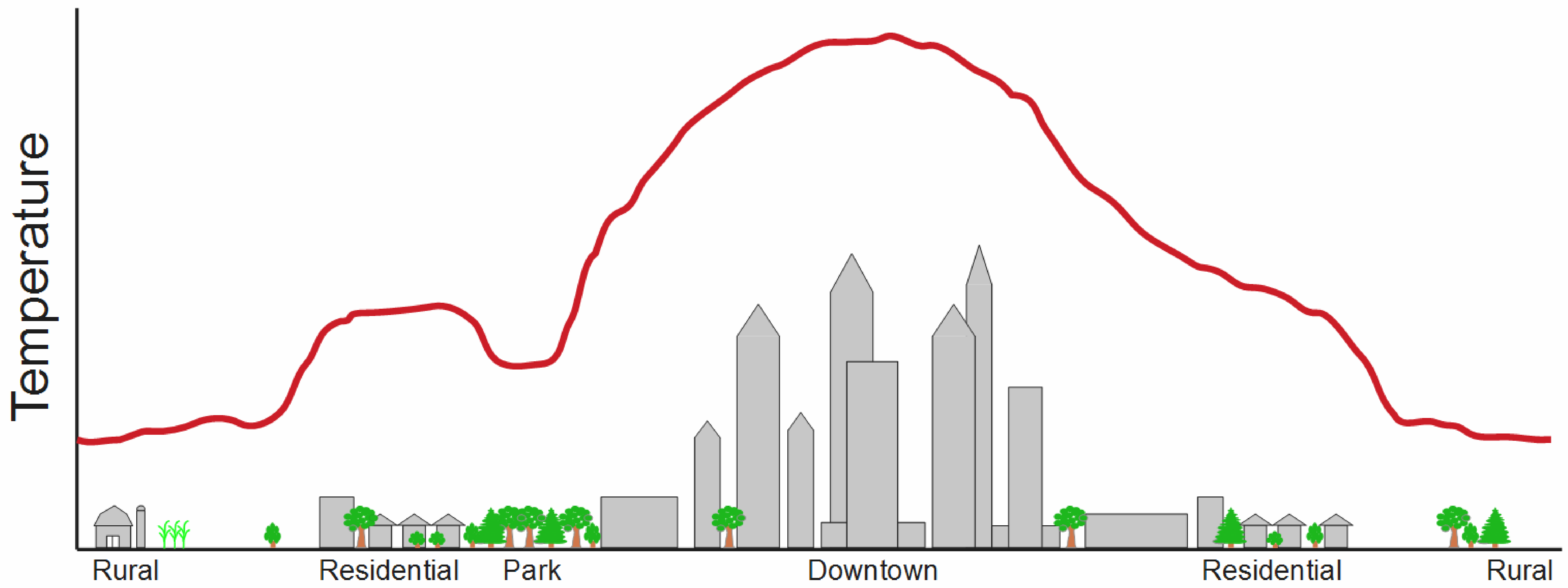
How can we use this information to improve quality of life in the Madison region?

What is an urban heat island (UHI)?

Cities retain more heat than rural landscapes

Typical effects of 2 to 10°F (up to 20°F in some conditions)

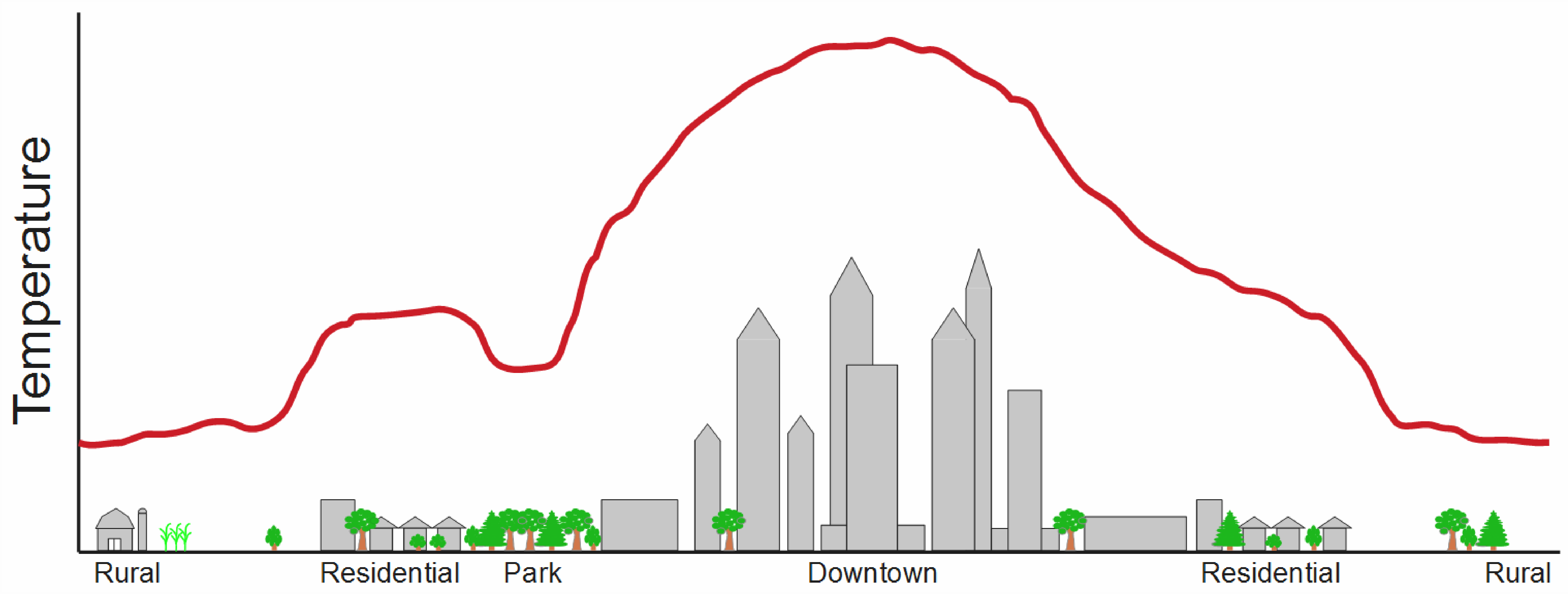
Greater effects at night than during the day



Why are UHIs important?

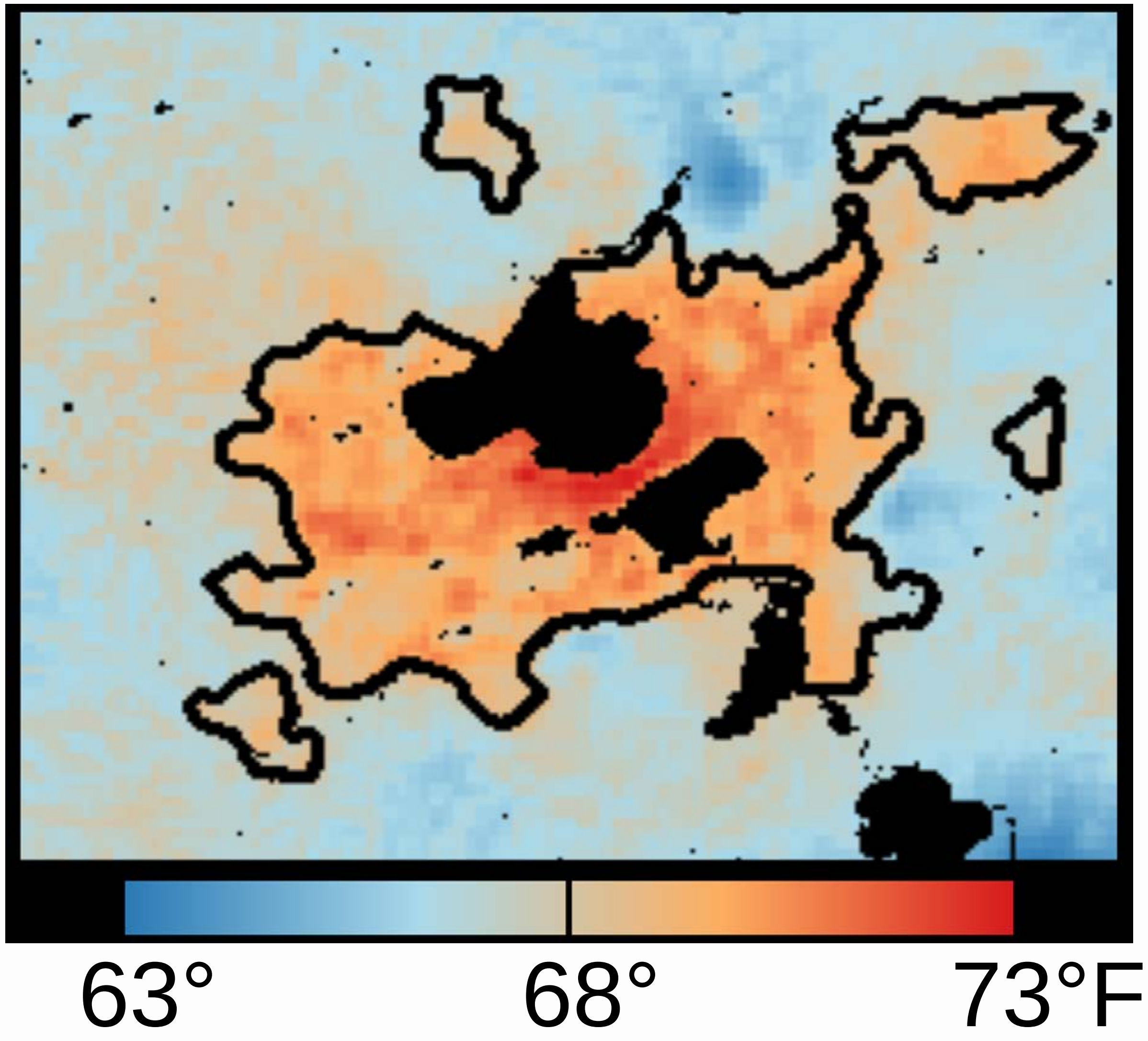
Heat stress ↑
Air conditioning costs ↑
Water consumption ↑

↓ Cold stress
↓ Heating costs



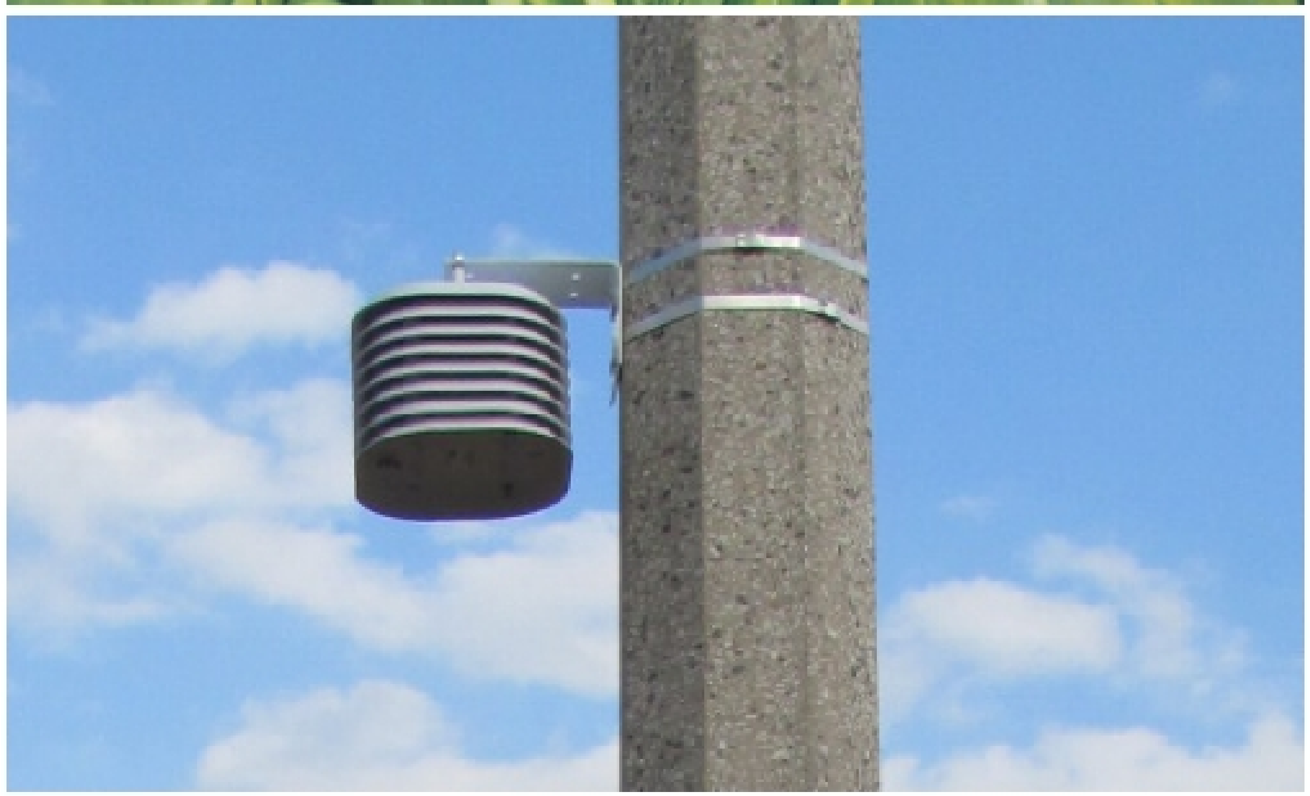
Does Madison have an UHI?

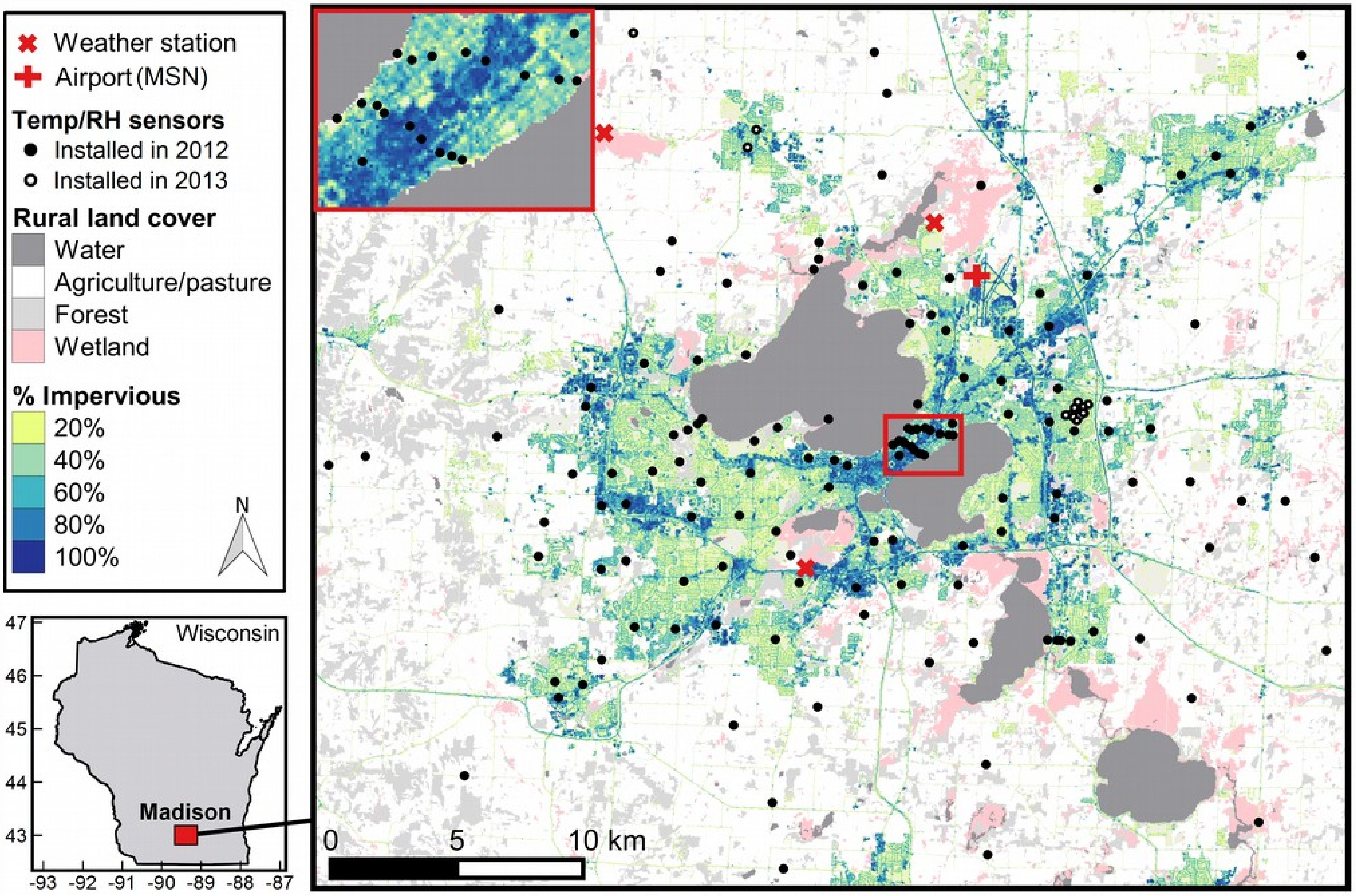
Average low temperature (July 2012)



How do we know?

Temp & humidity, every 15 min at 150 locations since March 2012



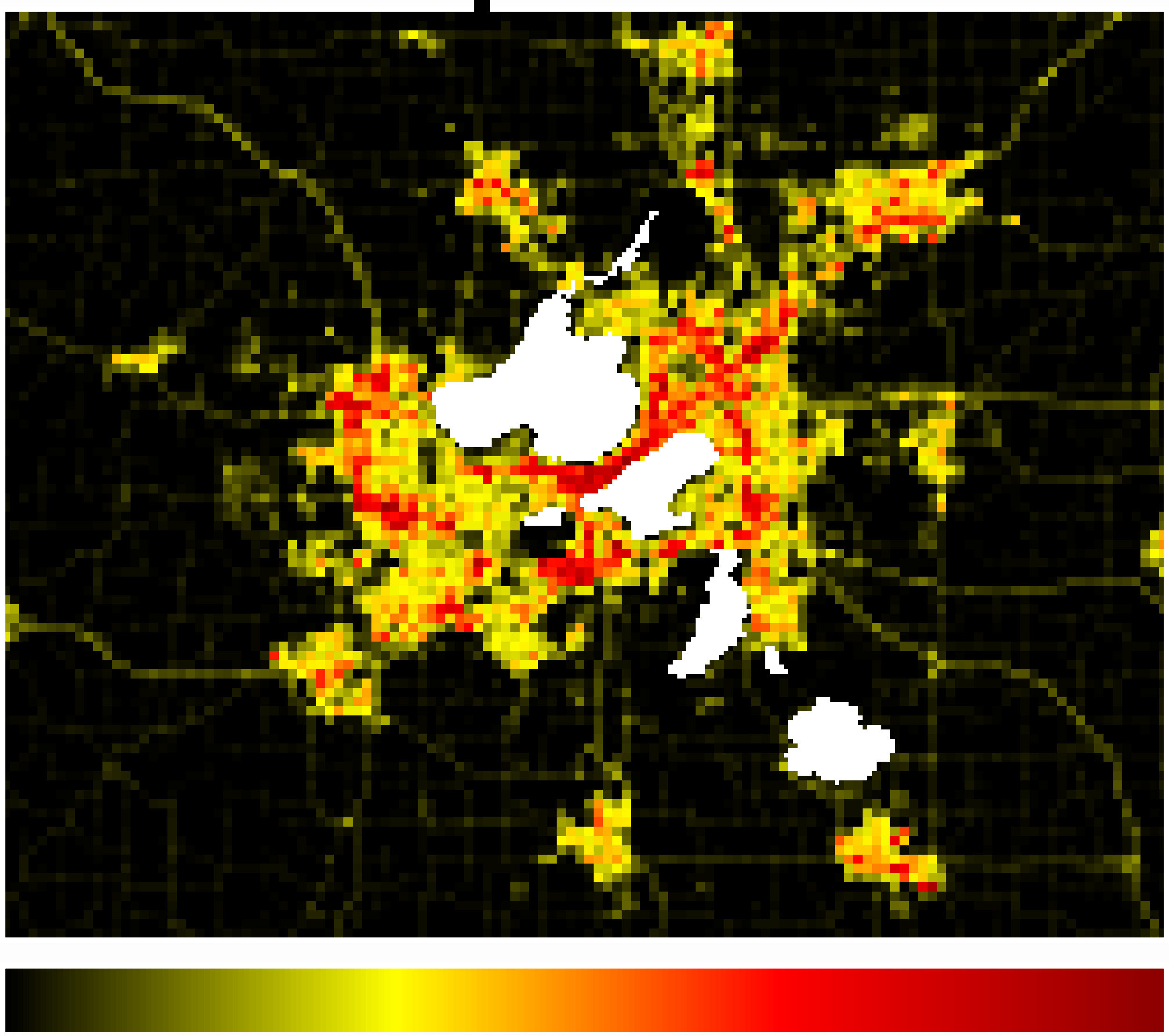


Weather station
Airport (MSN)
Temp/RH sensors
Installed in 2012
Installed in 2013
Rural land cover
Water
Agriculture/pasture
Forest
Wetland
% Impervious
20%
40%
60%
80%
100%
N
Wisconsin
Madison
47
46
45
44
43
-93
-92
-91
-90
-89
-88
-87
0
5
10 km

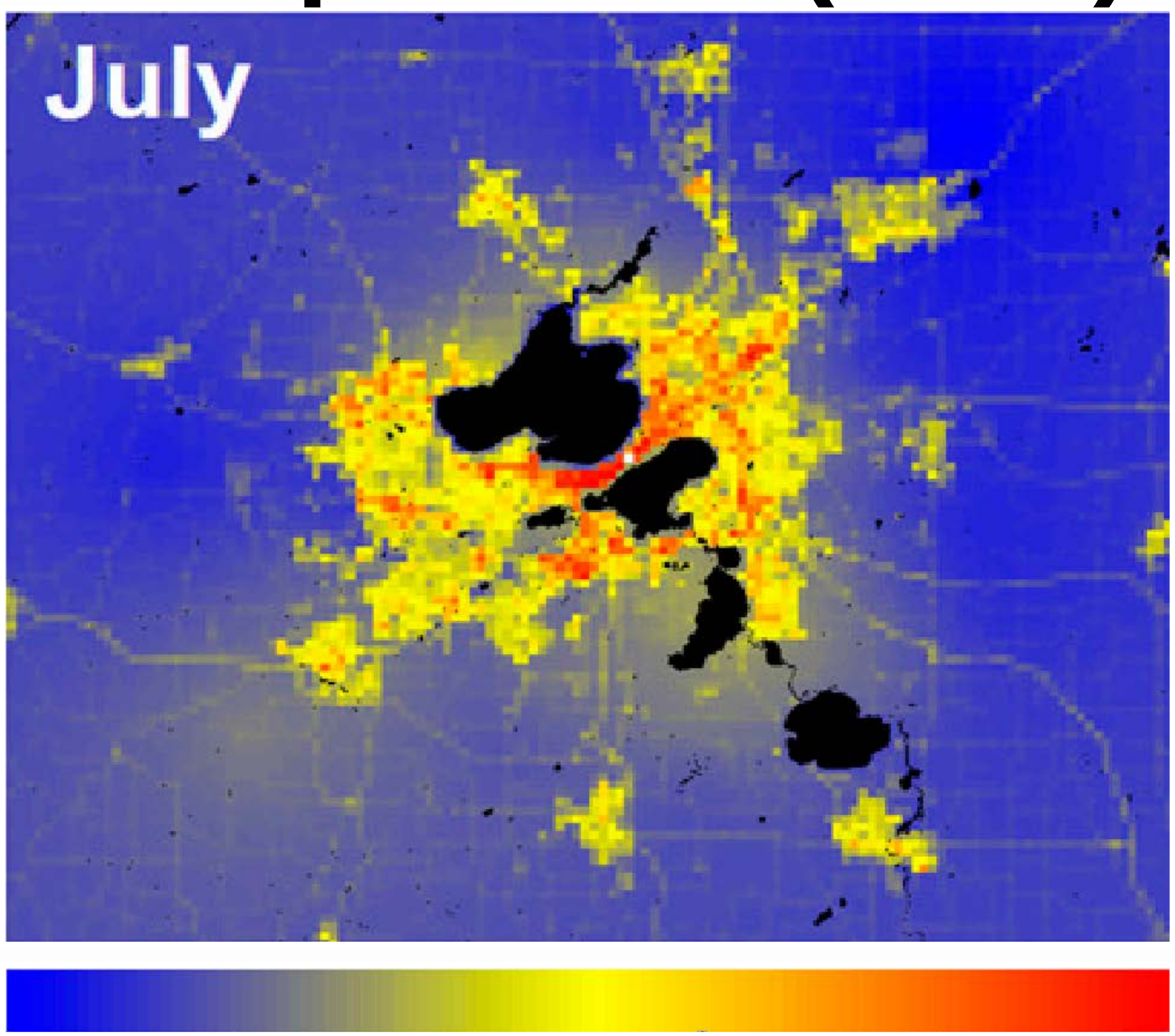
Spatial patterns

Impervious Surface is Extremely Important Driver

% Impervious



Temperature (2012)



Madison, WI
Urban Heat
Island
Nighttime Data
averaged from
April 2012-March
2013

(a)

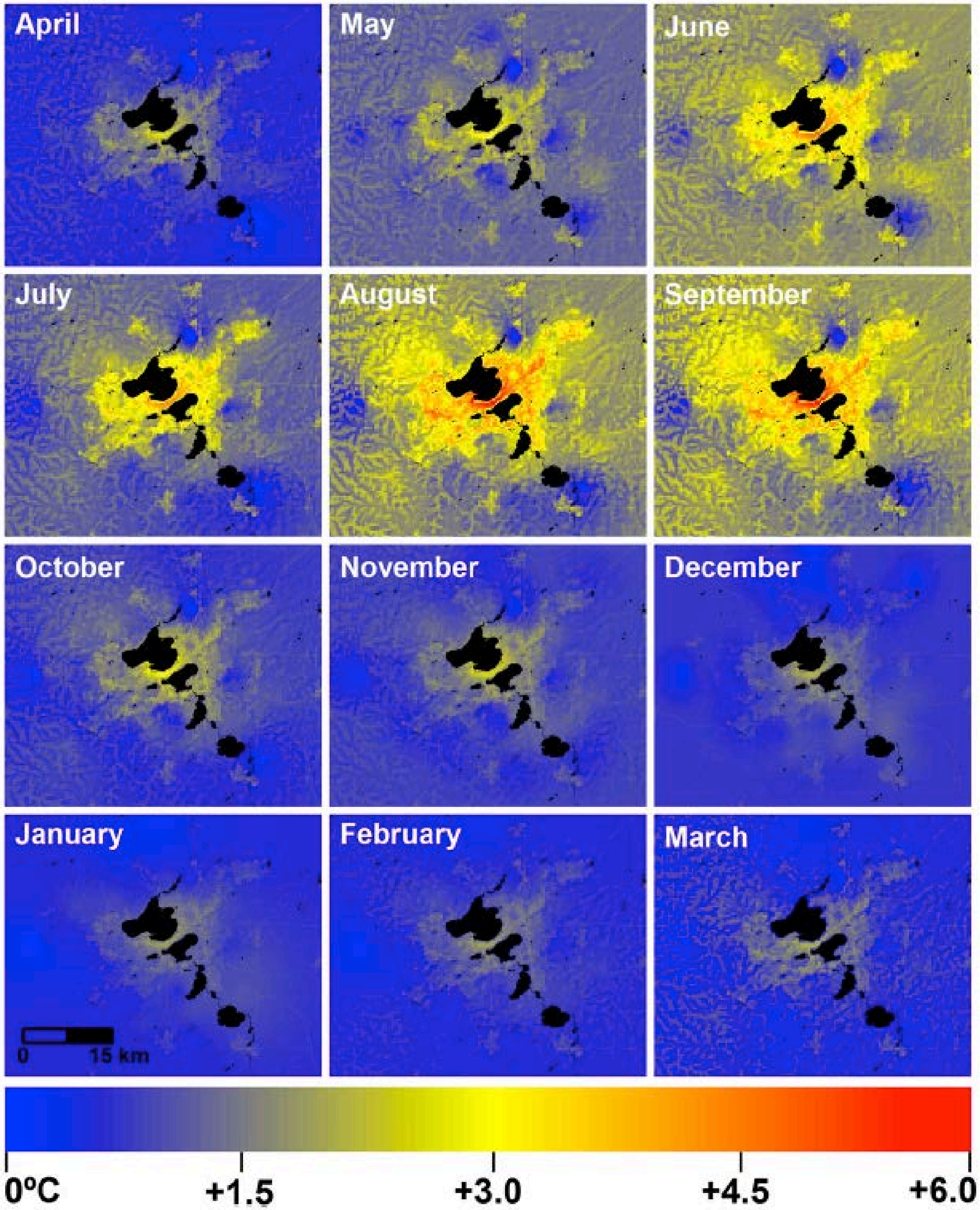
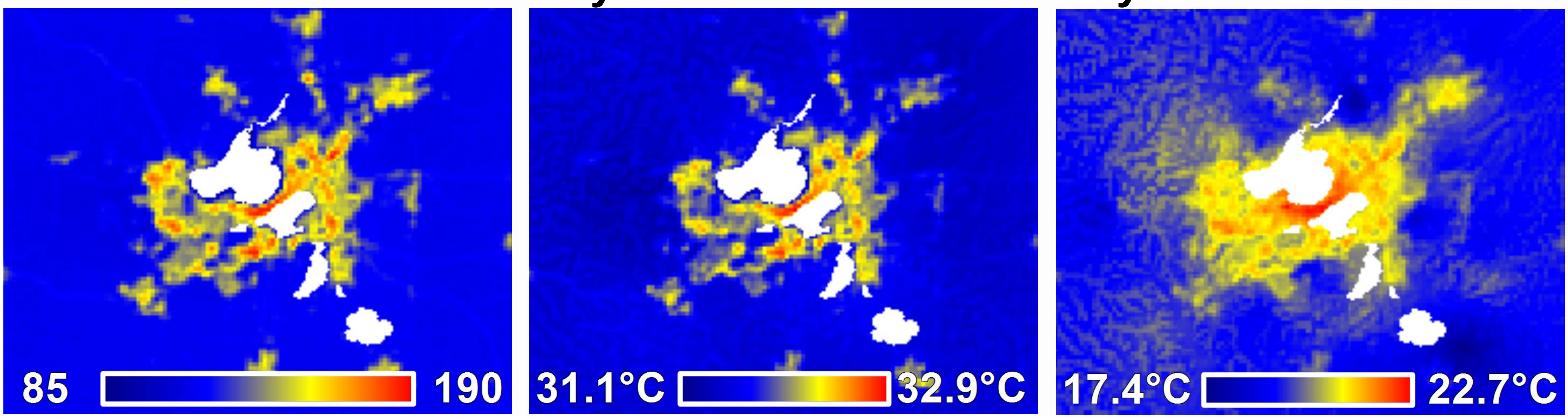


FIG. 4. The 400-m-resolution monthly average (a) nighttime and (b) daytime air temperature from April 2012 to March 2013 interpolated using regression kriging. Units are degrees Celsius difference from minimum sensor temperature. Black areas are lakes.

Schatz and Kucharik, 2014 *J. Applied Meteorology and Climatology*

Summer 2012

Hours over 90°F | **July T_{max}** | **July T_{min}**

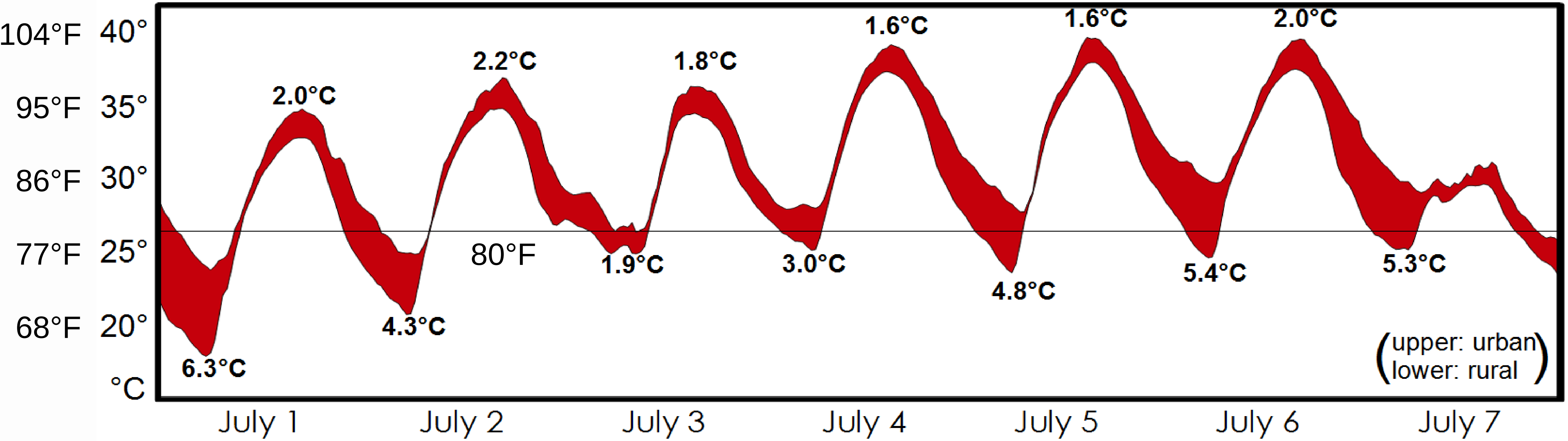


88°F 91.2°F 63.3°F 72.9°F

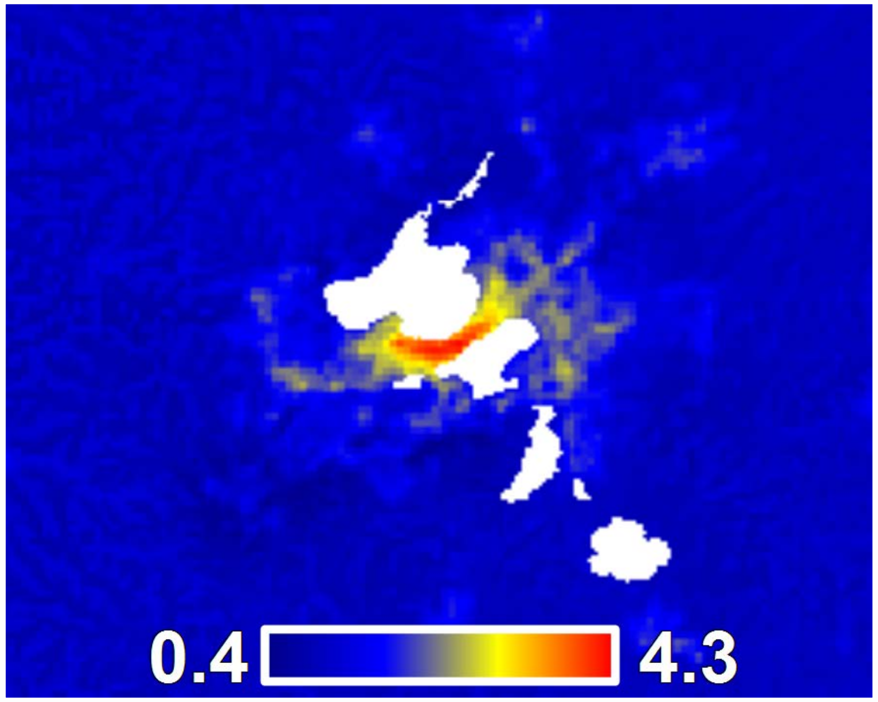
We estimated that downtown Madison had 49 days > 90ºF in 2012, which was 10 more than recorded at airport

Schatz and Kucharik, 2015 *Environmental Research Letters*

Heatwave 2012



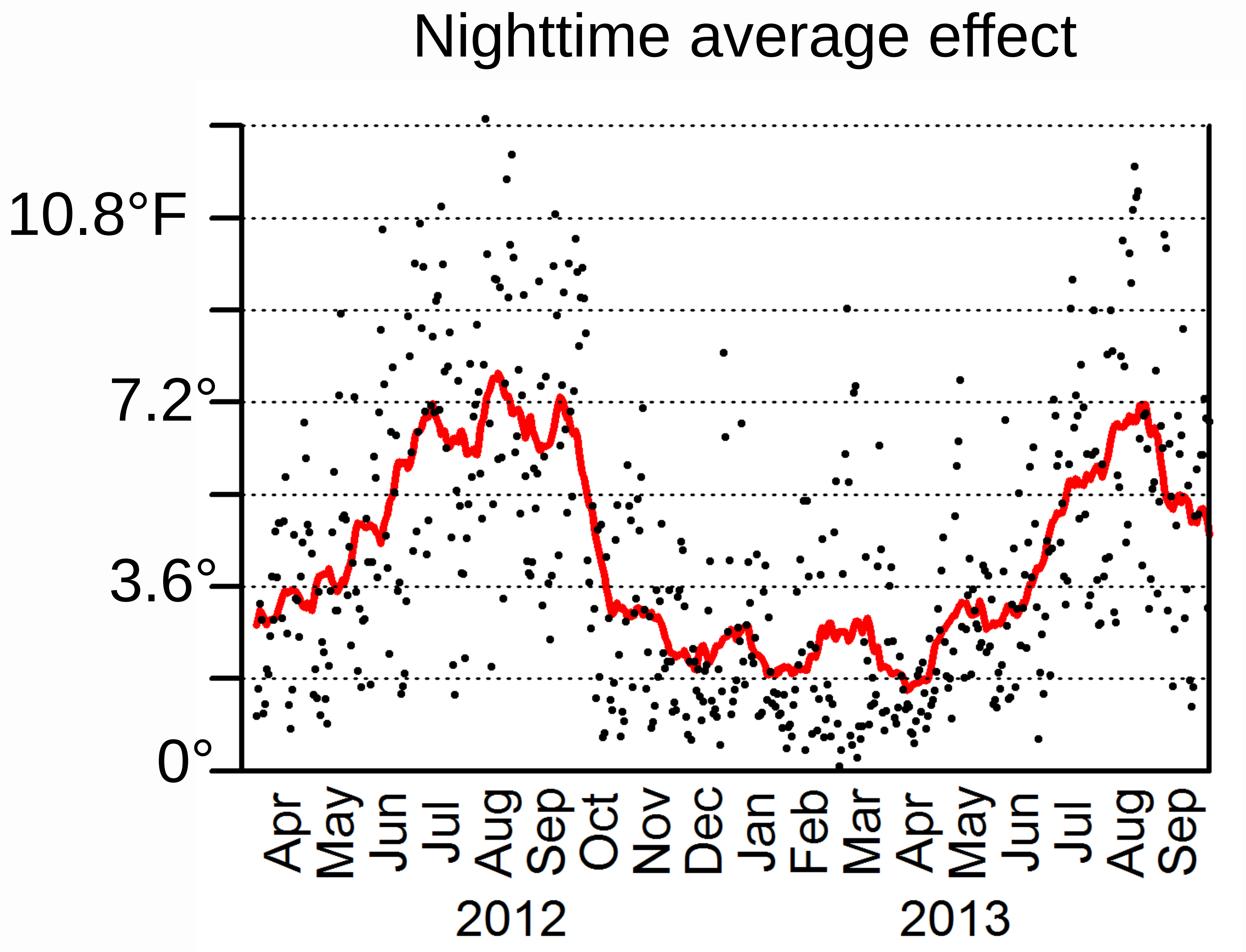
Consecutive days over 80°F



Urban warming tended to be <u>greater</u> on hot days

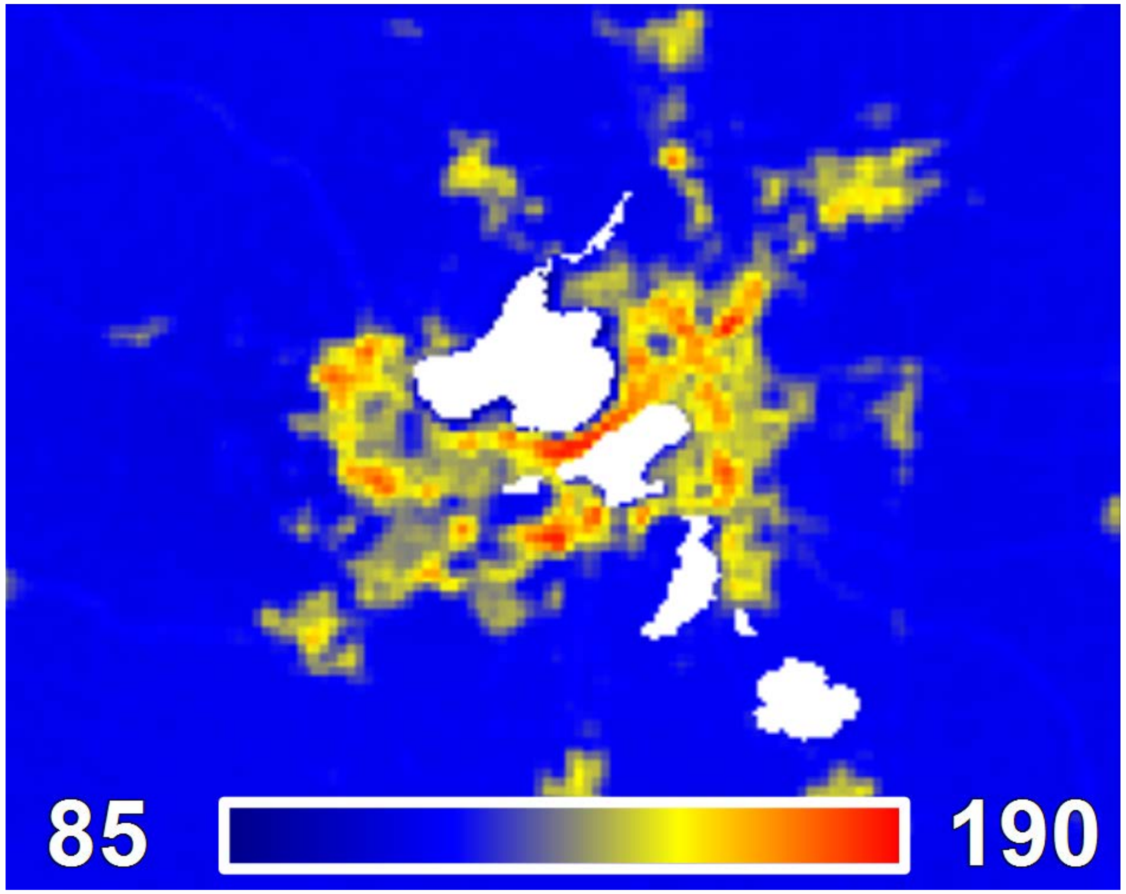
Schatz and Kucharik, 2015 *Environmental Research Letters*

Madison's UHI peaks in summer

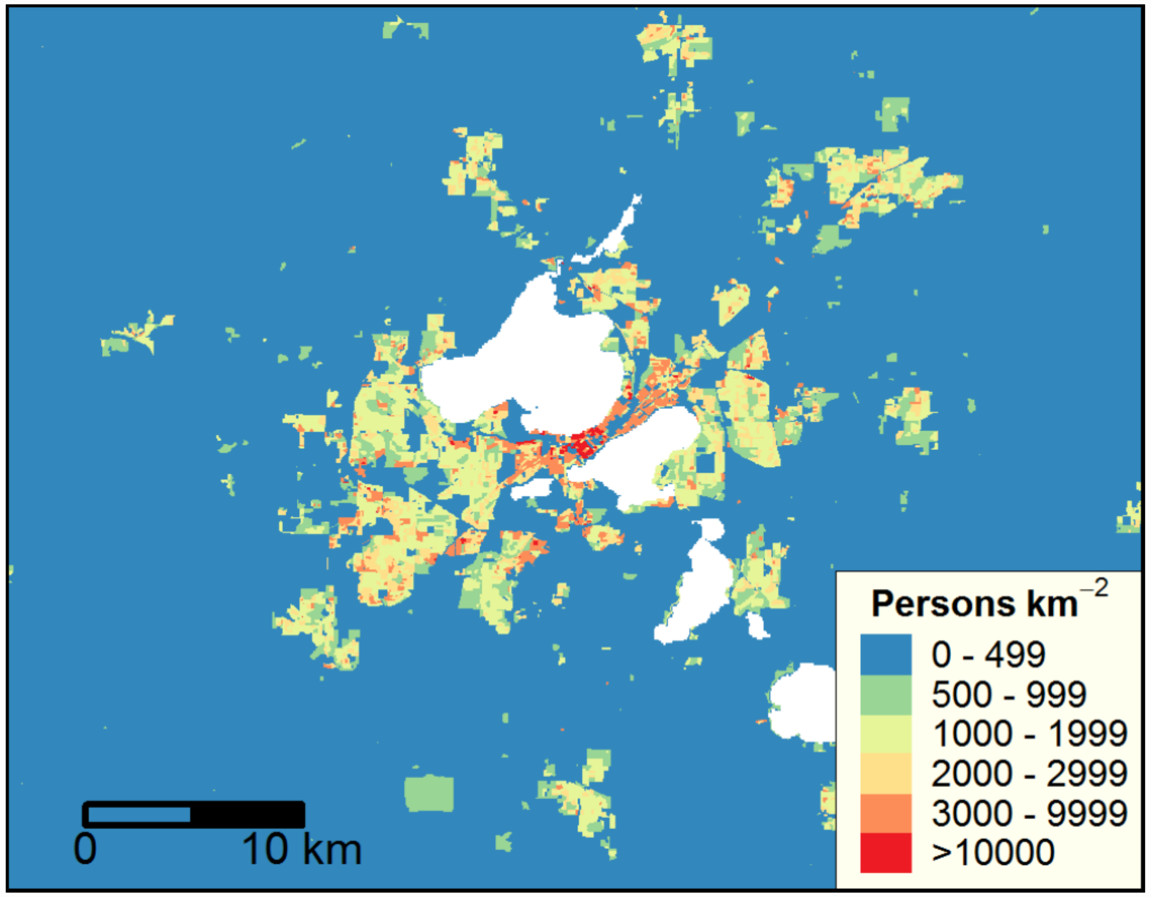


Who is affected?

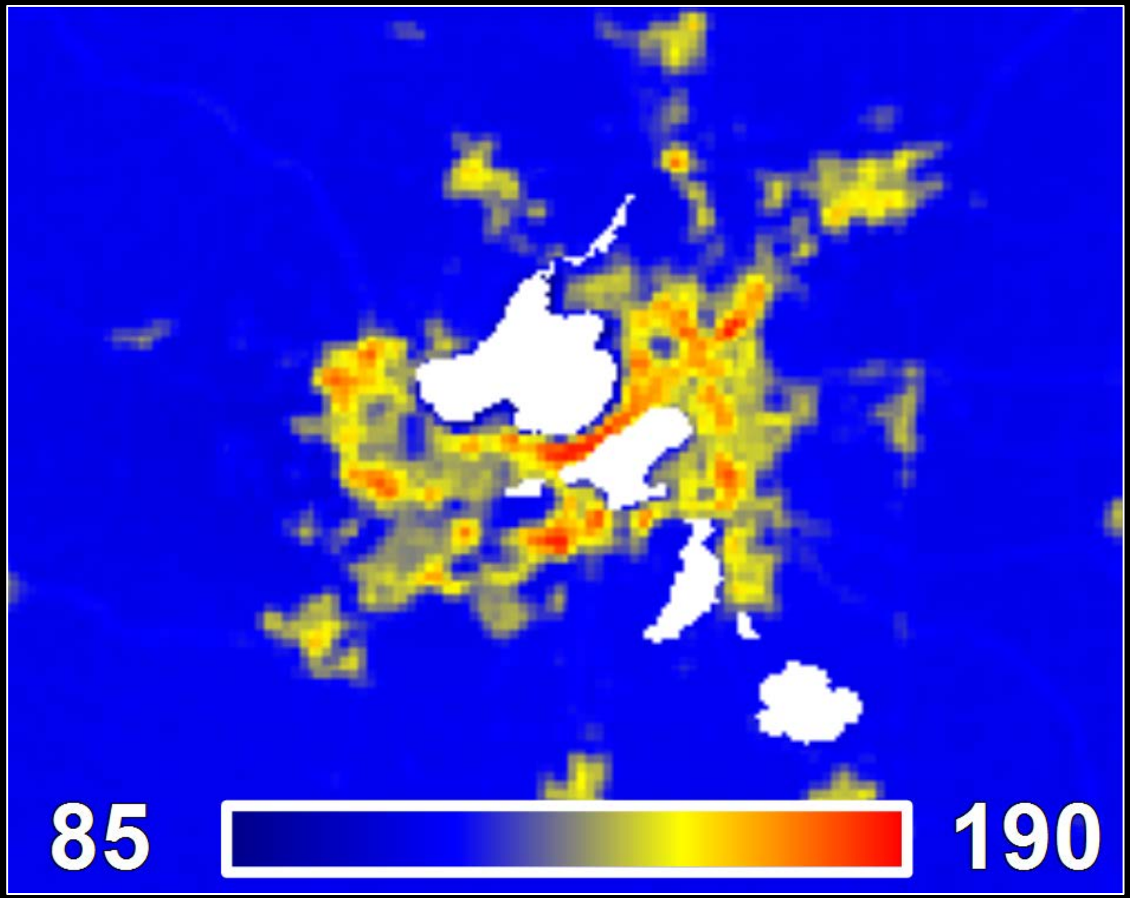
Hours over 90°F



Population density

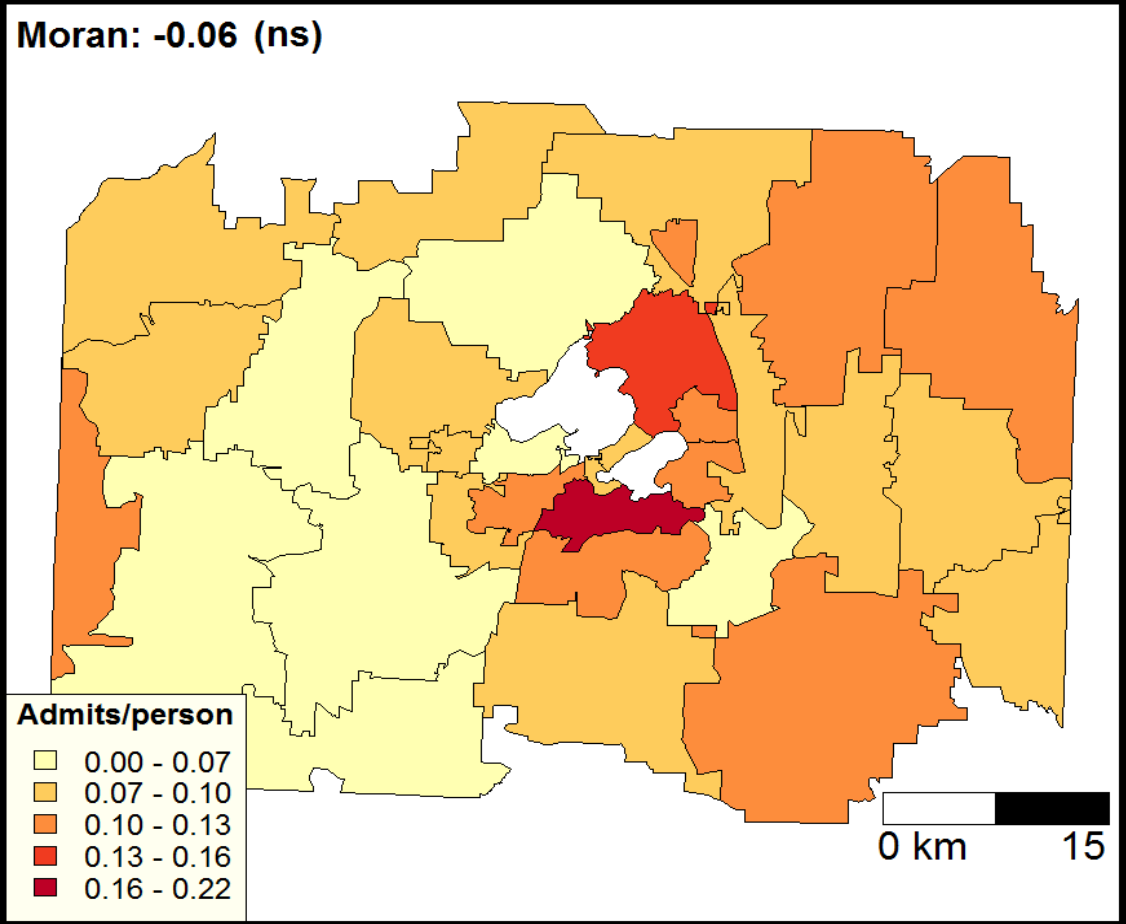


Climate data



Hours over 90°F 2012

Health data



May to Sep 2012 hospital admissions

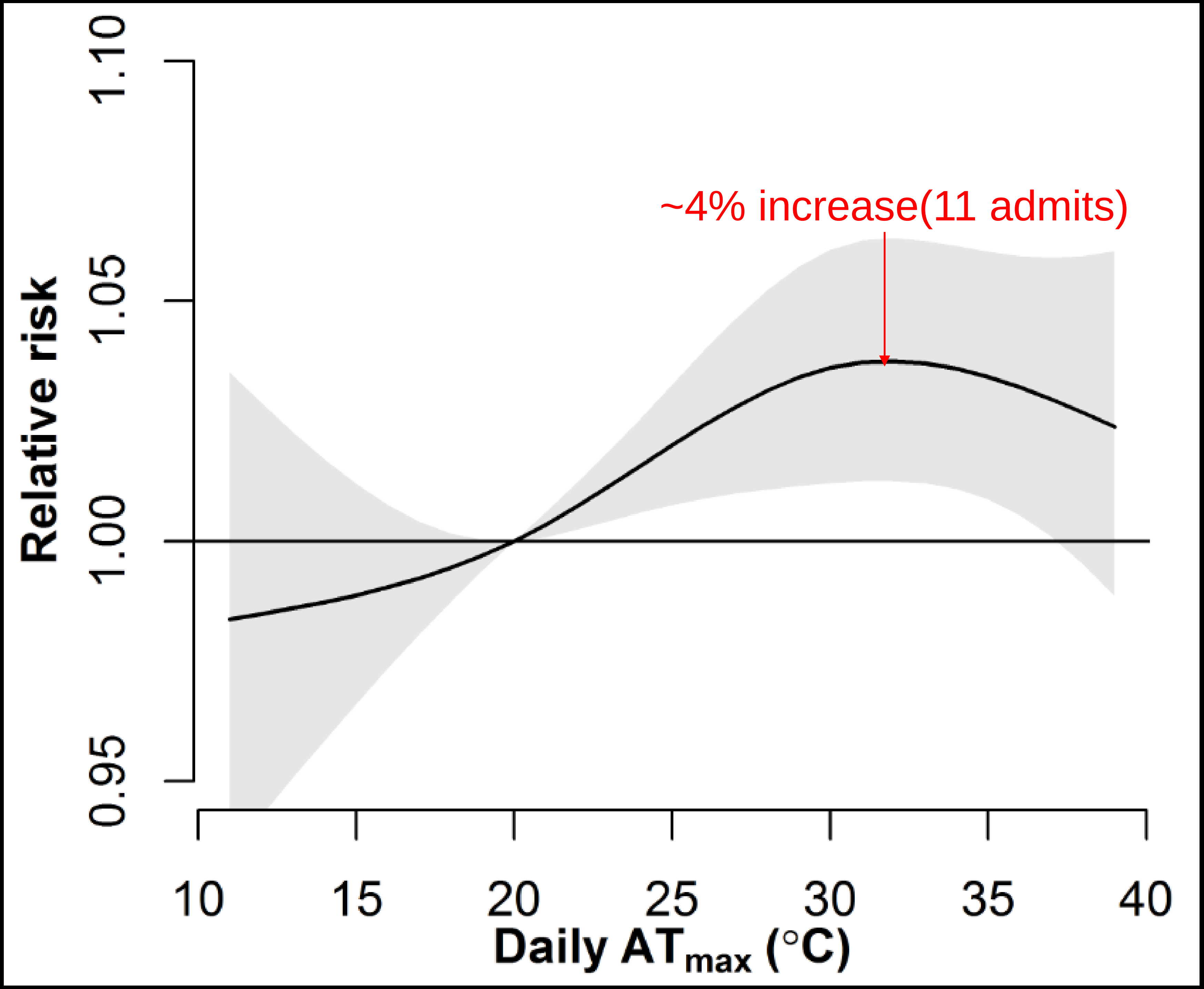
Does urban warming increase adverse health outcomes during hot conditions?

Did warmer zip codes have higher hospitalization rates during the hot summer of 2012?

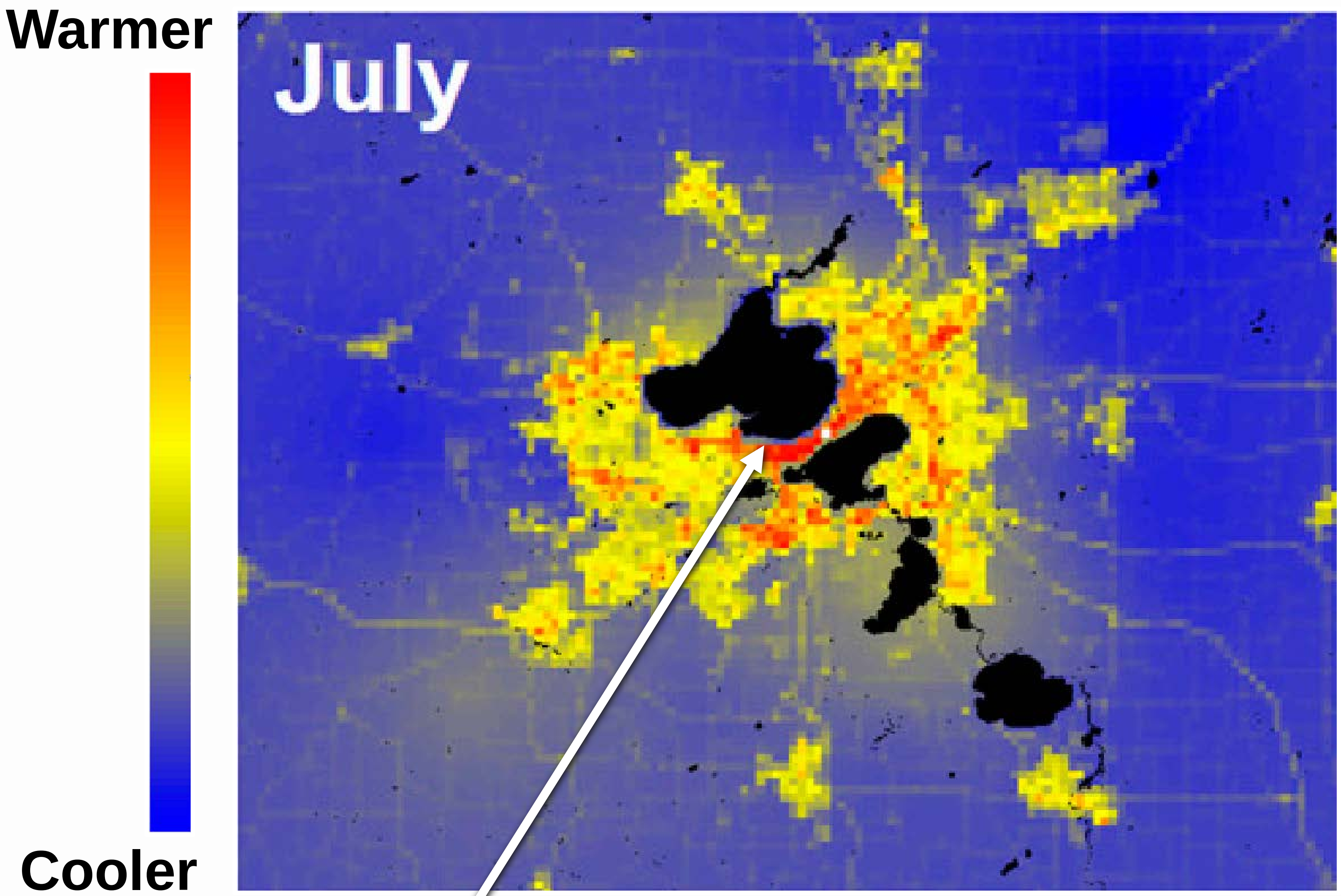
Were hospital admissions sensitive to temperature?

Yes!

Countywide hospital admissions (May to Sep 2012)



Do the lakes help during heatwaves?



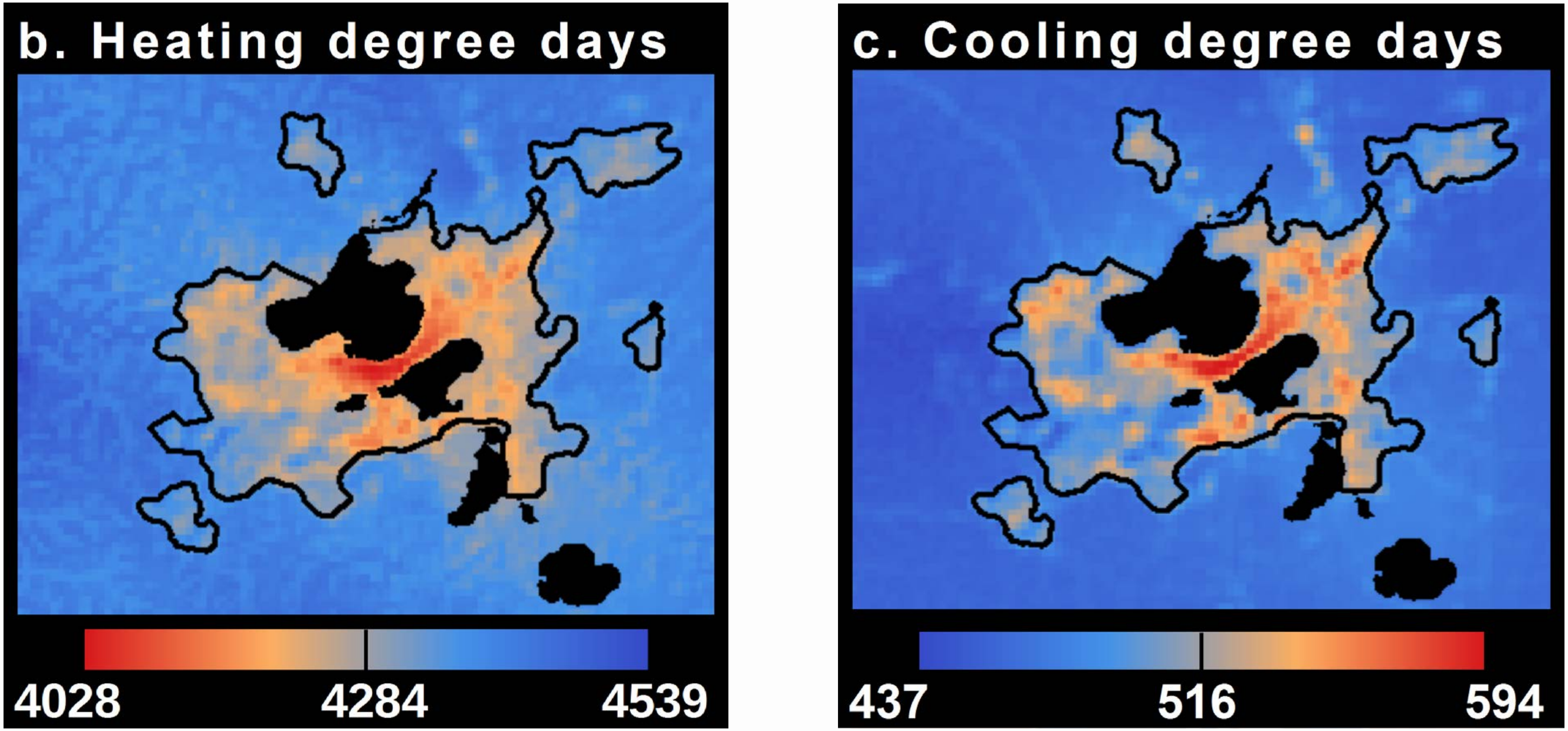
Thin blue halo around lakeshore

- Primarily a local, shoreline effect
- Diminishes very quickly inland (does not reach interior of isthmus)
- Lowers summer temperatures
- But, raises humidity

Energy effects:

-6% heating
+26% cooling

Net annual effect?
Peak demand (heat waves)



Schatz and Kucharik, 2016 *International J. of Climatology*

Takeaways

- **Heat island impacts are greatest:**
  - At night (e.g., up to ~10ºF July Tmin average in 2012)
  - During the summer
  - During extreme events (e.g., consecutive nights > 80ºF)
  - Where most people live

- **Large impacts on:**
  - Duration of extreme hot and cold temperatures
  - Urban agriculture: growing season length and accumulated growing degree days
  - Energy use/demand: accumulated CDDs, and HDDs
  - Need for heat advisories or excessive heat warnings
  - Effectiveness of frost advisories and freeze warnings

Tree Canopy Cover and Urban Heat

- Looked at small-scale variations in air temperature with canopy cover
- Used bike-mounted sensor
- Results suggested that maximum cooling occurs when tree cover is maximized at a spatial scale of a 90m radius
- Suggests that to achieve maximum cooling in Madison, tree planting coordination among neighbors is necessary!

Ziter et al. (2019) Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime heat in cities during summer, *Proceedings of National Academy of Sciences*.

Future work and other ideas

- Quantify impacts of urban expansion since 2012 on UHI strength and extent
- Detect impacts of emerald ash borer and loss of mature, urban trees on UHI
- Use data as part of new approach/algorithm to help determine improved road salt use?

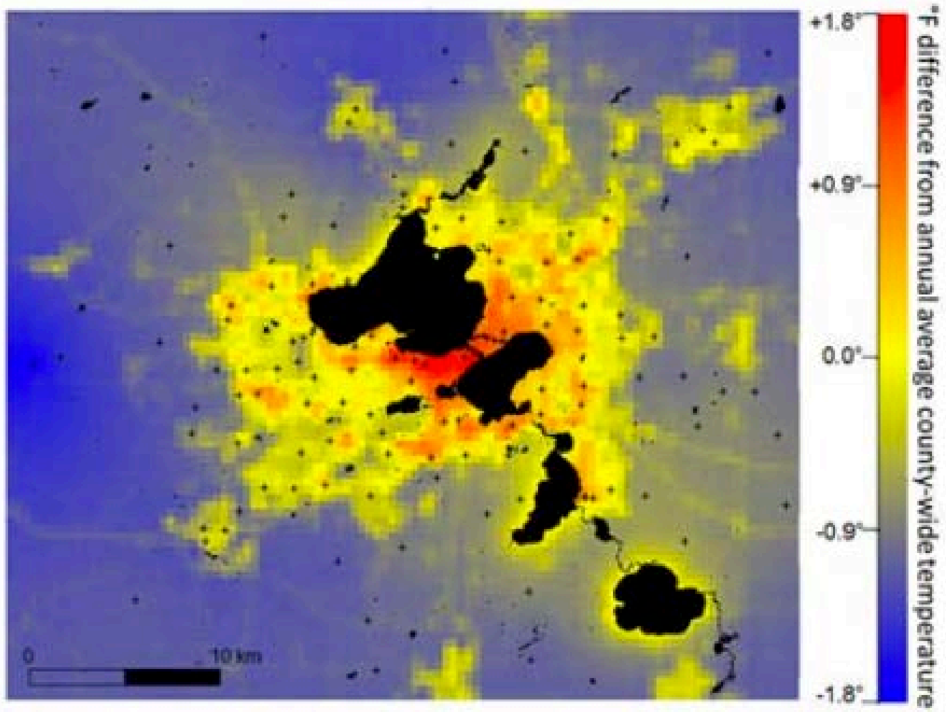
My long term wishes and goals

- Sensor network continues to collect data indefinitely, but…
  - Upgrade to wireless capabilities in future (real time info)
  - Add other sensors related to air quality, traffic, human health, etc.
  - ”Array of Things” in Chicago is a good example of the future!

- Information & data become integrated into weather forecasting and issuance of heat warnings
  - Given weather forecasts for region, we can combine with satellite and snow cover information to effectively model temperature patterns

- Public becomes more educated and aware of the influences of UHIs on their daily lives
  - Development of apps
  - Provide open access to all data collected in real time
  - Assist in better planning for city; lead to better quality of life

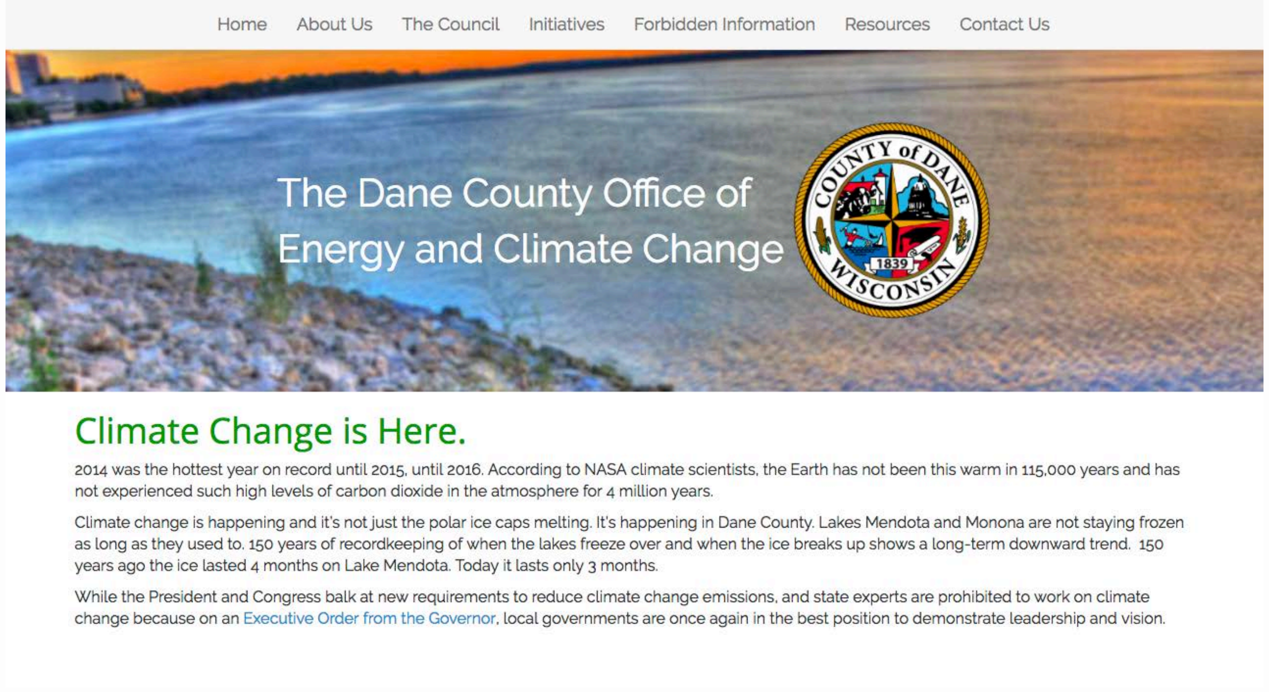
Dane County
Climate Change and Emergency Preparedness



A Report

by the
Dane County Climate Change Action Council

Coordinate with new Dane County office of Energy and Climate Change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The Dane County Office of Energy and Climate Change

COUNTY of DANE 1839 WISCONSIN

Climate Change is Here.

2014 was the hottest year on record until 2015, until 2016. According to NASA climate scientists, the Earth has not been this warm in 115,000 years and has not experienced such high levels of carbon dioxide in the atmosphere for 4 million years.

Climate change is happening and it's not just the polar ice caps melting. It's happening in Dane County. Lakes Mendota and Monona are not staying frozen as long as they used to. 150 years of recordkeeping of when the lakes freeze over and when the ice breaks up shows a long-term downward trend. 150 years ago the ice lasted 4 months on Lake Mendota. Today it lasts only 3 months.

While the President and Congress balk at new requirements to reduce climate change emissions, and state experts are prohibited to work on climate change because on an Executive Order from the Governor, local governments are once again in the best position to demonstrate leadership and vision.

Thank you

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Extra Slides

- **Current published literature**
  - Schatz, J. & Kucharik, C. J. . Seasonality of the Urban Heat Island Effect in Madison, Wisconsin. *Journal of Applied Meteorology and Climatology* 53, 2371 - 2386 (2014).
  - Schatz, J. & Kucharik, C. J. . Urban heat island effects on growing seasons and heating and cooling degree days in Madison, Wisconsin USA. *International Journal of Climatology* (2016).
  - Schatz, J. & Kucharik, C. J. . Urban climate effects on extreme temperatures in Madison, Wisconsin, USA. *Environmental Research Letters* 10, 094024 (2015).
  - Zipper, S. C. et al. Urban heat island impacts on plant phenology: intra-urban variability and response to land cover. *Environmental Research Letters* 11, 054023 (2016).During the summer
  - Zipper, S. C. , Schatz, J. , Kucharik, C. J. & Loheide, S. P. . Urban heat island-induced increases in evapotranspirative demand. *Geophysical Research Letters* (2017).

- **In preparation**
  - Williamson, M. and C.J. Kucharik. Urban Heat Island Impacts on the Validity and Effectiveness of Freeze Warnings and Frost Advisories in Madison (in prep)
  - Ph.D. dissertation chapter from Carly Ziter (UW-Madison Ph.D. candidate)
  - Ph.D. dissertation chapter from Tedward Erker (UW-Madison Ph.D. candidate)

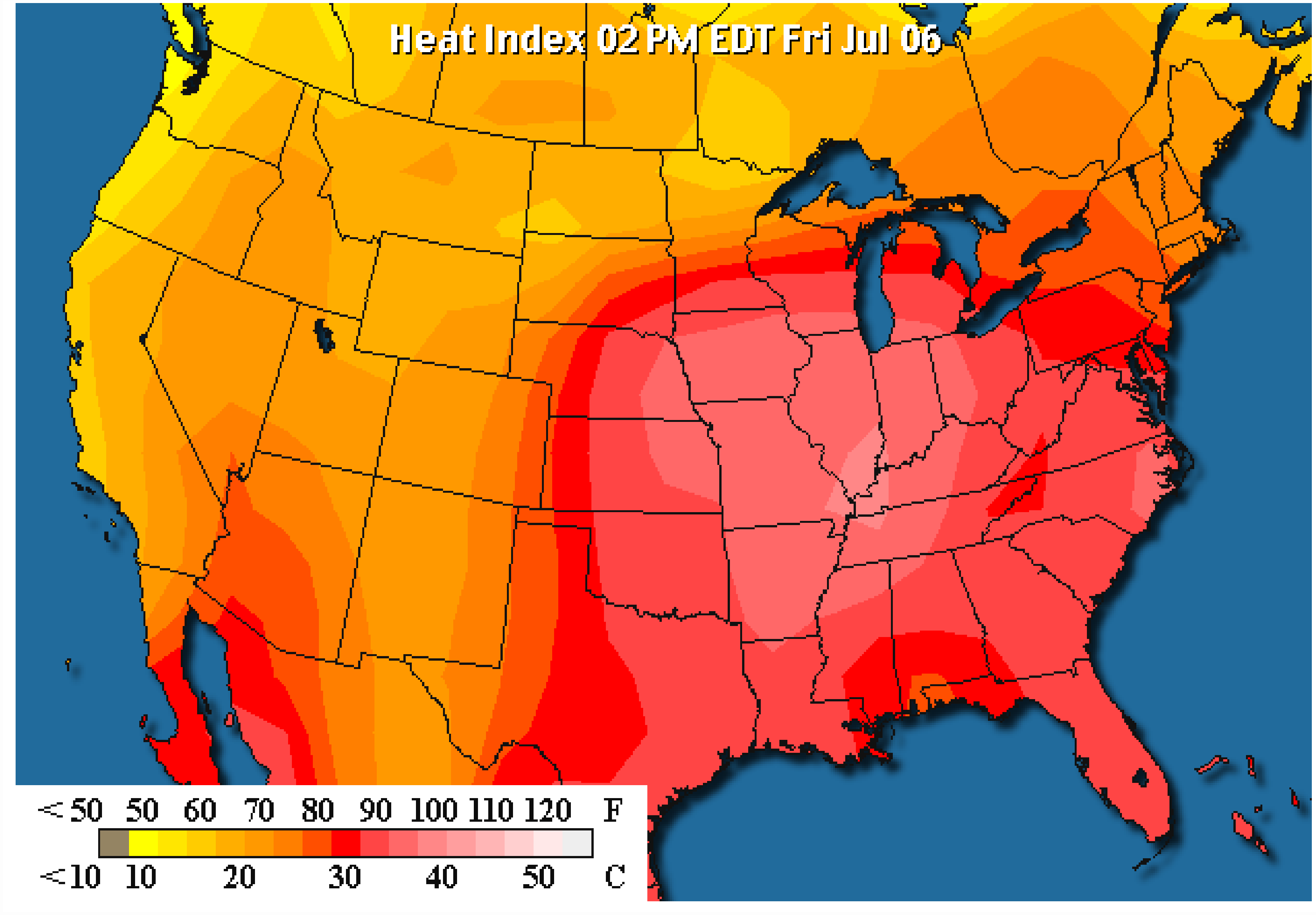
Extreme heat: 2012

Summer 2012

- 3rd hottest since 1869
- 39 days over 90° F (9 is normal)

June-July heat wave:

- 7 straight days over 95°F
- 3 straight days to 102°F (or higher)



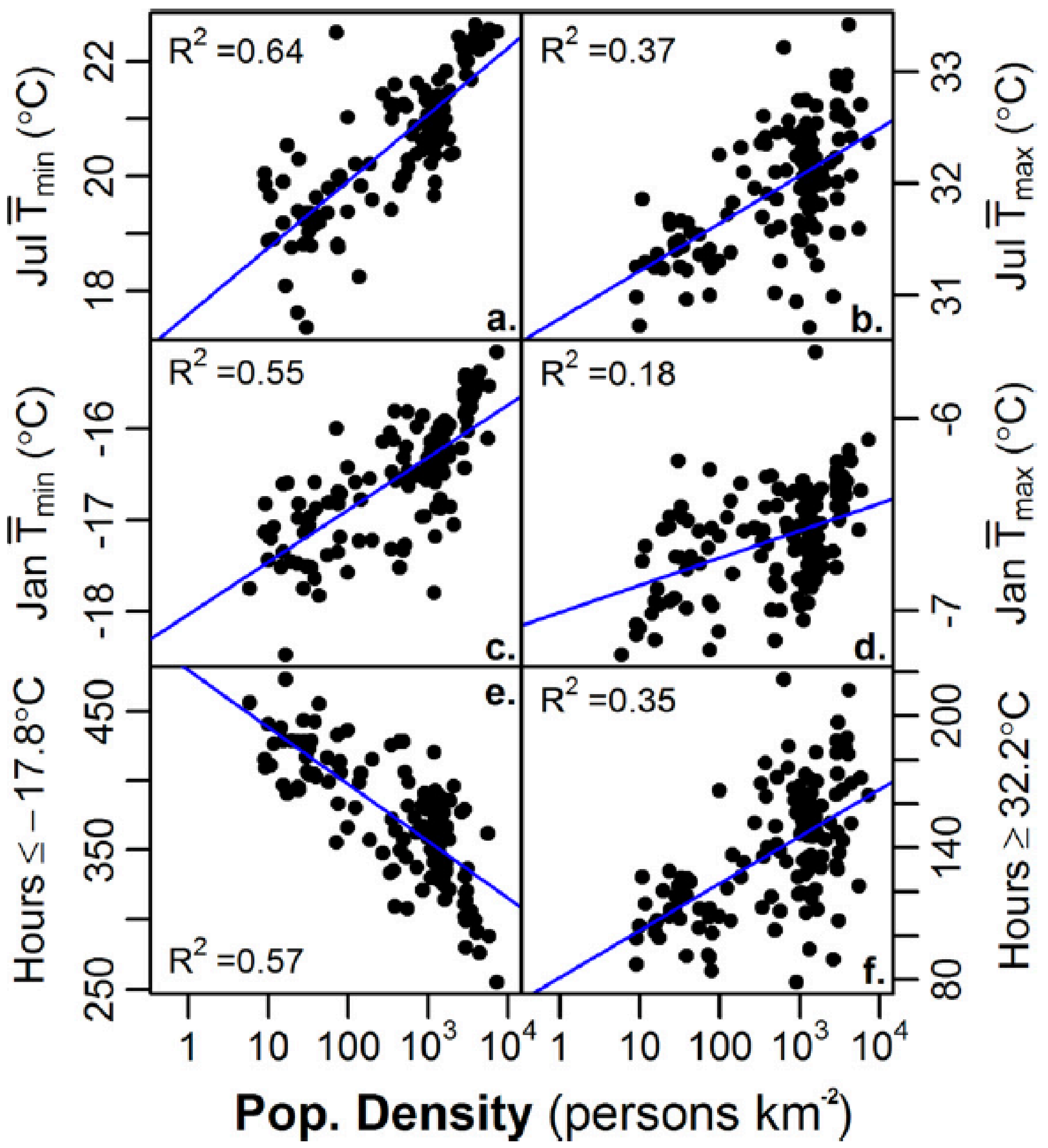


Figure 9. Population density versus (a) July 2012 mean T_{MIN}; (b) July 2012 mean T_{MAX}; (c) January 2014 mean T_{MIN}; (d) January 2014 mean T_{MAX}; (e) Hours $\leqslant -17.8$ °C in winter 2013–14; and (f) Hours $\geqslant 32.2$ °C in 2012, as recorded at our sensor locations. Population density was averaged from 2010 US Census block group data within a 1000 m radius of each sensor. All relationships were significant at $\alpha < 0.0001$.

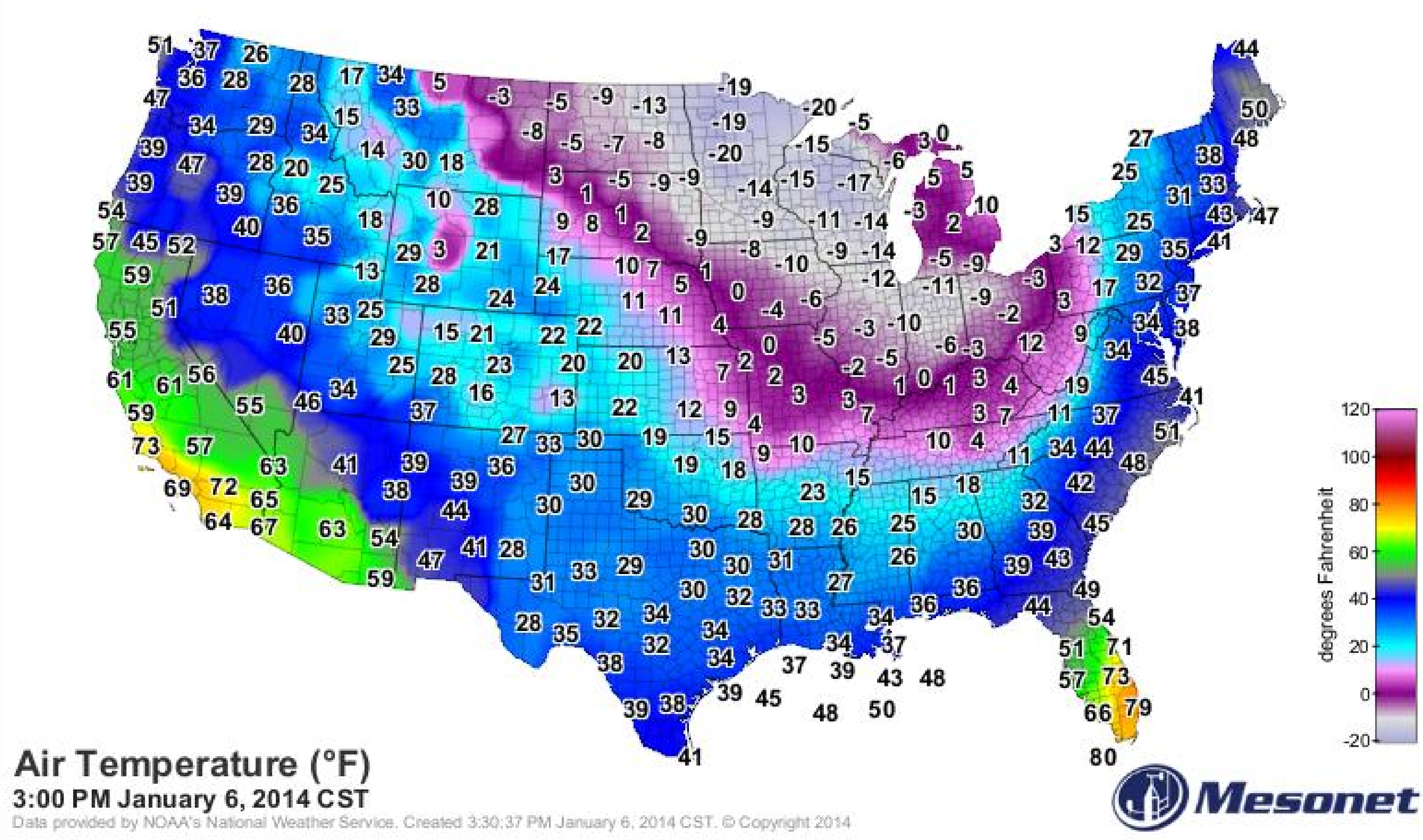
Schatz and Kucharik, 2015 *Environmental Research Letters*

Extreme cold: 2013-14

The "polar vortex"

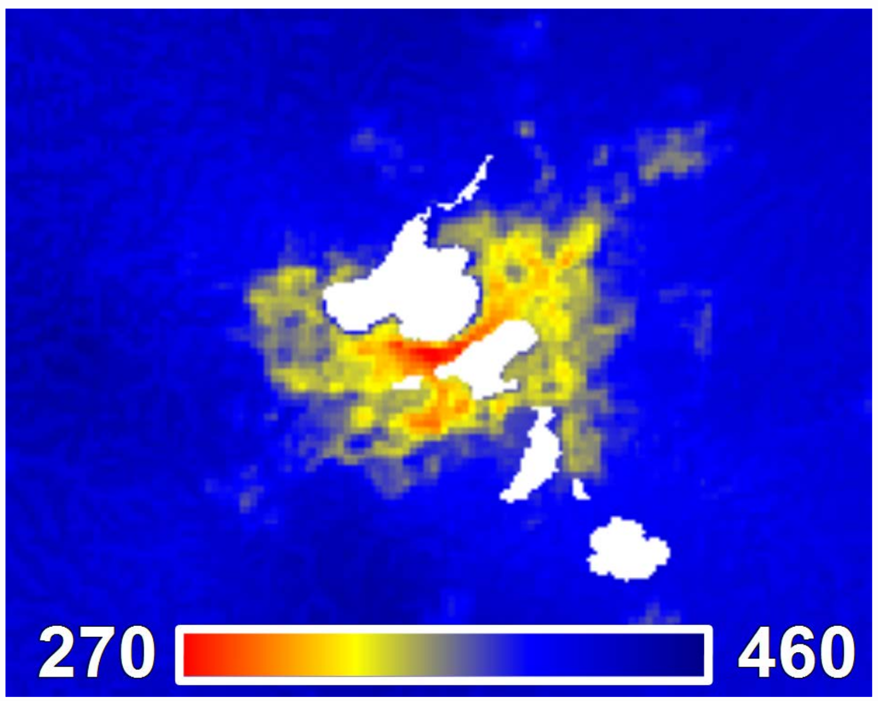
Coldest winter in 35 years (in Madison)

40 days below 0°F

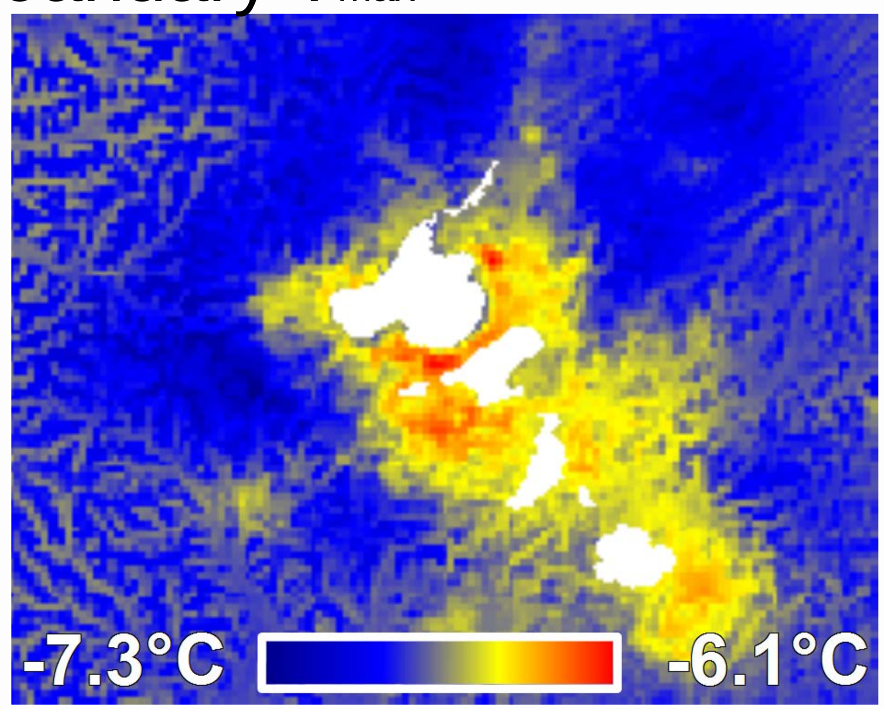


Winter 2013-14

Hours below 0°F

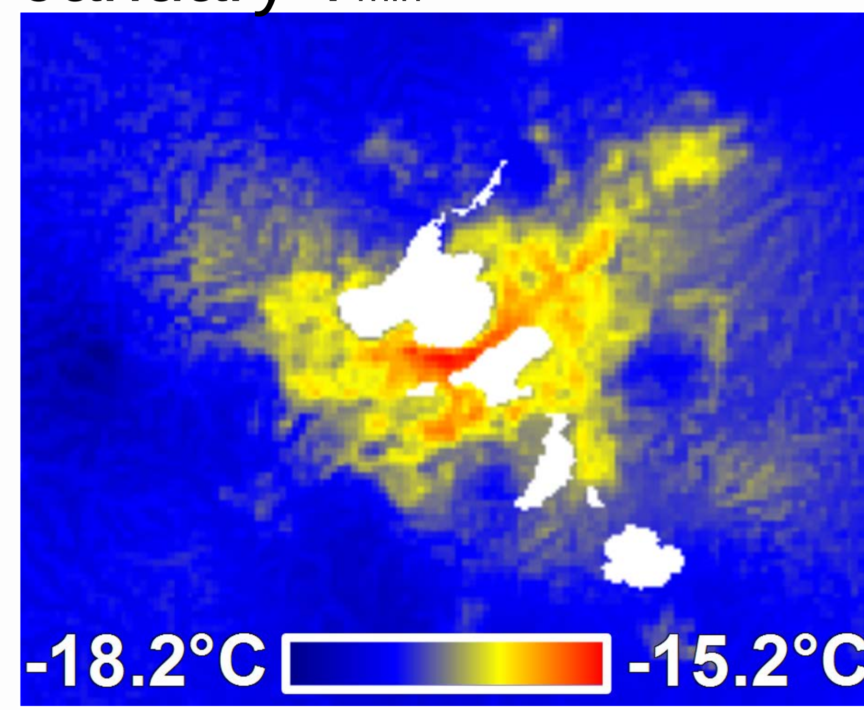


January T_{max}



18.9°F 21.0°F

January T_{min}



-1°F 4.6°F

Schatz and Kucharik, 2015 *Environmental Research Letters*

Madison, WI
Urban Heat Island
Daytime Data
averaged from
April 2012-March
2013

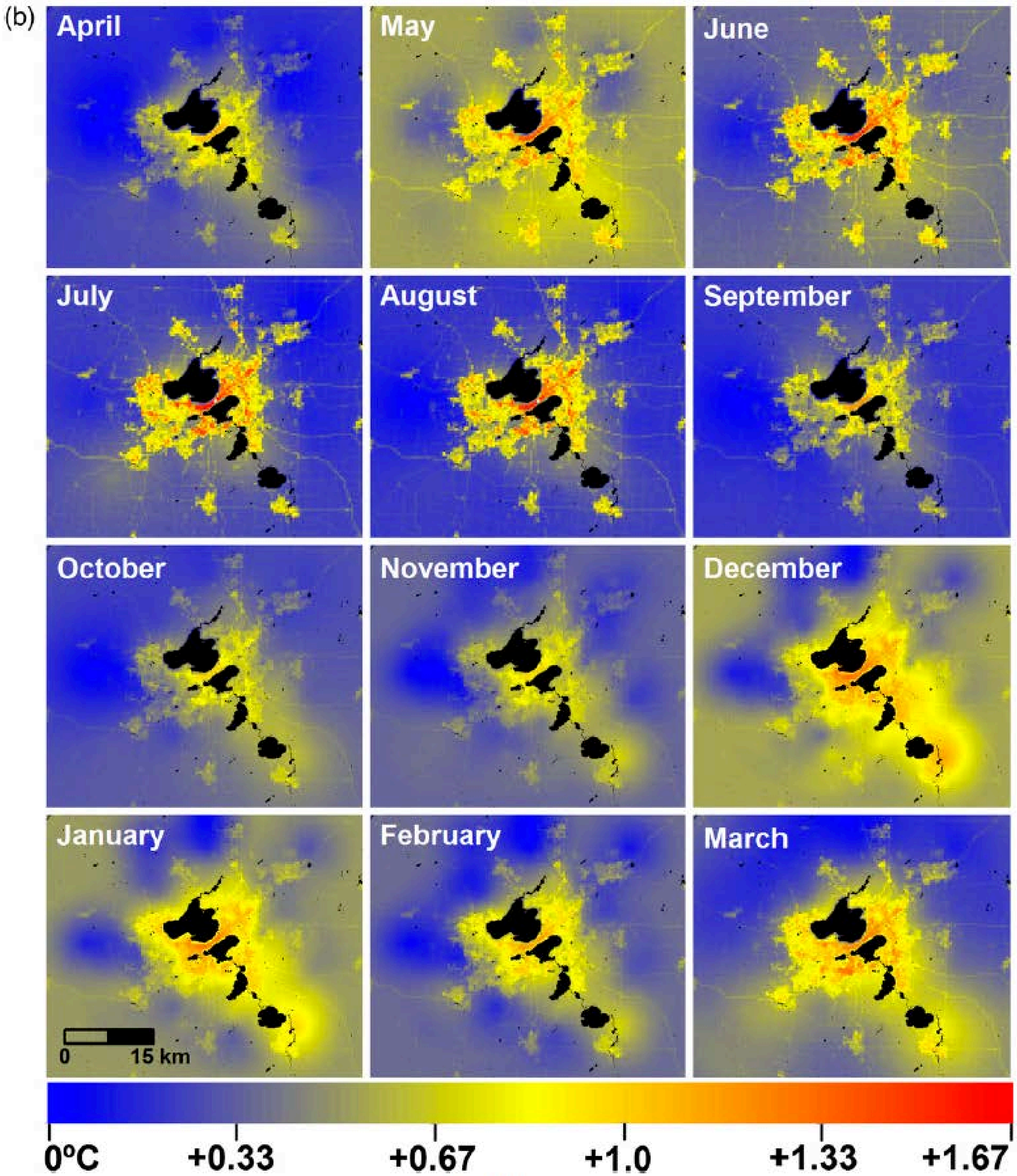


FIG. 4. (*Continued*)

Schatz and Kucharik, 2014 *J. Applied Meteorology and Climatology*

Impacts on growing season length: average 2012 to 2014

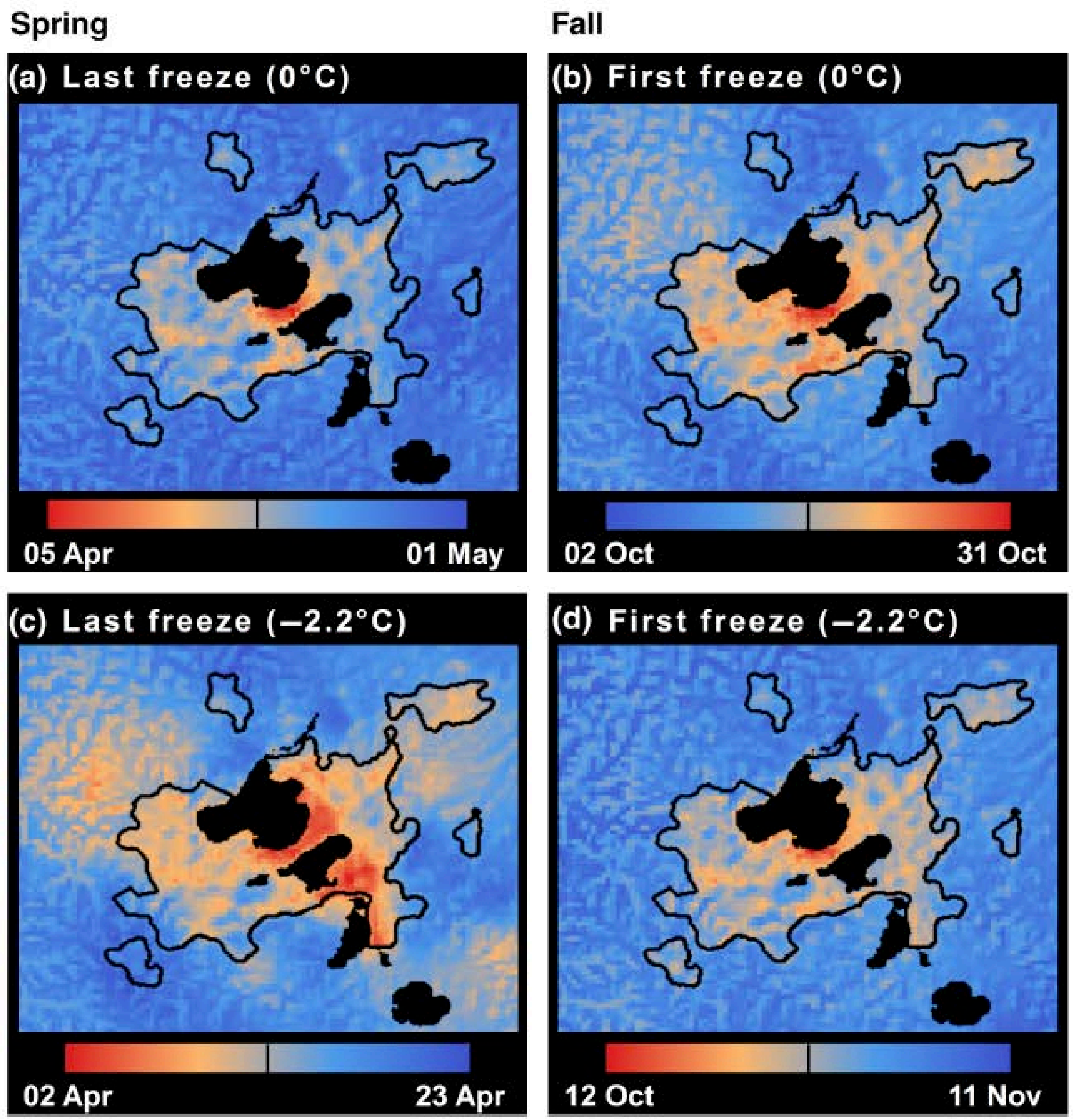
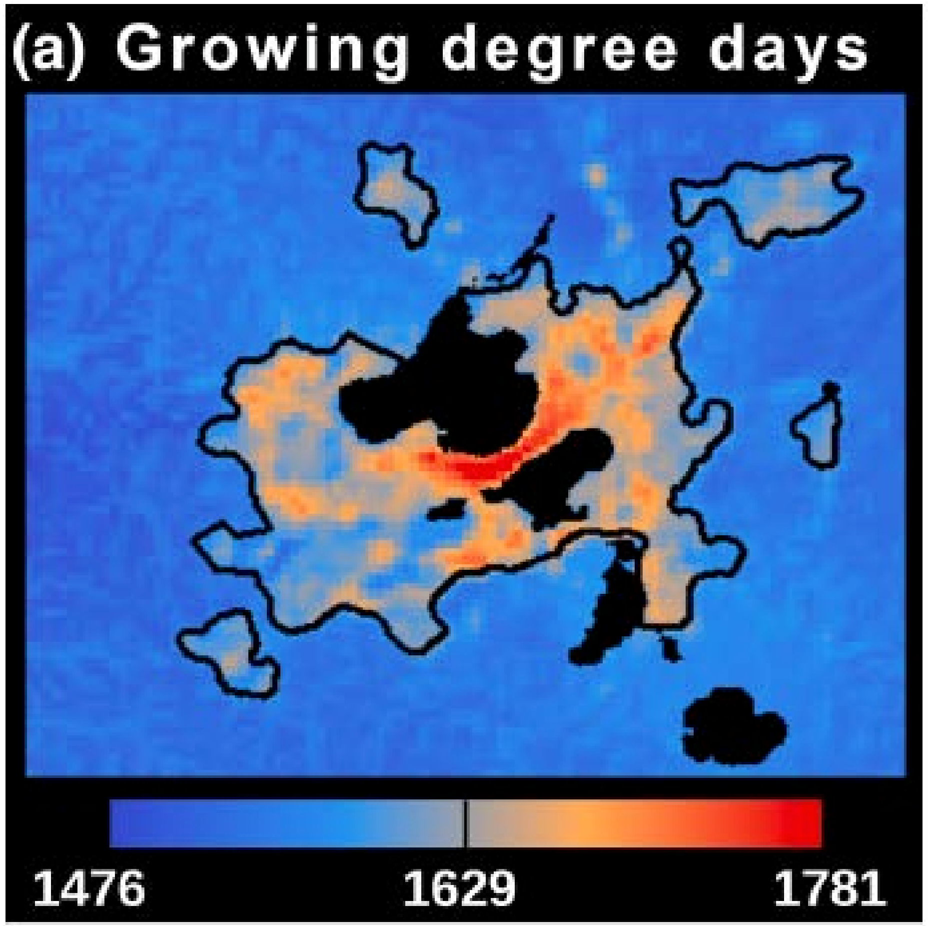


Figure 3. Urban climate effects on the onset of spring and fall in Madison, Wisconsin, interpolated to 400 m resolution using regression kriging. Plots are average (from 2012 to 2014) dates of (a) last spring freeze (0 °C threshold); (b) first fall freeze (0 °C threshold); (c) last spring freeze (−2.2 °C threshold) and (d) first fall freeze (−2.2 °C threshold). Black lines delineate approximate urban extent; filled black polygons represent lakes (compare to study area map in Figure 1).

Schatz and Kucharik, 2016 *International J. of Climatology*

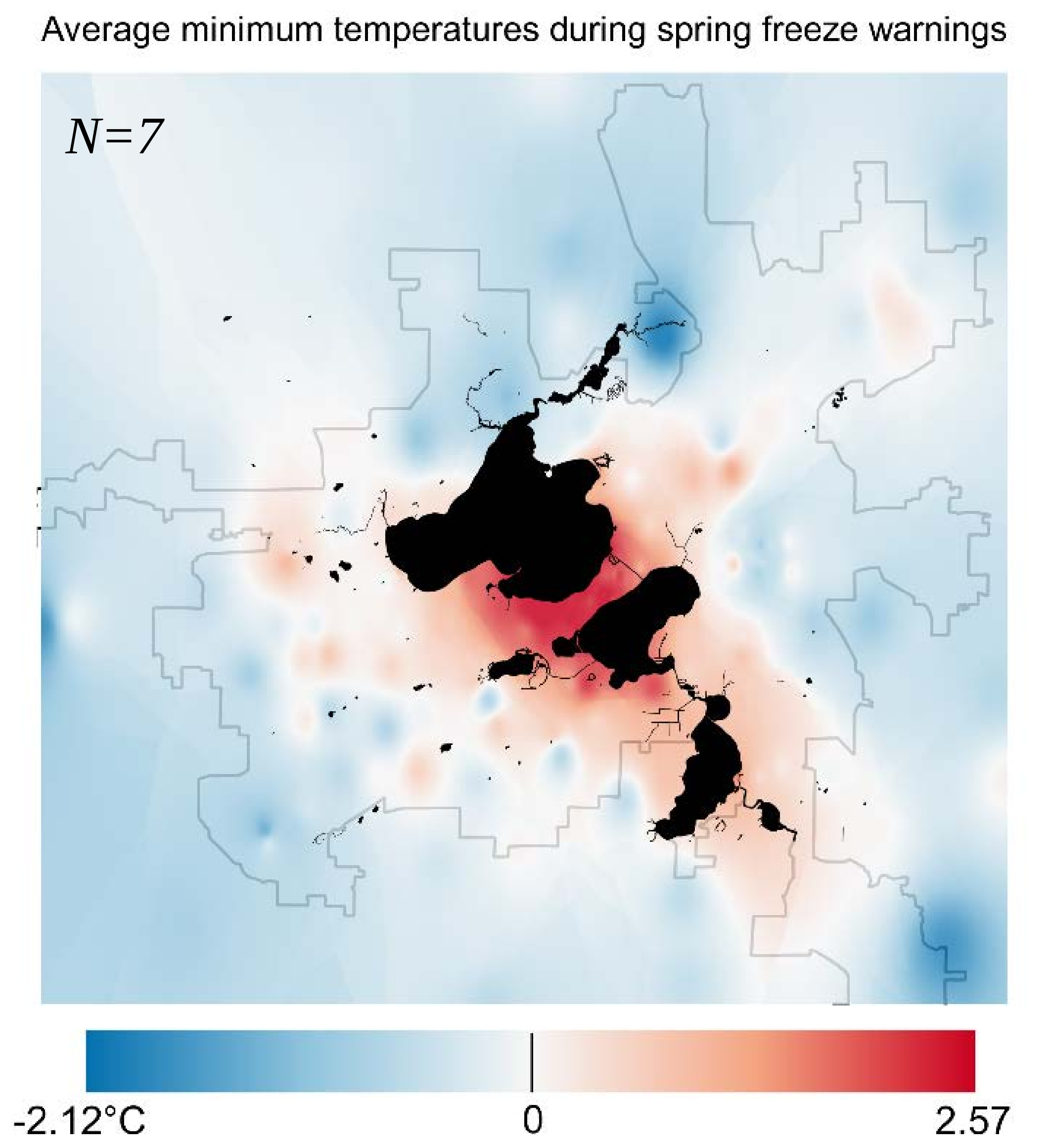
Impacts on growing degree days (GDDs, base 10ºC) and urban agriculture

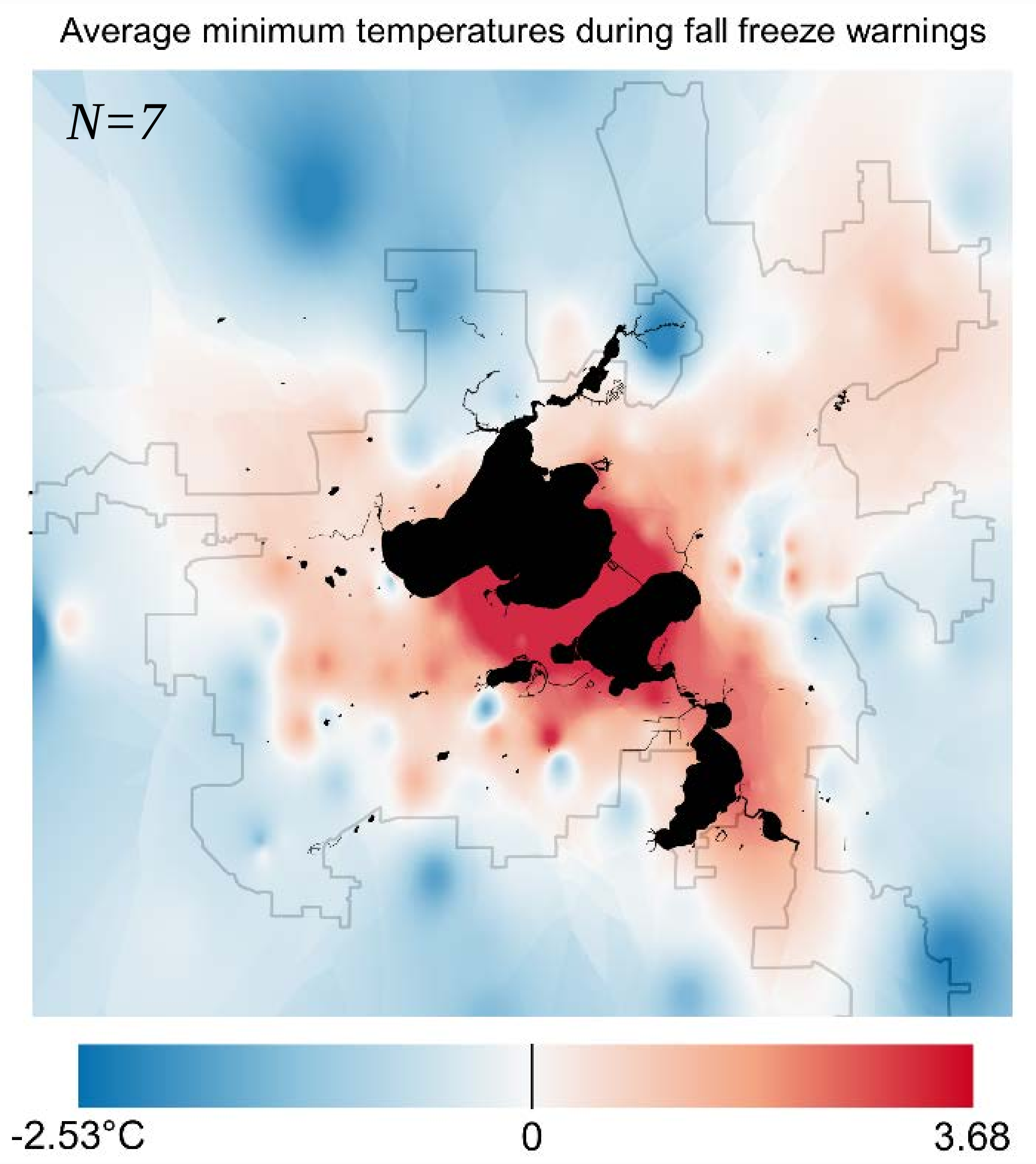


Approximately 225 GDDs higher in core of urban areas than rural locations

Schatz and Kucharik, 2016 *International J. of Climatology*

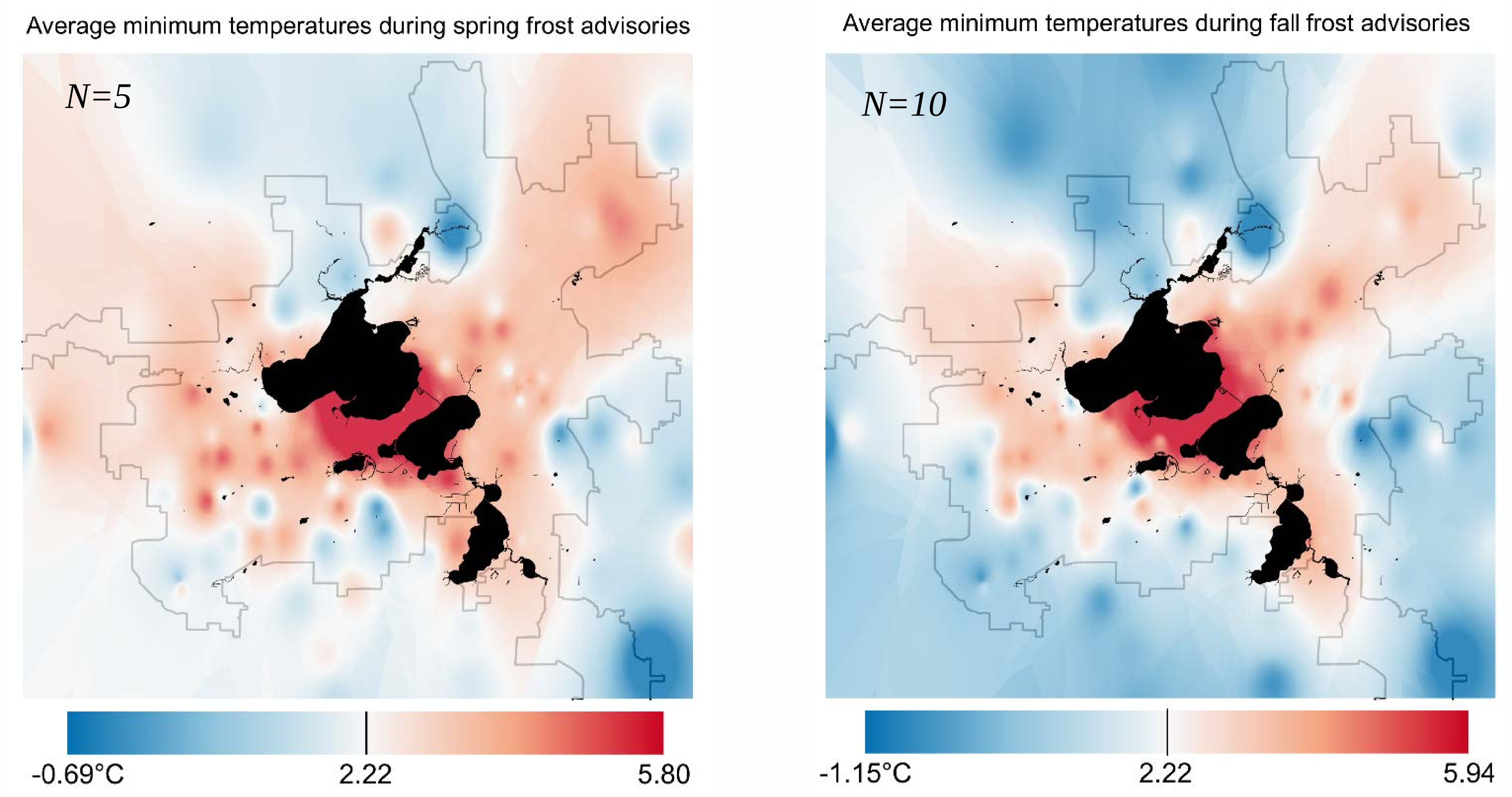
Impacts of UHI on Validity of Freeze Warnings
March 2012 – May 2016





Williamson and Kucharik, *in preparation*

Impacts of UHI on Validity of Frost Advisories
March 2012 – May 2016



Williamson and Kucharik, *in preparation*