Changing Climate, Extreme Weather and Challenges to Midwest Agriculture

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I ONS N–MAD SON

Objectives

- Review historical changes in climate
- Present model projections of changes to future weather and climate
- Describe the challenges to growers

Grand Challenges for Food and Agriculture

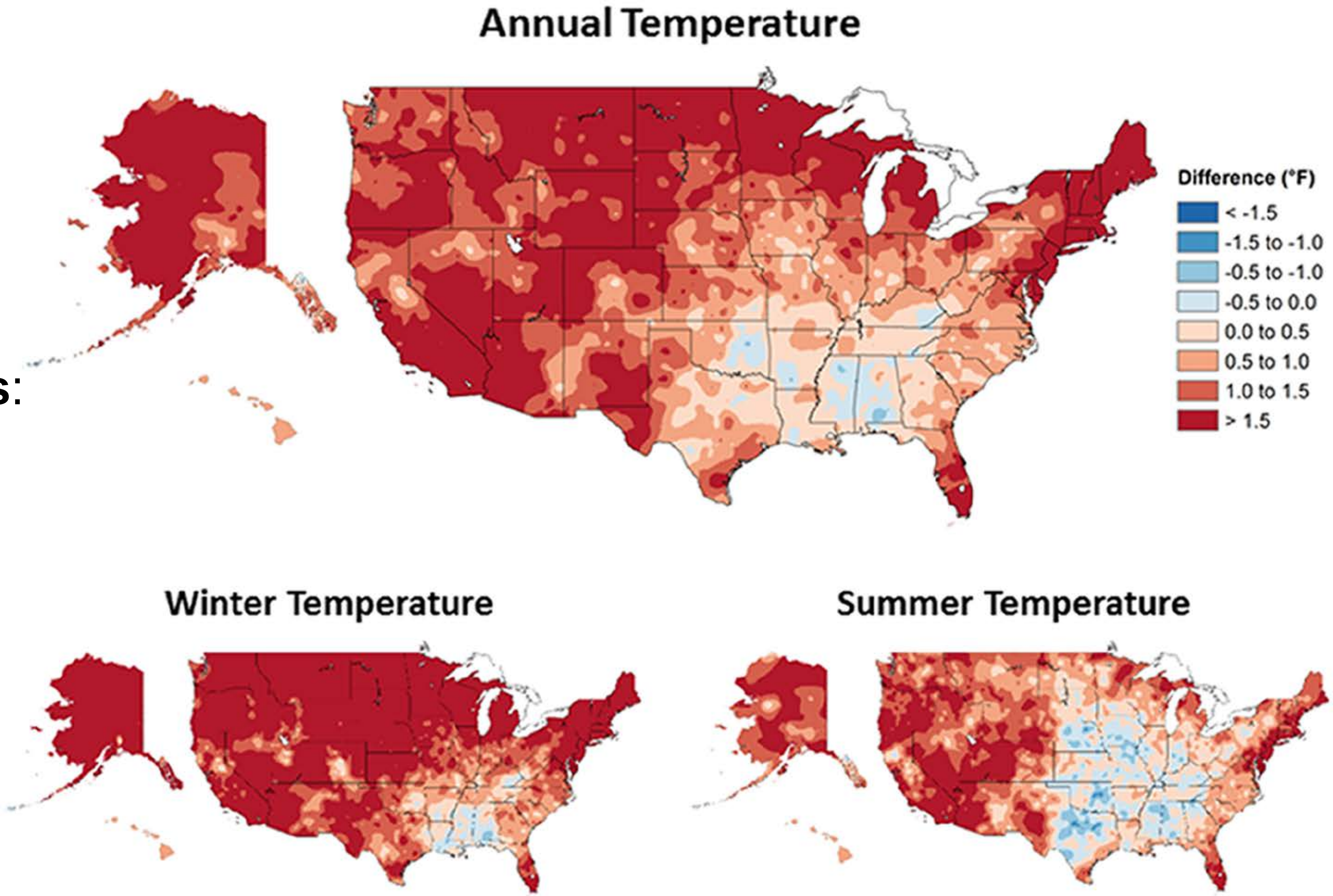
- Double food production by 2050 to feed 10B people

- Do so without expanding current land use footprint

- Adopt management practices that protect and improve quality of soils, water, and other natural resources

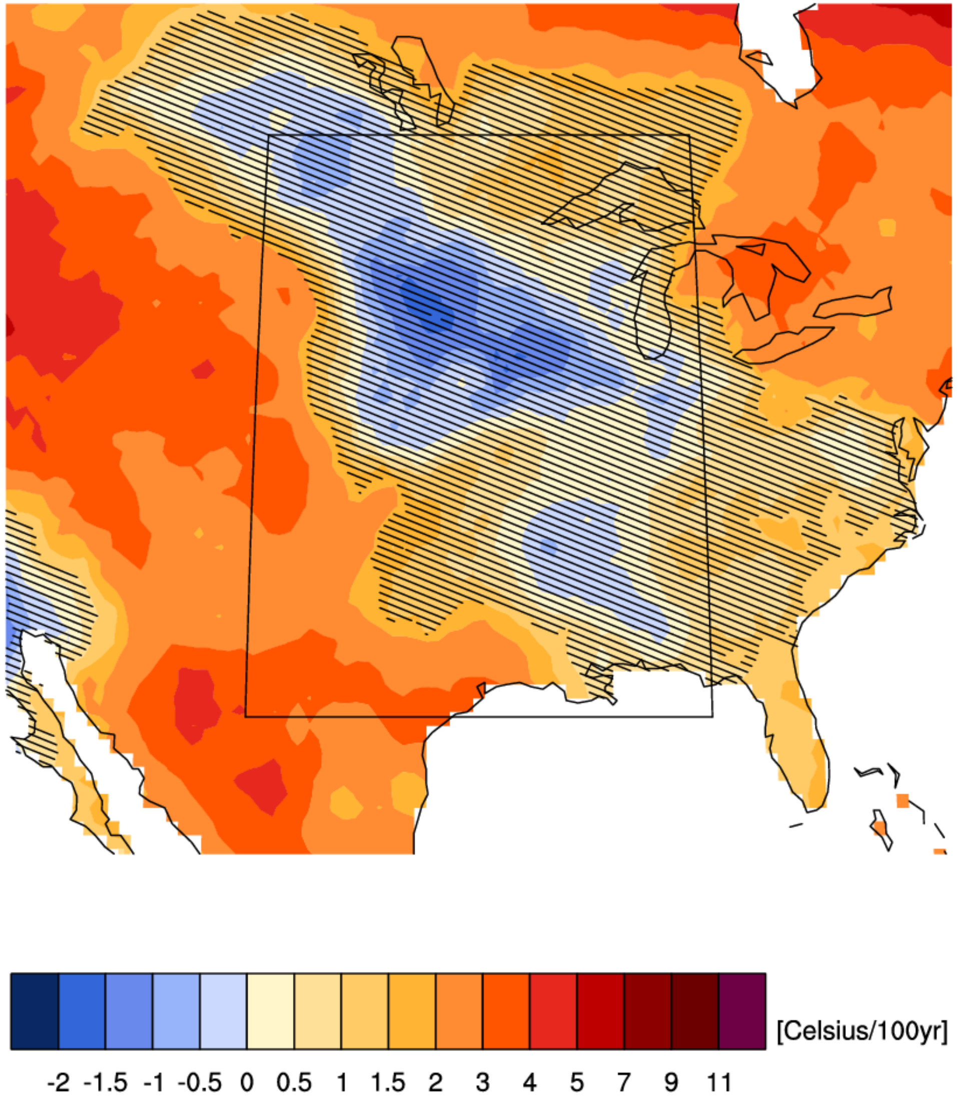
- Succeed at all of these with moving targets in place: *changing economies, human demands & climate change*

Observed US Temperature changes:
1986-2015 average
minus
1901-1960 average

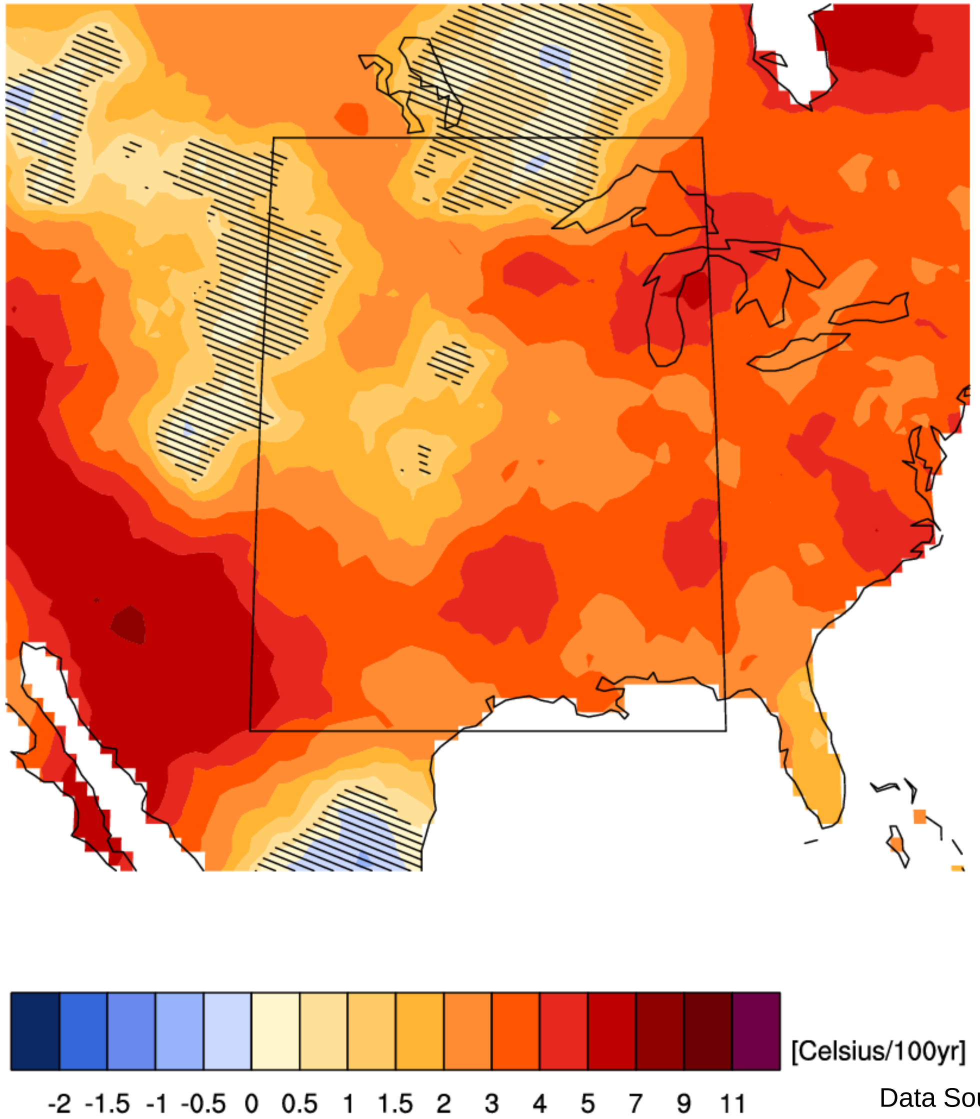


Source: US Global Change Research Program, 2017

Total change in average maximum temperature during summer (Jun-Aug) from 1976-2016

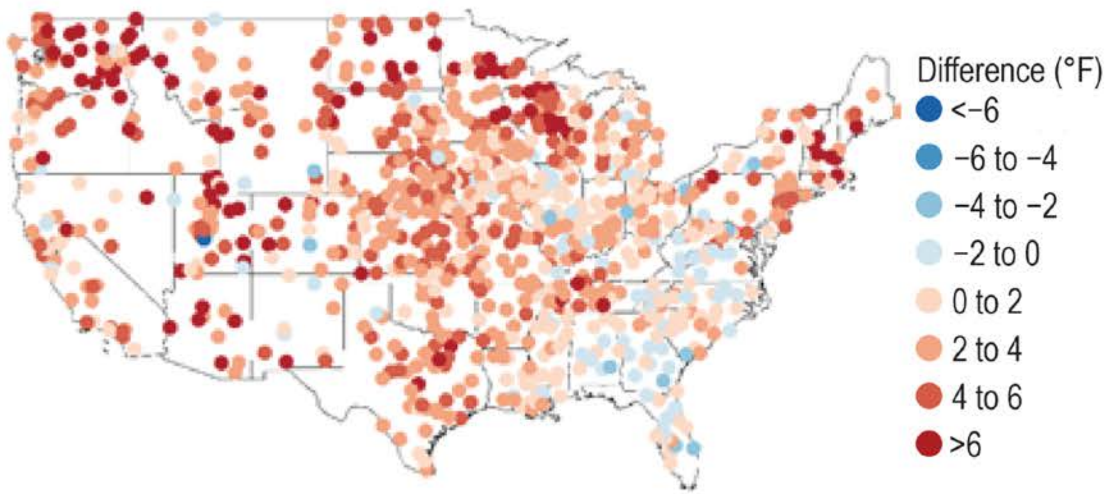


Total change in average minimum temperature during summer (Jun-Aug) from 1976-2016

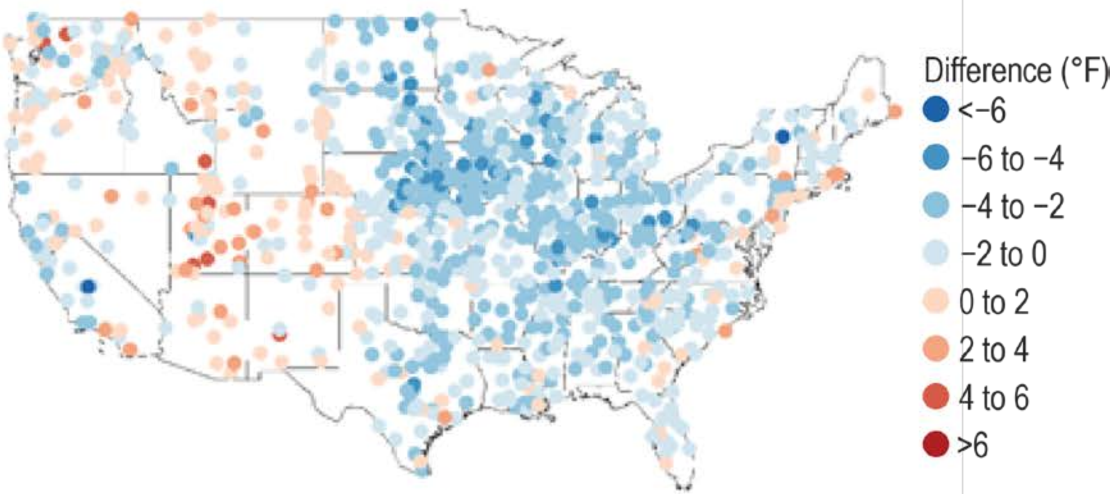


Data Source: CRU 4.0

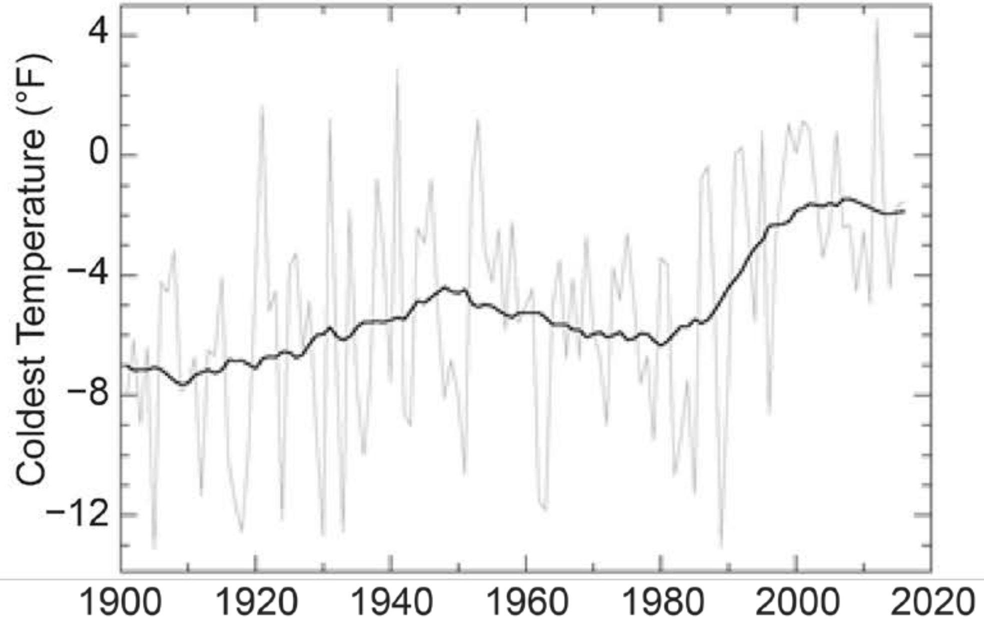
Change in Coldest Temperature of the Year
1986–2016 Average Minus 1901–1960 Average



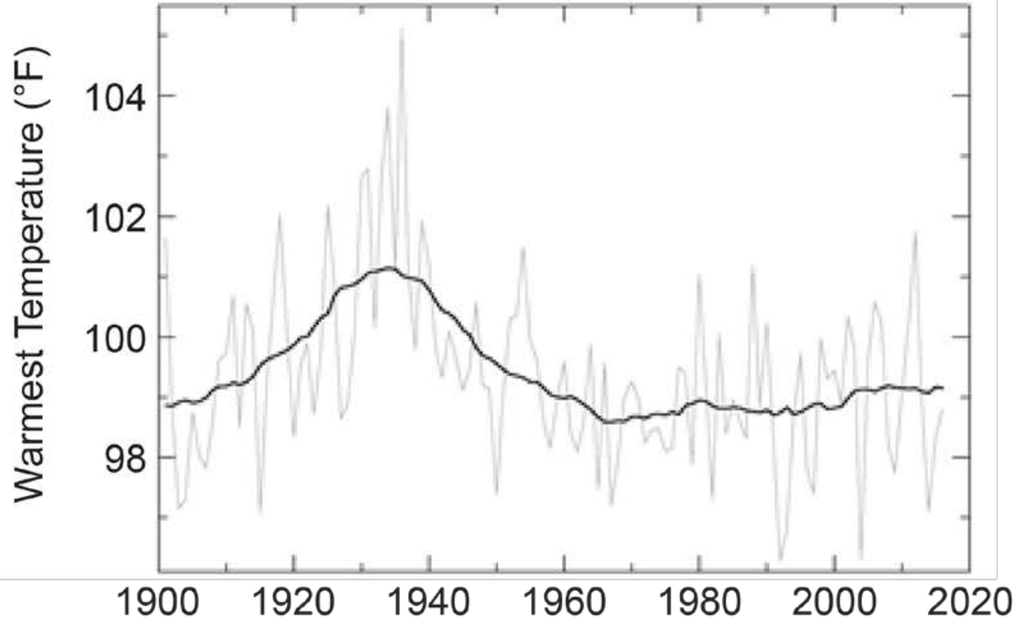
Change in Warmest Temperature of the Year
1986–2016 Average Minus 1901–1960 Average



Coldest days are warming

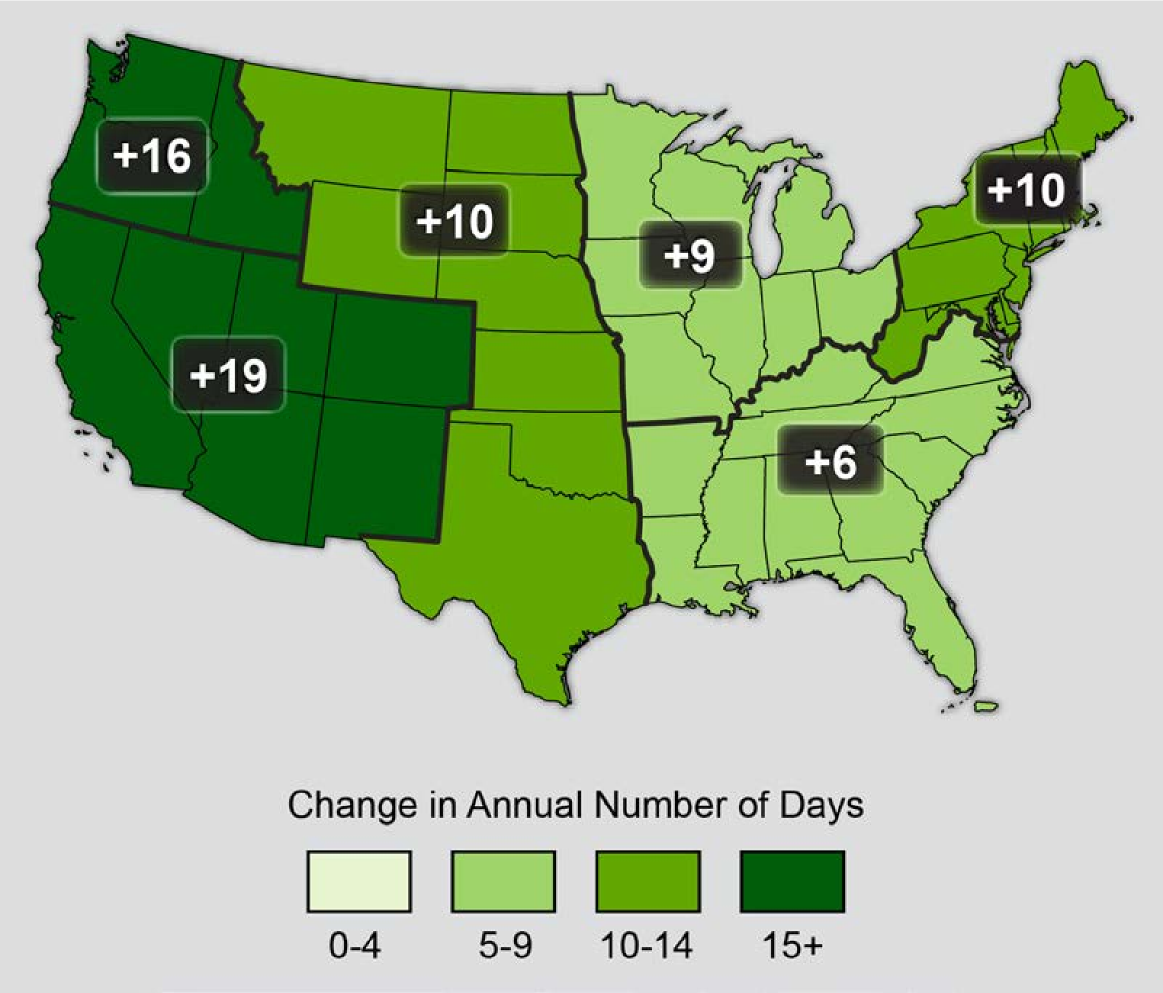


Hottest days are cooling



Source: US Global Change Research Program, 2017

Observed Increase in Frost-Free Season Length: 1991-2012 vs. 1901-1960



Source: US Global Change Research Program and National Climate Assessment 2014

Wisconsin Growing Season Changes 1950-2006

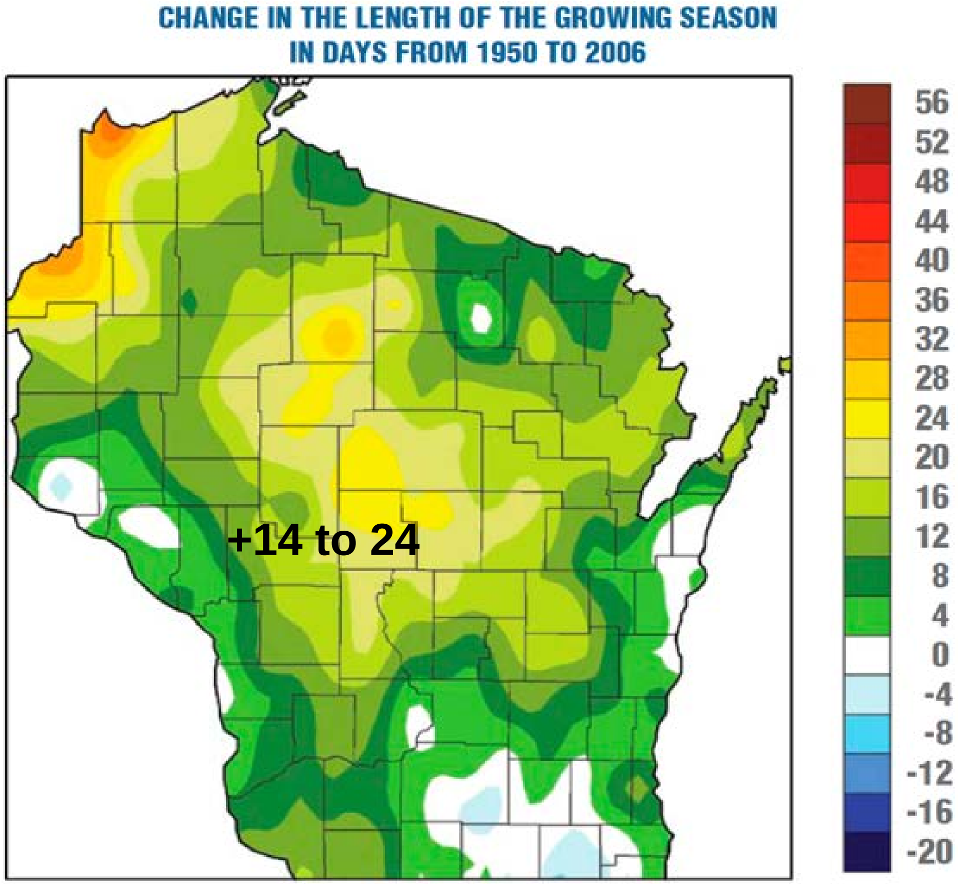


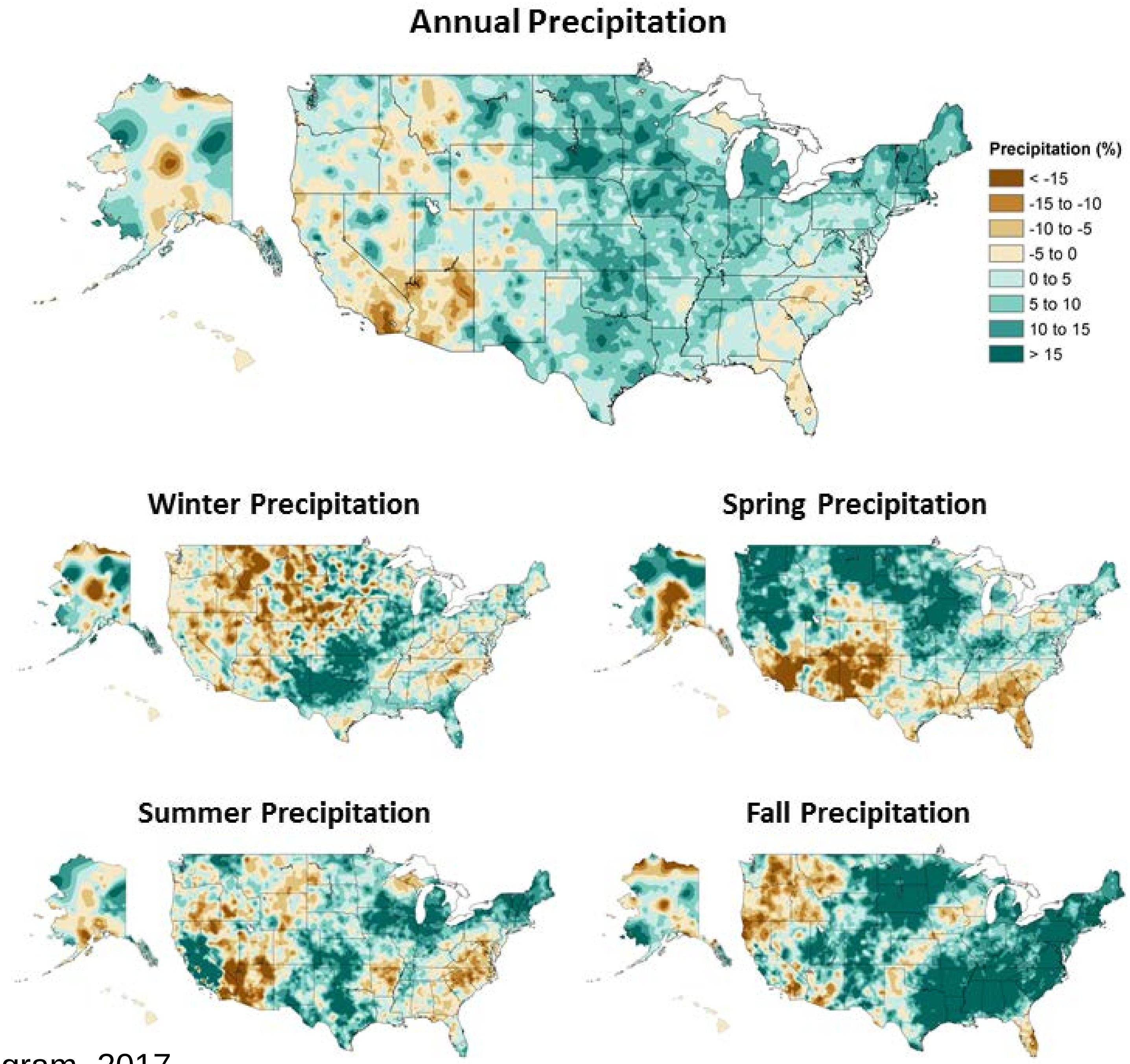
Figure 7. The length of the growing season has increased by as much as four weeks in

perature falls below 32 F.)

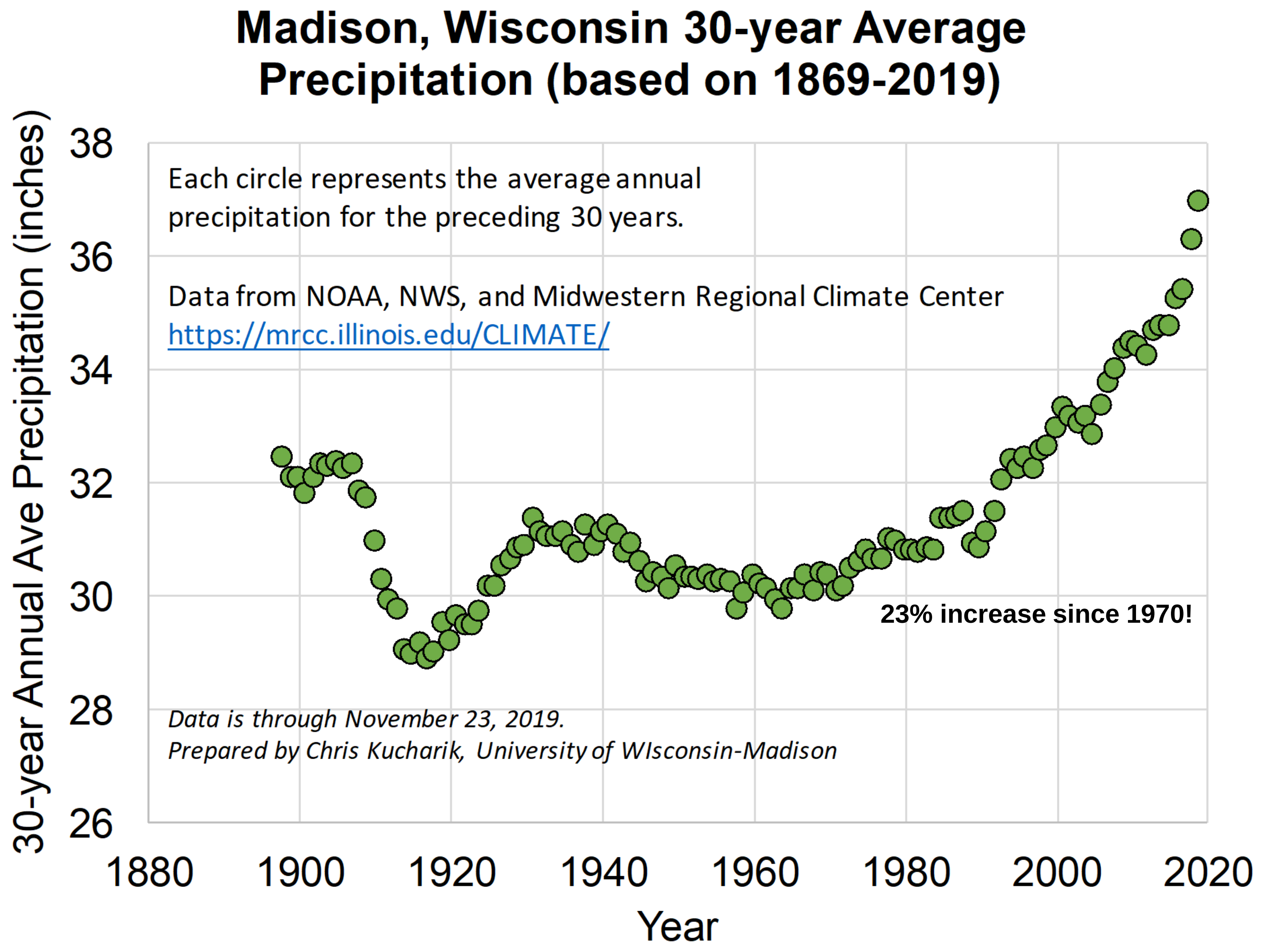
Source: Kucharik et al. 2010; WICCI 2011

Observed US Precipitation Change:

1986-2015 average
minus
1901-1960 average



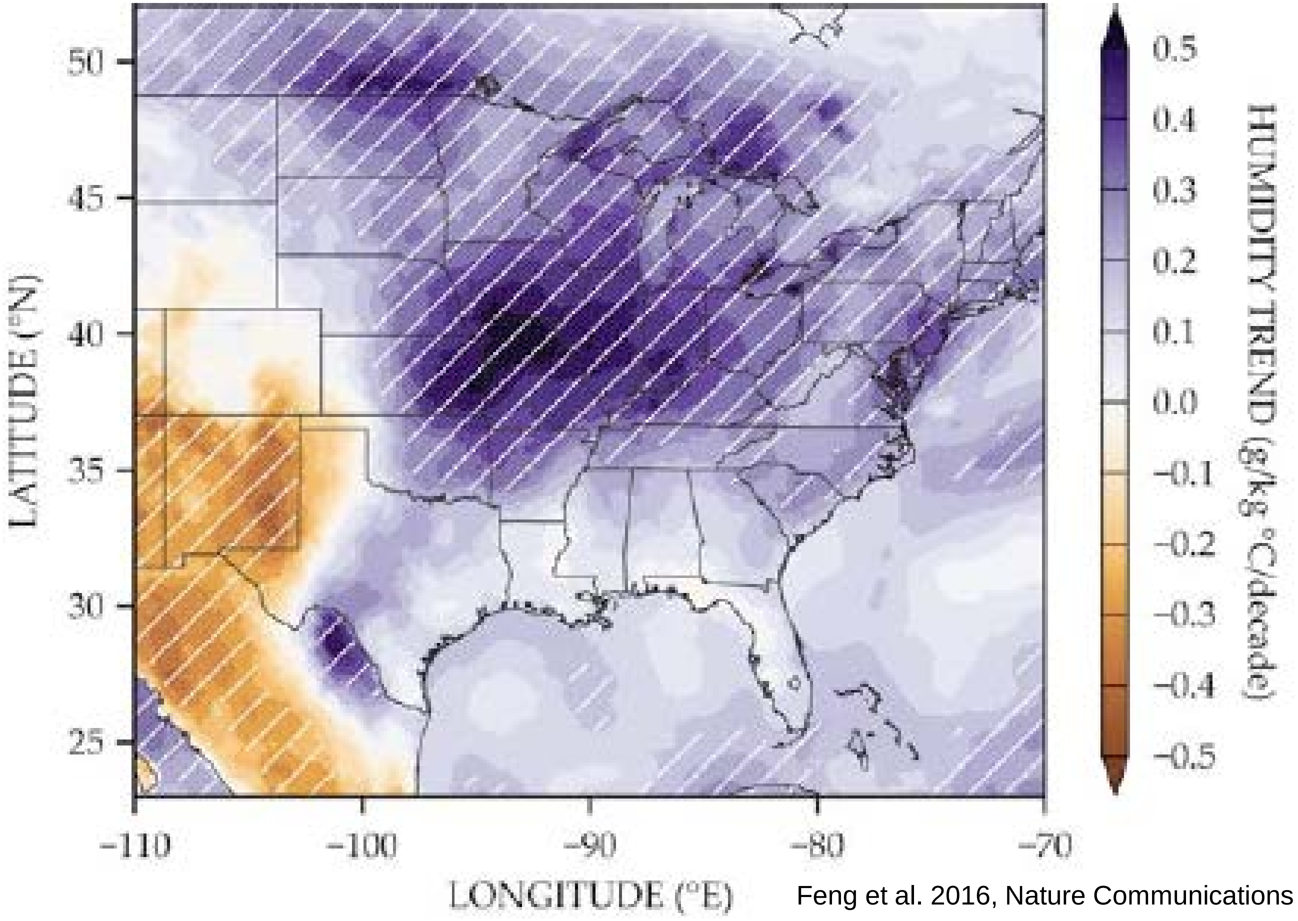
Source: US Global Change Research Program, 2017



Top 10 wettest years
In Madison all-time

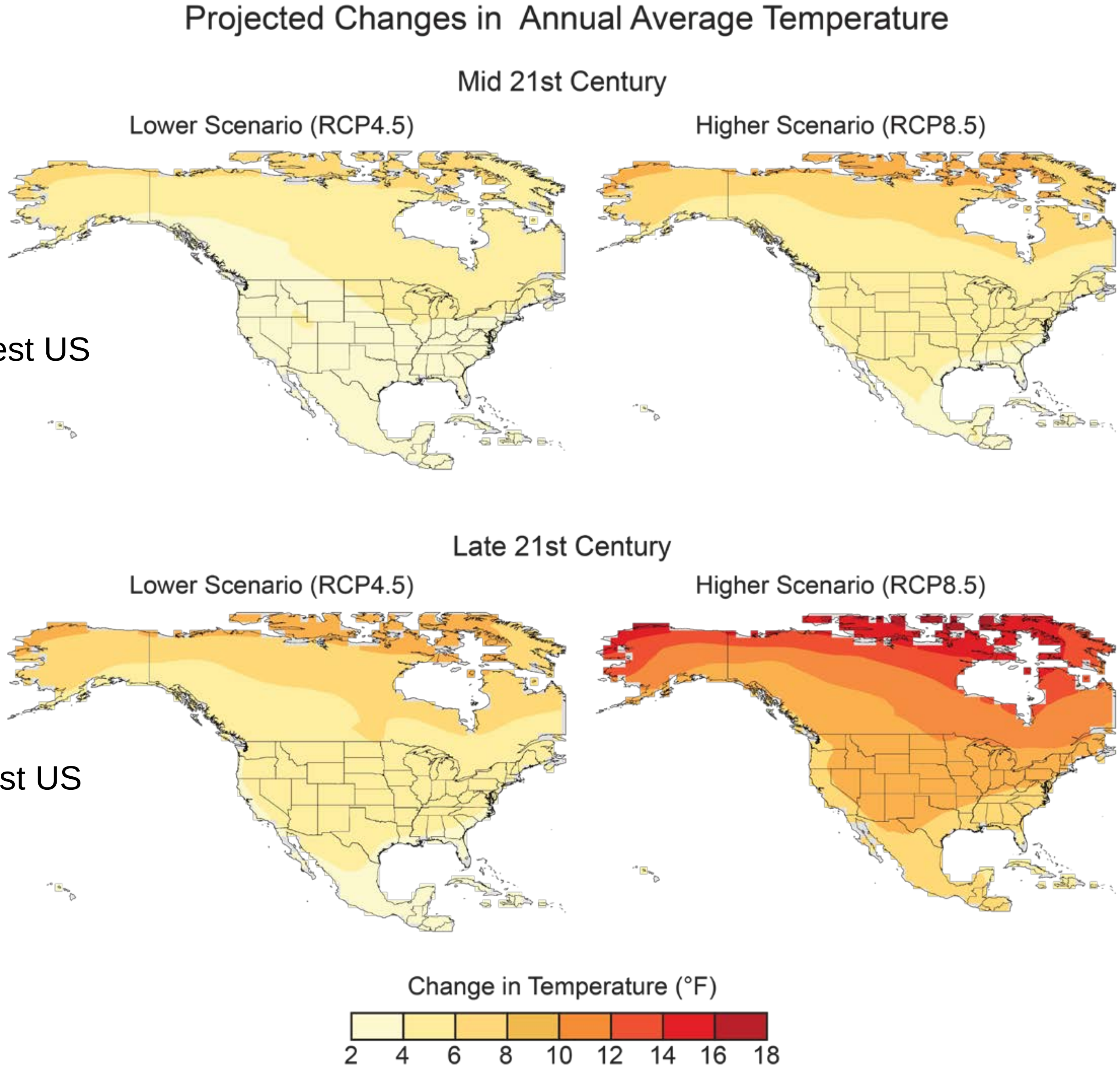
#2 – 2018 (50.64")
#5 – 2019 (46.38")
#6 – 2016 (45.56")
#7 – 2013 (45.38")
#8 – 2007 (44.41")
#9 – 2008 (44.06")
#10 – 1993 (43.34")

1979-2014 Trend in April-May-June Humidity



Feng et al. 2016, Nature Communications

In addition to warming temperatures, increases in humidity across the Midwest US are providing more fuel for nighttime convection that is forced by the low-level-jet.

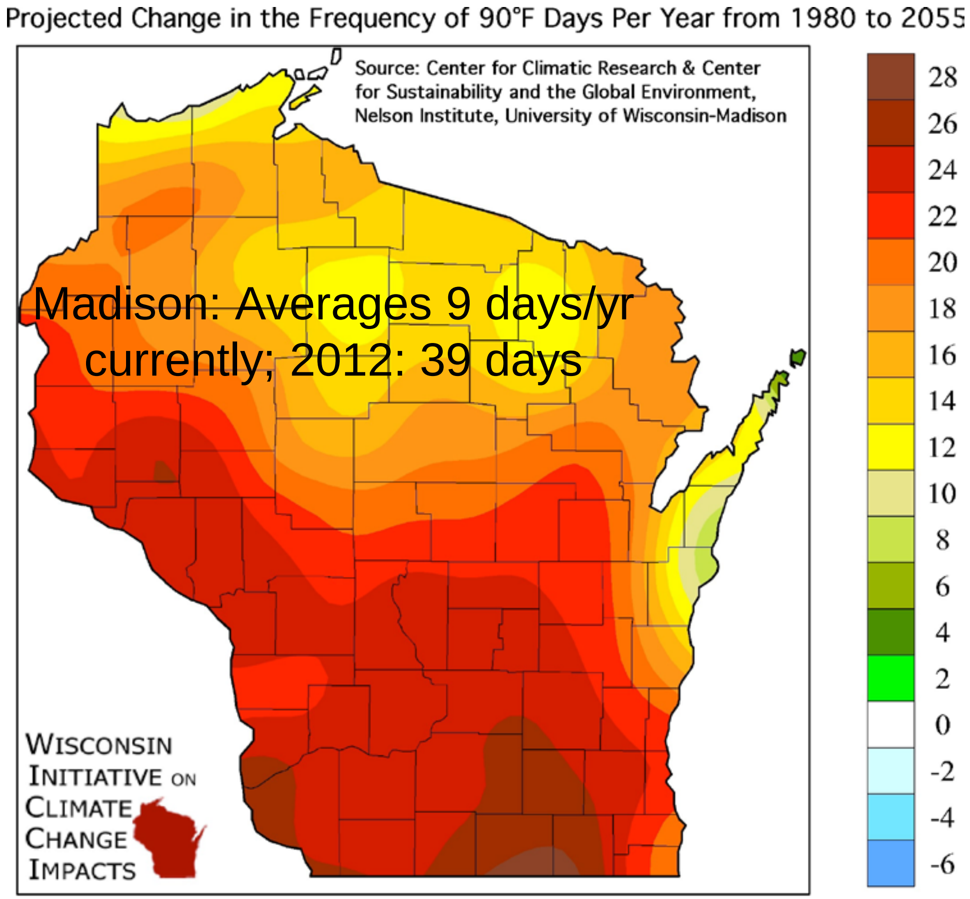


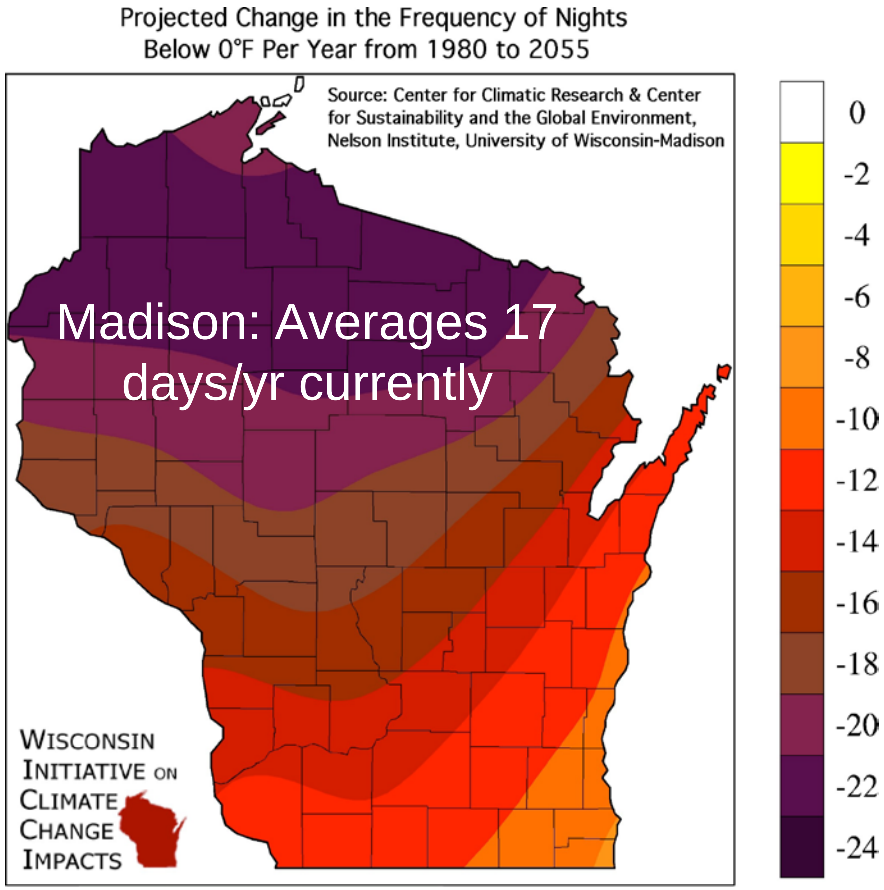
By 2050, +2 to 6ºF in Midwest US

By 2100, +4 to 9ºF in Midwest US

Source: US Global Change Research Program, 2017

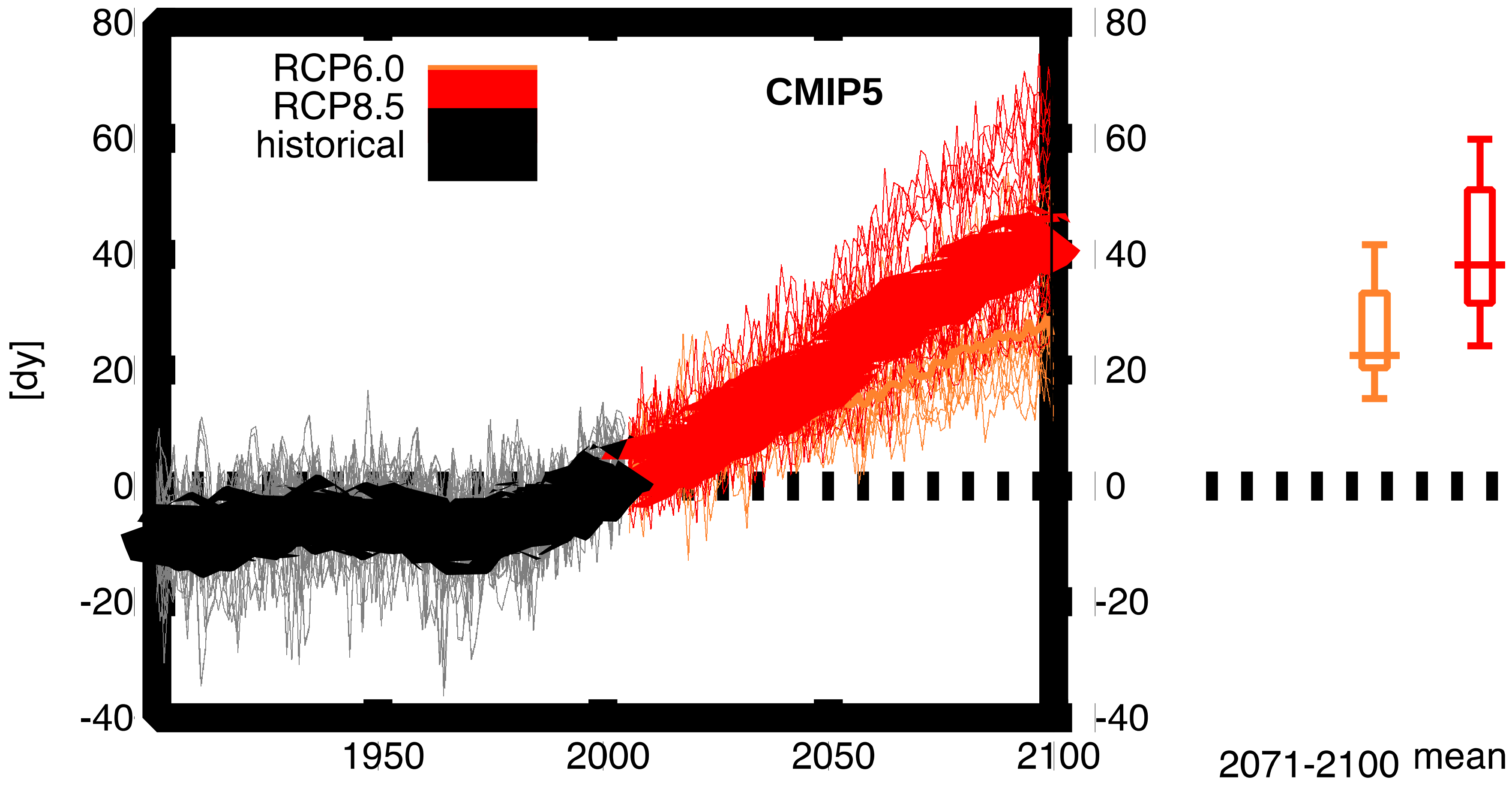
Number of >90° Days, <0° Nights





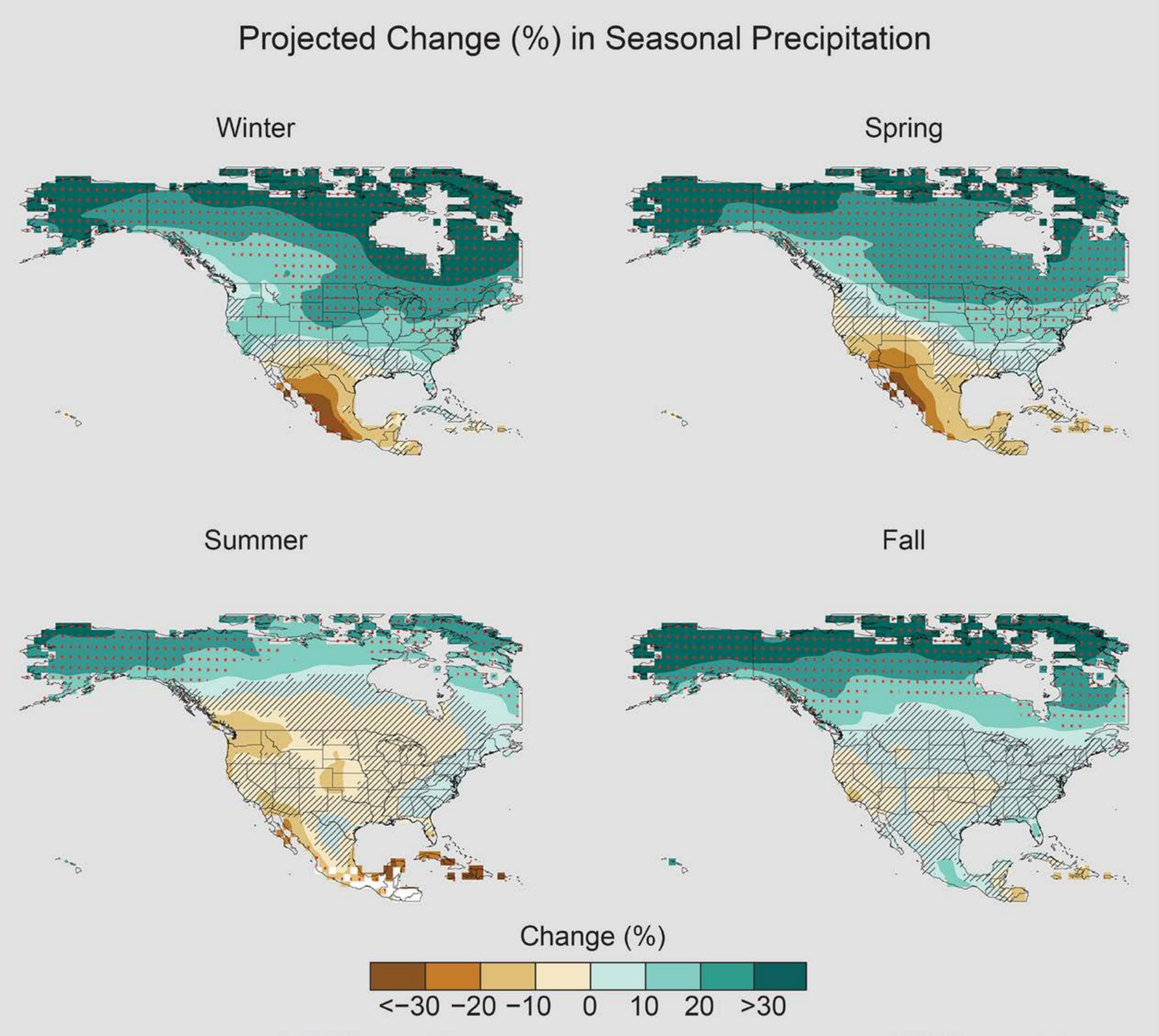
More "very hot" days, less "very cold" days

Growing season length change in Midwest



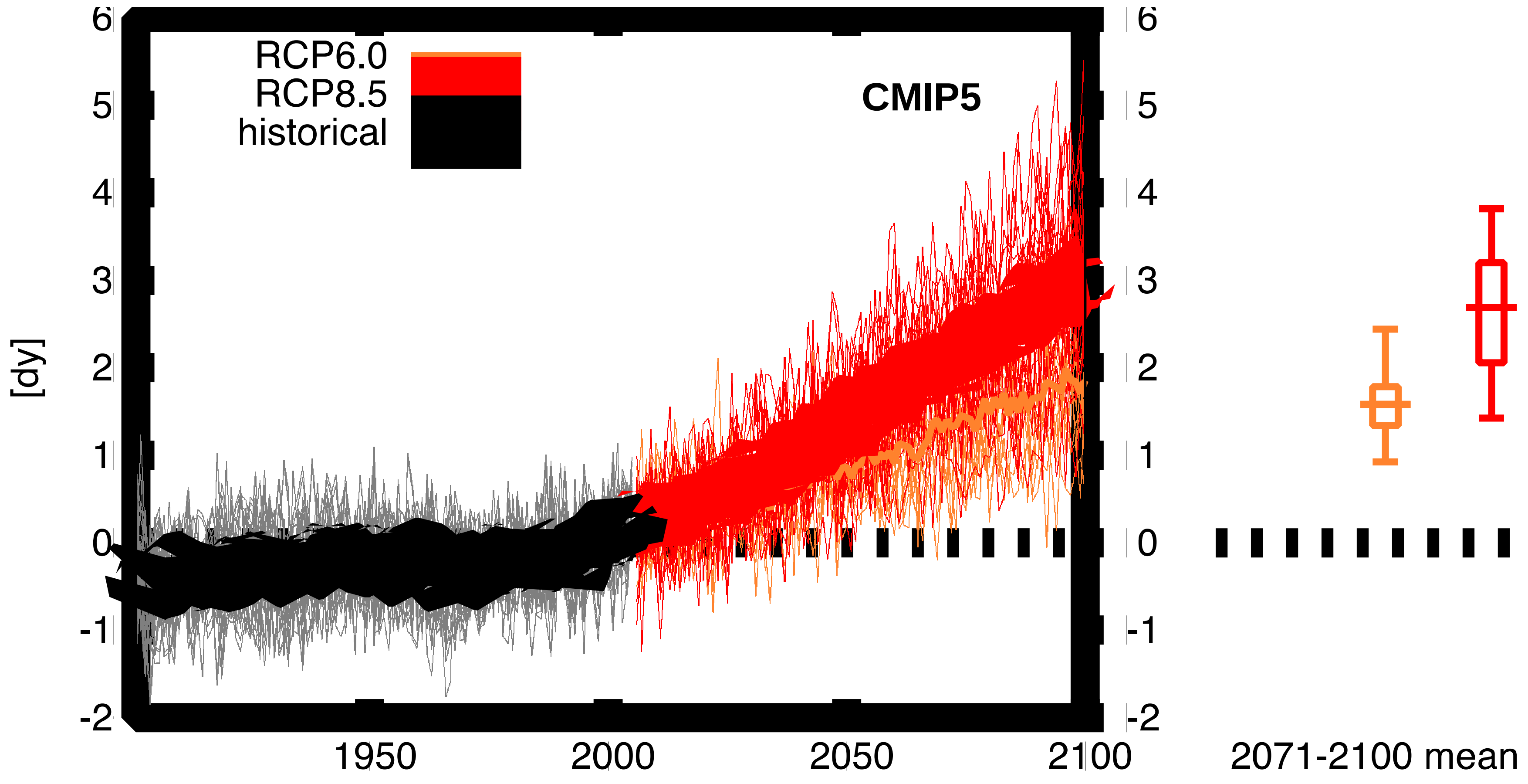
Future Precipitation Changes

2070-2099 relative to 1976-2005



Source: US Global Change Research Program, 2017

Annual frequency of 20mm+ (~0.78in) rainfall events in Midwest



Future Wisconsin Climate Change Summary

PROJECTIONS FOR WISCONSIN				
	Year 2050 High Emissions	Year 2050 Low Emissions	Year 2090 High Emissions	Year 2090 Low Emissions
Temperature	+6°F	+5°F	+11°F	+7°F
Annual precipitation	+1.3 inches	+1.5 inches	+2.3 inches	+1.5 inches
Growing season duration	24 days longer	20 days longer	48 days longer	32 days longer
Frequency of 90°F days	20 more days	15 more days	48 more days	20 more days
Frequency of sub-0°F nights	15 fewer nights	13 fewer nights	22 fewer nights	17 fewer nights
Frequency of 1" precipitation events	Additional event every 20 months	Additional event every 20 months	Additional event every 10 months	Additional event every 17 months

Source: Climate Working Group: WICCI First Adaptive Assessment Report, 2011

Given future climate projections, what are the key challenges to agriculture?

PNAS

Future warming increases probability of globally synchronized maize production shocks

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[a]Department of Atmospheric Sciences, University of Washington, Seattle, WA 98195; [b]Center on Food Security and the Environment, Stanford University, Stanford, CA 94305; and [c]Institute on the Environment, University of Minnesota, St. Paul, MN 55108

Edited by B. L. Turner, Arizona State University, Tempe, AZ, and approved May 9, 2018 (received for review October 16, 2017)

Meeting the global food demand of roughly 10 billion people by the middle of the 21st century will become increasingly challeng-

variability and resulting changes in soil moisture also affect crop yields, the negative effects of future warming are expected to out-

ARTICLE

Received 1 Sep 2014 | Accepted 28 Nov 2014 | Published 22 Jan 2015 DOI: 10.1038/ncomms6989 OPEN

Climate variation explains a third of global crop yield variability

Deepak K. Ray[1], James S. Gerber[1], Graham K. MacDonald[1] & Paul C. West[1]

nature climate change LETTERS

PUBLISHED ONLINE: 3 MARCH 2013 | DOI:10.1038/NCLIMATE1832

The critical role of extreme heat for maize production in the United States

David B. Lobell[1]*, Graeme L. Hammer[2], Greg McLean[3], Carlos Messina[4], Michael J. Roberts[5] and Wolfram Schlenker[6]

OPEN ACCESS

IOP Publishing Environmental Research Letters

Environ. Res. Lett. 8 (2013) 024001 (9pp) doi:10.1088/1748-9326/8/2/024001

Evidence for a climate signal in trends of global crop yield variability over the past 50 years

T M Osborne[1,2] and T R Wheeler[2,3]

[1] National Centre for Atmospheric Science (NCAS), University of Reading, UK
[2] Walker Institute for Climate System Research, University of Reading, UK
[3] Department of Agriculture, University of Reading, UK

Greater Sensitivity to Drought Accompanies Maize Yield Increase in the U.S. Midwest

David B. Lobell,[1]* Michael J. Roberts,[2] Wolfram Schlenker,[3] Noah Braun,[4] Bertis B. Little,[5] Roderick M. Rejesus,[4] Graeme L. Hammer[6]

A key question for climate change adaptation is whether existing cropping systems can become less sensitive to climate variations. We use a field-level data set on maize and soybean yields in the central United States for 1995 through 2012 to examine changes in drought sensitivity. Although yields have increased in absolute value under all levels of stress for both crops, the sensitivity of maize yields to drought stress associated with high vapor pressure deficits has increased. The greater sensitivity has occurred despite cultivar improvements and increased carbon dioxide and reflects the agronomic trend toward higher sowing densities. The results suggest that agronomic changes tend to translate improved drought tolerance of plants to higher average yields but not to decreasing drought sensitivity of yields at the field scale.

OPEN ACCESS Freely available online PLOS ONE

Yield Trends Are Insufficient to Double Global Crop Production by 2050

Deepak K. Ray*, Nathaniel D. Mueller, Paul C. West, Jonathan A. Foley

Institute on the Environment (IonE), University of Minnesota, Saint Paul, Minnesota, United States of America

1. <u>Nitrogen management</u> – challenged by changing rainfall variability, extremes

2. <u>Water management</u> – challenged by increased crop water demand and more chaotic rainfall patterns and heavier rainfall events

3. <u>Soil management</u> – more erosion; tillage operations more challenging

4. <u>Pest/disease management</u> – more overwintering, expanded ranges

5. Temperatures move outside optimal physiological ranges and increased stress at pollination stages

6. Increased rate of plant development (phenology)

7. Earlier onset of spring and higher frequency of “false springs”

8. Increased soil moisture stress

9. Increased atmospheric CO_2 could offset some negative impacts, but also favor more weeds to flourish

10. More challenging planting and harvest seasons with more variable weather

11. More rain falling during winter and on frozen ground: more runoff

12. Lengthening growing season: plant longer season summer crop varieties? Or cover crops?

Key Challenges in Farming

- We are being confronted with unprecedented changes in mean climate and weather variability
  - *There is an absence of "analogs" in the past historical record that represent growing conditions we are now experiencing or what is projected in the future*
- "**Stationarity is dead**" in future planning: the amount of historical daily, seasonal to interannual variability that was typically helpful in future planning is now useless.

- *Milly et al. 2008, Science*
- *Smith et al. 2009, Ecology*
- *Dietze et al. 2018, Proc. Natl. Acad. Sci.*

New ”lakes in the landscape”

Madison Magazine, December 2019

Farming Adaptations to Increasing Rainfall

- More N fertilizer is being added to make up for the increased risk of leaching losses

> *"If it keeps raining and it's warm, we're going to lose nitrogen, big time lose nitrogen, and that's when you've got to come back in and put some more [nitrogen] on or you're going to lose the crop, and there's 'why did you lose the crop?' when with another 10 to 15 gallon of [liquid nitrogen fertilizer] you can fix it"* – Indiana Farmer.

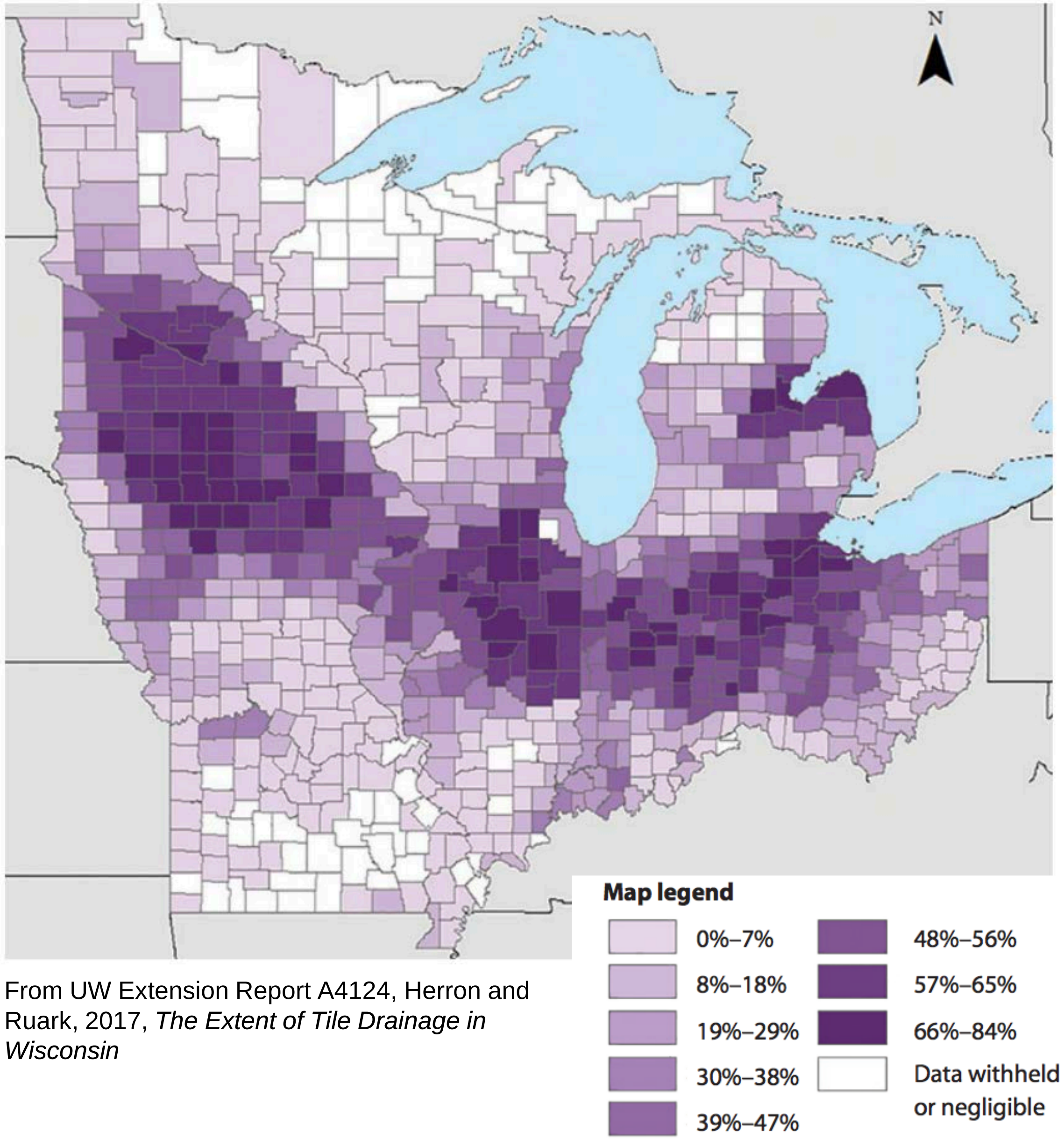
> *"We usually put [a little extra nitrogen on] just to make sure if we have a really wet year, like we had last year and how this year is turning out, that we still have some nitrogen left over [to ensure sufficient yields]"* – Iowa Farmer.

Source: Houser, M., Gunderson, R. and Stuart, D., 2019. *Farmers' Perceptions of Climate Change in Context: Toward a Political Economy of Relevance*. Sociologia Ruralis, 59(4), pp.789-809.

How are farmers adapting to changing weather? More tile-drainage.

https://www.wisfarmer.com/story/news/2017/05/08/new-sites-added-tile-monitoring-project/101421238/

FIGURE 1. Percent of tile-drained cropland in the upper Midwest, 2012.



From UW Extension Report A4124, Herron and Ruark, 2017, *The Extent of Tile Drainage in Wisconsin*

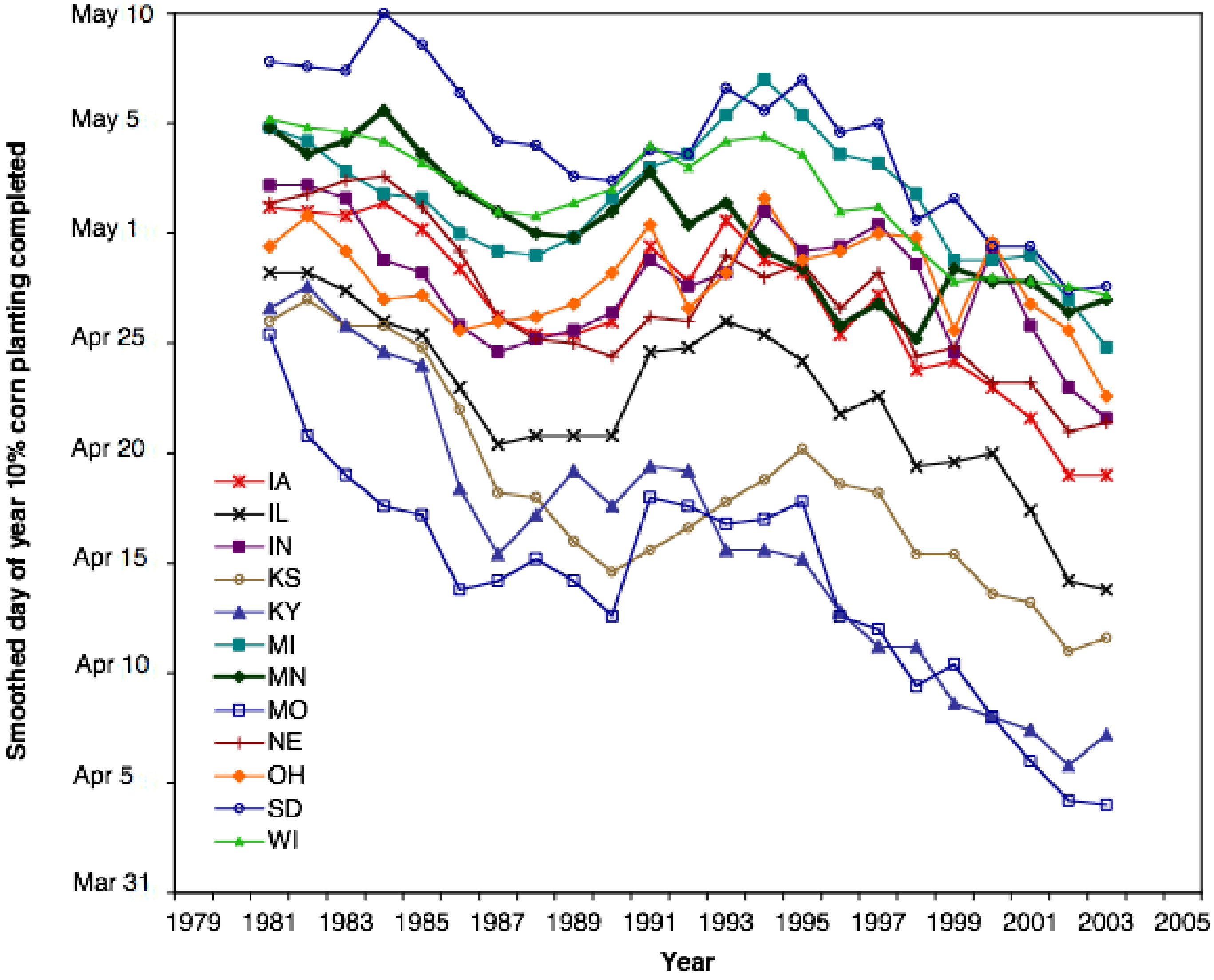
Takeaway Message

Degradation of Midwest Soil and Water Resources

The degradation of critical soil and water resources will expand as extreme precipitation events increase across our agricultural landscape. Sustainable crop production is threatened by excessive runoff, leaching, and flooding, which results in soil erosion, degraded water quality in lakes and streams, and damage to rural community infrastructure. Management practices to restore soil structure and the hydrologic function of landscapes are essential for improving resilience to these challenges.

Extra Slides

State level corn 10% planting completed trends 1979-2005

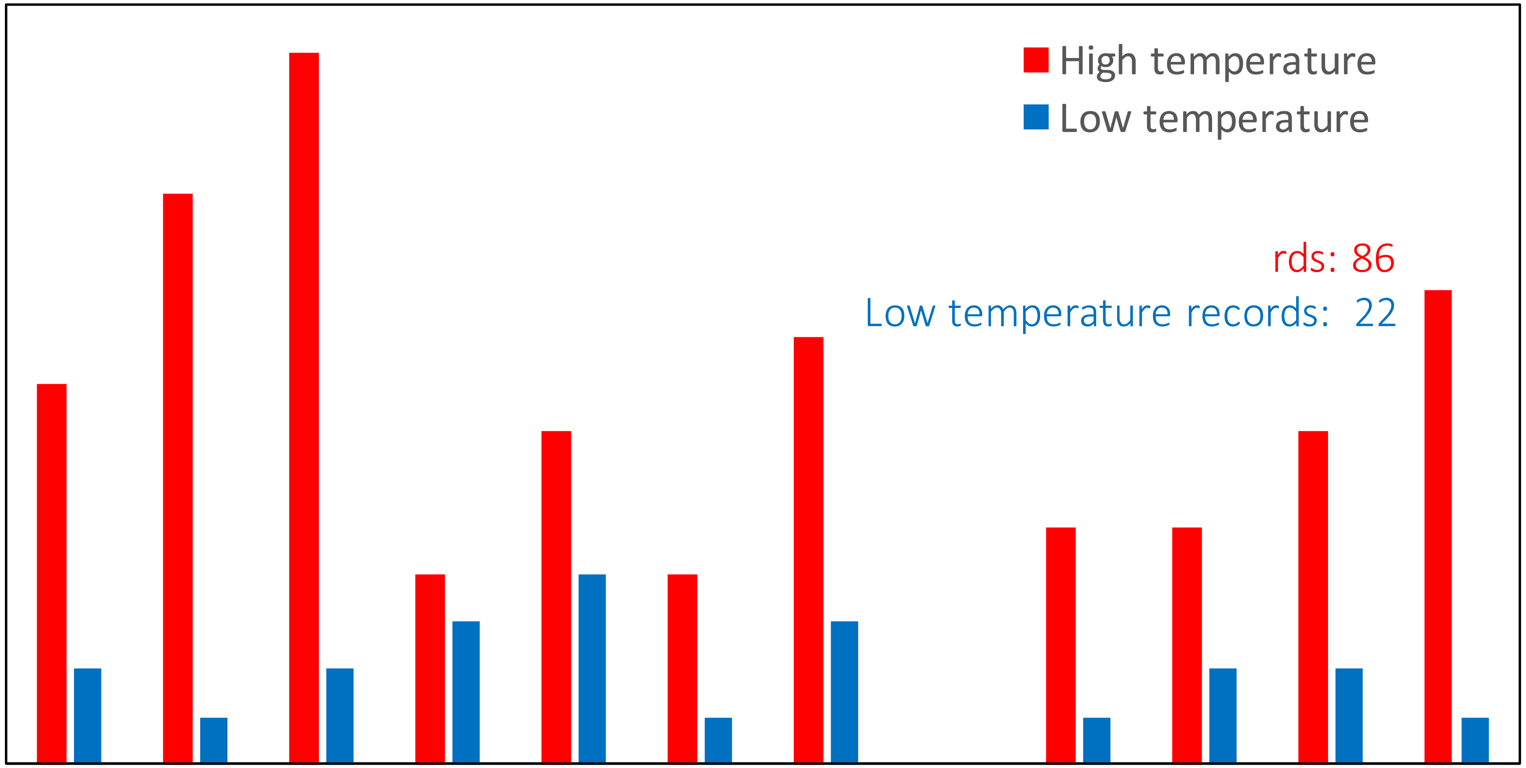


~4-5 days earlier per decade

Contributed to 20-30% of the yield trend

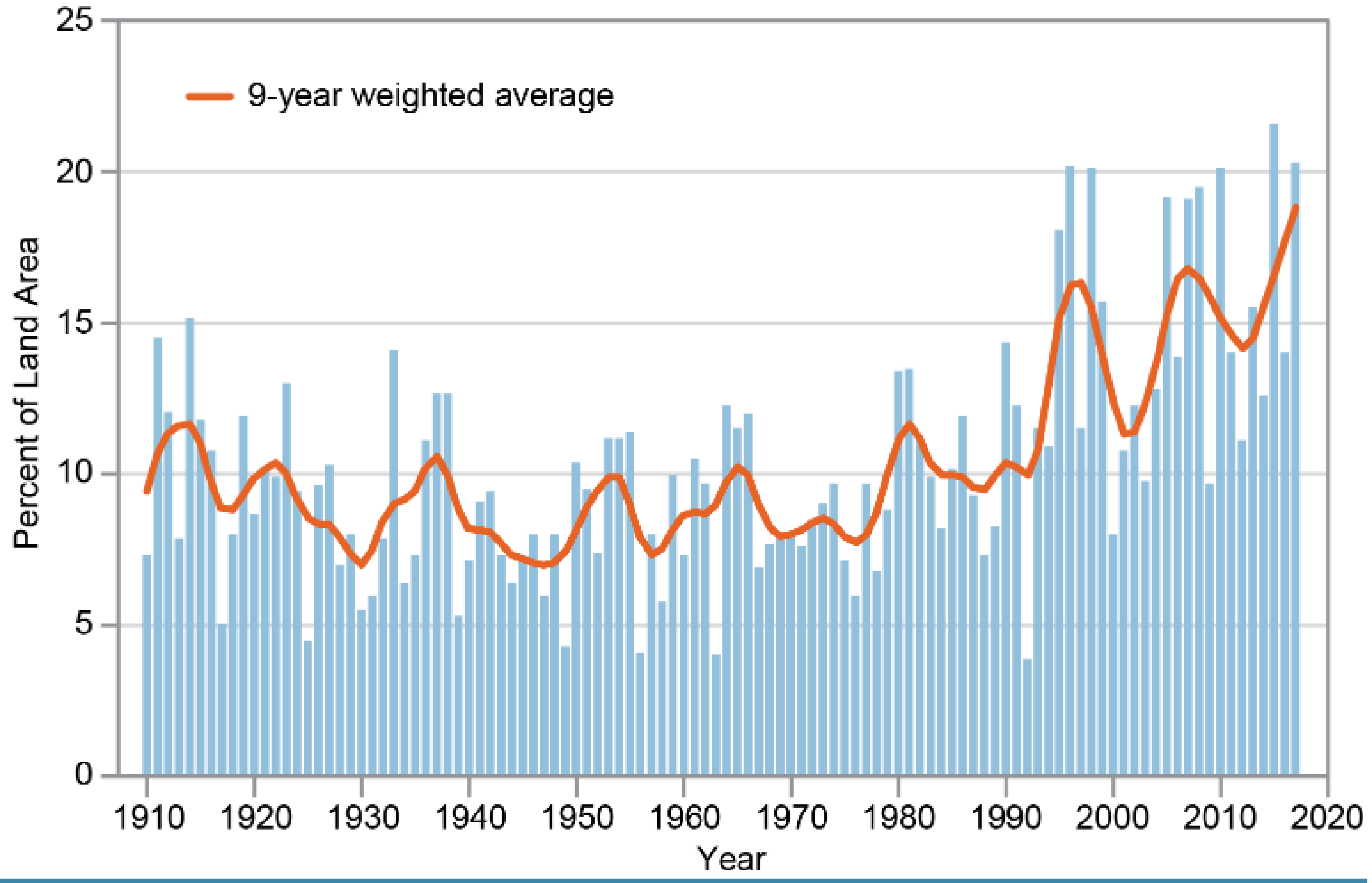
Kucharik, 2006 *Agron. Journal*

Record highs are being set much more frequently than record low temperatures in past 20 years



C. Kucharik, UW-Madison unpublished data

Frequency of 1”, 2” and 3” daily rainfall events is increasing and impacting more land area

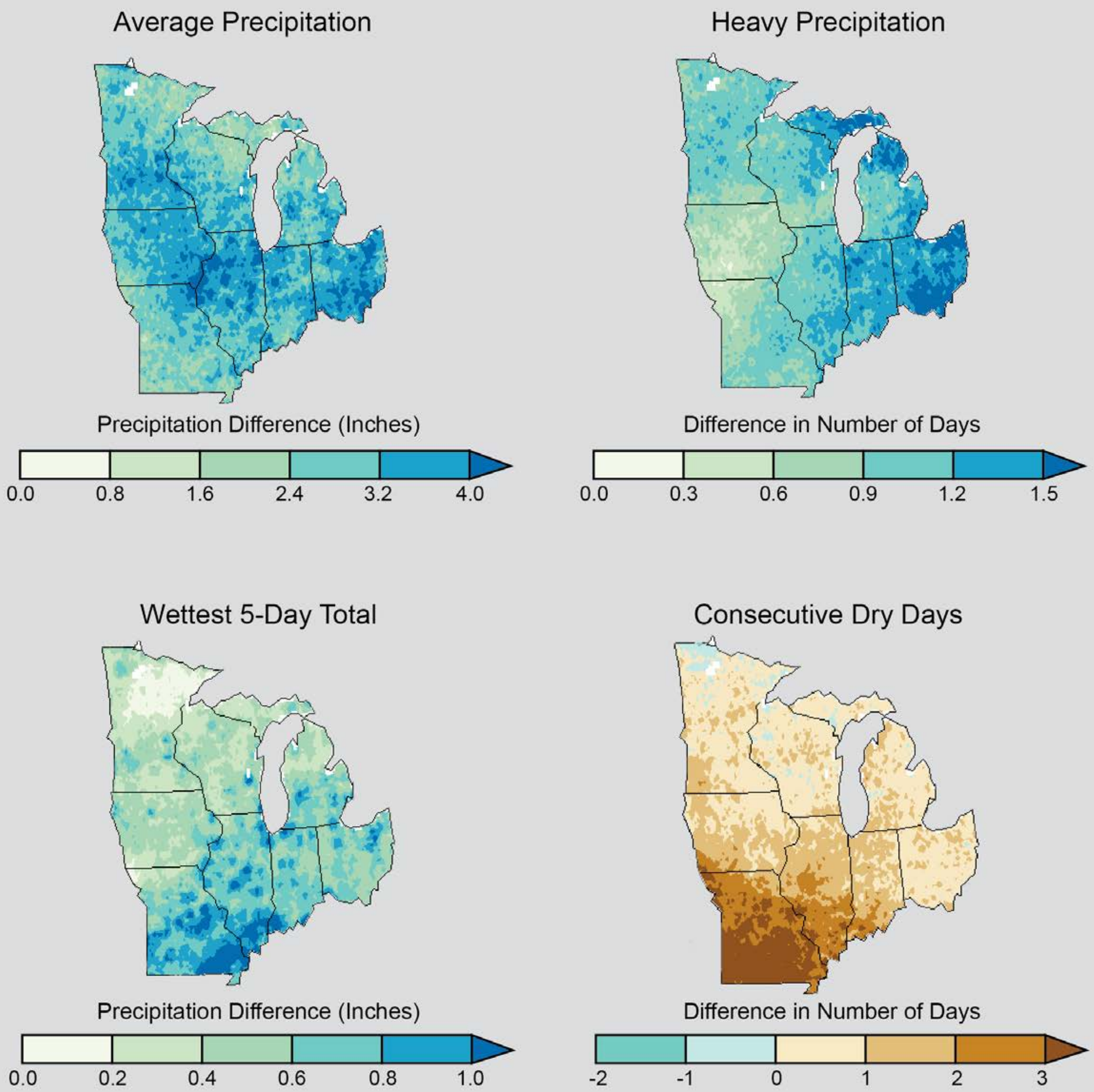


Land Area and Extreme Precipitation

The figure shows the percent of land area in the contiguous 48 states experiencing extreme one-day precipitation events between 1910 and 2017. These extreme events pose erosion and water quality risks that have increased in recent decades. The bars represent individual years, and the orange line is a nine-year weighted average. *Source: adapted from EPA 2016.*[171]

Midwest Precipitation Changes by mid-Century

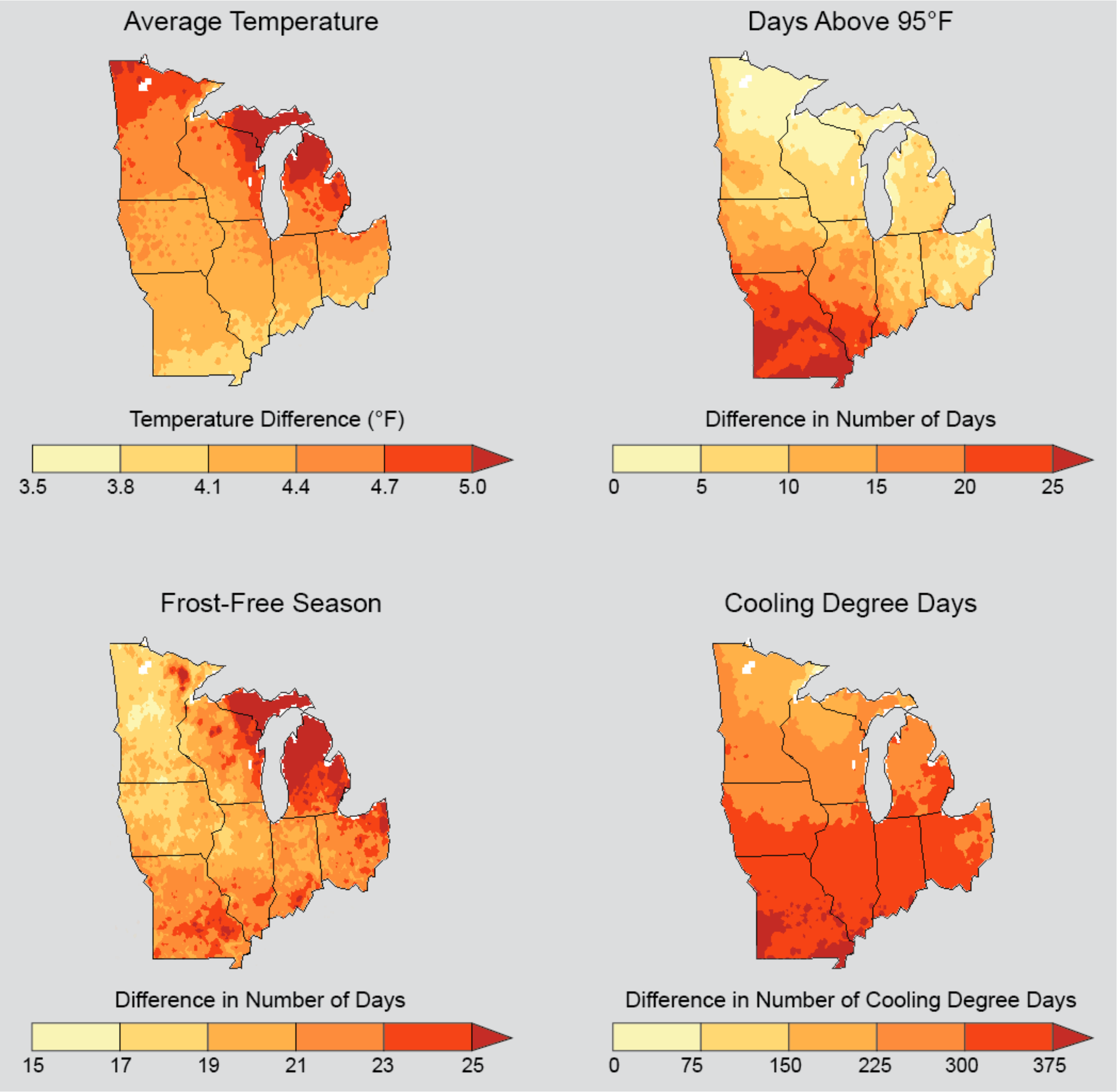
2041-2070 relative to 1971-2000



Source: US Global Change Research Program

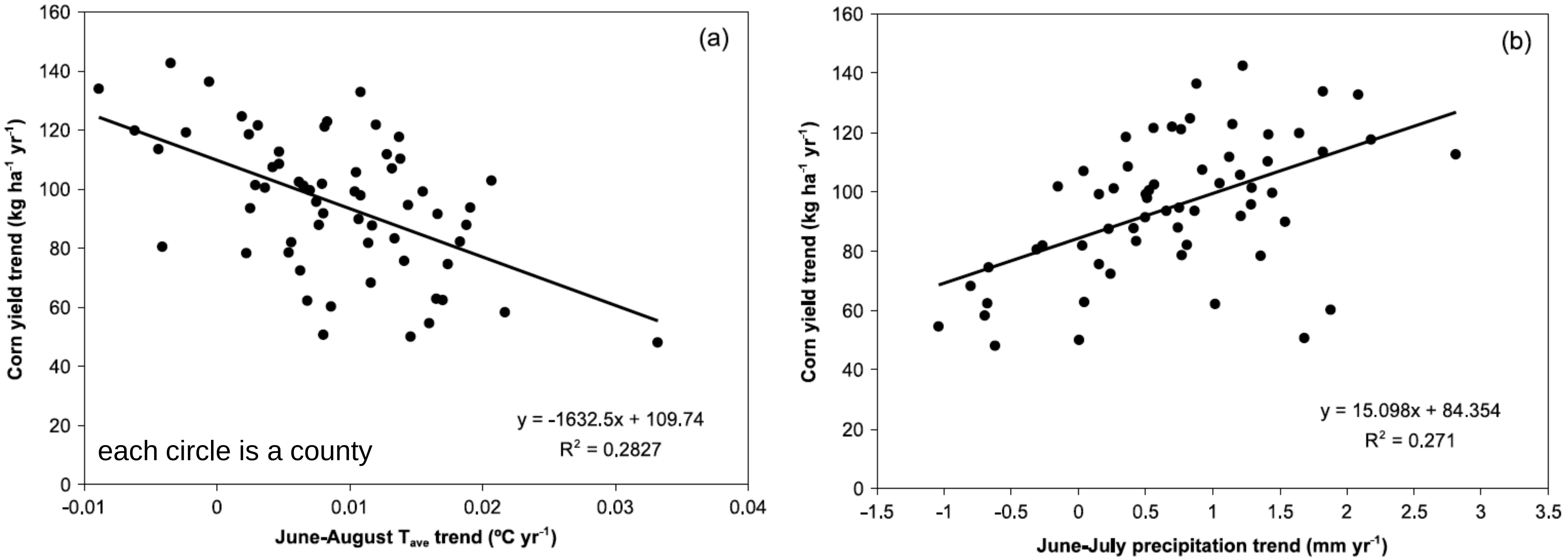
Projected Mid-Century Temperature Changes in the Midwest

2041-2070 compared to 1971-2000



Source: US Global Change Research Program

Wisconsin Maize Yield Trends Impacted by Temperature and Precipitation Trends: 1976-2006

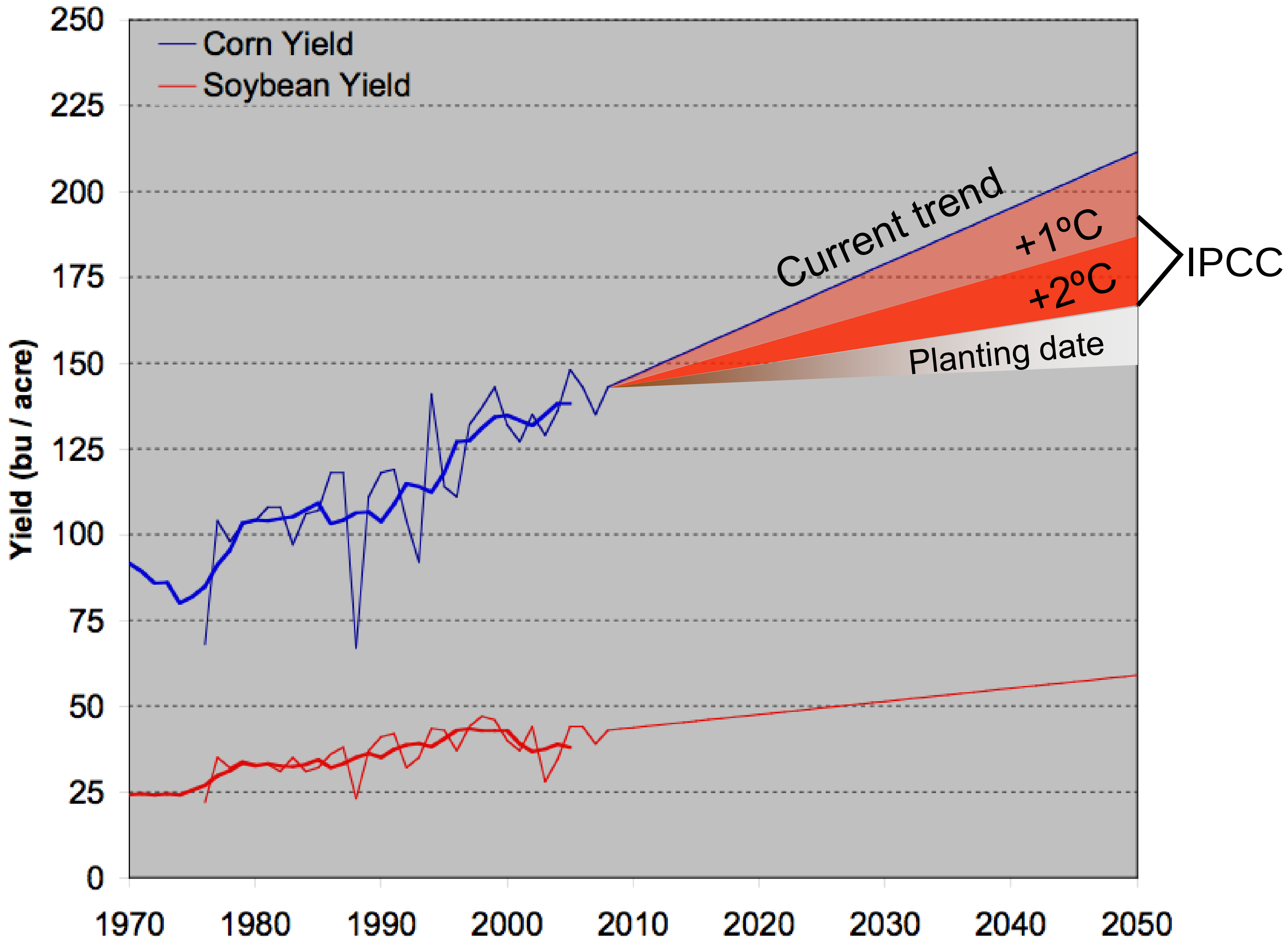


Trends towards cooler & wetter summer favor larger yield gains

Every 1ºC increase in summer temperature causes ~15% decline in yields

Kucharik and Serbin, 2008 *Env Res Letters*

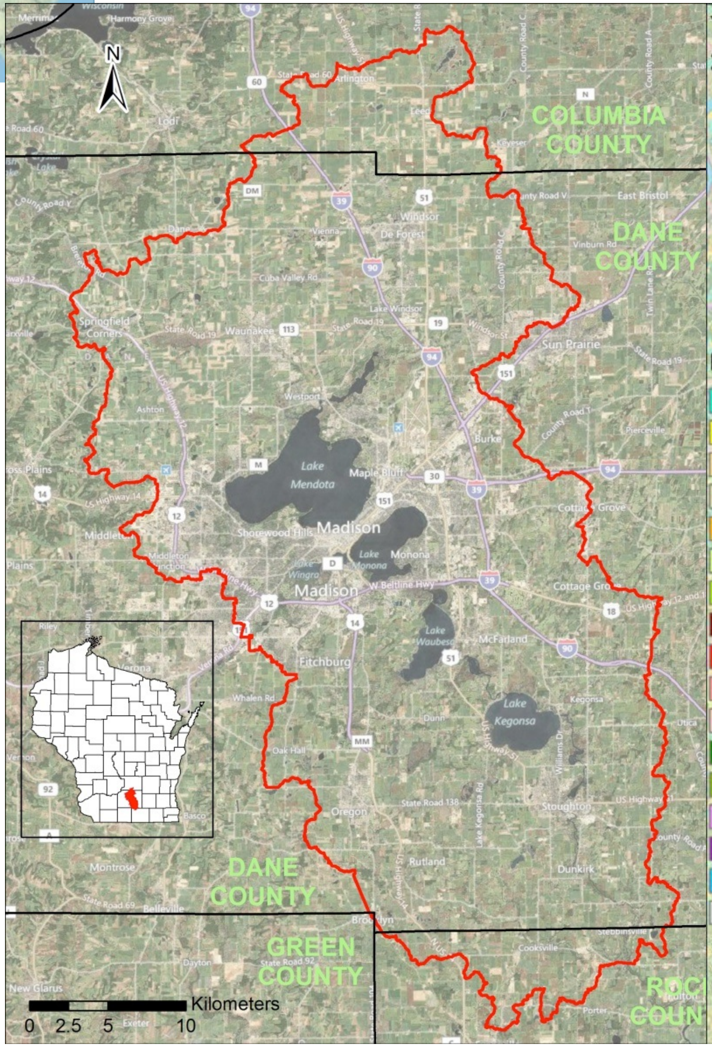
Future summertime warming impacts on productivity?



Yahara River Watershed

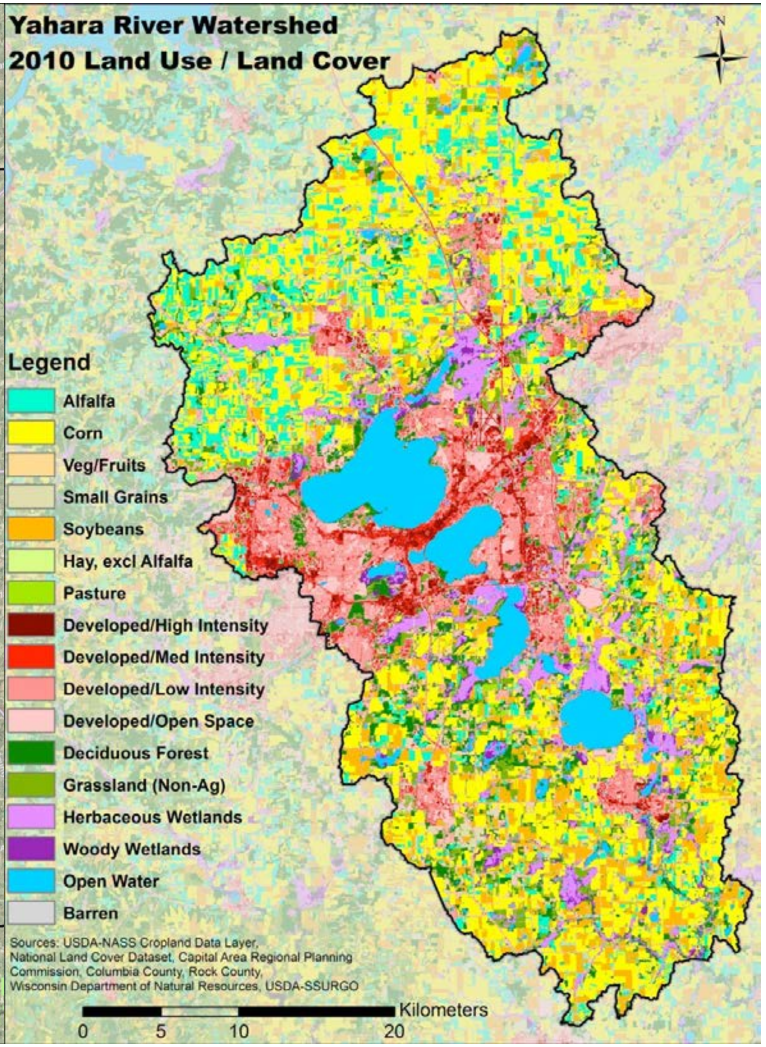
- Heavily Influenced by glaciation
- Urbanizing agricultural region
- Seat of government, flagship university
- Lakes are environmental centerpiece

Aerial Photo (2011)



Imagery from Microsoft Bing Maps

Land Cover (2010)



Data from USDA-NASS

Madison Gas and Electric

ALLIANT ENERGY

Madison

SunPrairie Utilities

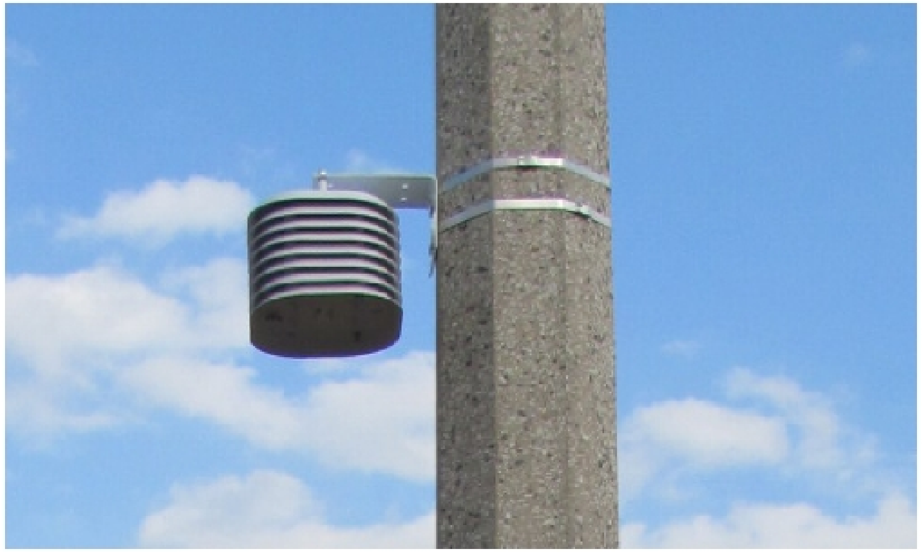
WAUNAKEE UTILITIES

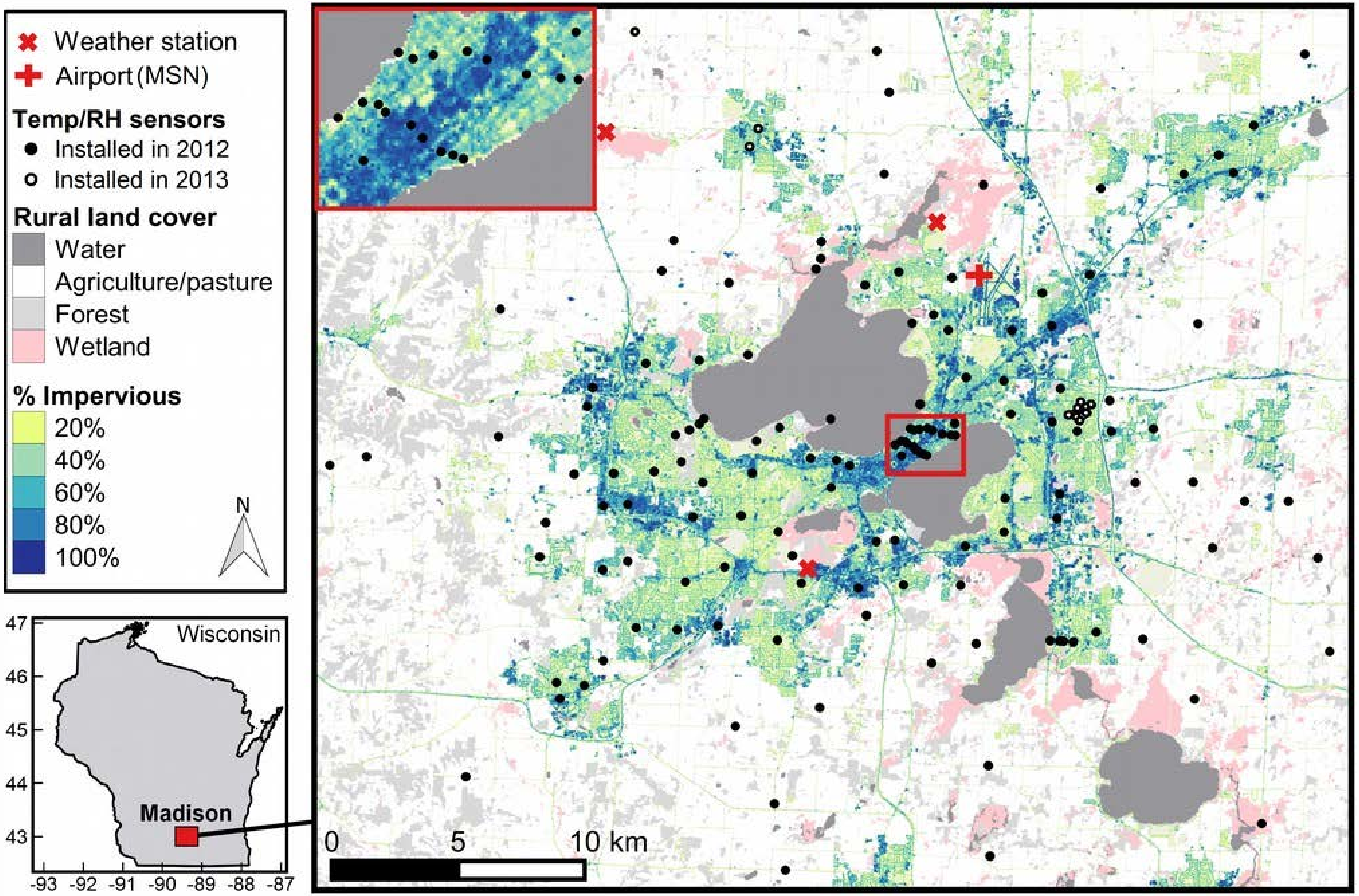
THE UNIVERSITY of WISCONSIN MADISON

COUNTY of DANE WISCONSIN 1839

Fitchburg

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



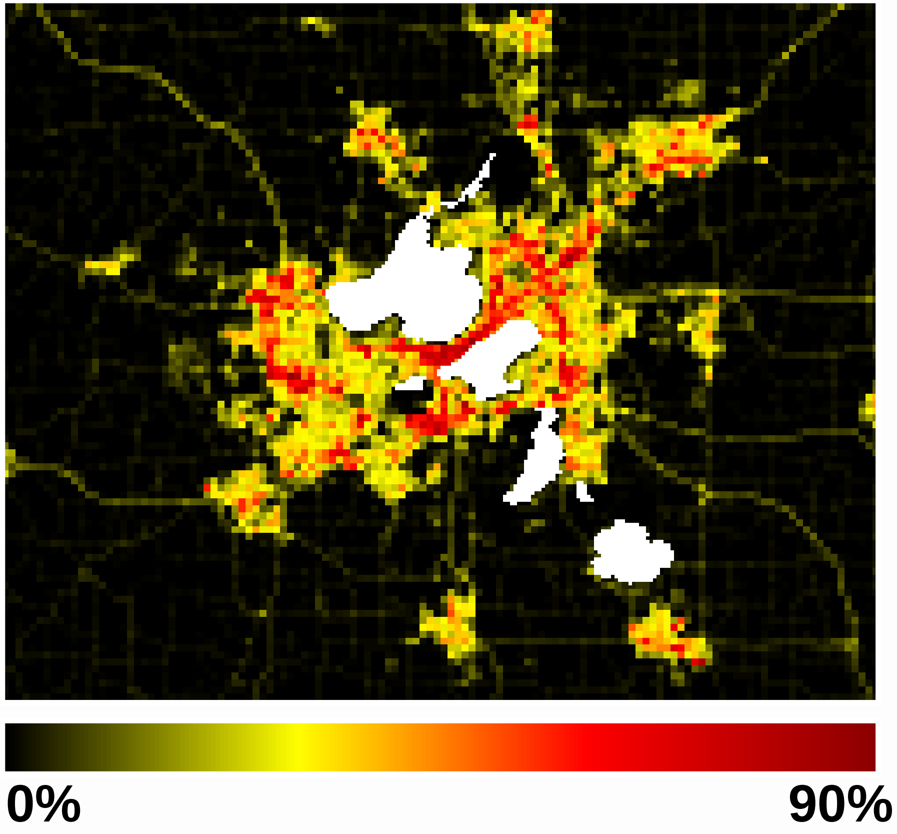


Weather station
Airport (MSN)
Temp/RH sensors
Installed in 2012
Installed in 2013
Rural land cover
Water
Agriculture/pasture
Forest
Wetland
% Impervious
20%
40%
60%
80%
100%
N
Wisconsin
Madison
47
46
45
44
43
-93
-92
-91
-90
-89
-88
-87
0
5
10 km

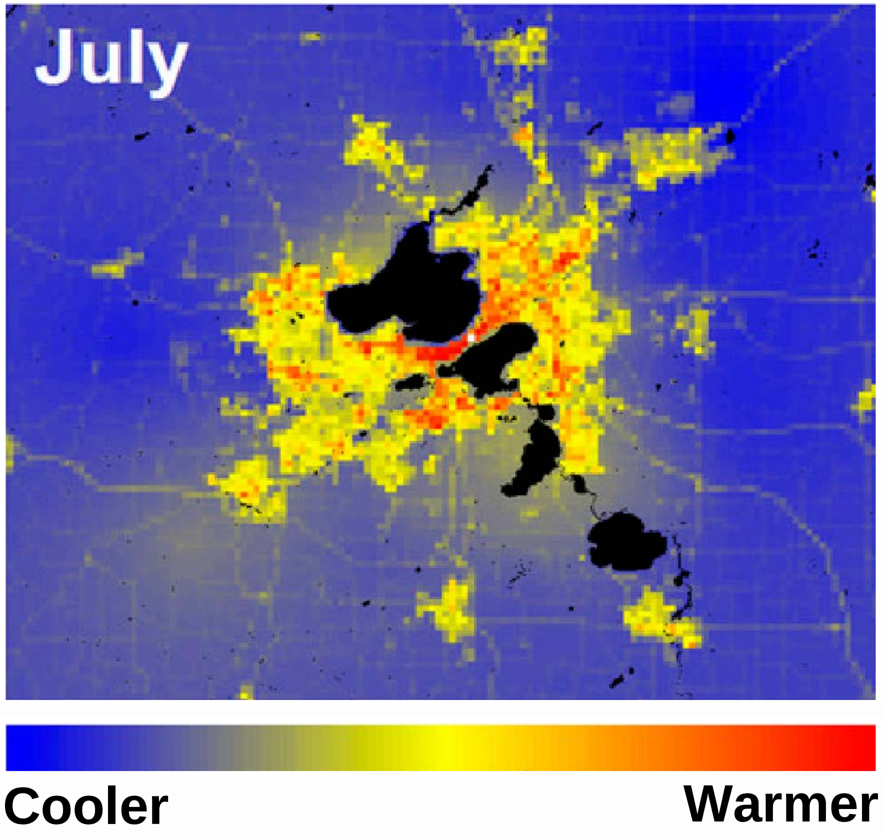
Spatial patterns

Impervious Surface is Extremely Important Driver

% Impervious

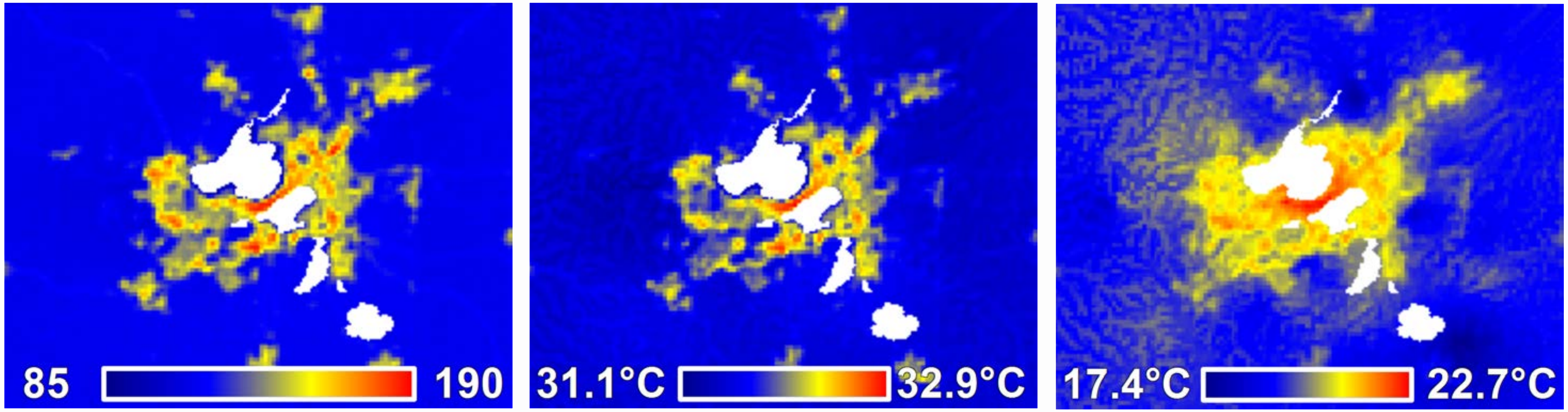


Temperature



Summer 2012

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



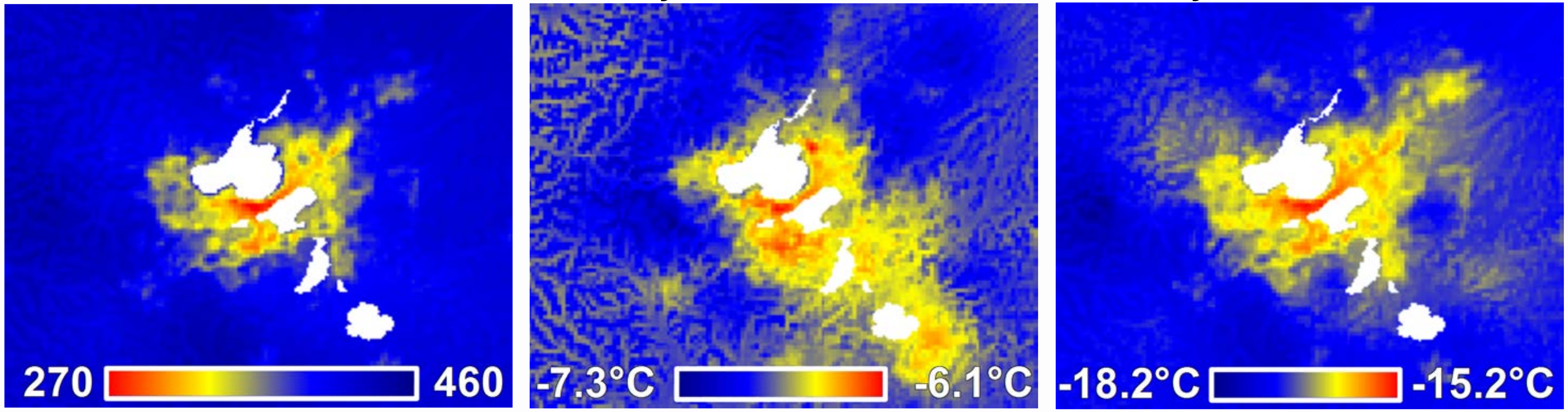
88°F 91.2°F 63.3°F 72.9°F

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*

Winter 2013-14

Hours below 0°F | January T_{max} | January T_{min}



18.9°F 21.0°F -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

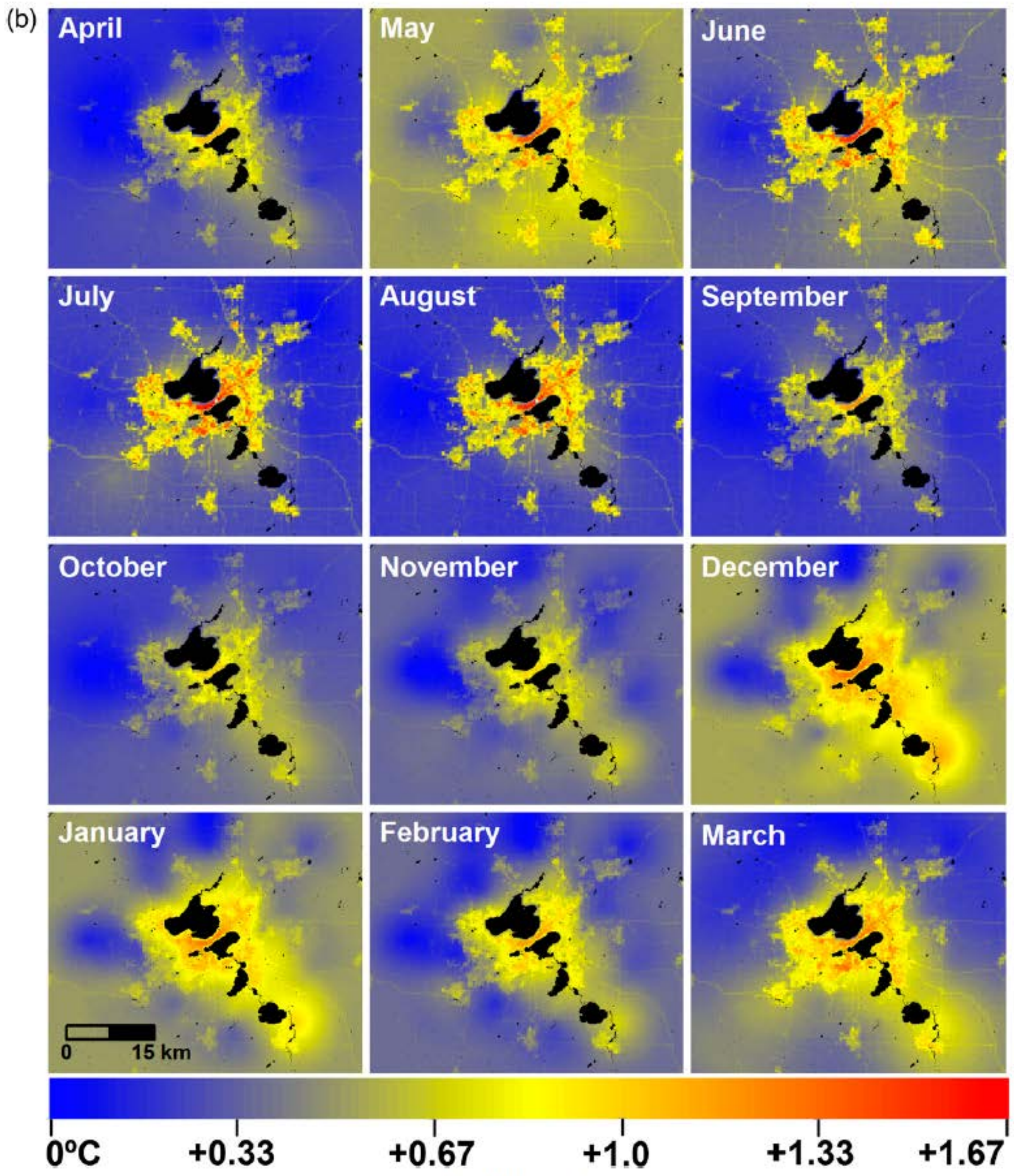


FIG. 4. (*Continued*)

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

Impacts on growing season length: average 2012 to 2014

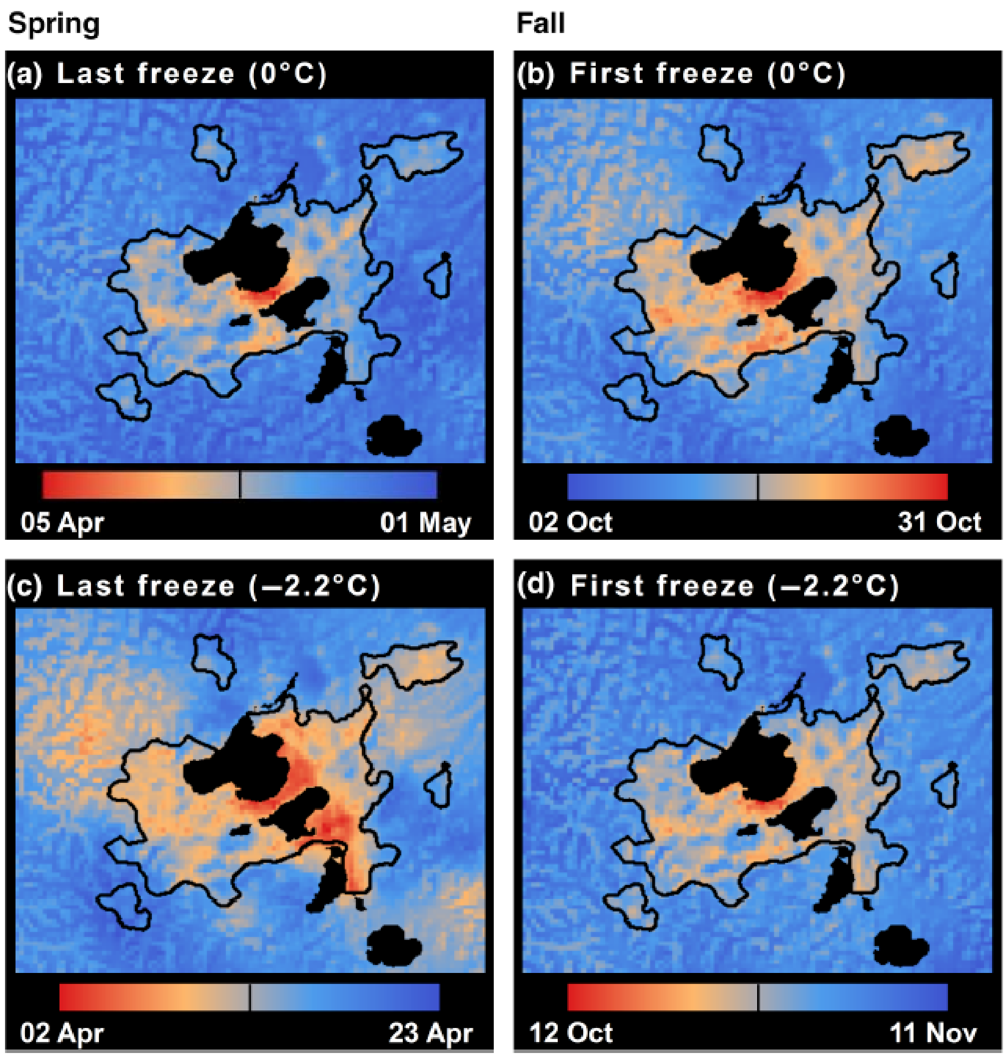
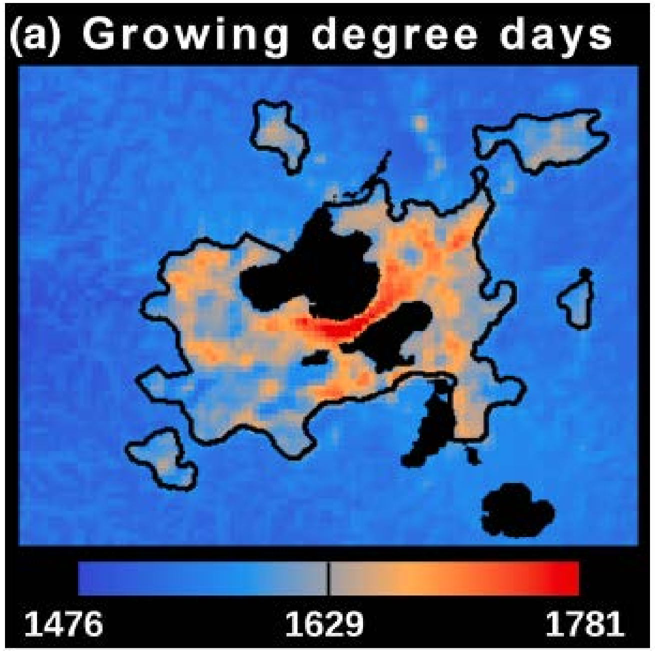


Figure 3. Urban climate effects on the onset of spring and fall in Madison, Wisconsin, interpolated to 400 m resolution using regression kriging. Plots are average (from 2012 to 2014) dates of (a) last spring freeze (0 °C threshold); (b) first fall freeze (0 °C threshold); (c) last spring freeze (–2.2 °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*