Past and projected future impacts of climate on agriculture in the Great Lakes region

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GREAT LAKES INTEGRATED SCIENCES + ASSESSMENTS

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EXTENSION

Climate Change and Food Production

- Historical Precedents?
- Climatological Trends
- Future Projections
- Agricultural Impacts

"Weather remains among the most important uncontrollable factors involved in agricultural production systems…"

A Global Challenge

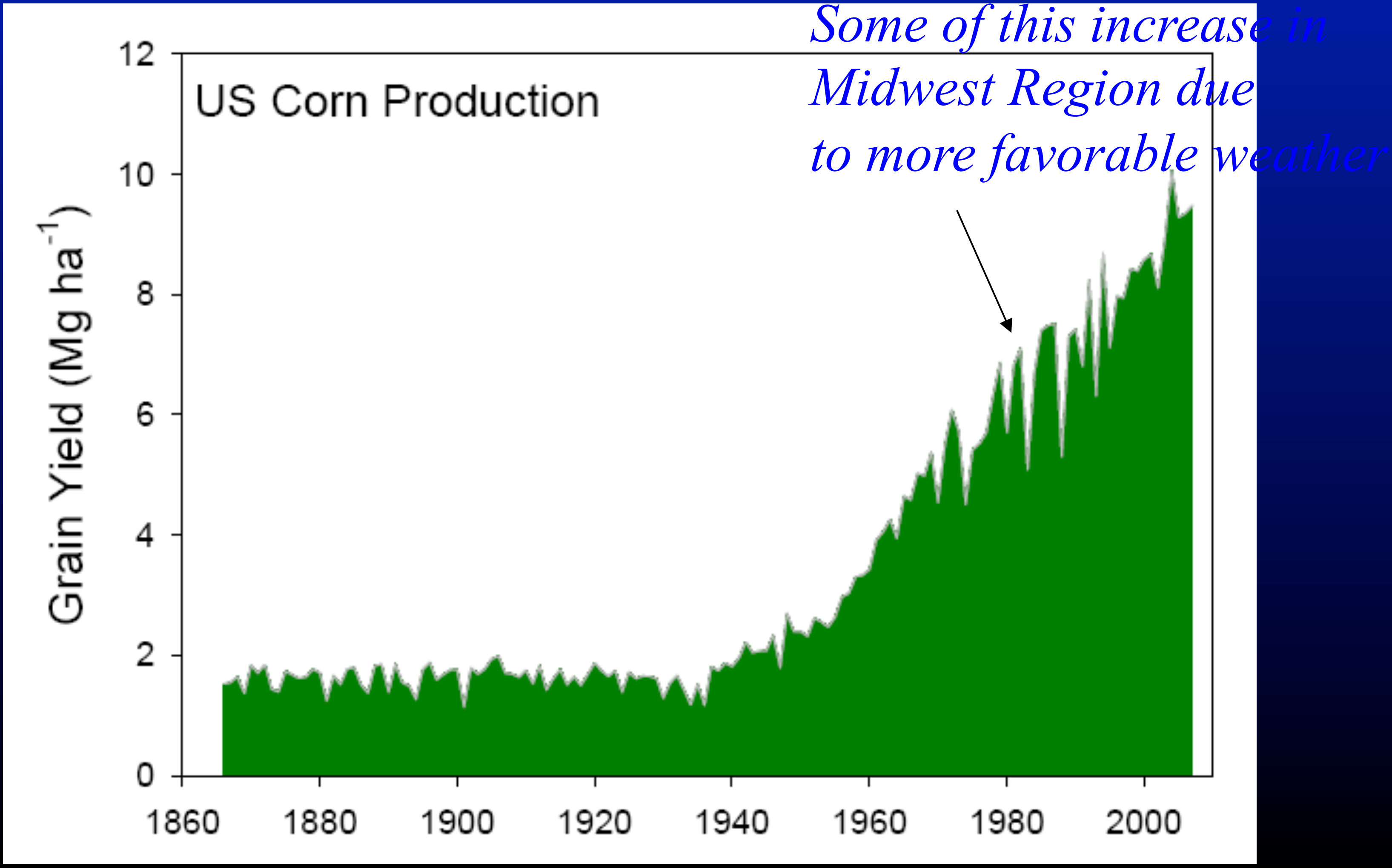
- sustainably increase the net photosynthetic productivity of managed landscapes.

- Crop yields have risen dramatically in recent decades
  - genetic improvements
  - management changes
    - More fertilizers
    - more pesticides
    - better equipment
    - better agronomic knowledge.

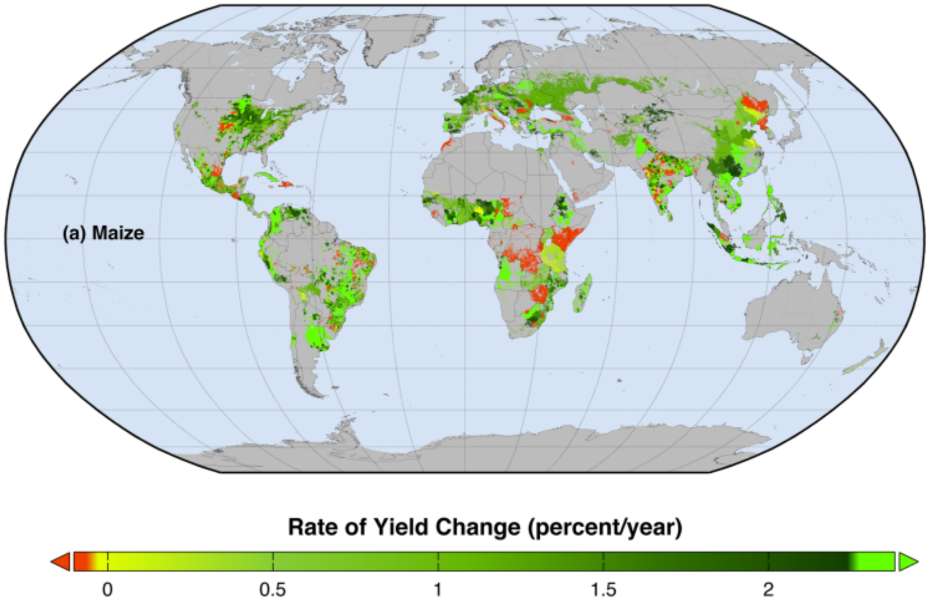
A Global Challenge (2)

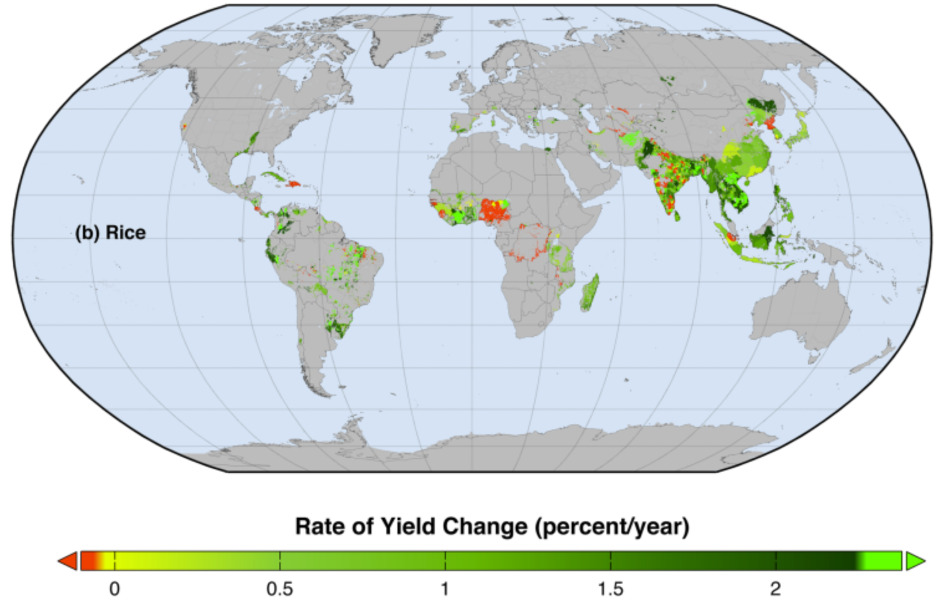
- However, the likelihood of continuing the current yield trajectory is uncertain
- 80% plateau of theorestical yield potential
- Unsustainable practices
- Wiser stewardship

Improvements in Technology have led to Major Increases in Agronomic Productivity

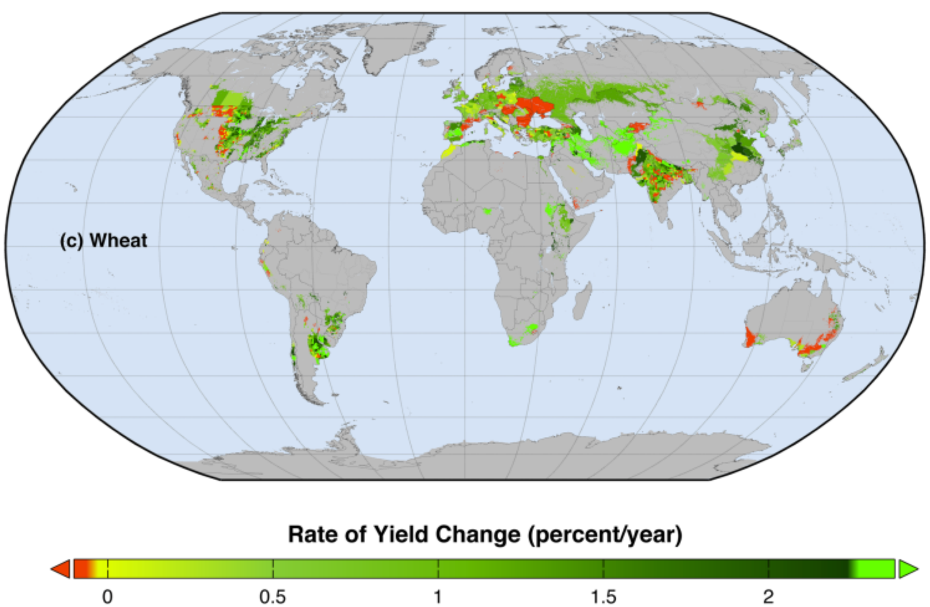


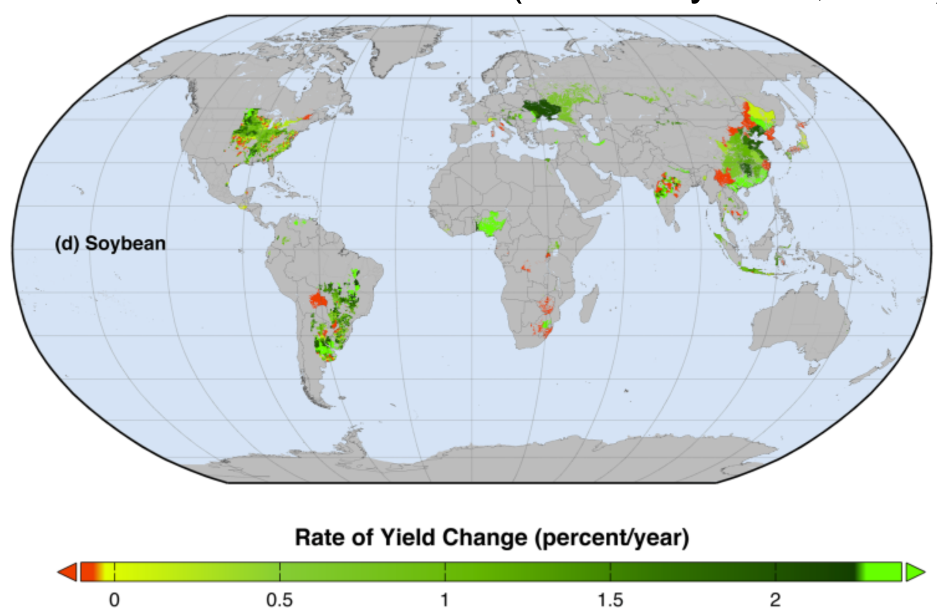
Crop Yield Changes, 1961-2008

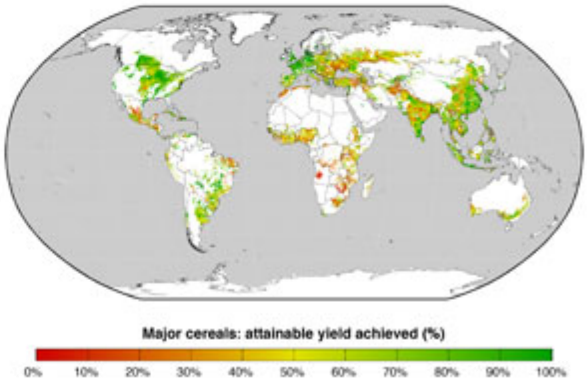




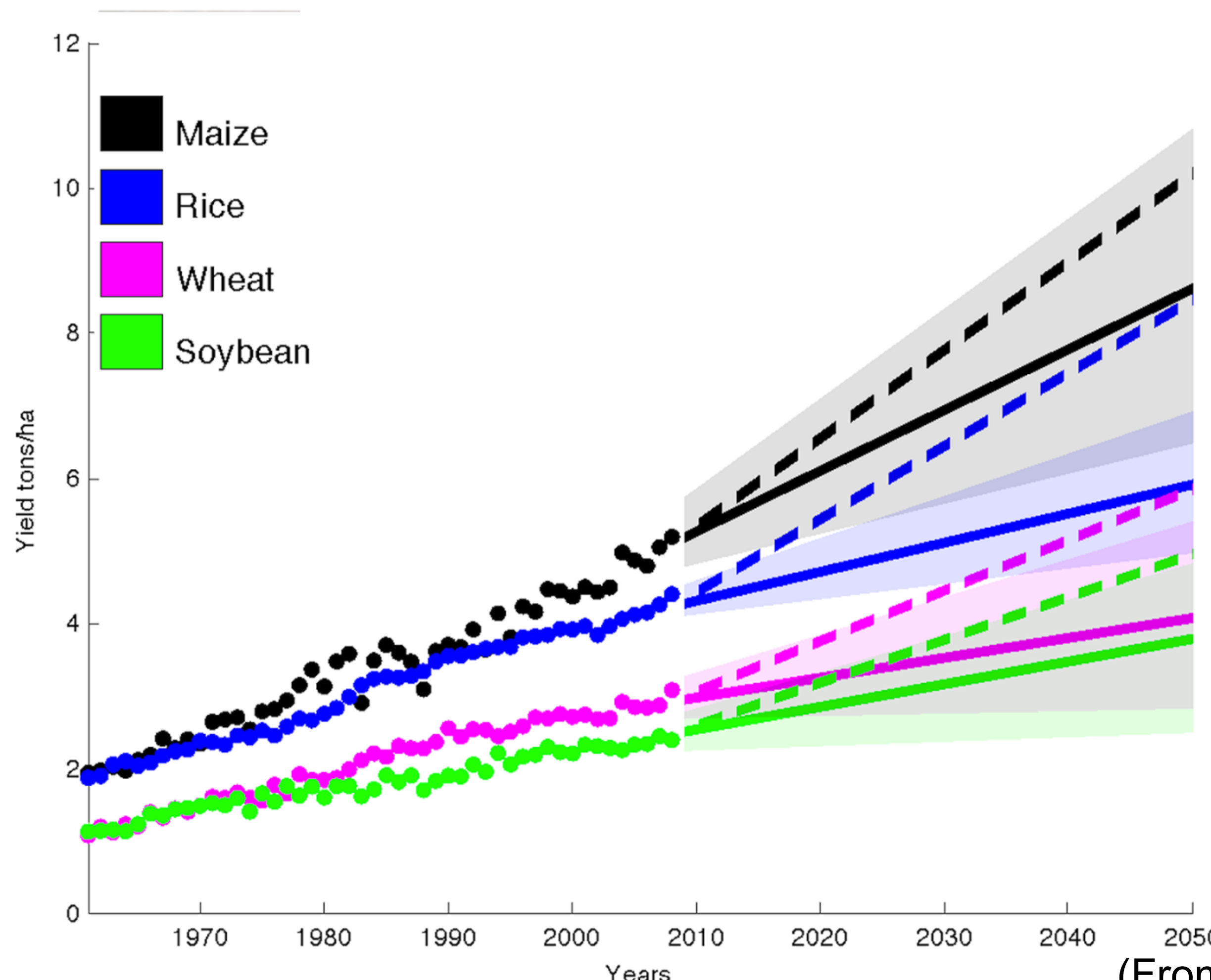
(From Ray et al., 2013)







Global production is still increasing...but can it keep up in the future?



(From Ray et al., 2013)

Historical Precedents?

Some Climate-Related Historical Landmarks

• 50,000 BC	Australia settled by humans, climate shift?
• 10,000 BC	Natufians abandon hunting/gathering for labor intensive subsistence ag. (Mesopotamia)
• 8,000 BC	Humans cross land bridge from Asia to North America
• 6,400 BC	200 year drought forces abandonment of ag. settlements in Mesopotamia
• 5,500 BC	Catastrophic flood in Black Sea basin (Great Flood?), beginning of ag. in Europe
• 4,000 BC	Advent of irrigation in Tigris/Euphrates basin
• 2,200 BC	Catastrophic drought terminates early bronze age civilizations in Palestine, Greece, Egypt

Some Climate-Related Historical Landmarks (continued)

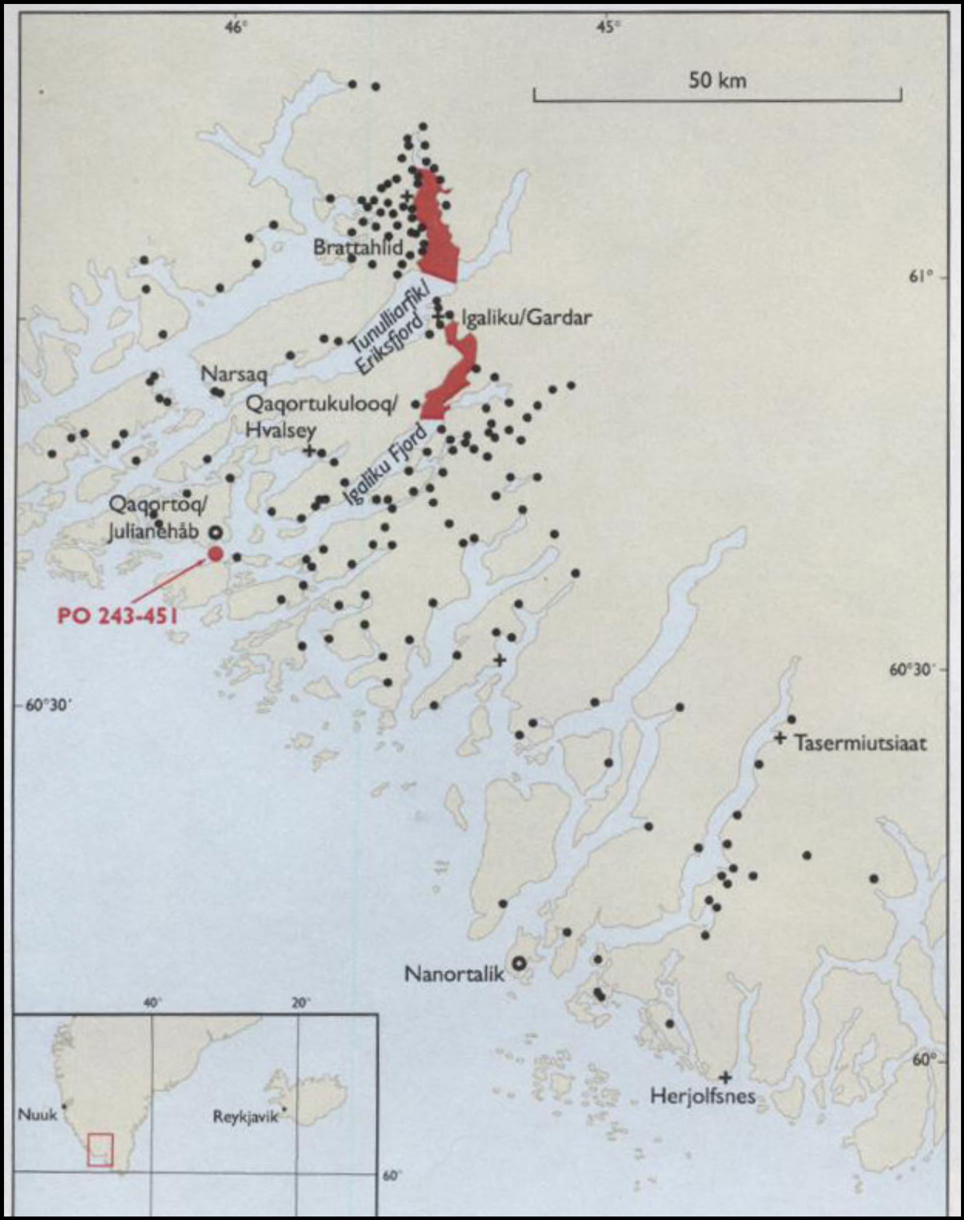
• 900 AD	Collapse of Mayan civilization in Central America (drought)
• 986 AD	Settlement of Greenland by Norse
• 1,400 AD	End of Viking settlement in Greenland
• 1,300-1,900 AD	‘Little Ice Age’

Early Human Response Strategies to Climate Change

1) Somehow adapt to changes (new food sources, new crops, technologies, etc.)

2) Move to more suitable area (‘habitat tracking’)

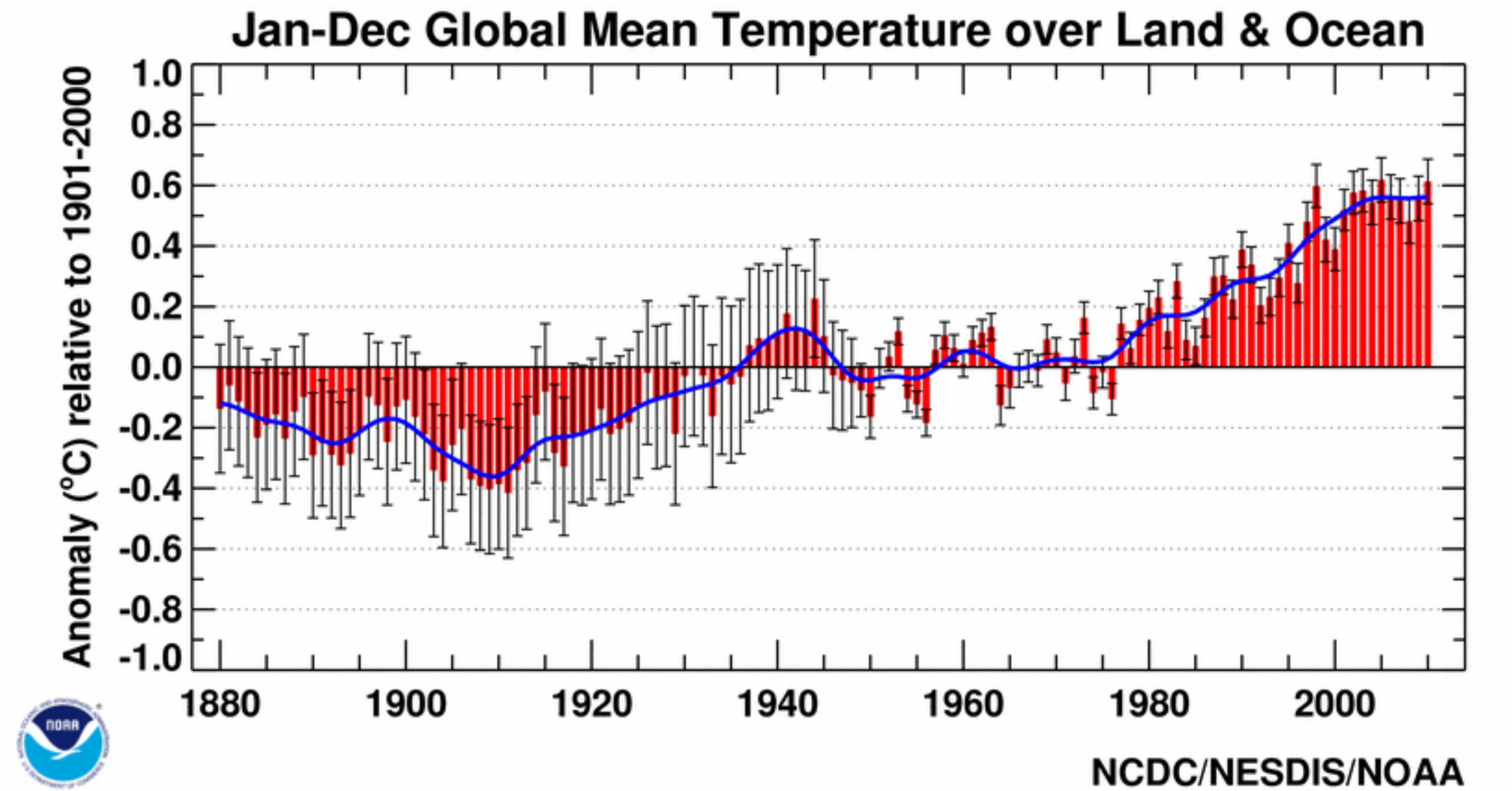
Viking Settlement in Greenland, 986-1400 AD



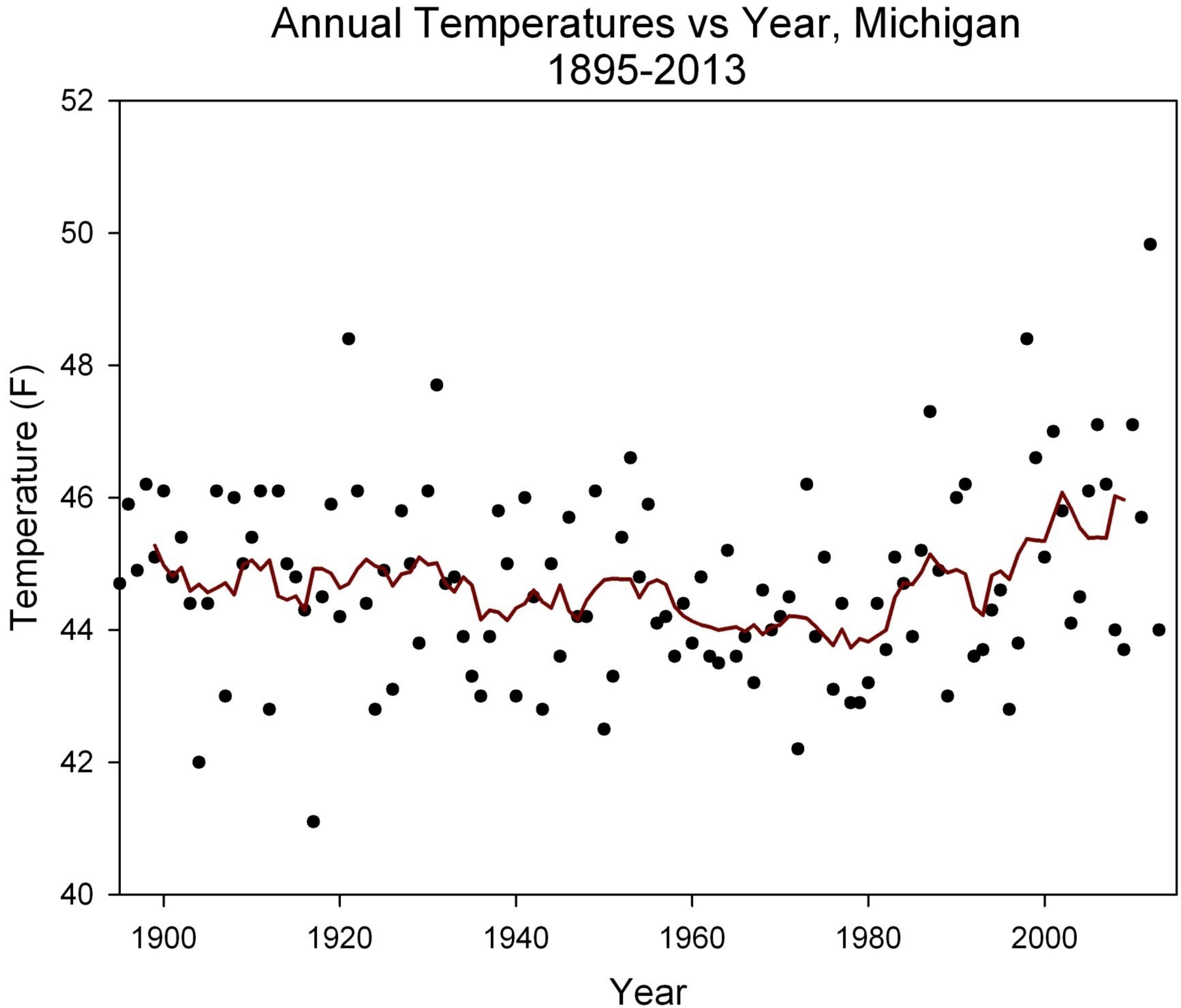
Viking Settlement in Greenland Historical Landmarks

• 986 AD	Colony founded by Eric the Red, when 14 of 32 ships with 400-500 people reach SW Greenland from Iceland.
• 1124 AD	Ordination of bishop in eastern settlement
• 1200 AD	Settlements reach maximum population of 3000-6000
• 1308 AD	First of several multi-year cool periods
• 1361 AD	End of western settlement
• 1400 AD	End of remaining settlements in Greenland
• 1300-1900 AD	'Little Ice Age'

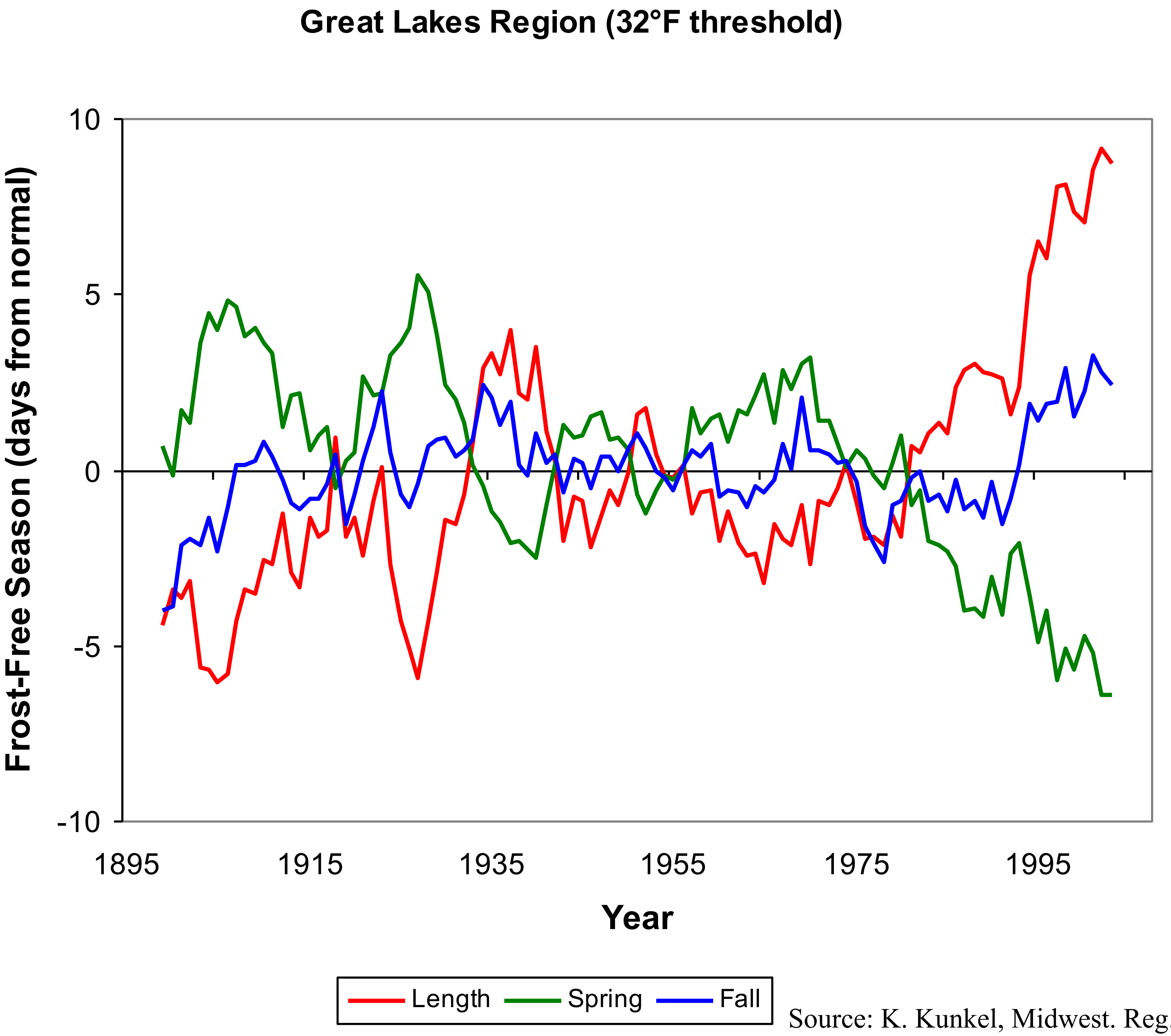
Historical Trends



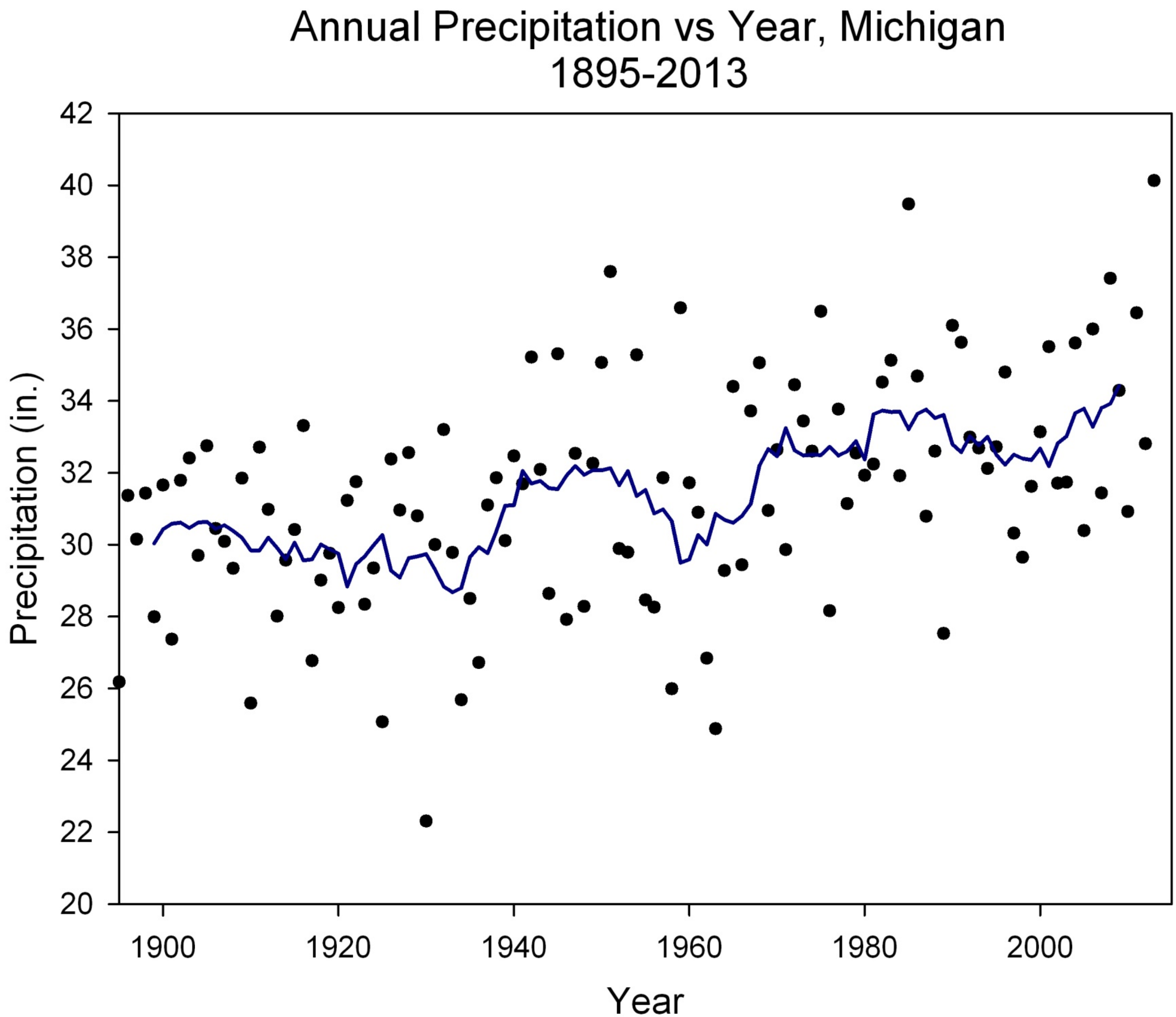
Jan-Dec Global Mean Temperature over Land & Ocean
Anomaly (°C) relative to 1901-2000
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1880
1900
1920
1940
1960
1980
2000
NCDC/NESDIS/NOAA



Annual Temperatures vs Year, Michigan
1895-2013
Temperature (F)
40
42
44
46
48
50
52
1900
1920
1940
1960
1980
2000
Year



Source: K. Kunkel, Midwest. Reg. Clim. Center

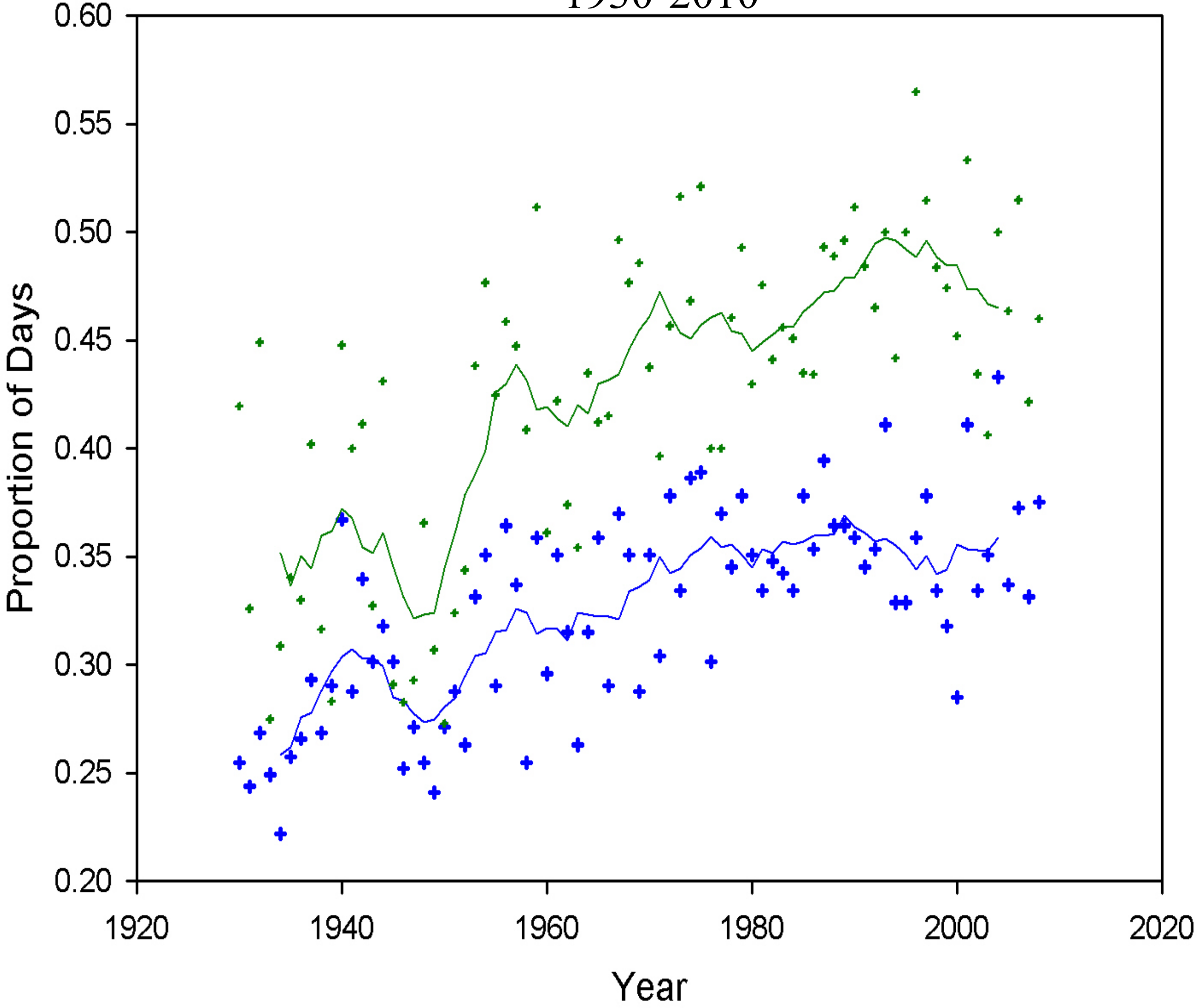


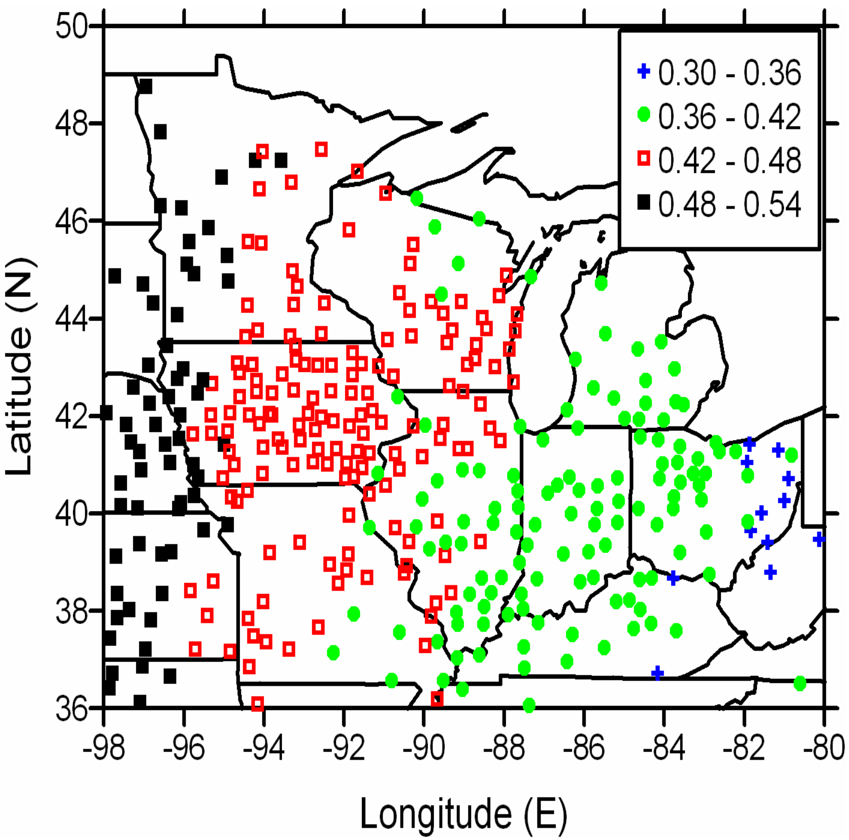
Annual Precipitation vs Year, Michigan
1895-2013
Precipitation (in.)
Year
20
22
24
26
28
30
32
34
36
38
40
42
1900
1920
1940
1960
1980
2000

Frequency of Wet Days and Wet/Wet Days

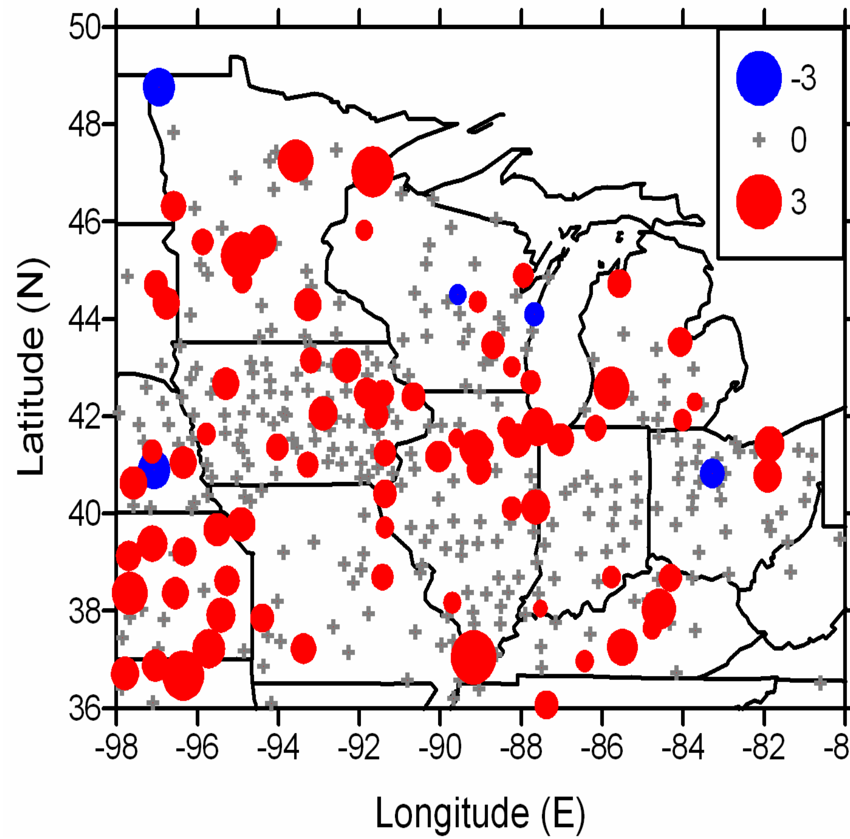
Caro, MI

1930-2010





Mean fraction of annual precipitation derived from10 wettest days
1971-2000



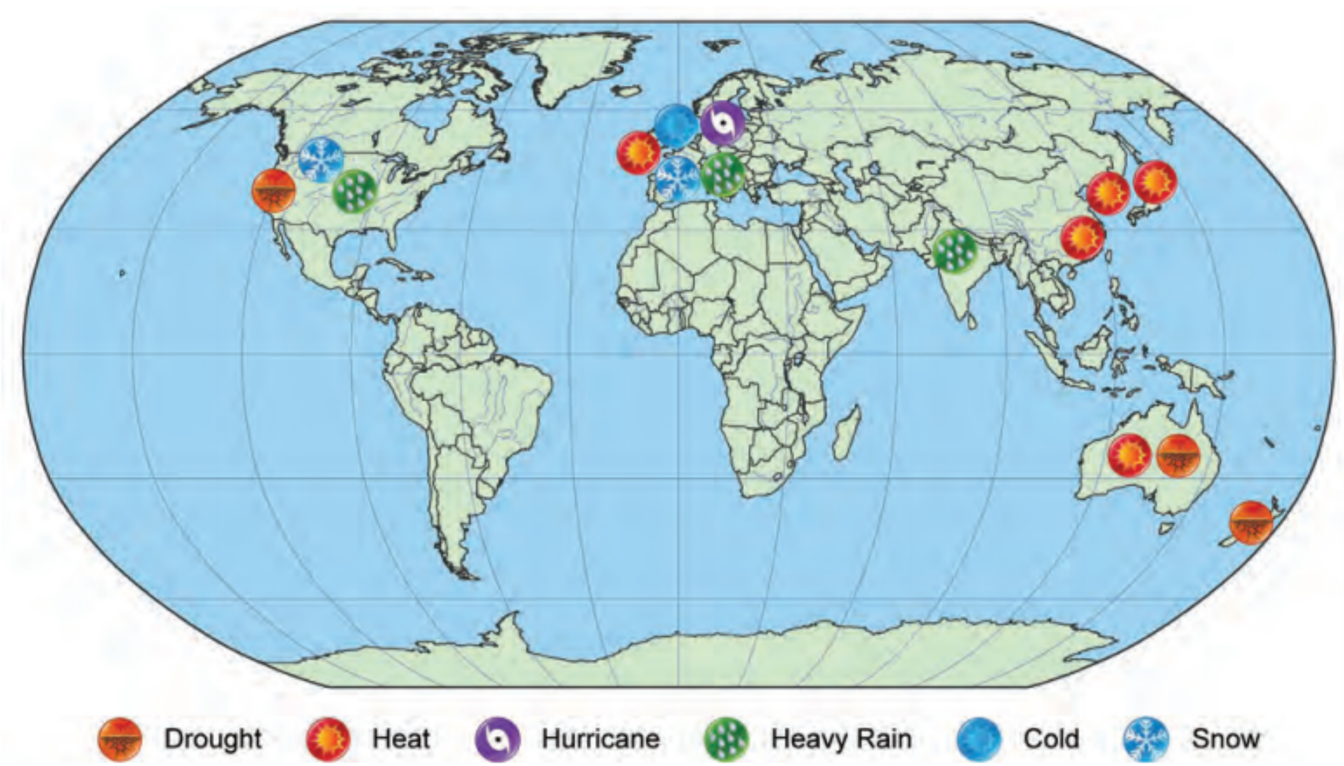
Trend in sum of the top-10 wettest days in a year (%/decade)
1901-2000

(Pryor et al., 2009)

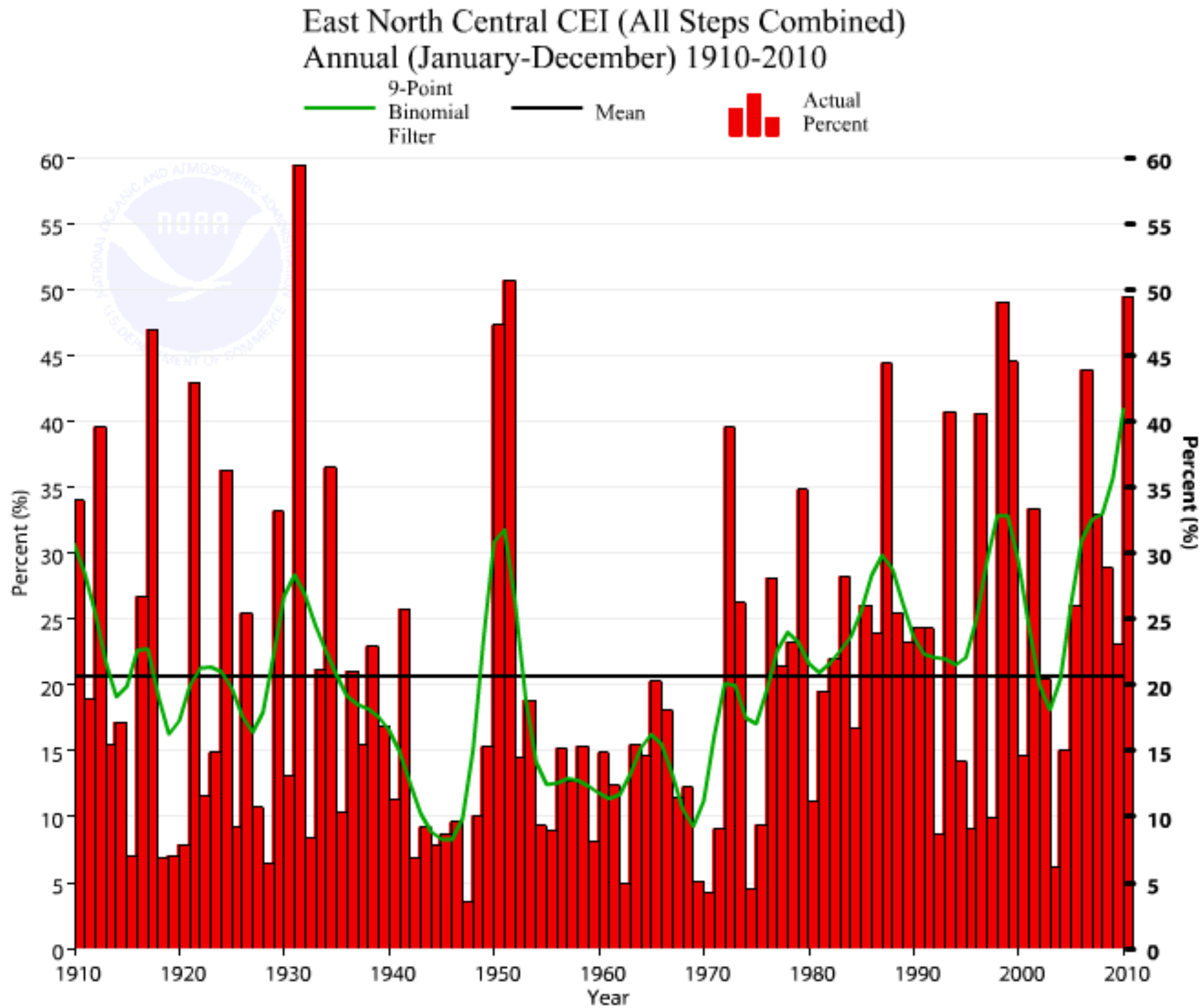
Impacts of Climatic Variability

Past history suggests that society may be able to cope/adapt with steady climatic changes, but possibly not with changes in variability (e.g. changes in extremes, storminess)

Explaining Extreme Weather Events, 2013



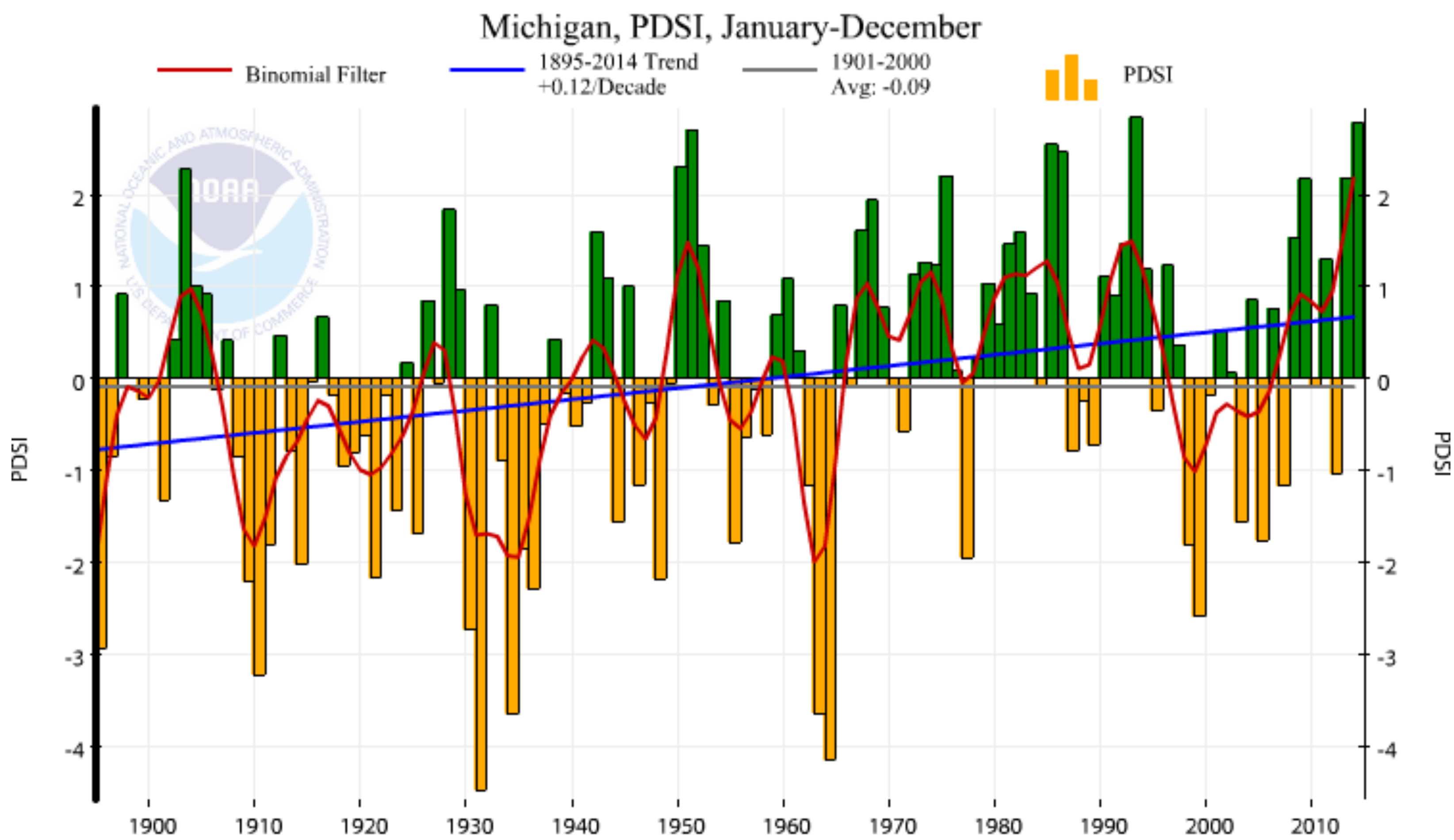
(From Herring et al., 2014)



(Source: NCDC, 2011)

Drought Severity vs. Year

Michigan, 1895-2014



Future Projections

Projected Annually-Averaged Temperature ChangeProjections

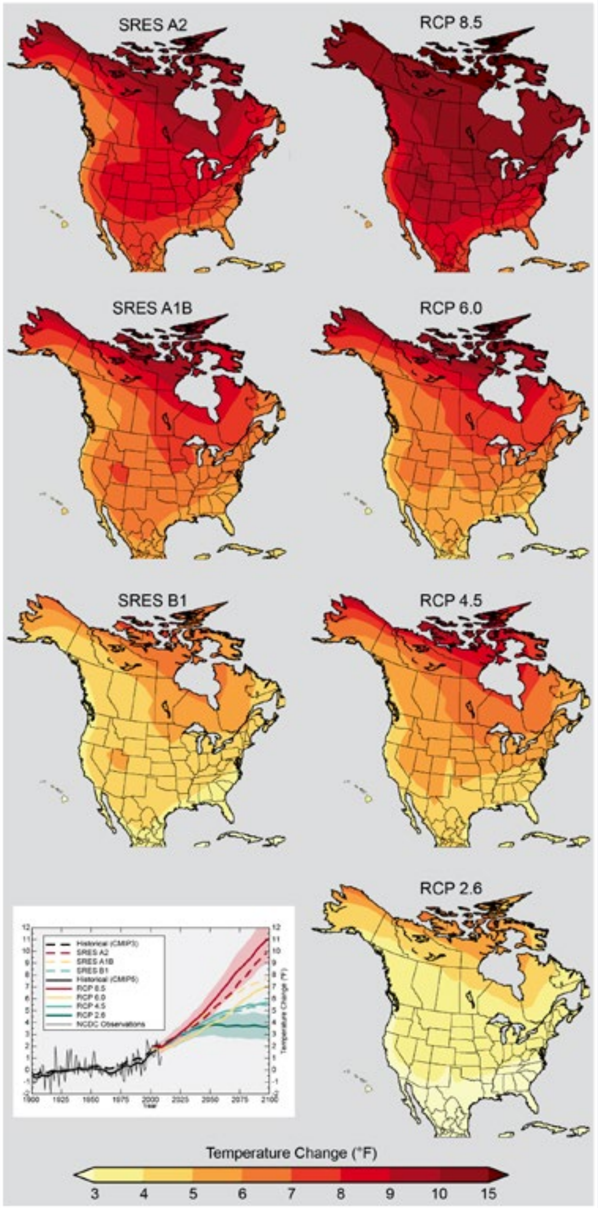
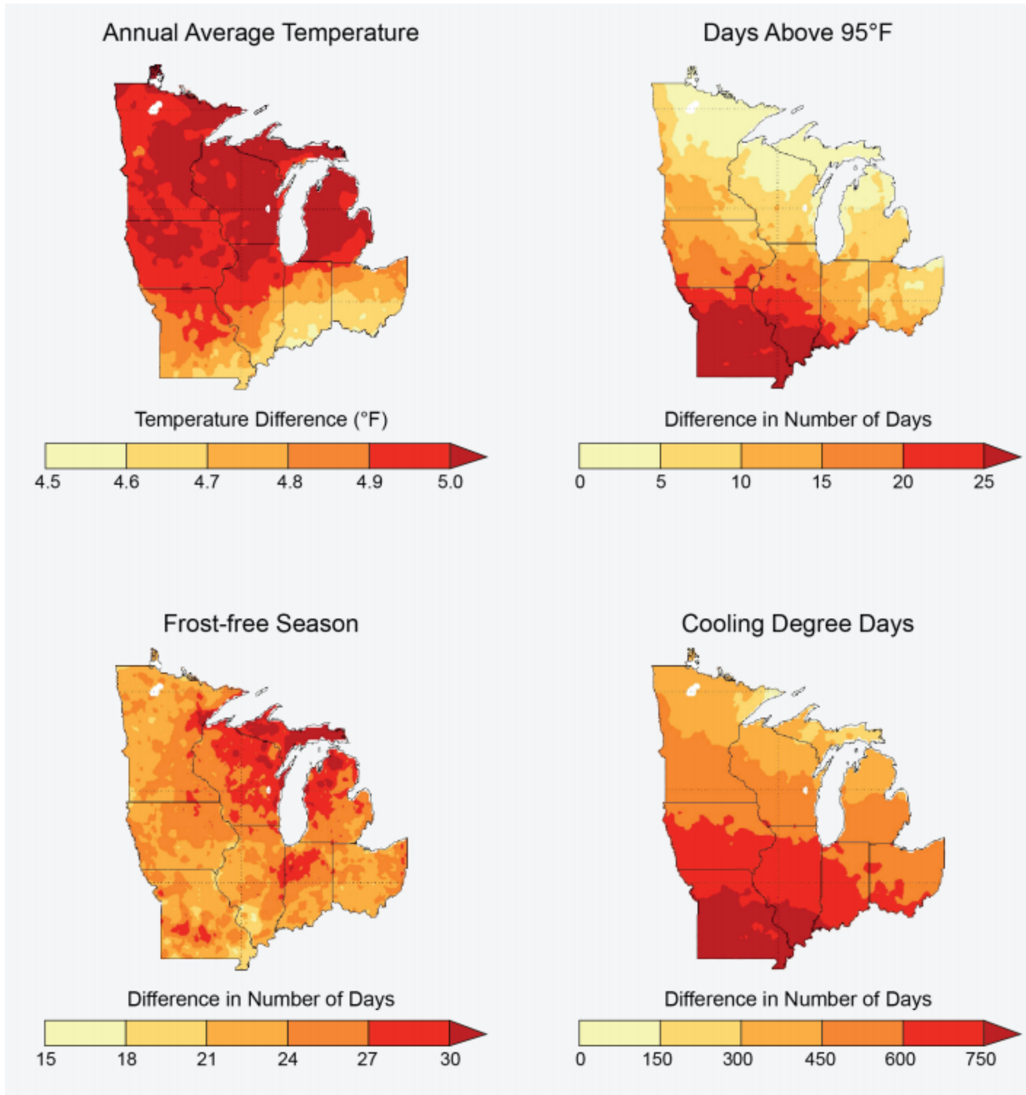


Figure 20. Projected change in surface air temperature at the end of this century (2071-2099) relative to the end of the last century (1970-1999). The older generation of models (CMIP3) and SRES emissions scenarios are on the left side; the new models (CMIP5) and scenarios are on the right side. The scenarios are described under Supplemental Message 5 and in Figure 19. Differences between the old and new projections are mostly a result of the differences in the scenarios of the emission of heat-trapping gases rather than the increased complexity of the new models. None of the new scenarios are exactly the same as the old ones, although at the end of the century SRES B1 and RCP 4.5 are roughly comparable, as are SRES A1B and RCP 6.0. (Figure source: NOAA NCDC / CICS-NC).

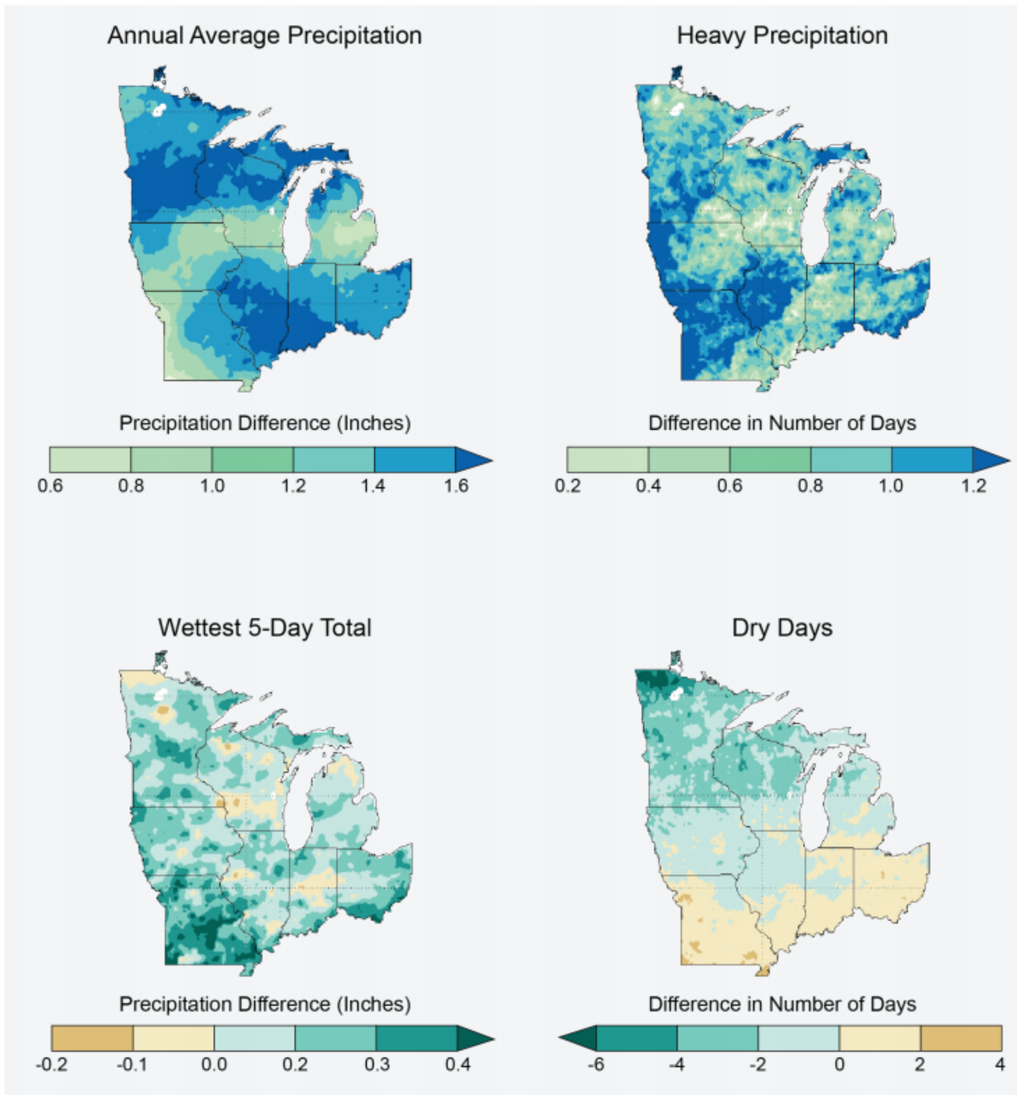
Projected Temperature-Related Changes
2041-2070 vs. 1971-2000



(Pryor and Scavia, 2013)

Projected Precipitation-Related Changes

2041-2070 vs. 1971-2000



(Pryor and Scavia, 2013)

Projected Changes in Seasonal Precipitation

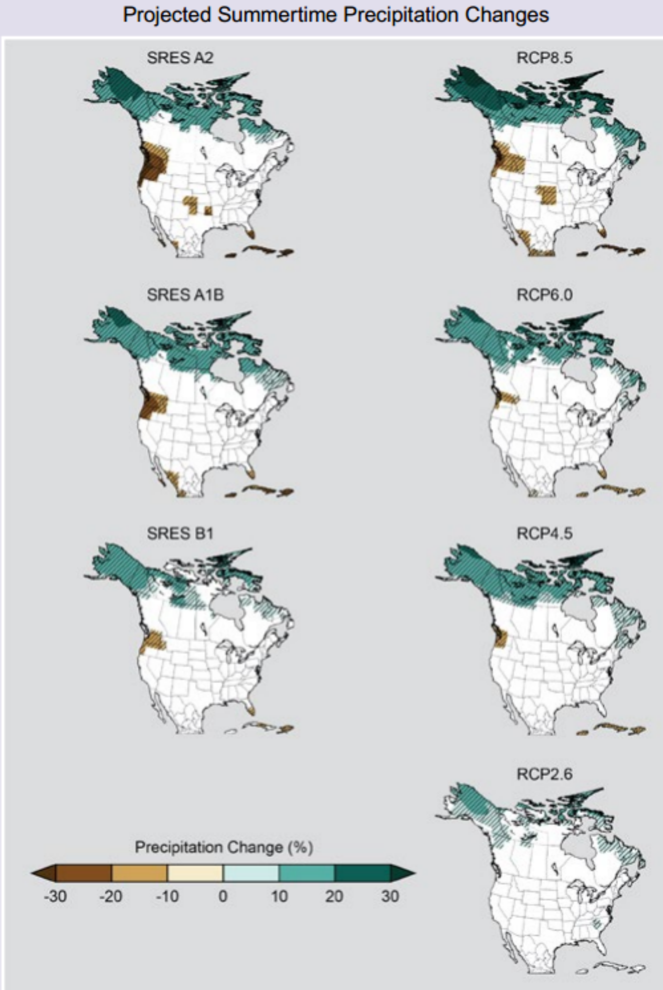


Figure 22. Projected changes in summertime precipitation toward the end of this century (2071-2099) relative to the average for 1970-1999. The older generation of models (CMIP3) and emissions scenarios are on the left side; the new models (CMIP5) and scenarios are on the right side. Hatched areas indicate that the projected changes are significant and consistent among models. White areas indicate confidence that the changes are not projected to be larger than could be expected from natural variability. In most of the contiguous U.S., decreases in summer precipitation are projected, but not with as much confidence as the winter increases. When interpreting maps of temperature and precipitation projections, readers are advised to pay less attention to small details and greater attention to the large-scale patterns of change. (Figure source: NOAA NCDC / CICS-NC).

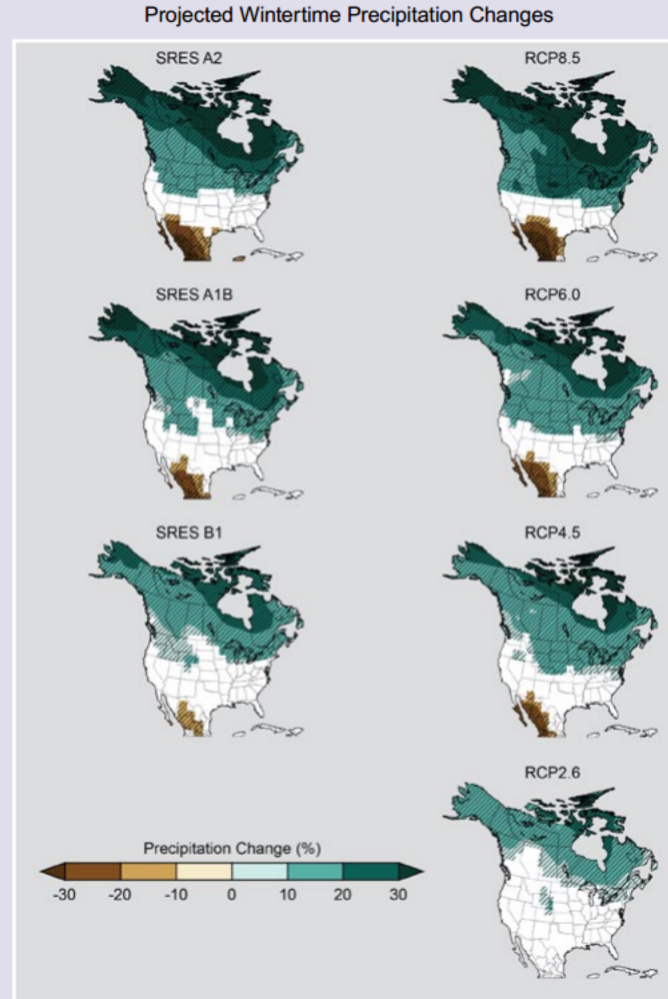


Figure 21. Projected changes in wintertime precipitation at the end of this century (2071-2099) relative to the average for 1970-1999. The older generation of models (CMIP3) and emissions scenarios are on the left side; the new models (CMIP5) and scenarios are on the right side. Hatched areas indicate that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. In both sets of projections, the northern parts of the U.S. (and Alaska) become wetter. Increases in both the amount of precipitation change and the confidence in the projections go up as the projected temperature rises. In the farthest northern parts of the U.S., much of the additional winter precipitation will still fall as snow. This is not likely to be the case farther south. (Figure source: NOAA NCDC / CICS-NC).

Agricultural Impacts

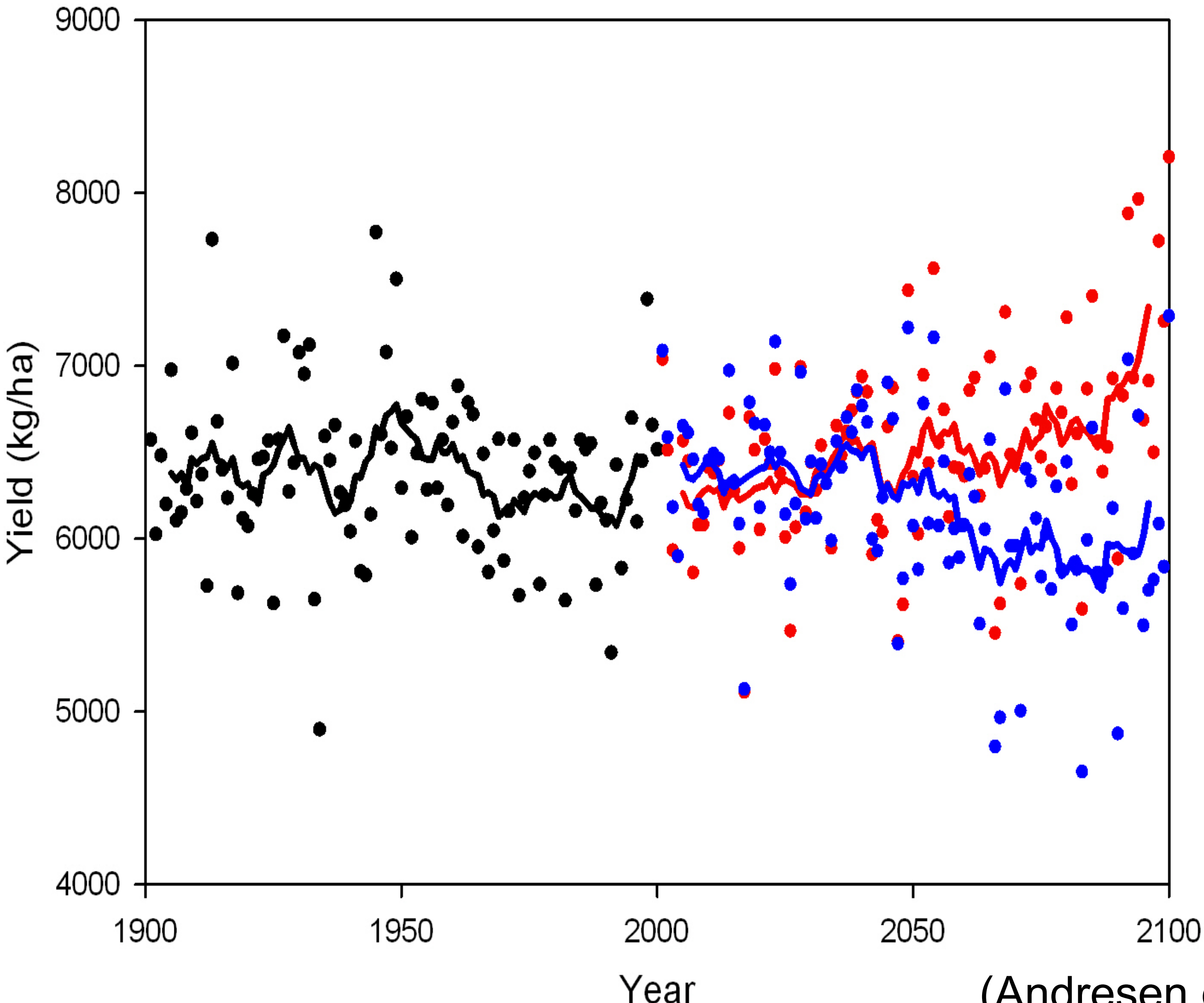
Climate Change and Ag. Productivity: Direct Impacts, Midwest Region

- Primary historical climate yield determinant has been the magnitude and timing of plant available moisture
- Recent research suggests increasing temperatures (esp. nighttime) will play an increasingly important role
- CO_2 enrichment
- Occurrence of extremes

Carbon Dioxide Enrichment

- Increased radiation use efficiency, biomass production, mainly with C-3 species
- Increased water use efficiency, through reductions in stomatal conductance, transpiration
- Some uncertainty remains with respect to long term impact (e.g. species acclimation) and degree of productivity enhancement

Historical and Projected Wheat Yields by Year With and Without CO_2 Enrichment
Pontiac, MI



(Andresen et al., 2012)

Climate Change and Global Agricultural Productivity

- International Impacts
  - Most notable decreases in productivity in tropical areas of the world, associated with increases in temperature
  - Theoretical increases in productivity in N. Hemisphere growing areas, notably Russia and Canada

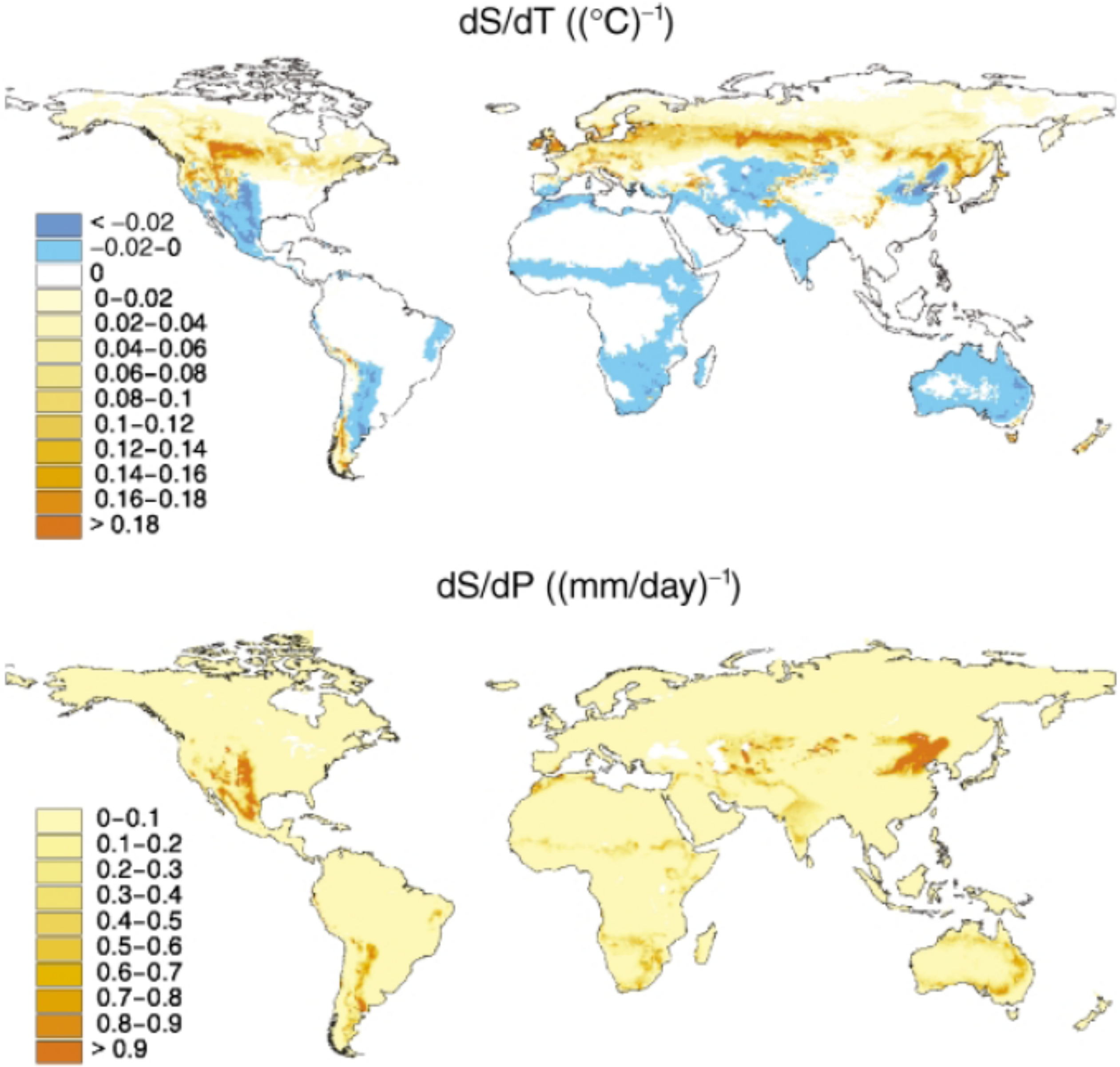
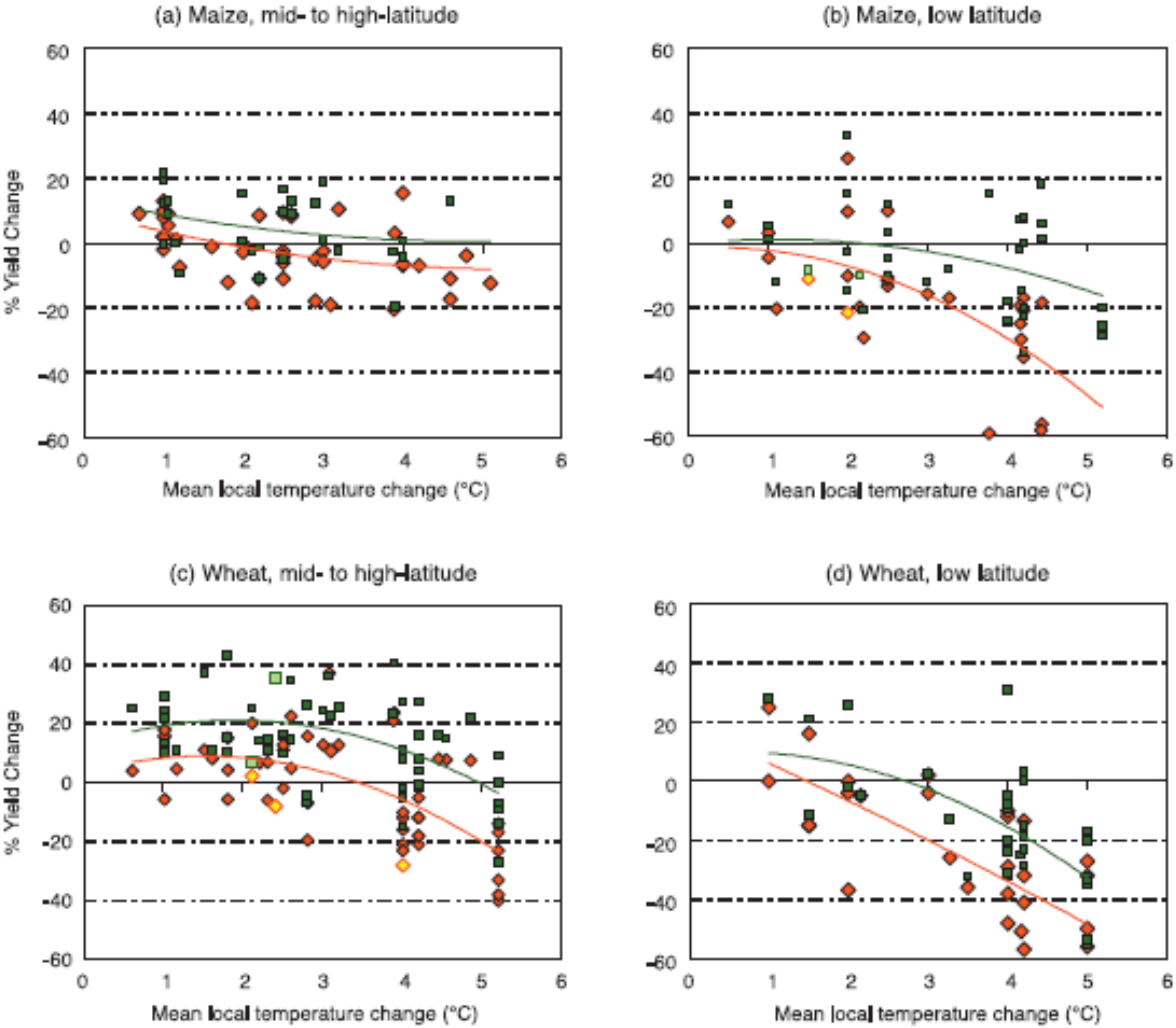


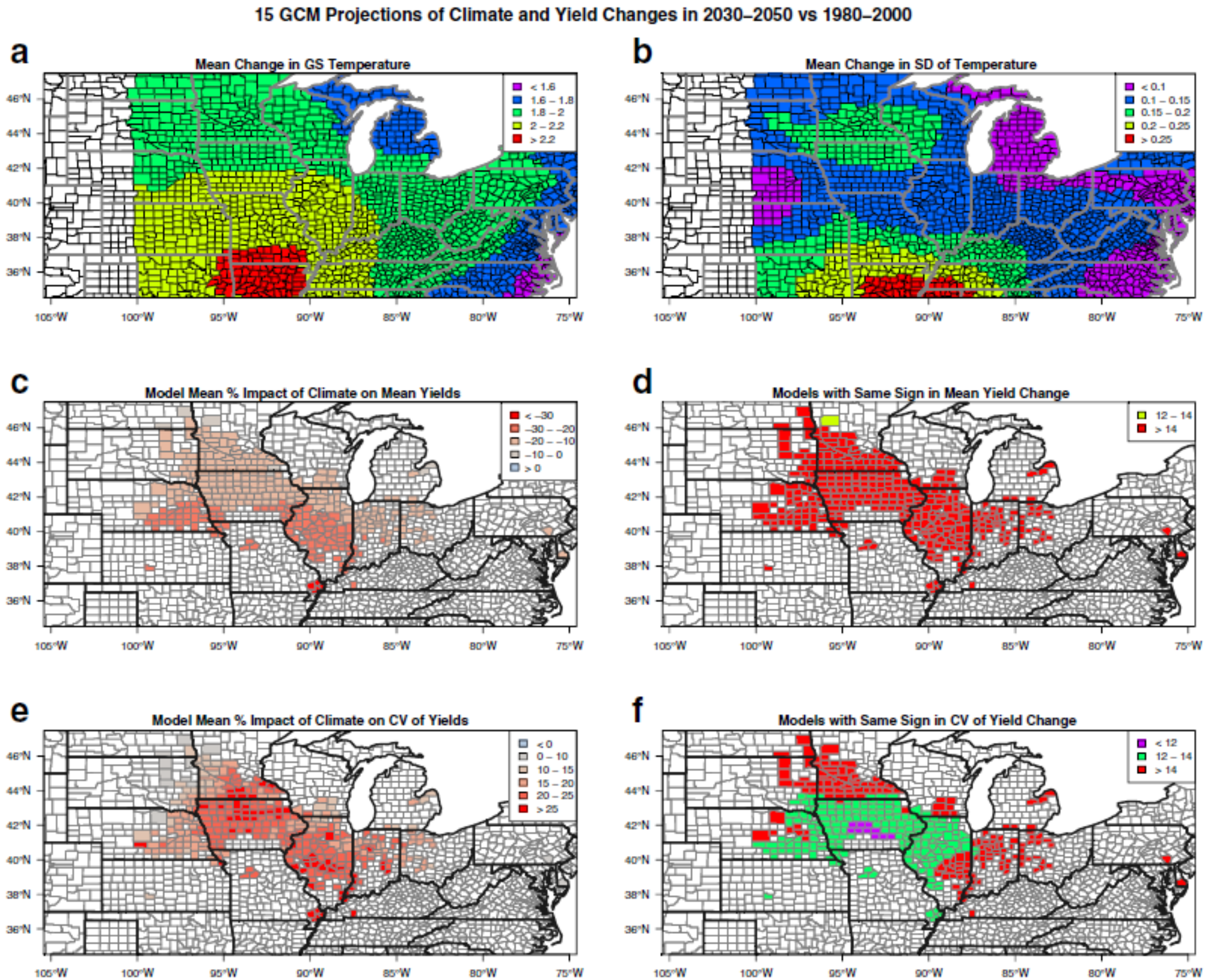
Fig. 5 The sensitivity of the index of cropland suitability to climate change. Partial derivative of cropland suitability index with respect to temperature (top panel) and precipitation (bottom panel). The regions lying at the margins of temperature and precipitation limitation to cultivation are most sensitive to changes in climate.

(Source: Ramankutty et al., 2002)



(Easterling et al., 2007)

Climate Change and Yield Variability



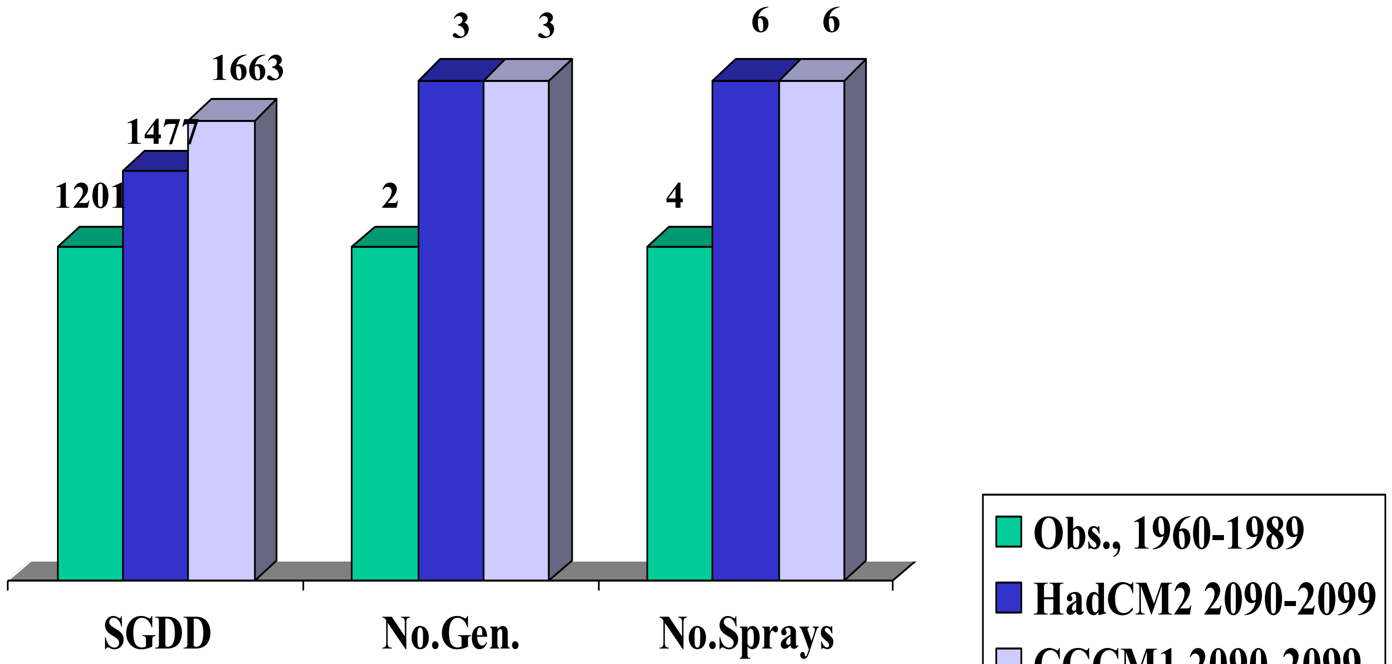
(Urban et al., 2012)

Indirect Impacts of Climate Change

- Incidence of pests and pathogens
- Increased rates of soil erosion and degredation
- Increased pressure on environmental and natural resources, loss of biodiversity
  – Surface and ground water availability
  – Loss of species
- Possible imbalance between production areas in cool/temperate zones and those in tropical areas

Simulated Pest Management Parameters, Apple Codling Moth

East Jordan, MI



Other CO_2-related impacts

Herbicide Loses Effectiveness at Higher CO_2

Current CO_2 (380 ppm) Potential Future CO_2 (680 ppm)

The left photo shows weeds in a plot grown at a carbon dioxide (CO_2) concentration of about 380 parts per million (ppm), which approximates the current level. The right photo shows a plot in which the CO_2 level has been raised to about 680 ppm. Both plots were equally treated with herbicide.[233]

(Wolf et al., 2007)

Indirect Impacts of Climate Change: Biofuels

- Biofuels offer a potentially renewable and sustainable source of energy
- Most all of the increase in global corn production during the past decade was consumed in bioenergy production, and prices for most commodities have increased significantly
- The GHG emissions associated with bioenergy production are still unclear, but strongly linked to land use patterns

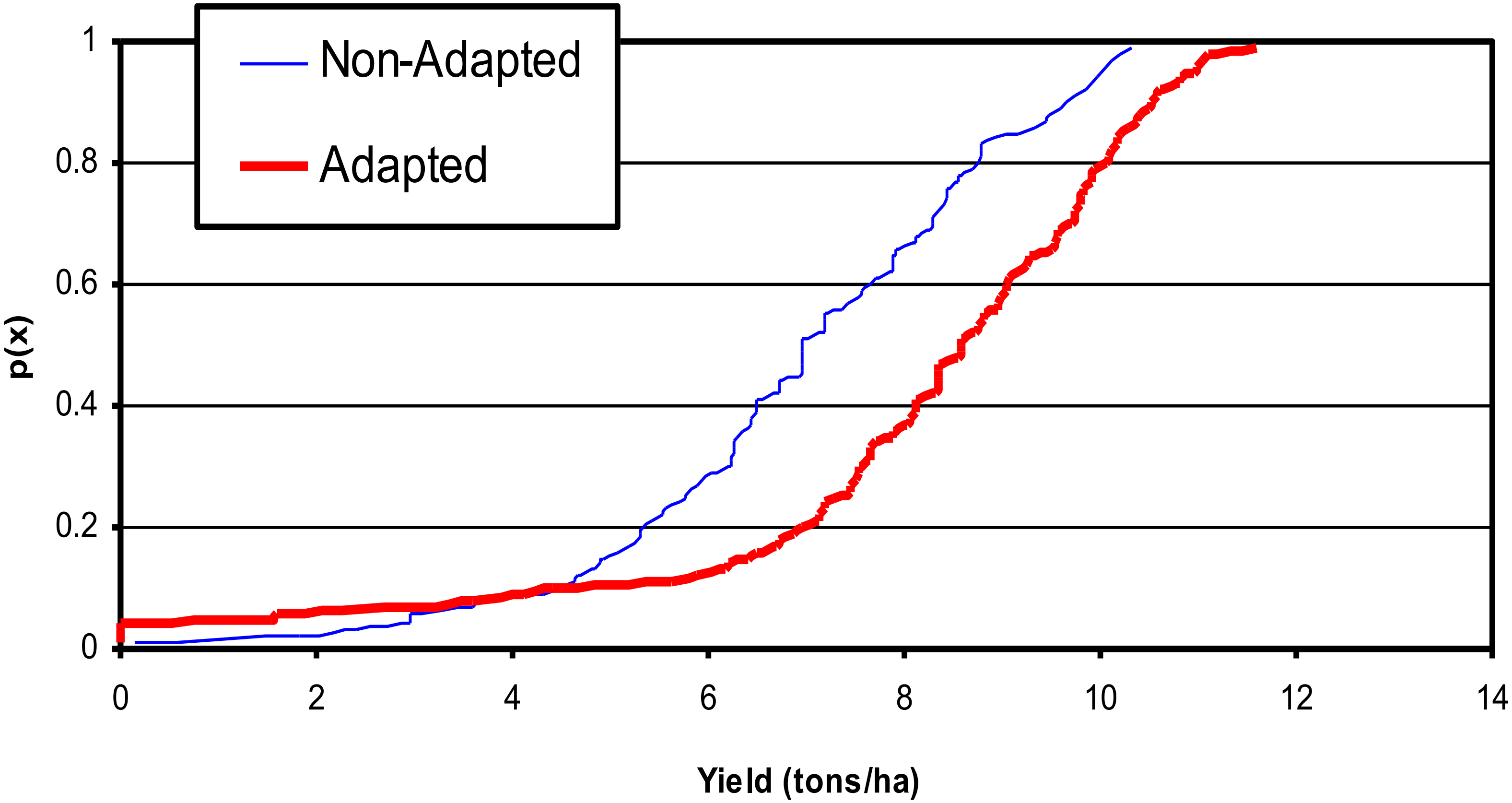
Agricultural strategies for coping with climate change

- Adaptation
  - Learn to change, adapt
  - New crop varieties and crops
  - New technologies
- Mitigation
  - Reduction of carbon and other GHG
    - Carbon sequestration
    - Production of fuels/energy from biomass/animal waste
    - Reduction of CH_4 and N_2O
    - Use of alternative energy sources in production

Agriculture and Adaptive Capacity

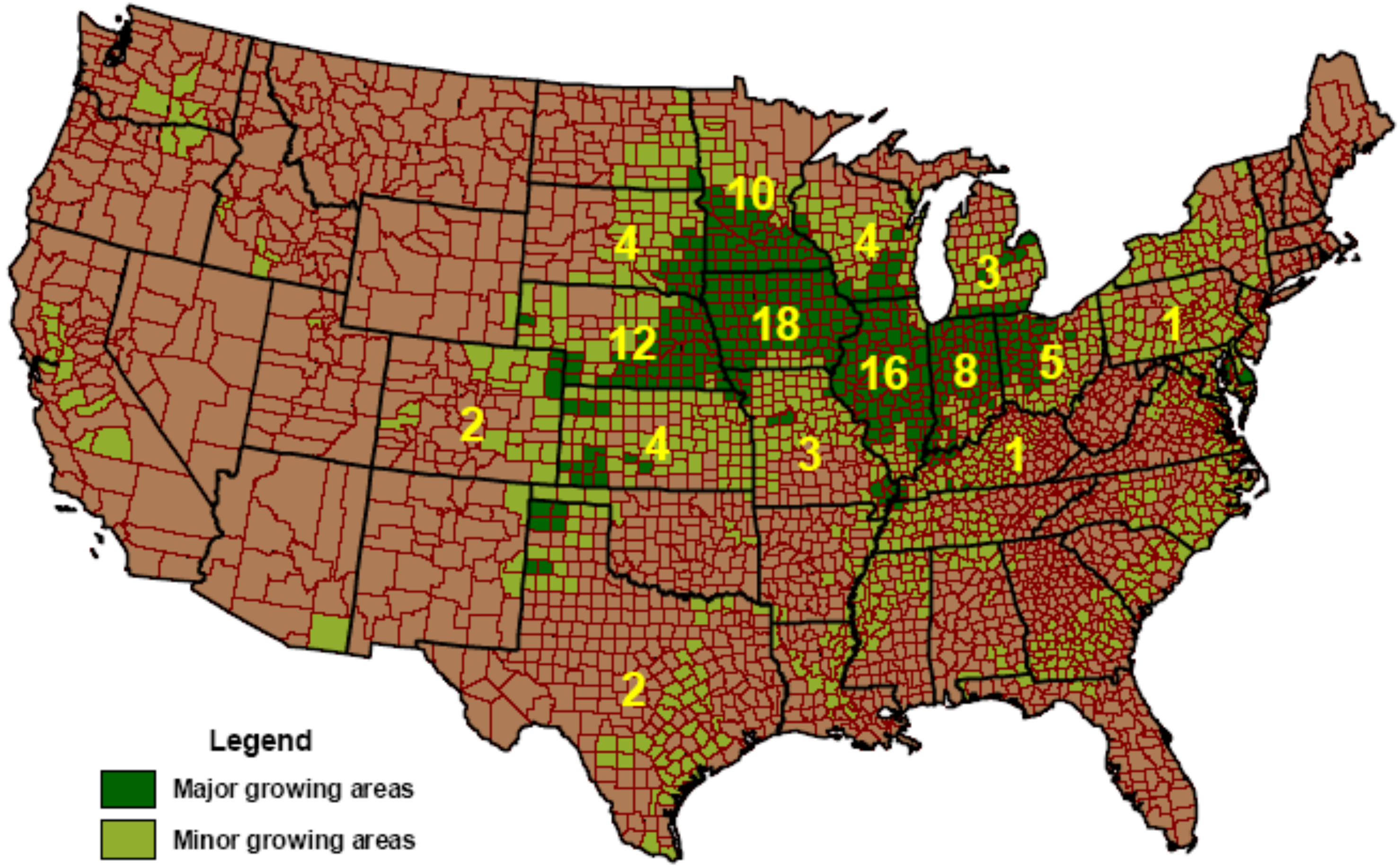
- Mitigation strategies are likely insufficient to avoid further negative impacts.
- Best strategies will combine sound science with ongoing experience-based producer response process.
- Development of effective long term adaptation strategies will require well-structured frameworks connecting science with action. The science must be salient, credible, and legitimate.

Cumulative Simulated Frequency Distributions of Adapted vs. Non-adapted Crop Cultivars, 2000-2099, with HADCM2 Model Data, Coldwater, MI



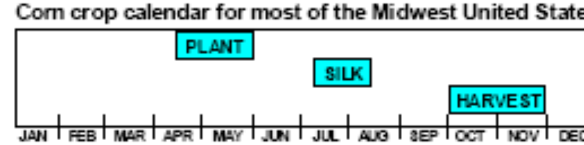
United States: Corn

Yellow numbers indicate percent of national total each state contributes to national production annually. States not numbered contribute less than 1% to the national total.



- Major growing areas combined account for 75% of total national production annually
- Major and minor growing areas combined account for 99% of total national production annually
- Major and minor growing areas and state production percentages based upon averaged NASS county-level and state production data from 1996-2000

Corn crop calendar for most of the Midwest United States



The corn crop calendar is typically 1 month ahead across the southern United States.

Major Land-Resource Areas in the USA

Summary

- Overall, mean average temperatures in Michigan rose approximately 1.0ºF during the past century. Warming of about 2.0ºF has occurred between 1980 and the present.
- Milder winter temperatures have led to less ice cover on the Great Lakes and the seasonal spring warm-up is occurring earlier than in the past.
- Annual precipitation rates increased from the 1930's through the present, due both to more wet days and more extreme events.
- Most recent GCM simulations of the Great Lakes region suggest a warmer and wetter climate in the distant future, with much of the additional precipitation coming during the cold season months.
- Projections of future climate change in Michigan suggest a mix of beneficial and adverse impacts.
- A changing climate leads to many potential challenges for dependent human and natural systems, especially with respect to climate variability.
- Given the expected rate of climate change, adaptive planning strategies should be dynamic in nature
- Recent research results support the need for considerable investment in adaptation and mitigation actions toward a "climate smart food system" that is more resilient to climate change influences on food security

Questions?