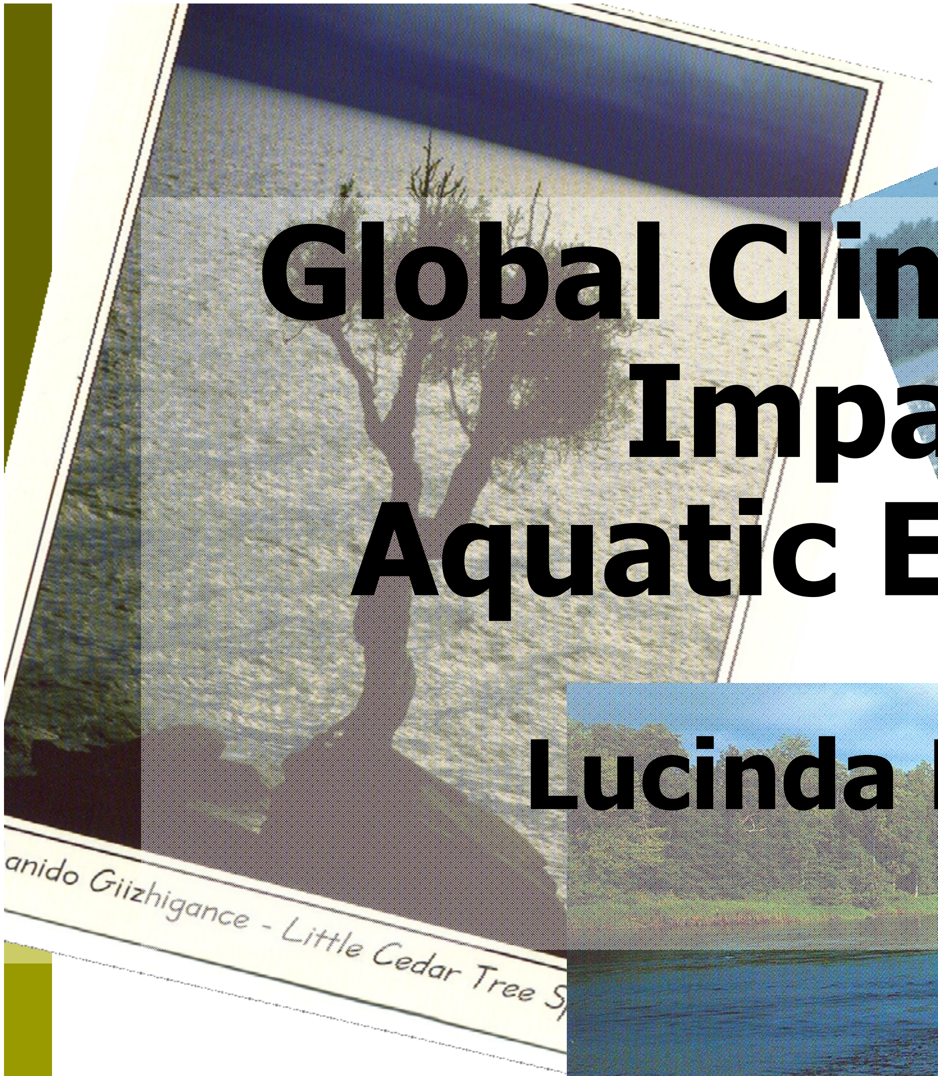
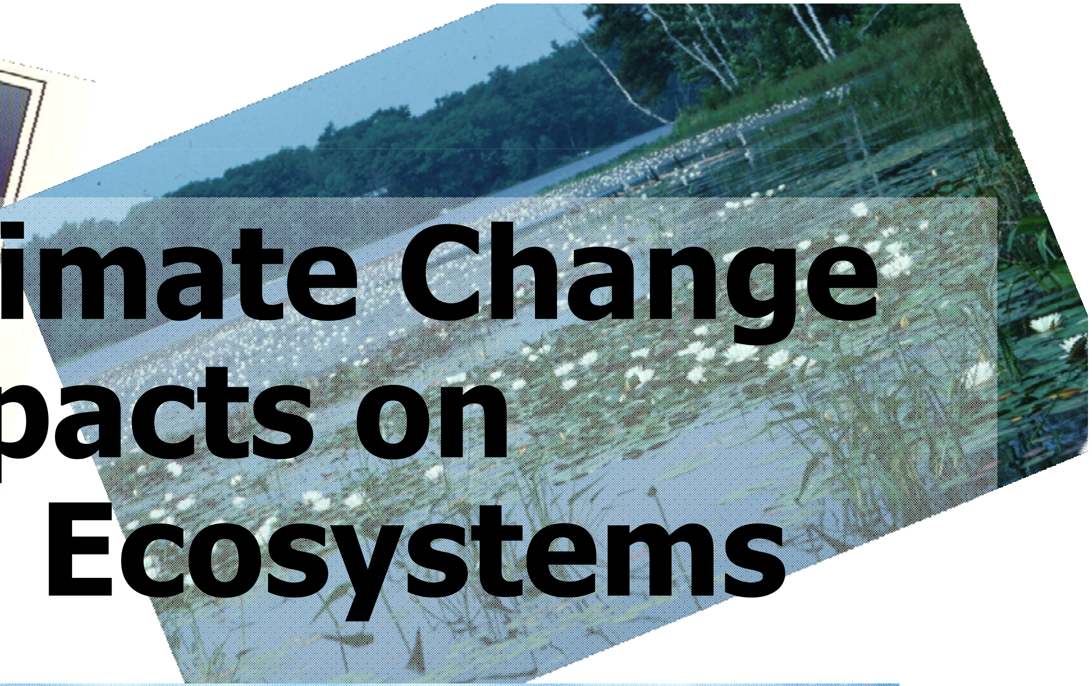
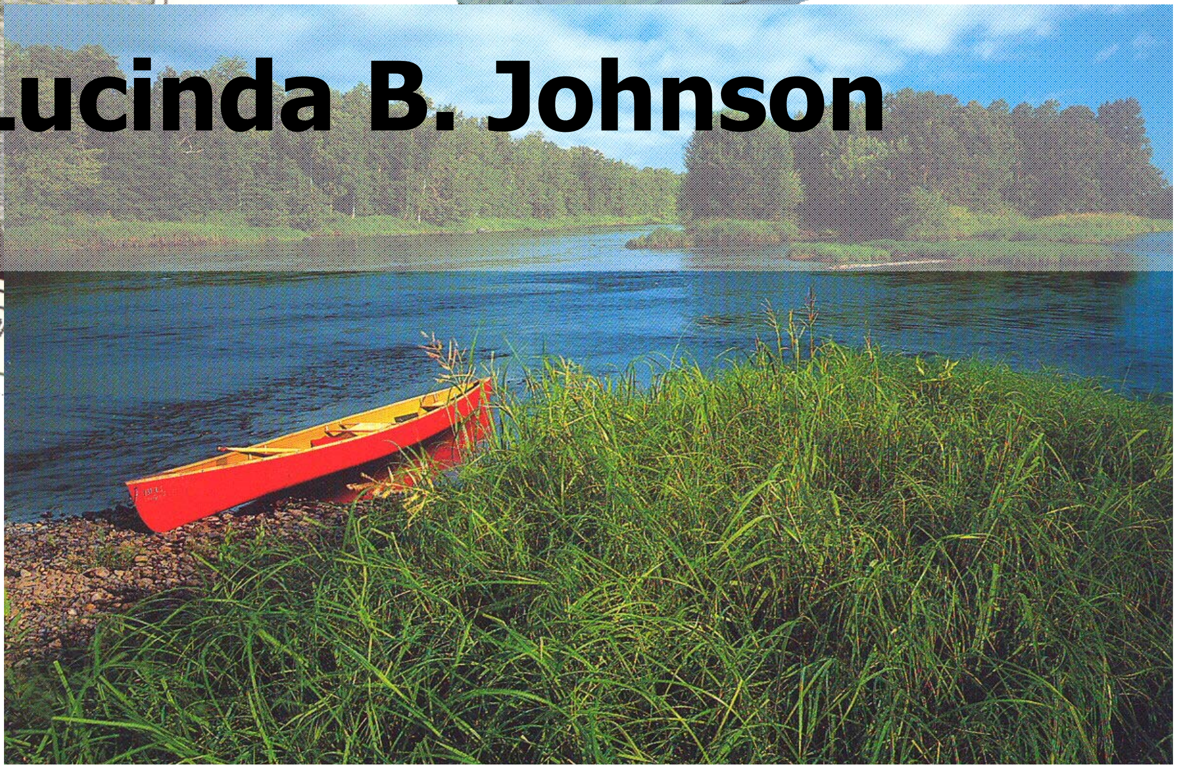
Global Climate Change Impacts on Aquatic Ecosystems





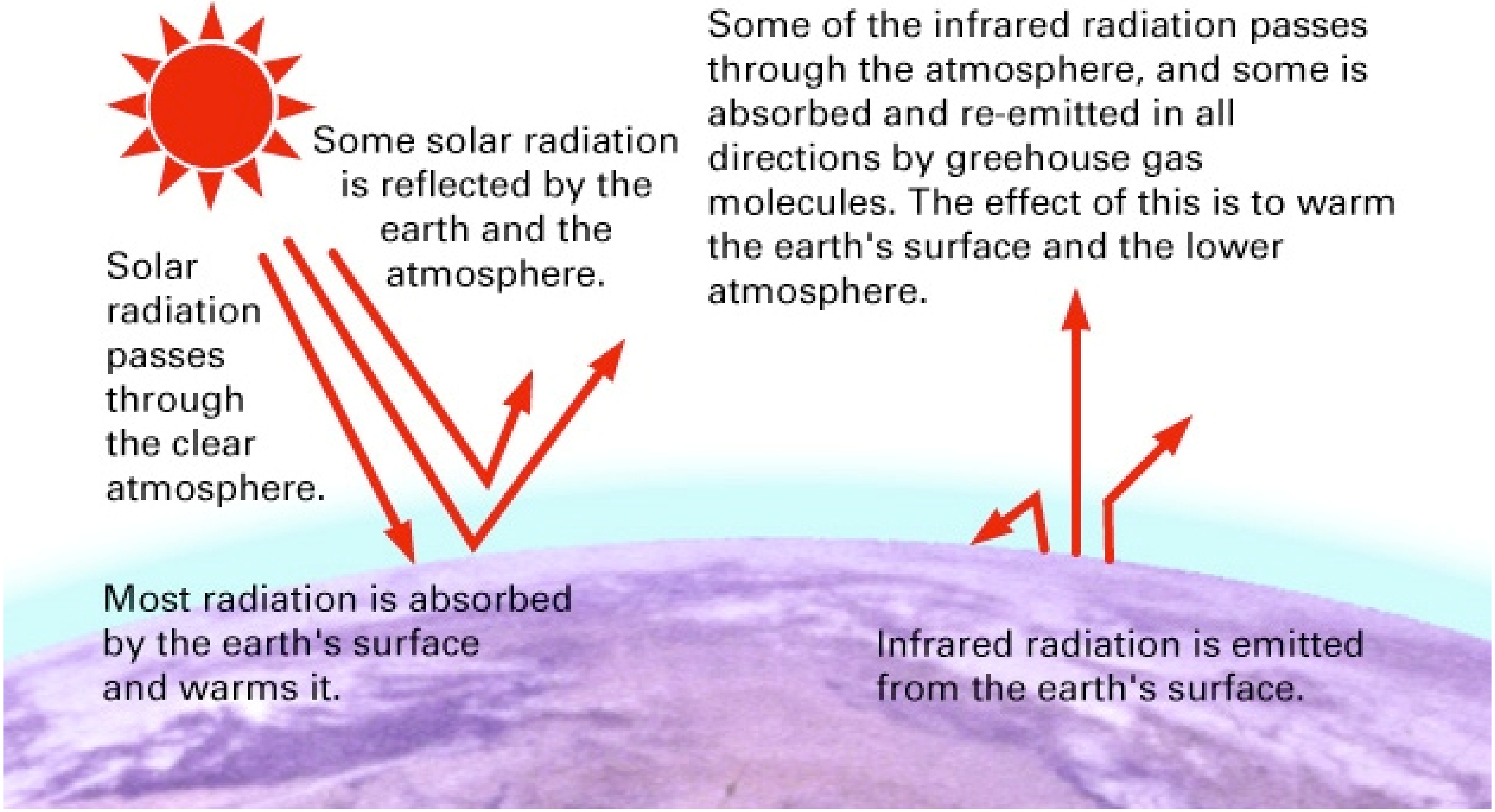
Lucinda B. Johnson



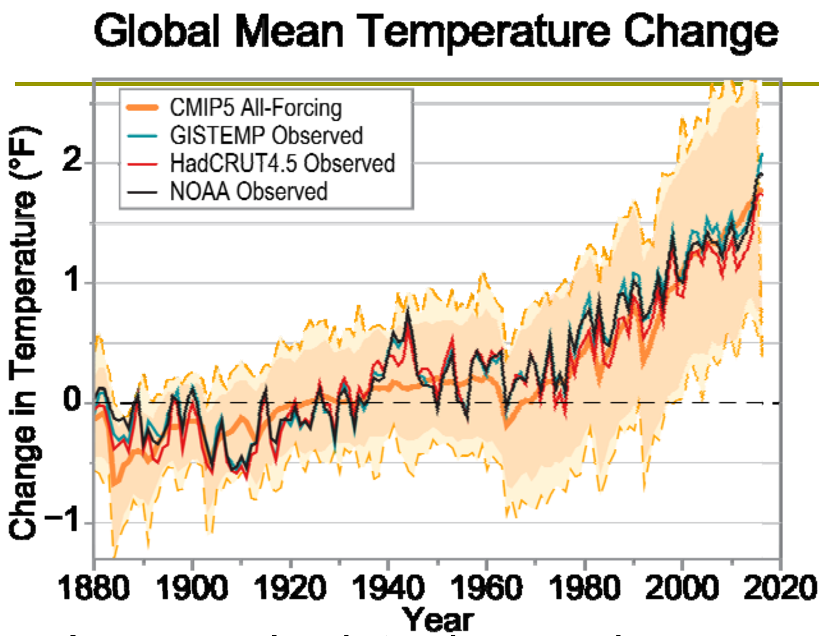
Roadmap

- Climate Change 101 and climate predictions for Minnesota
- Climate trends for Minnesota- 1898 to present
- Predictions of climate change impacts
- Impacts on ecosystems, wetlands
- *What we can do*

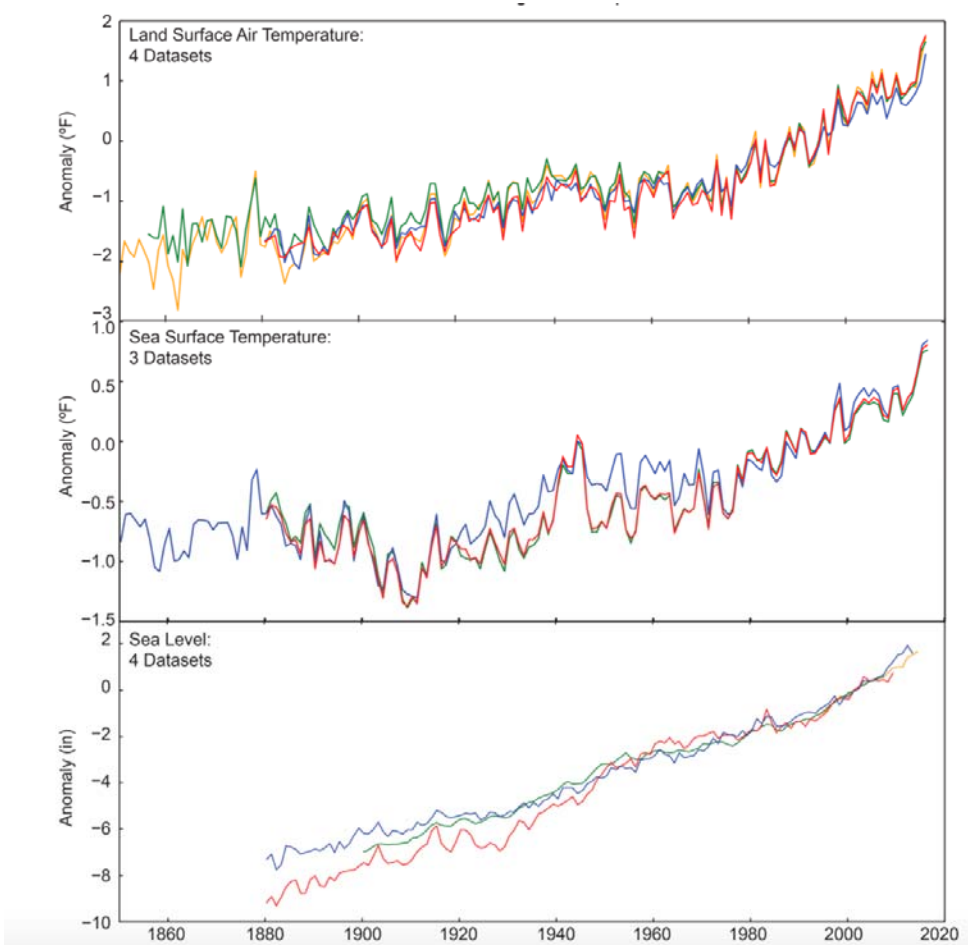
What is climate change?



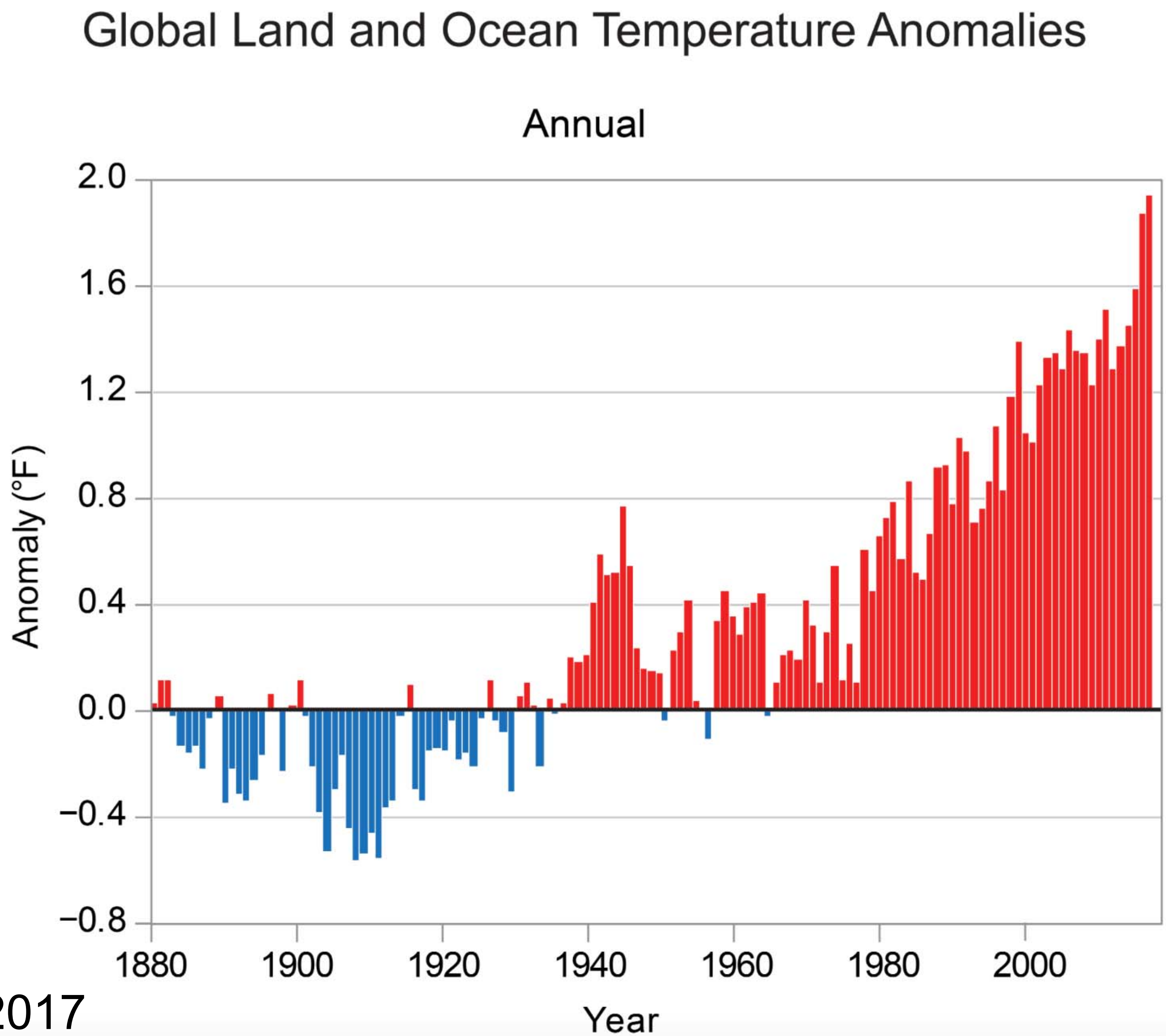
The Impact of GHGs on Climate
Increase in Global Air Temperature



Average global temperatures 1901 – 2016 have increased by 1.8° F (1.0° C). NCA4 2017



- In general, winter is warming faster than summer (especially in northern latitudes).
- Nights are warming faster than days
- 16 of the 17 warmest years in the instrumental record (since the late 1800s) occurred in the period from 2001 to 2016 (1998 was the exception). NCA4 2017


Global Land and Ocean Temperature Anomalies
Annual
2.0
1.6
1.2
0.8
0.4
0.0
−0.4
−0.8
Anomaly (°F)
1880
1900
1920
1940
1960
1980
2000
Year

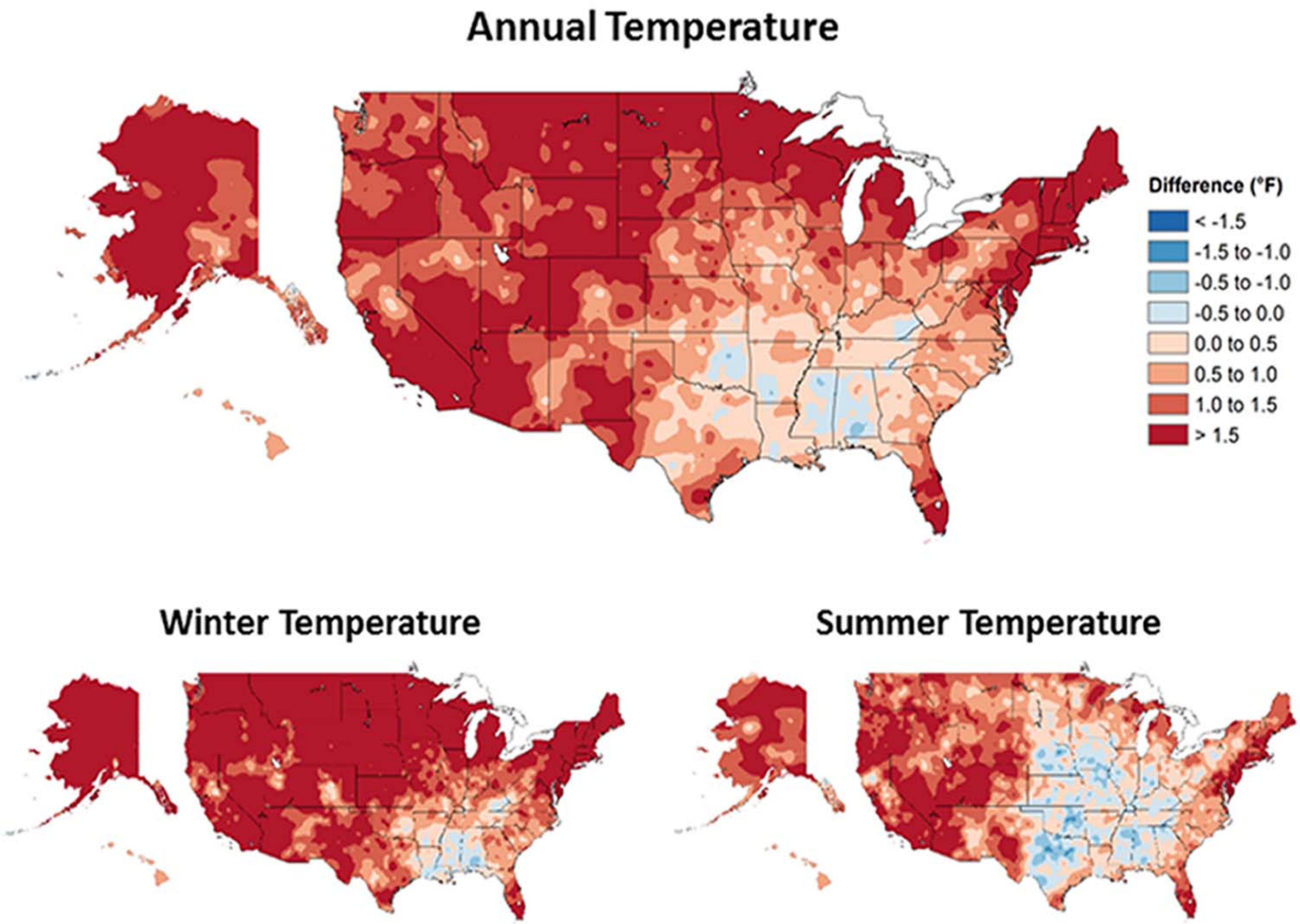
NCA4 2017

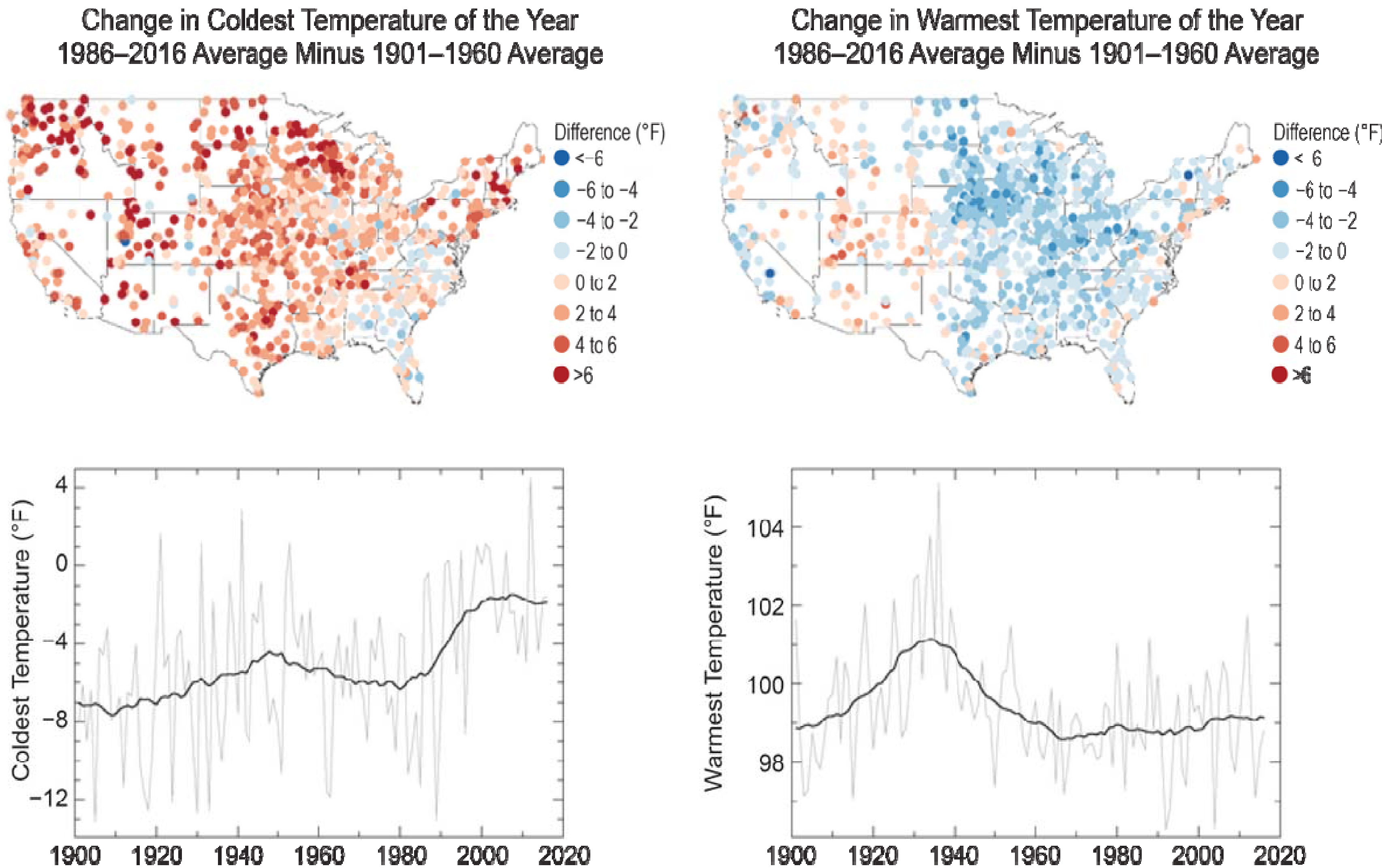
Observed changes in annual average temperature (° F) for each National Climate Assessment region.

NCA Region	Change in Annual Average Temperature	Change in Annual Average Maximum Temperature	Change in Annual Average Minimum Temperature
Contiguous U.S.	1.23°F	1.06°F	1.41°F
Midwest	1.26°F	0.77°F	1.75°F
Great Plains North	1.69°F	1.66°F	1.72°F
Great Plains South	0.76°F	0.56°F	0.96°F

Changes are the difference between the average for present-day (1986–2016) and the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska, Hawai‘i, and the Caribbean). Estimates are derived from the nClimDiv dataset.

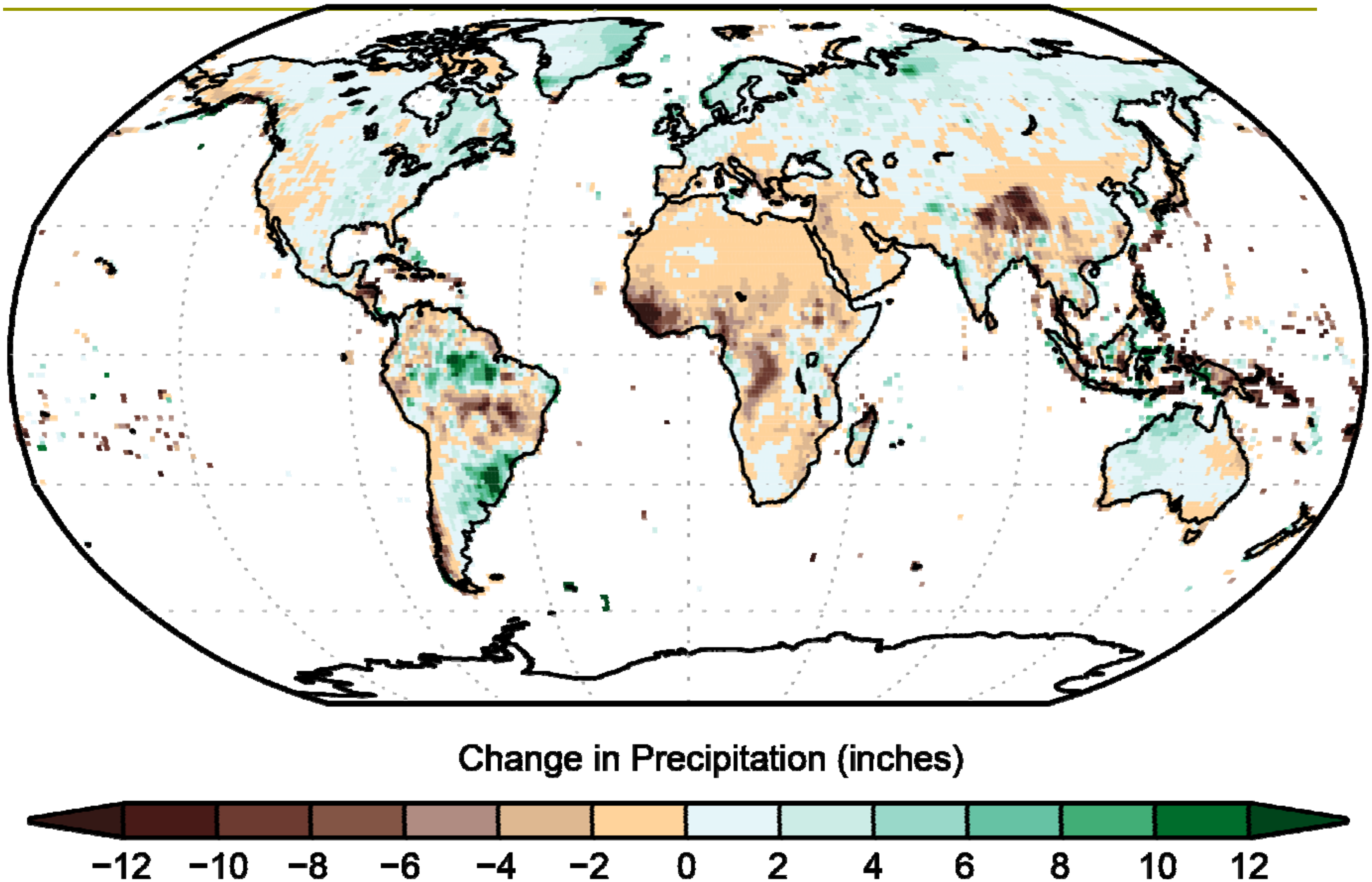
1986-2016
Seasonal Changes

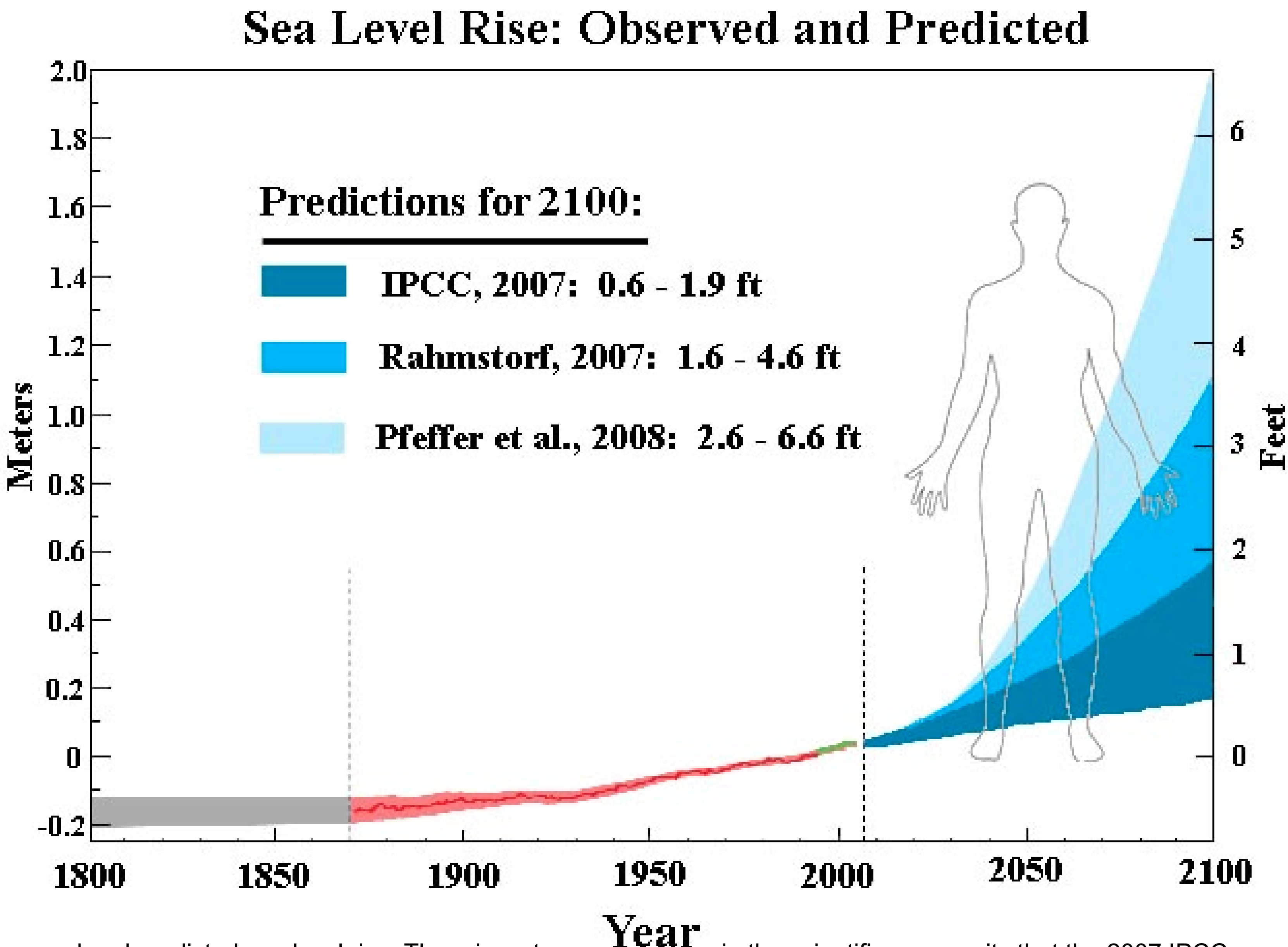



Change in Coldest Temperature of the Year
1986–2016 Average Minus 1901–1960 Average
Difference (°F)
<−6
−6 to −4
−4 to −2
−2 to 0
0 to 2
2 to 4
4 to 6
>6
Coldest Temperature (°F)
4
0
−4
−8
−12
1900
1920
1940
1960
1980
2000
2020
Change in Warmest Temperature of the Year
1986–2016 Average Minus 1901–1960 Average
Difference (°F)
−6 to −4
−4 to −2
−2 to 0
0 to 2
2 to 4
4 to 6
>6
Warmest Temperature (°F)
104
102
100
98
1900
1920
1940
1960
1980
2000
2020

NCA4 2017

Annually-averaged Precipitation Trends

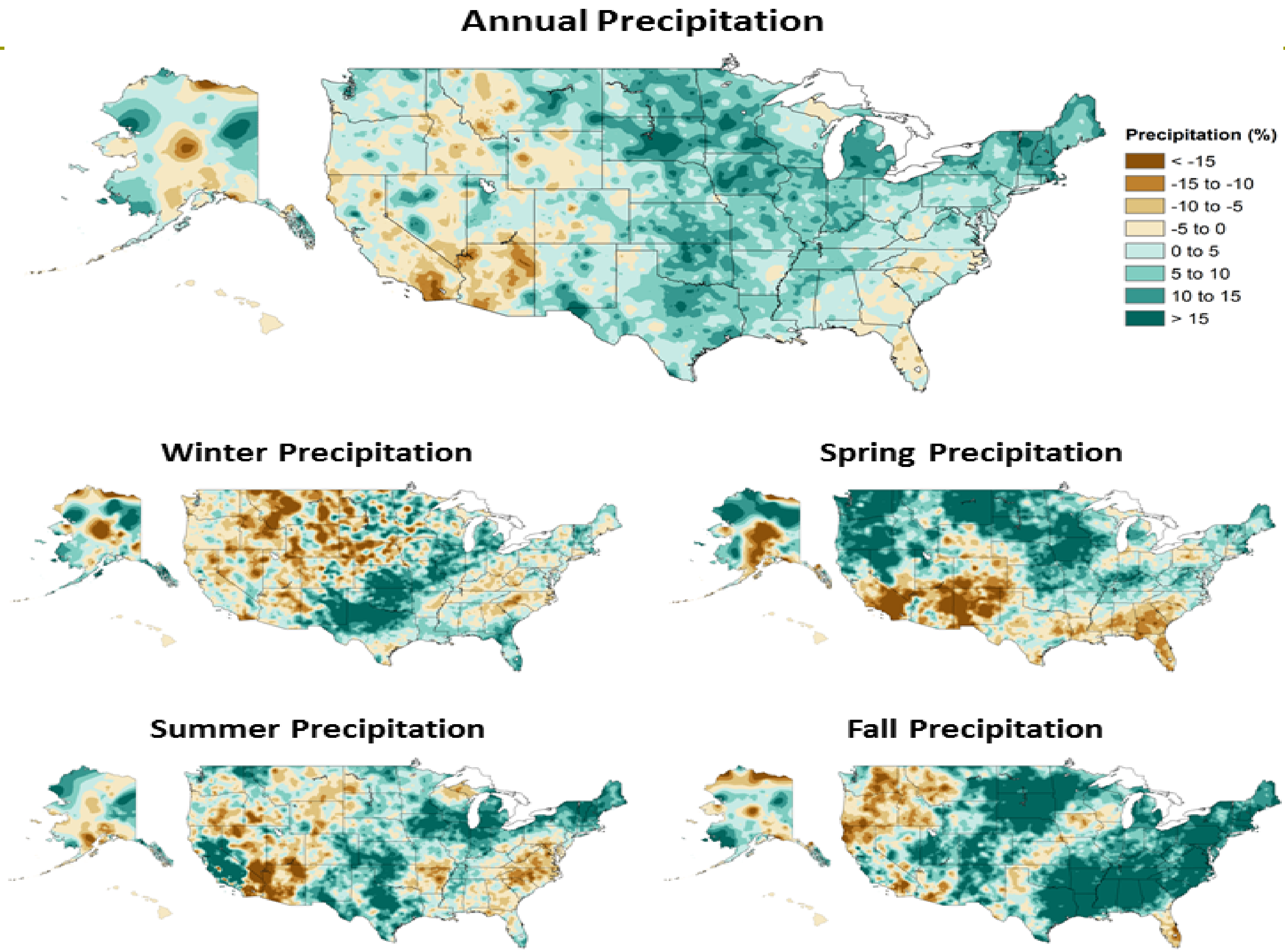


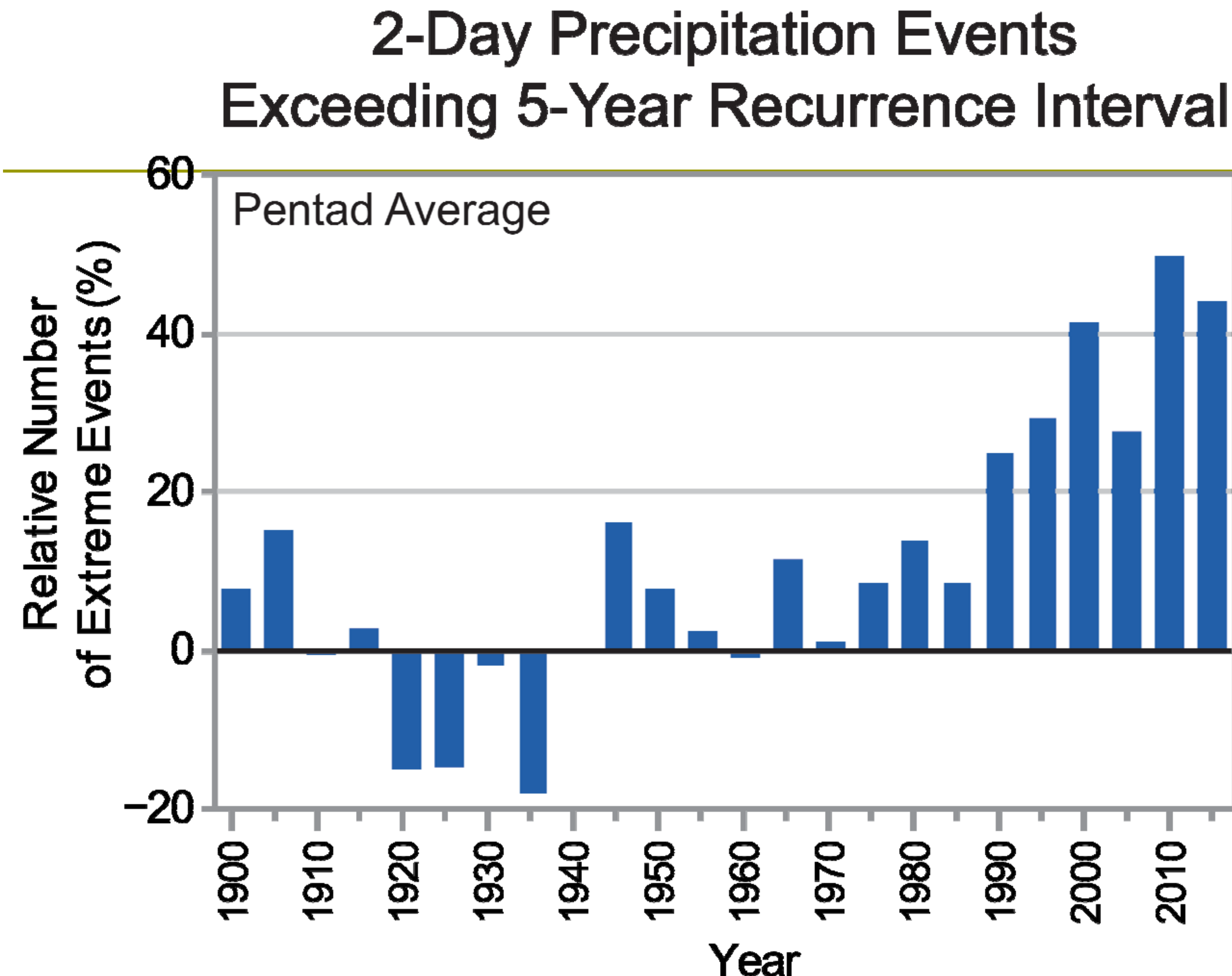


Observed and predicted sea level rise. There is a strong consensus in the scientific community that the 2007 IPCC estimates of 21st century sea level rise are far too low. Obeservations in the first decade of the century support that view. Most experts think the projections of Rahmstorf are more likely. See http://www.nature.com/climate/2010/1004/pdf/climate.2010.29.pdf for an update on Rahmstorf's projections.

https://www.e-education.psu.edu/geog438w/node/261

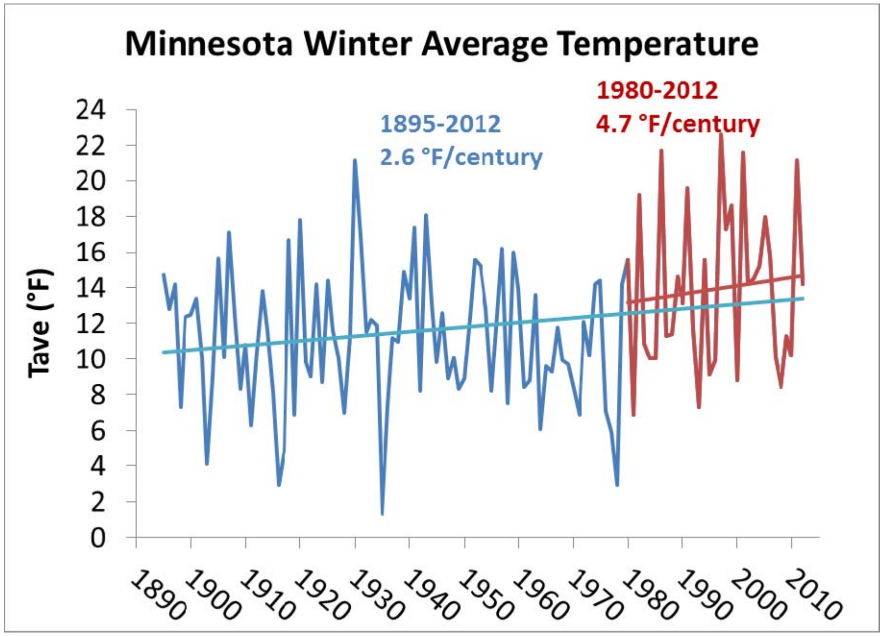
Precipitation: Seasonal change from baseline



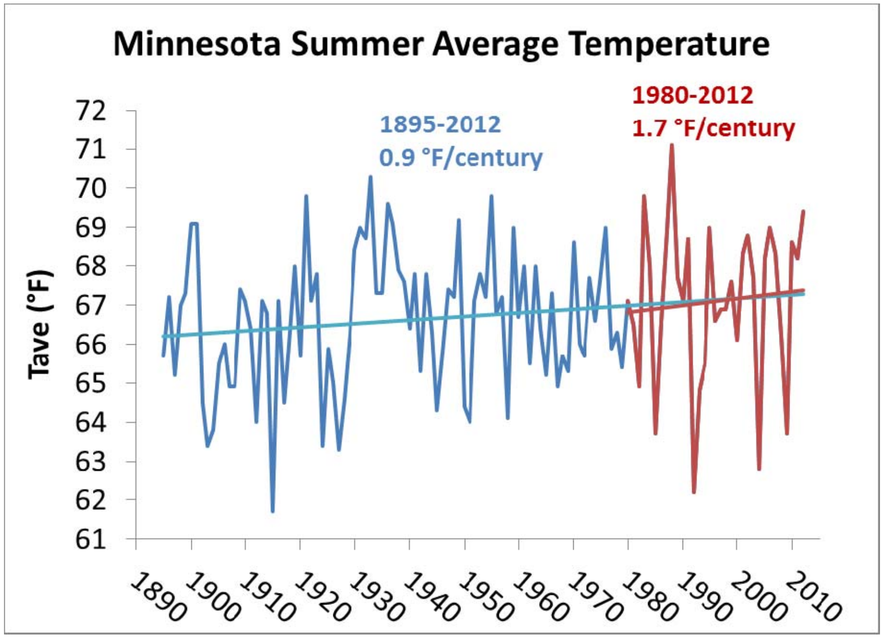

2-Day Precipitation Events
Exceeding 5-Year Recurrence Interval
Pentad Average
Relative Number of Extreme Events (%)
60
40
20
0
−20
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year

NCA4 2017

Local Evidence for Global Warming
Minnesota Temperature Increases



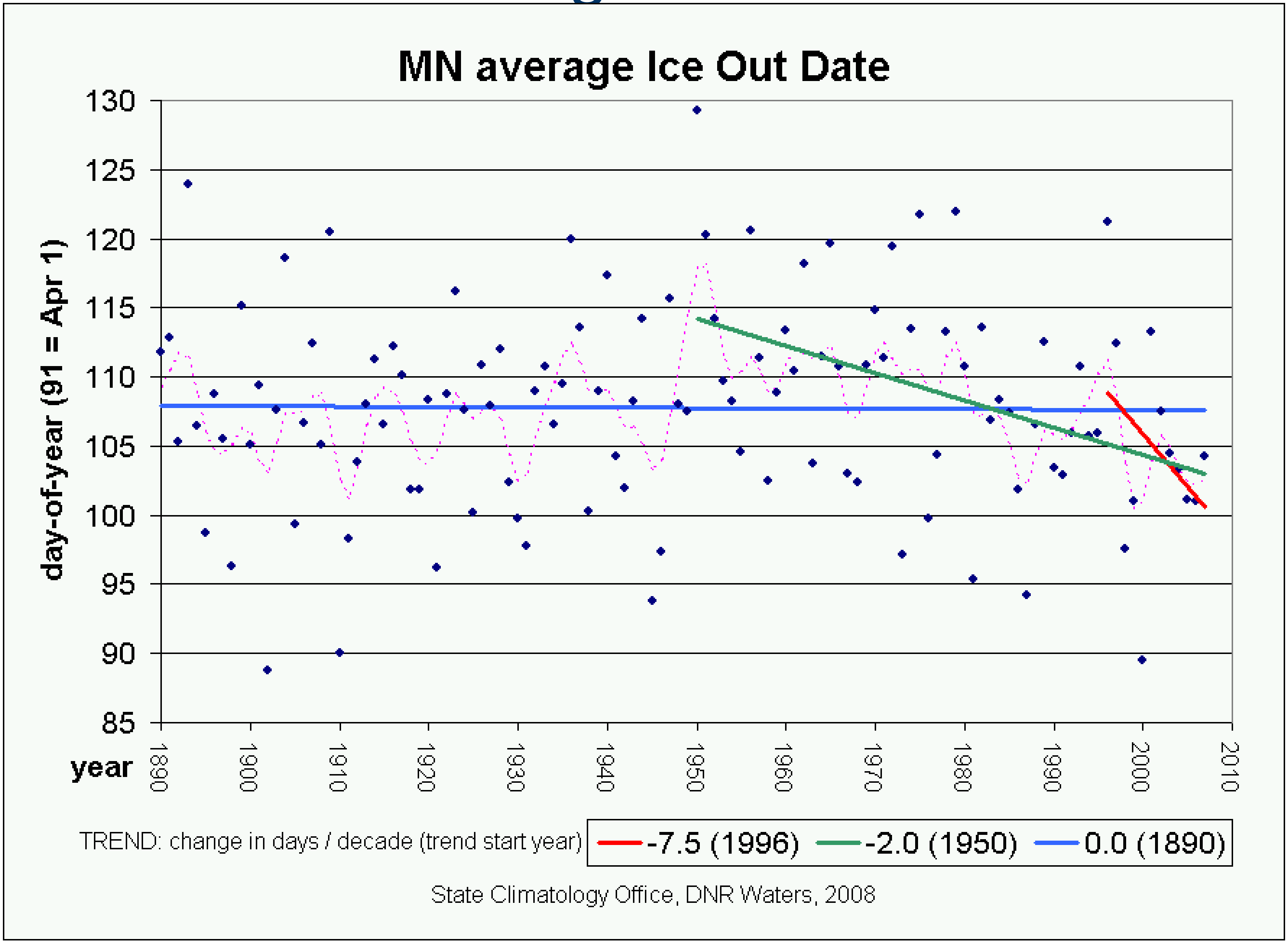
MN Temperature Trends (1895-2012)



Winter T_{avg} +2.6^{o}F; 4.7^{o}F 1980-2012

Data from National Climatic Data Center

Declining Ice Cover



Confidence that climate change has *already* impacted common Minnesota weather/climate hazards

Confidence	**Hazard**	**Recent & Current Observations**
Highest	**Extreme cold**	Rapid decline in severity, frequency
	Extreme rainfall	Becoming larger and more frequent
Moderately High	**Heavy snowfall**	Large events more frequent
Moderately Low	**Severe thunderstorms & tornadoes**	Historical comparisons difficult; Few major tornadoes in MN since late 2010
Lowest	**Heat waves**	No recent increases or worsening
	Drought	

Source: Kenneth Blumenfeld, MN DNR

Causation…from IPCC 2013

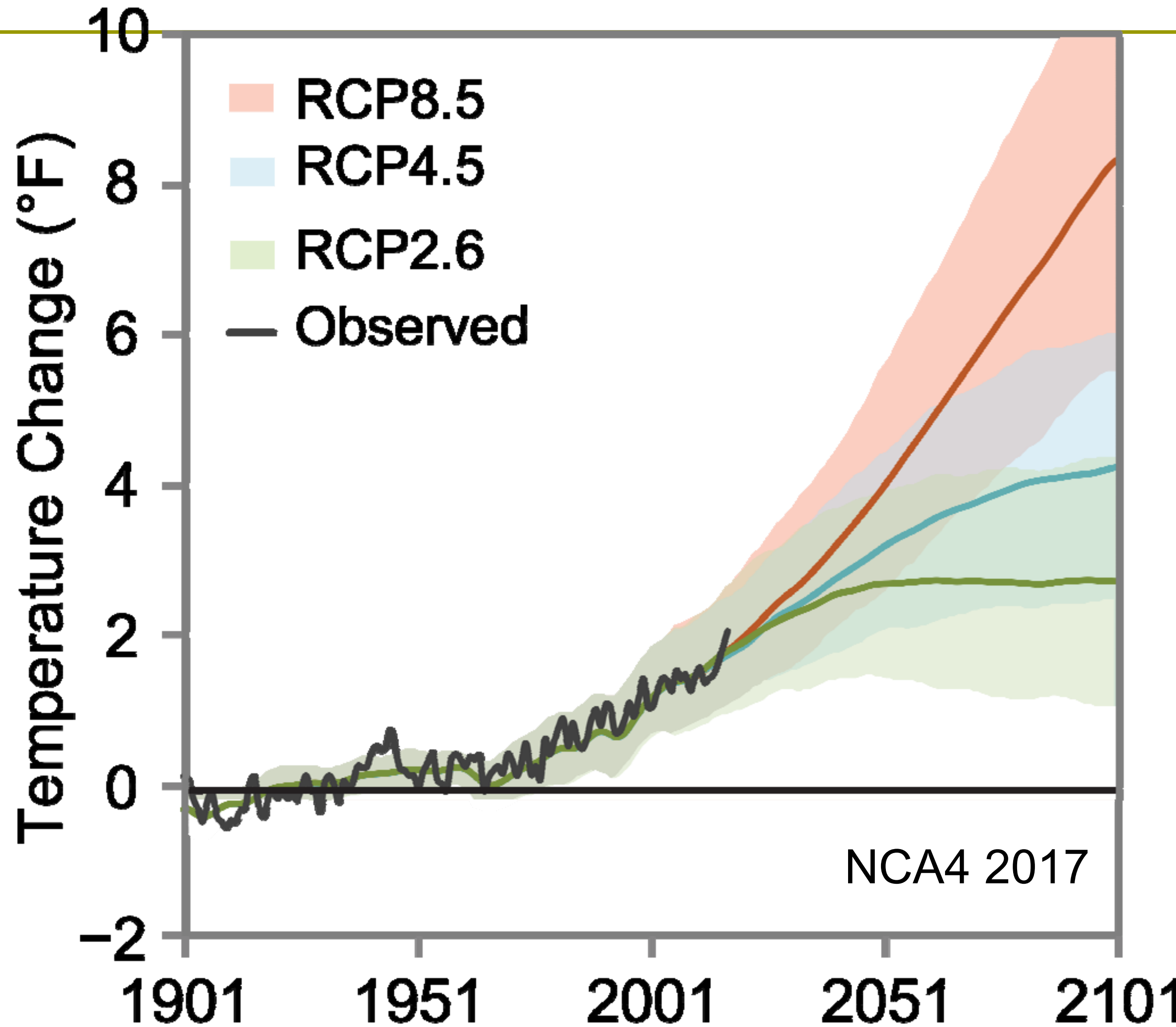
“Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system.”

“Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes. ... It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.”

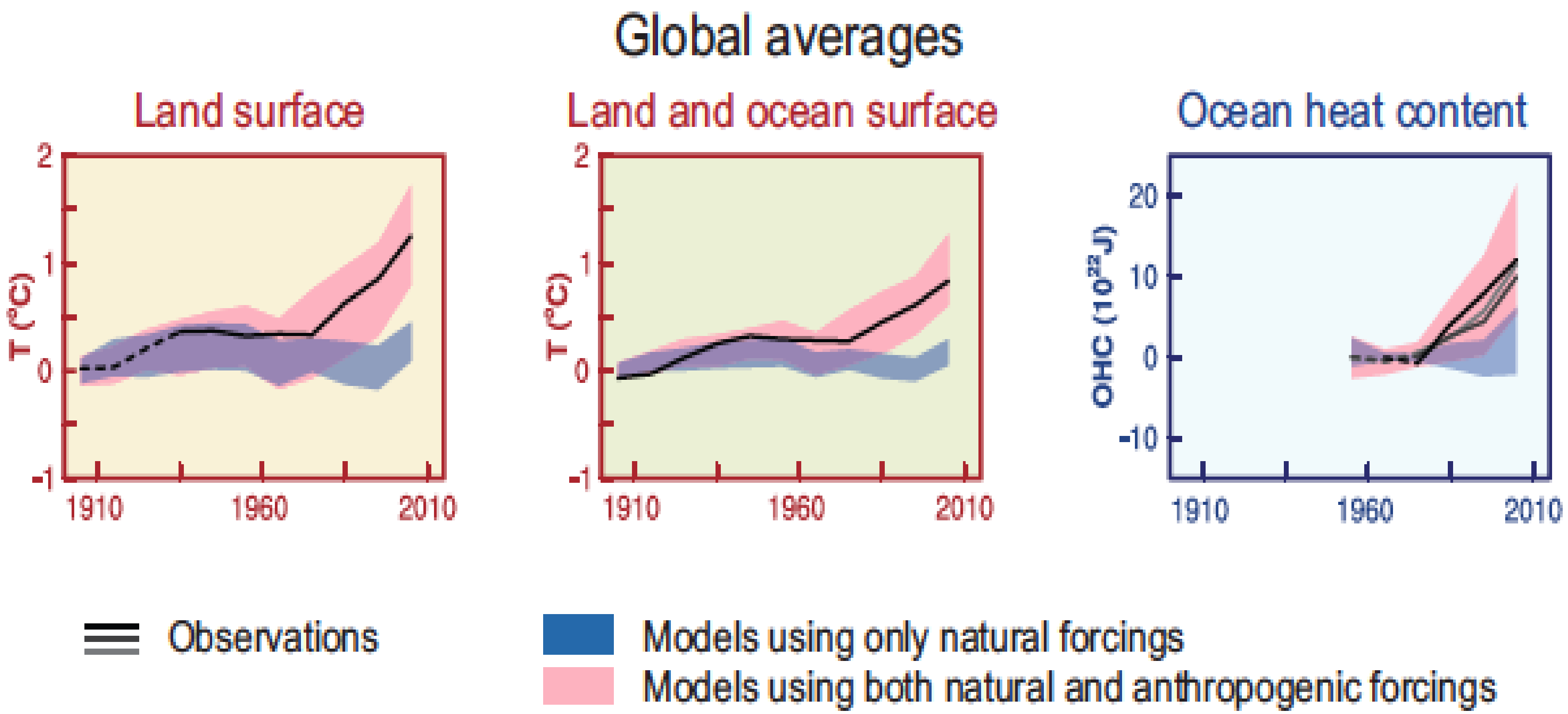
Causation: /NCA4 2017

- “Many lines of evidence demonstrate that it is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century.
- Over the last century, there are no convincing alternative explanations supported by the extent of the observational evidence.”

Projected Global Temperatures

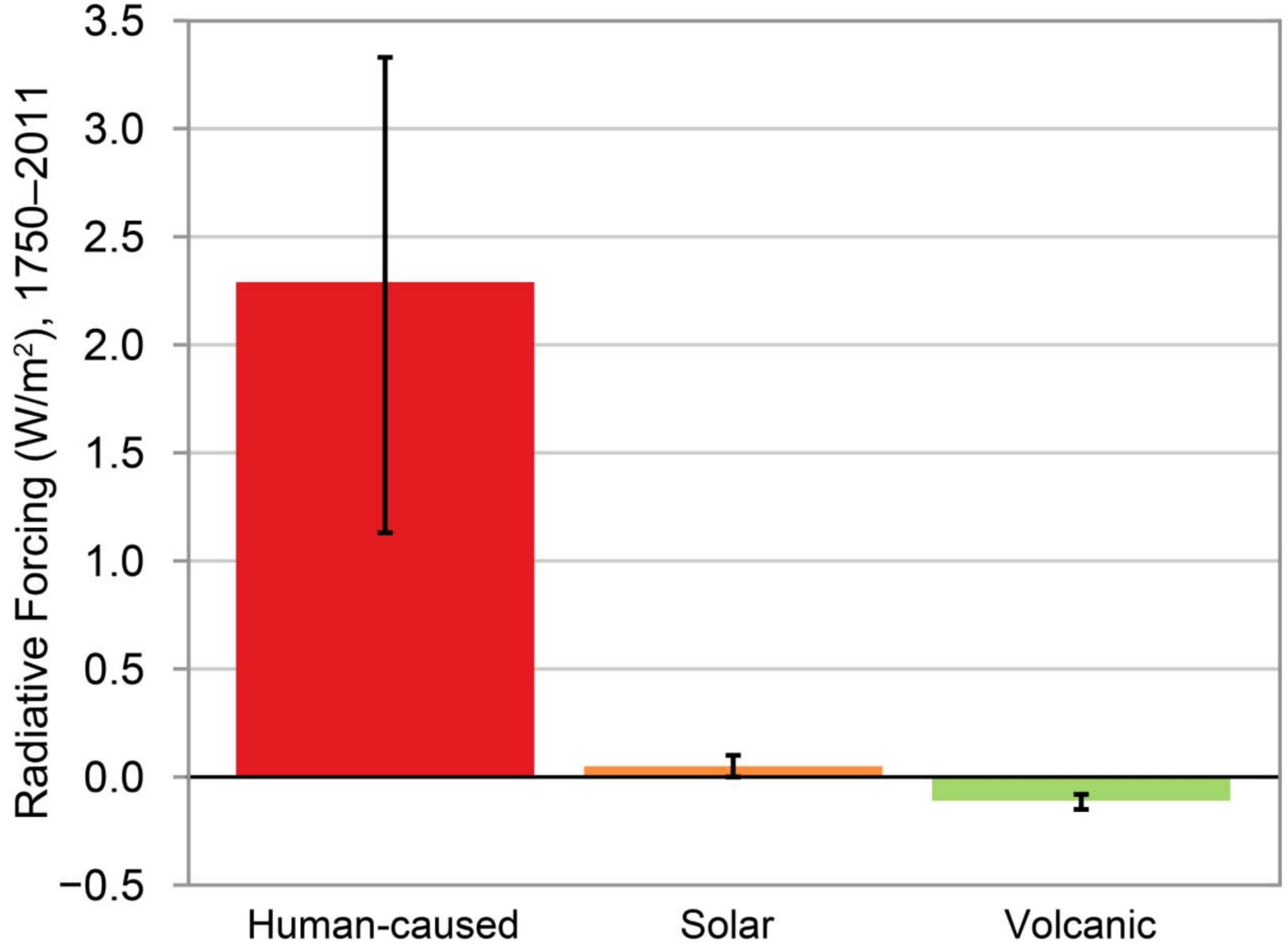


Climate Models: simulated using only natural vs natural and anthropogenic forcings

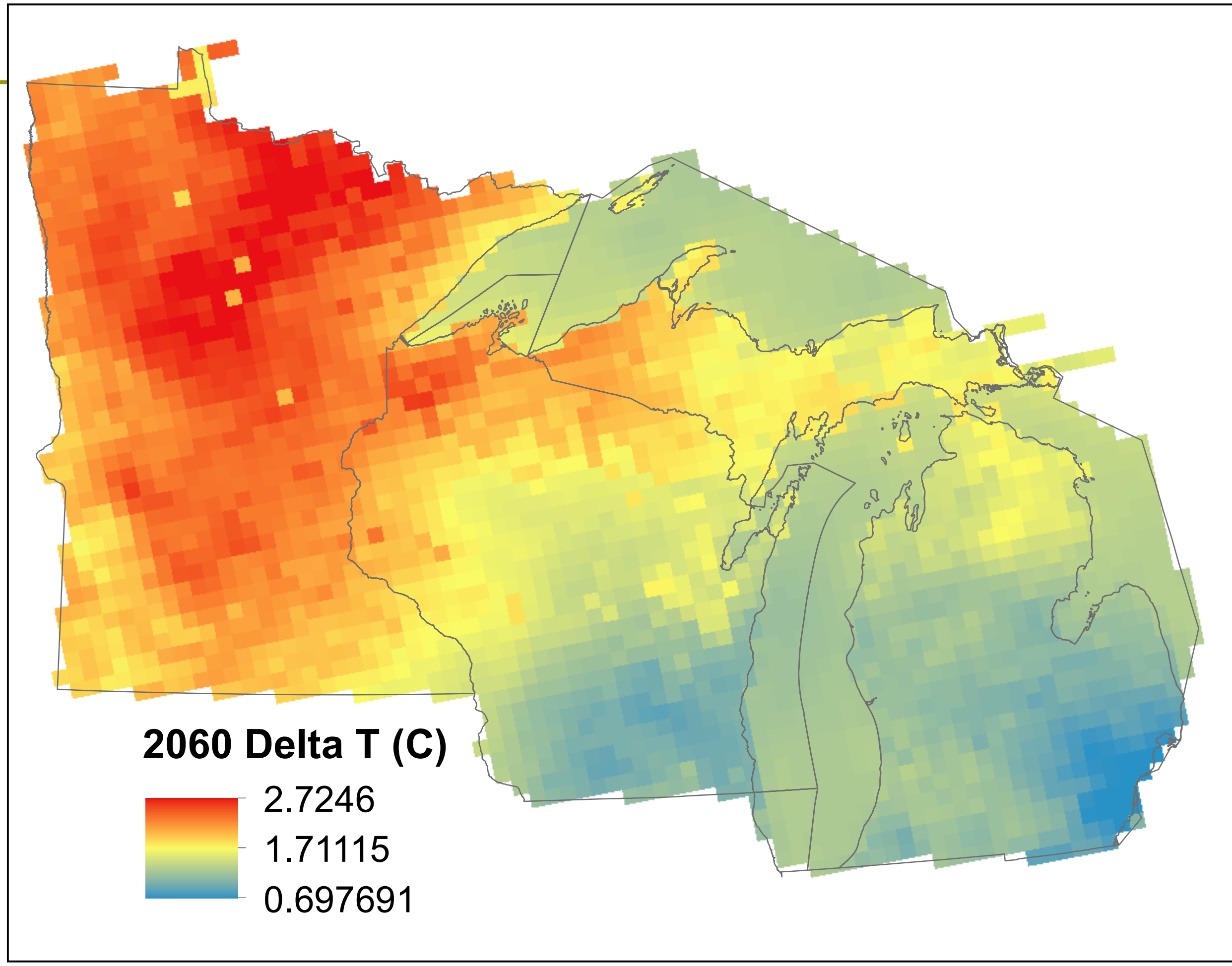


IPCC 2013

Human Activities Are the Primary Driver of Recent Global Temperature Rise



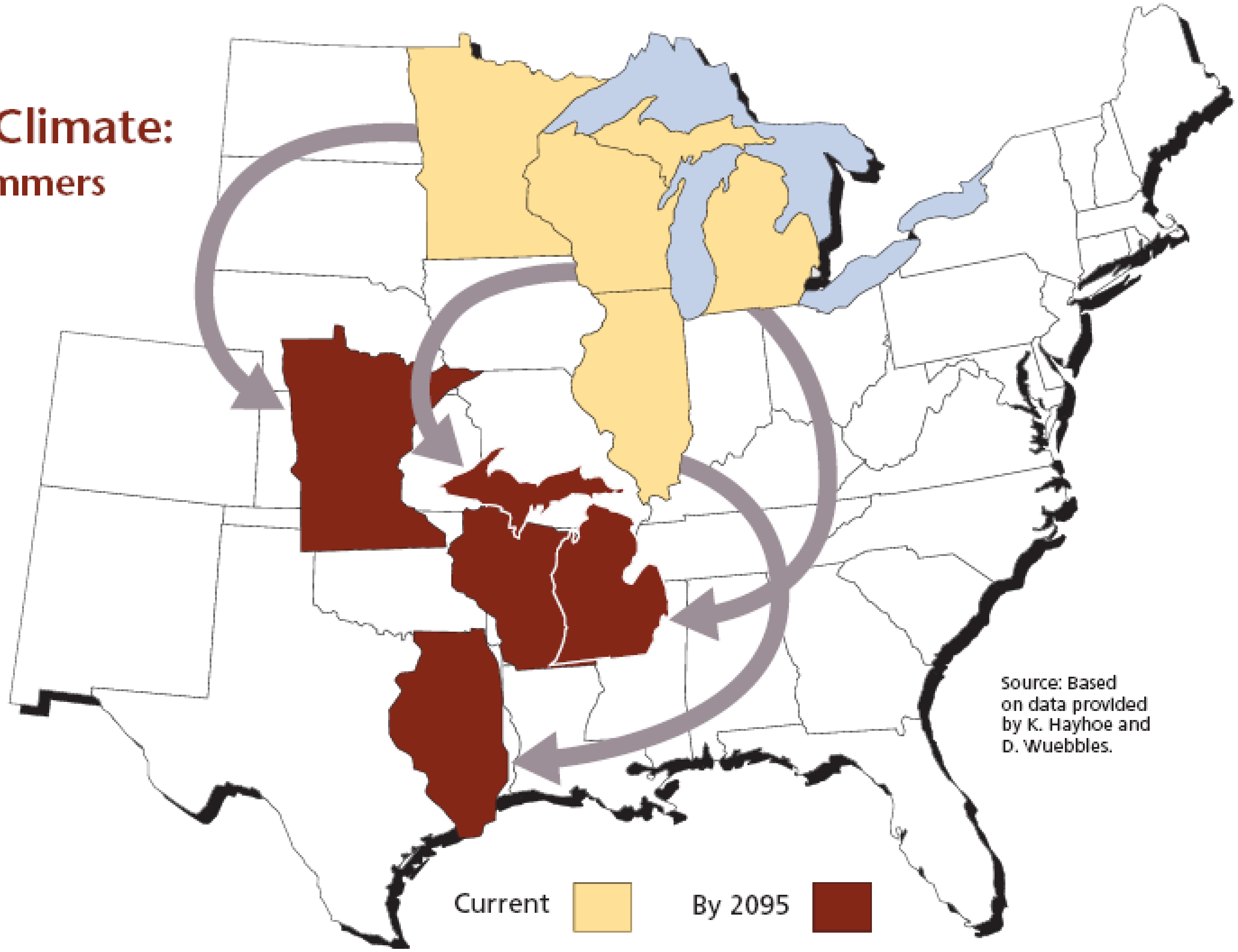
Change in mean July air temperature (^{o}C), 1980-89 to 2050-69, GENMOM



•Future climate projections supplied by Steve Hostetler, Oregon State/USGS

•Downscaled (15 km) climate projections available for 3 GCMs (GENMOM, GFDL, ECHAM5)

Migrating Climate:
Changing Summers in the Region

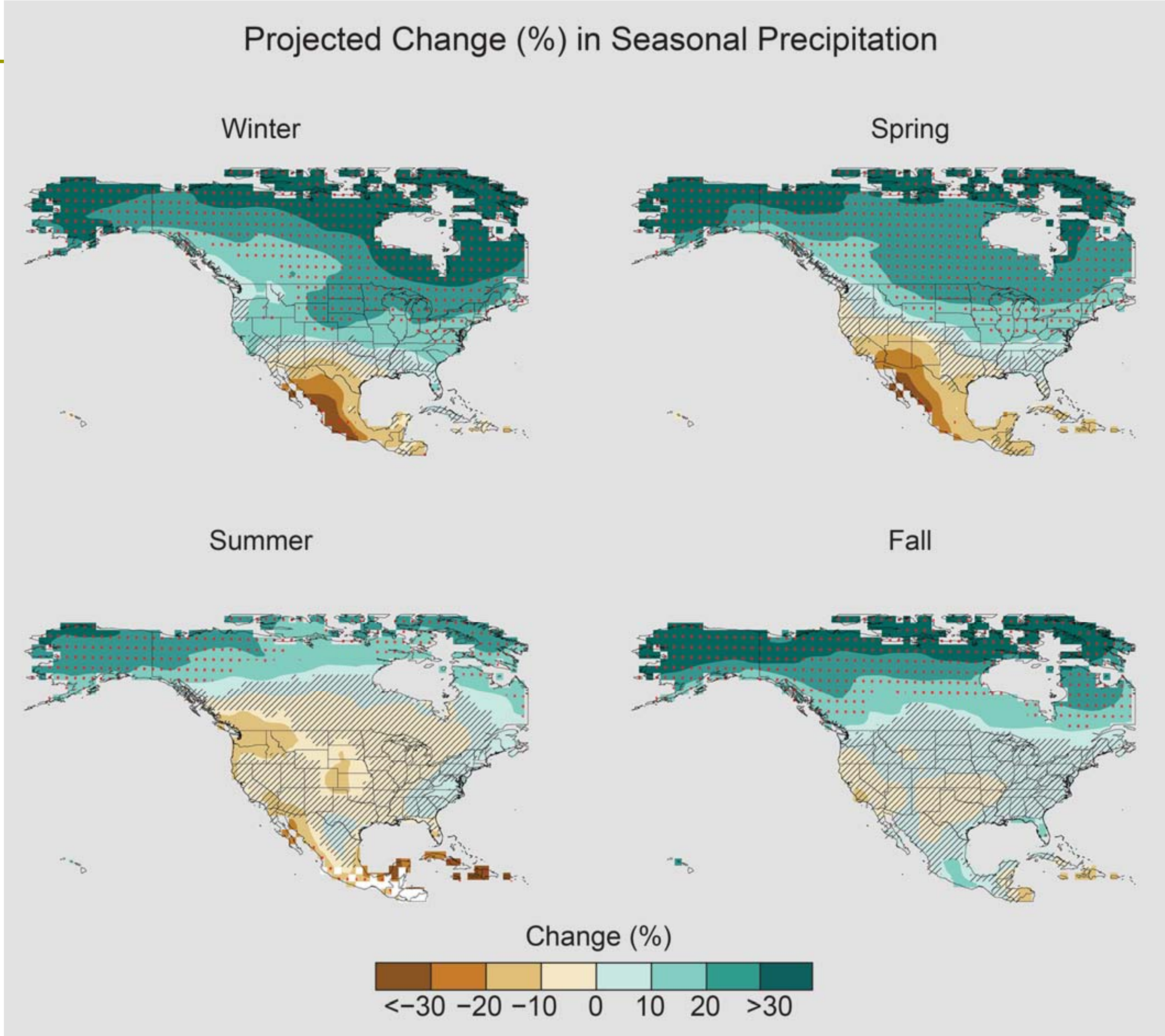


CONFRONTING CLIMATE CHANGE IN THE GREAT LAKES REGION

Union of Concerned Scientists • The Ecological Society of America

2003

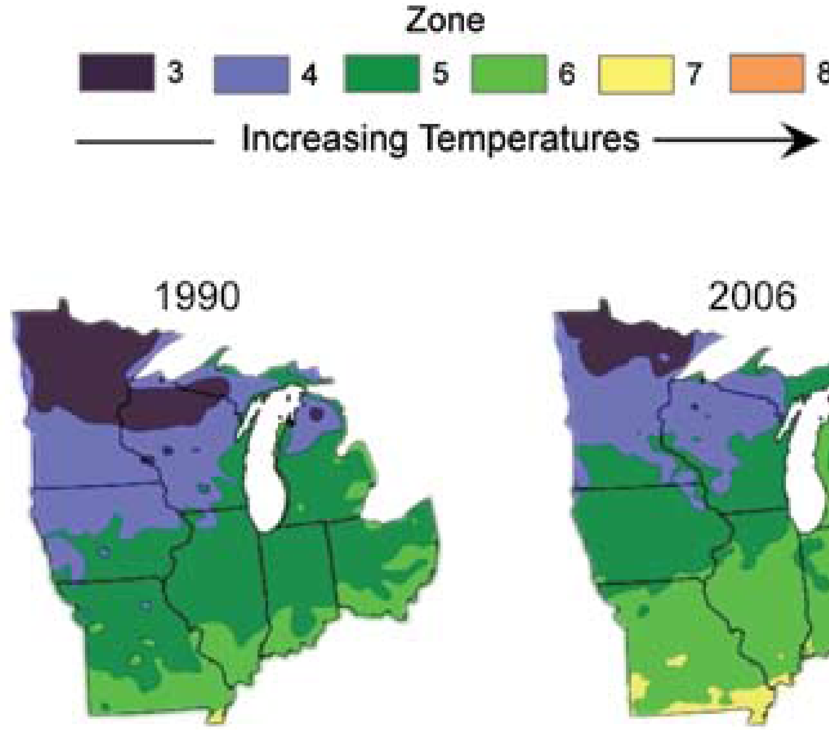
Projected Change (%) Seasonal Precipitation

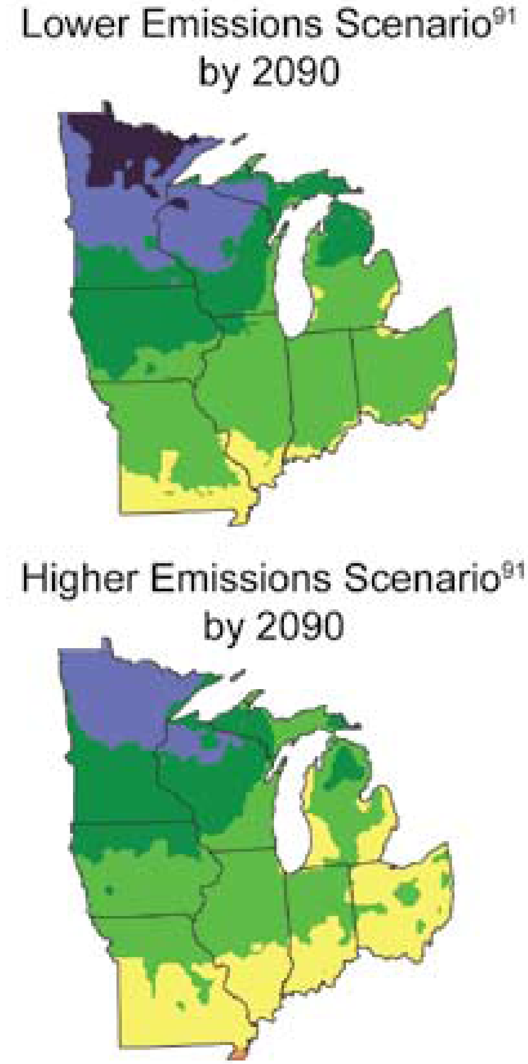


Confidence that climate change will impact common Minnesota weather/climate hazards beyond 2025

Confidence	Hazard	Expectations beyond 2025
Highest	Extreme cold	Continued rapid decline
	Extreme rainfall	Unprecedented events expected
High	Heat waves	Increases in severity, coverage, and duration expected
Moderately High	Drought	Increases in severity, coverage, and duration possible
Moderately Low	Heavy snowfall	Large events less frequent as winter warms
Moderately Low	Severe thunderstorms & tornadoes	More “super events” possible, even if frequency decreases

Plant Hardiness Zones





Plant winter hardiness zones in the Midwest are projected to shift one-half to one full zone every 30 years. By the end of this century, plants now associated with the Southeast are likely to become established throughout the Midwest.

"Global Climate Change Impacts in the United States" (USGCRP, 2009).

Climate Change Impacts

- Higher temperatures
- Increased incidence of intense storms
- Likely drier conditions in summer

Canal Park, Duluth, MN, Nov 27, 2001

Impacts on ecosystems:

Increasing Temperatures:

- Drought
- Reduced snowpack
- Invasive species
- Species range shifts
- Phenology changes
- Ice cover reduced / lost
- Flood
- Erosion

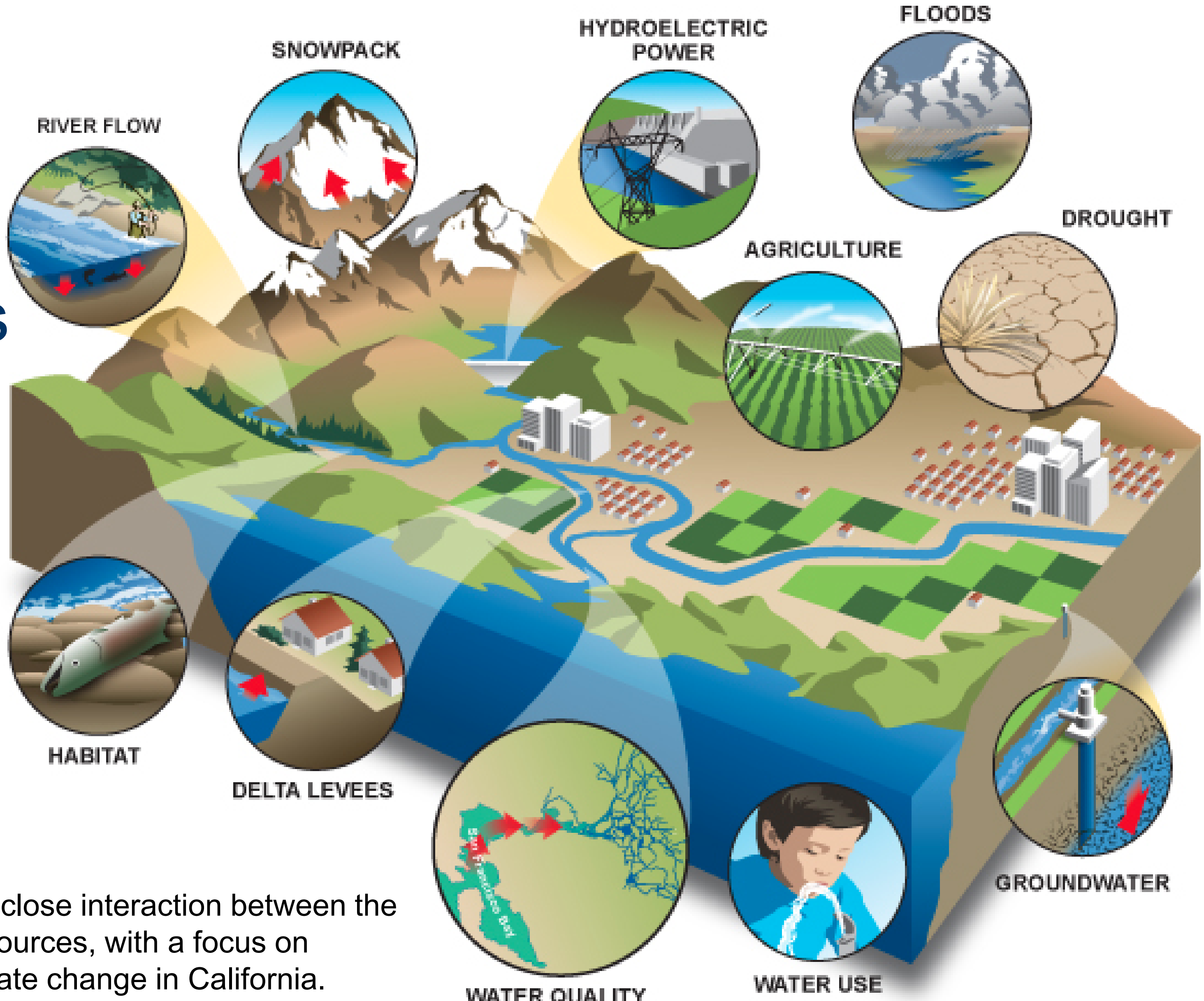
Changing Precipitation Patterns

- Flood / drought
- Introduce toxics
- Nonpoint source pollution
- Pathogens / disease
- Wave action
- High winds

Drier summer conditions

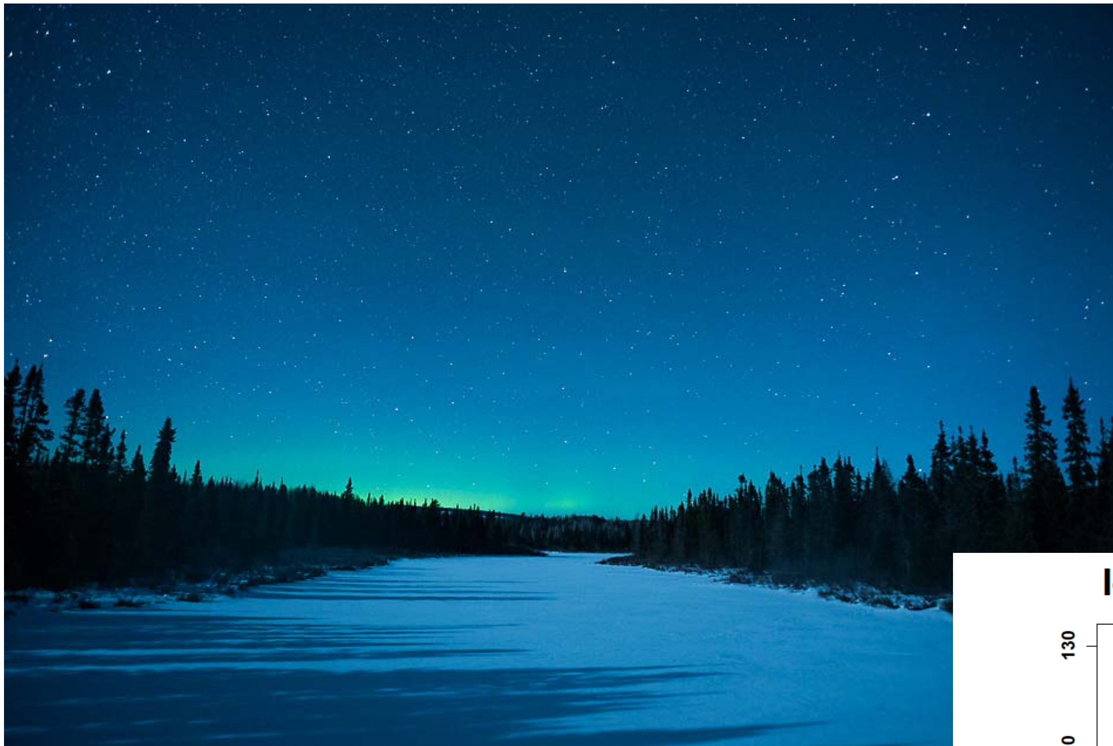
- Low water levels
- Increased water temperature
- Algae blooms
- Hypoxia
- Increased biogeochemical processing

Climate Change Impacts on Water Resources



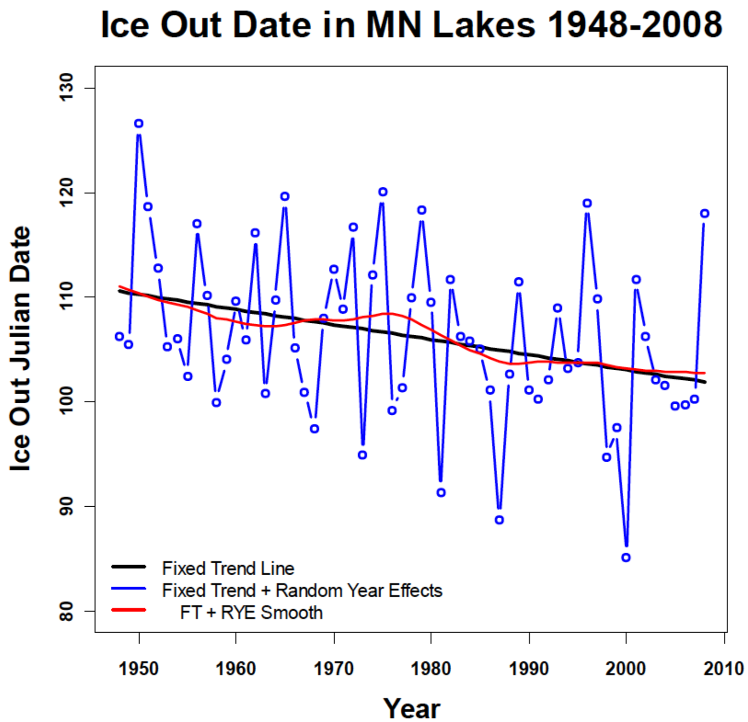
This diagram shows the close interaction between the hydrology and water resources, with a focus on potential impacts of climate change in California.
http://www.water.ca.gov/climatechange/factsheet.cfm

https://www.e-education.psu.edu/geog438w/node/240



http://minnesota.publicradio.org/display/web/2013/01/25/regional/minnesota-cold-winter-photos#3

Ice Out Minnesota Lakes 1948 - 2008

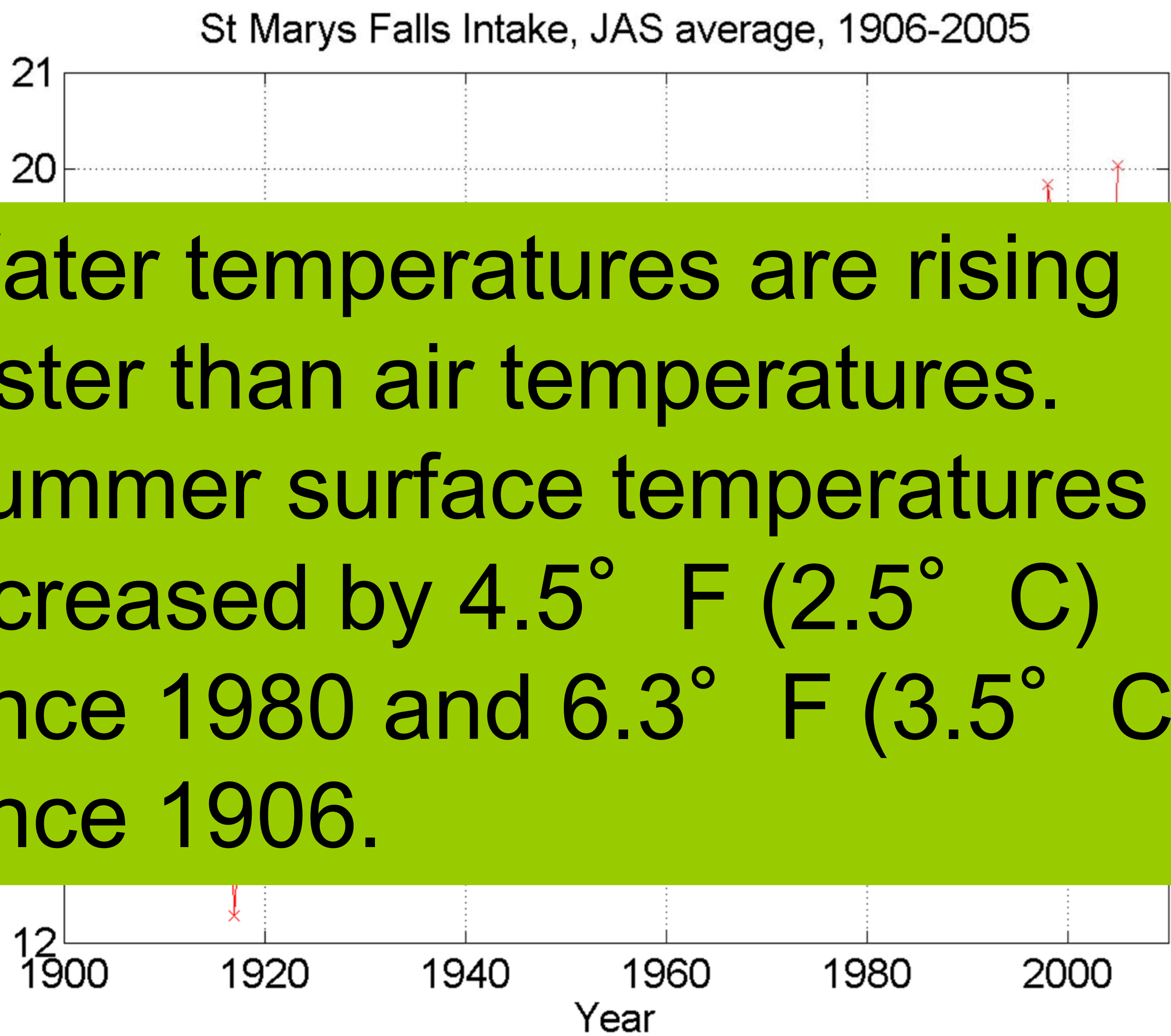


Trend = 1.4 days / decade
Since 1950's (n = 71)

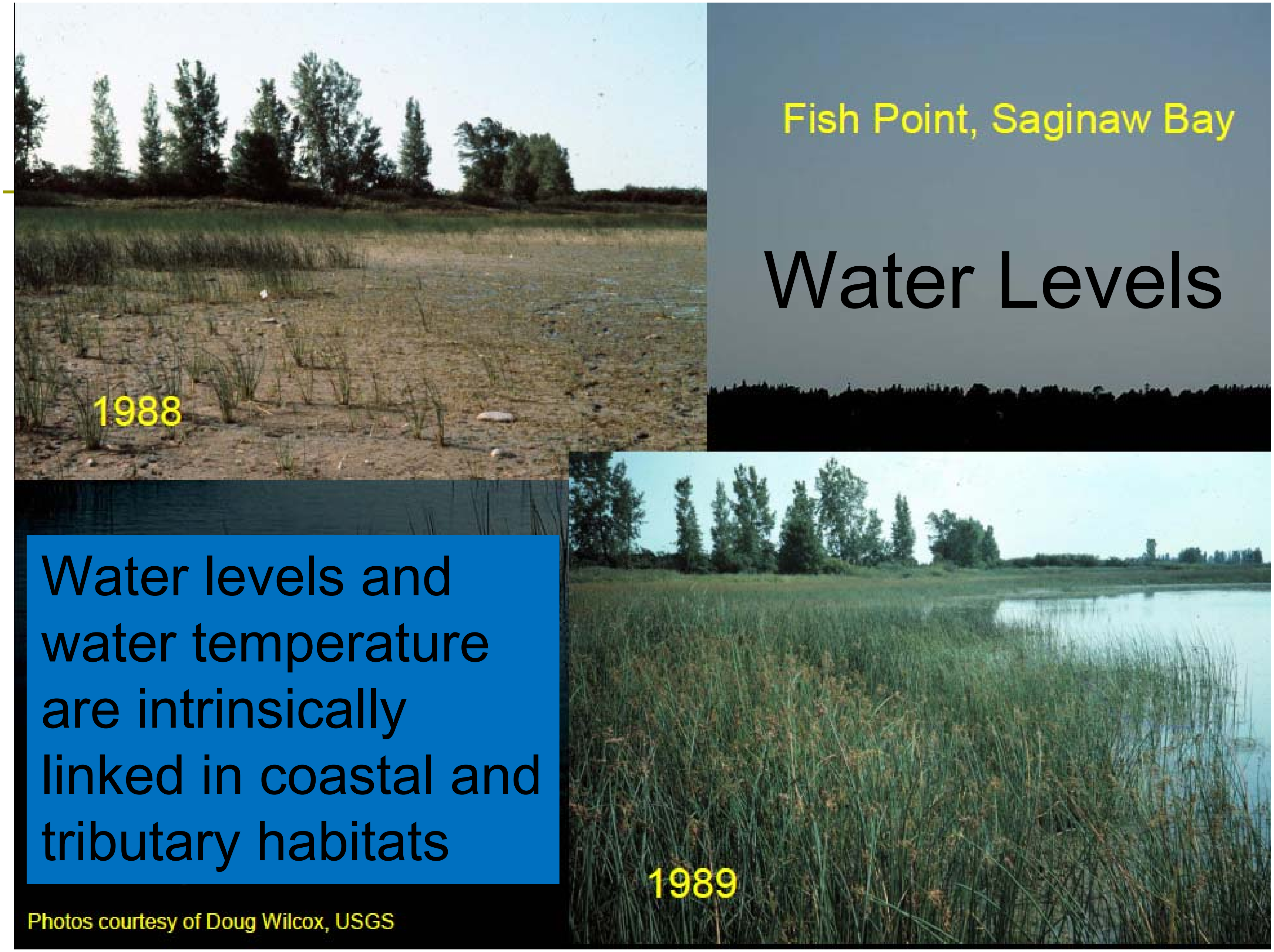
Staples, et al. *in prep.*

Summer Temperatures: Lake Superior

From: Jay Austin, 2006.



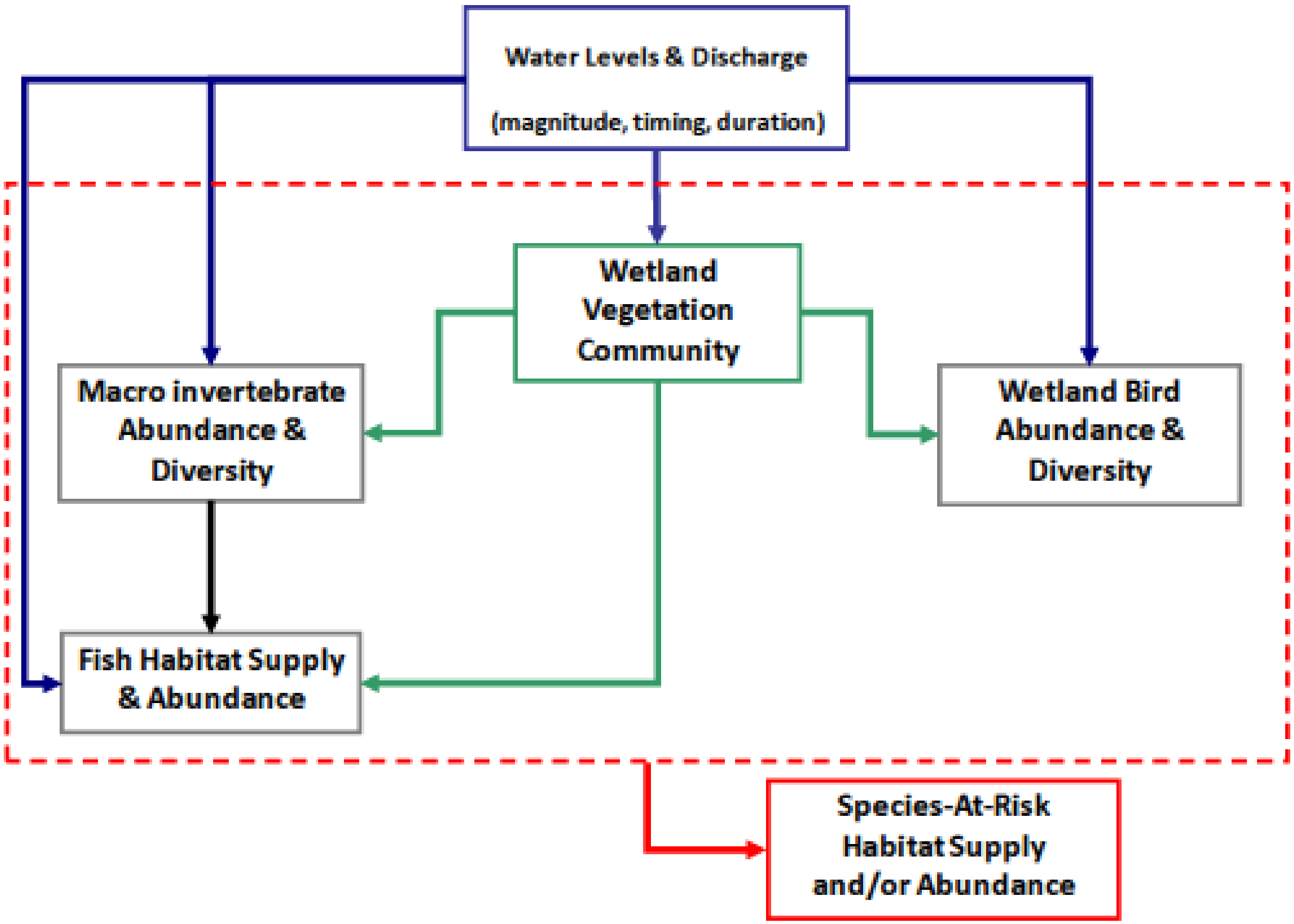
Water temperatures are rising faster than air temperatures. Summer surface temperatures increased by 4.5° F (2.5° C) since 1980 and 6.3° F (3.5° C) since 1906.


Fish Point, Saginaw Bay
Water Levels
1988
Water levels and water temperature are intrinsically linked in coastal and tributary habitats
1989
Photos courtesy of Doug Wilcox, USGS

Predictions: Water Levels

- Shorter duration of ice cover will **increase evaporation** in winter
- Warmer air temperatures will **increase evapotranspiration**
- If lower precipitation in summer - **decrease in soil moisture** and draw-down of water tables
- Great Lakes water level predictions are uncertain; current levels at almost record highs

IJC Upper Lakes Water Level Study



Coastal Habitats

Open-coast wetland

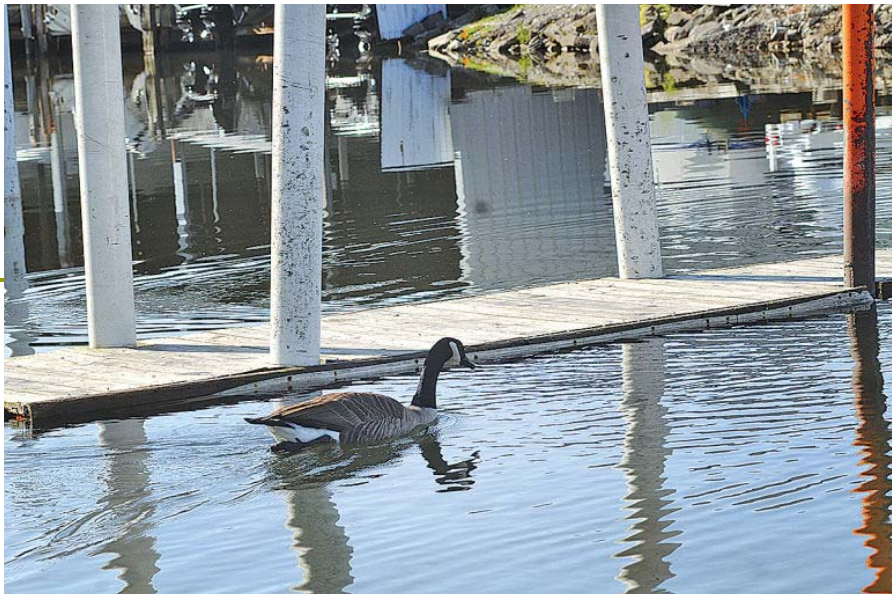
Tributary / Riverine wetland

Protected wetland / high energy shoreline

high energy shoreline

Connectivity

Dredging in harbor, Michigan City, Indiana, Lake Michigan. Credit: National Park Service. Source: EPA Great Lakes National Program Office.



By: Kevin Bunch | **Roseville - Eastpointe Eastsider** | **Published May 20, 2016**

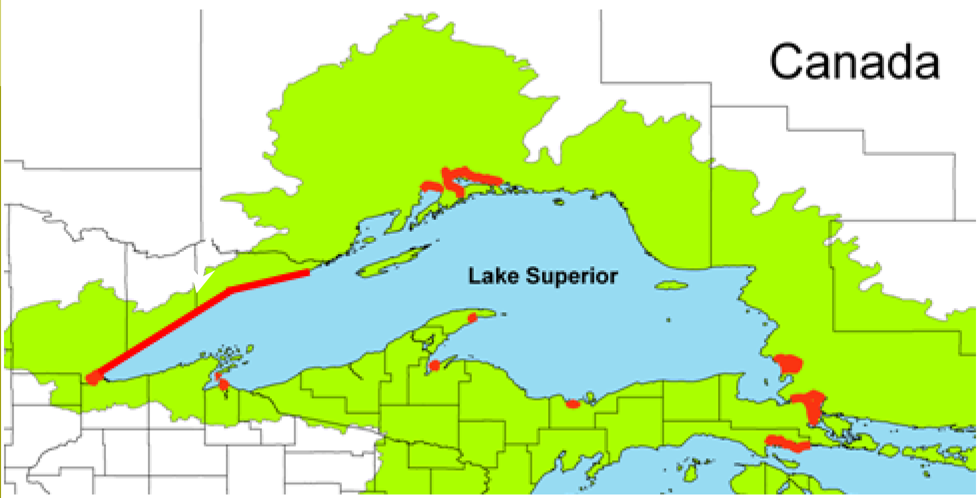
Low water levels in Eagle Harbor, Wisconsin, Lake Superior. Credit: Kate Houston. Source: NOAA GLERL.

Rivermouth Connectivity

Bedrock Sill

Erodible Stream

Devils Track River

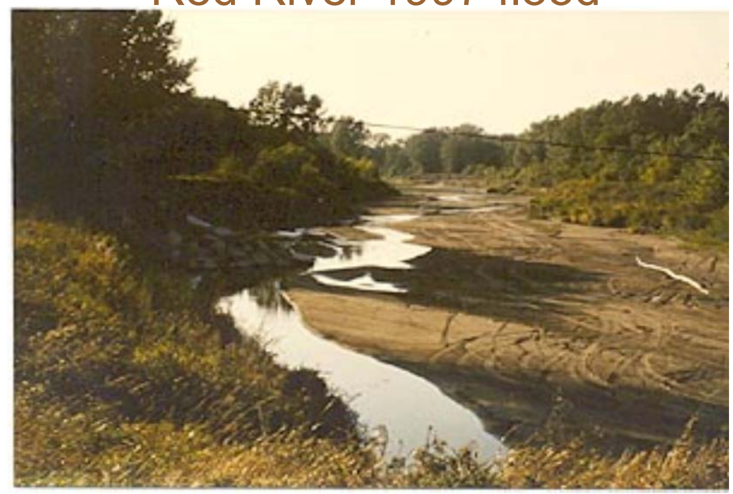


Box Culverts

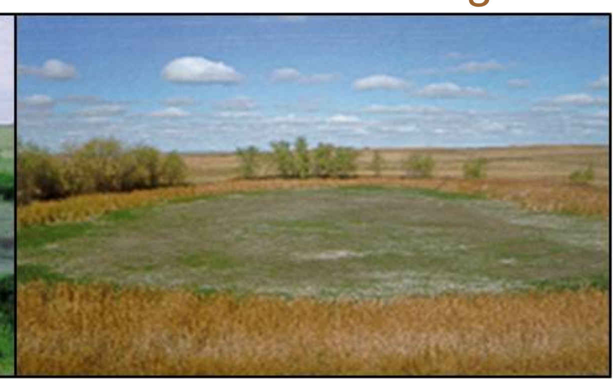
Water quality impacts

- Higher temperatures
  - Reduced DO / Hypoxia
  - Increased primary production rates
  - Increased BOD
- Increased intensity of storm events
  - Increased surface runoff
  - Increased erosion (sedimentation, channel modification)
  - Increased runoff (contaminant, nutrient, sediment load)

Red River 1997 flood



Red River 1988 drought

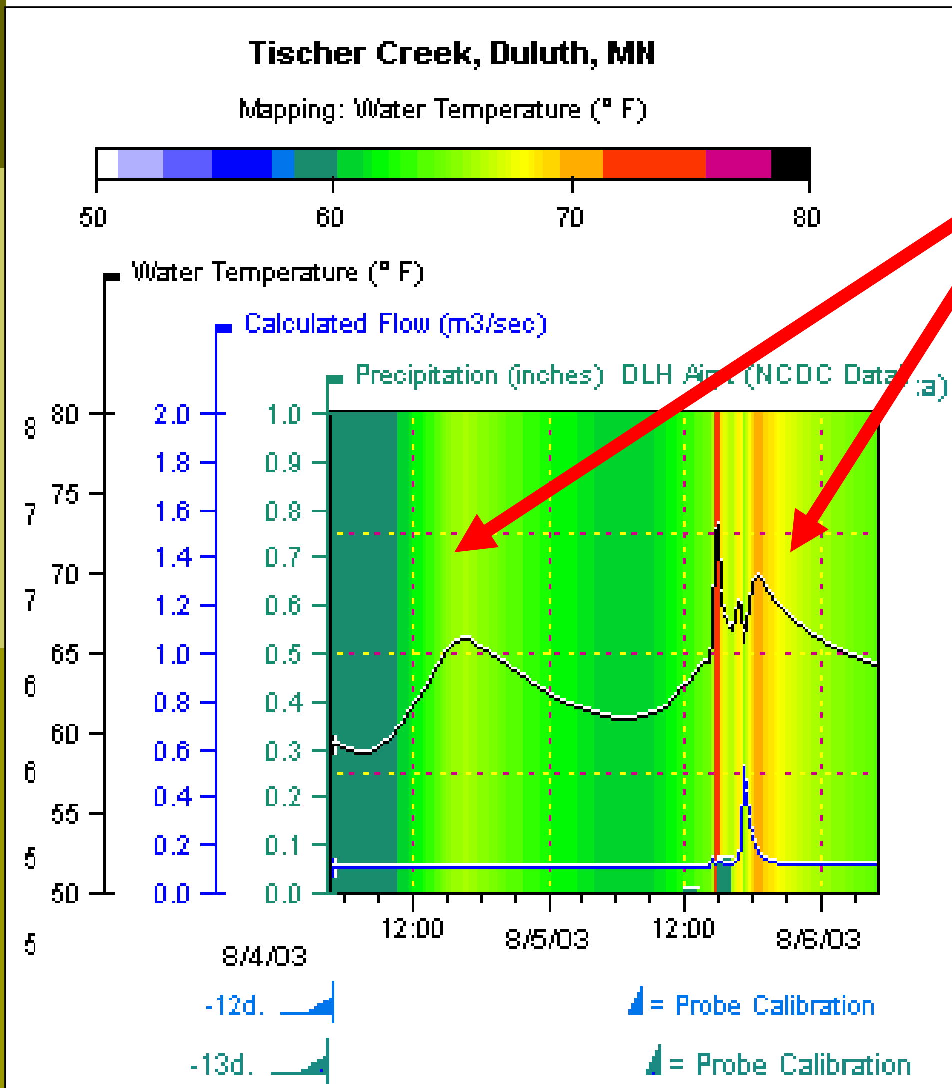


Water quality impacts:

- Earlier and longer summer oxygen stress ➔ higher risk of dead zones and fish kills.
- Anoxic sediments ➔ release redox-sensitive metals (Hesslein et al. 1980).
- Acidic sediments ➔ mobility of metals (e.g., Al, Cd) increases; ➔bioaccumulates in the food chain.
- Higher temps increase geochemical process rates

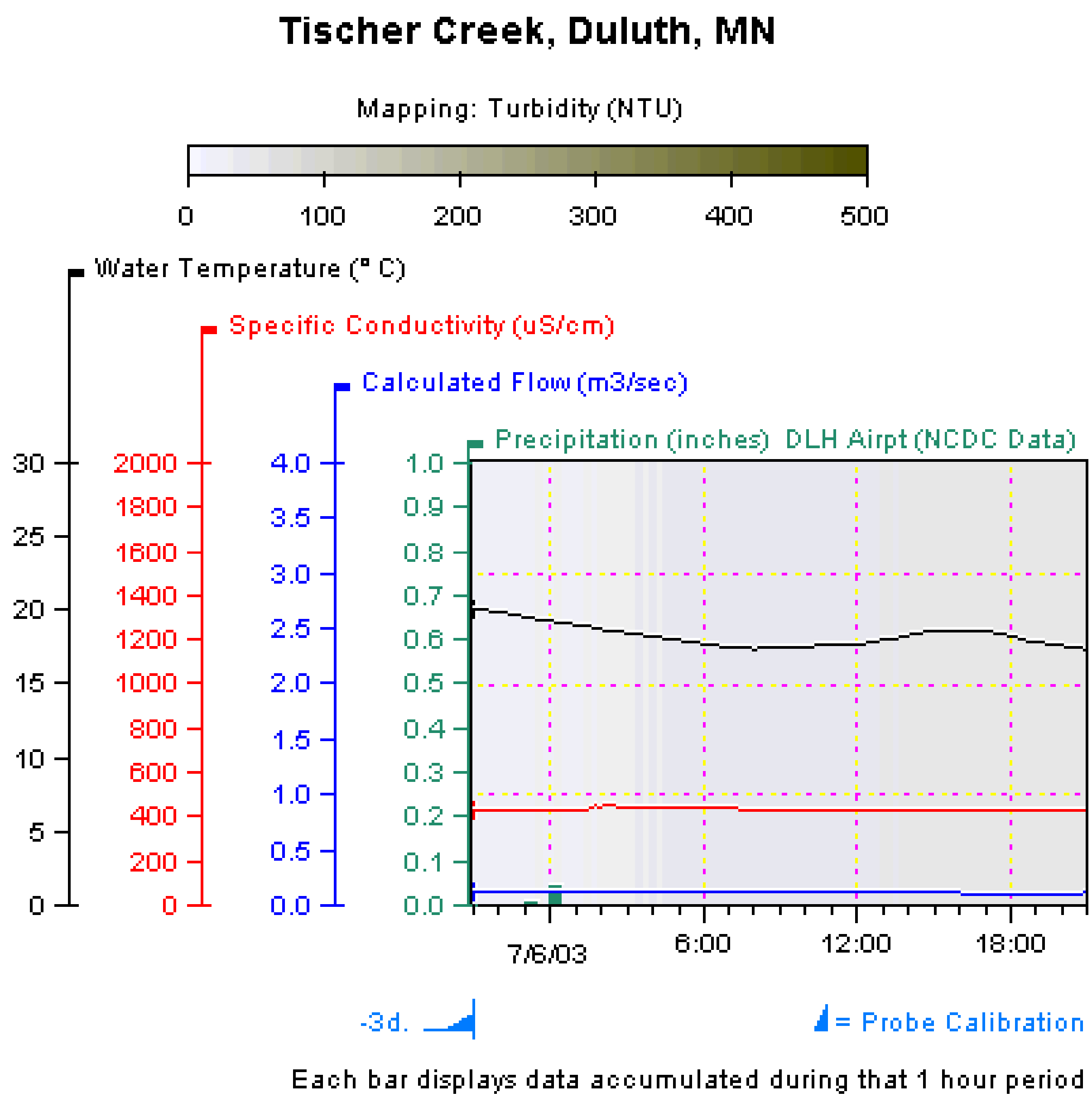
*see Crane et al. 2005. Climate change effects on environmental and human health chemical standards. Human and Ecological Risk Assessment 11:289-318.

Middle of the night spikes of 3-6^{o}C stormwater road/lot runoff



Stream temperature is a major stressor of Duluth trout. See how roads and lots warm the water by >5 ^{o}F

Lesson – even moderate rain can cause a 5-11 ^{o}F jump as water moves across warm asphalt.


Tischer Creek, Duluth, MN
Mapping: Turbidity (NTU)
0
100
200
300
400
500
Water Temperature (° C)
Specific Conductivity (uS/cm)
Calculated Flow (m3/sec)
Precipitation (inches) DLH Airpt (NCDC Data)
30
25
20
15
10
5
0
2000
1800
1600
1400
1200
1000
800
600
400
200
0
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
7/6/03
6:00
12:00
18:00
-3d.
= Probe Calibration
Each bar displays data accumulated during that 1 hour period

What does this mean for wetlands?

Region-specific implications and studies

Drought in Northern Ecosystems

*Small wetlands, such as this one near Red Feather Lakes in Larimer County, Colorado, are often ephemeral. Drying conditions may cause such freshwater sites to disappear altogether, threatening the survival of boreal chorus frog (*Pseudacris maculata*) tadpoles and other species. The image on the left was taken in early June, the one on the right in mid- July. Photographs: Staci Amburgey.*
Ogden 2017

- Increasing…
  - Frequency
  - Intensity
- Reduced total observed organic matter export
- Oxidized wetland soils releases stored contaminants into streams after rain events

Now, there are even fish in the “duck” PPR!

Tadpoles in the San Pedro Mezquital River, in Nayarit, Mexico. Tadpoles are an aquatic phase in the lives of many amphibians, making their presence and survival an excellent indicator of freshwater quality. Photograph: Octavio Aburto/World Wildlife Fund.

- Baseline: no fish
  - Frequent drying
  - Freezing
  - High salinity
- Recent precipitation increases have resulted in higher water levels and wetland/lake freshening
- In 2012–13: found fish present in a majority of sites sampled (84% of 162 PPR wetlands & small lakes)

McLean, K.I., Mushet, D.M. & Stockwell, C.A. Wetlands (2016) 36(Suppl 2): 407. https://doi.org/10.1007/s13157-016-0766-3

WETLANDSCAPE

Johnson, W.C. & Poiani, K.A. Wetlands (2016) 36(Suppl 2): 273. https://doi.org/10.1007/s13157-016-0790-3

Wetland impacts: summary

- Increasing decomposition rates due to higher temperatures and lowering of water tables.
- Water level changes alter the type and quality of plants, transforming biodiversity.
- Reduction of the carbon store, increased flux of CO_2 and possibly of CH_4, contribute to further amplification of greenhouse gas production.
- Wet-dry cycles enhance mercury methylation, and mobility of other heavy metals.

Wetlands are more sensitive to climate change

- Flora and fauna in wetlands are more sensitive to changes in water levels than those of lakes, rivers, and streams. (Why?)
- Wetlands have been cut off from other wetlands by dams, dikes, roads, and other alterations. (What is the consequence of this?)
- Mankind has already stressed wetlands which has reduced the biodiversity. (Why do we care about this?)

Wetland types affected…
why? how? consequences?

- Coastal and estuarine wetlands
- Permafrost and other open tundra wetlands
- Wetland boreal forests
- Alpine wetlands
- Prairie potholes

Climate Change Impacts: Summary

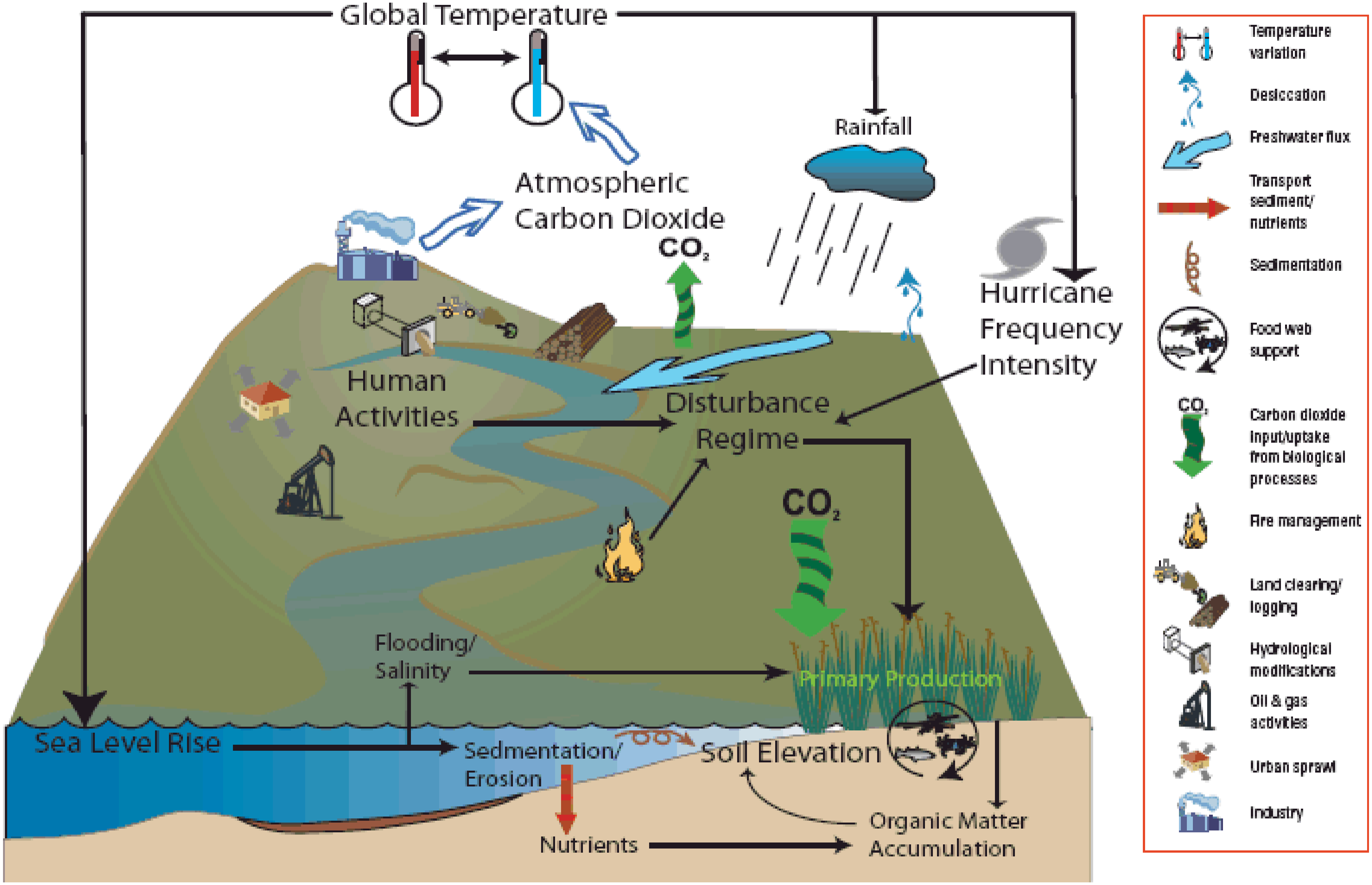
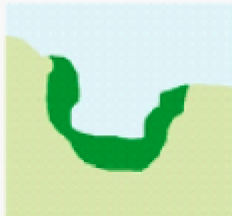
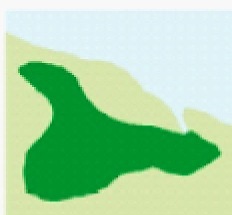


Table 8: Summary of Impact of Climate change on Great Lakes Coastal Wetlands

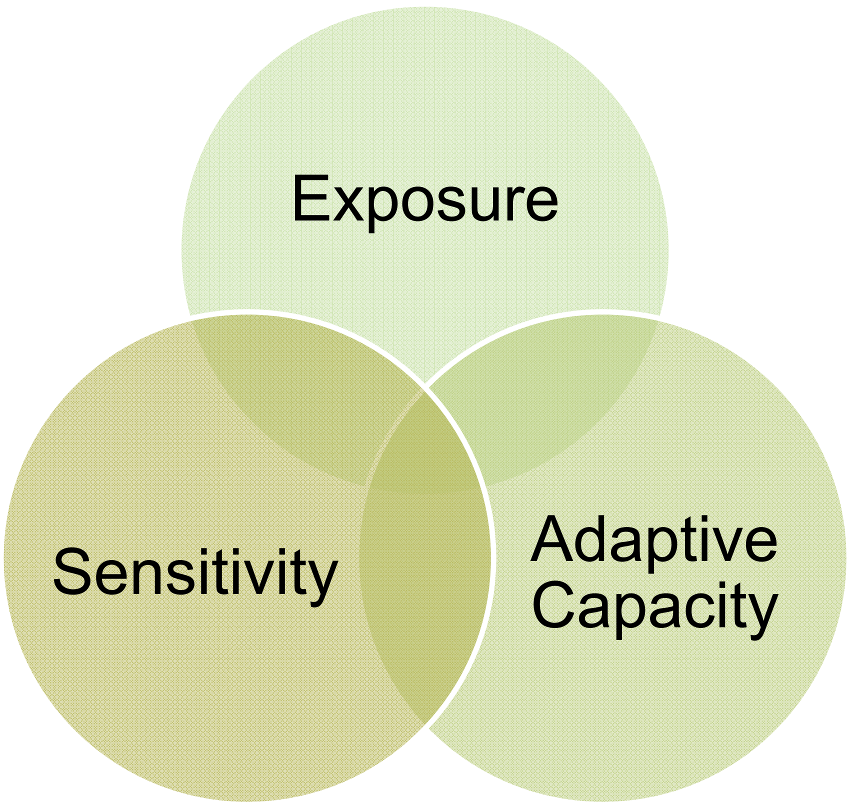
Wetland Site Type (study site examples)	**Major Characteristics**	**Main Impacts of Climate Change**
Lacustrine (e.g. Long Point, Turkey Point, Presqu'ile, South Bay) 	• open to and most affected by Great Lakes, including water level fluctuations, nearshore currents, seiches, and ice scour • wetlands in open and protected bays • varying degrees of organic sediment and vegetation development • bathymetry, gentle to steep slope, dependent on degree of protection from lake effects and geology (ice scour and seiches)	• potential for more exposure to extreme winter storms and less ice protection • aquatic, submergent and emergent vegetation may migrate lakeward with lower levels if suitable sediment, slope, seed banks exist • drier vegetation communities (sedges, grasses and shrubs) expand in current wetland • warmer temperatures may result in vegetation community shifting over decades and centuries, starting with changes in species composition and dominance, if seed access (e.g. corridor, birds) • cumulative stresses may encourage spread of invasive species • loss and contamination from increased demands for dredging • mud flats exposed • less interspersion
Riverine (e.g. Dunnville, Lynde Creek, Hay Bay, Lake St. Clair wetlands) 	• occur near the mouth of tributaries to and connecting channels of the Great Lakes • water quality, inflow and sediment loading are strongly influenced by runoff from the watershed but also affected by the lake • often protected from waves • types include: open to the lake, along connecting channels, behind barrier bars and in delta • steep river bank and river channel, with flat flood plain	• more variable river flooding regimes affect wetland which can lessened influence of lake levels • more sedimentation from more extreme precipitation events causing more erosion upstream; vegetation covered with sediments and fish and wildlife habitat adversely affected • lower flows may increase pollutant concentrations • warmer water temperatures decrease dissolved oxygen • may be able to migrate toward river-mouth as levels decline but dependent on sediment, slope and seed bank • warmer temperatures may result in vegetation community shift over decades and centuries, starting with changes in species composition and dominance • cumulative stresses may encourage spread of invasive species
Barrier-Enclosed 	• occur behind a barrier beach formed by coastal processes • gradual slope but barrier beach is an obstruction to downslope vegetation movement once a particular water level threshold has been reached • generally protected from waves but may be lake-connected during high water periods (or extreme storms) • varying connectivity to lake and influence by lake water levels • includes barrier beach and swale complexes between relic beach ridges with decreasing lake level influence as move landward • more prevalent in lower lakes where more coastal sediments are available	• unable to shift lakeward with lower lake levels so gradual drying of wetland; dominated by meadow, shrub and tree communities with associated shift in diversity, productivity and habitat value • drying may increase risk of fire • shifting coastal processes may alter barrier or re-form a lakeward one • warmer temperatures may result in vegetation community shift over decades and centuries, starting with changes in species composition and dominance, if seed access (e.g. corridor, birds) • warmer water temperatures decrease dissolved oxygen • cumulative stresses may encourage spread of invasive species • wetland area decreases

(Mortsch and Koshida 1996; Mortsch 1998; IPCC 2001b; Hebb 2003; Kling *et al.* 2003; Wilcox 2004; Albert *et al.* 2005)

Impacts on Wetland Goods and Services

- **Reduction in cold water fish** such as trout while warm water fish such as bass increase. As coastal wetlands disappear, ocean fish that depend on them will be reduced.
- **Shellfish reduction** due to a decrease in the size of coastal wetlands and rising sea levels above the coastal flat regions.
- **Waterfowl production reduced** especially in the Prairie Pothole Region.
- **Habitats for rare and endangered species reduced** leading to species extinctions.
- **Decrease in food chain support** for all species that depend on coastal and inland wetlands.
- **Water quality and pollution buffering decreased** with decreasing wetlands.
- **Loss of coastal wetlands which provide wave and storm buffering** may lead to more coastal erosion and higher storm surges in hurricanes and winter storms.

Building Resilience



- All scales
  - Time
    - Now → future
  - Space
    - Lakes/streams → ecoregions
  - Levels of organization
    - Population → ecosystem

- **Limit** exposure
- **Identify** sensitivity
- **Increase** adaptive capacity

Concept credit: Olivia LeDee, MN DNR Fish and Wildlife Planning Consultant

Mitigation

- Reduce emissions and environmental stress
- Restore Habitat
  - Watershed
    - Slow run-off of pollutants and sediment
  - Shoreline
    - Filter run-off
    - Stabilize banks to prevent erosion
    - Replant native vegetation
  - Aquatic
    - Replace woody debris
    - Enhance connectivity
    - Restore natural flow regime

Slide from: B. Bethke

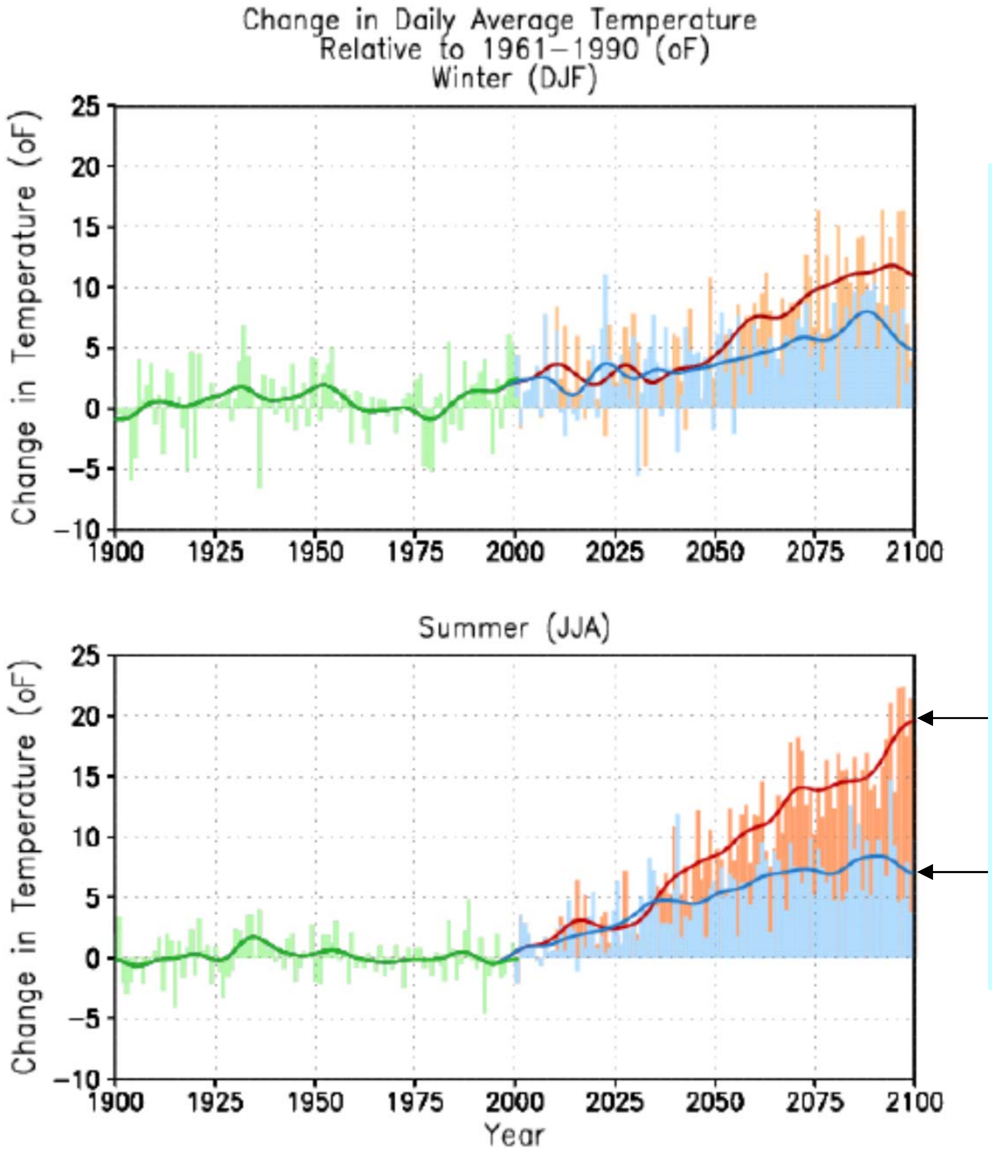
Adaptation

- Assess / Implement Policy
  - Protect aquatic ecosystems from degradation
- Coordination
  - DNR forestry uses selective harvest and buffer zones around streams when setting up timber sales
  - Pollution Control Agency and DNR work together to monitor water quality and fish communities
- Public lands conservation
  - Strategic purchase of sensitive lands

Social Adaptation

- Despite our best efforts, some aquatic communities will change
- Identify transitional fisheries, alert stakeholders

HadCM3 projections of winter and summer temperature change for the A1FI 'high' emissions scenario (red) and the B1 'low' emissions scenario (blue). Historical data is shown in green.



Low vs high emission scenarios result in different degrees of warming.

We can reduce the rate of increase through our actions.

10 Personal Solutions

- **The car you drive: the most important personal climate decision**
- **Choose clean power**
- **Look for Energy Star**
- **Unplug a freezer**
- **Get a home energy audit**
  Follow recommendations!
- **Light bulbs matter**
- **Think before you drive**
- **Buy good wood**
- **Plant a tree**
- **Recycle!**
- **Let our leaders know you are concerned about global warming.**

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