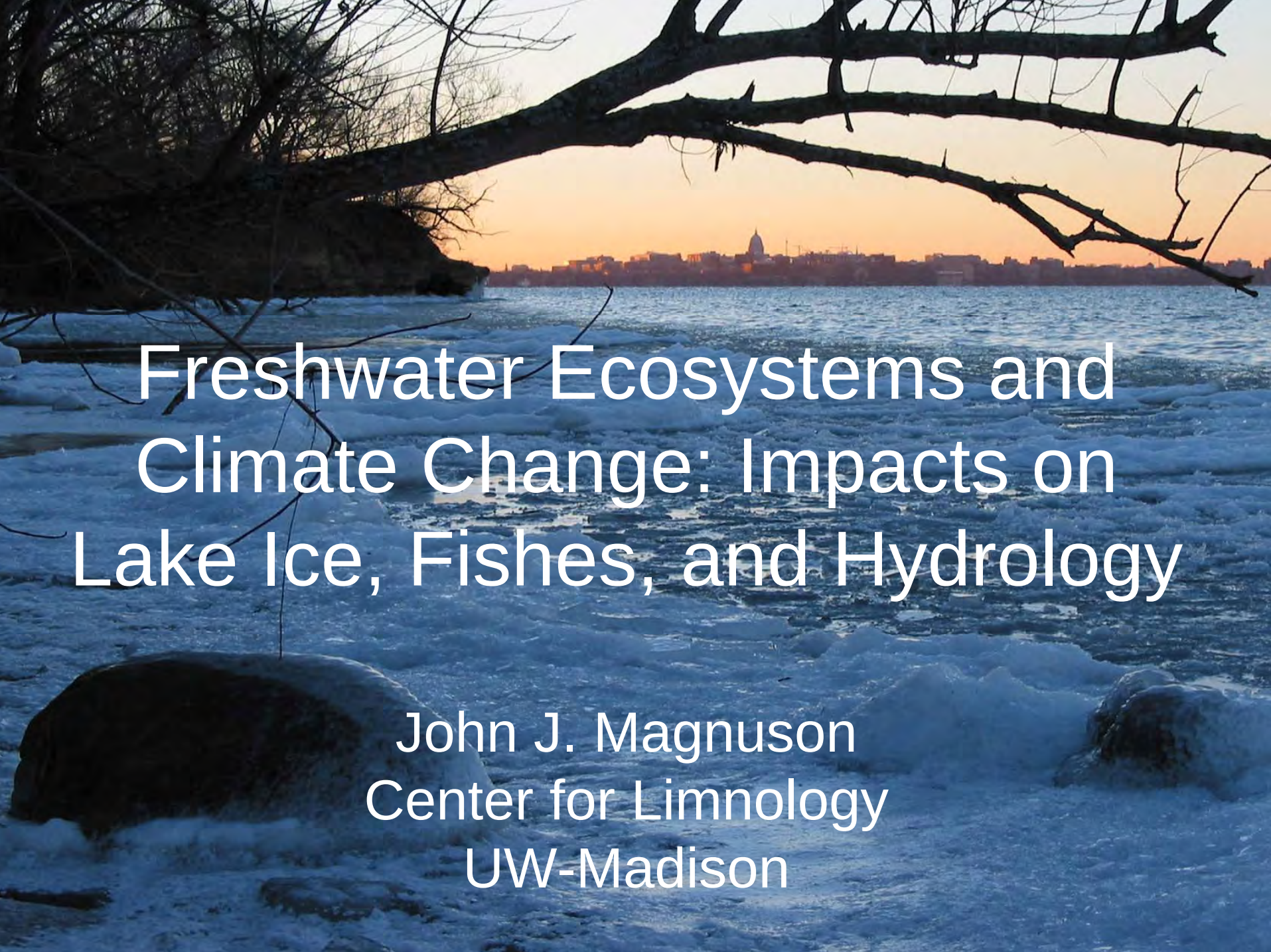


Freshwater Ecosystems and Climate Change: Impacts on Lake Ice, Fishes, and Hydrology

John J. Magnuson
Center for Limnology
UW-Madison

Main Points of Confronting Climate Change in the Great Lakes Region

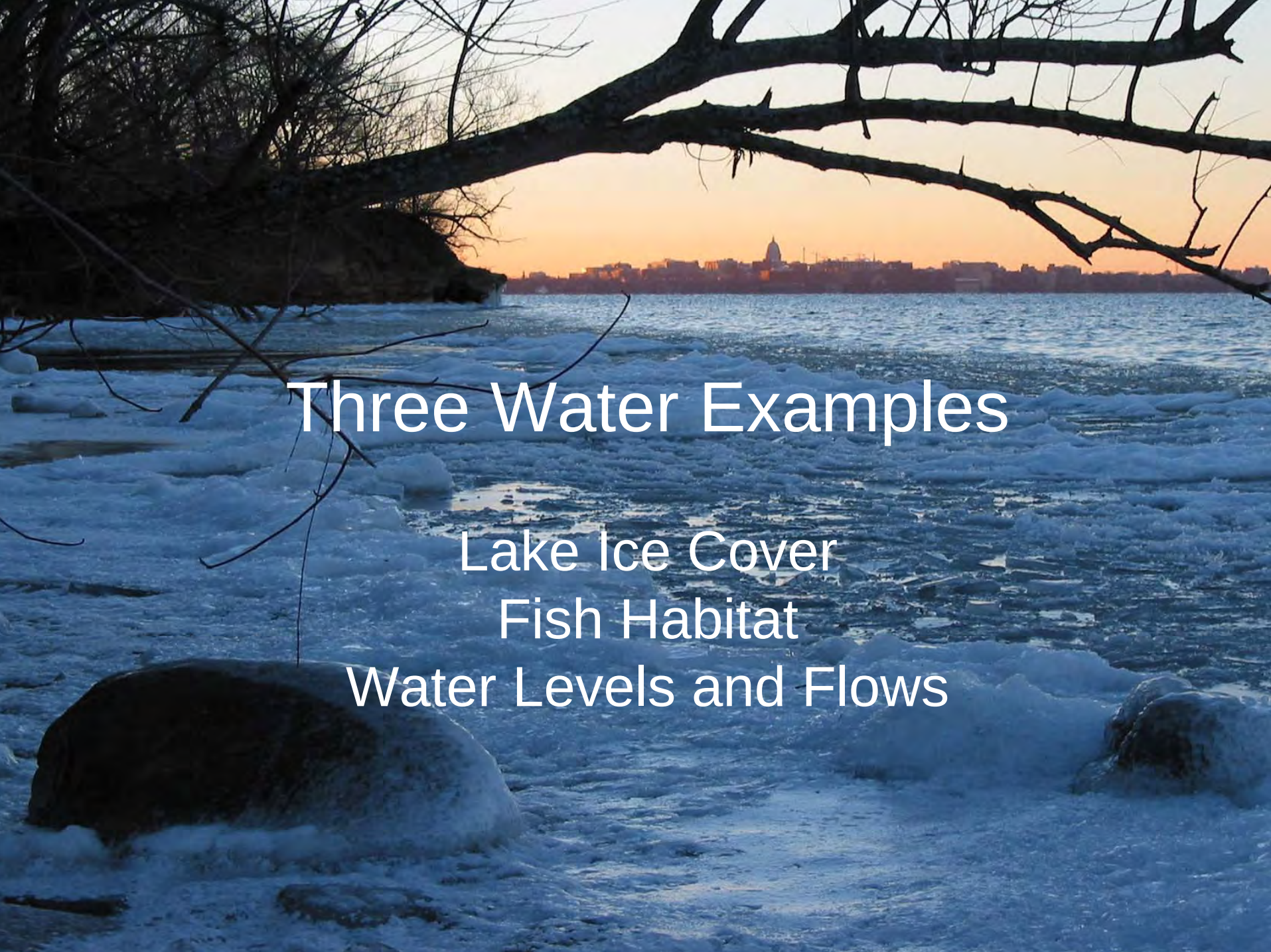
1. Climate is changing globally and in our region.

2. Impacts have already occurred and will get worse.

3. Emissions of greenhouse gases especially CO_2 contribute to these changes.

4. Actions taken now can reduce the most severe future impacts.

UCS & ESA 2003.



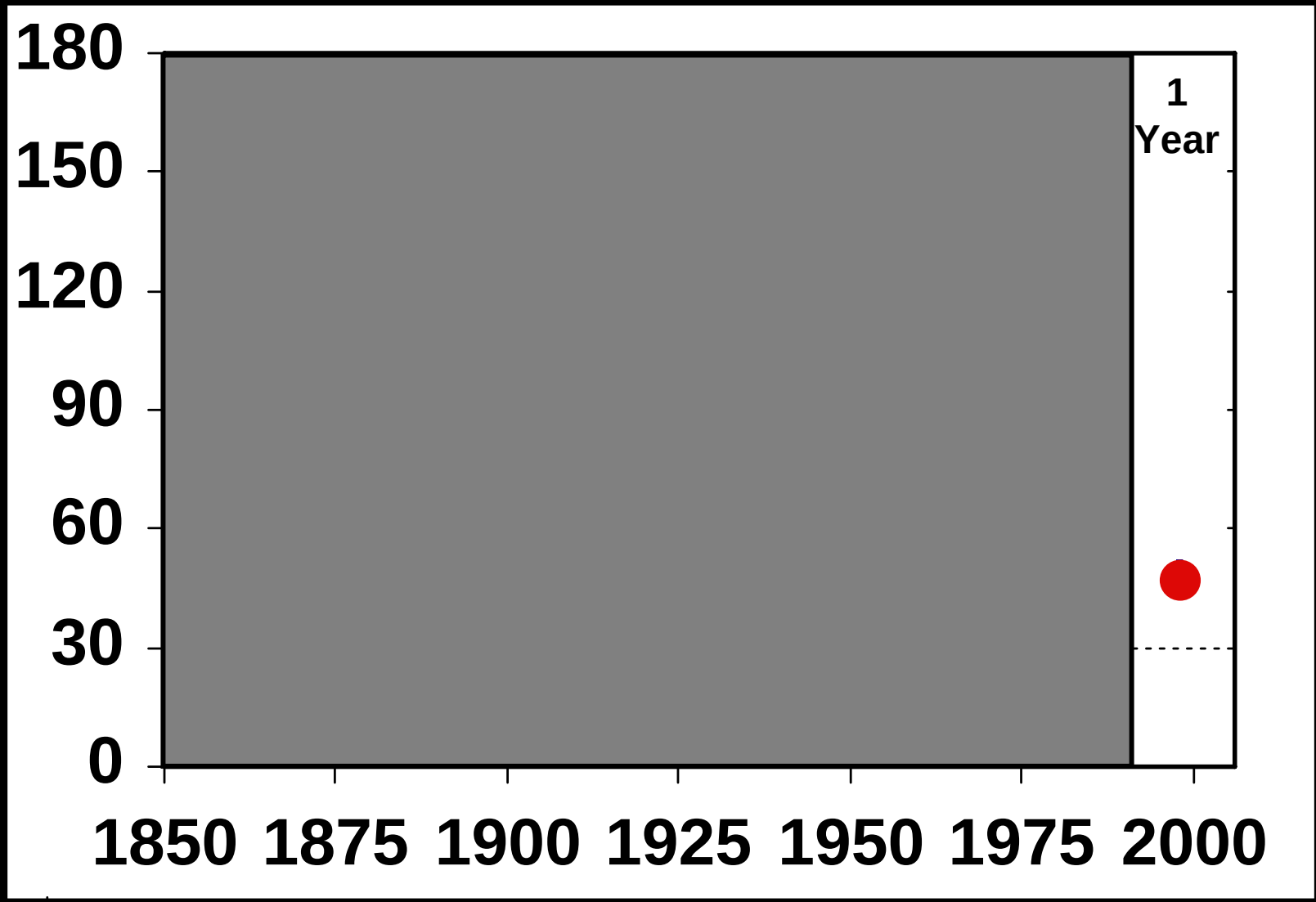
Three Water Examples

Lake Ice Cover
Fish Habitat
Water Levels and Flows

The Invisible Present

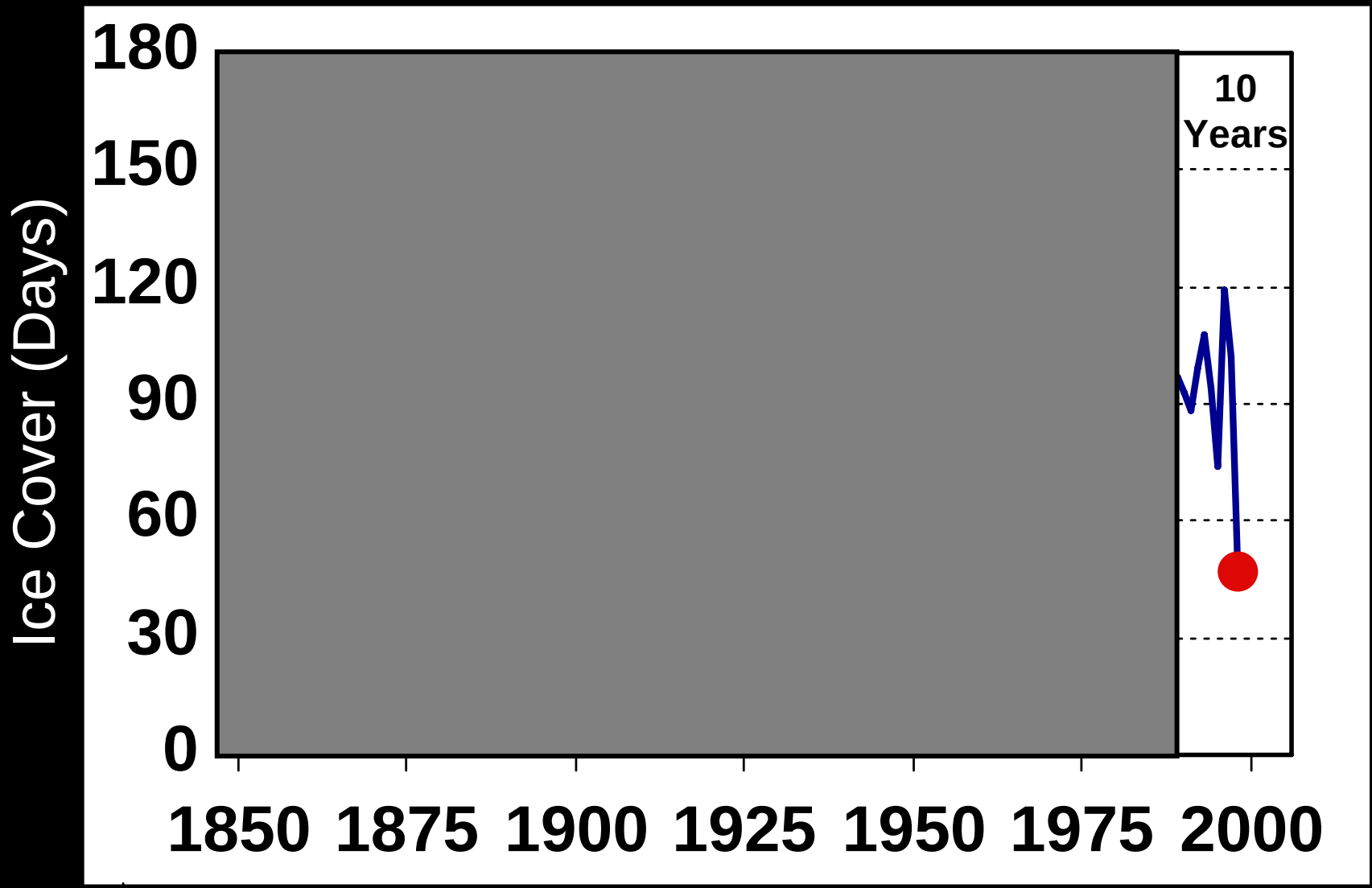
The Invisible Place

Lake Mendota, Wisconsin



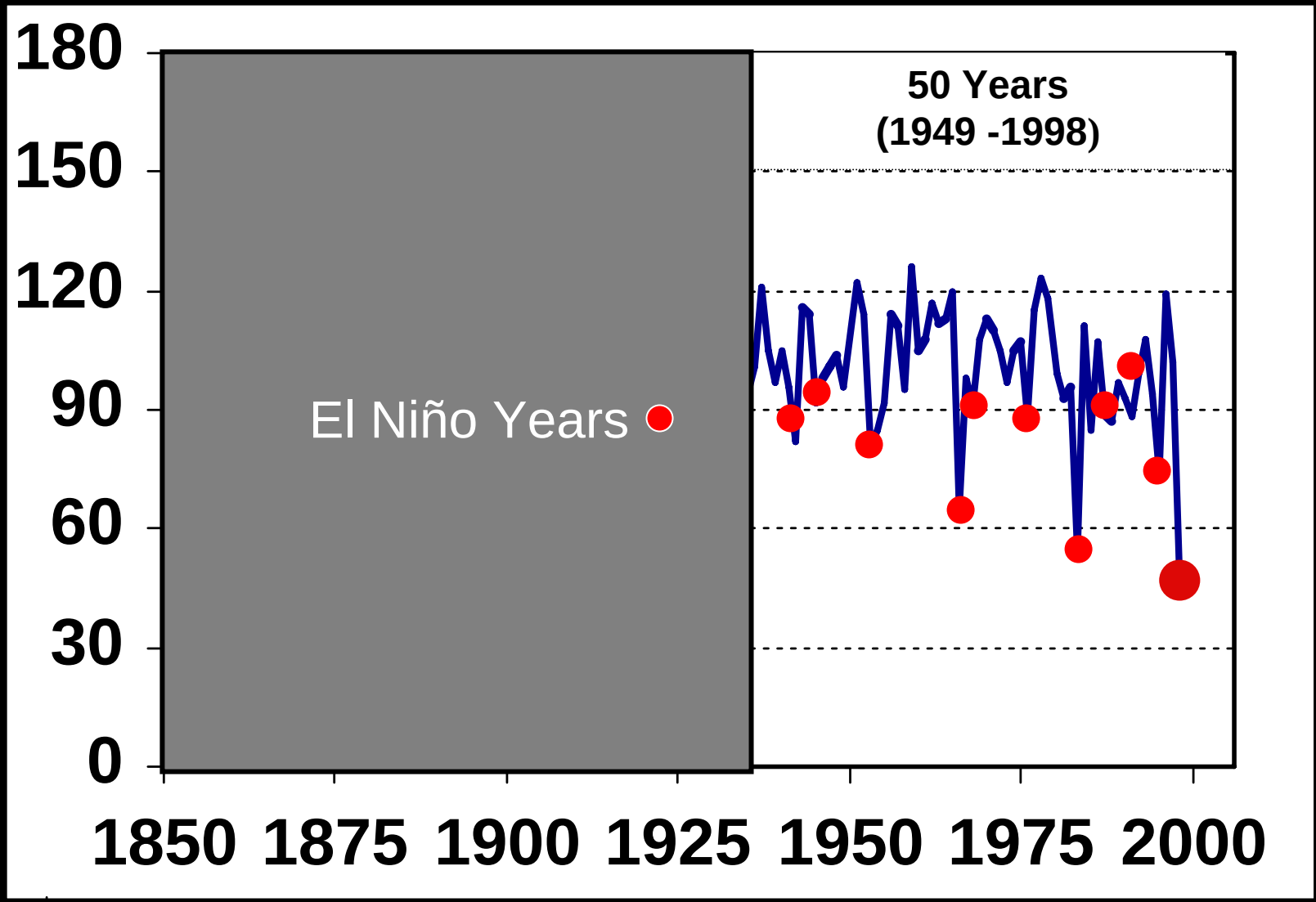
Magnuson 2004

Interannual Variability



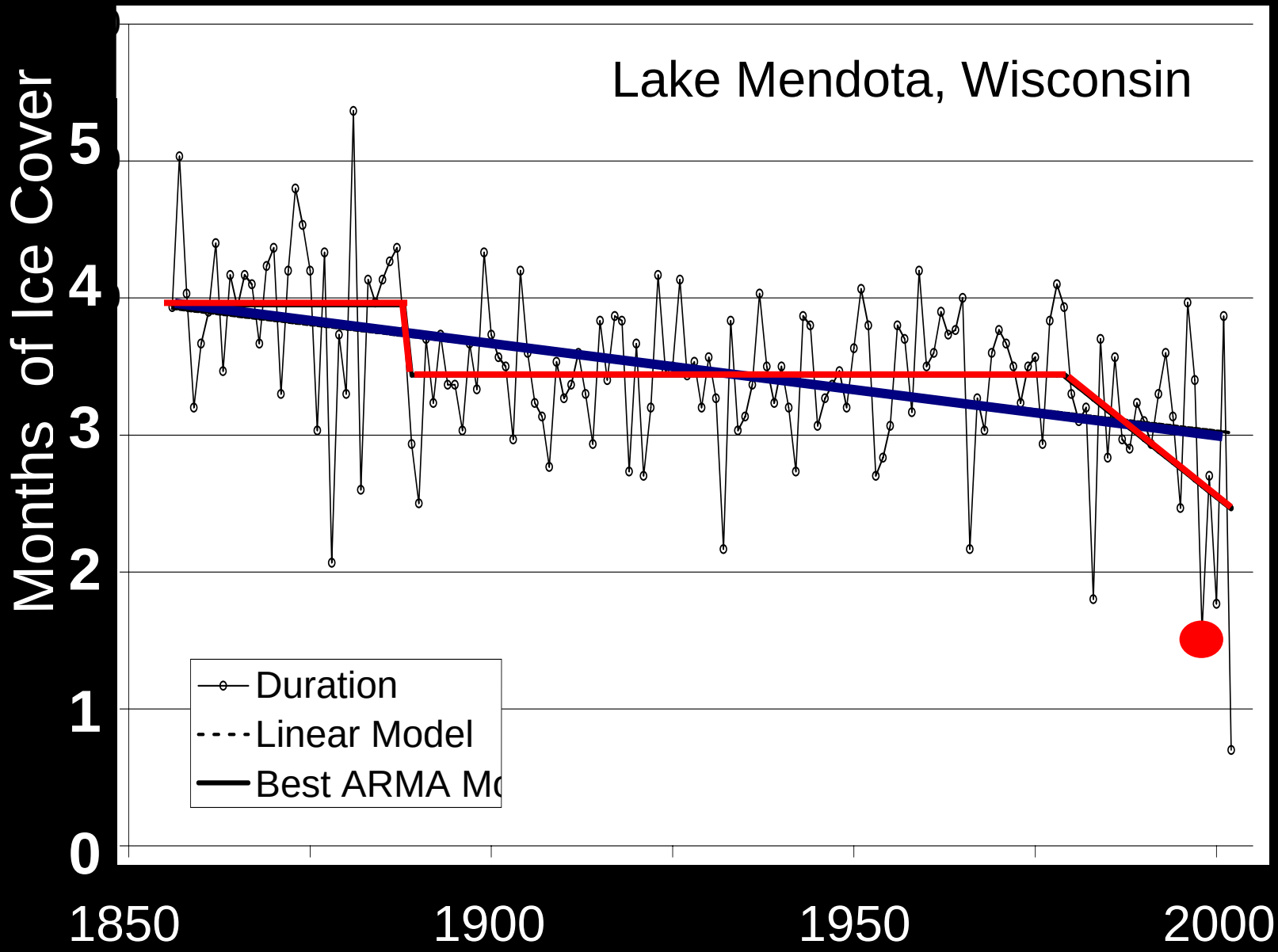
Magnuson 2004

Dynamics from the Central Pacific

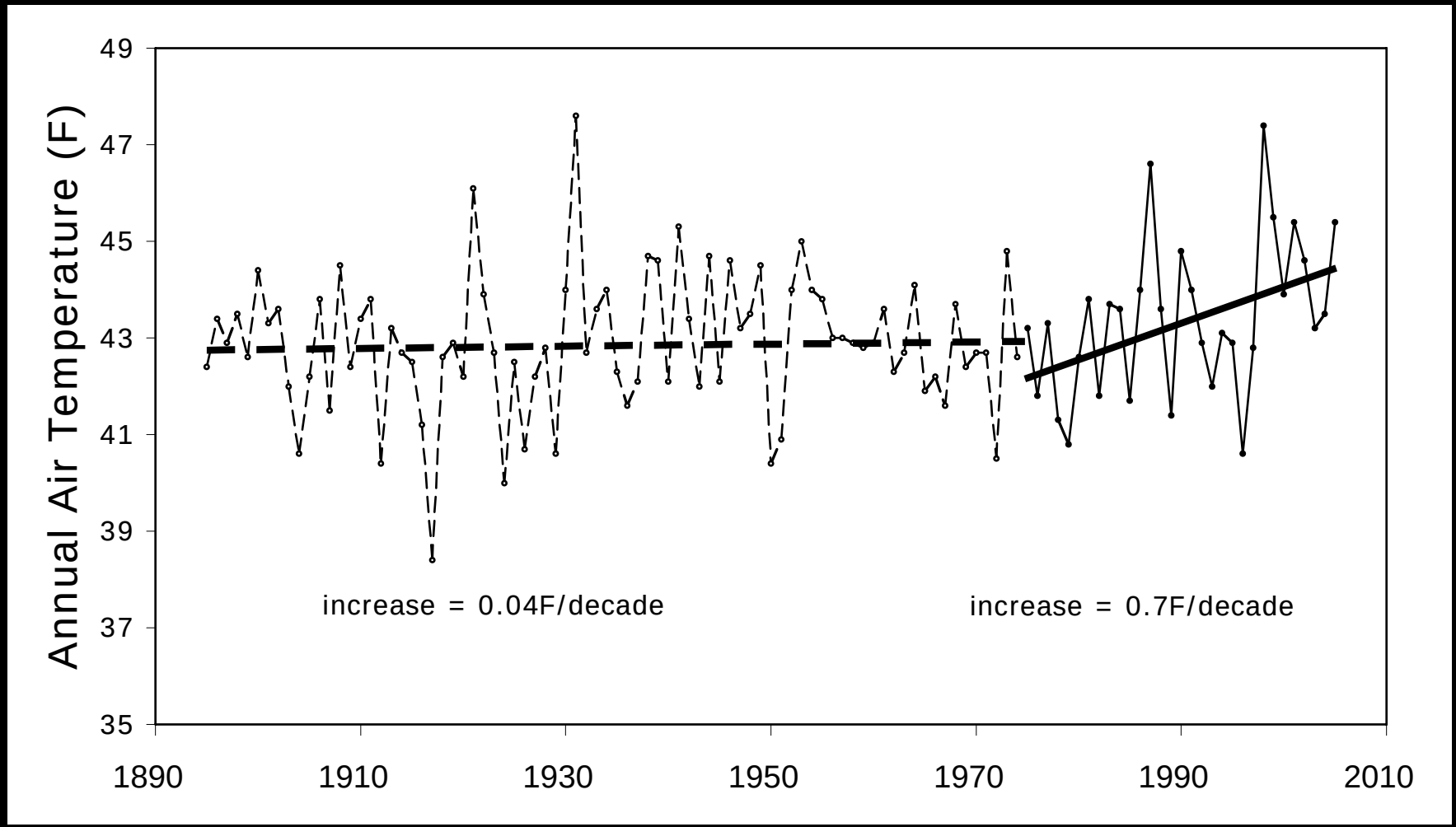


Magnuson 2004

Long-Term Changes in Ice Cover Duration

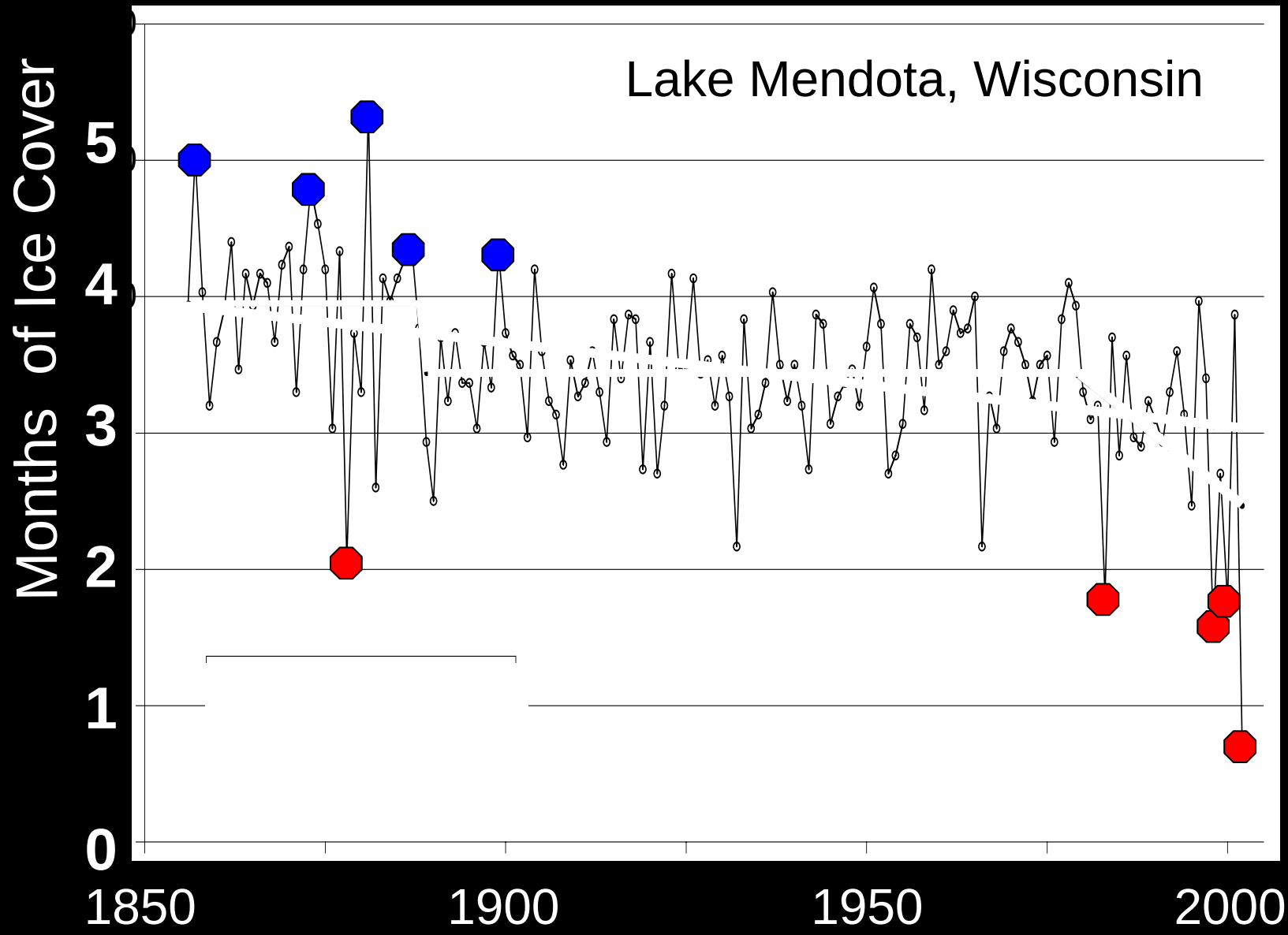


Wisconsin Air Temperatures 1895-2005

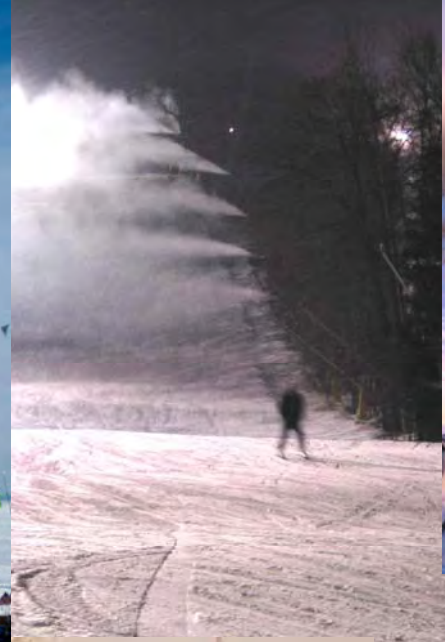


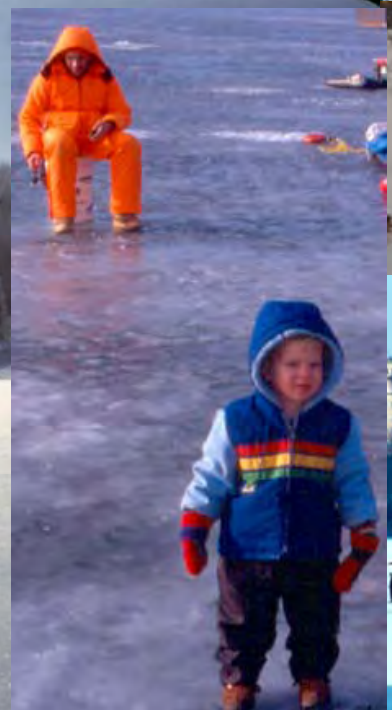
Data from State Climatology Office

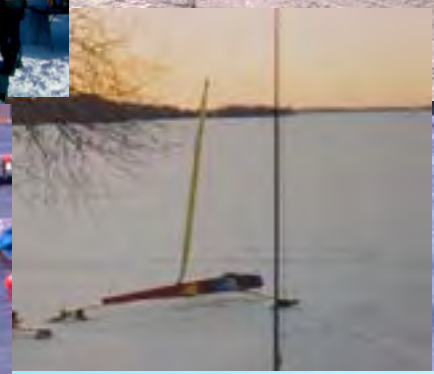
Press & Pulse - Change in Extreme Events



Winter is a part of our “Sense of Place.”





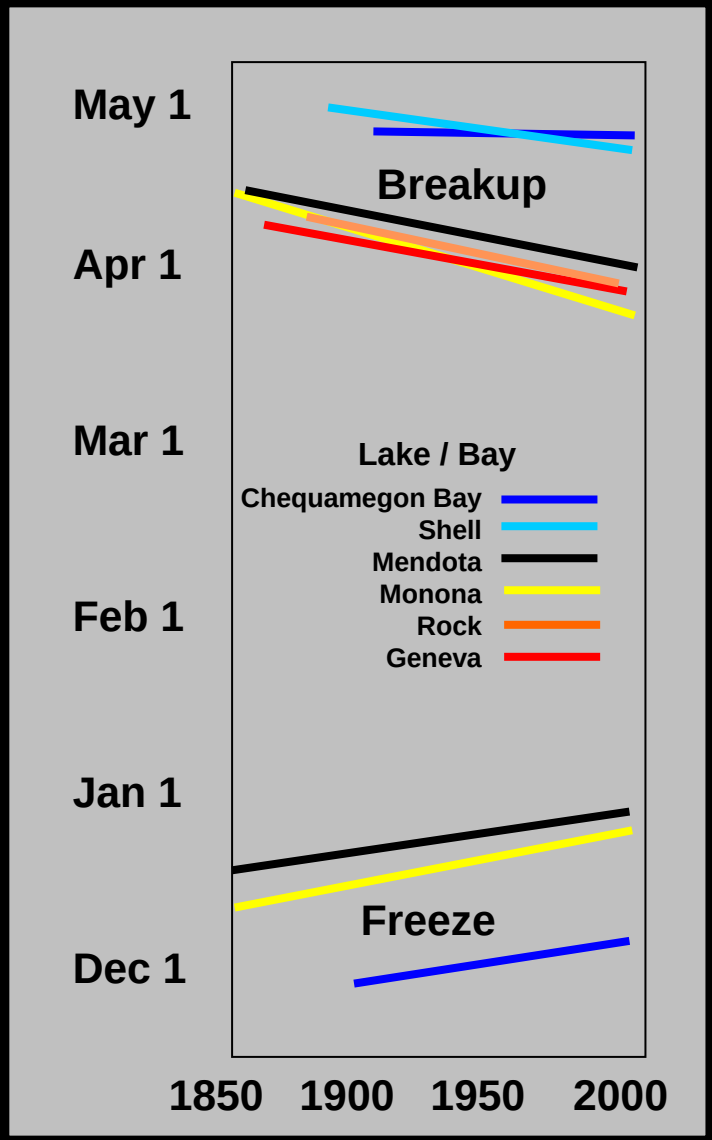


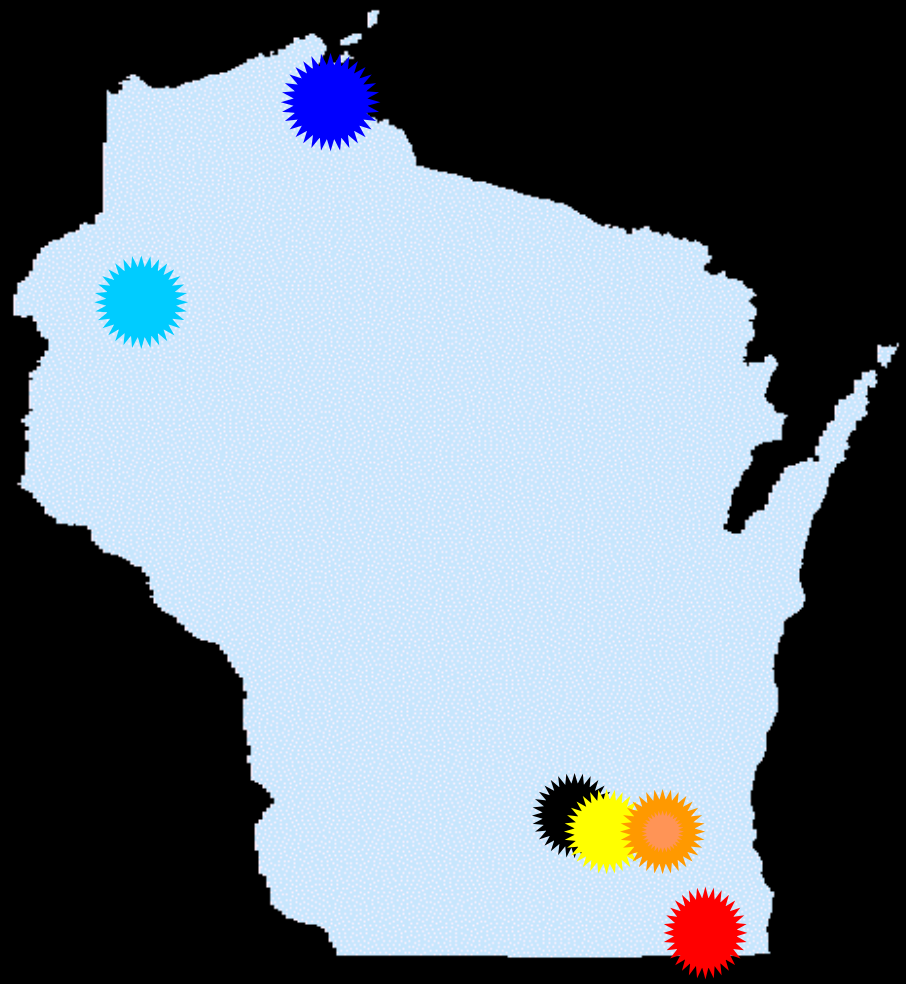
We are losing winter as we knew it!

The Invisible Present

The Invisible Place

Changes in Ice Dates Around Wisconsin





Magnuson 2004

Changes around the Northern Hemisphere

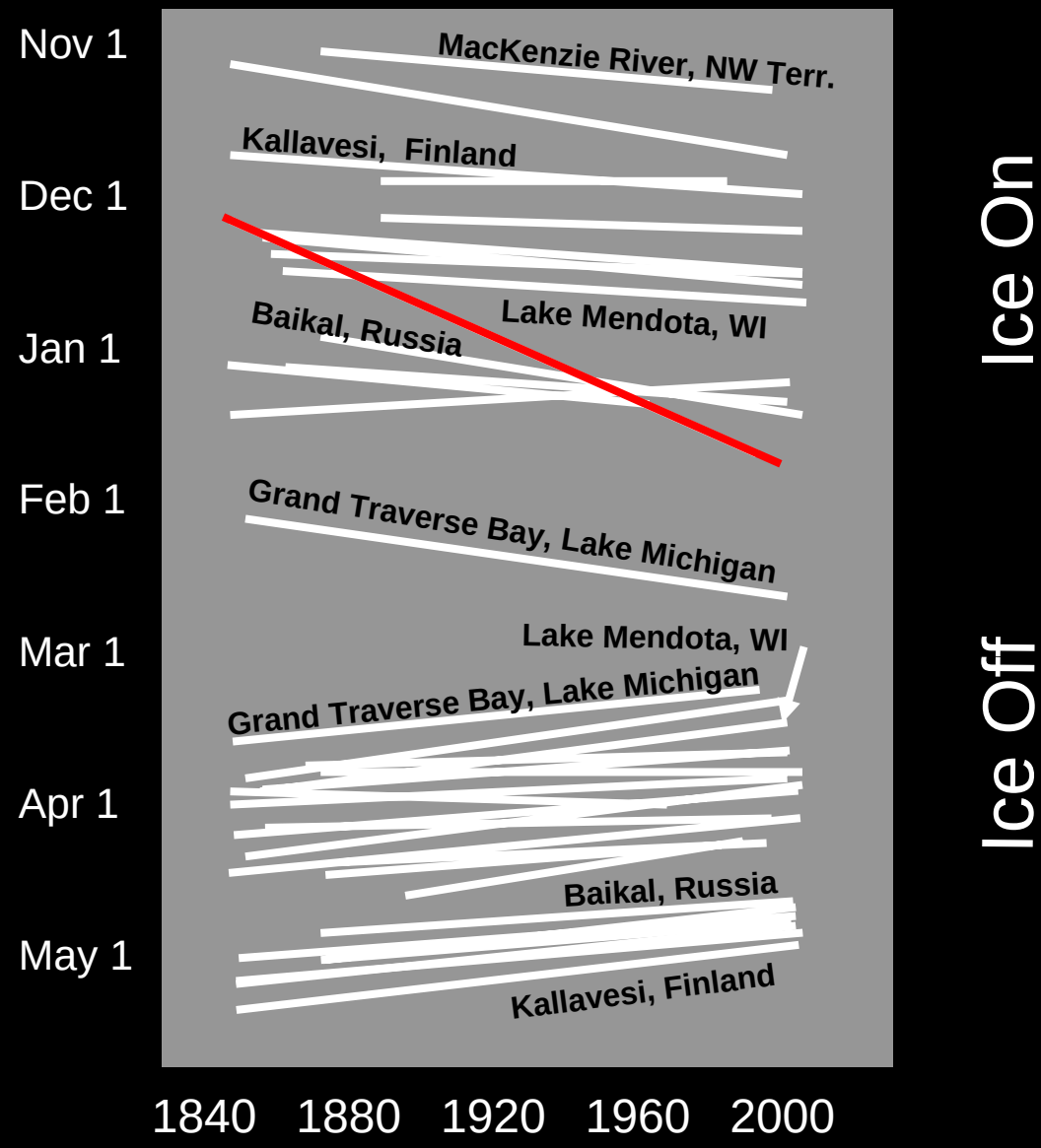
(36-37 of the 39 time series are in the direction of warming)

Source: IPCC 3rd Assessment 2001 Modified from Magnuson et al. 2000

Changes around the Northern Hemisphere

Toronto Harbor

(36-37 of the 39 time series are in the direction of warming)



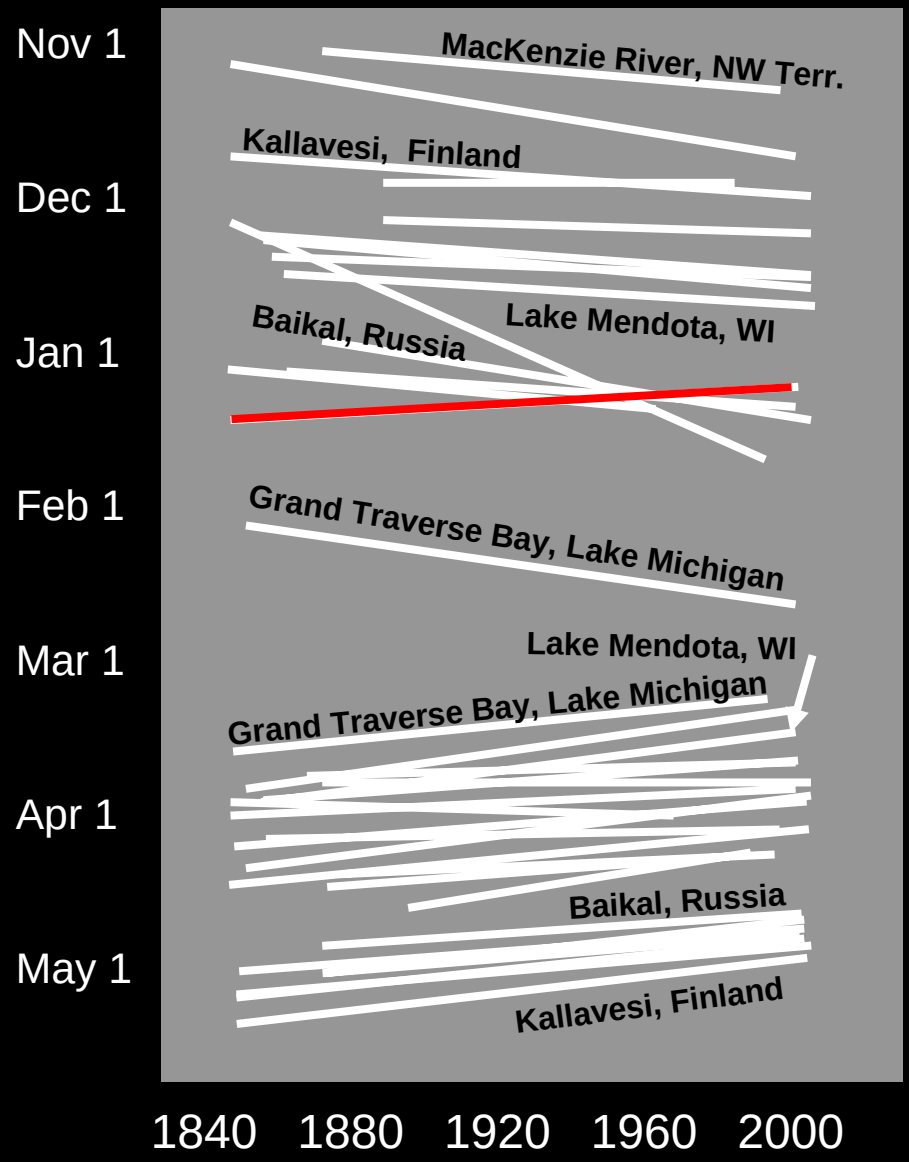
Source: IPCC 3rd Assessment 2001 Modified from Magnuson et al. 2000

Toronto Harbor, Ontario

Changes around the Northern Hemisphere

Suwa Ko, Japan

(36-37 of the 39 time series are in the direction of warming)



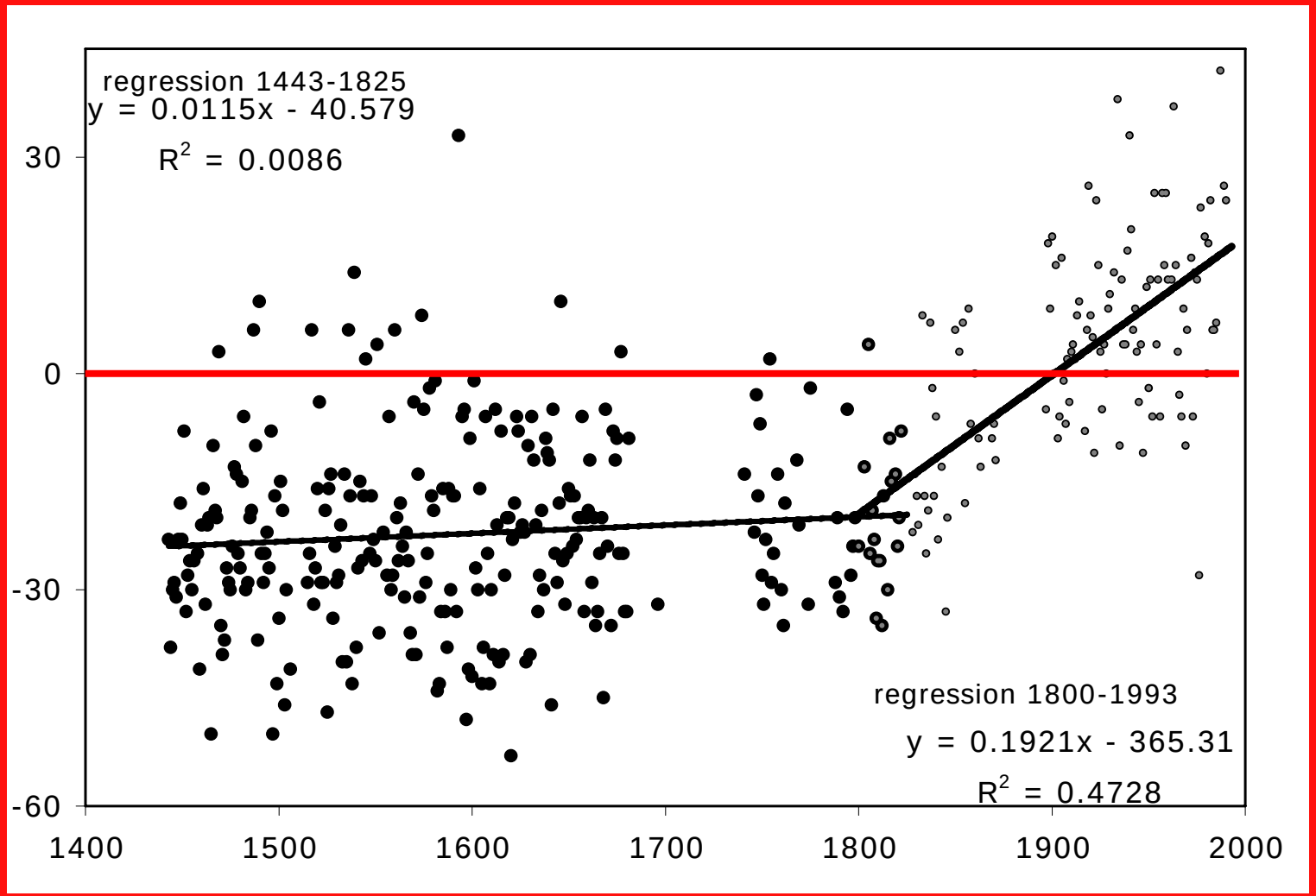
Source: IPCC 3rd Assessment 2001 Modified from Magnuson et al. 2000

Omiwatari on Suwa Ko on January 12, 2003

Takayuki Hanazato

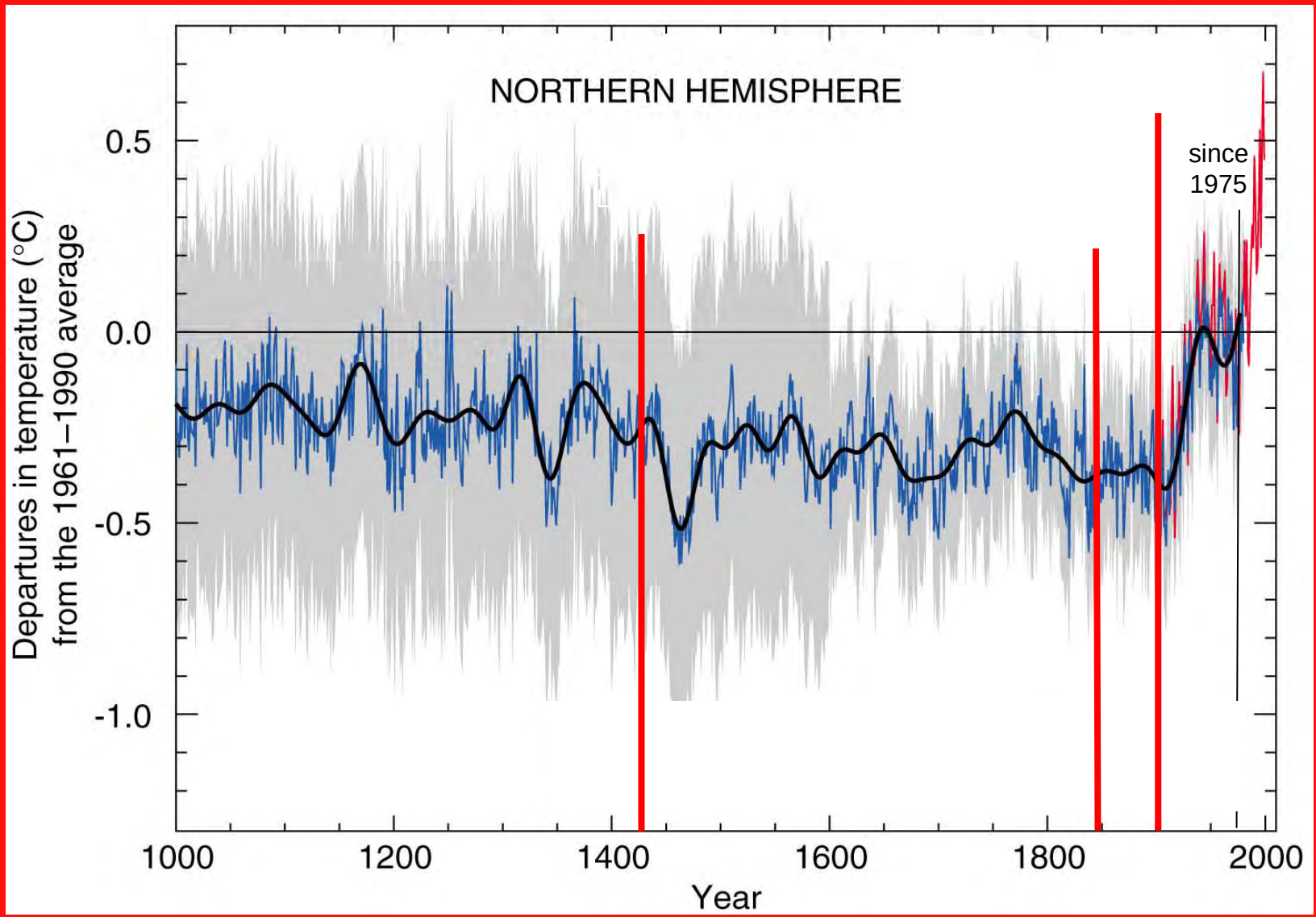

湖上御渡注進録
小和田

Lake Suwa, Japan, Ice-on Time Series from 1443 - 1993 (30 days subtracted from years before 1880)



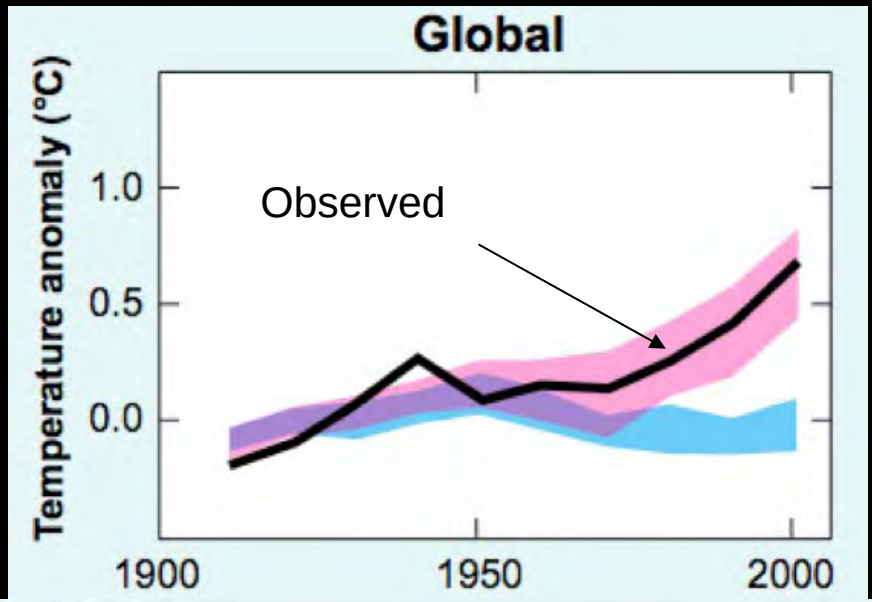
What is Happening?

Lake Ice Data Extent versus Thermometer Measurements



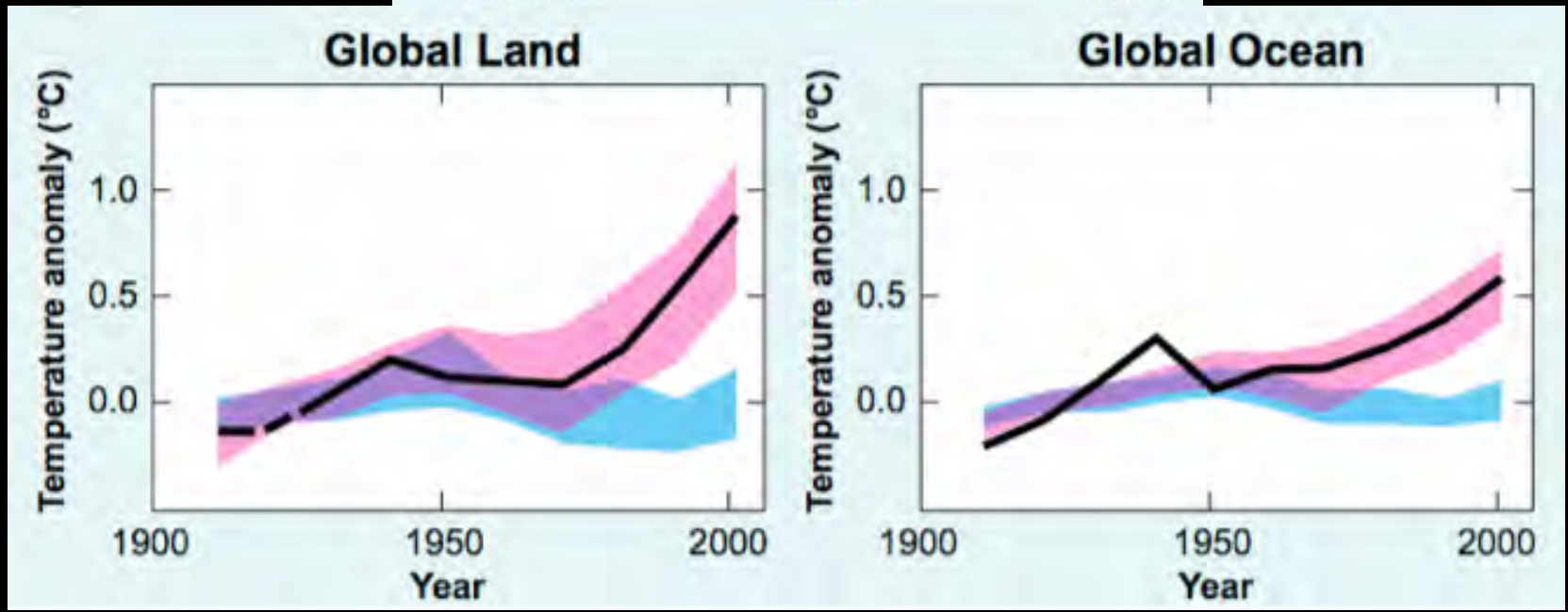
IPCC 2001

Simulated Annual Mean Surface Air Temperatures



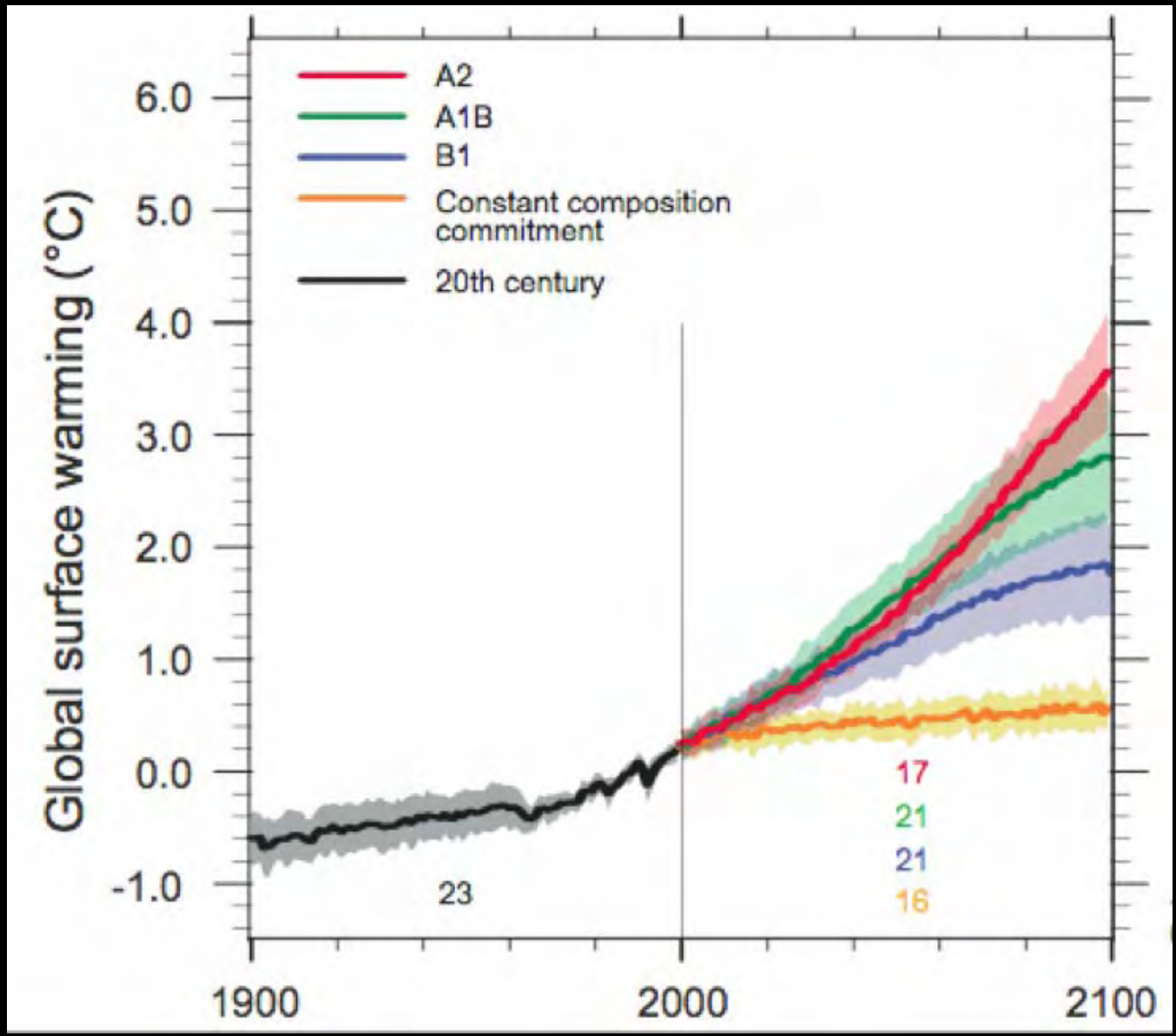
Natural and Anthropogenic Forcing

Natural Forcing Alone



IPCC 2007

Temperature Change in IPCC Scenarios



7.2°F

3.2°F

IPCC 2007

Confronting Climate Change in the Great Lakes Region

Past, Current, and Future Climate Change

http://www.ucsusa.org/greatlakes

2003 updated 2005

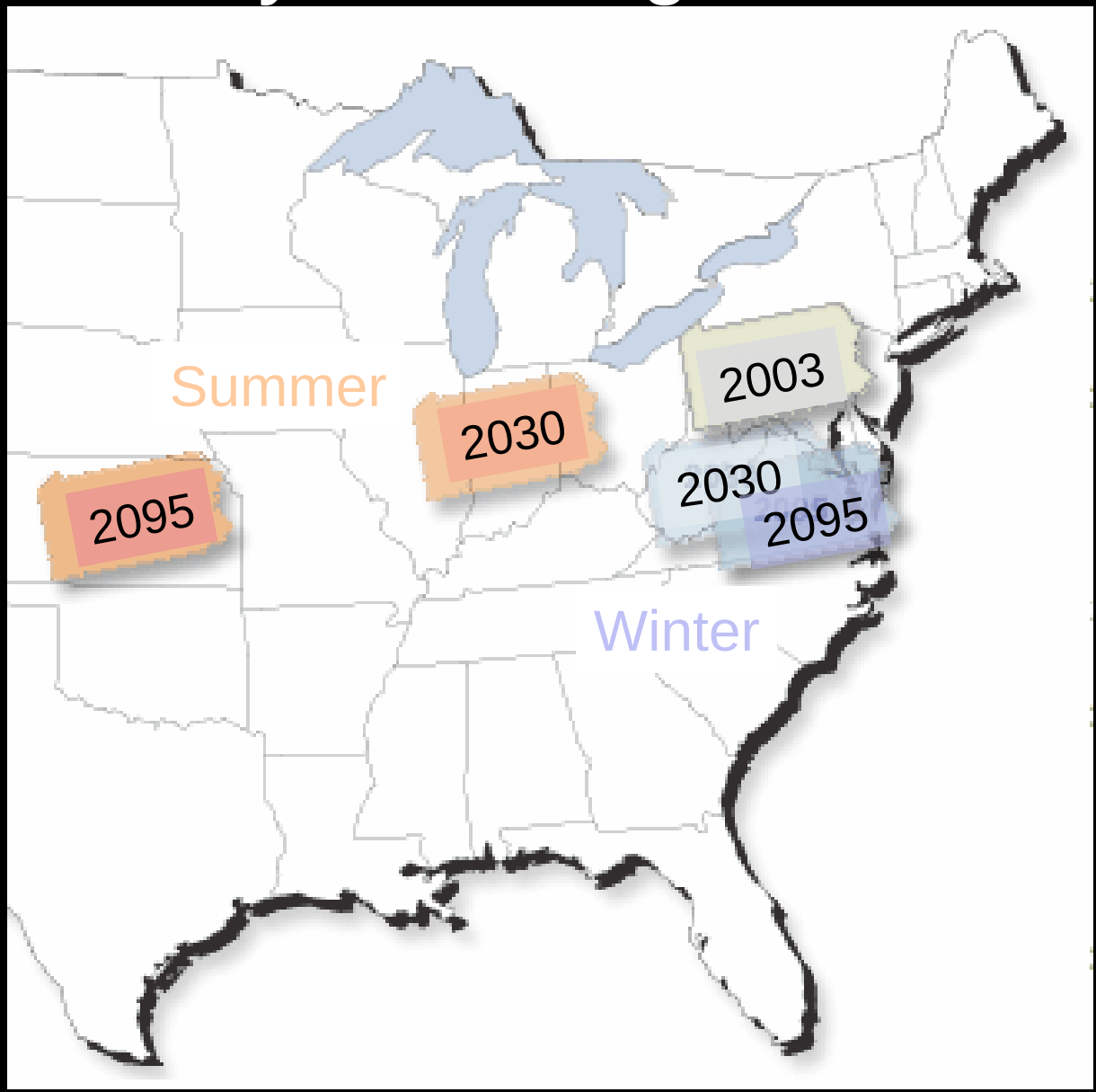
Pennsylvania
End of this century scenarios

Temperatures
Summer 7-9°F Warmer
Winter 6-8°F Warmer

Precipitation
Summer Decrease 10-15%
Winter Increase 15-20%

Extreme heat more common.
Frequency of extreme rain events more common

Pennsylvania Migrates Too!



http://www.ucsusa.org/greatlakes/

Migrating Climates

Changing Summers in Great Lakes Region

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Current

By 2095

http://www.ucsusa.org/greatlakes/

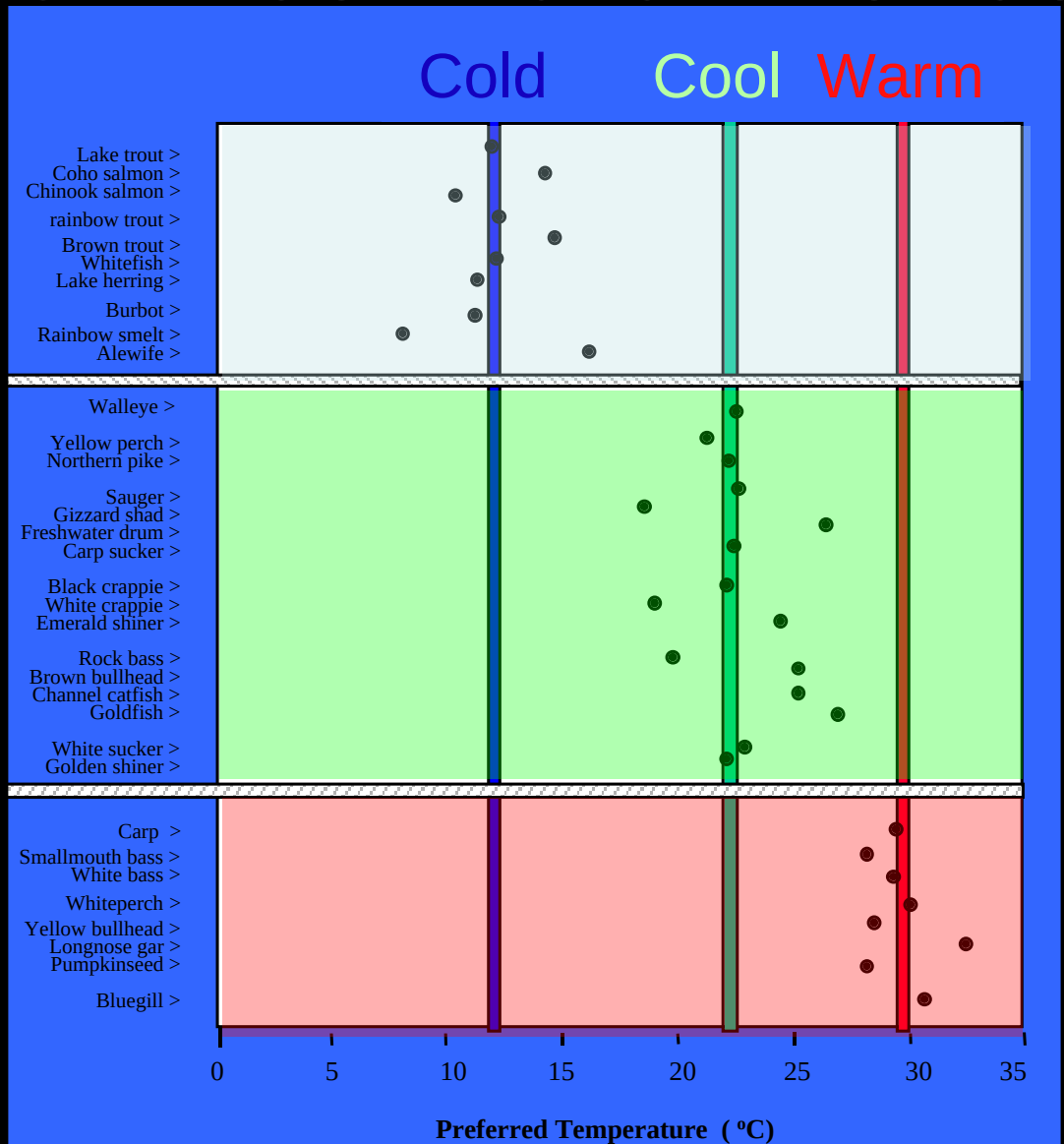
Do Fishes Care about Climate Change?

Warm Water Fishes

Cool Water Fishes

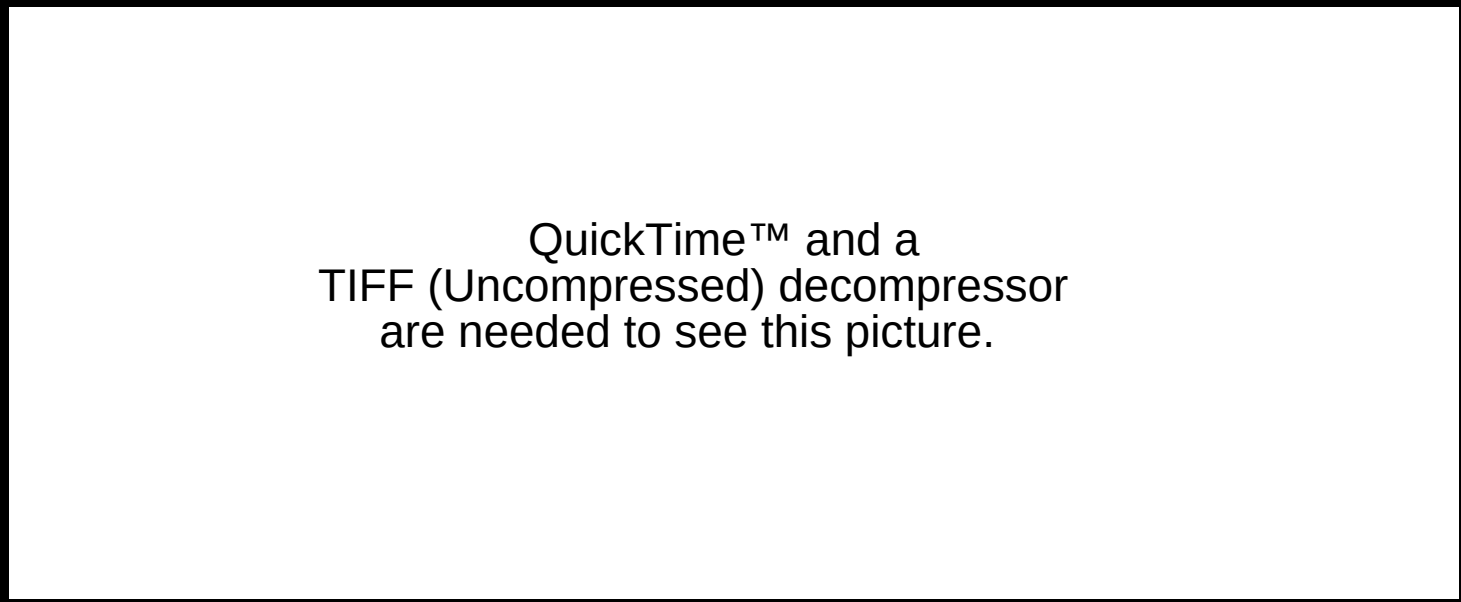
Cold Water Fishes

Thermal Guilds of Freshwater Fishes

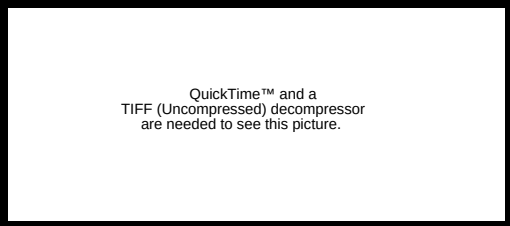


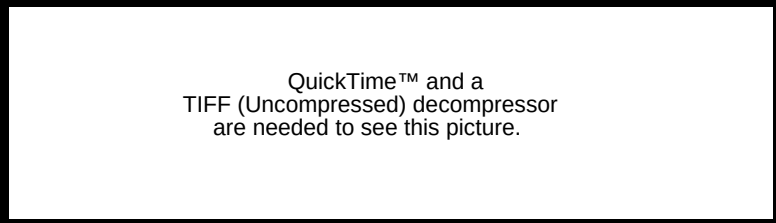
UCS/ESA

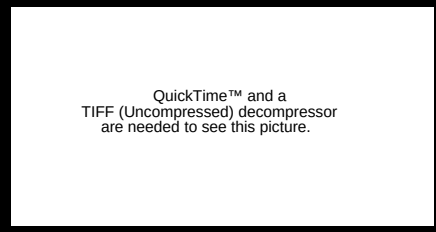
White Sucker Coolwater Fish



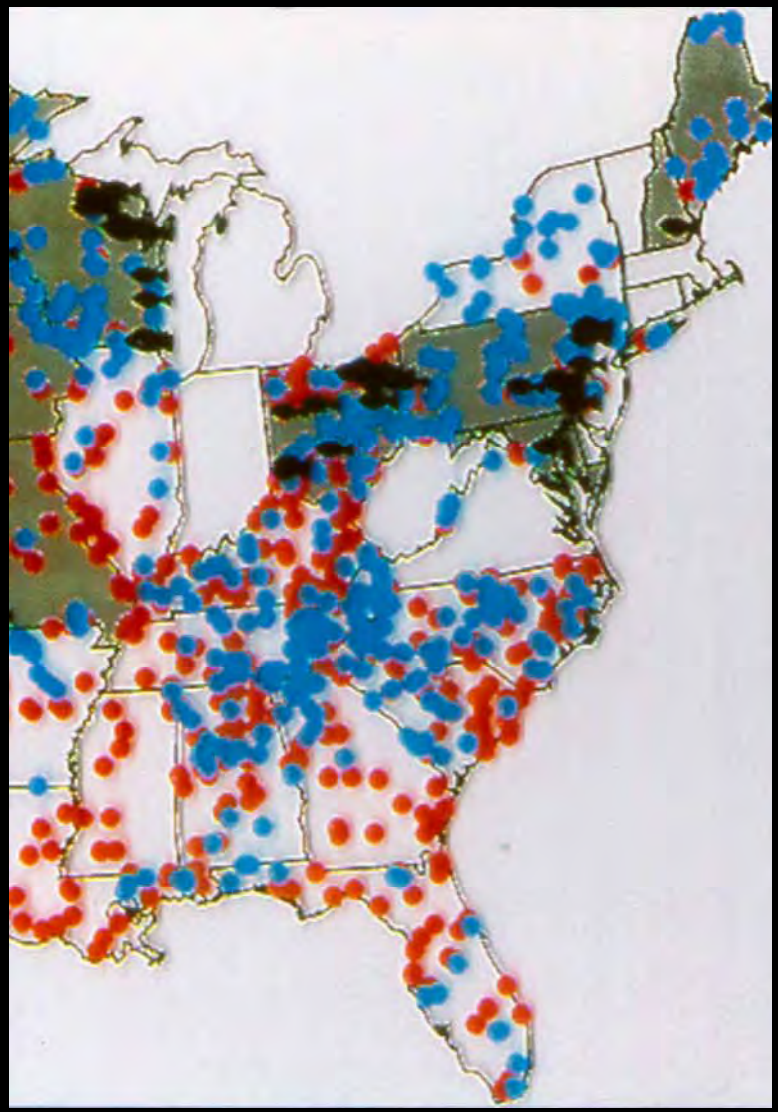
Other Coolwater Game Fishes





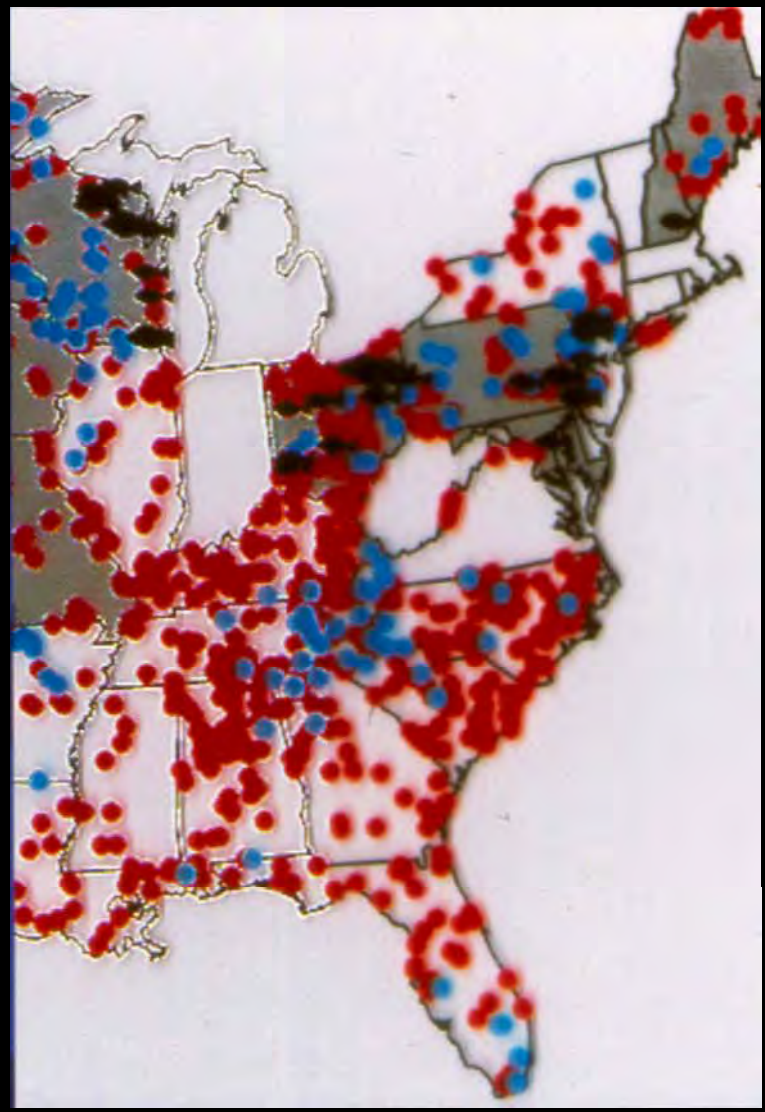


Where White Sucker Could Persist



NO

YES

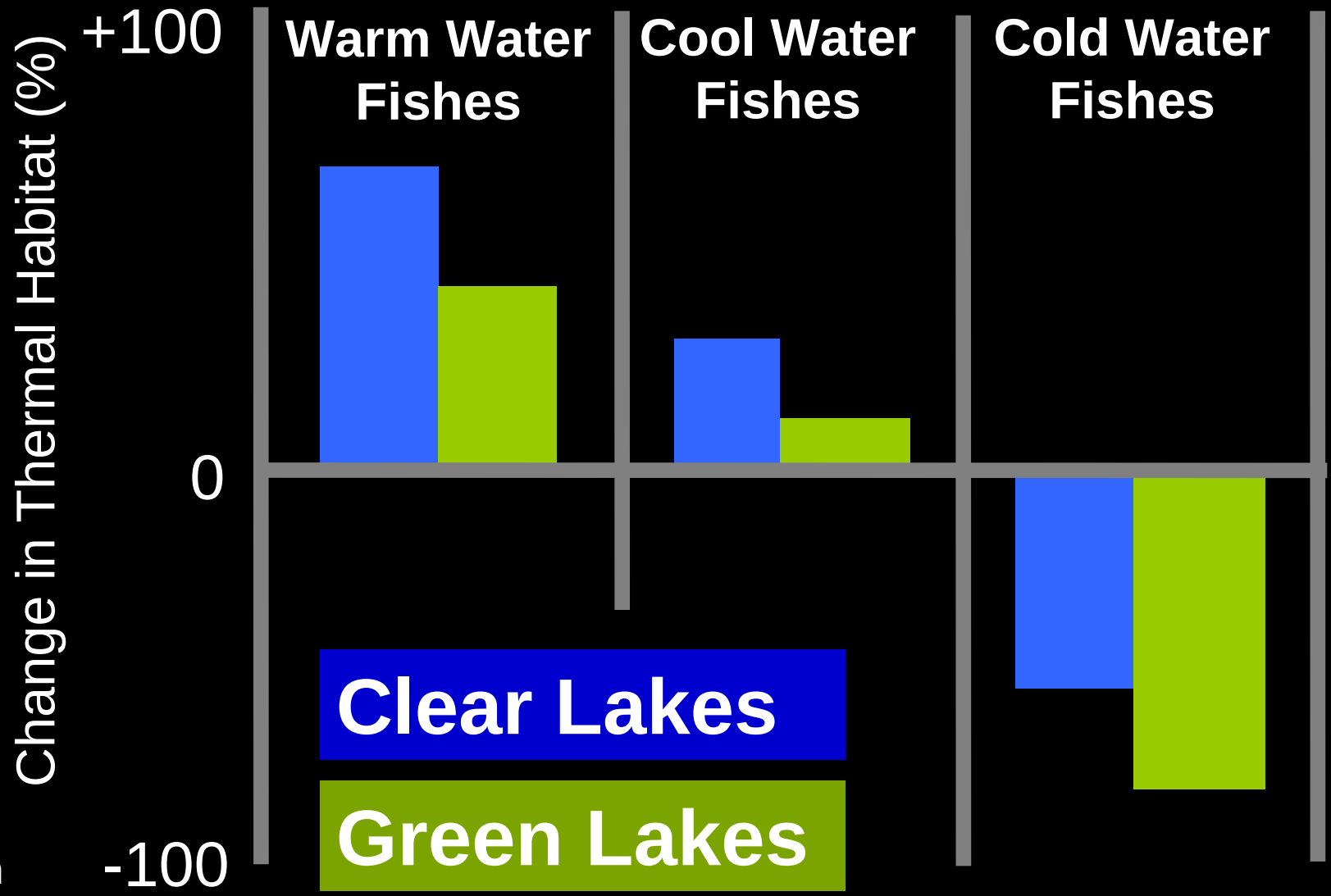


Base Climate

Doubled Greenhouse Gases

John Eaton and others

Minnesota Inland Lakes: Simulated Change in Thermal Habitat with CO_2 Doubling

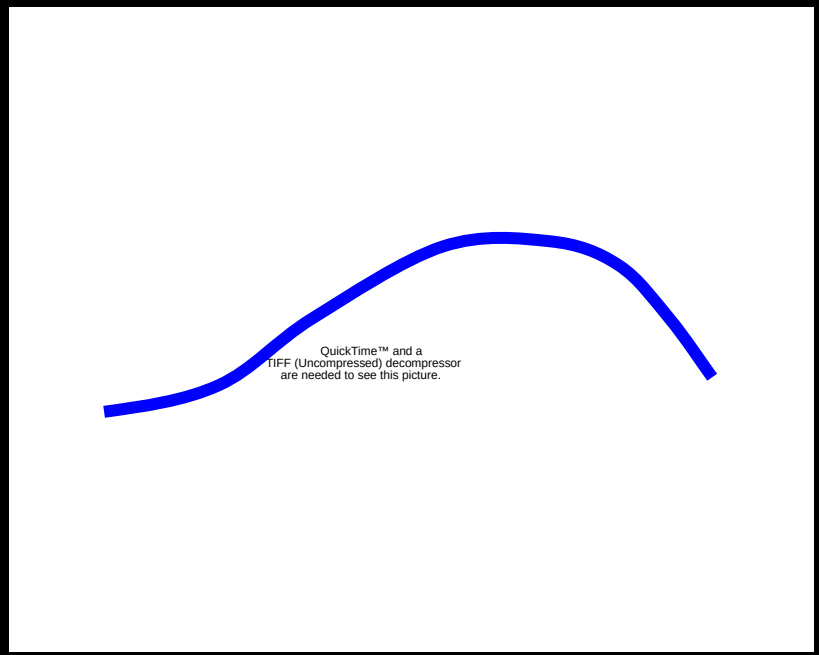


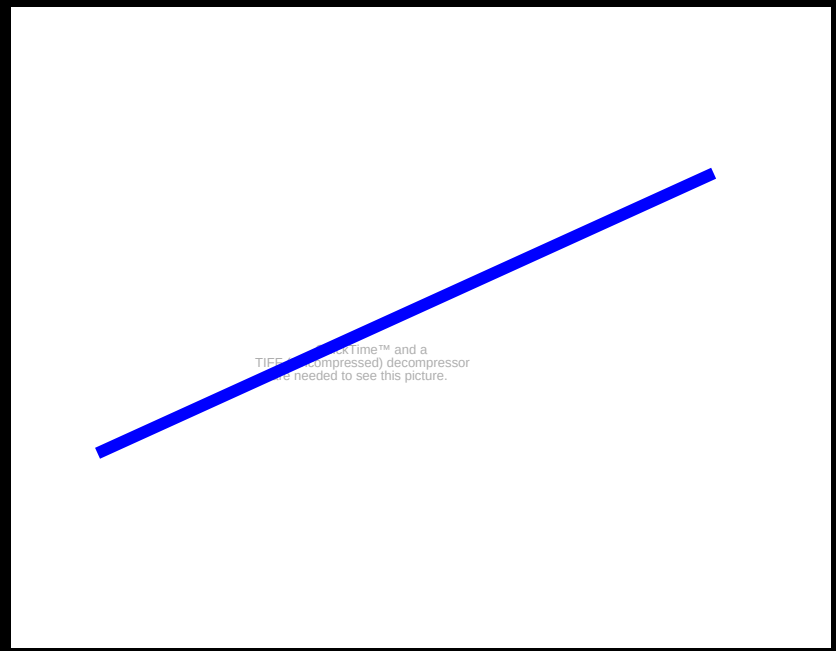
Stefan et al.

Relation between Year-Class Strength and Summer Water Temperatures in the Bay of Quinte

Northern Pike

Smallmouth Bass





July/August Water Temperature (°C)

Casselman 2002

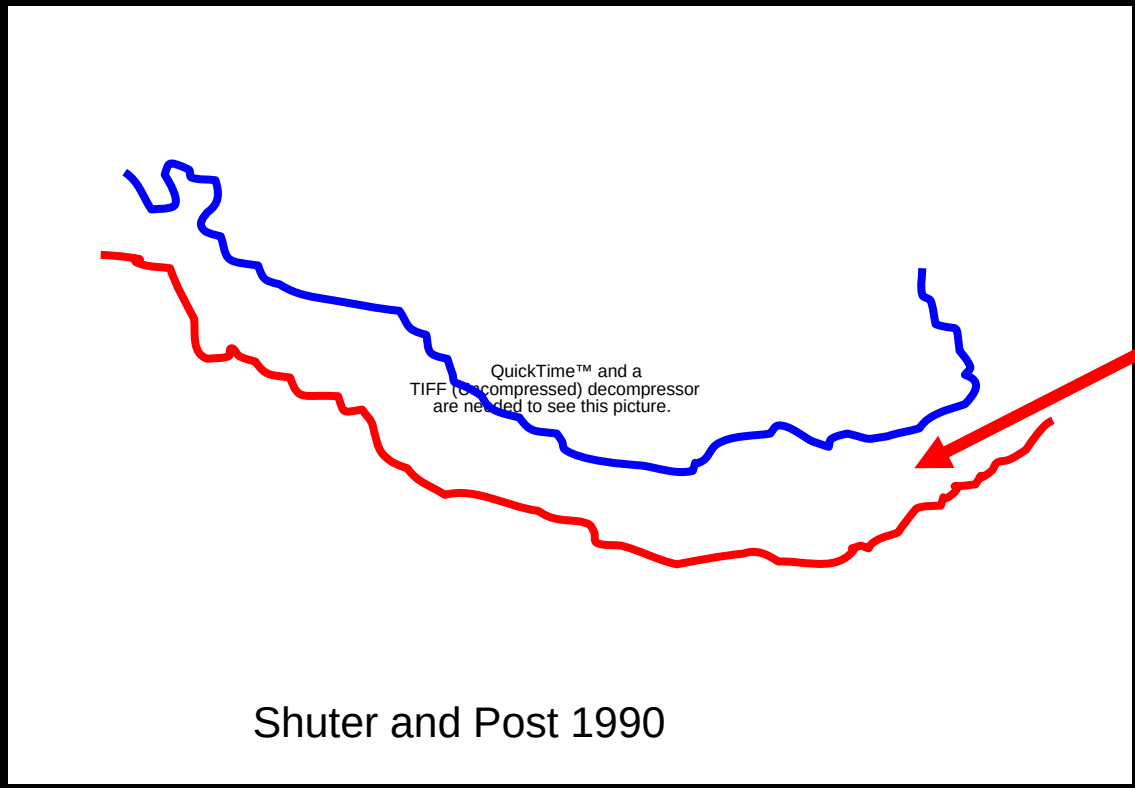
Smallmouth Bass dispersal

Move north 120 km per 1°C warming Shuter et al. 2002

Extirpation of native species

25,000 cyprinid populations extirpated to date from spread of smallmouth bass in Ontario Jackson & Mandrak 2002

Change in Distribution with +4°C Temperature



Shuter and Post 1990

What will Happen to the Fishes?

- Extinctions and extirpations at southern boundaries
- Northward movement of northern boundaries by 500km with CO_2 doubling, again leading to extinctions and extirpations
- Greater losses of fishes in streams and shallow ponds than in deep lakes
- The Great Lakes refugia for cold water species
- Invaders will cause extinction of some resident species and changes in water quality.

Effects of Global Warming on Water Cycle

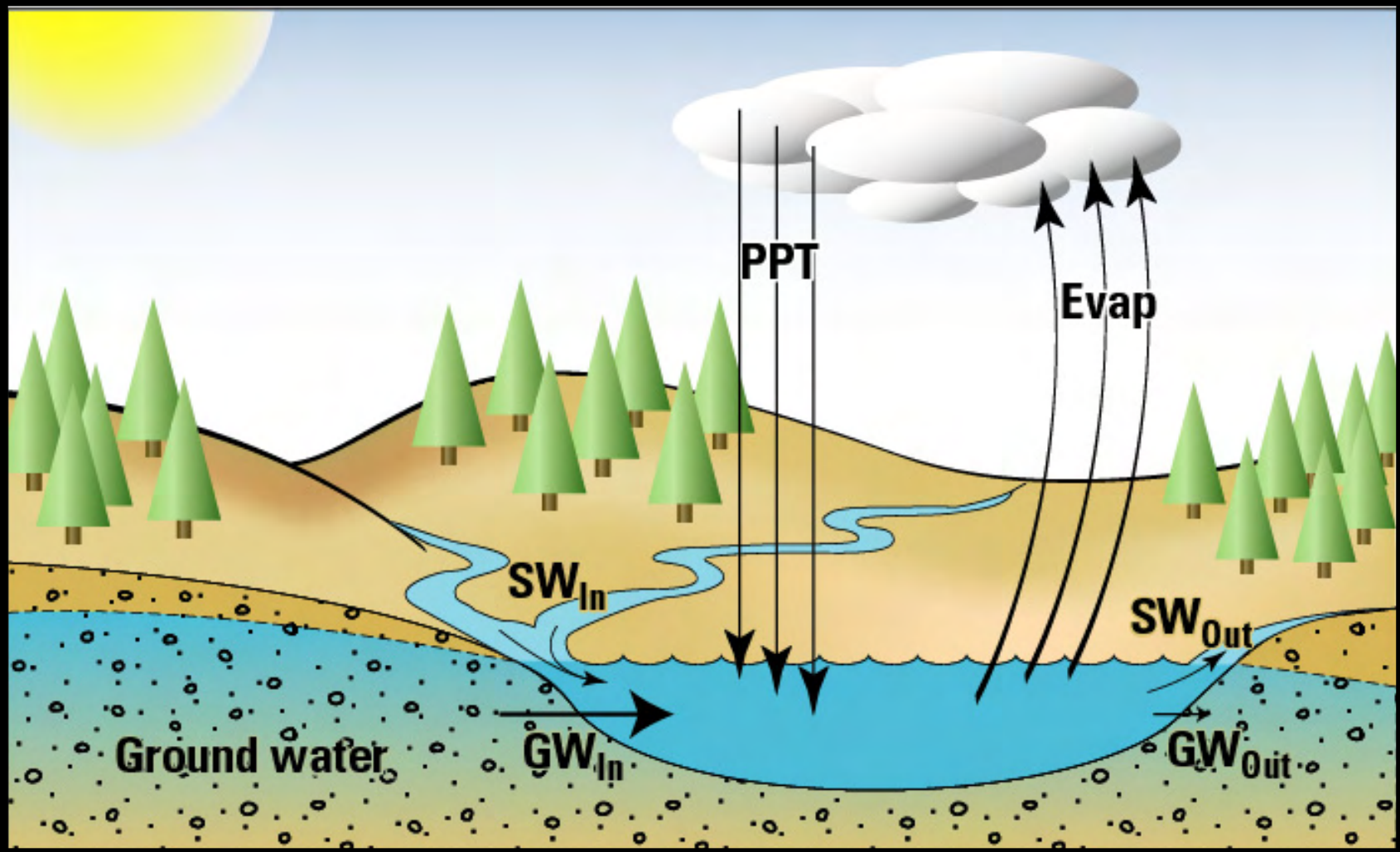
Global Warming (temperature increase) → Speeds up Global Water Cycle

↓

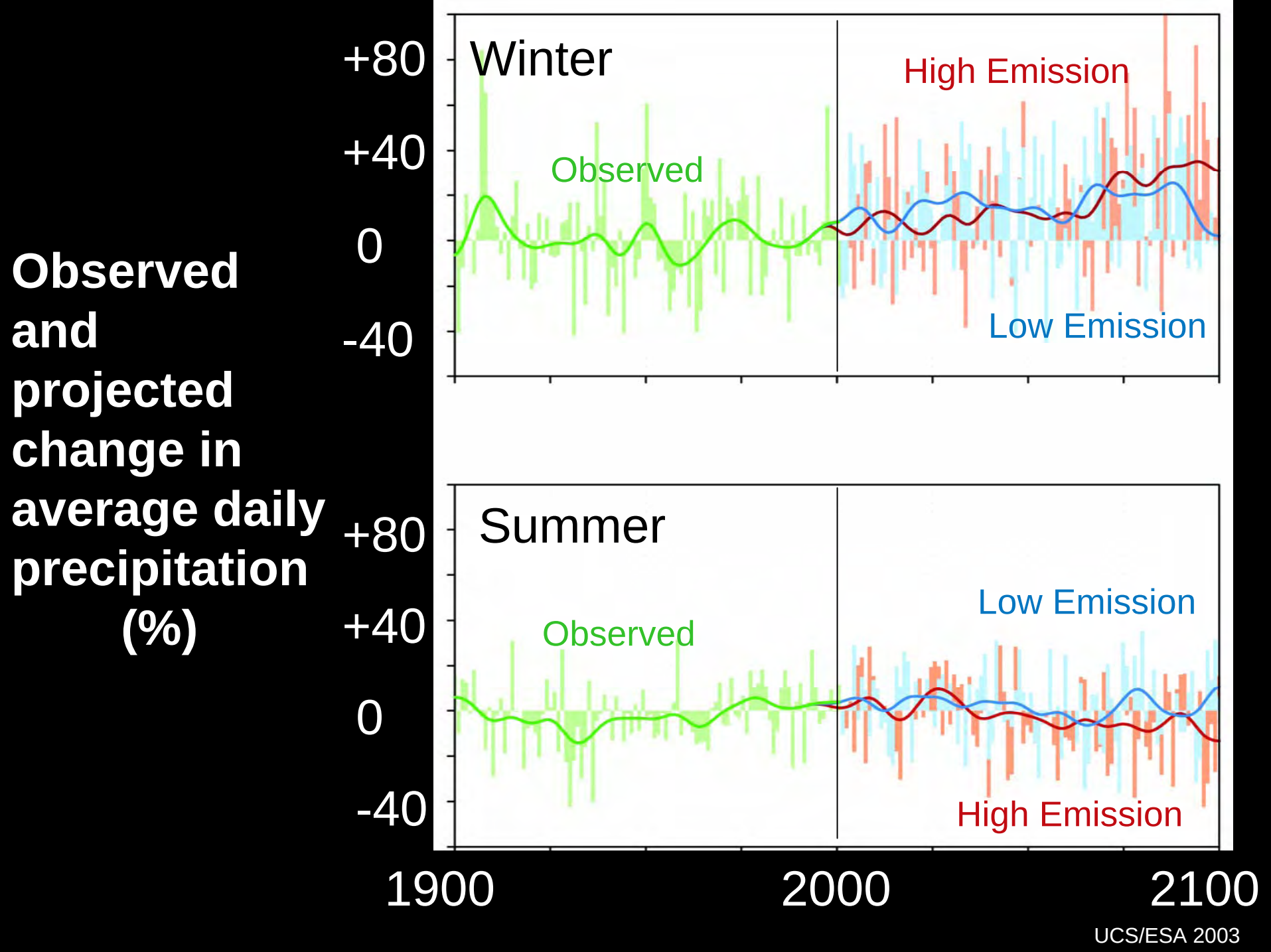
More Extreme Weather Events

- Droughts
- Storms
- Floods

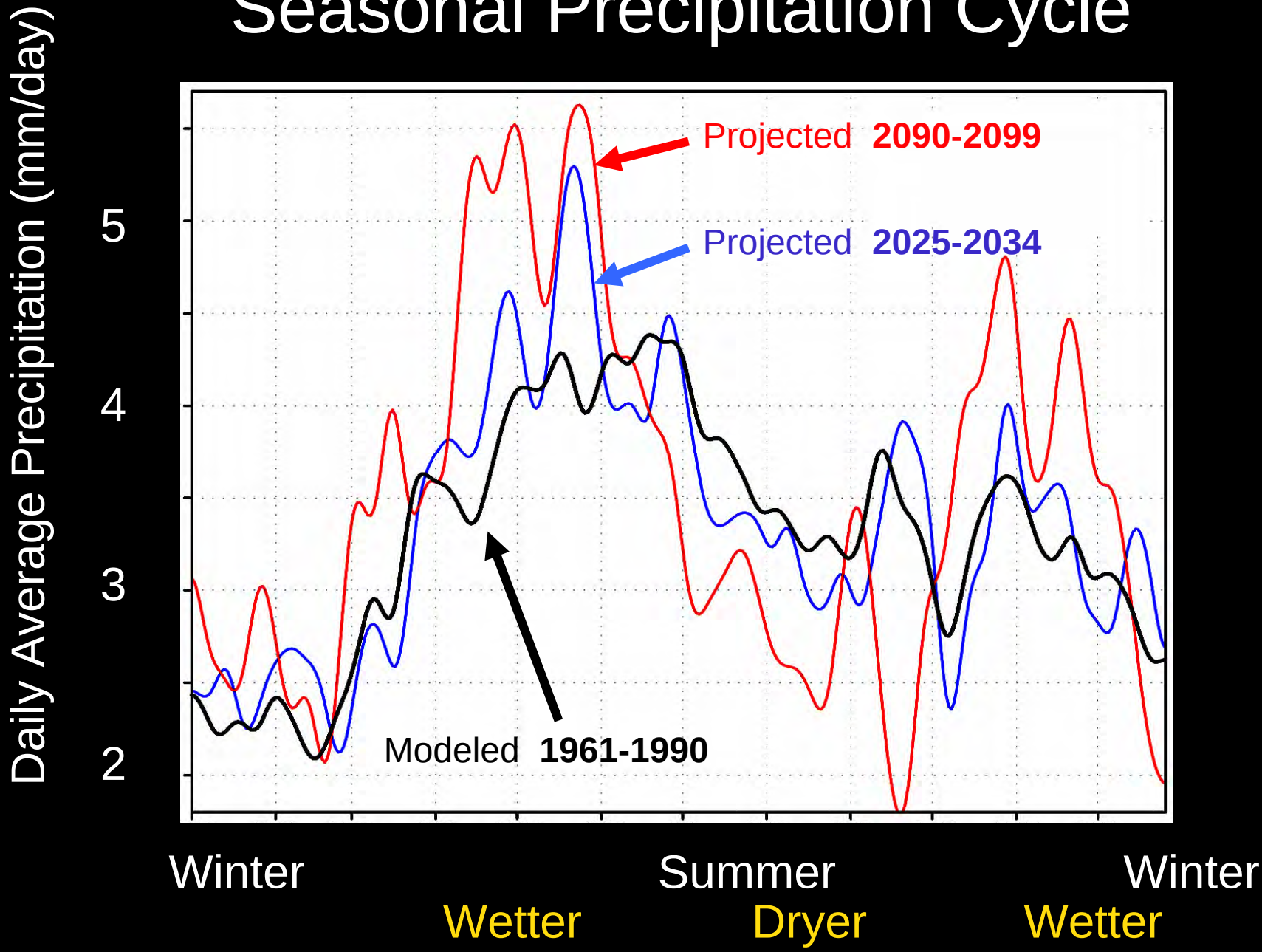
Changes in the Hydrologic Cycle



Expectations

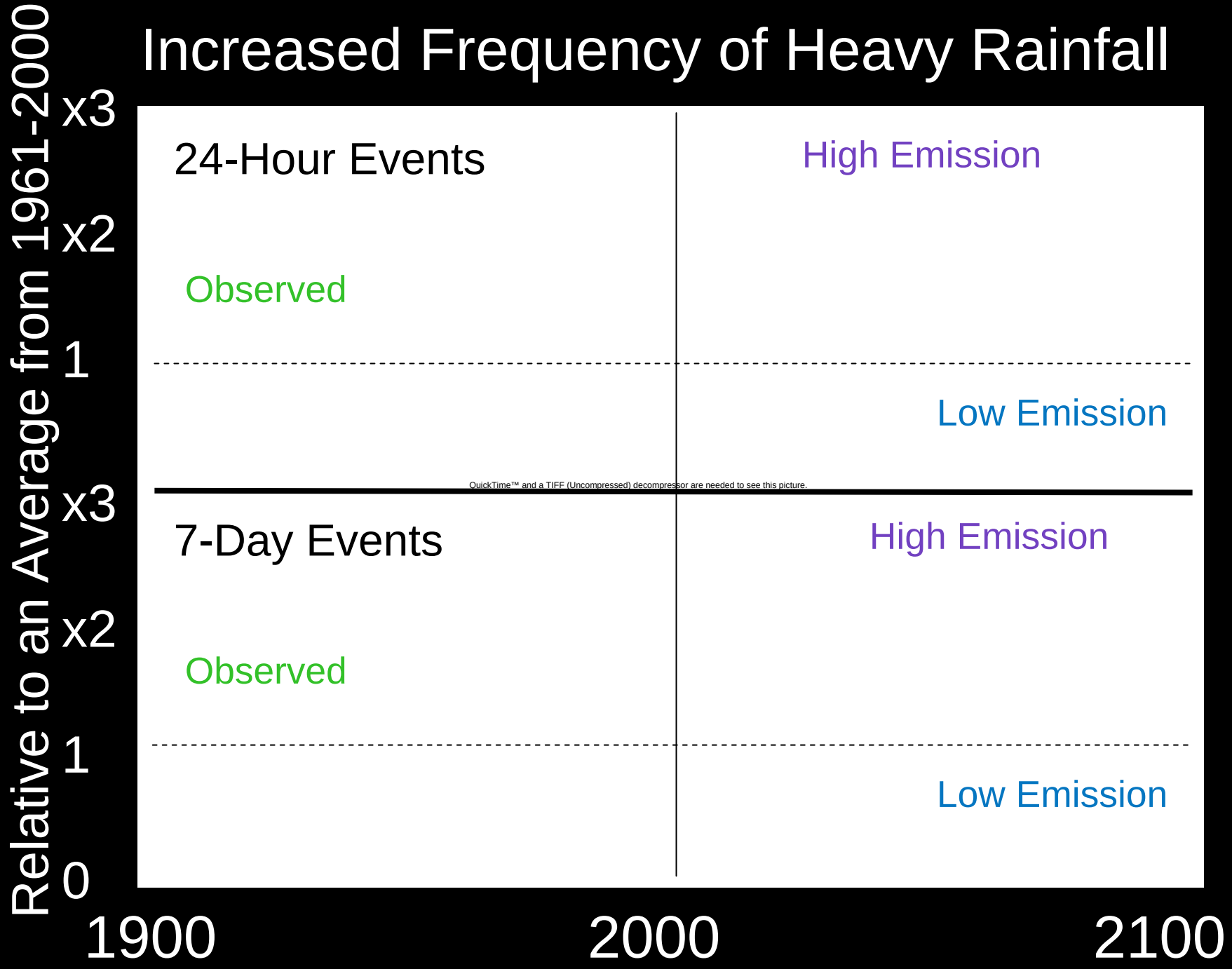

Observed and projected change in average daily precipitation (%)
+80
+40
0
-40
Winter
Observed
High Emission
Low Emission
+80
+40
0
-40
Summer
Observed
Low Emission
High Emission
1900
2000
2100
UCS/ESA 2003

Seasonal Precipitation Cycle



UCS/ESA 2003

Increased Frequency of Heavy Rainfall



UCS/ESA 2003

Water Levels and Flows
Last 50 Years

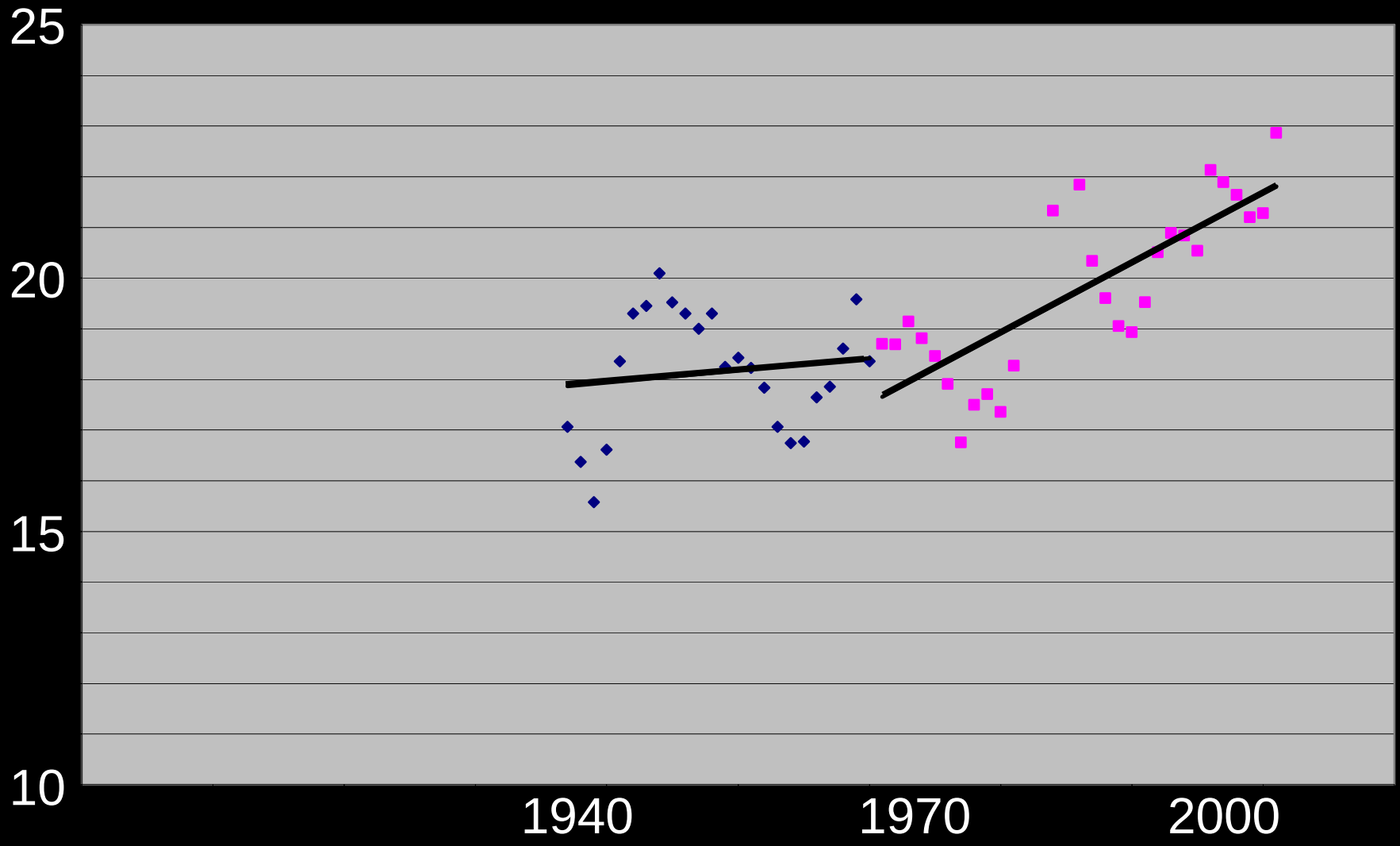
Magnuson 2003

Lake Stage Gages

Shell Lake (WI) June 2002

Krohelski 2003

Shell Lake Annual Average Stage (feet)



Krohelski 2003

Fish Lake July 2000

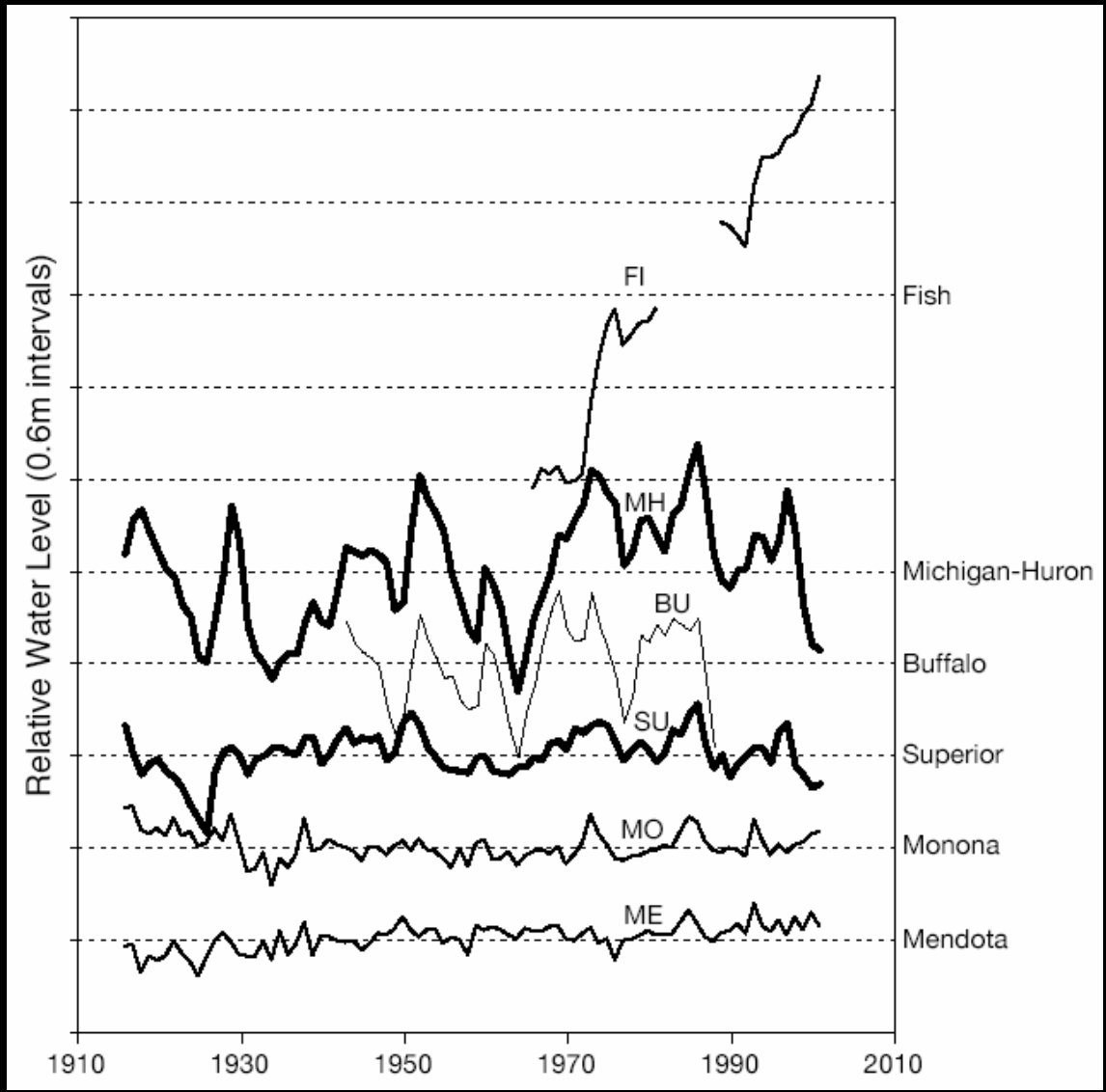
Long-Term Water Level of Wisconsin Lakes and two Great Lakes

Great Lakes are BOLD.

Buffalo is in northern Wisconsin.

Mendota, Monona, and Fish are in southern Wisconsin.

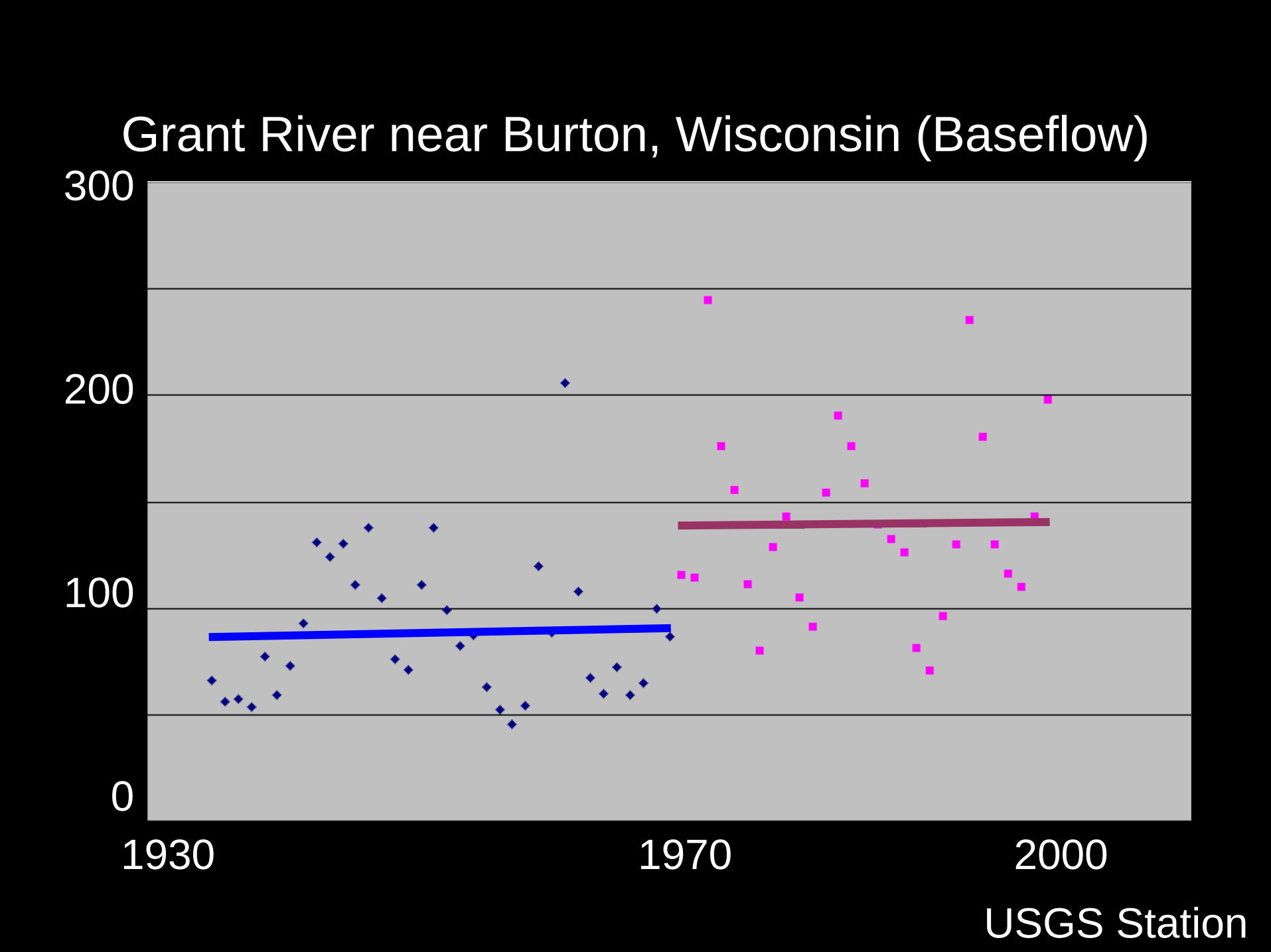
Fish Lake is a seepage lake.



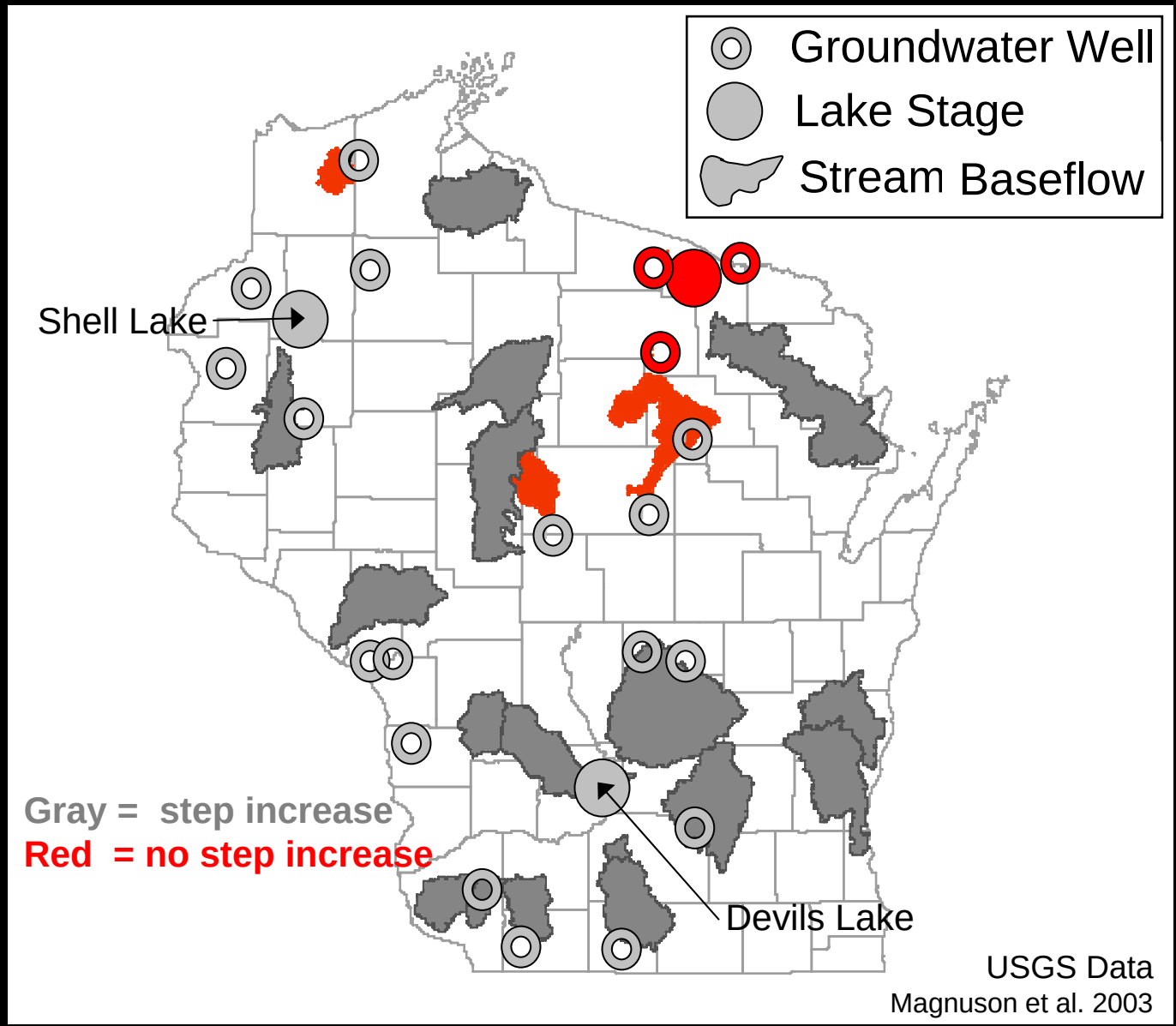
Magnuson et al. 2006

Stream Flows

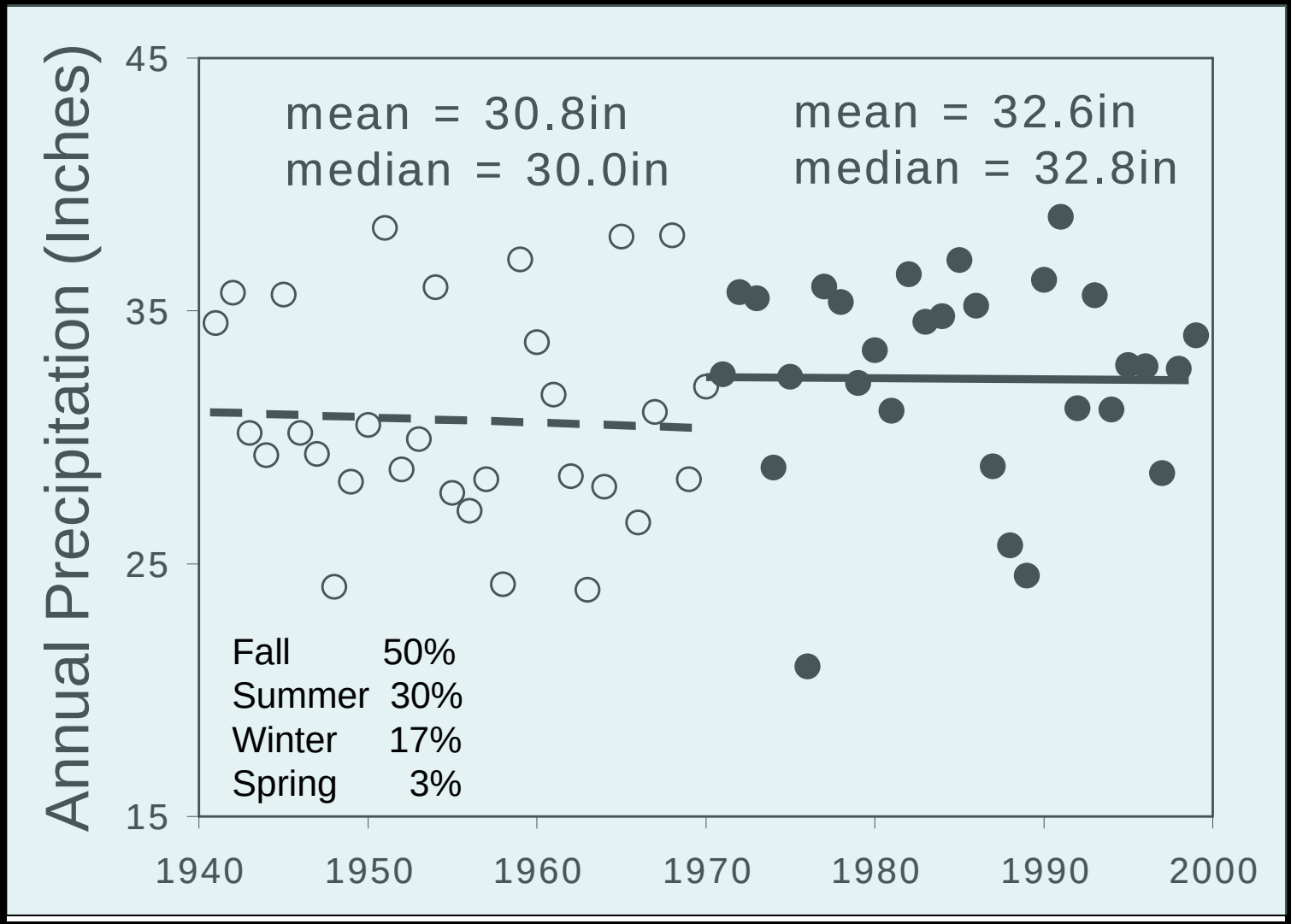
Krohelski 2003


Grant River near Burton, Wisconsin (Baseflow)
300
200
100
0
1930
1970
2000
USGS Station

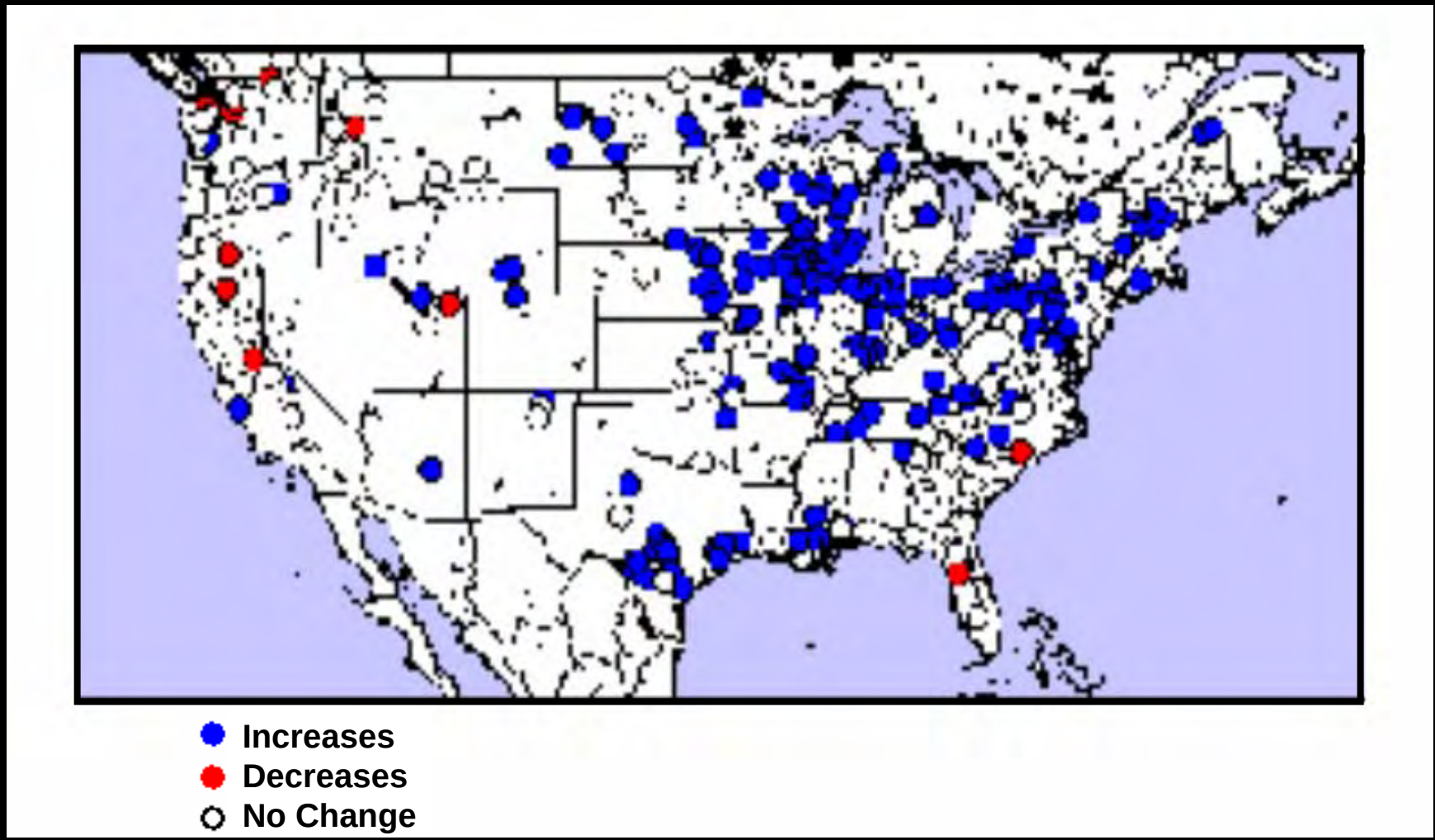
Step Increase in Lake Stage, Stream Flow, and Groundwater Levels after 1970



What happened to precipitation in Wisconsin?

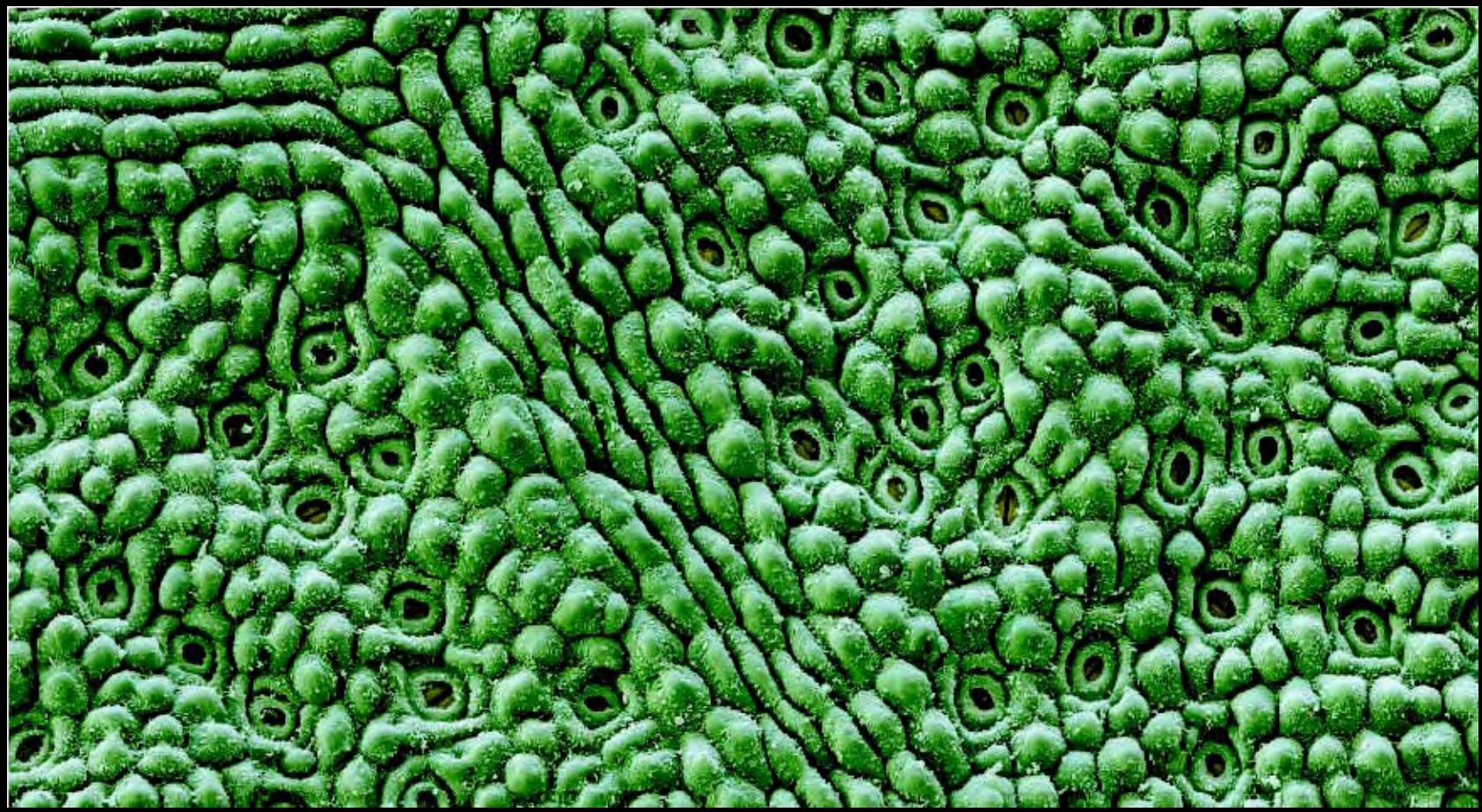


Stream-flow Sites with Significant Increases in Minimum Daily Flow between Two Periods (1941-70 and 1971-99)

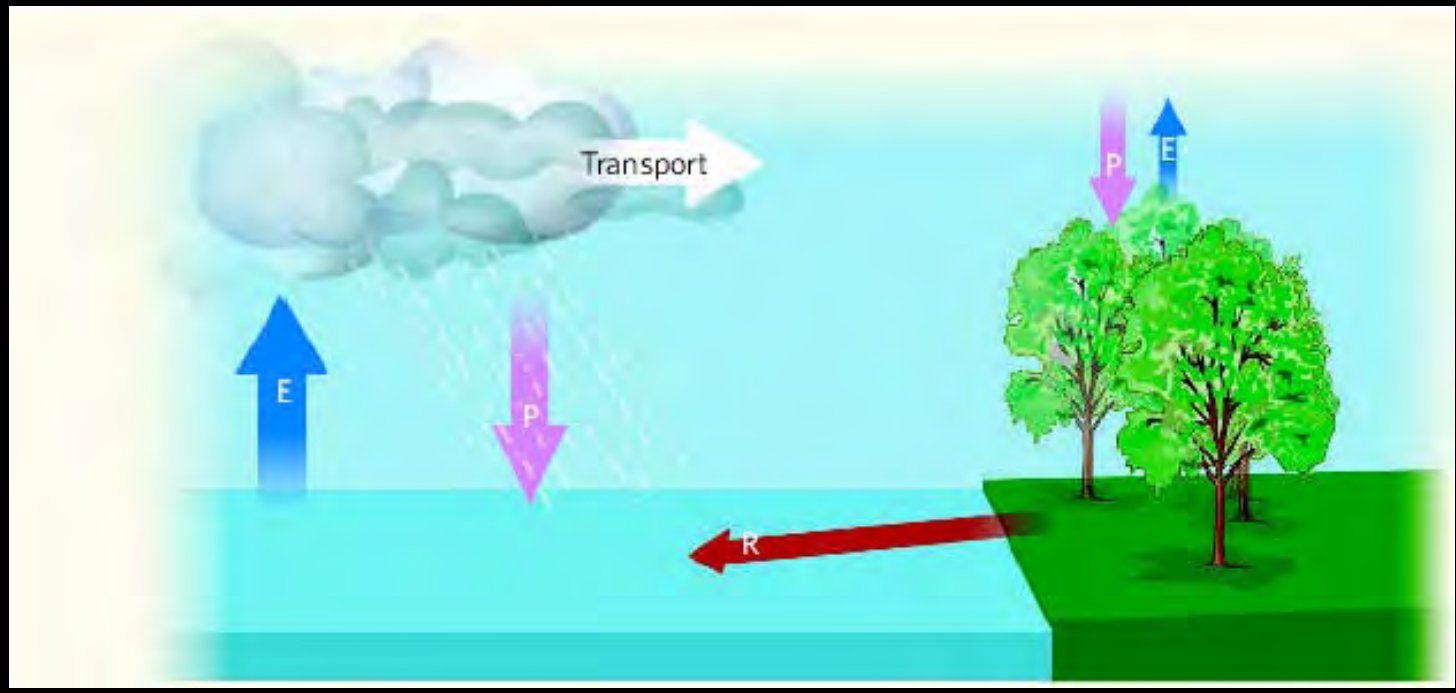


McCabe and Wolock

Another Cause of Increase in Water Levels and Flows



The Water Cycle Freshens Up



“Rivers are delivering increasing amounts of fresh water to the oceans.

The cause seems to be that higher concentrations of atmospheric carbon dioxide are having on water use by plants.water to the ocean.”

(Don Matthews Nature Feb 2006, see also Gedney et al.Nature Feb. 2006))

Water Levels and Flows Conclusions

- Lake stage (seepage lakes), baseflow in streams, and groundwater table have gone up in Wisconsin except for north central area.

- Reasons for the increases are varied and include change in precipitation, CO_2 changes in plant physiology, land use, and perhaps the shorter winters.

- Scenarios for the future.

Overview of Main Points

1. Climate is changing globally
and in our region.

2. Impacts have already occurred
and will get worse.

3. Emissions of greenhouse gases
especially CO_2 contribute to these changes.

4. Actions taken now can reduce
the most severe future impacts

Ways to Think about Uncertainty

Uncertainties will continue to change.

Do and apply science.

Risk averse versus risk prone behavior.

Do right thing regardless.

Preserve future options.

All decisions are long term.

Reflect on other Issues for wisdom.

How Do Natural and Social Scientists Deal with Uncertainty

Kai Lee 1993. Compass and Gyroscope

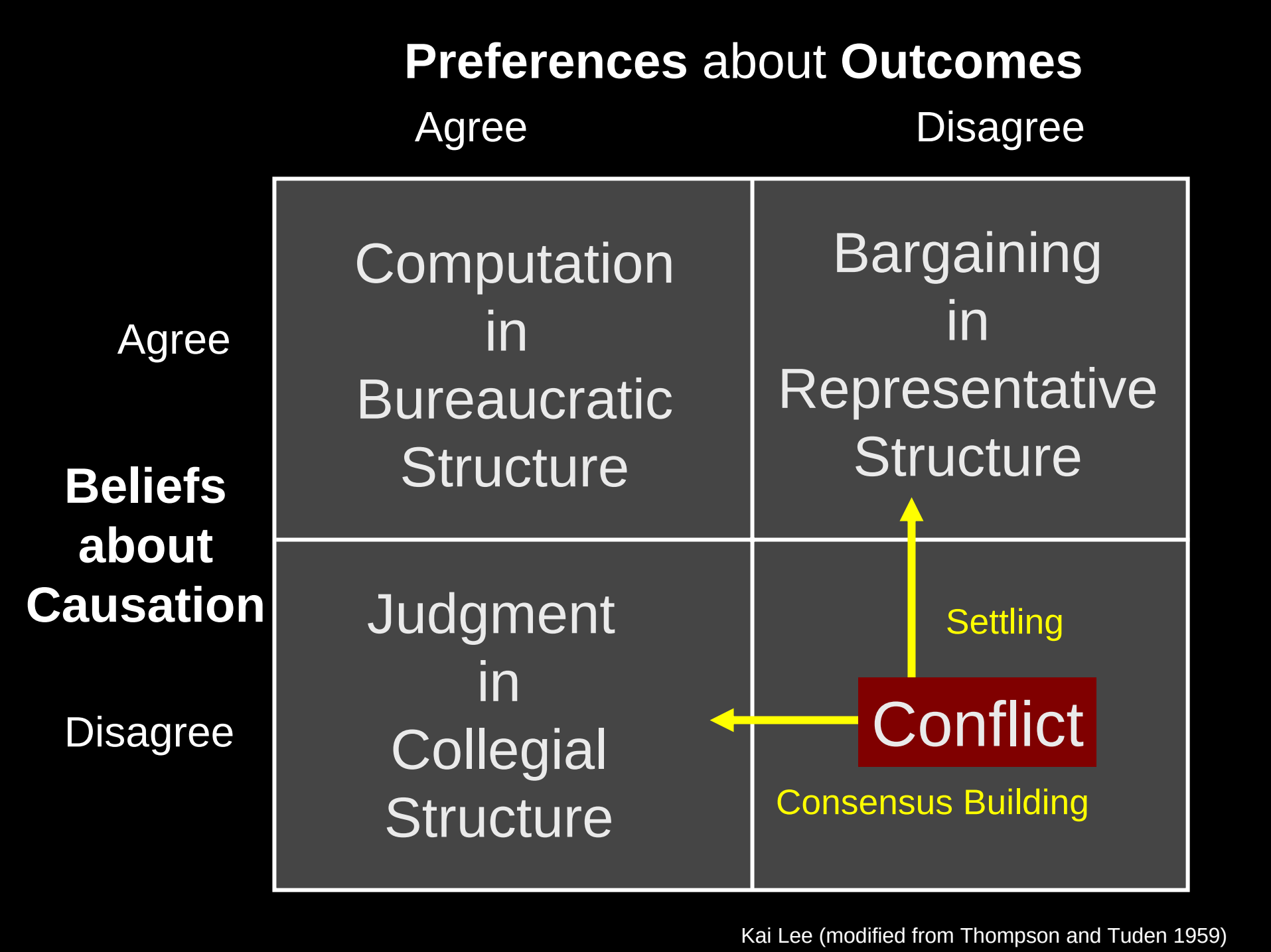
Compass = Science and its Idealistic Application in Adaptive Management.

Gyroscope = Bounded Conflict as a Pragmatic Application of Politics Disciplines the Discord of Unavoidable Error.

What to do?
Relevant Time Scales are Long Term.

- Include Climate Change and Variability in planning and making decisions concerning natural resources, agriculture, energy production, cities, and other activities.

- Reduce greenhouse gas emissions in all sectors.



Kai Lee (modified from Thompson and Tuden 1959)