Northwest Power and Conservation Council



April 25, 2006

# MEMORANDUM

**TO:** Council Members

**FROM:** John Fazio, Senior System Analyst

**SUBJECT:** Global Warming - State of the Science Presentation

Dr. Philip Mote of the Climate Impacts Group at the University of Washington (www.cses.washington.edu/cig/) will brief the Council on current research on global warming in the Pacific Northwest. The Climate Impacts Group is an interdisciplinary research group studying the impacts of natural climate variability and climate change in the Pacific Northwest. Dr. Mote will present evidence that has led many scientists to believe that the earth's temperature is warming. He may also describe current research efforts and tools his group uses to assess potential future conditions.

Dr. Mote is the State Climatologist for Washington State. He is also a research scientist for the Climate Impacts Group and acts as a consultant for Northwest Research Associates. He has had numerous papers published and has extensive teaching experience at the University of Washington (http://www.cses.washington.edu/db/pdf/motecv04.pdf). Dr. Mote received a B.A. in physics from Harvard University and a Ph.D. in atmospheric sciences from the University of Washington.



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# Climate Change and Hydropower in the Northwest

Philip Mote
University of Washington

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# What we know (high confidence)

- Earth's climate is changing
- Humans are involved and the pattern is unlike natural changes
- Global average temperature is likely to increase substantially during this century
- We know this through peer-reviewed research and assessments (IPCC, NAS,…)

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# Outline

- How we know that global climate is changing and that humans are involved
- Observed and projected changes of relevance to the Northwest's hydropower

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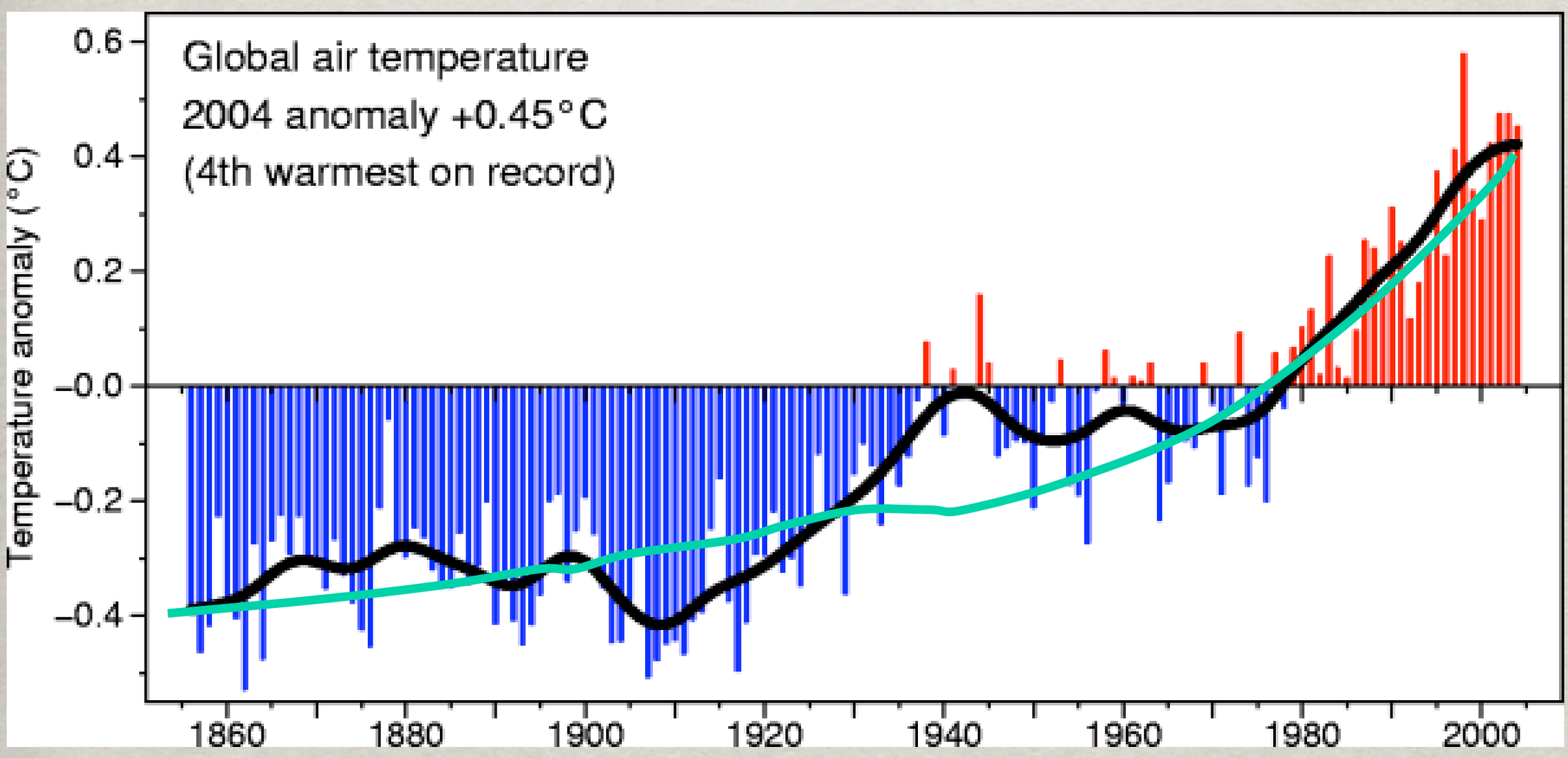
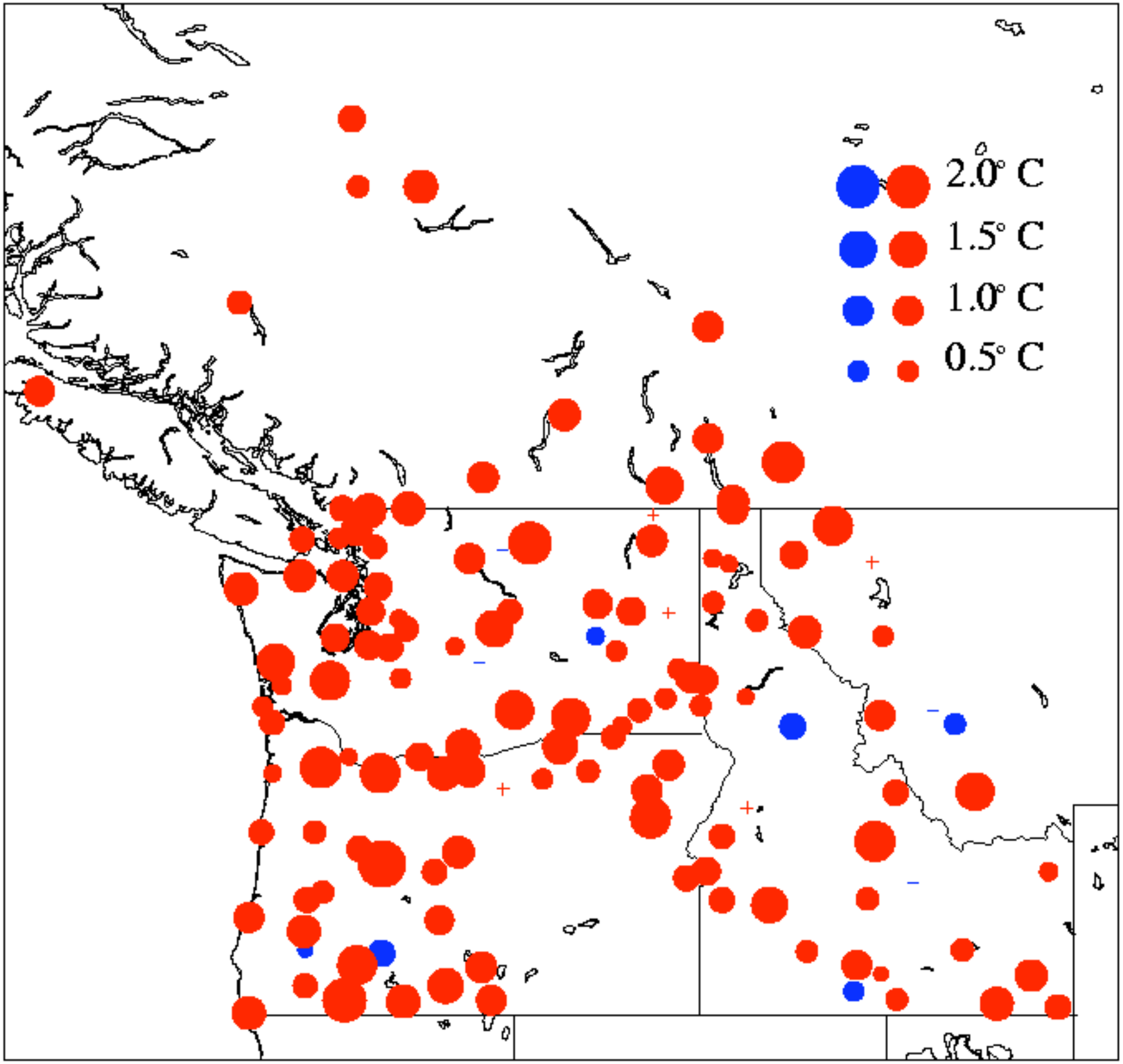
# Variations of the Earth's surface temperature




Global mean 14.0°C

Annual $CO_2$

# Temperature trends (°C per century), since 1920

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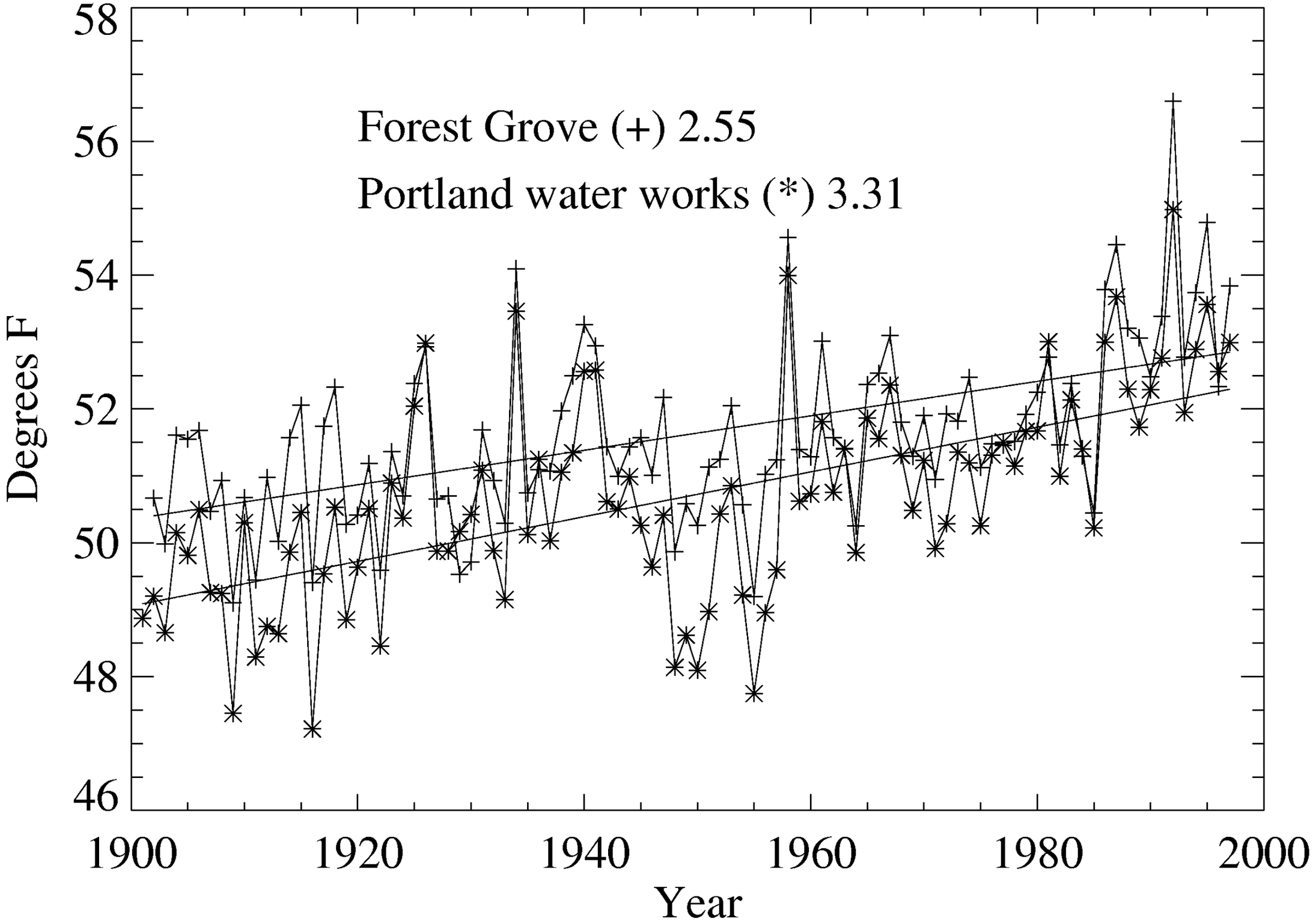
# Annual average temperature

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# Other evidence of warming

- Receding glaciers
- Thinning and retreat of Arctic sea ice
- Collapse of ice shelves
- Changes in phenological indicators and species ranges

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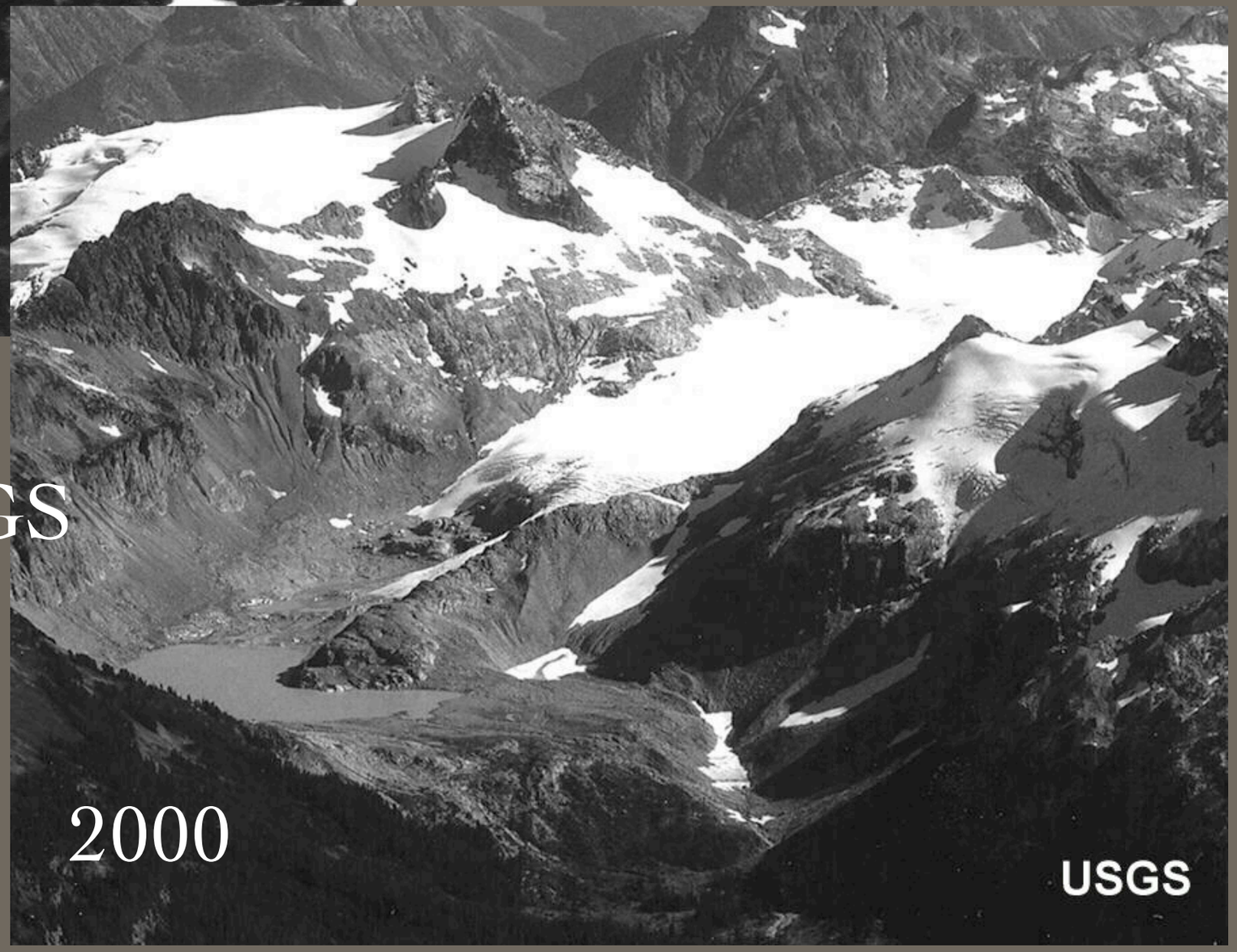
1928

The South Cascade glacier retreated dramatically in the 20th century



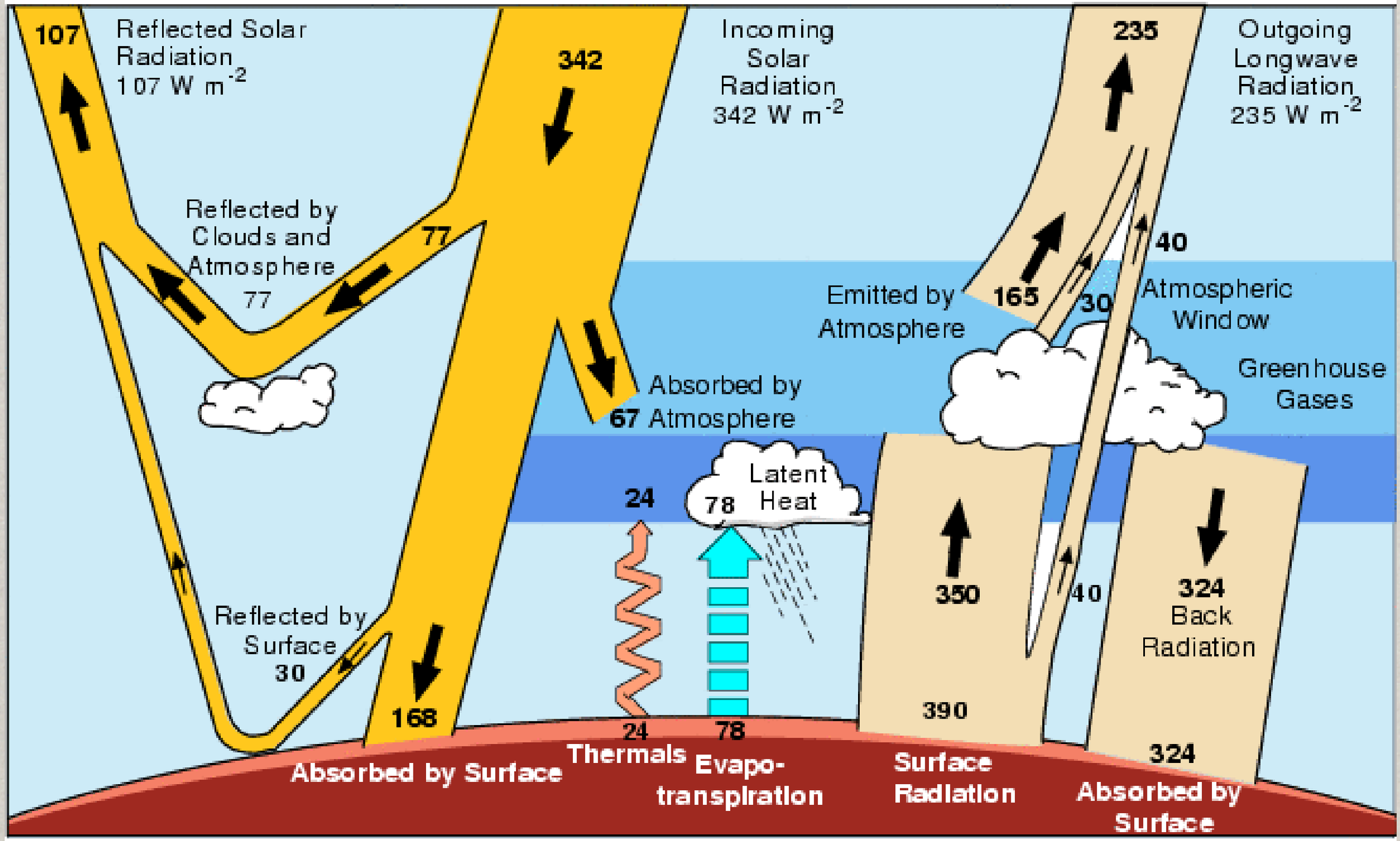

2000

Courtesy of the USGS glacier group

# How do we know it's not natural?

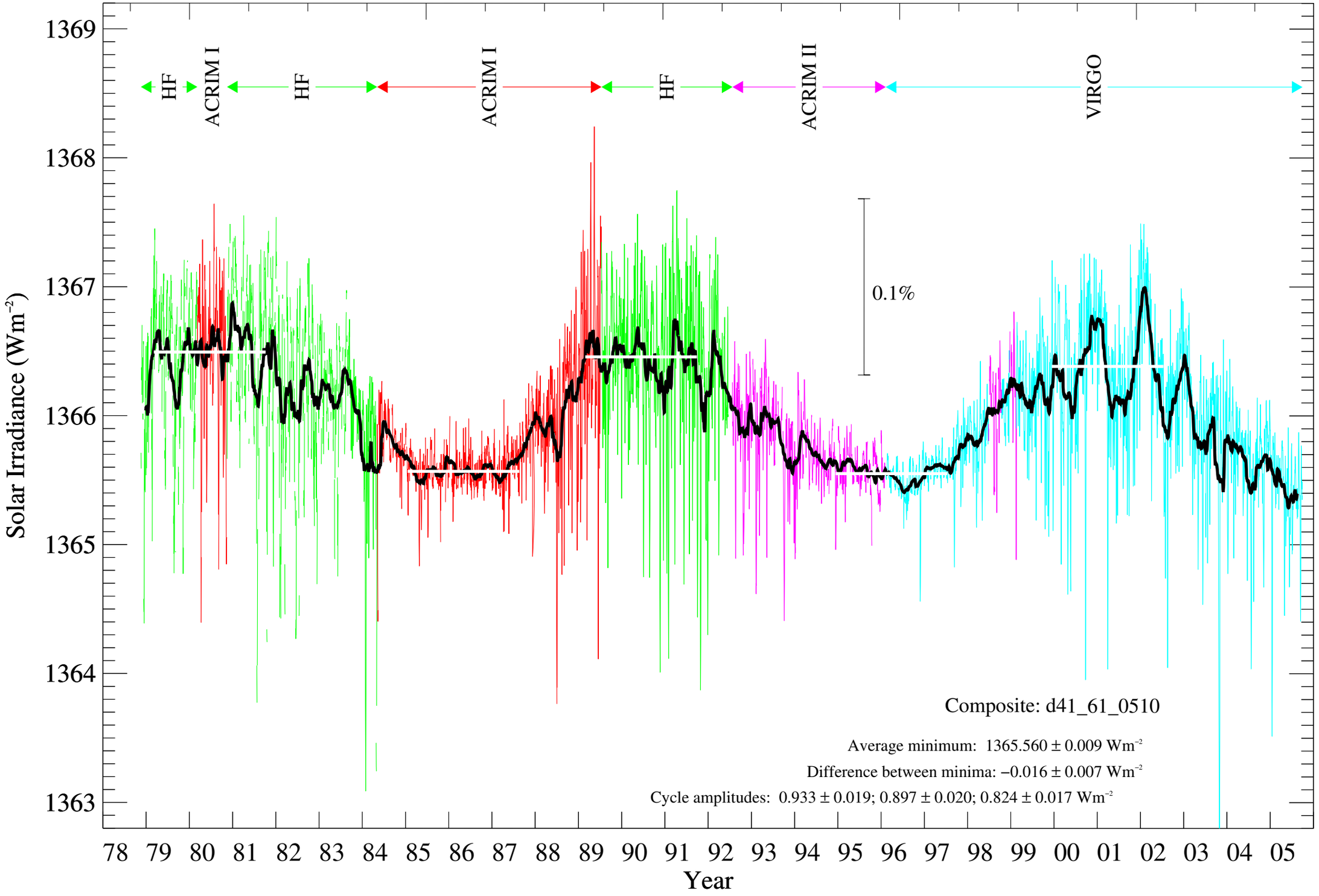
- Basic physics
- Known patterns of natural variability cannot explain the pattern of warming
- Heat going *into* the oceans and land
- Simulations with climate models cannot reproduce recent warming without rising greenhouse gases

# Global Heat Flows



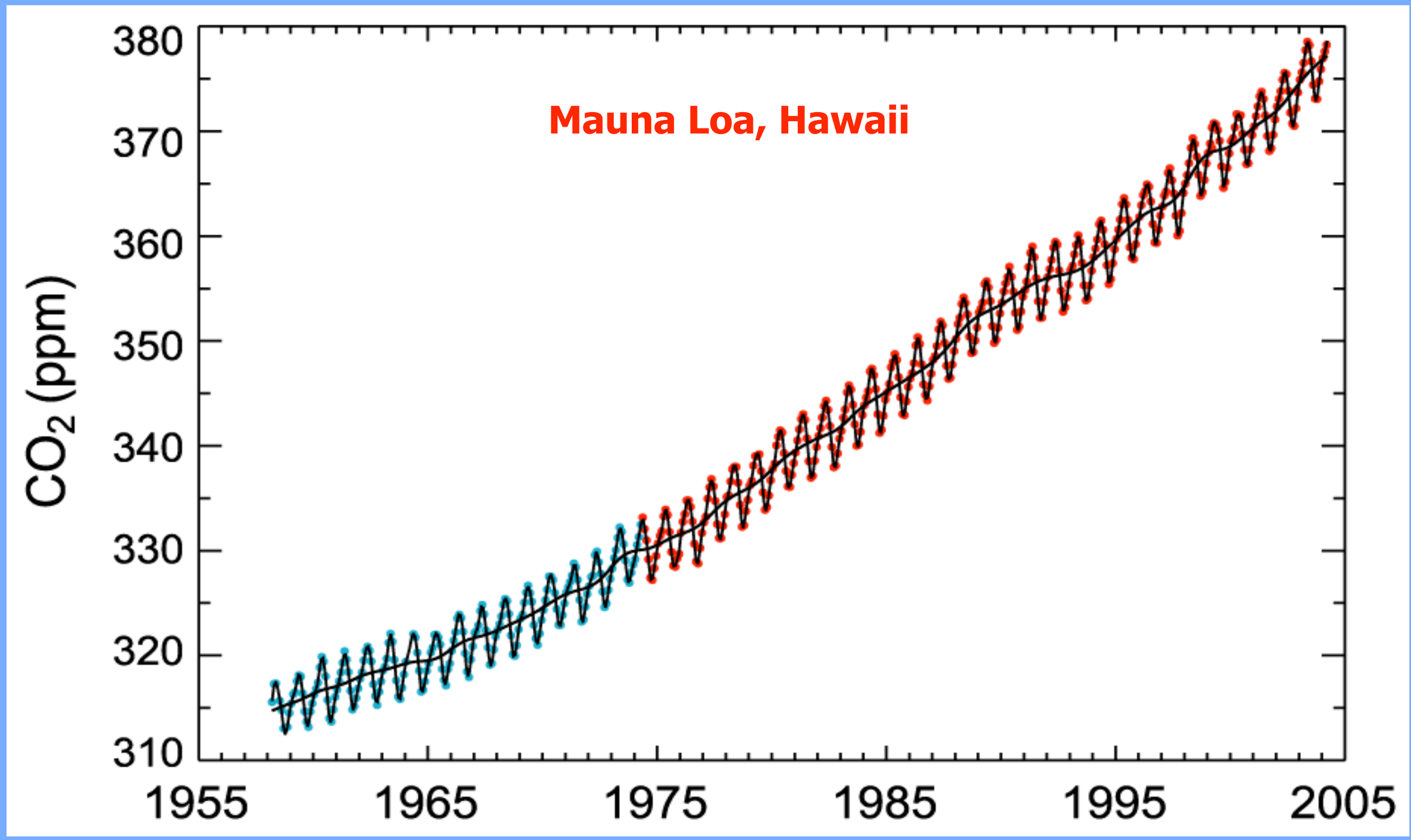

*Kiehl and Trenberth 1997*

# Total Solar Irradiance Data (referred to SARR via ACRIM–II)

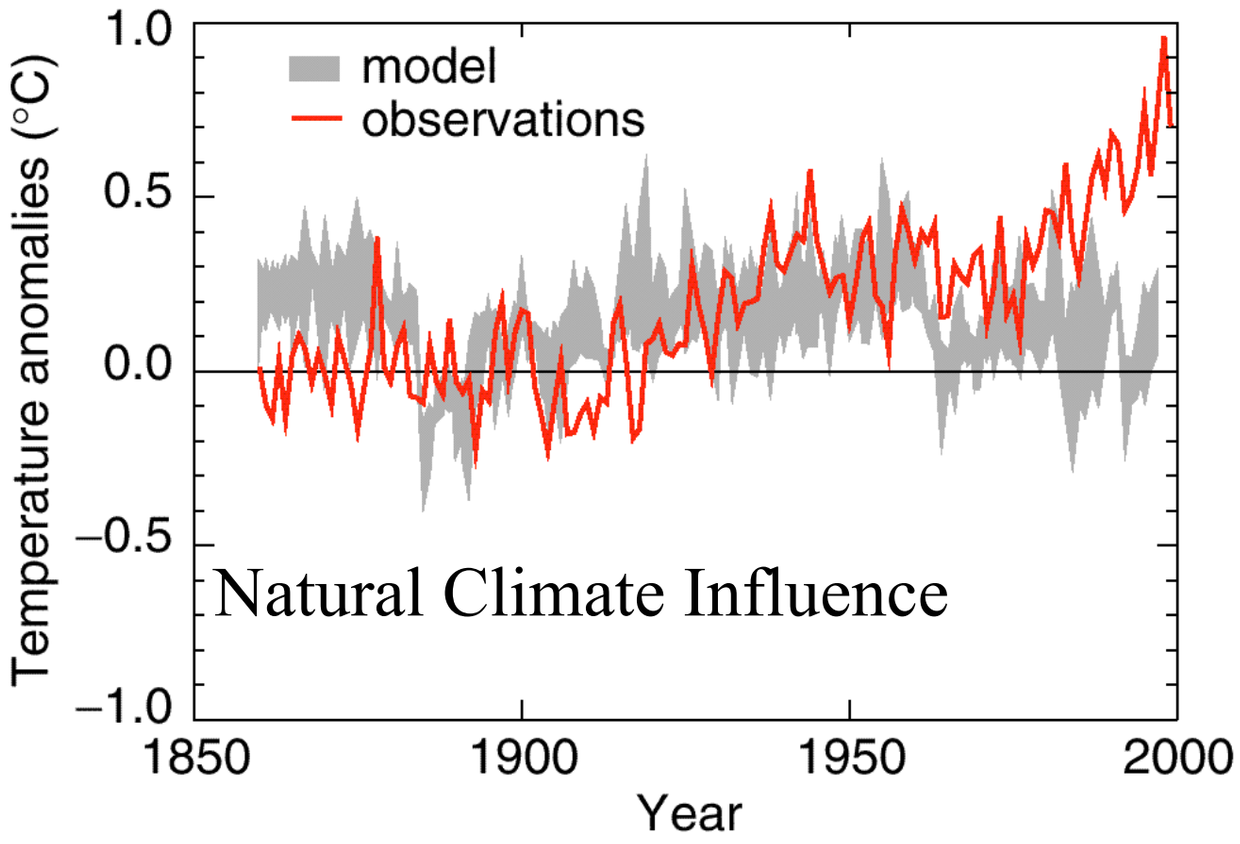


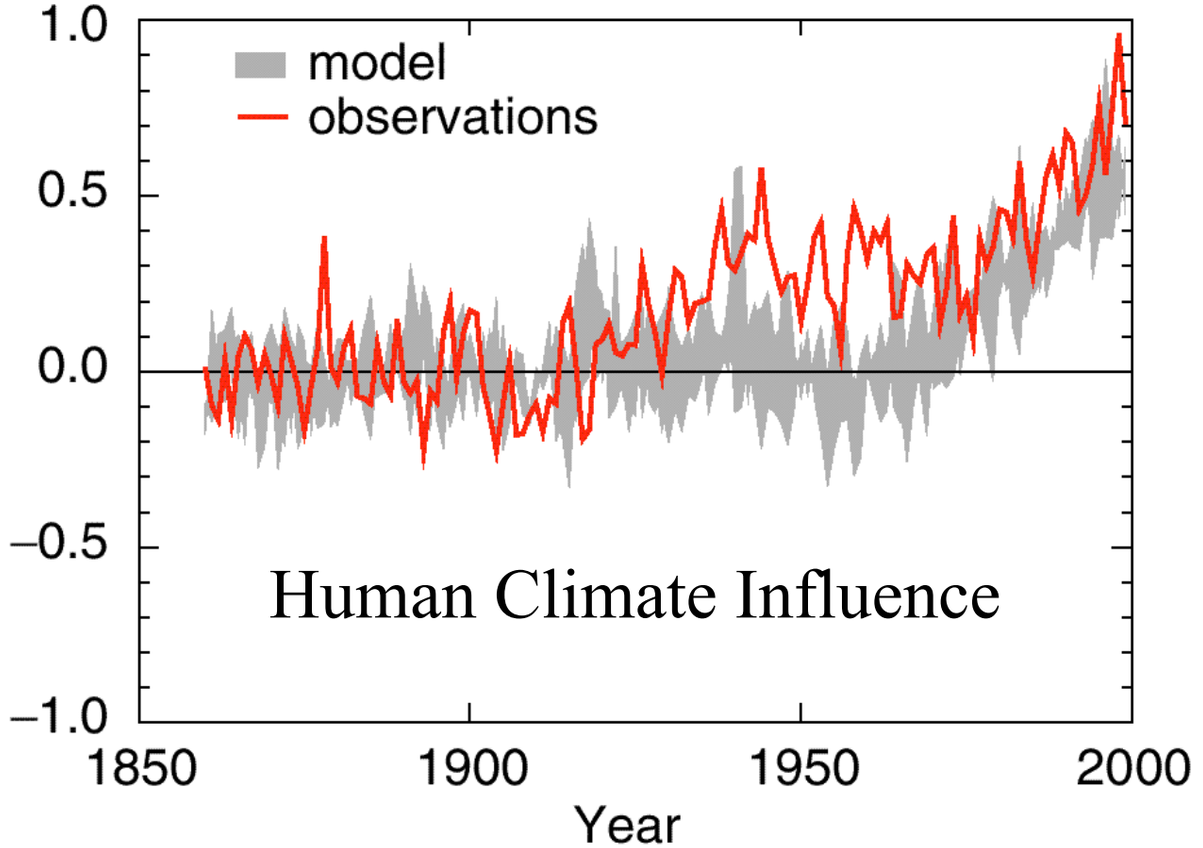

from: C. Fröhlich, Space Science Reviews, **94**, pp.15–24, 2000, with composite (vers d41_61_0510), ACRIM–II/III (vers II:101001) and VIRGO 6_001_0510 data (Oct 07, 2005)

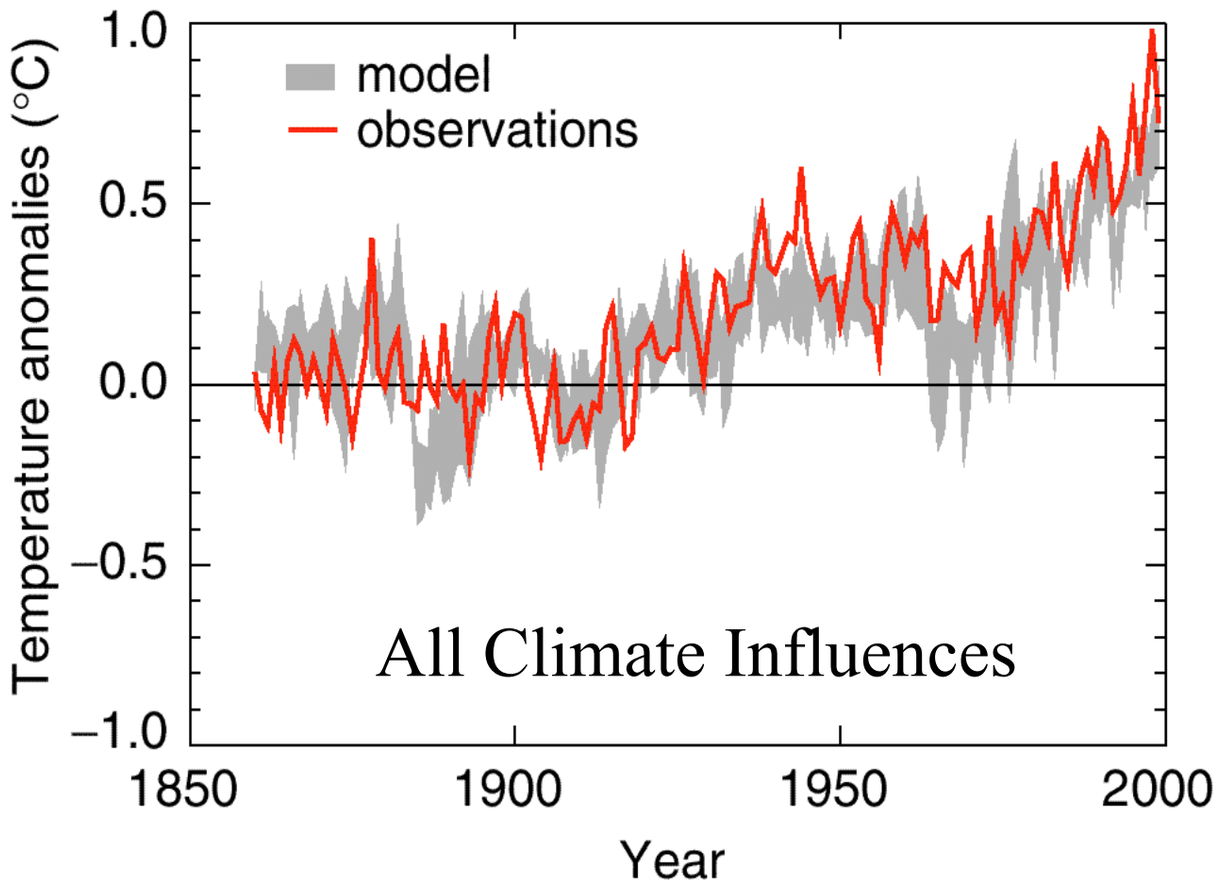
# Changing atmospheric composition: $CO_2$




Data from Climate Monitoring and Diagnostics Lab., NOAA. Data prior to 1973 from C. Keeling, Scripps Inst. Oceanogr.

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# Hydro Resources implications

- Warming has already caused a reduction in Northwest snowpack and a consequent shift in flow from summer to winter

- Continued shifts in timing of flow are very likely

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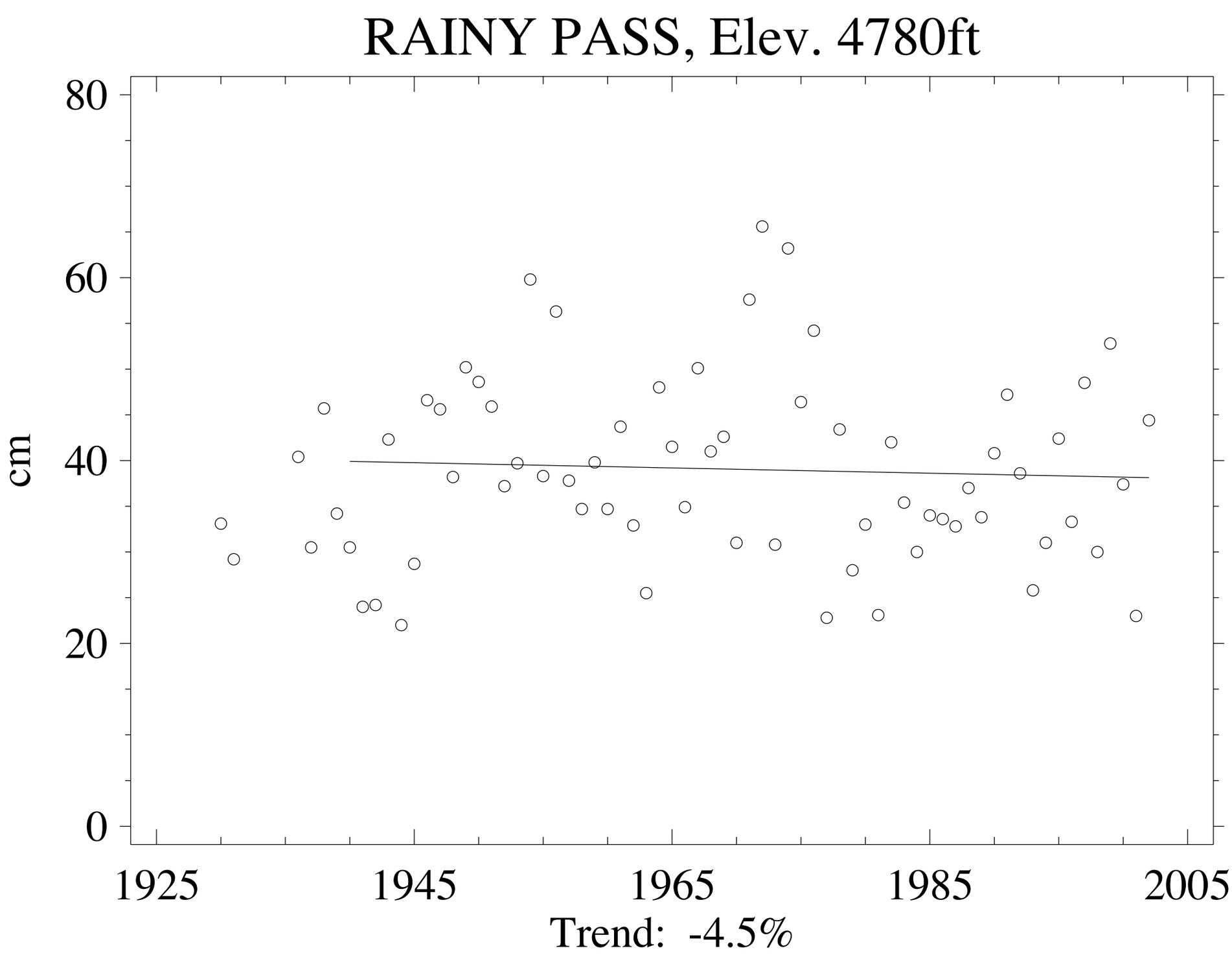
# April 1 snowpack: no decline at high elevations

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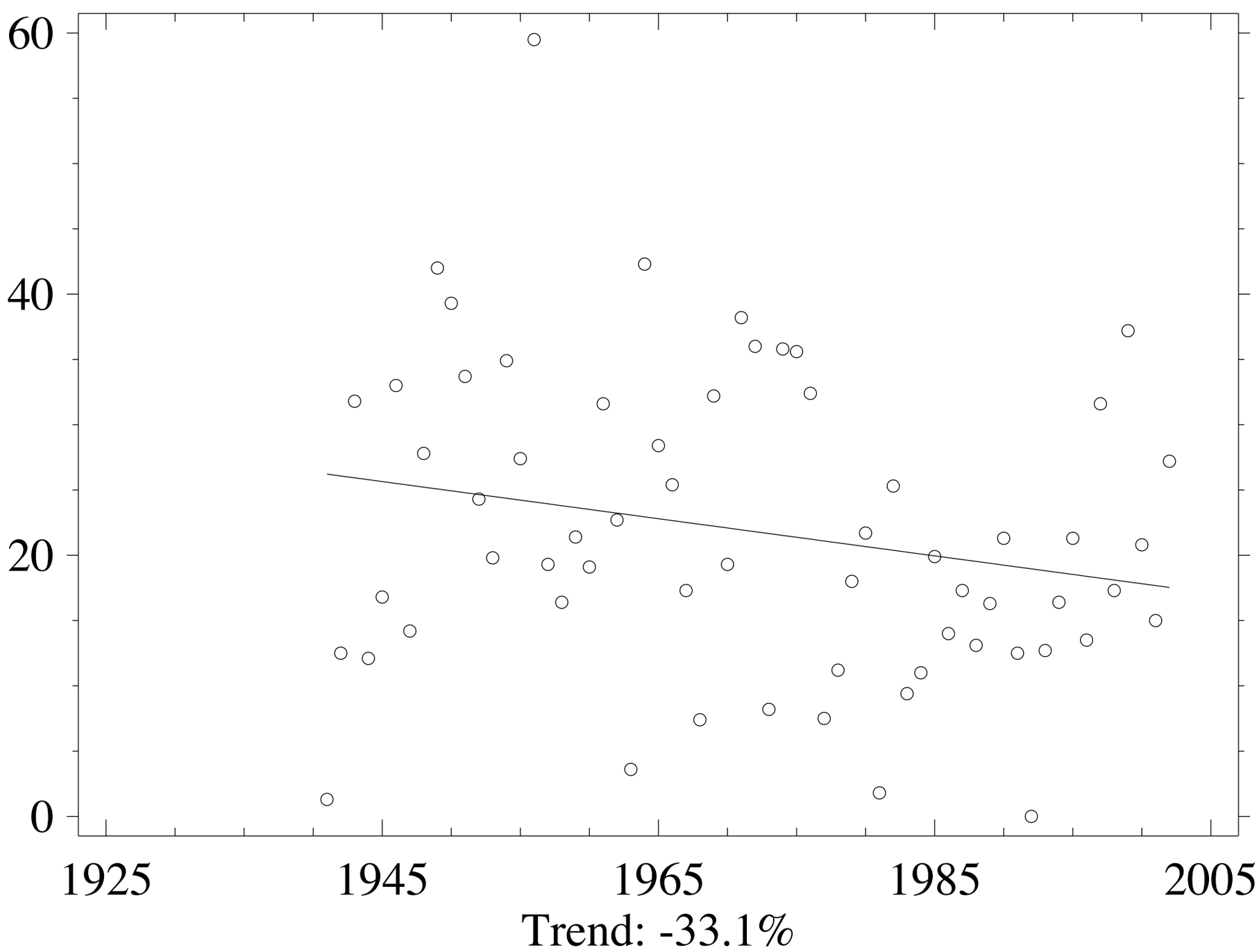
# ...but large declines at low elevations

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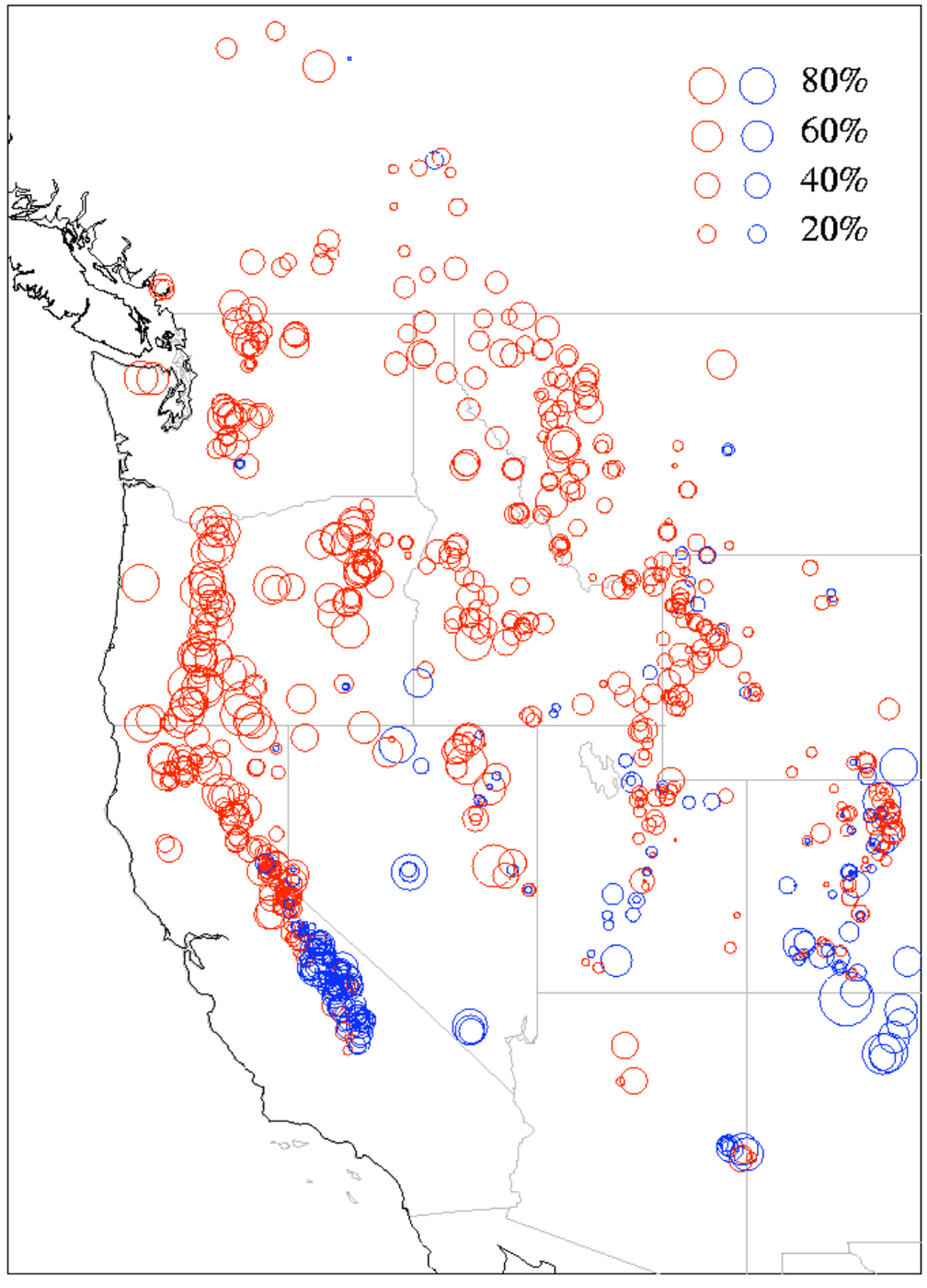
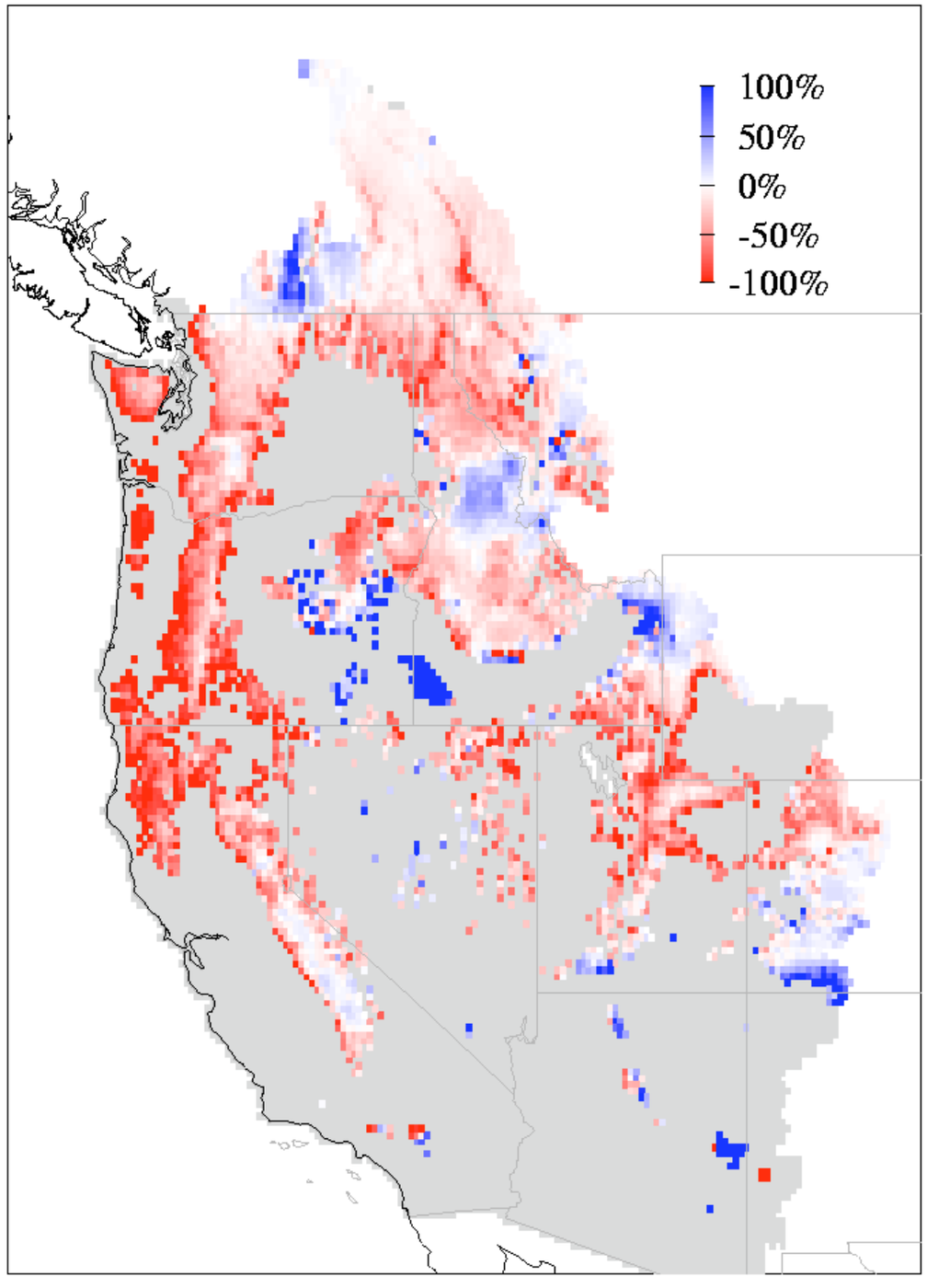
# Declining April 1 snowpack, 1950-1997

a. Observations

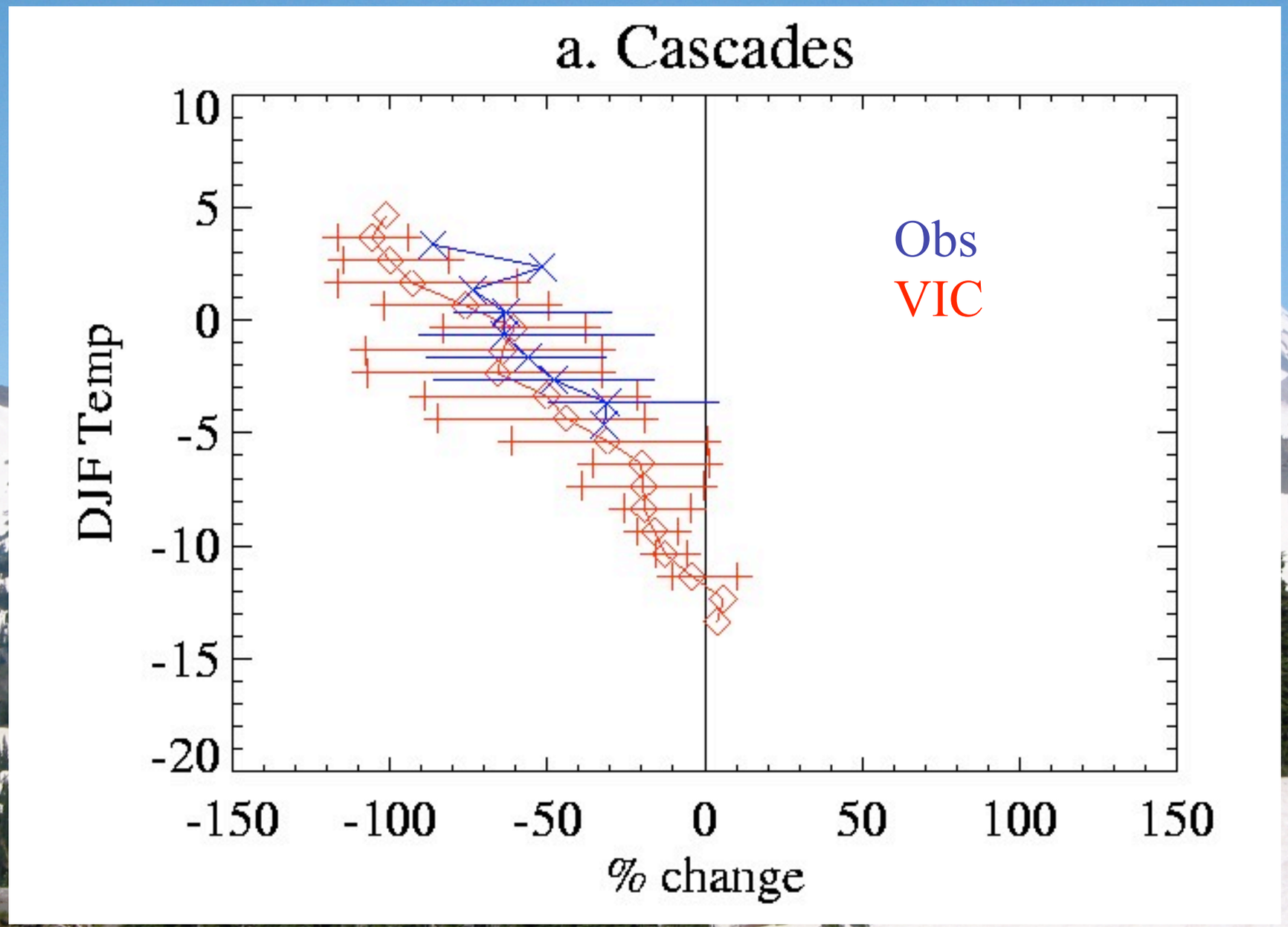



b. VIC



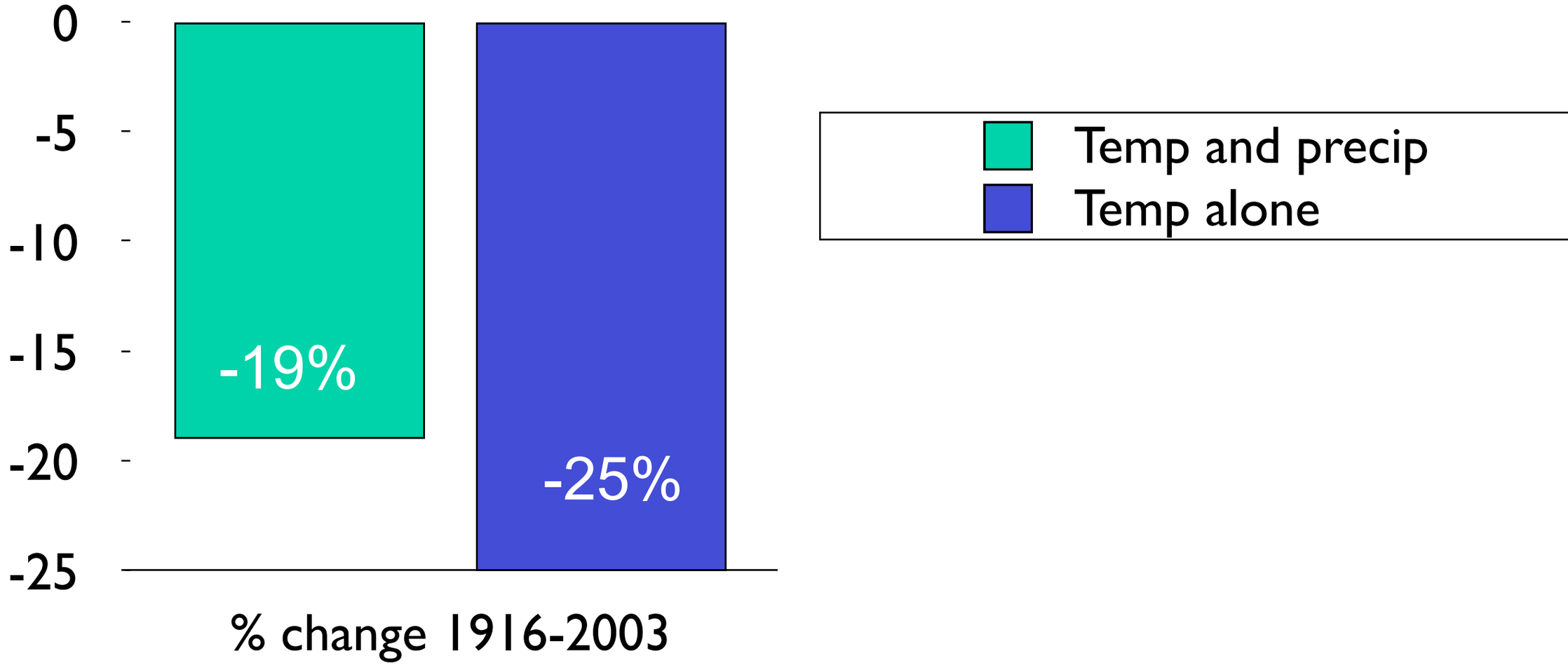

Mote et al., BAMS 2005

# 1950-1997 relative trends in April 1 SWE vs DJF temperature




Mote et al., BAMS 2005

# Trends in April 1 SWE for the WA and OR Cascades 1916-2003

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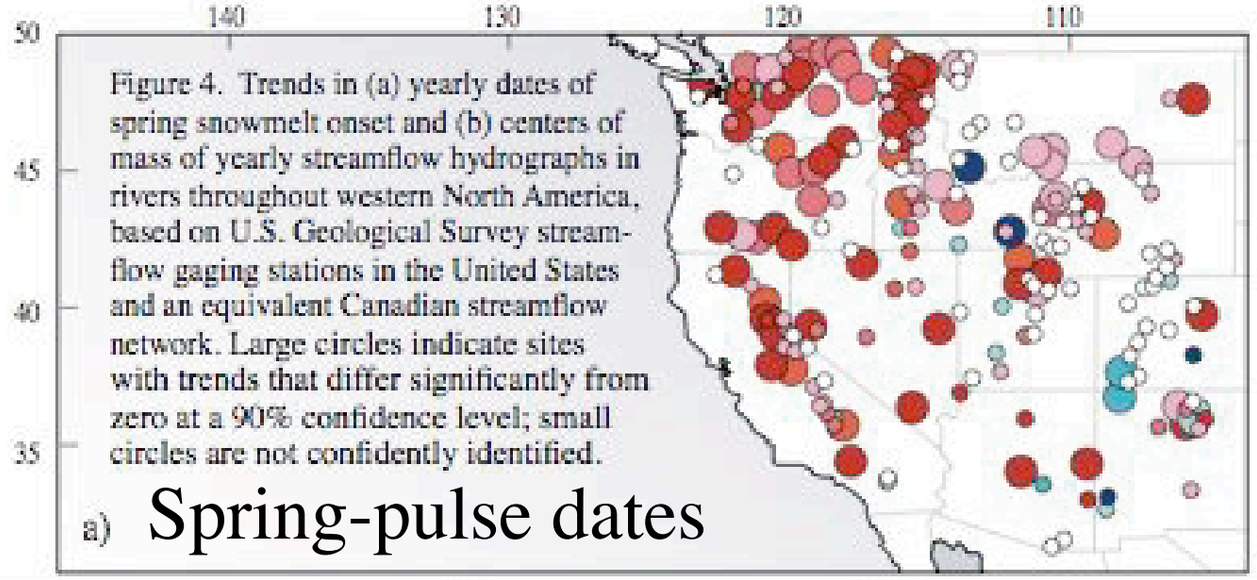
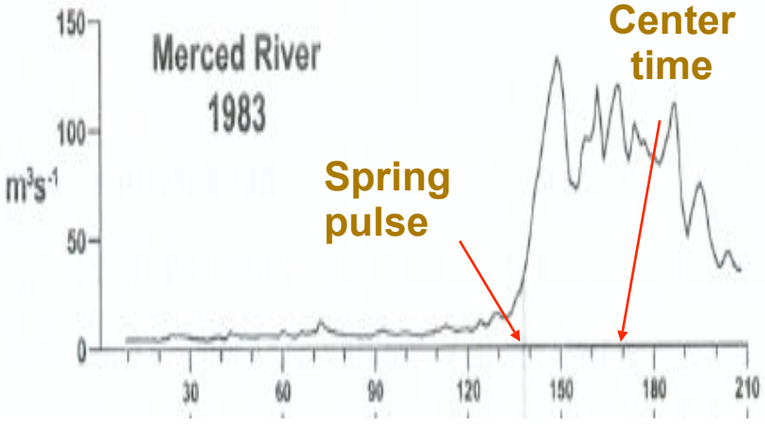
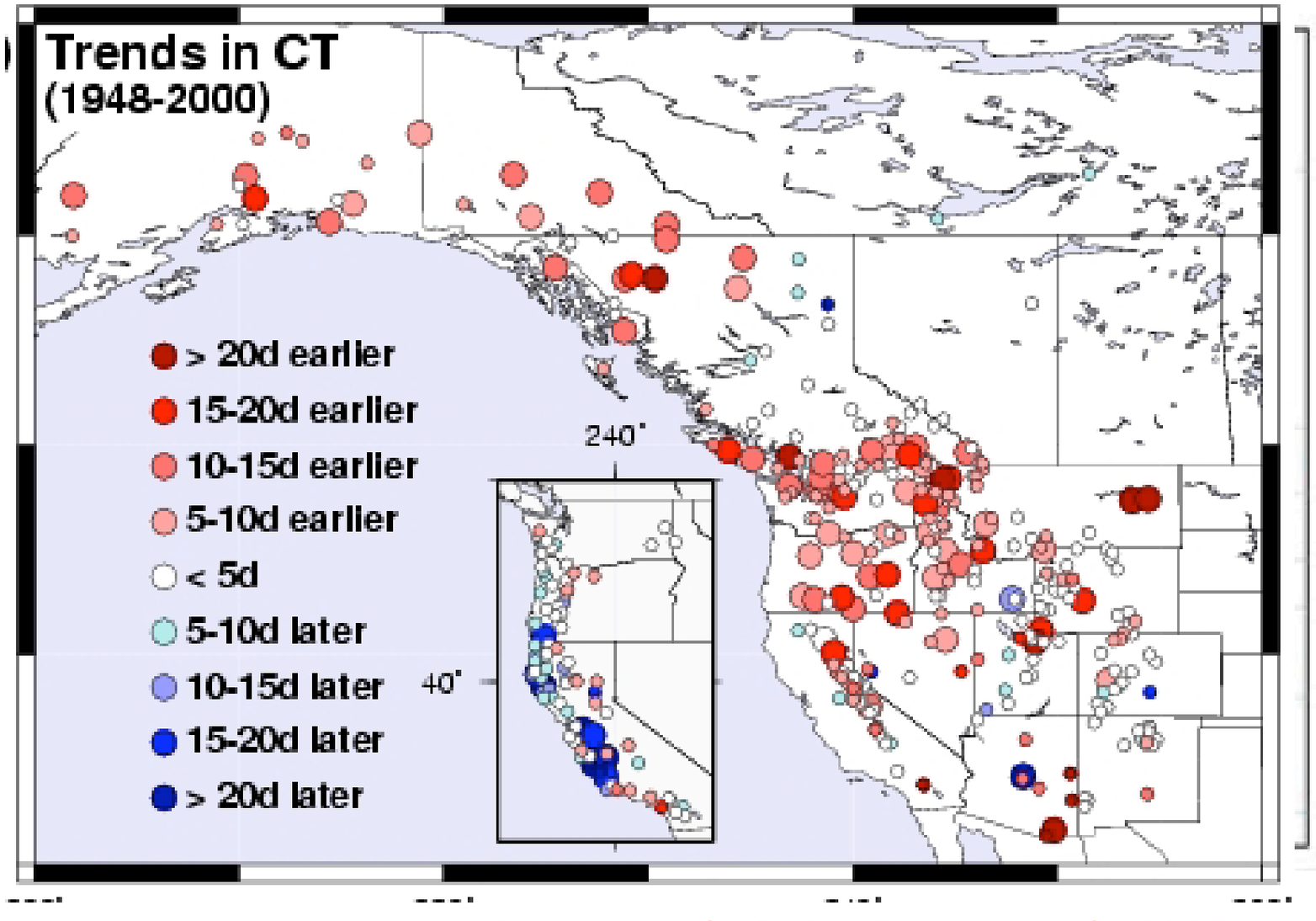
Hamlet et al., J Climate 2005

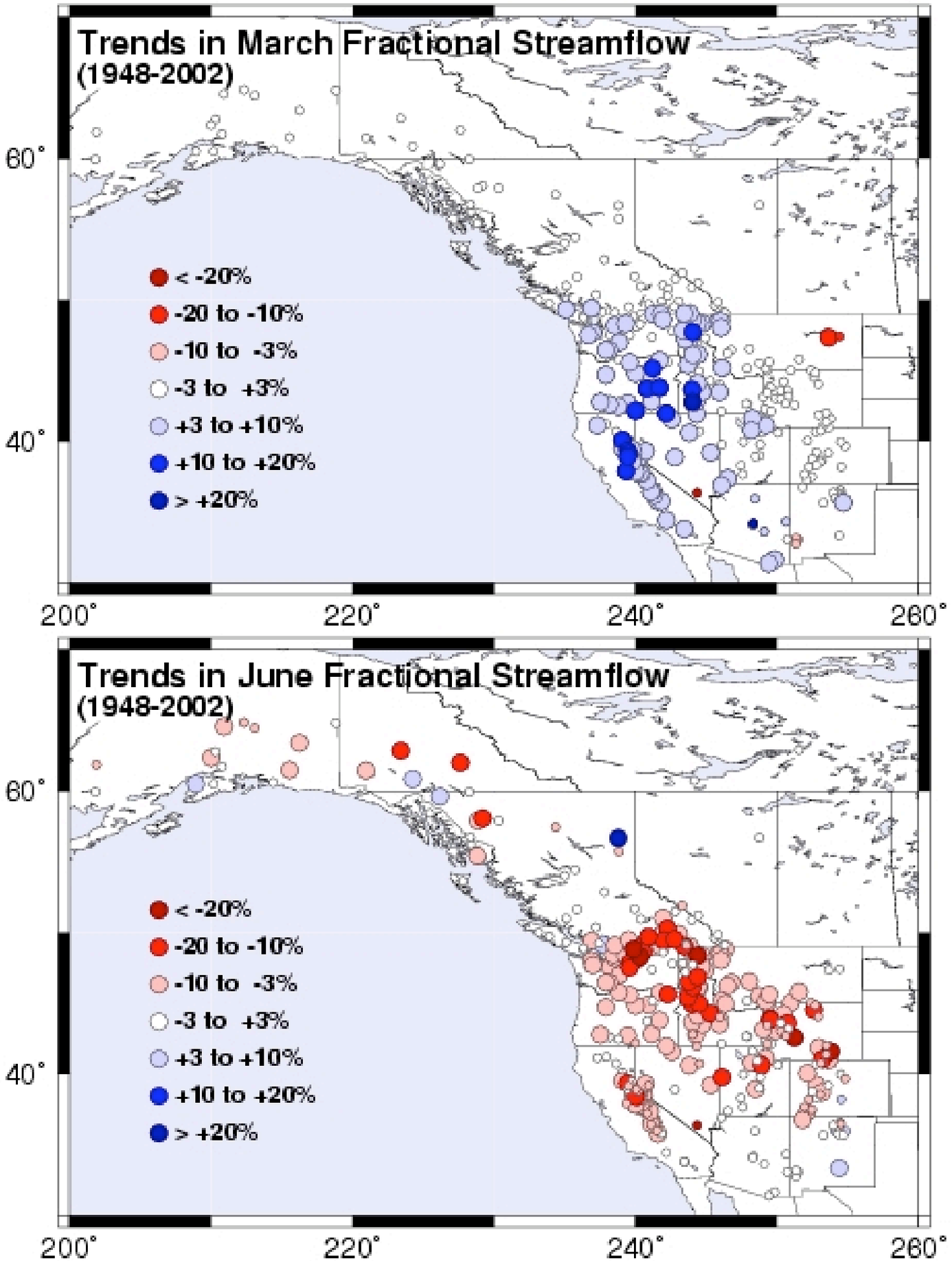
**By several measures, Western snowfed streamflow has been arriving earlier in the year in recent decades**




Stewart et al., 2004; Stewart et al., 2005




As the West warms, winter flows rise and summer flows drop

Figure by Iris Stewart, Scripps Inst. of Oceanog. (UC San Diego)

Stewart et al., J Climate 2005

# Summary of observed changes in the Northwest

- Substantial warming
- Elevation-dependent loss of snowpack
- Shift in flow from late spring/summer to winter/early spring

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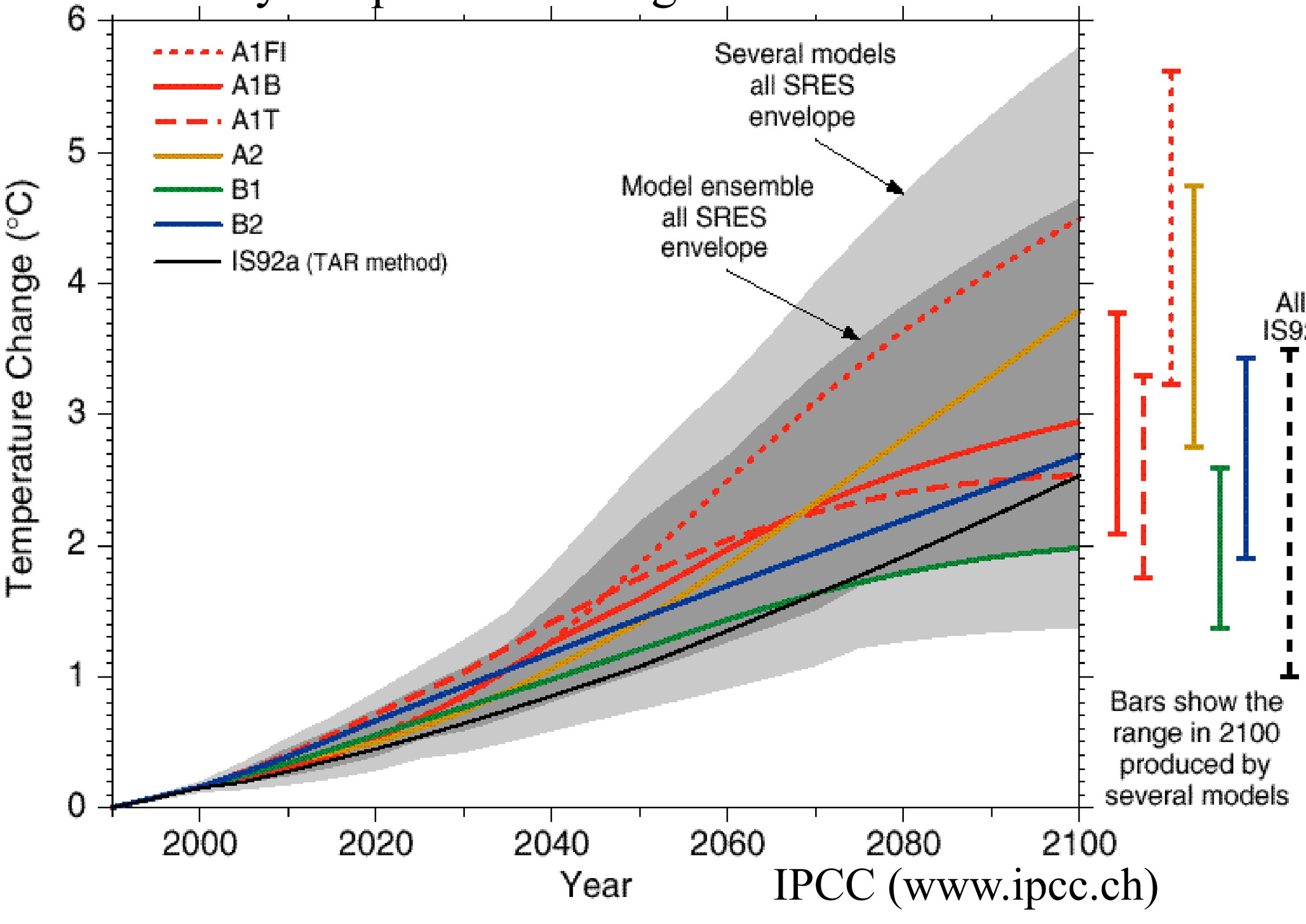
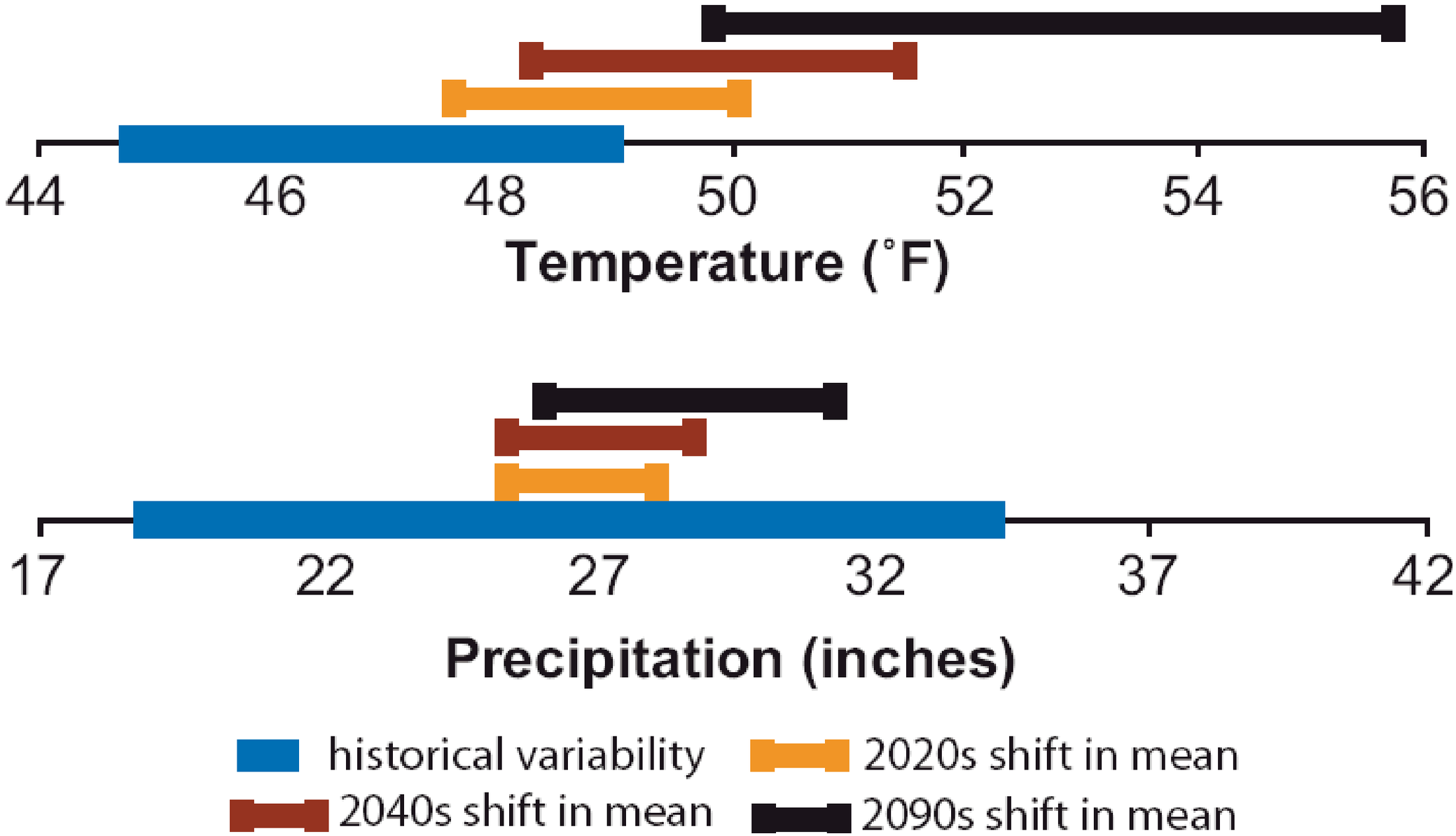
# 21st century temperature change




IPCC (www.ipcc.ch)




# Comparison of observed year-to-year variability and projected shifts in temperature and precipitation from climate models

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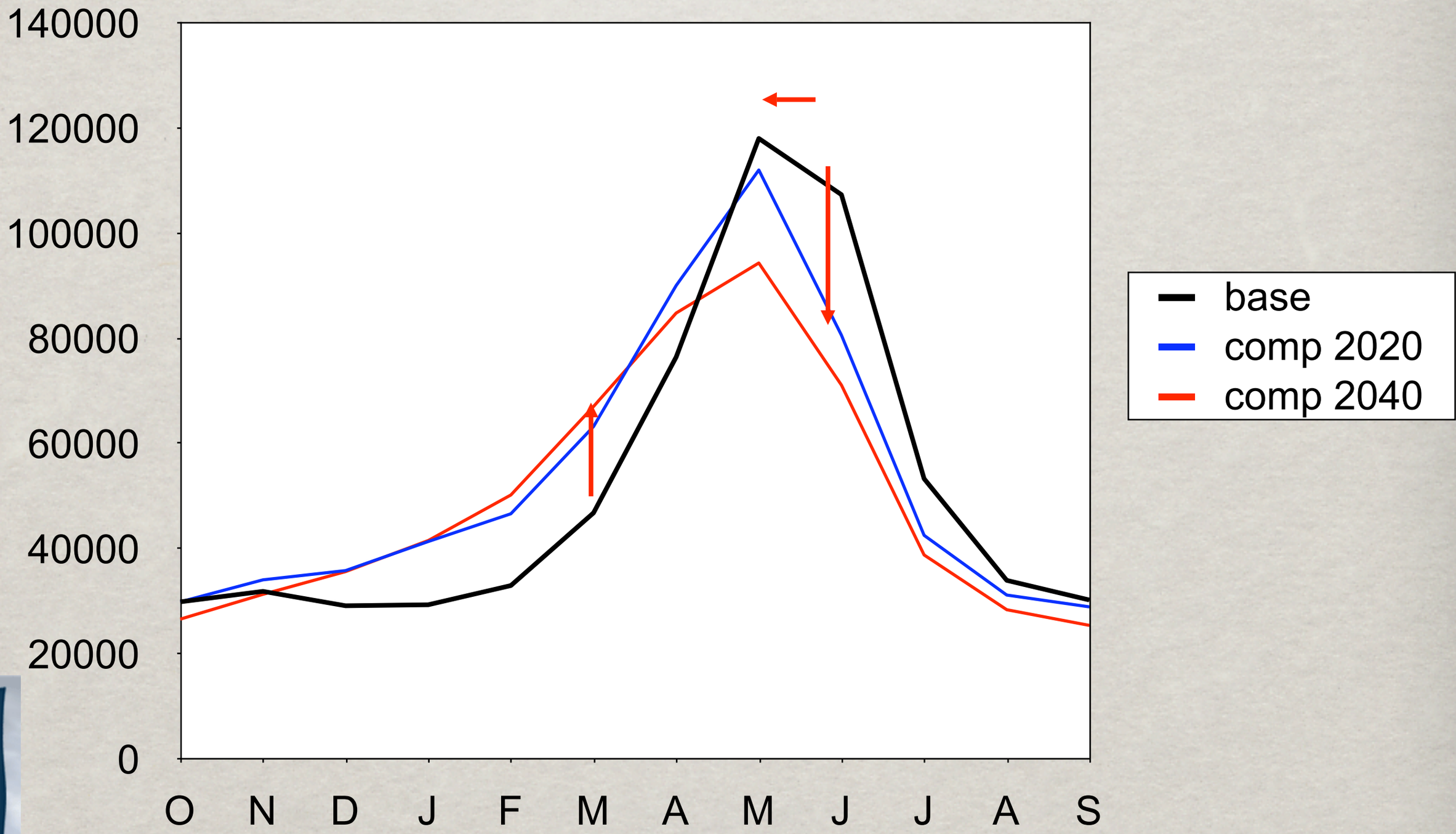
# Snake River at Ice Harbor




Three changes

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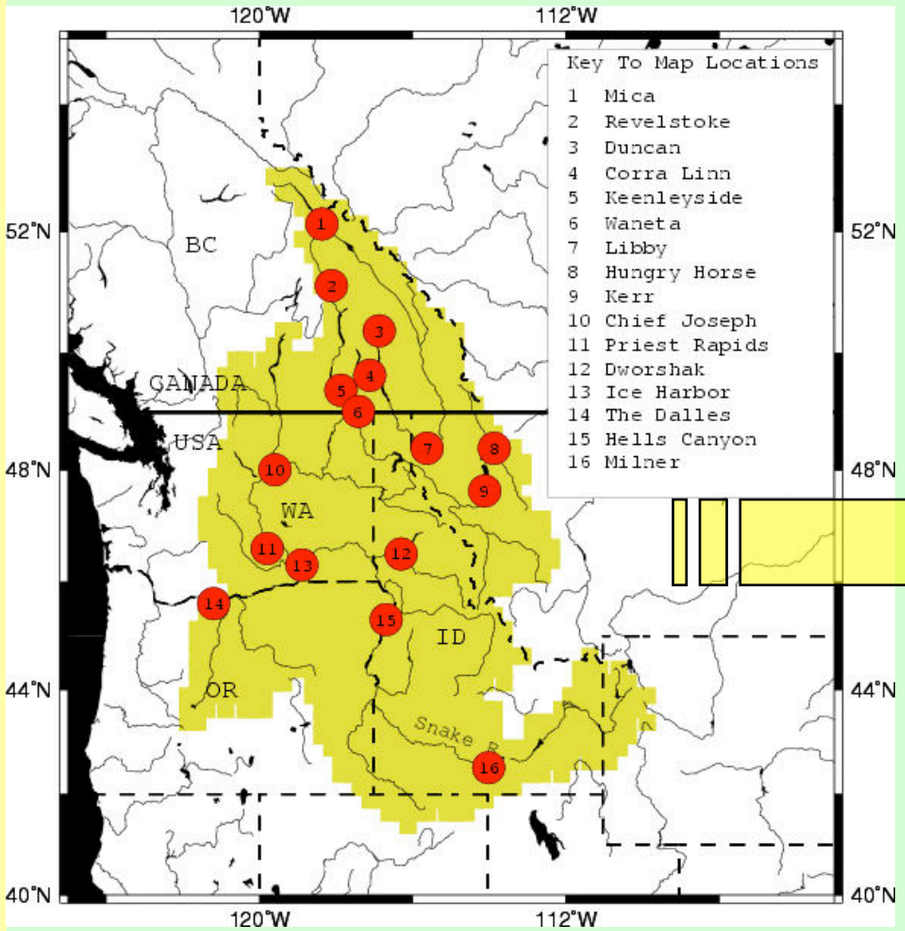
# Planning for climate change: water resources in the Columbia basin

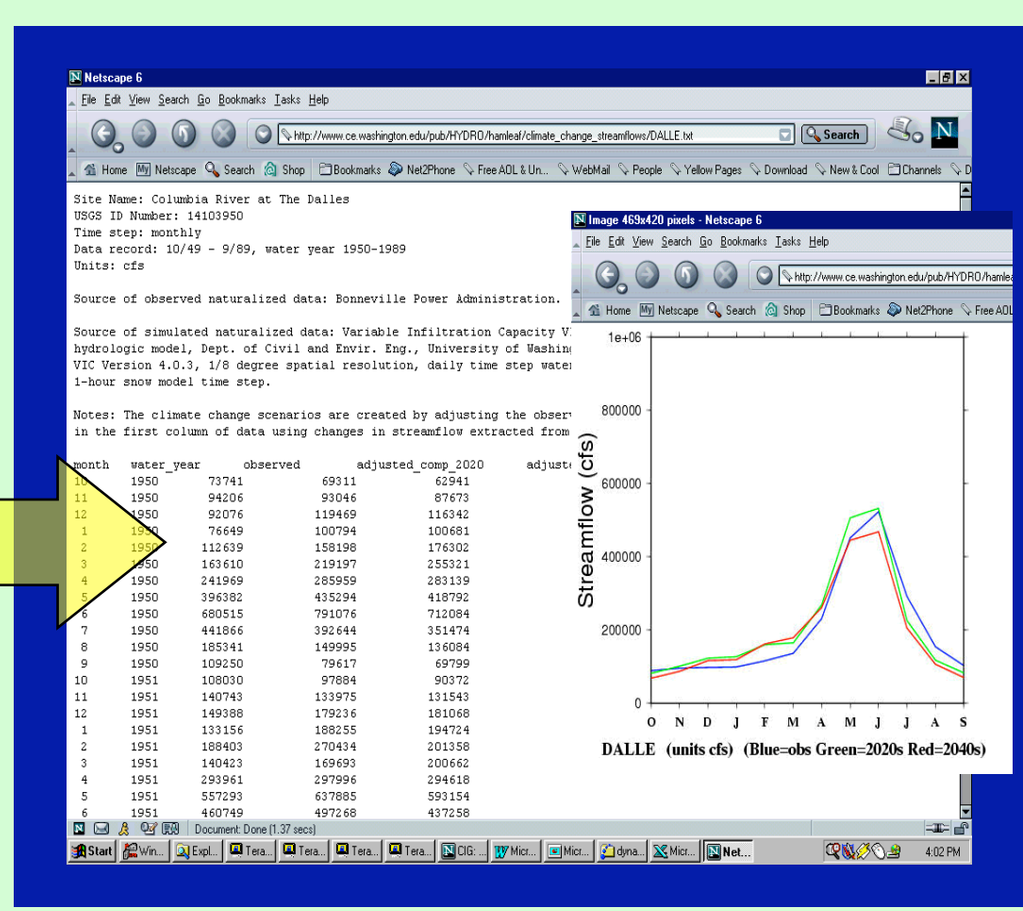
Water policy workshops have highlighted the need to inject climate change information into existing river basin planning activities and to provide free access to streamflow scenarios.

Partners:

Northwest Power and Conservation Council

Idaho Dept of Water Resources




www.cses.washington.edu/cig planning tools

# Conclusions

- Human influence on climate and water resources of the Northwest is emerging
- Temperature and precipitation changes have different effects

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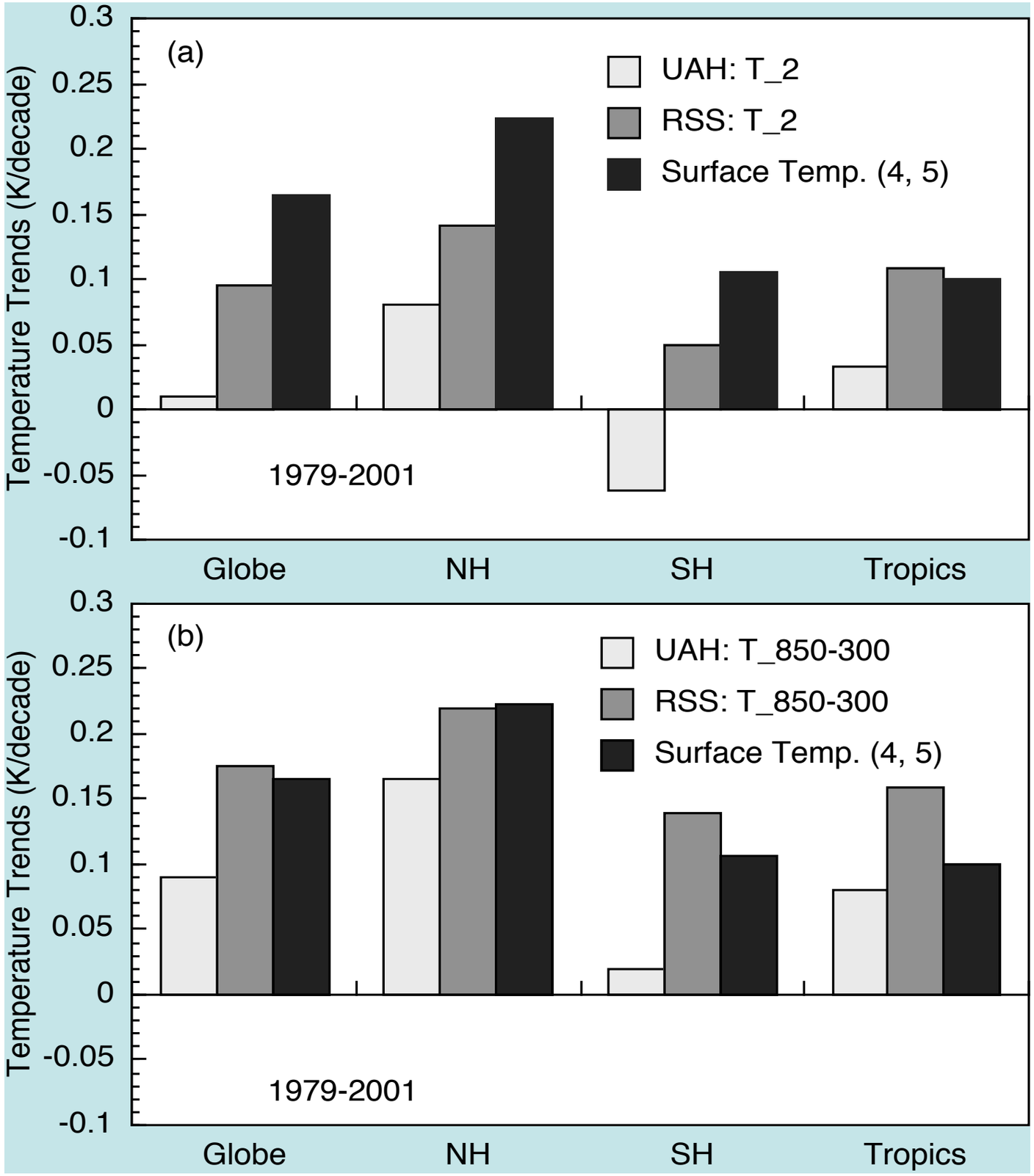
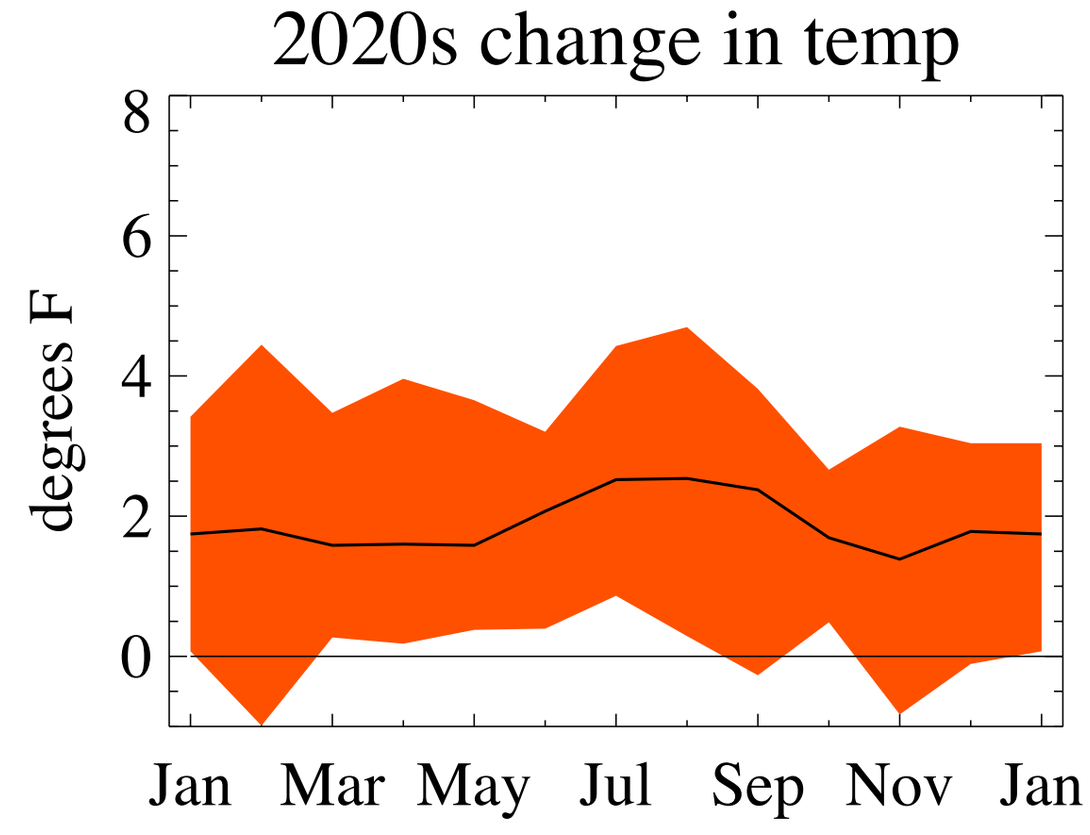
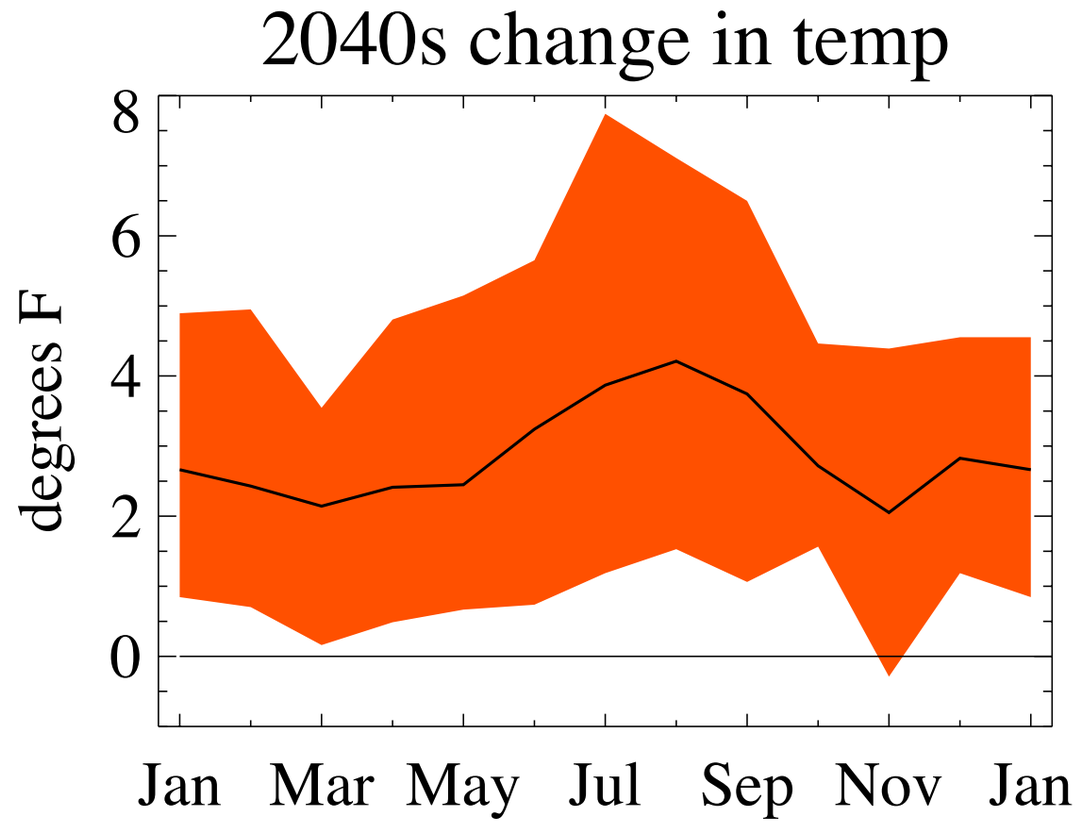
www.cses.washington.edu/cig planning tools

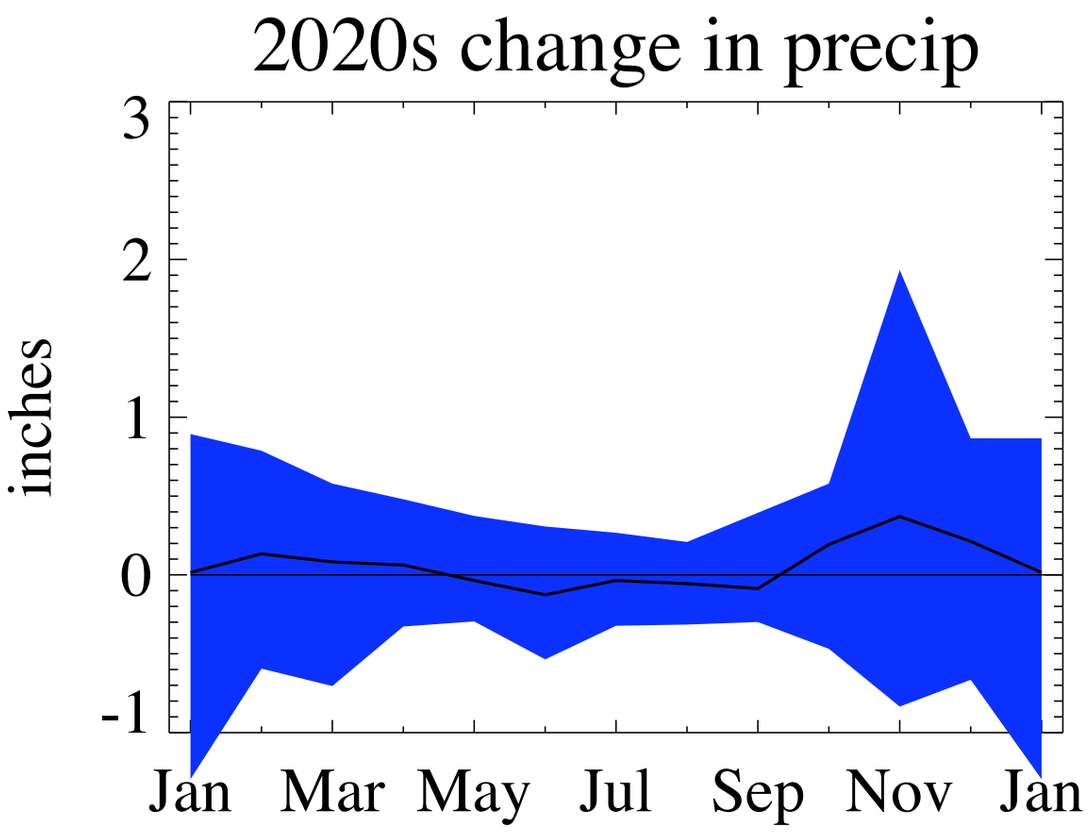
# Temperature Trends

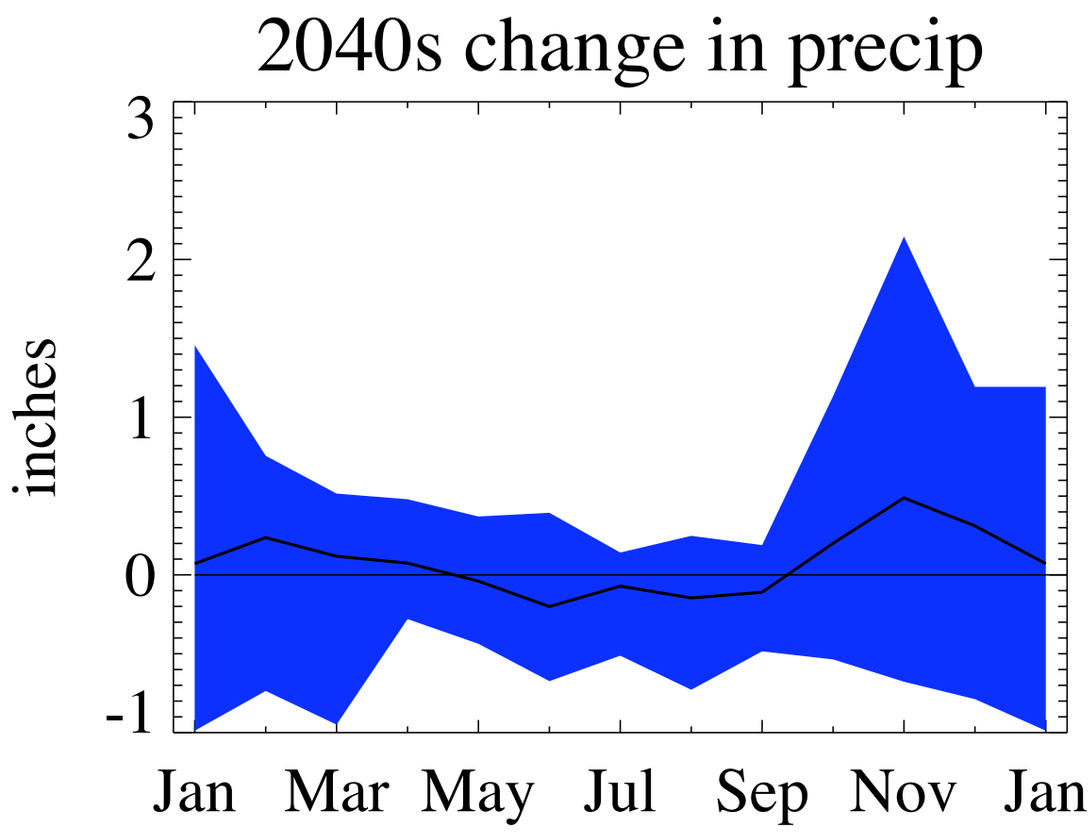



Fu et al. (2004)


2020s change in temp
degrees F
8
6
4
2
0
Jan
Mar
May
Jul
Sep
Nov
Jan


2040s change in temp
degrees F
8
6
4
2
0
Jan
Mar
May
Jul
Sep
Nov
Jan


2020s change in precip
inches
3
2
1
0
-1
Jan
Mar
May
Jul
Sep
Nov
Jan


2040s change in precip
inches
3
2
1
0
-1
Jan
Mar
May
Jul
Sep
Nov
Jan

# Change in temperature

IPSL
Miroc
CCSM
HadCM3
CGCM
Echam5
CNRM
CSIRO
PCM
GISS

6
4
2
0
-2

°C

1950
2000
2050
2100

Observed 20th century variability

+0.7°C
0.4-1.0°C

+1.7°C
0.9-2.4°C

+3.2°C
1.2-5.5°C

Pacific Northwest

# Change in precipitation

25
20
15
10
5
0
-5
%

CSIRO
IPSL
CGCM
Echam5
CNRM
GISS
Miroc
CCSM
PCM
HadCM3

Observed 20th century variability

+1%
+2%
+6%

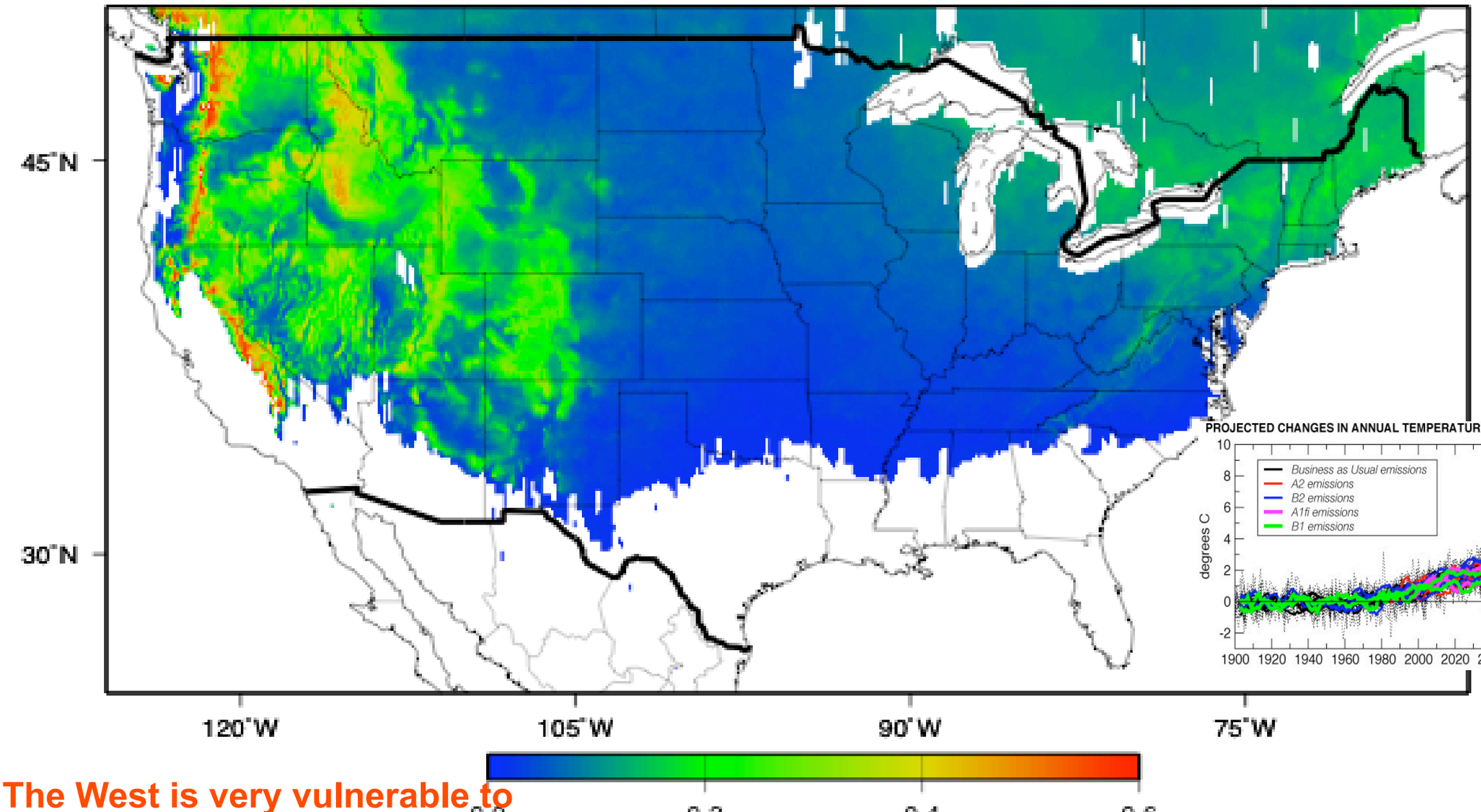
-1 to +3%
-1 to +9%
-2 to +21%

1950
2000
2050
2100

Pacific Northwest

**Based on 1950-1999 VIC 1/8 degree input data. Preliminary analysis.**

FRACTION OF ANNUAL PRECIPITATION FALLING
IN THE DAILY TEMPERATURE RANGE: -6C < Tavg < 0C
[from 1950-1999 VIC 1/8-degree INPUT DATA]





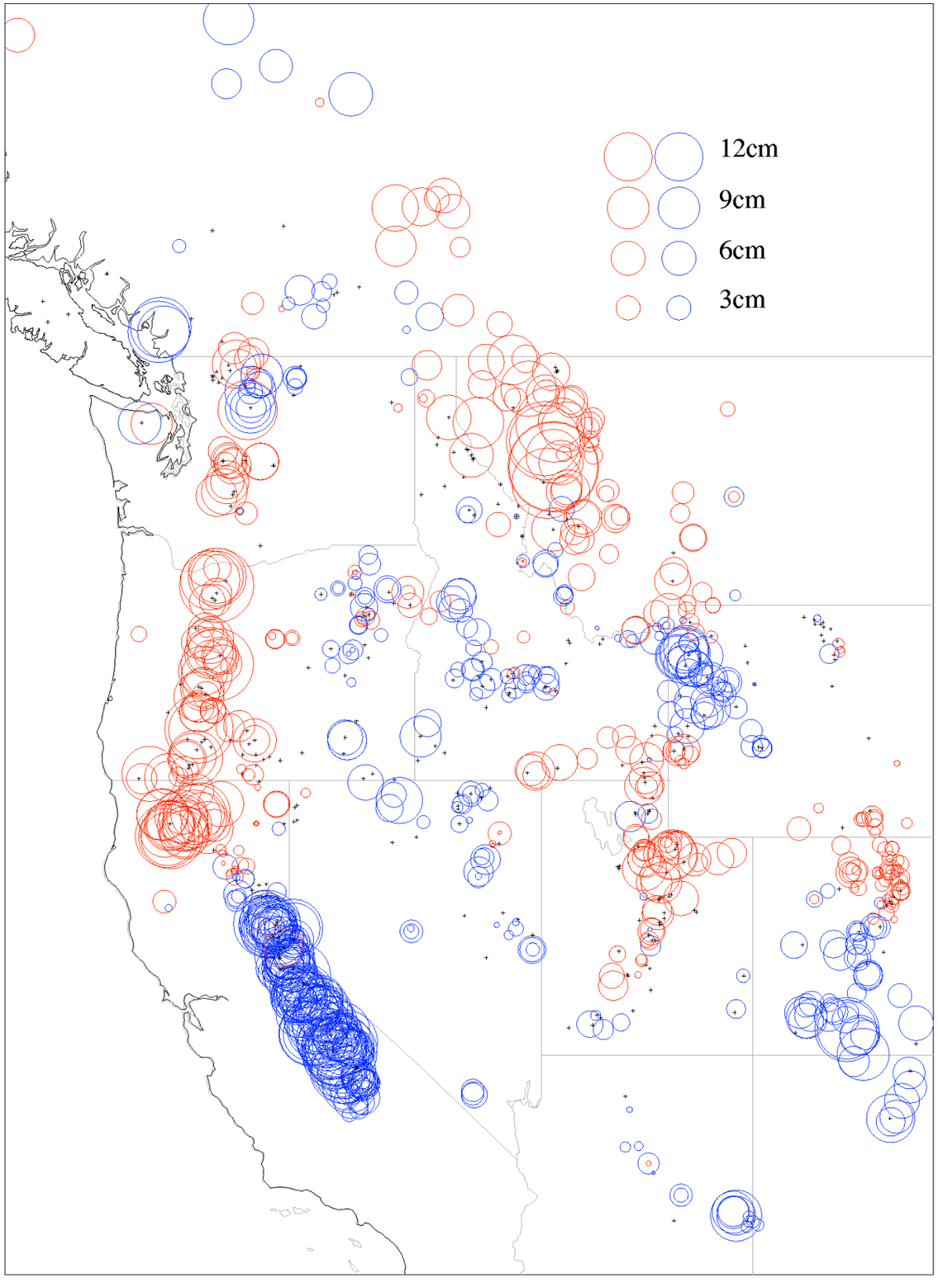


**The West is very vulnerable to changes from snow to rain, with modest winter temperature rises of only 2-4 F.**

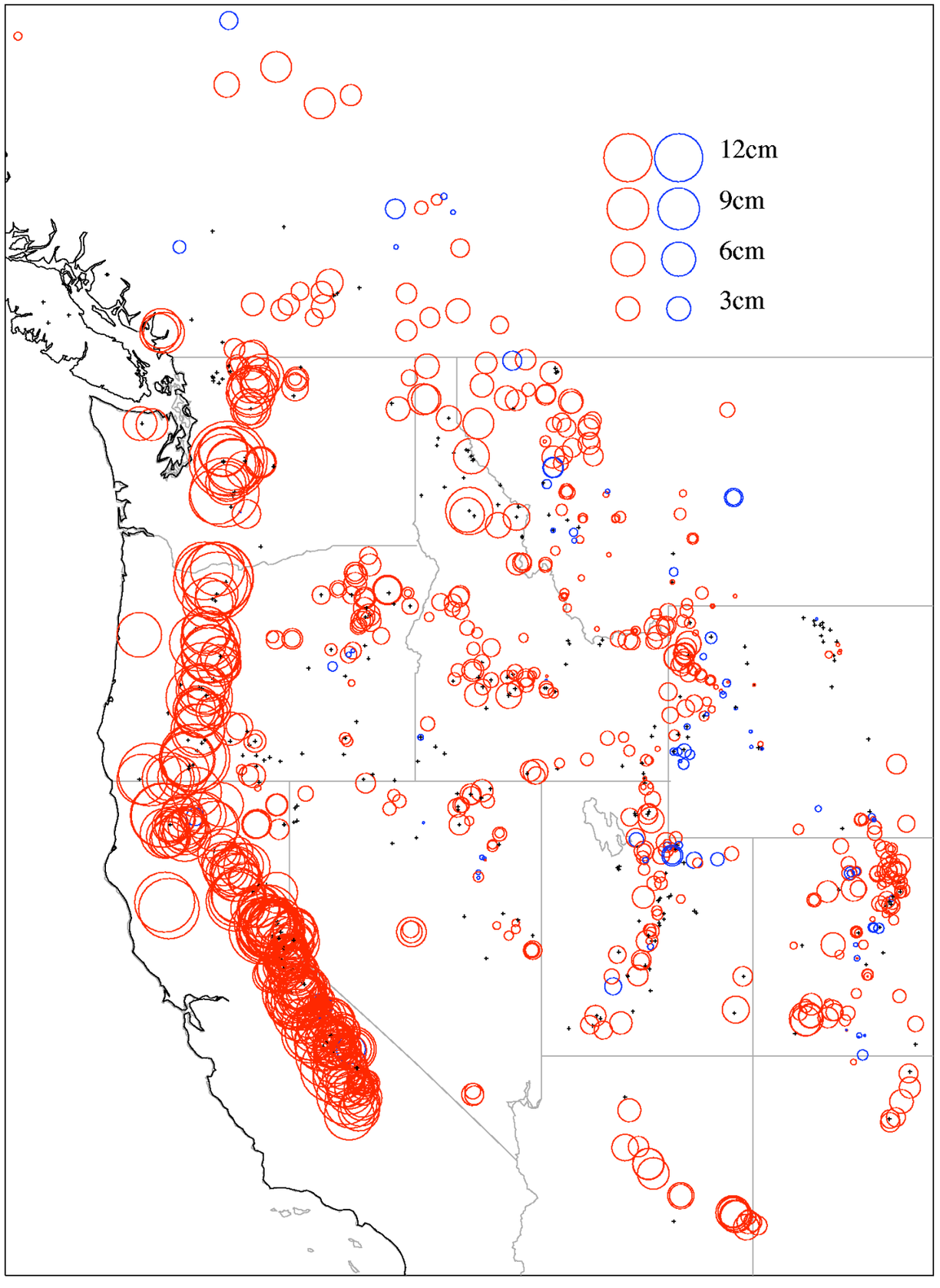
**Preliminary unpublished figure courtesy of Mike Dettinger, Scripps.**

# April 1 SWE trends, 1950-2002

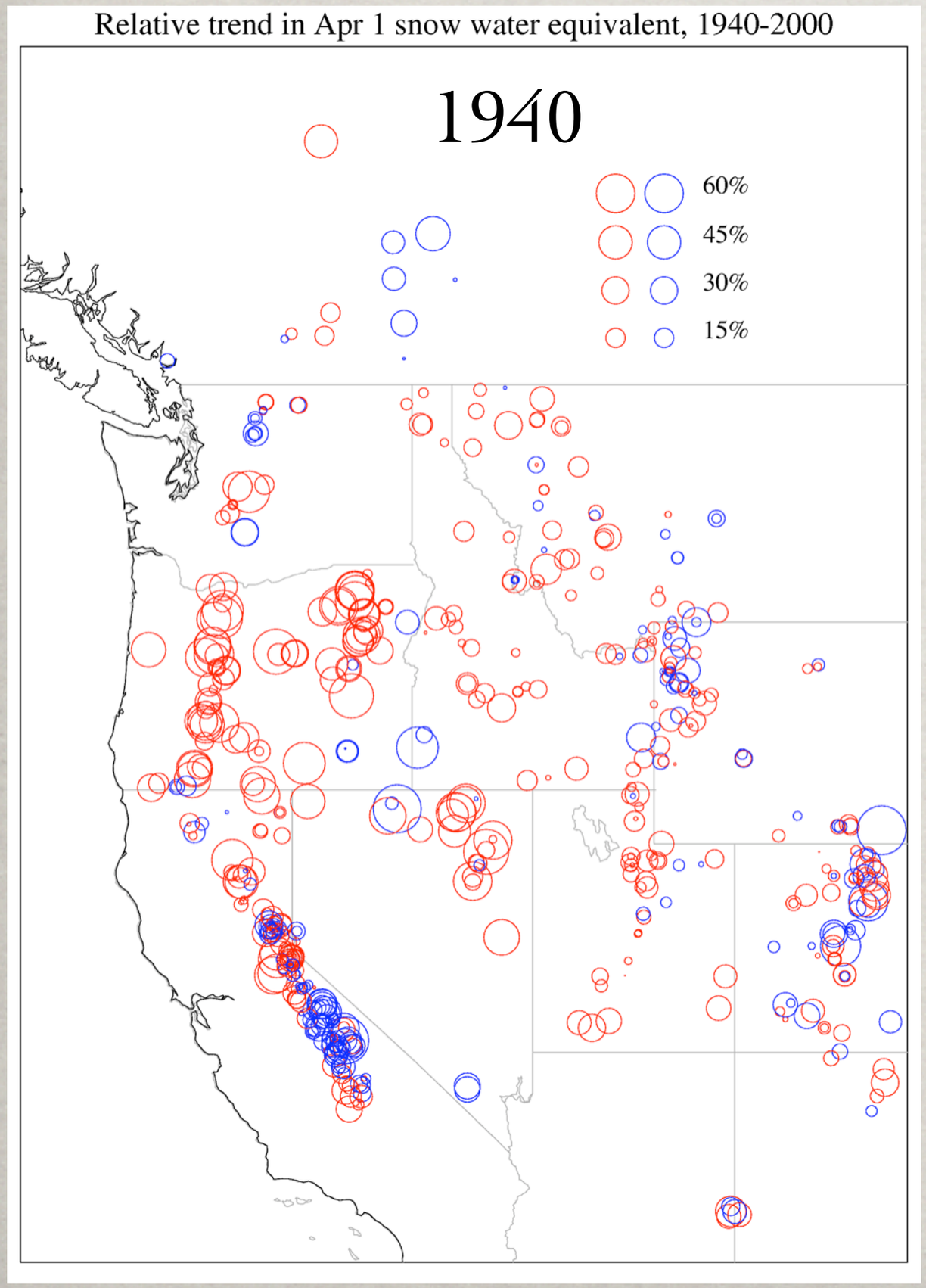
$a_P\langle P\rangle$ SWE trends from precipitation

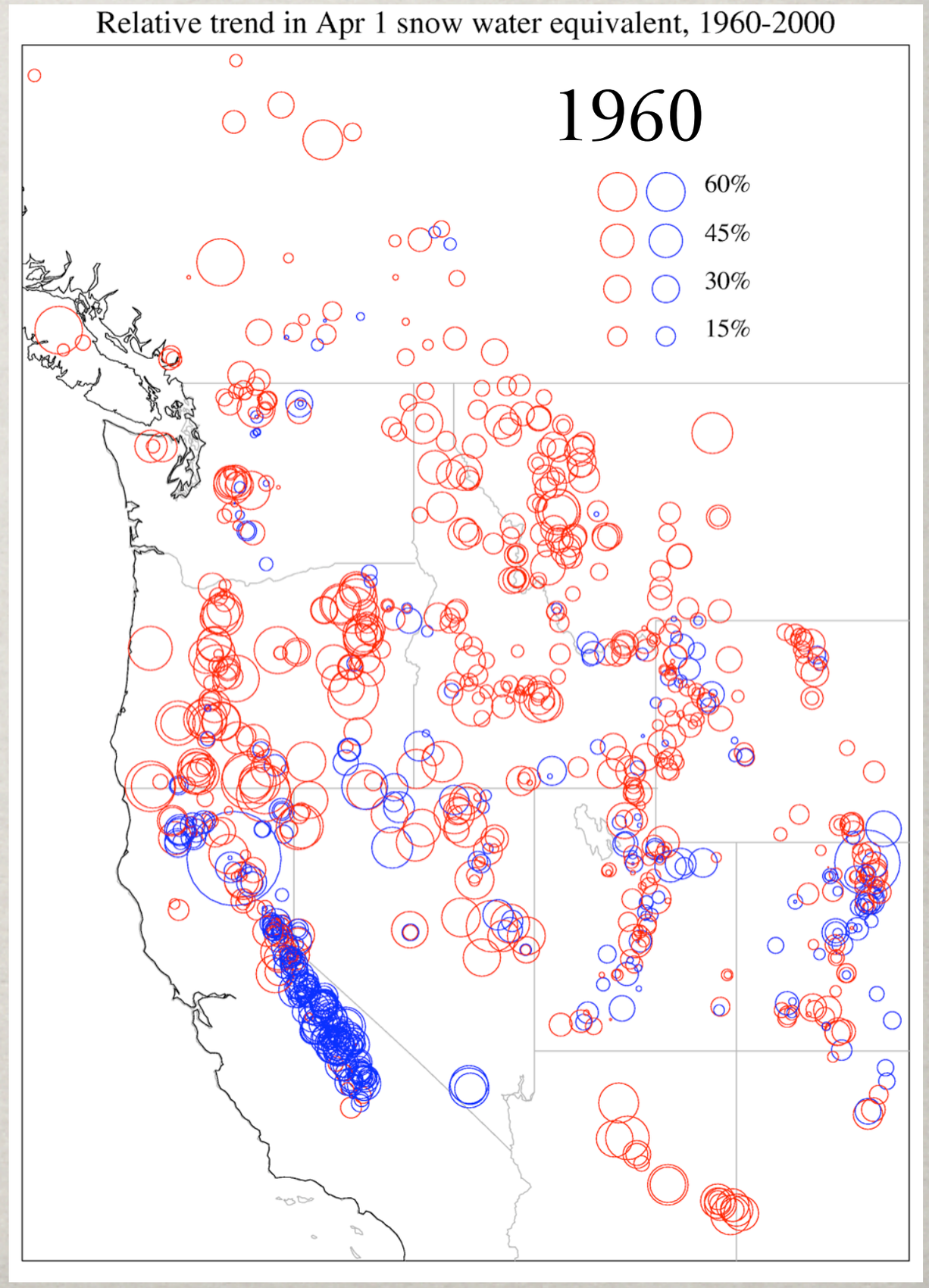



$a_T\langle T\rangle$ SWE trends from temperature



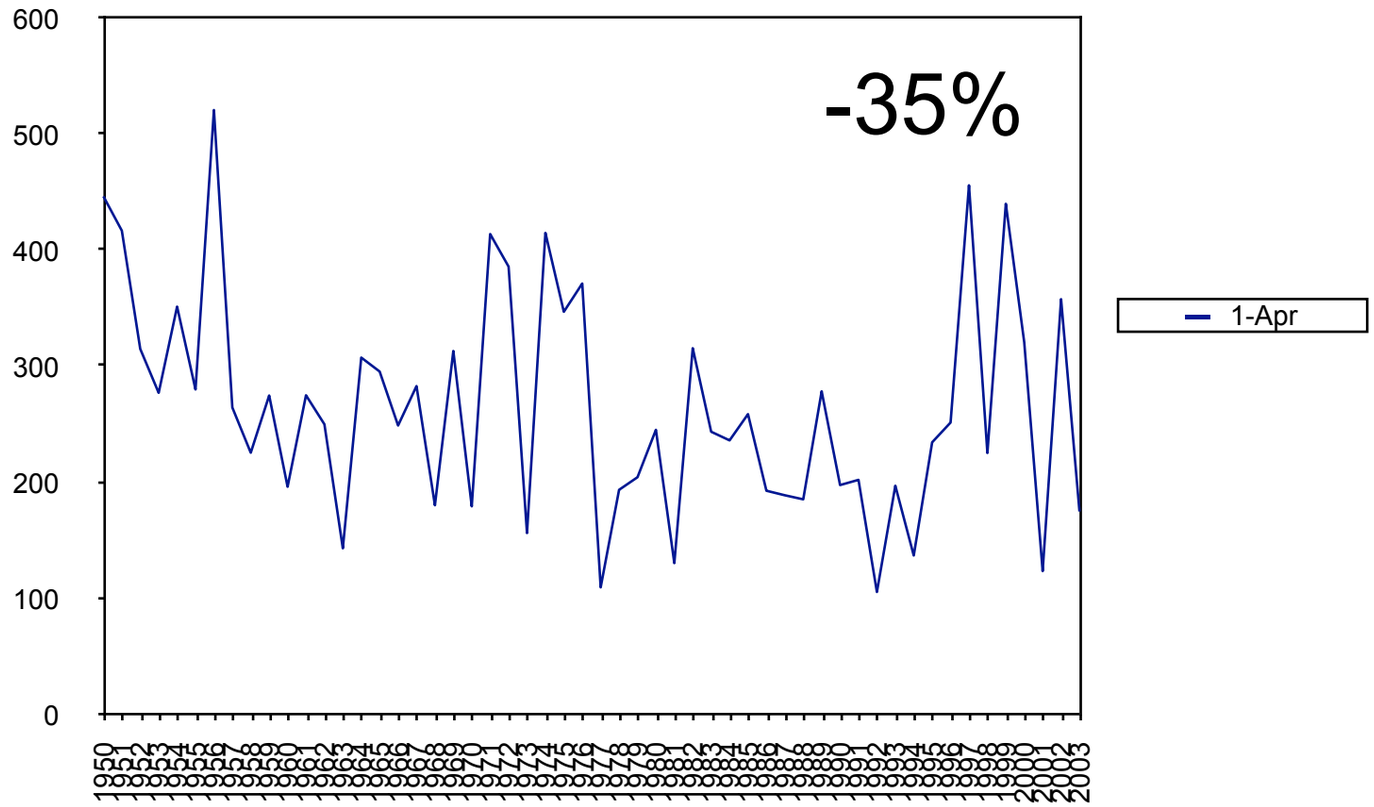
# Different starting years



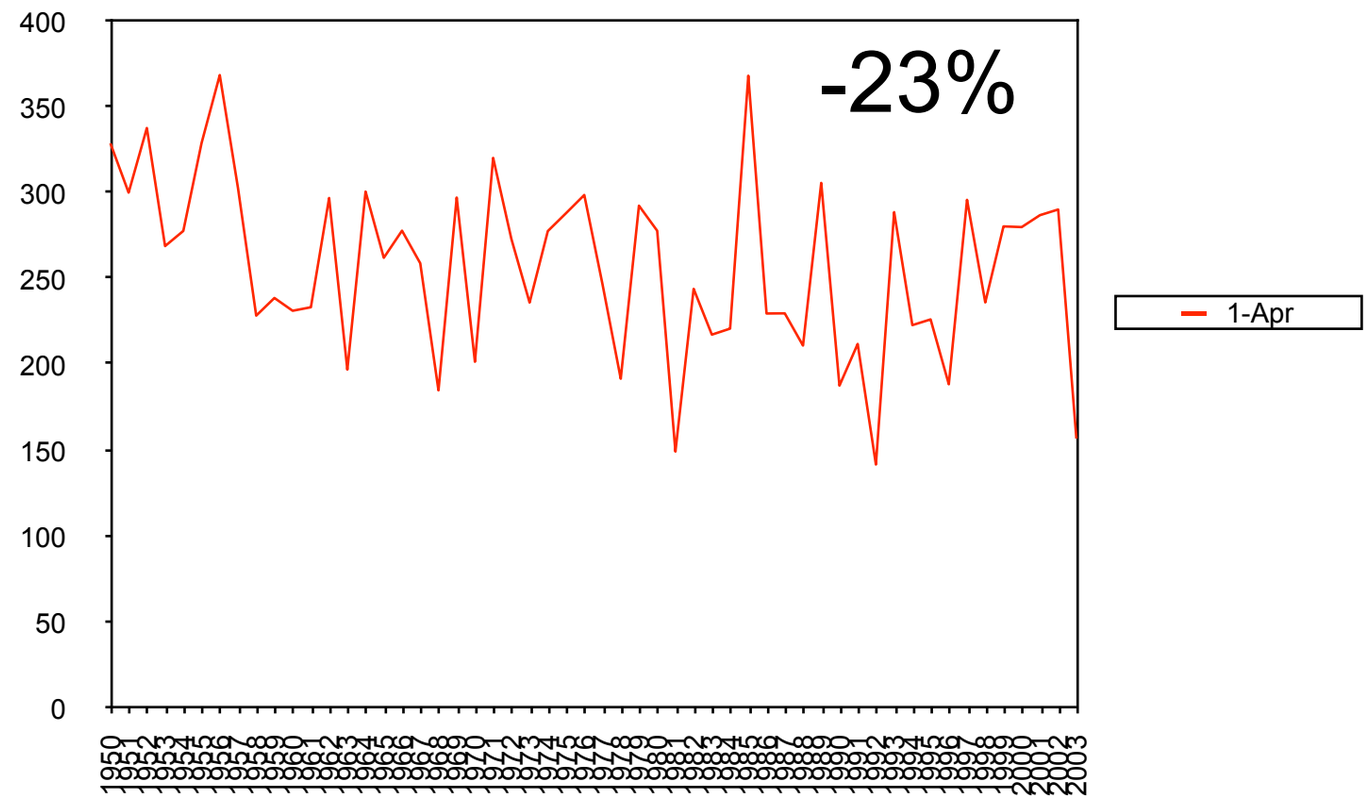



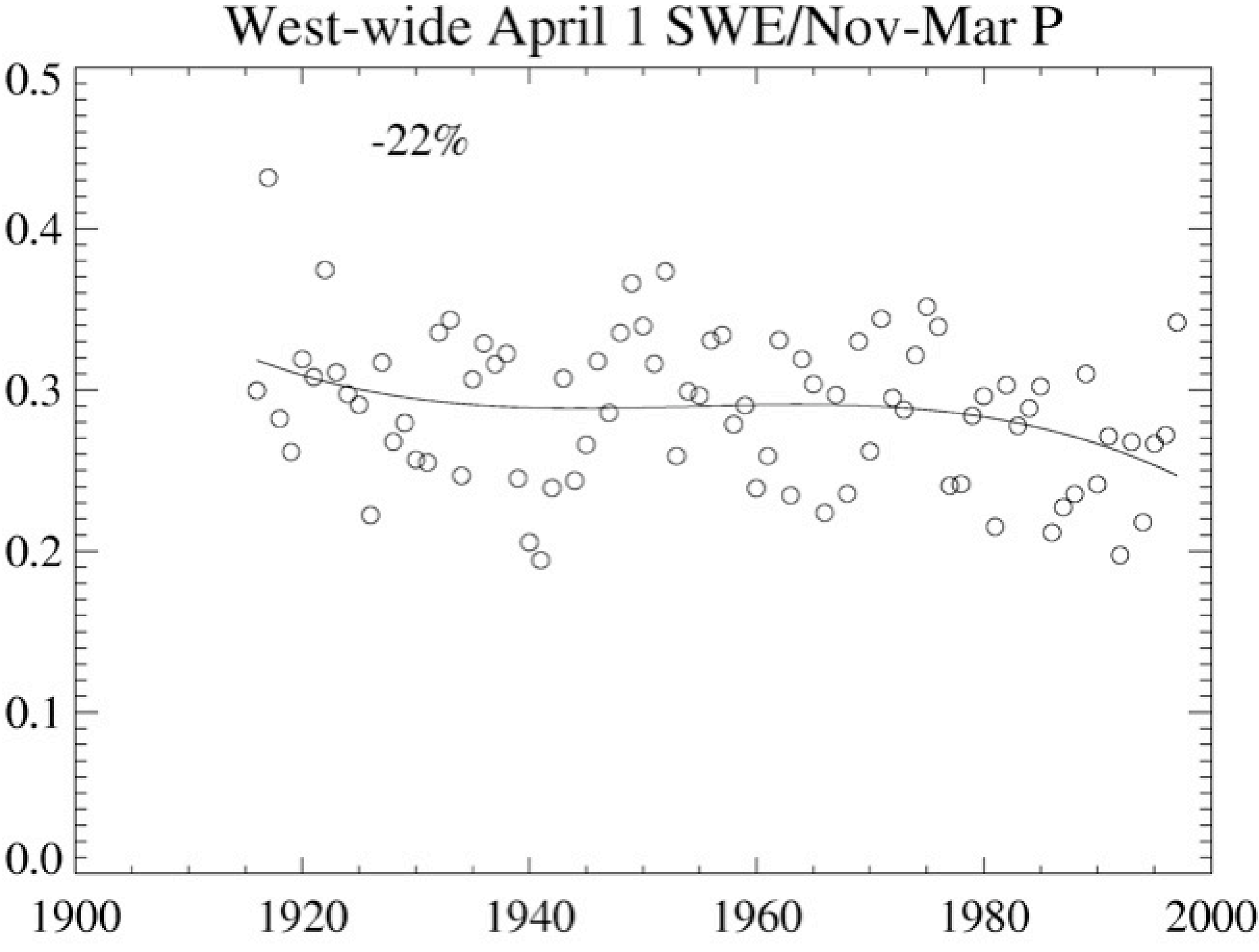
# Trends in April 1 SWE for the WA and OR Cascades 1950-2003

Effects of Temperature And Precipitation

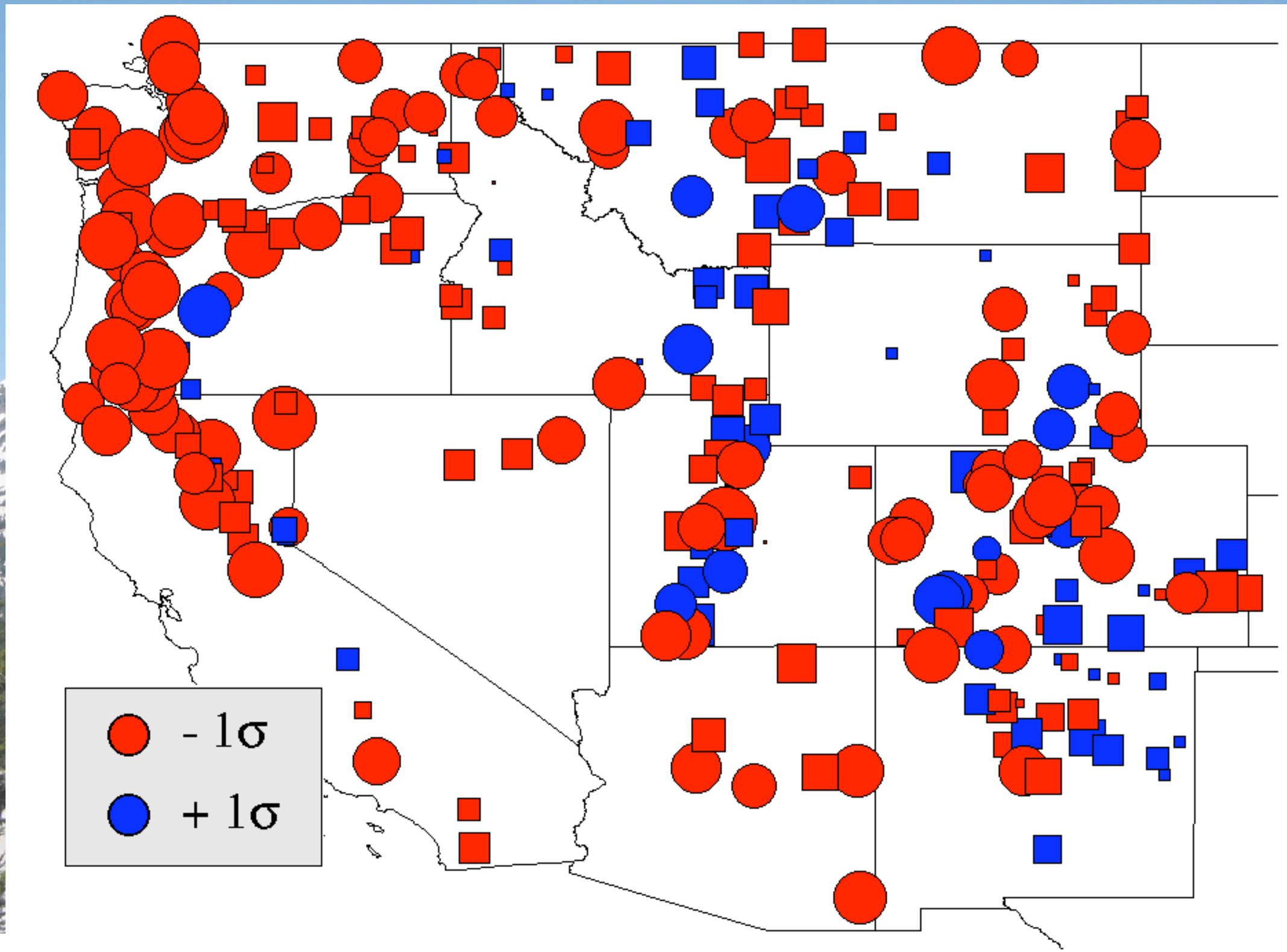


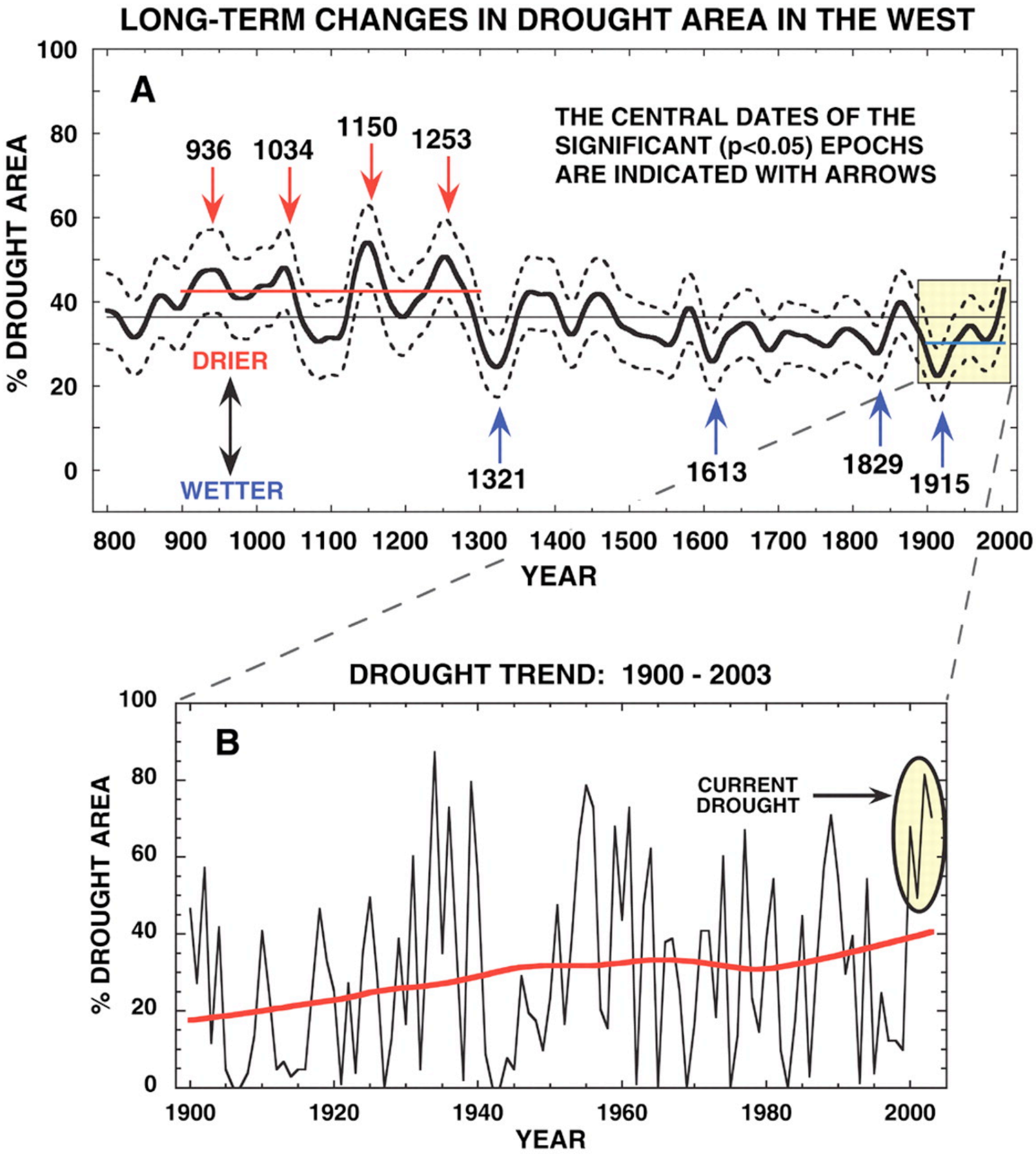

Effects of Temperature Alone




West-wide April 1 SWE/Nov-Mar P
-22%
0.5
0.4
0.3
0.2
0.1
0.0
1900
1920
1940
1960
1980
2000

# Trend in SFE/P, 1949-2004






60 yr smoothed reconstruction Western US

Cook et al Science Nov 2004