Implications of climate change for the Northern Rocky Mountains

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Intergovernmental Panel on Climate Change

Governments require information on climate change for negotiations

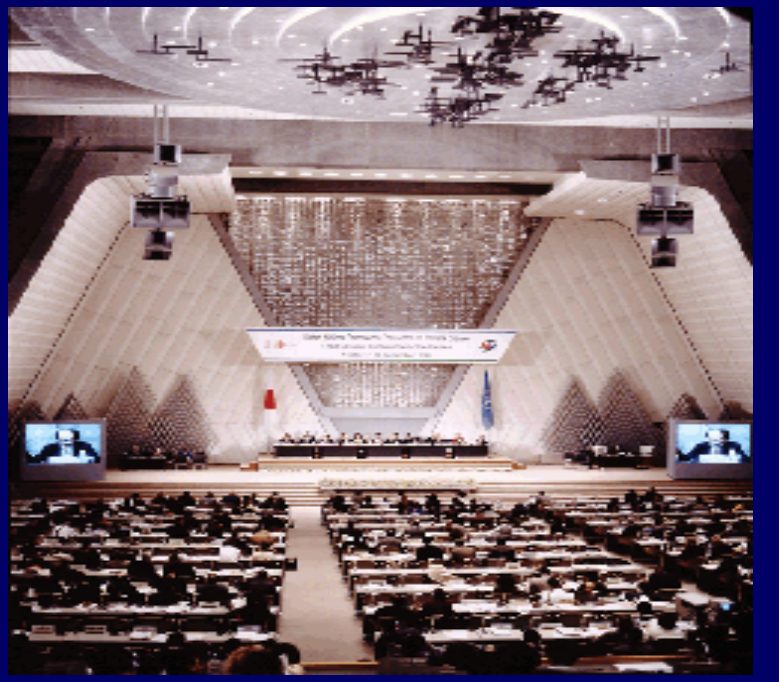
The IPCC formed in 1988 under auspices of the United Nations

Function is to provide assessments of the science of climate change

Scientific community contributes widely and on a voluntary basis

75% of the authors in WG1 IPCC (2007) did not work on WG1 IPCC (2001)

Substance of IPCC WG1 report in the hands of scientists



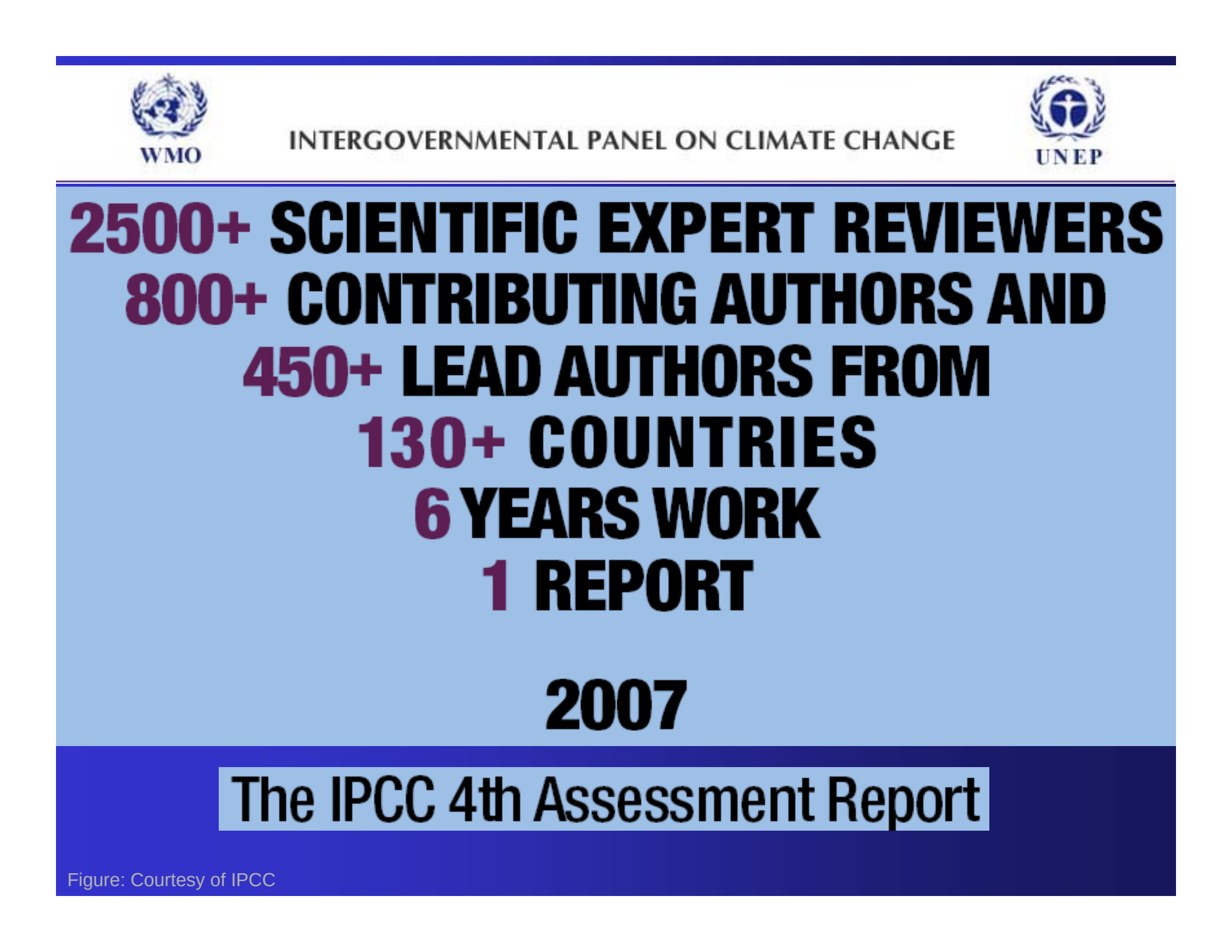


Figure: Courtesy of IPCC

MAUNA LOA OBSERVATORY, HAWAII
MONTHLY AVERAGE CARBON DIOXIDE CONCENTRATION
MLO-145

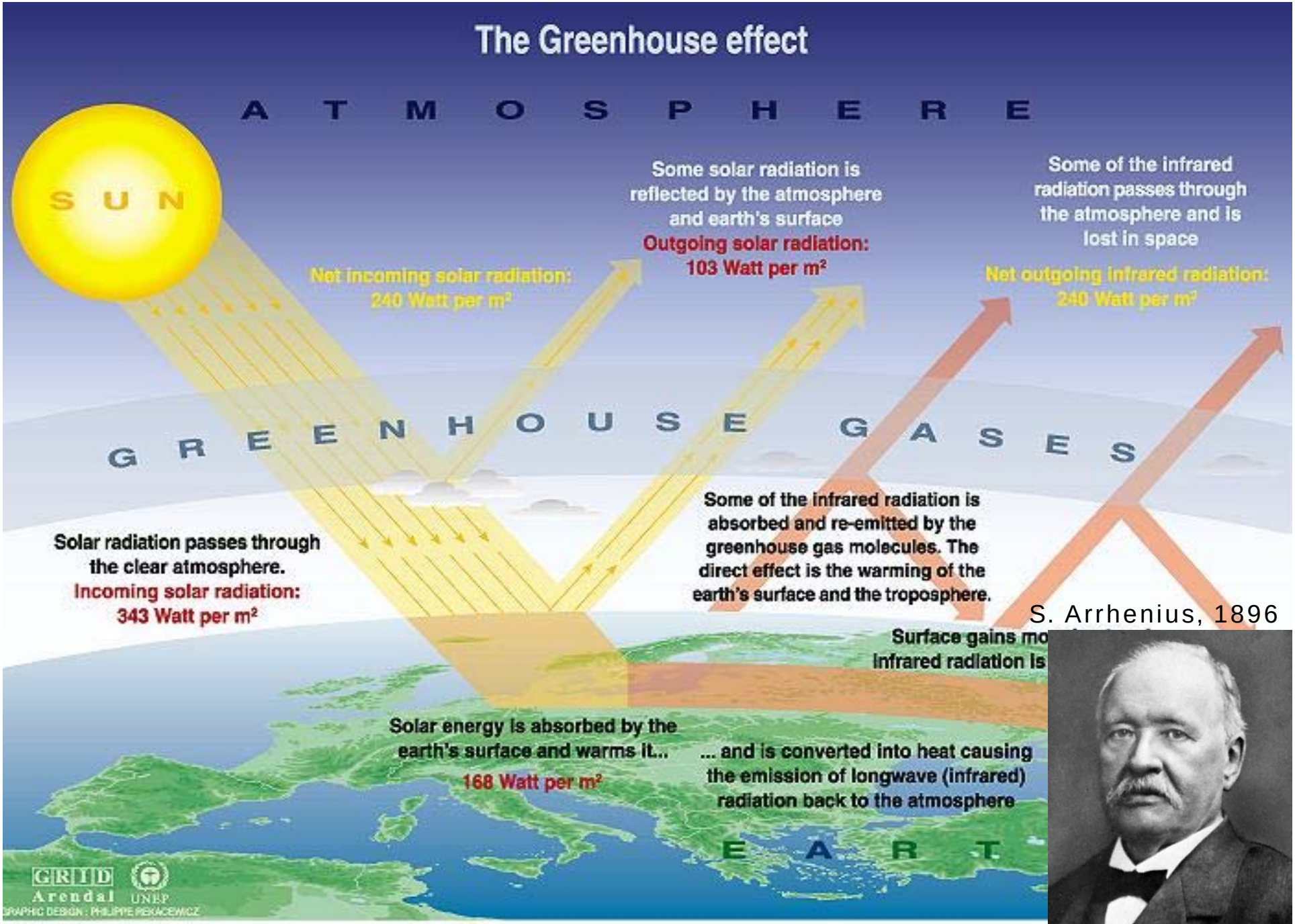
CO2 CONCENTRATION, (PPM)

390
385
380
375
370
365
360
355
350
345
340
335
330
325
320
315
310

1958 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 00 02 04

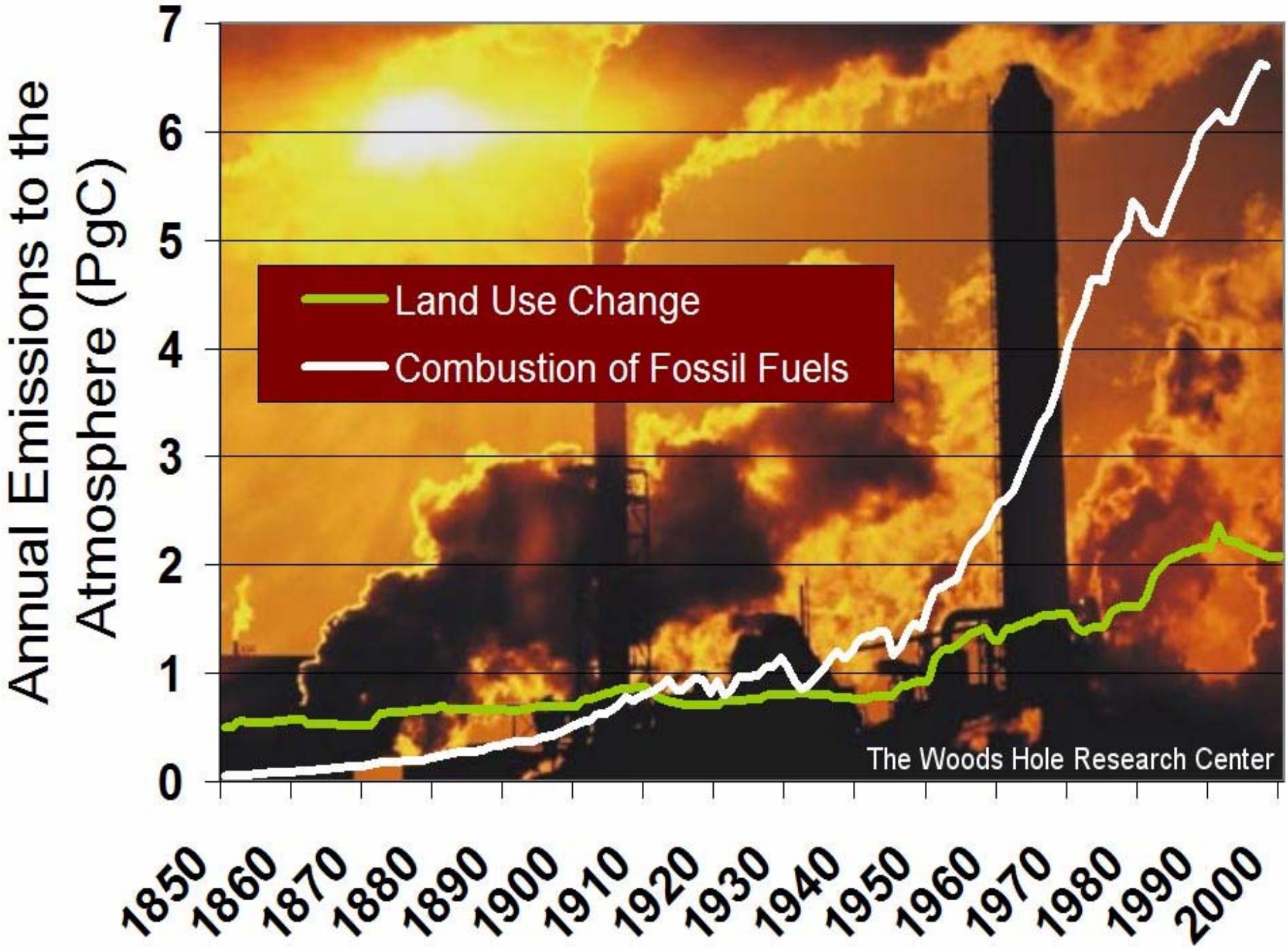
YEAR

19-May-05



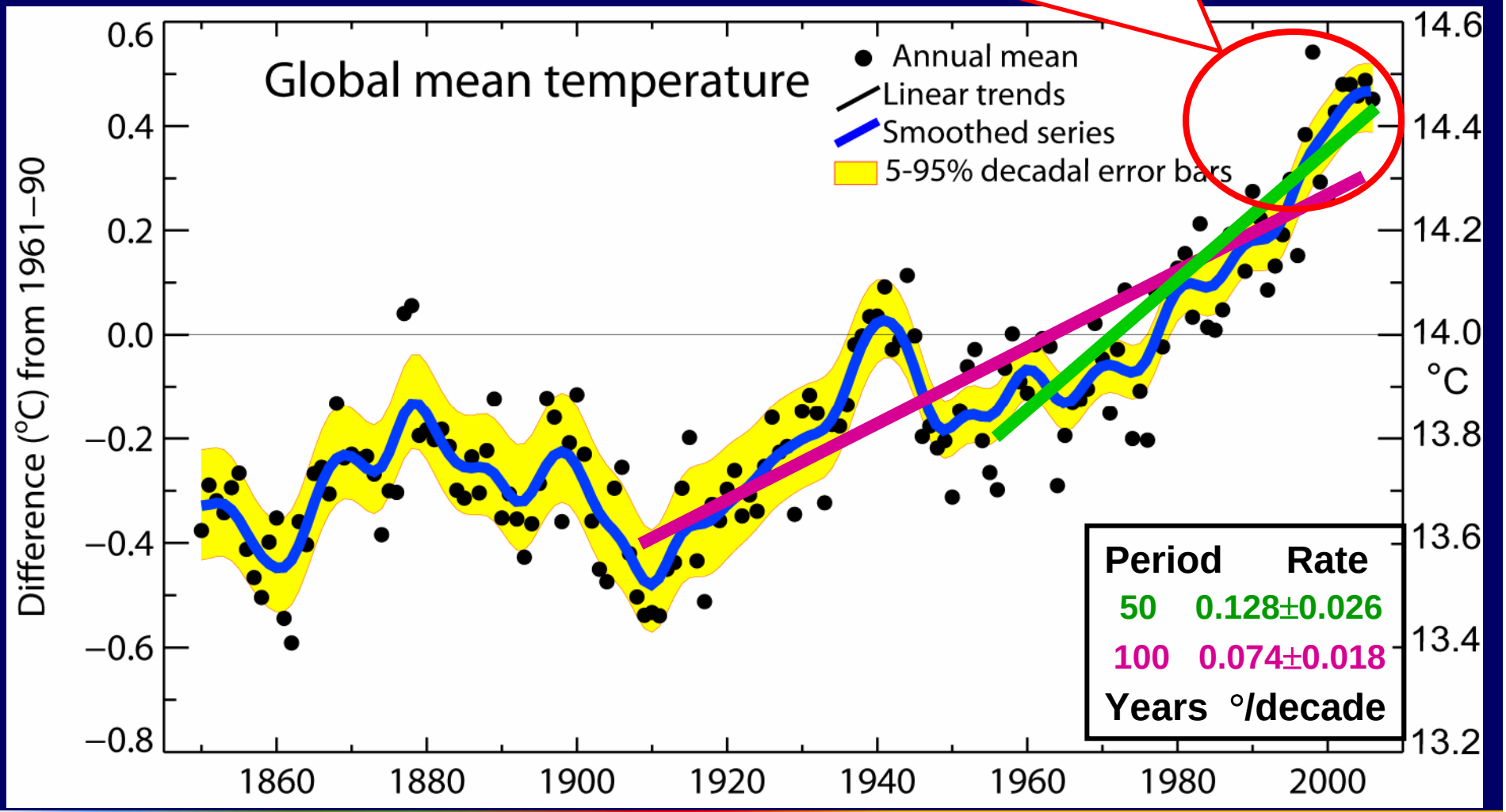
S. Arrhenius, 1896

Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EP
1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO

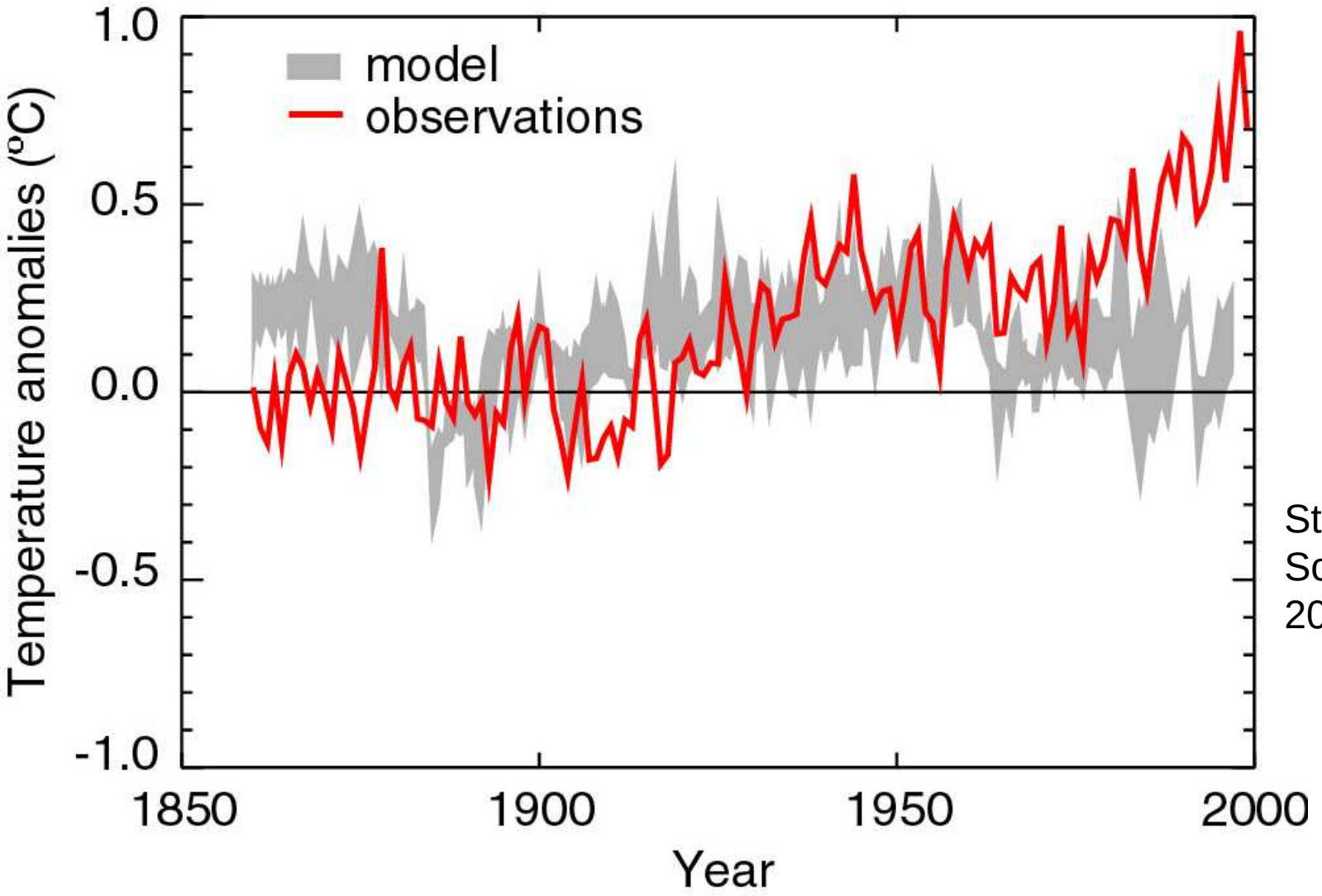

Annual Emissions to the Atmosphere (PgC)
7
6
5
4
3
2
1
0
Land Use Change
Combustion of Fossil Fuels
The Woods Hole Research Center
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

Global mean temperat

Warmest 12 years:
1998,2005,2003,2002,2004,2006,
2001,1997,1995,1999,1990,2000

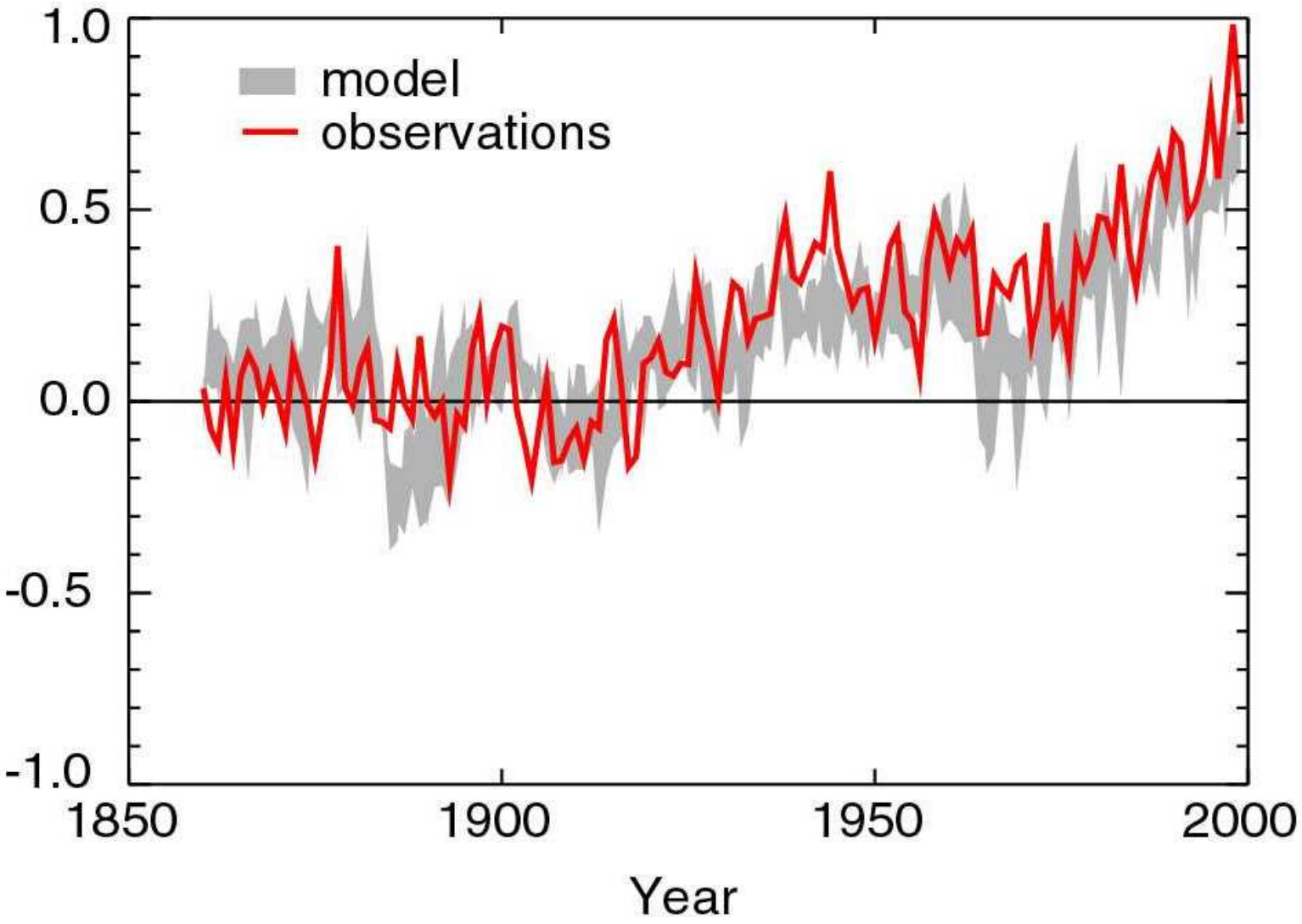


“Simulations of the response to natural forcings alone … do not explain the warming in the second half of the century” SPM

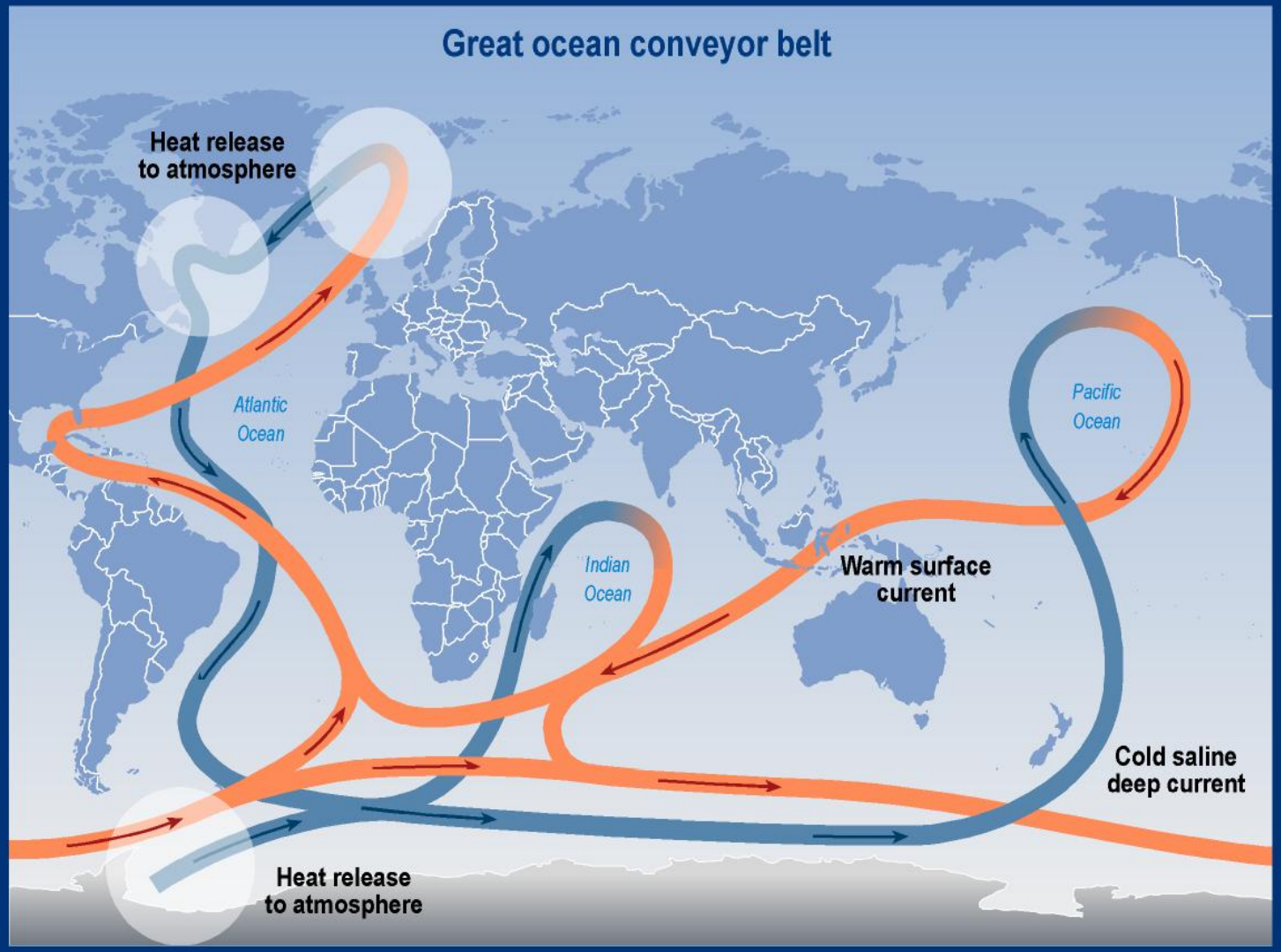


Stott et al, Science 2000

“..model estimates that take into account both greenhouse gases and sulphate aerosols are consistent with observations over this period” SPM



Stott et al, Science 2000



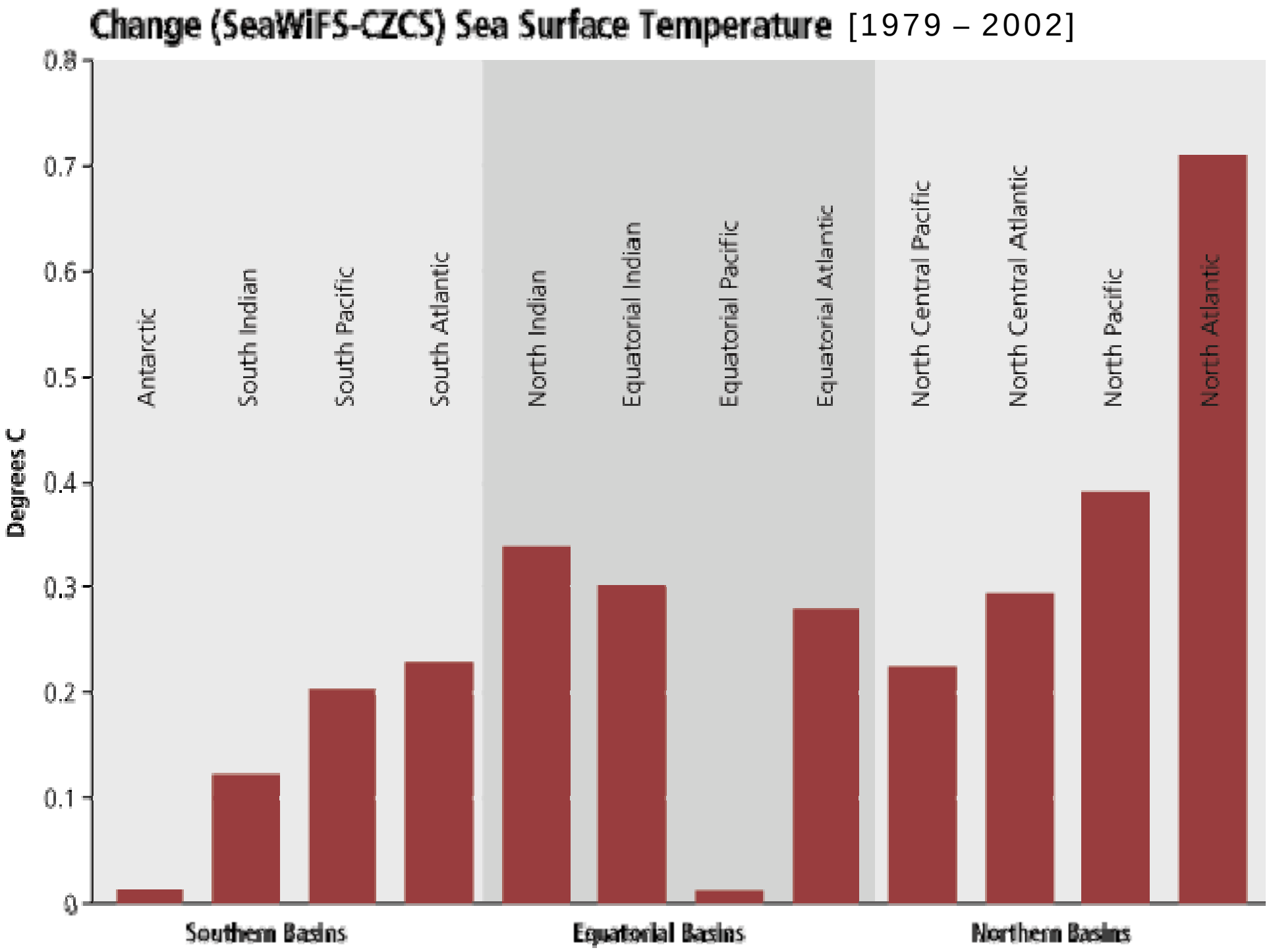
SYR - FIGURE 4-2

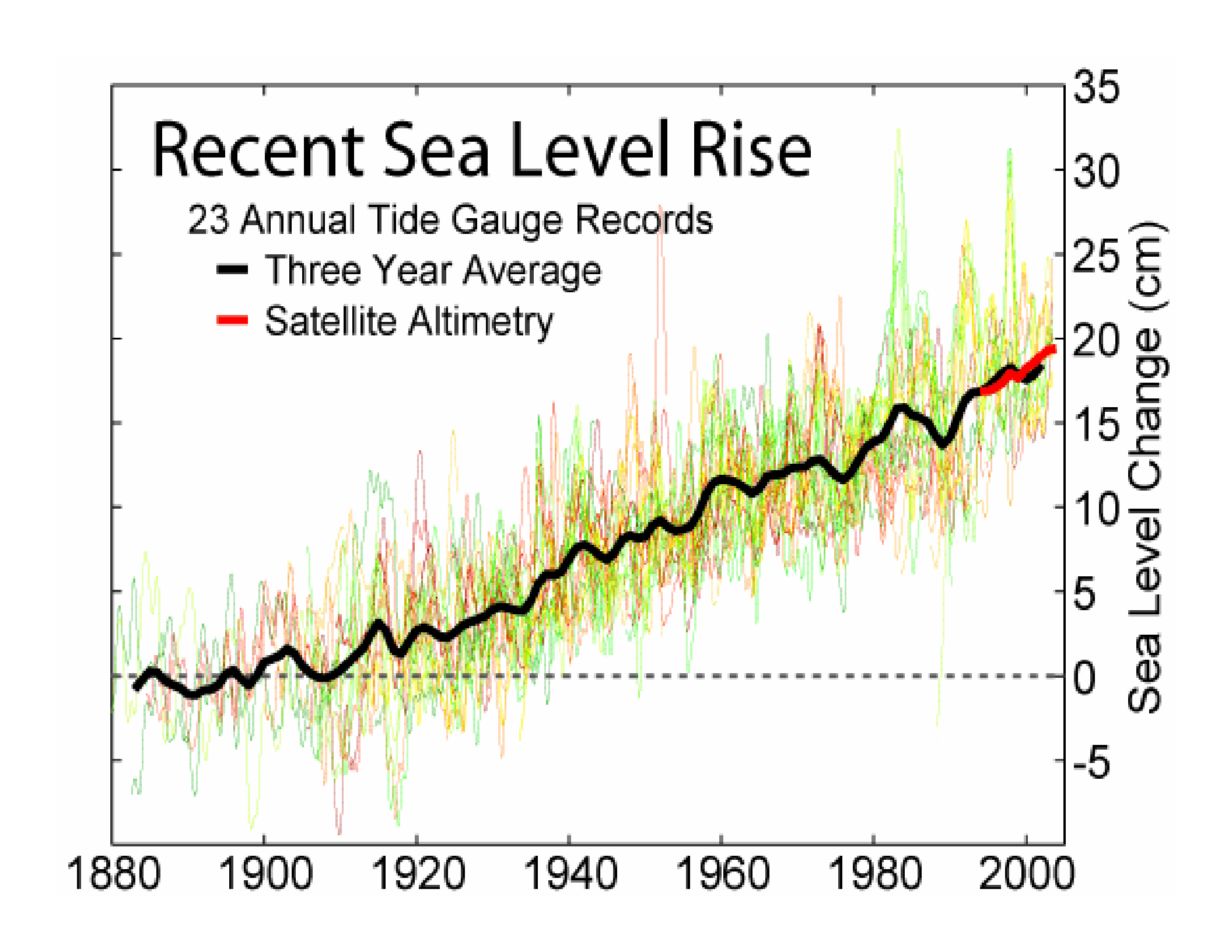
Comparison of the heat balance of the climate system

Levitus et al (2001). Science Vol. 292, pp. 268.

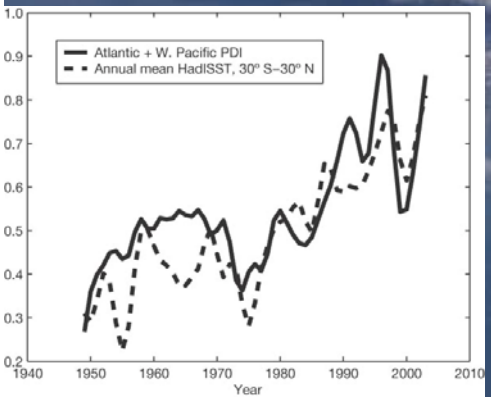
Component of the climate system and source of data	Time period of change	Observed or estimated change	Heat content increase or total heat of fusion	%
World ocean	1955-1996	Observed temperature increase	18.2×10^{22} J	90
Global atmosphere	1955-1996	Observed temperature increase	6.6×10^{21} J	3
Decrease in the mass of continental glaciers	1955-1996	-	8.1×10^{21} J	4
Decrease in Antarctic sea ice extent	1950s-1970s	Estimated 311-km reduction in sea ice edge	3.2×10^{21} J	1
Mountain glacier decrease	1961-1997	3.7×10^{3} km decrease in mountain glacier ice volume	1.1×10^{21} J	.5
Decrease in Northern Hemisphere sea ice extent	1978-1996	Areal change based on satellite measurements	4.6×10^{19} J	.02
Decrease in Arctic perennial sea ice volume	1950s-1990s	40% decrease in sea ice thickness	2.4×10^{19} J	.01

90%

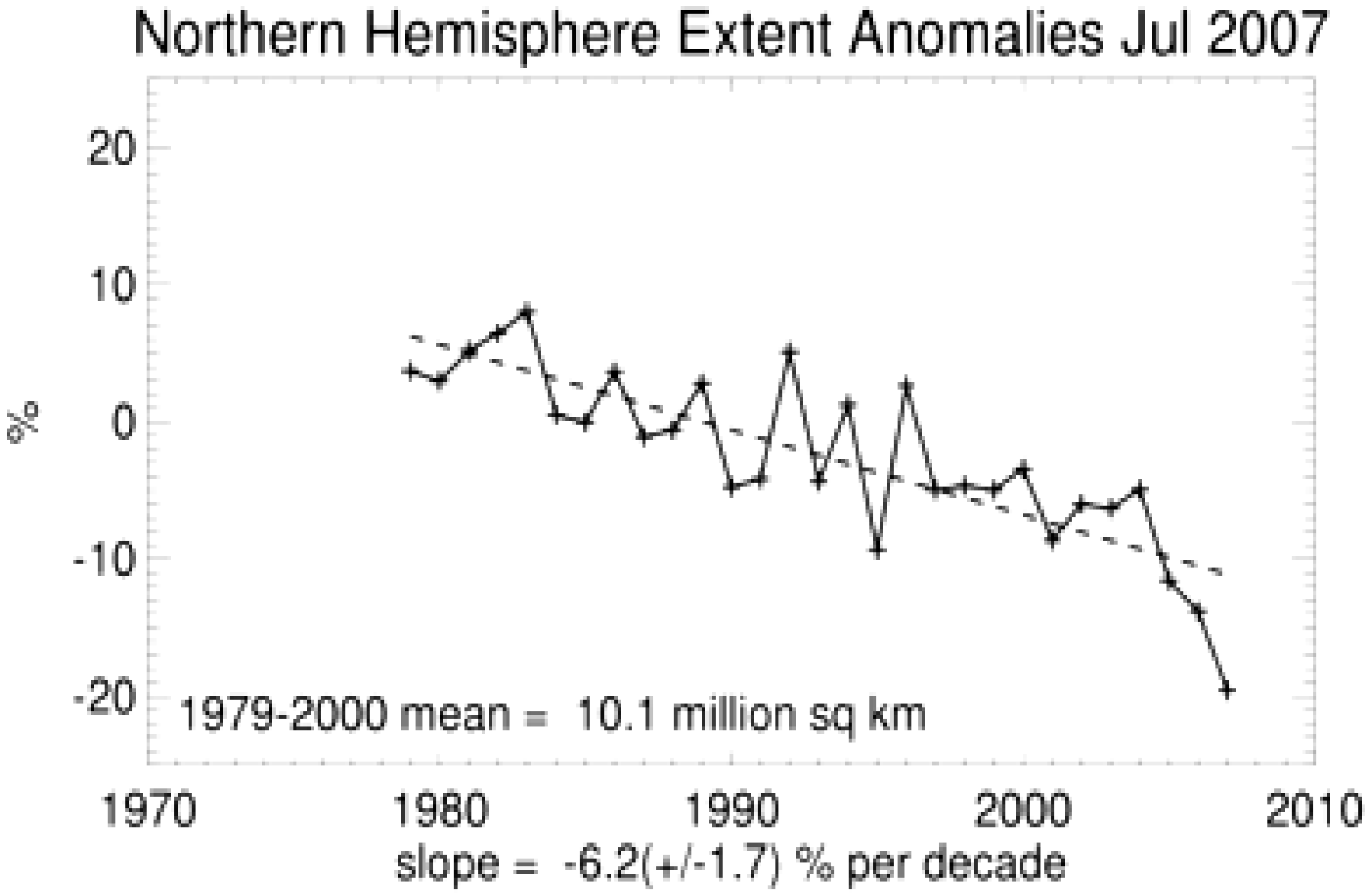

Change (SeaWiFS-CZCS) Sea Surface Temperature [1979 – 2002]
Degrees C
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Antarctic
South Indian
South Pacific
South Atlantic
North Indian
Equatorial Indian
Equatorial Pacific
Equatorial Atlantic
North Central Pacific
North Central Atlantic
North Pacific
North Atlantic
Southern Basins
Equatorial Basins
Northern Basins


Recent Sea Level Rise
23 Annual Tide Gauge Records
Three Year Average
Satellite Altimetry
35
30
25
20
15
10
5
0
-5
Sea Level Change (cm)
1880
1900
1920
1940
1960
1980
2000

Increased Hurricane Activity



Arctic sea ice gets thinner



0.6m km2/decade
Montana = 0.4m km2

Source: Nat Snow&Ice Data Center

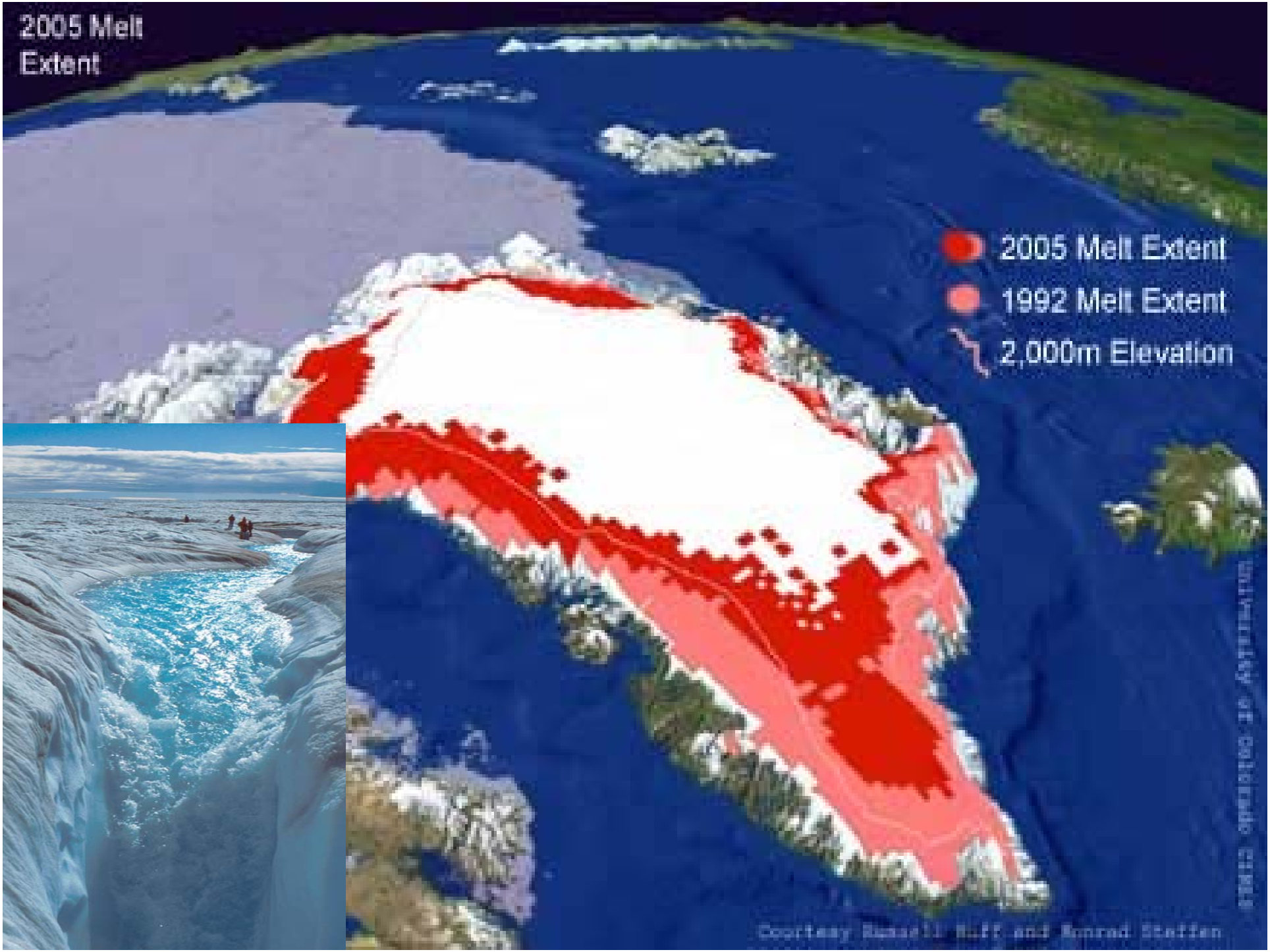
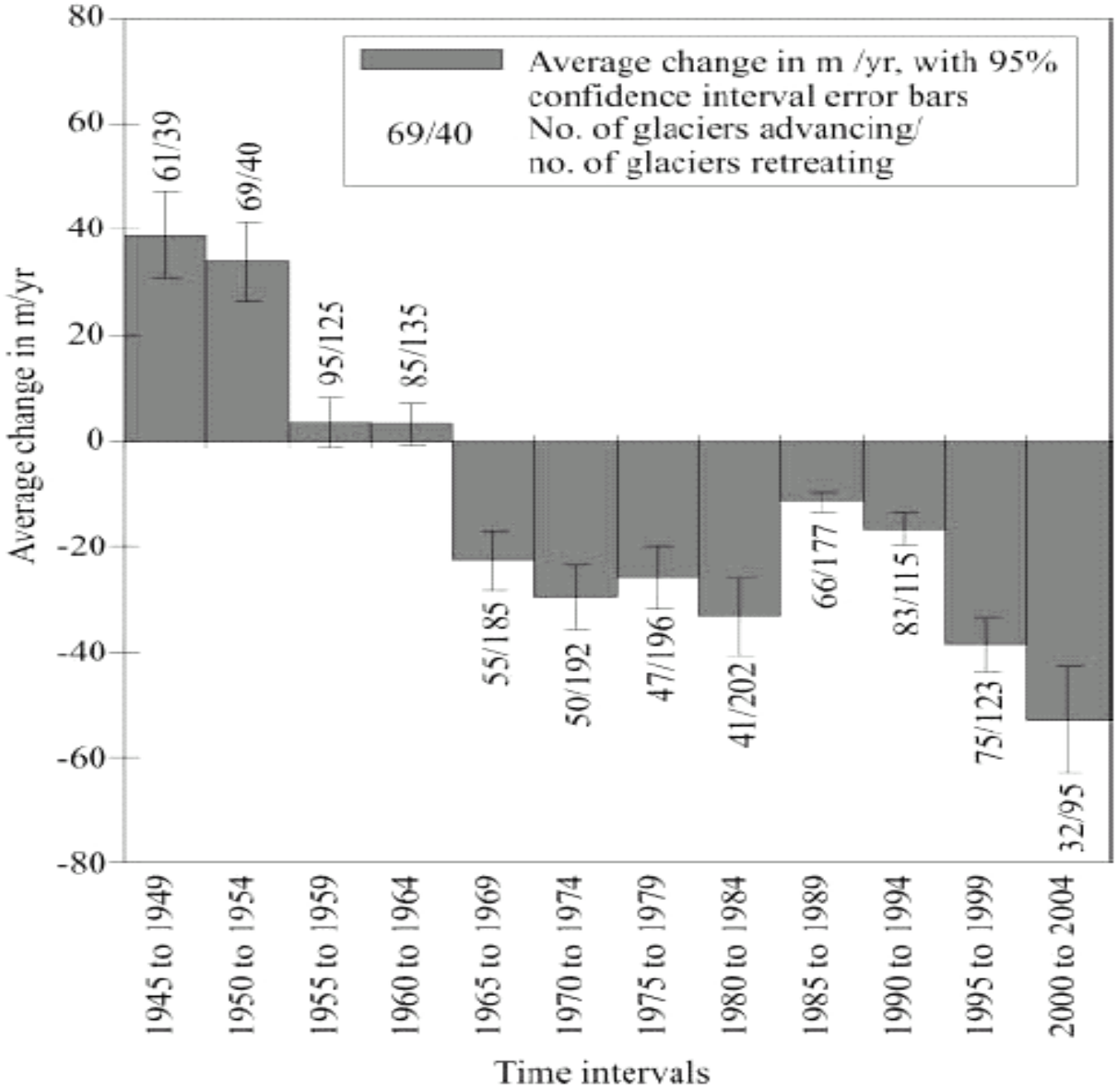

2005 Melt Extent
2005 Melt Extent
1992 Melt Extent
2,000m Elevation
Courtesy Russell Huff and Konrad Steffen

Fig. 3. Average change (with uncertainties) and average latitudes of glaciers across Antarctic Peninsula. Mean advances of 30 to 40 m/year in the 1940s and 1950s became close to stability in the 1950s and 1960s followed by an increase in rate of retreat up to the present, when retreats of 50 m/year are occurring.

Antarctic Glaciers 1945-2004

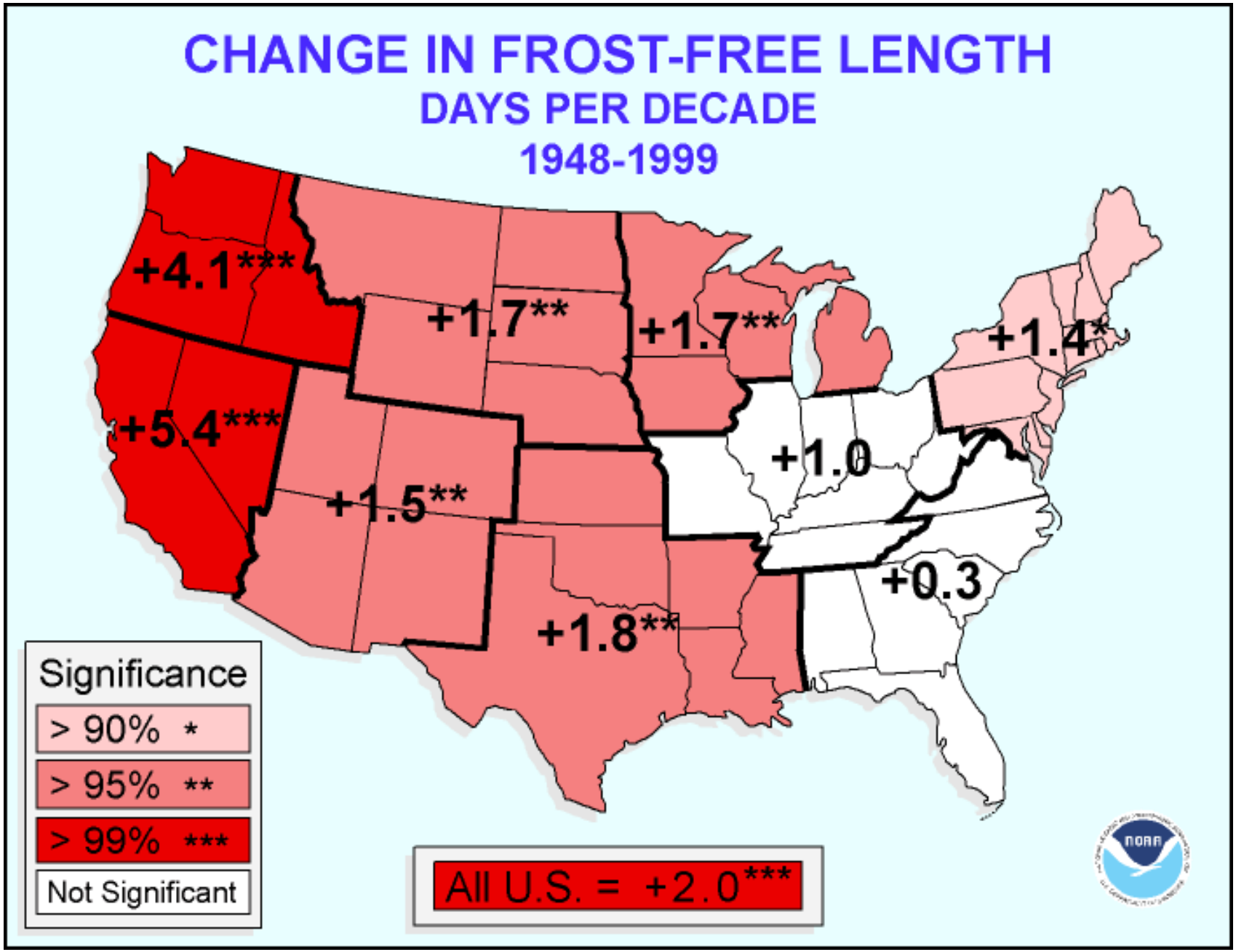


Cook et al 2005. Science

Shepard Glacier
Glacier National Park

Photo by W.C. Alden, USGS ***1913***

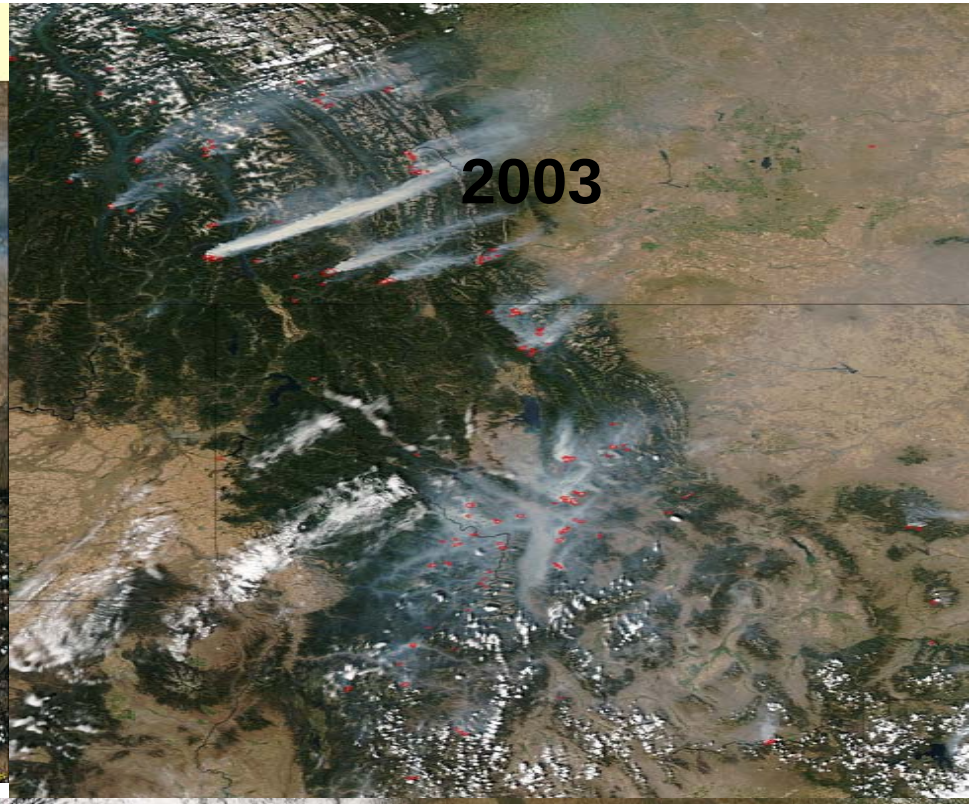
Photo by B. Reardon, USGS ***2005***

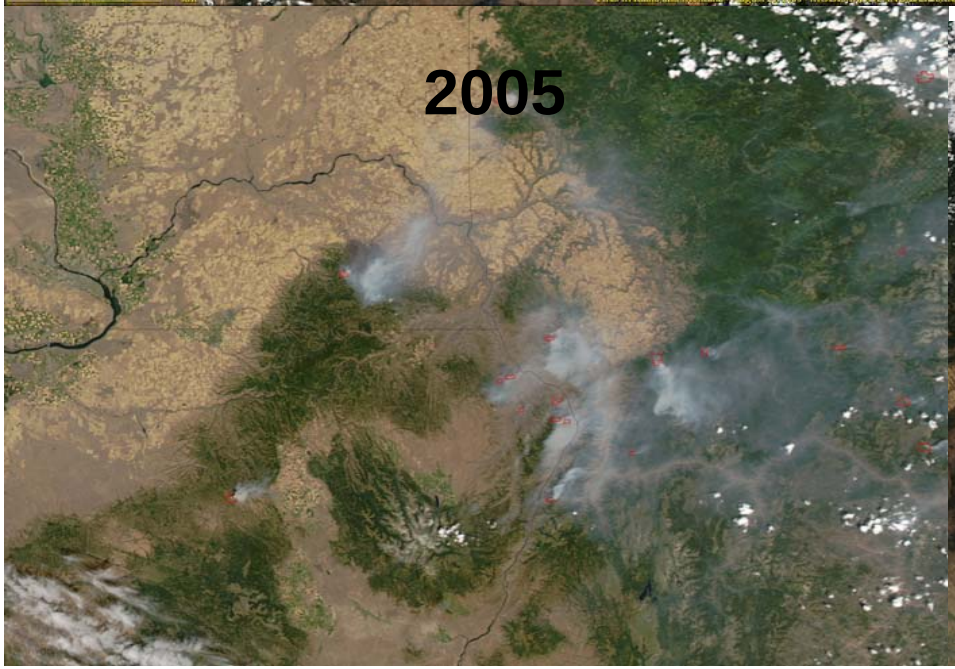

CHANGE IN FROST-FREE LENGTH
DAYS PER DECADE
1948-1999
+4.1***
+1.7**
+1.7**
+1.4*
+5.4***
+1.0
+1.5**
+0.3
+1.8**
Significance
> 90% *
> 95% **
> 99% ***
Not Significant
All U.S. = +2.0***
NOAA

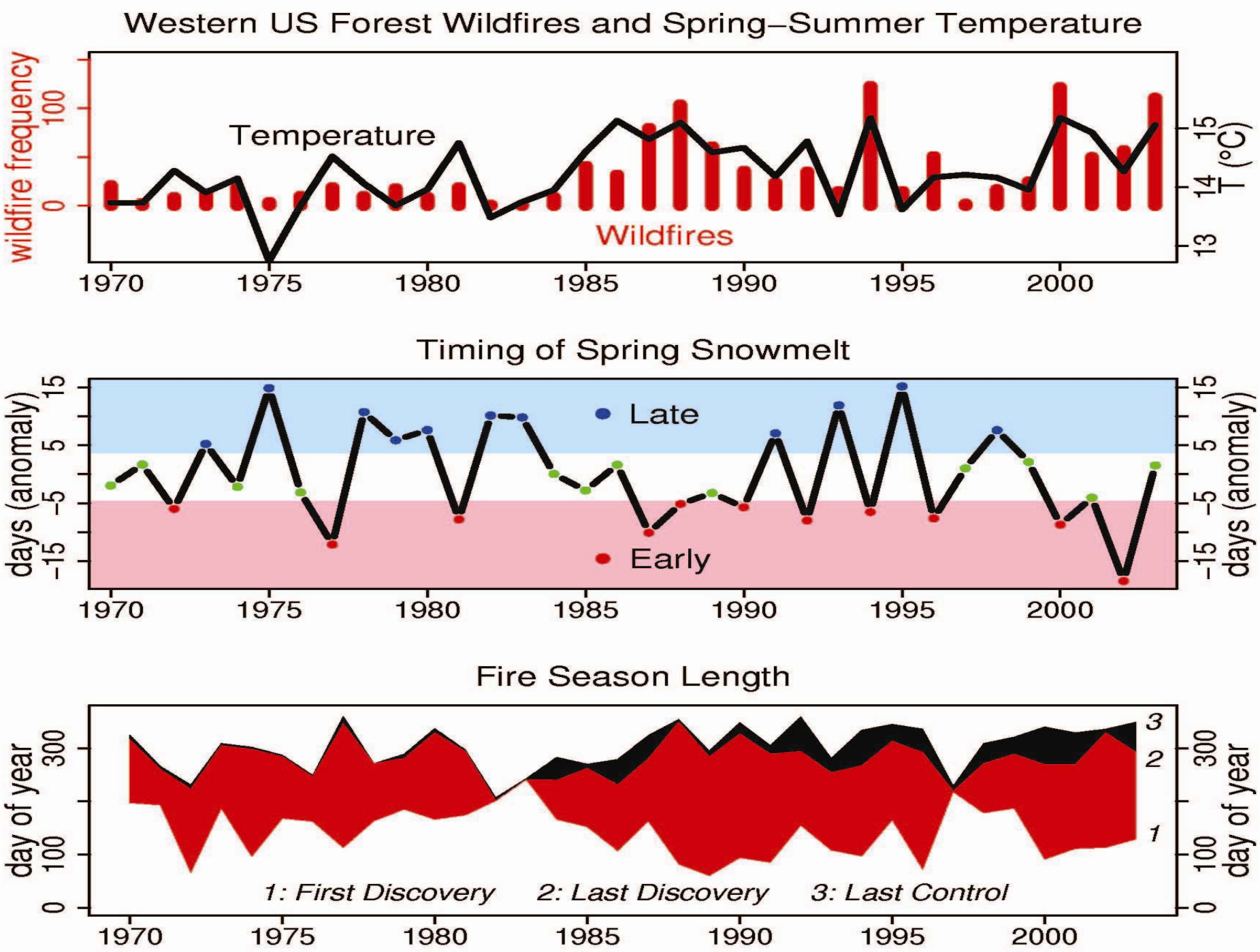
Space Shuttle picture of Montana Fires August 13, 2007

Since 1986:
Western Fire Season 78 days longer
4X Increase in Fires > 1000acres
6X Increase in Acres Burned
> Increase in Forests above 6500ft

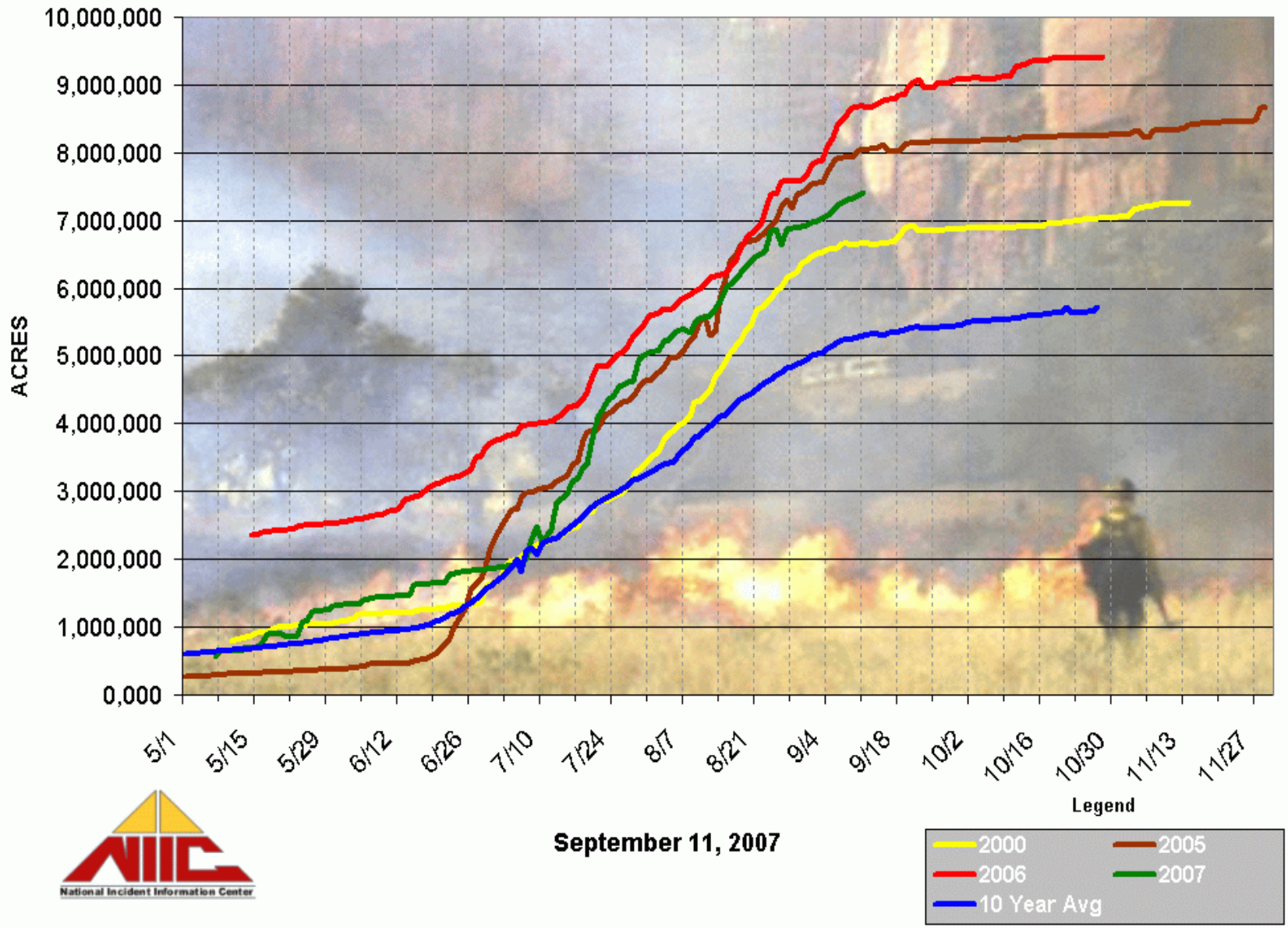
Fires in Montana/Idaho in August 2000
monitored from the EOS/MODIS satellite






Western US Forest Wildfires and Spring–Summer Temperature
wildfire frequency
100
0
Temperature
Wildfires
15
14
13
T (°C)
1970
1975
1980
1985
1990
1995
2000
Timing of Spring Snowmelt
days (anomaly)
15
5
−5
−15
Late
Early
Fire Season Length
day of year
300
100
0
3
2
1
1: First Discovery
2: Last Discovery
3: Last Control

WILDLAND ACRES BURNED 2007

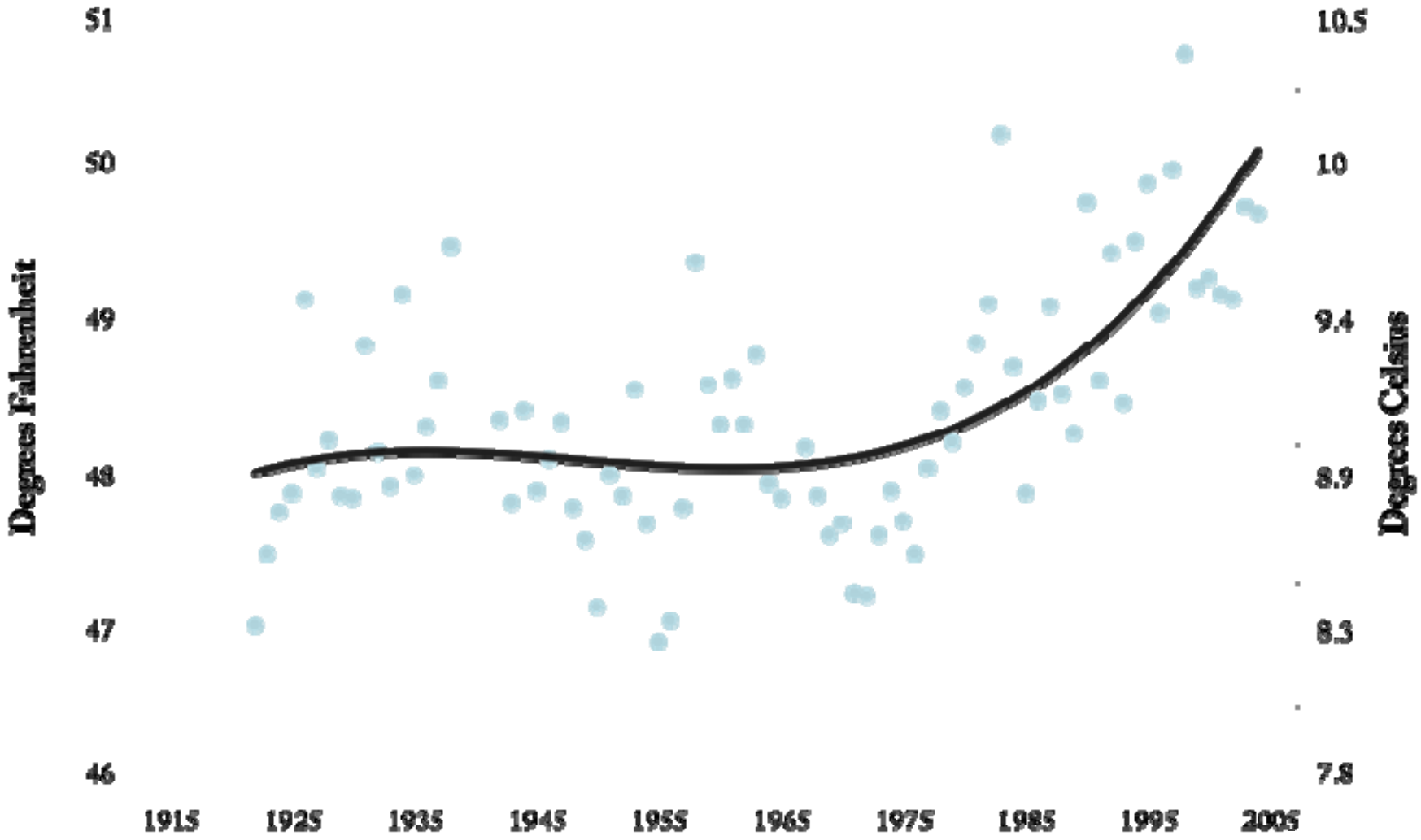


National Incident Information Center

September 11, 2007

CURRENT CLIMATE TRENDS IN THE PACIFIC NORTHWEST

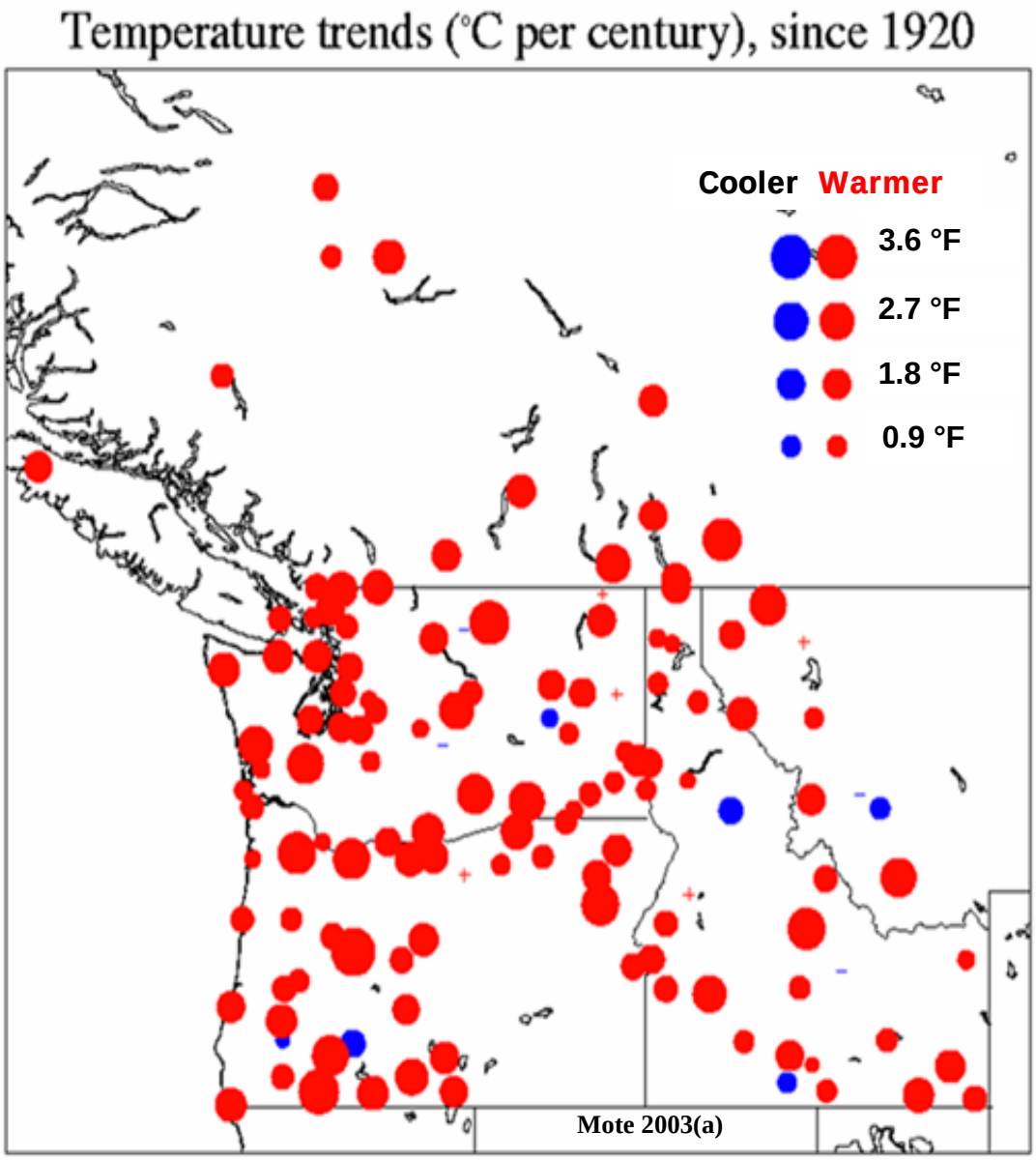
Sea Surface Temperature
(Race Rocks lighthouse, Victoria)



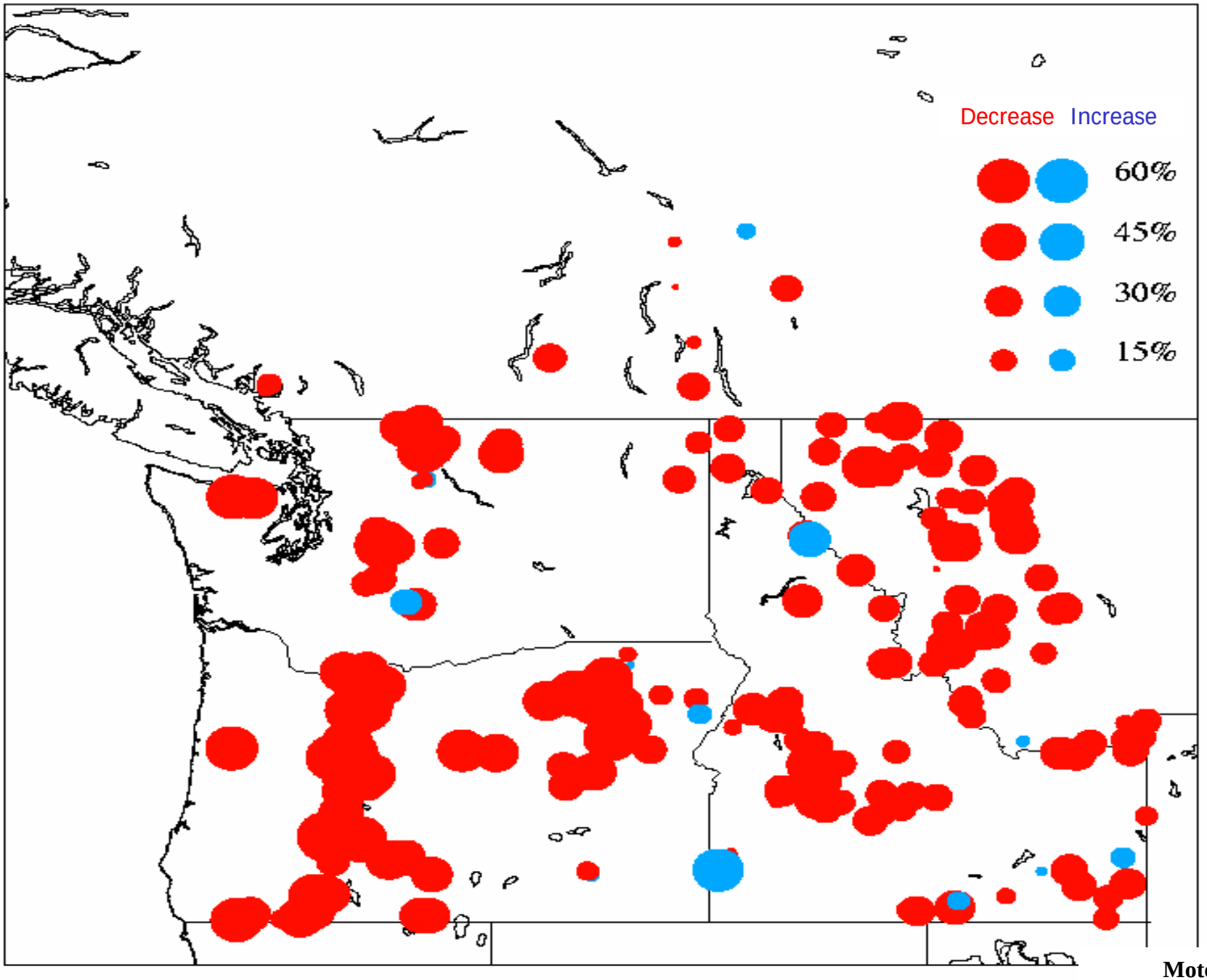
PNW Temperature Trends by Station

- **Average annual temperature increased +1.5°F in the PNW during the 20th century *(+2.3°F in the Puget Sound)***

- **Almost every station shows warming**
- **Extreme cold conditions have become rarer**
- **Low temperatures rose faster than high temperatures**



Relative trend in Apr 1 snow water equivalent, 1950-2000

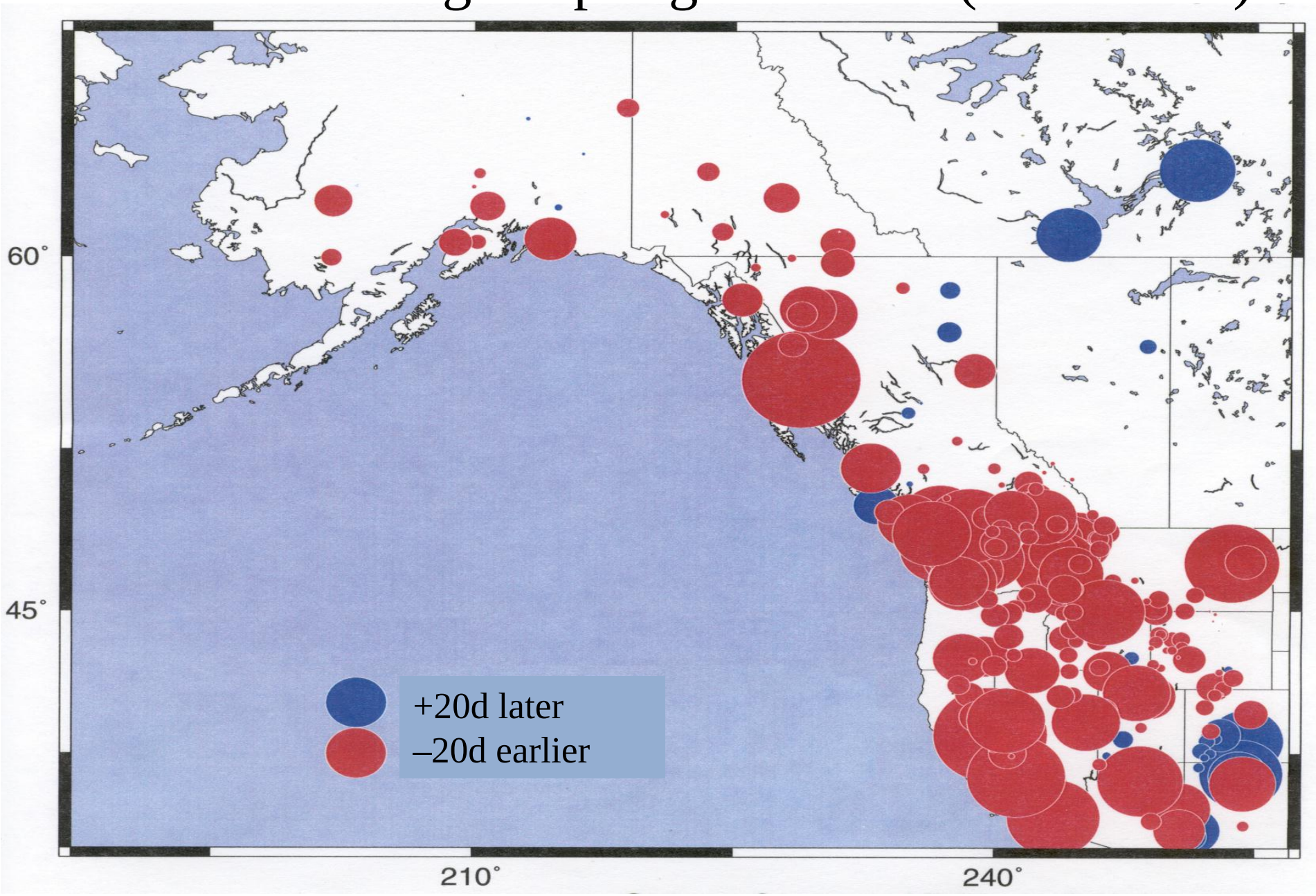


CLIMATE IMPACTS GROUP

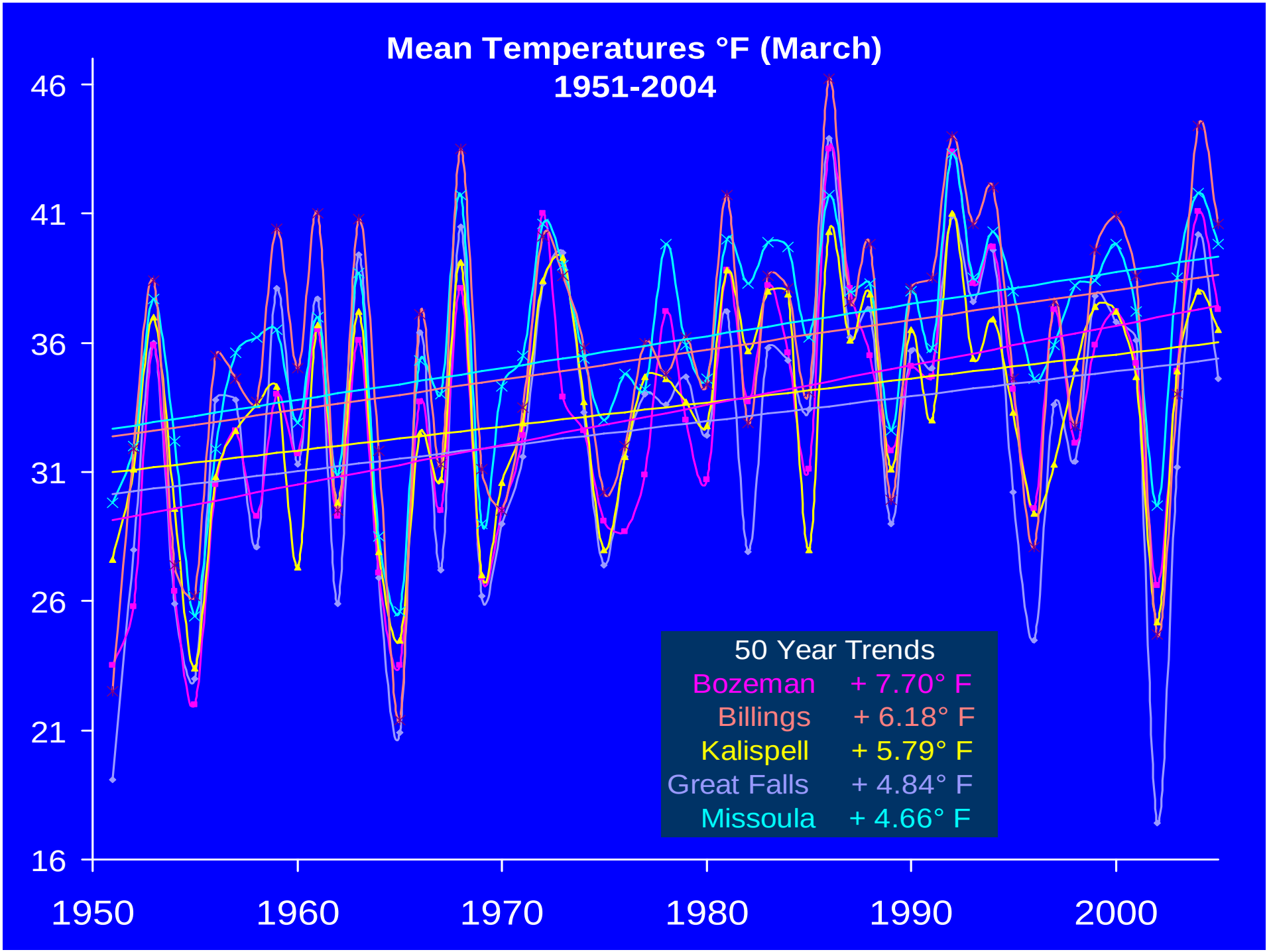
Climate Science in the Public Interest

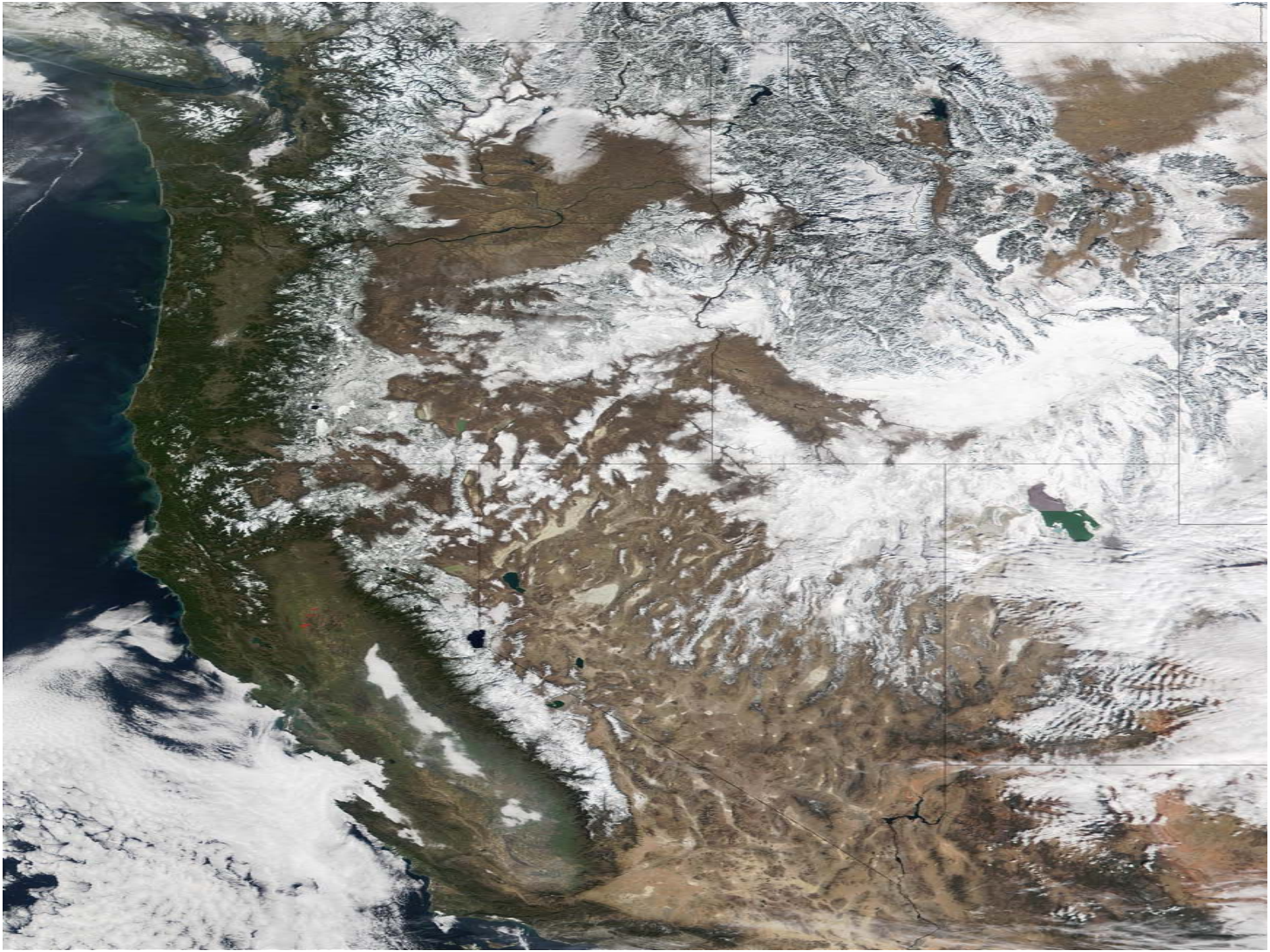
Mote 2003(b)

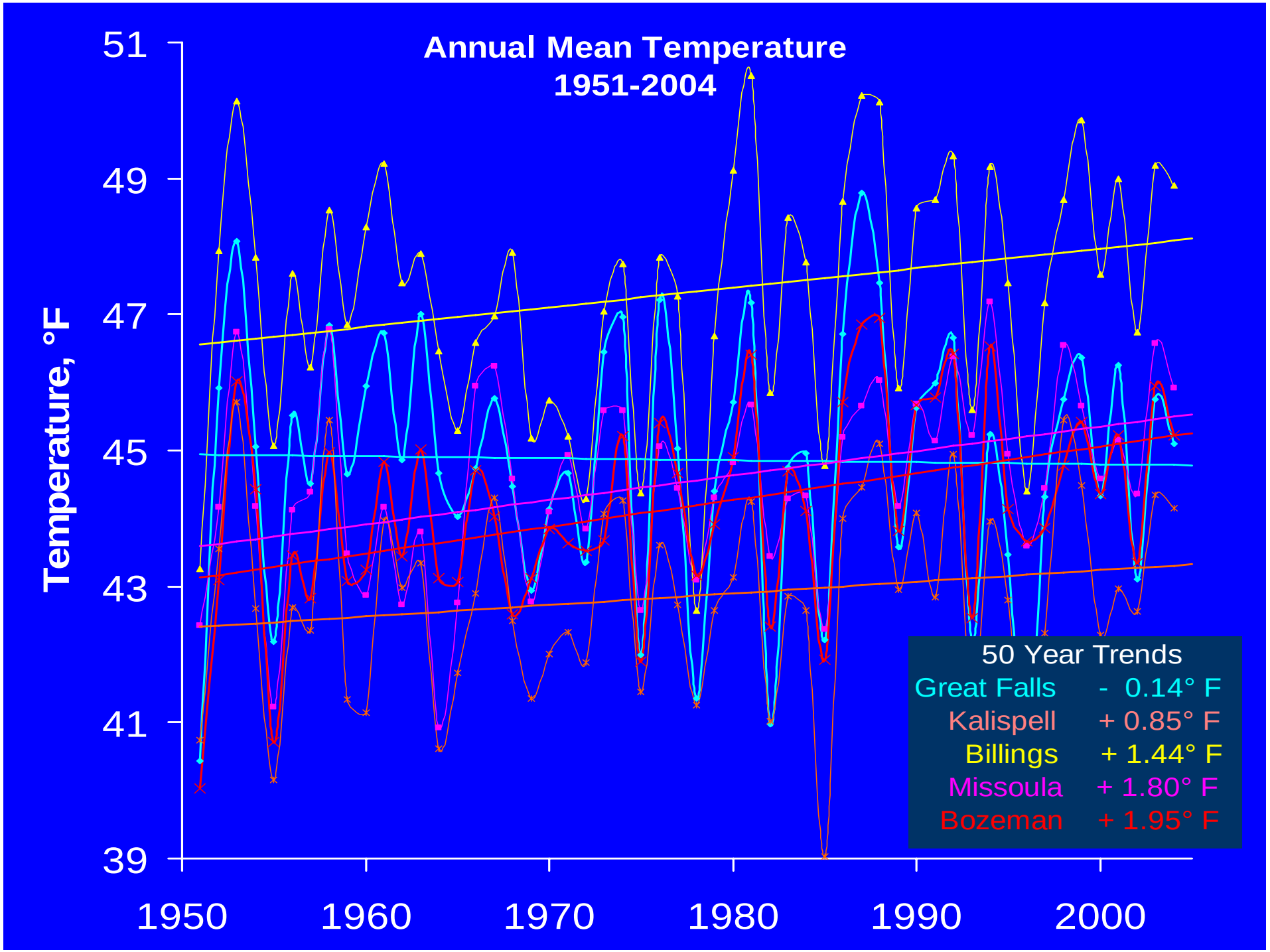
Trends in timing of spring snowmelt (1948-2000)

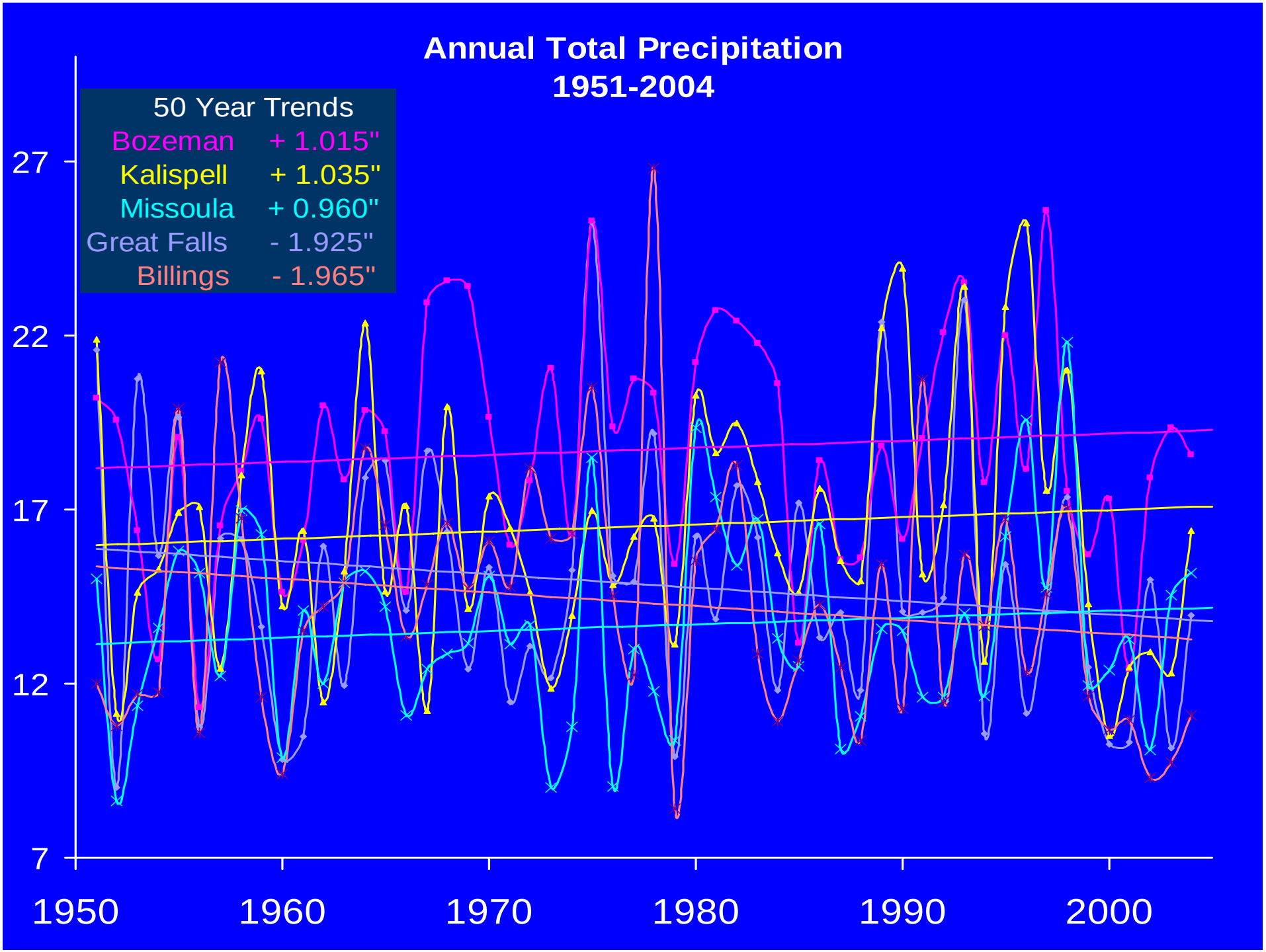


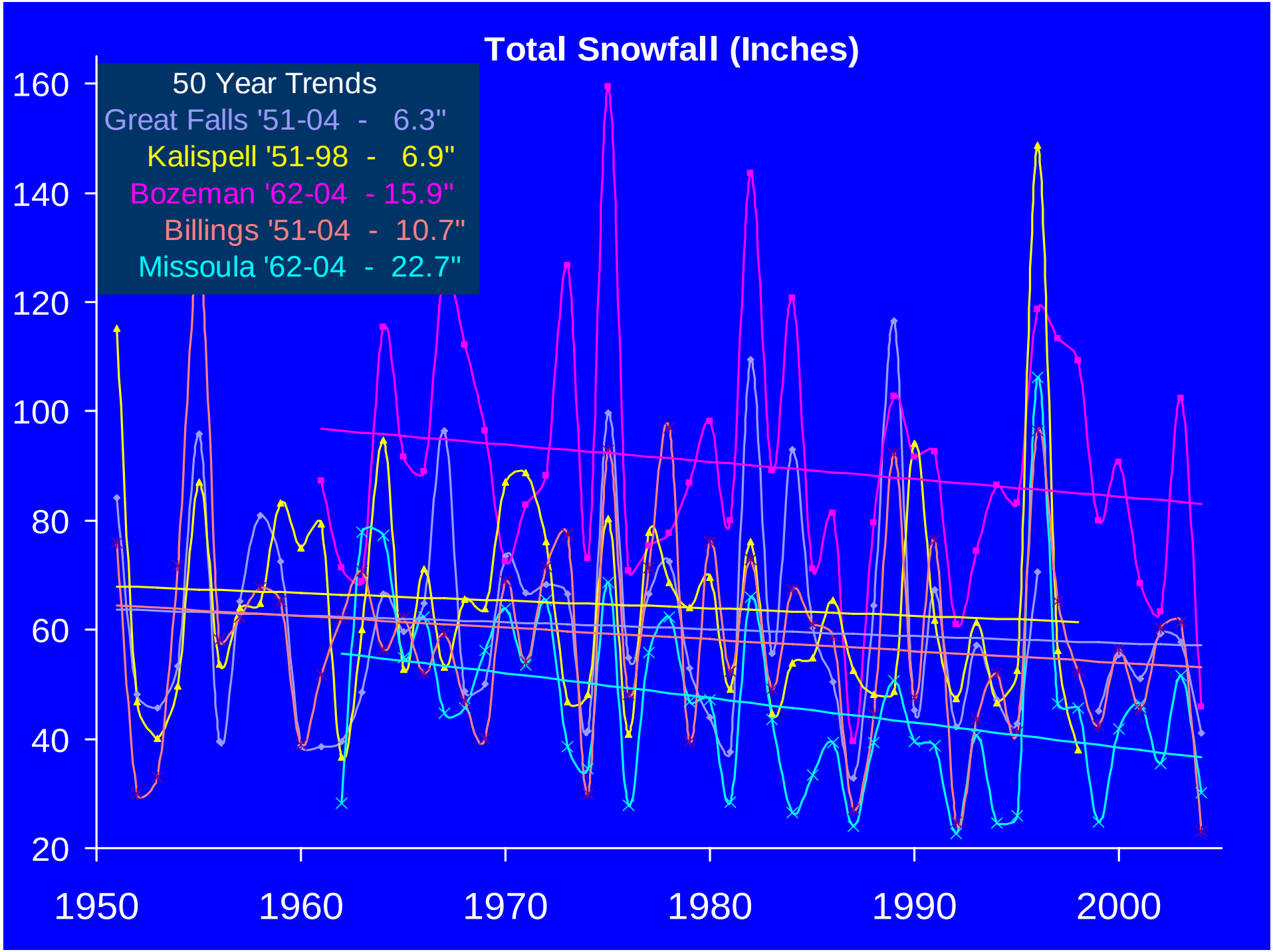
Courtesy of Mike Dettinger, Iris Stewart, Dan Cayan


Mean Temperatures °F (March)
1951-2004
46
41
36
31
26
21
16
1950
1960
1970
1980
1990
2000
50 Year Trends
Bozeman + 7.70° F
Billings + 6.18° F
Kalispell + 5.79° F
Great Falls + 4.84° F
Missoula + 4.66° F

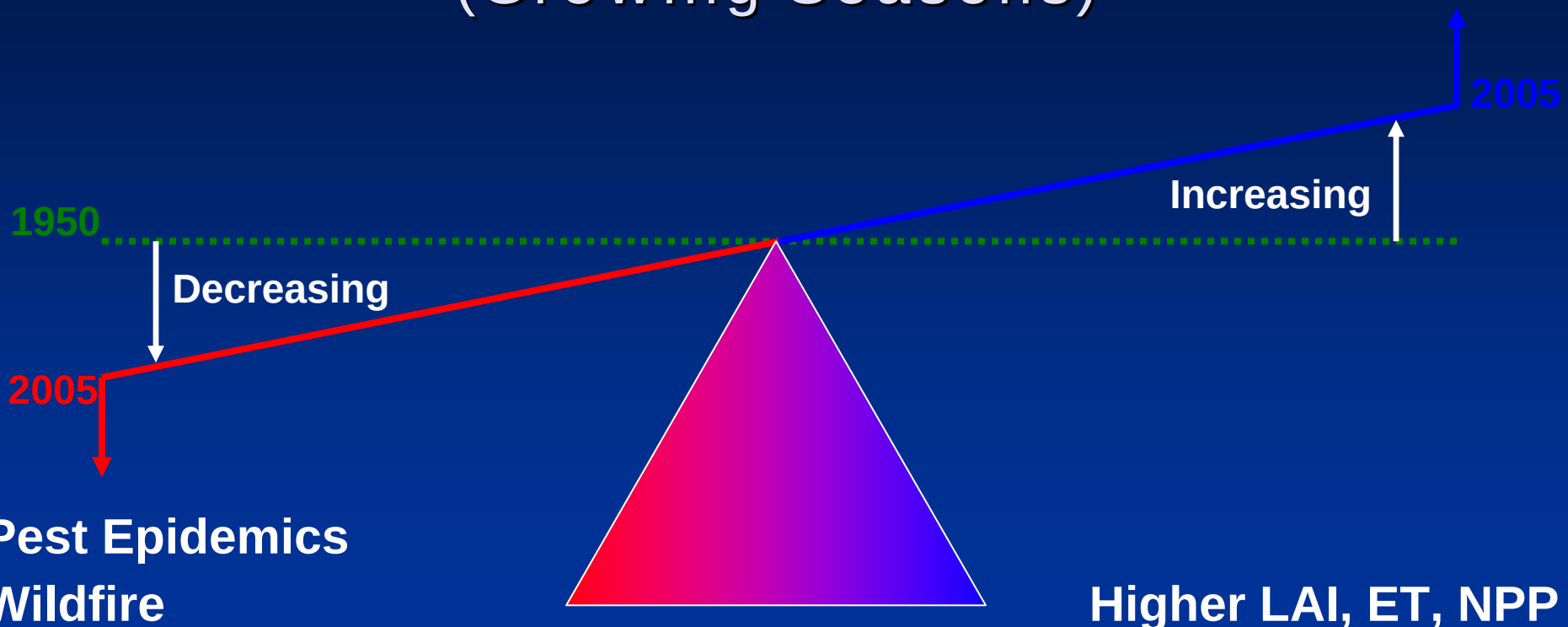



Annual Mean Temperature
1951-2004
Temperature, °F
51
49
47
45
43
41
39
1950
1960
1970
1980
1990
2000
50 Year Trends
Great Falls - 0.14° F
Kalispell + 0.85° F
Billings + 1.44° F
Missoula + 1.80° F
Bozeman + 1.95° F


Annual Total Precipitation
1951-2004
50 Year Trends
Bozeman + 1.015"
Kalispell + 1.035"
Missoula + 0.960"
Great Falls - 1.925"
Billings - 1.965"
27
22
17
12
7
1950
1960
1970
1980
1990
2000


Total Snowfall (Inches)
50 Year Trends
Great Falls '51-04 - 6.3"
Kalispell '51-98 - 6.9"
Bozeman '62-04 - 15.9"
Billings '51-04 - 10.7"
Missoula '62-04 - 22.7"
160
140
120
100
80
60
40
20
1950
1960
1970
1980
1990
2000

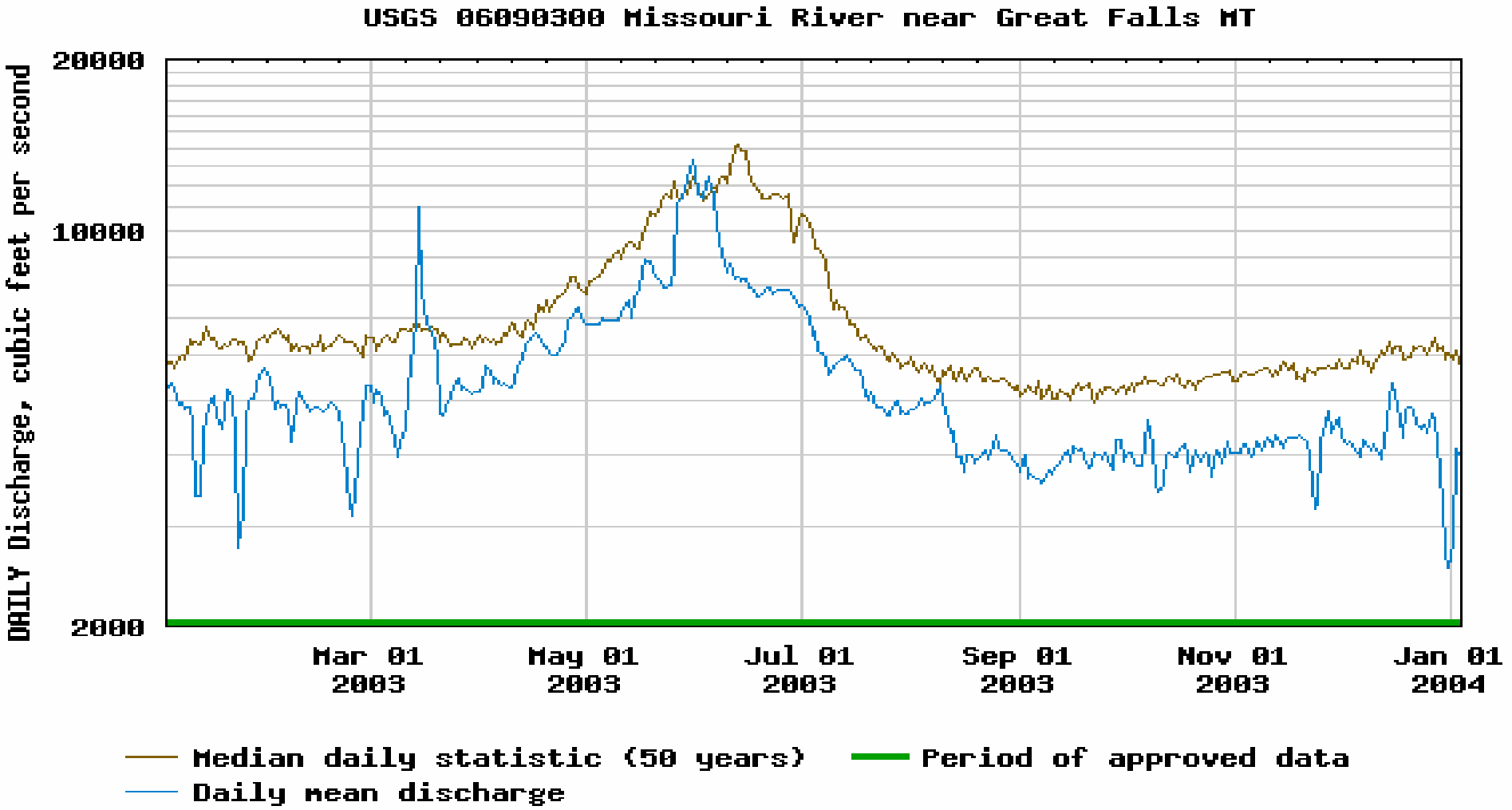
Land Water Balance Tipping Points
(Growing Seasons)



Pest Epidemics
Wildfire
Forest Mortality
Low Streamflows
Reduced Nutrient Cycling
Lower NPP
Biodiversity?
Invasives?

Higher LAI, ET, NPP
Higher Streamflows
Streambank Erosion
Insect-borne diseases
Human Health
Improved wildlife habitat?
Biodiversity?

Montana's Streamflow is decreasing and peaking earlier



MONTANA TROUT UNLIMITED

By 2050 Global Climate Models project Montana to be 5deg F. warmer in summer, but receive 10% less rainfall

Water Management
Recreation versus Agriculture

The MonDak Region has an enormous amount of potential for irrigation development.

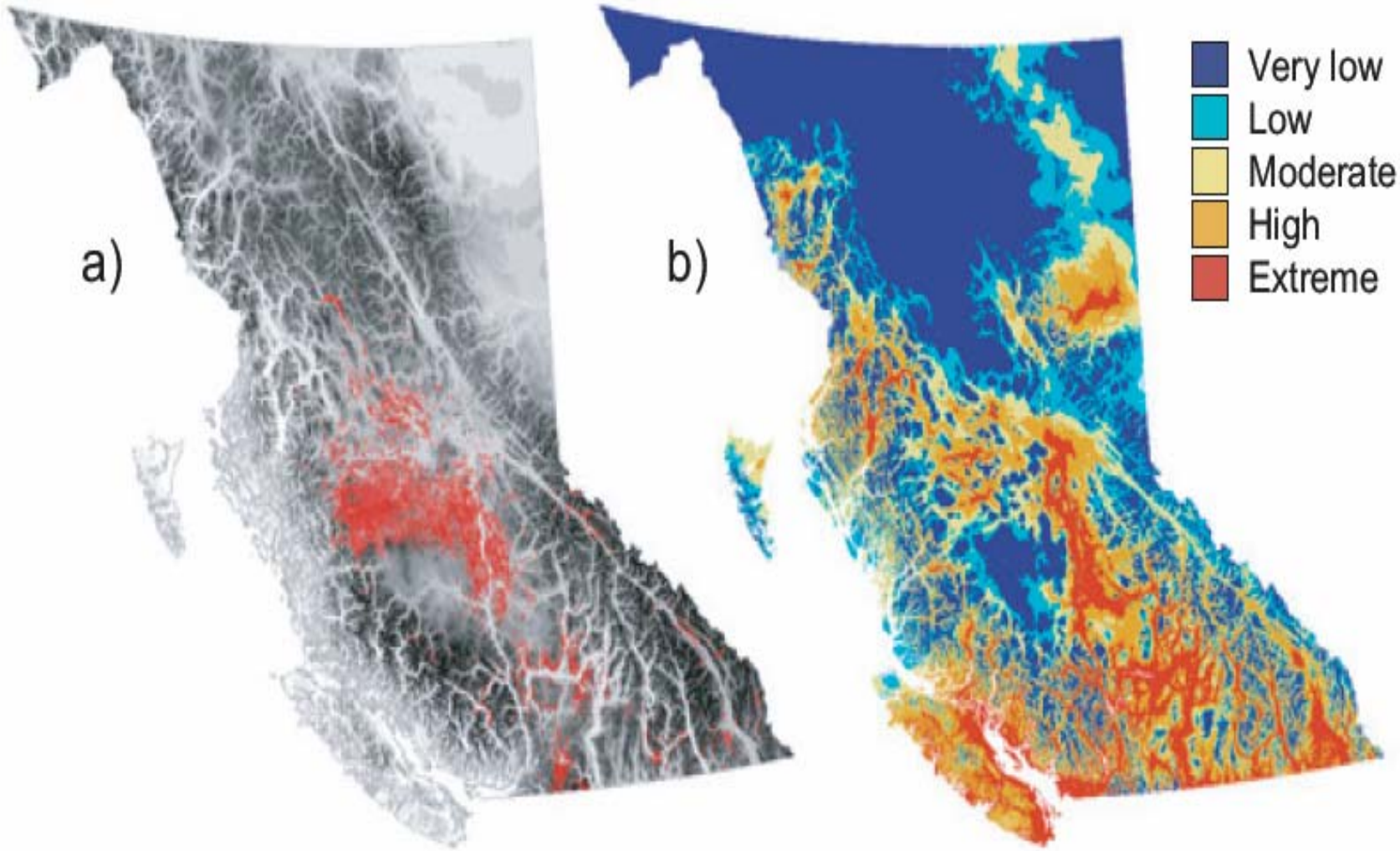


Figure 2. Mountain pine beetle infestations (all severity classes) from 1998 to 2002 (a), and the distribution of climatic suitability classes derived from 1971-2000 climate normals [30-year monthly means and extreme minima and maxima (b)] for the mountain pine beetle in BC. "Very low" CSCs are habitats with climatic conditions unsuitable for mountain pine beetle, whereas "extreme" CSCs are those considered climatically optimal.

Carroll et al 2004

Missoula July 07 Records

- Hottest Temperature Ever – 107
- Warmest Night Ever – 71
- Average Temp – 78.1 – 11.2 F above average
  - Breaks the old record by 3.3F
- Most number of 100 F days – 11
  - Old record – 6 in 1936
- Most number of nights 60F and above – 18
  - Old record – 10 in 1985
- Driest July on record at Missoula Airport
  - 0.03” – old Airport record is 0.09”

IPCC 4th Assessment GCMs

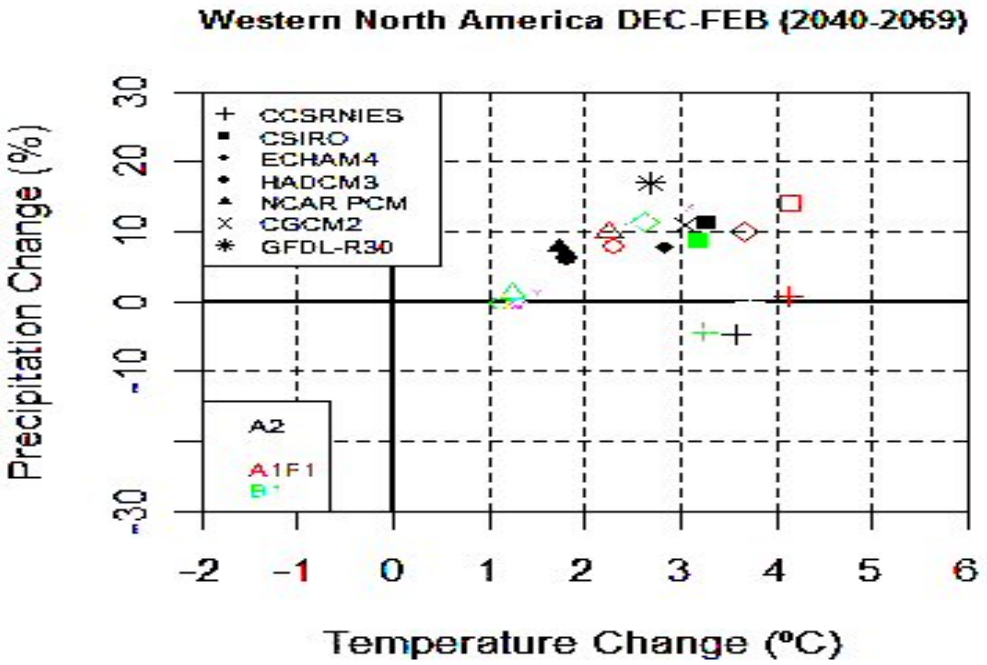
All Year

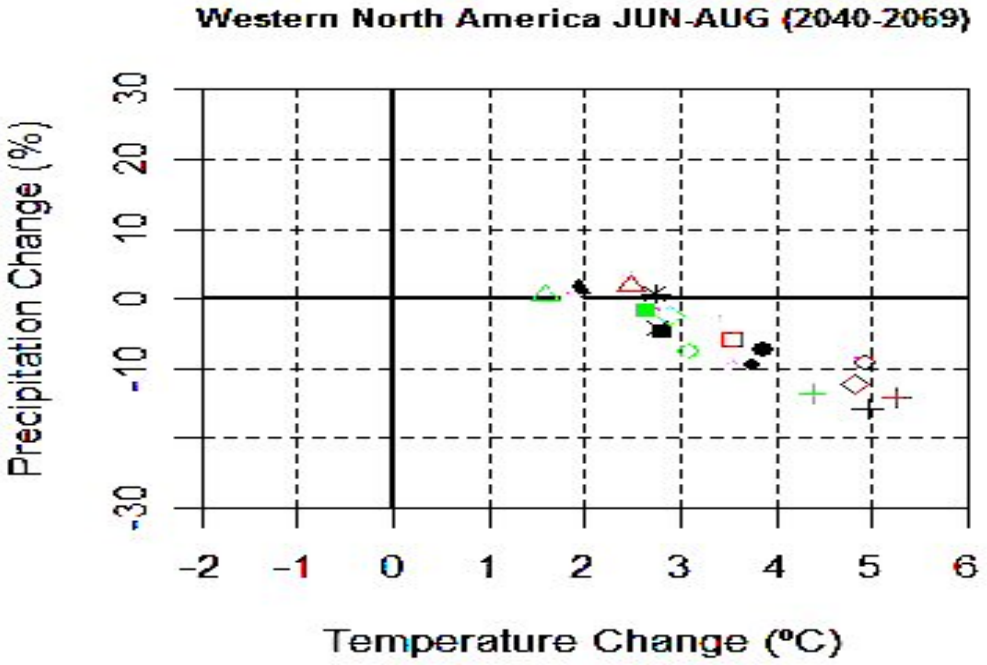
3 deg warmer

BUT

Winter – wetter

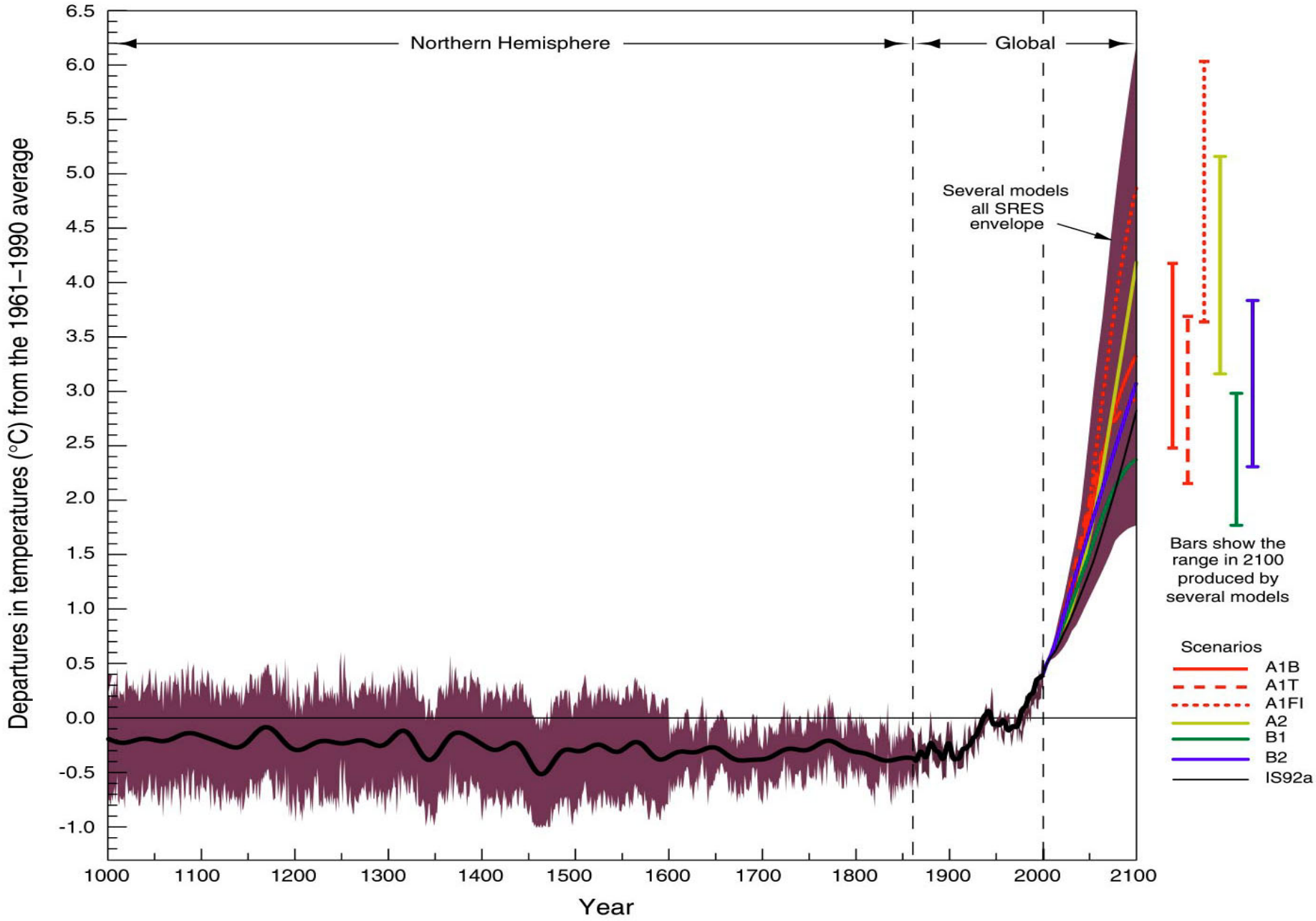
Summer – drier

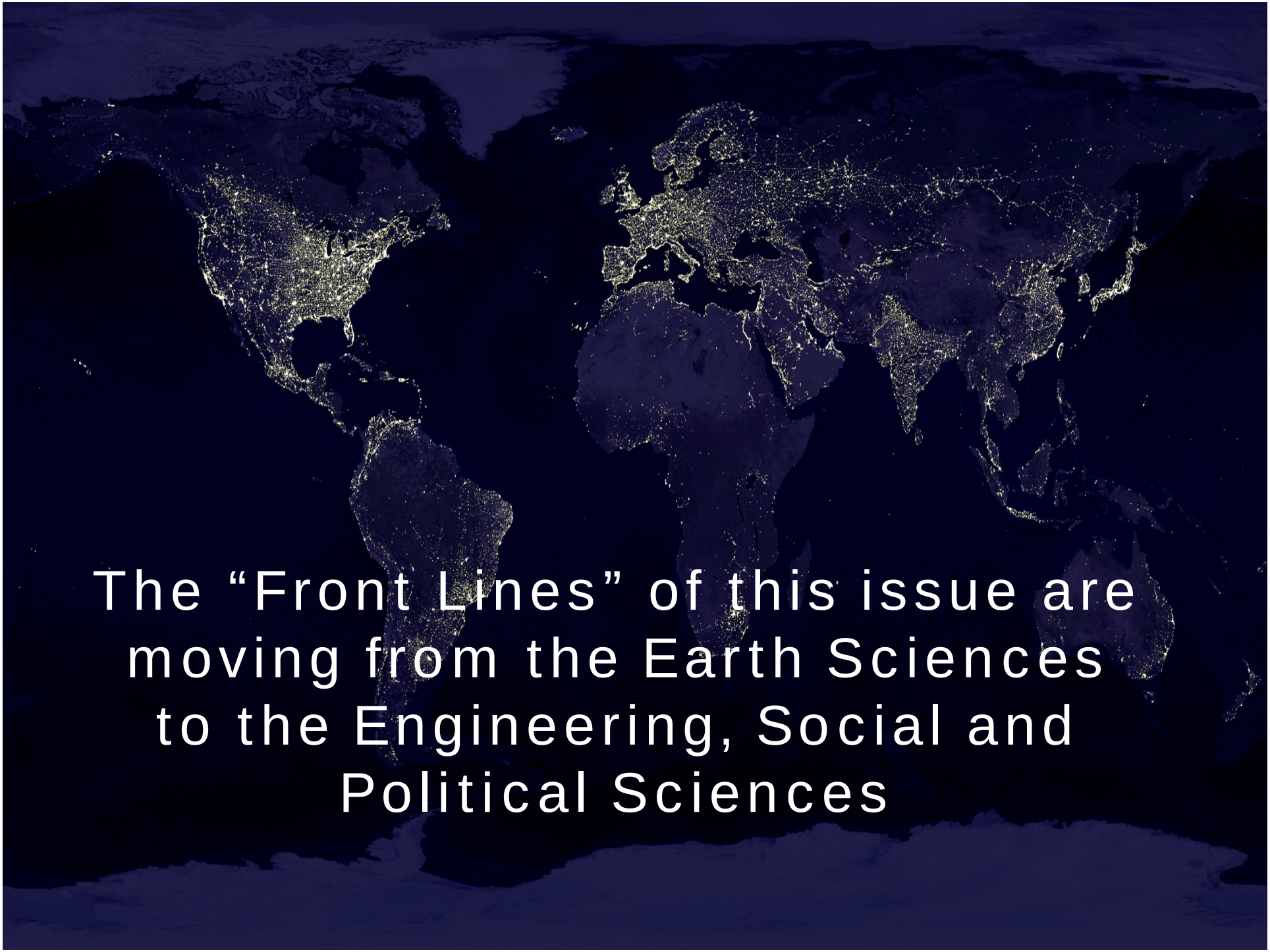




Variations of the Earth's surface temperature; 1000 to 2100

1000 to 1861, N.Hemisphere, proxy data; 1861 to 2000 Global, instrumental; 2000 to 2100, SRES projections




The “Front Lines” of this issue are moving from the Earth Sciences to the Engineering, Social and Political Sciences