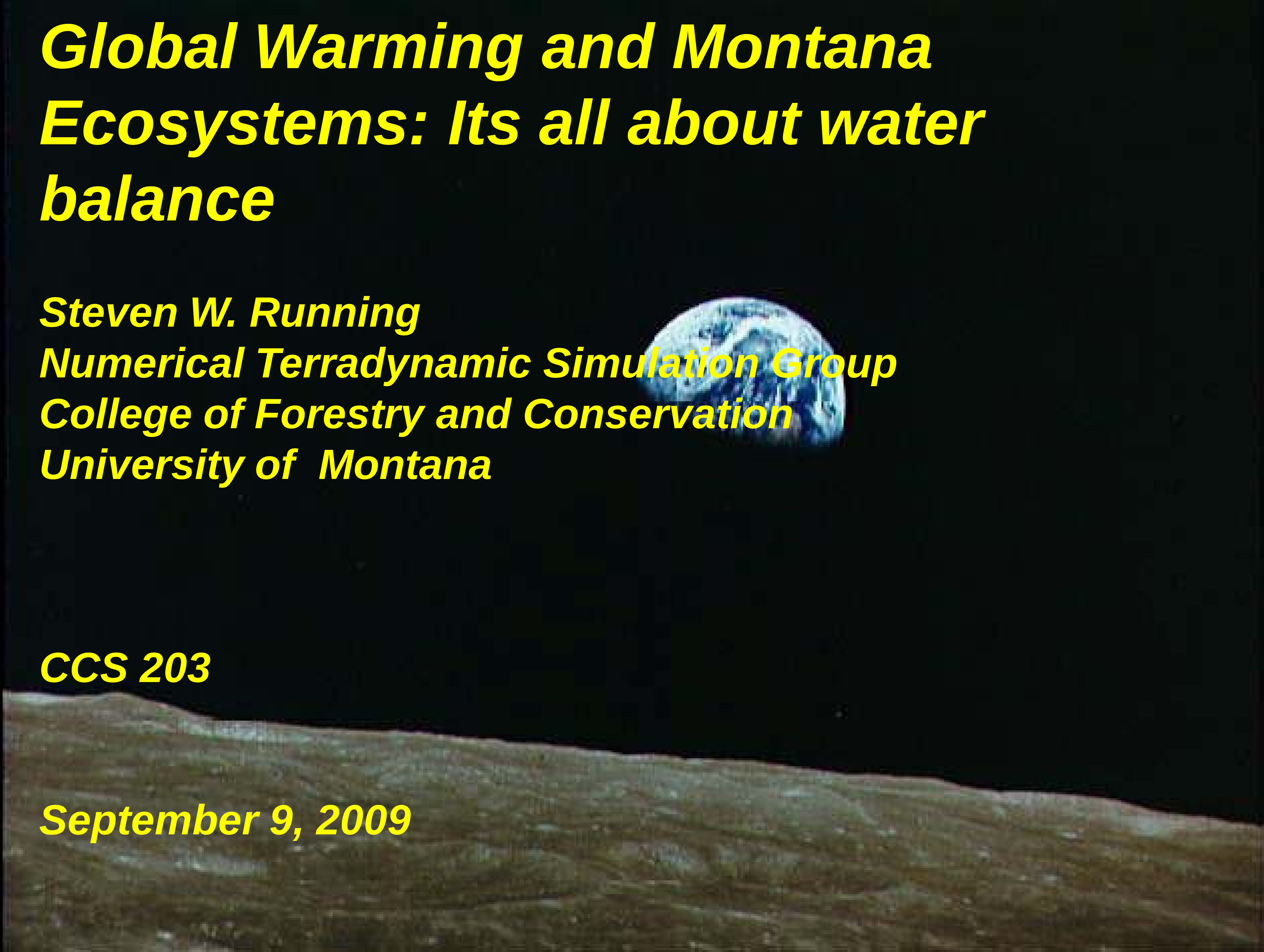
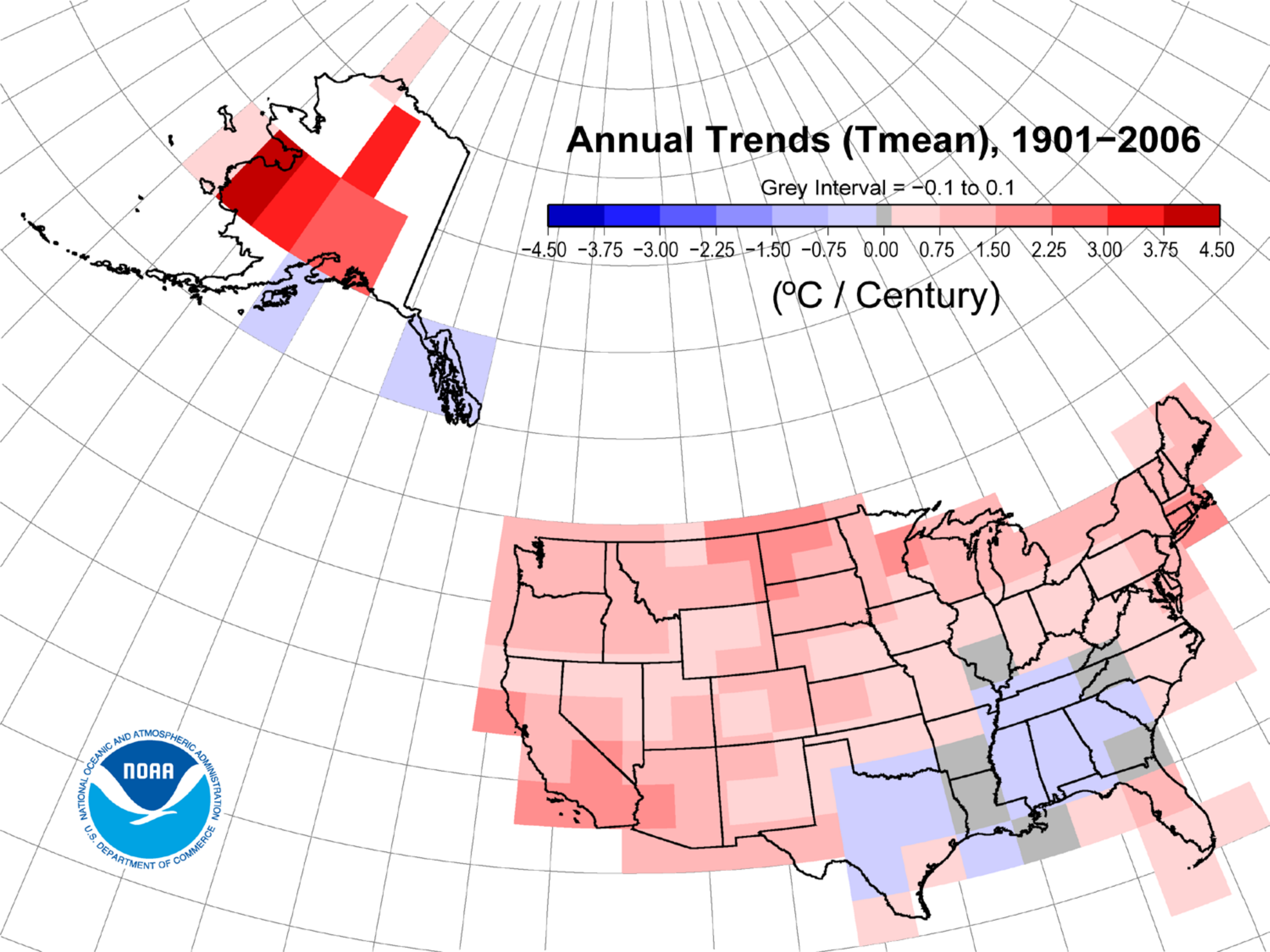


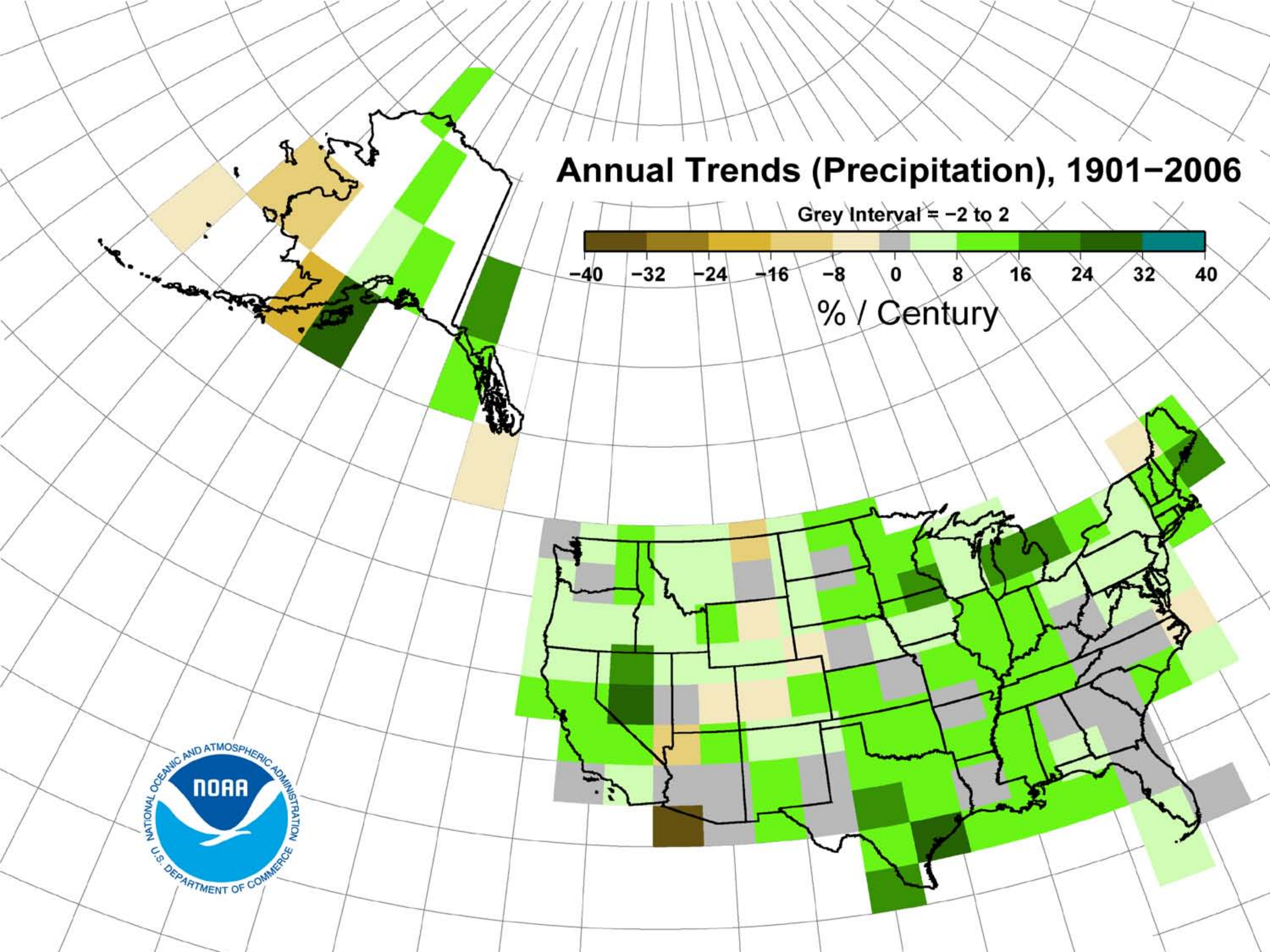
Global Warming and Montana Ecosystems: Its all about water balance

Steven W. Running
Numerical Terradynamic Simulation Group
College of Forestry and Conservation
University of Montana

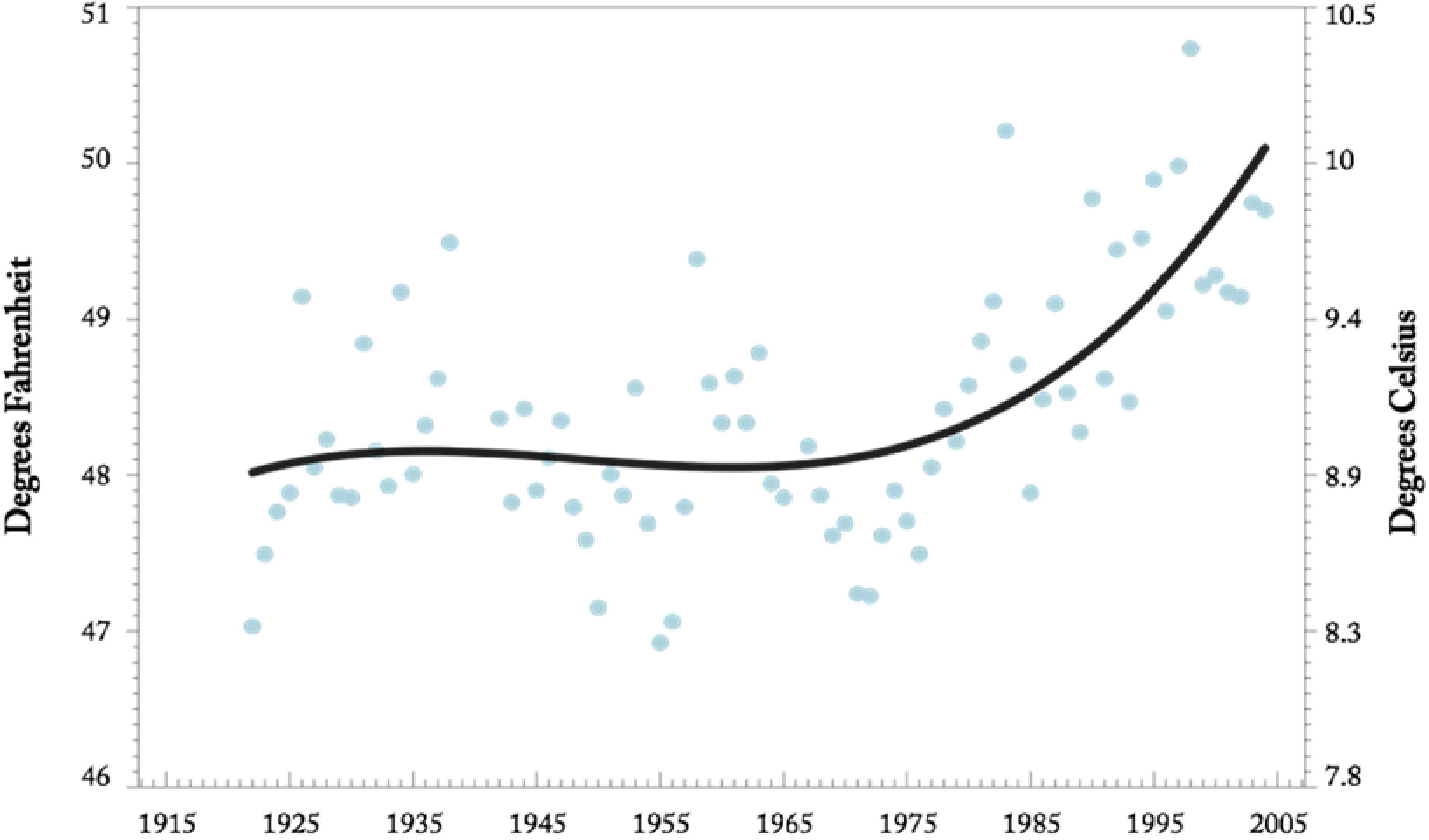
CCS 203

September 9, 2009

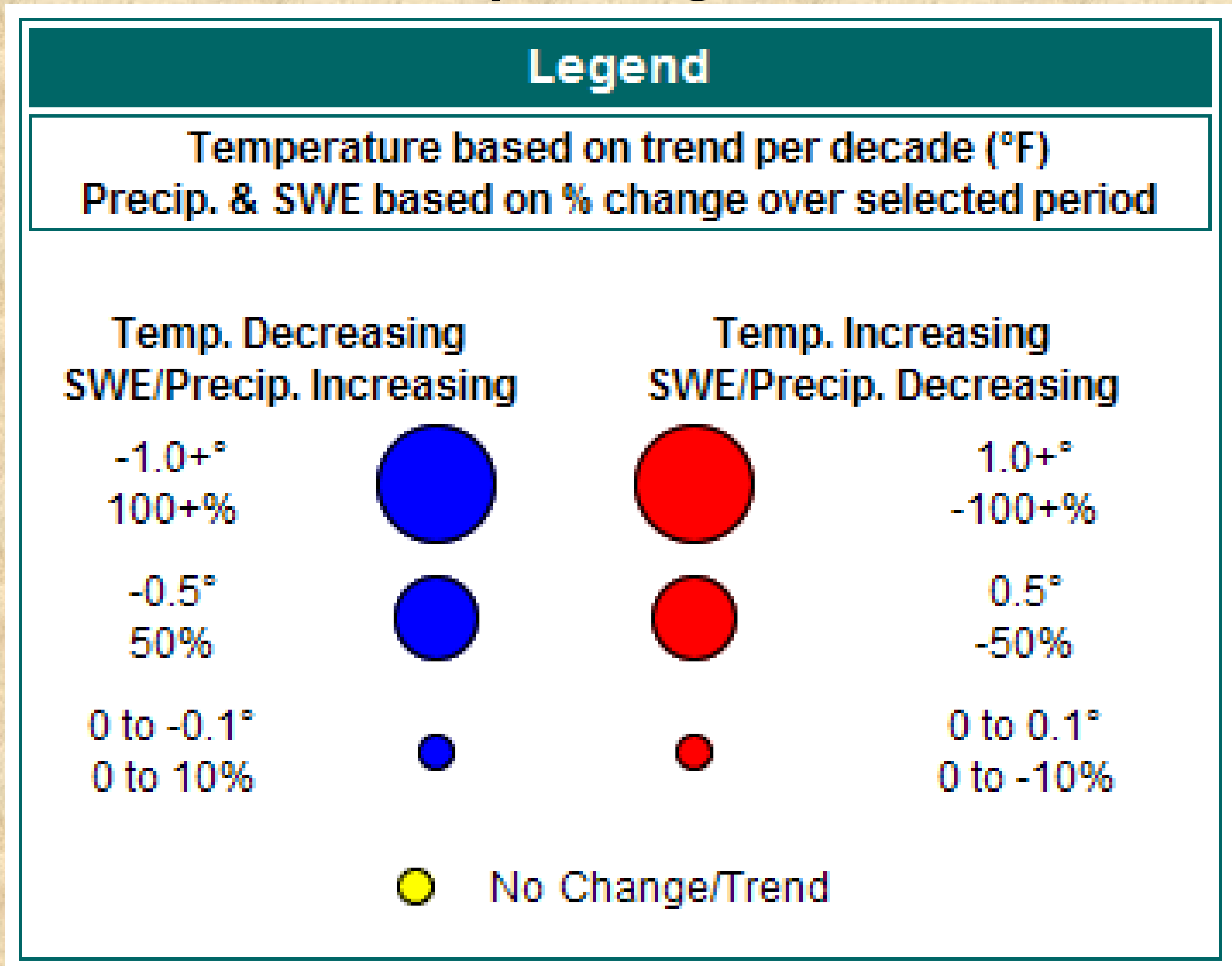

Annual Trends (Tmean), 1901−2006
Grey Interval = −0.1 to 0.1
−4.50 −3.75 −3.00 −2.25 −1.50 −0.75 0.00 0.75 1.50 2.25 3.00 3.75 4.50
(°C / Century)
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE


Annual Trends (Precipitation), 1901−2006
Grey Interval = −2 to 2
−40 −32 −24 −16 −8 0 8 16 24 32 40
% / Century
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

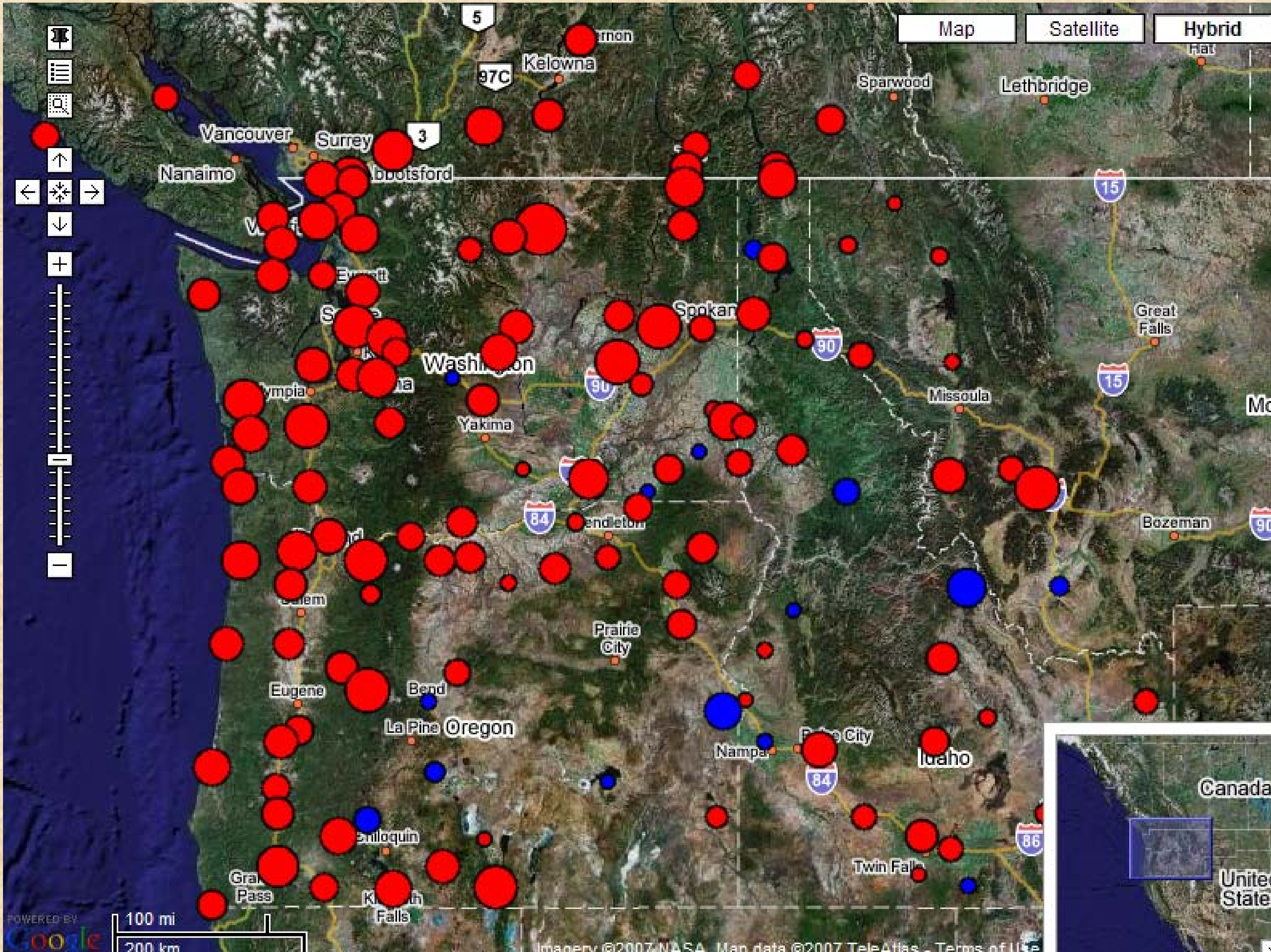
Sea Surface Temperature
(Race Rocks lighthouse, Victoria)



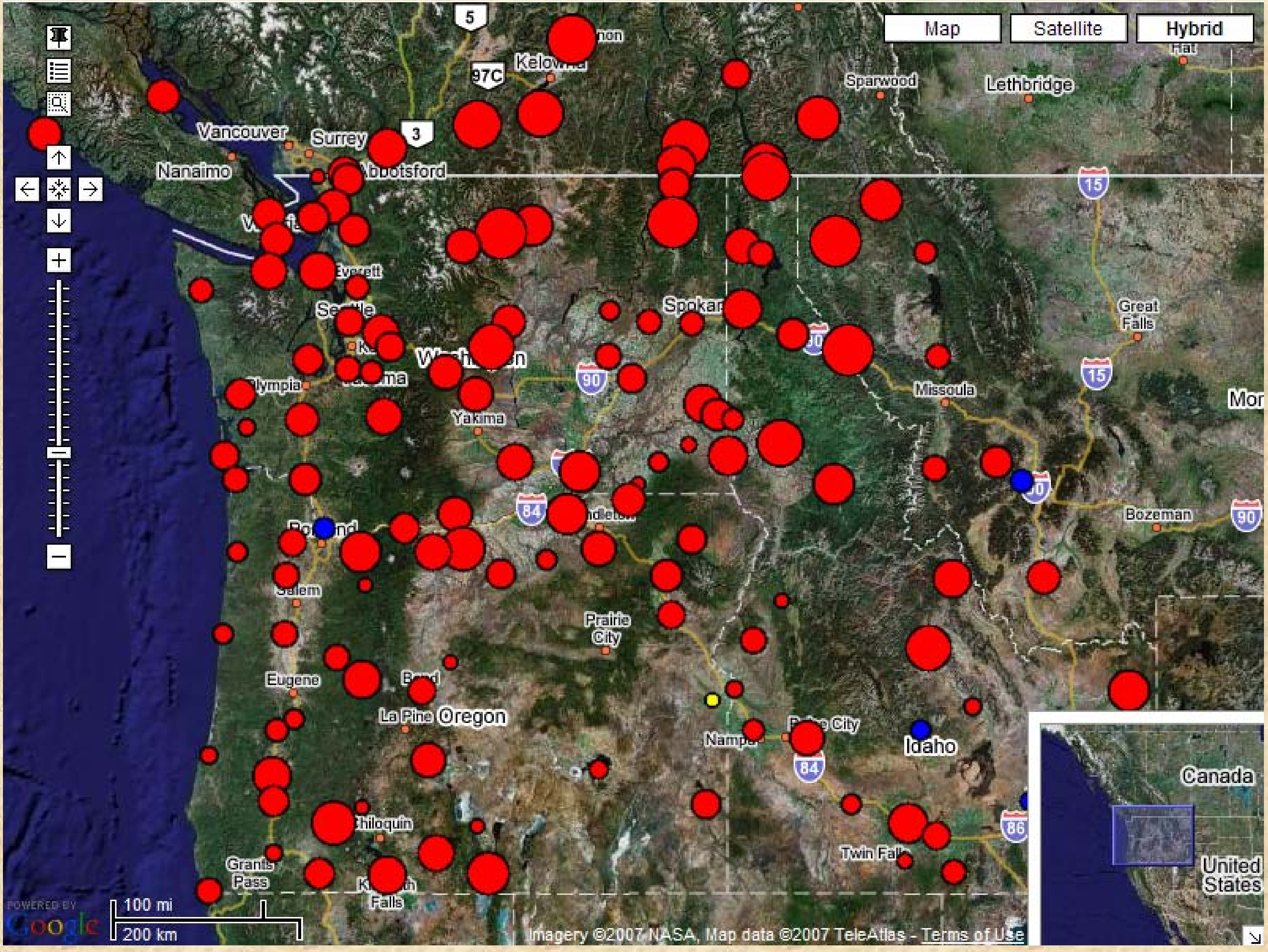
Map Legend


Legend
Temperature based on trend per decade (°F)
Precip. & SWE based on % change over selected period
Temp. Decreasing
SWE/Precip. Increasing
Temp. Increasing
SWE/Precip. Decreasing
-1.0+°
100+%
1.0+°
-100+%
-0.5°
50%
0.5°
-50%
0 to -0.1°
0 to 10%
0 to 0.1°
0 to -10%
No Change/Trend

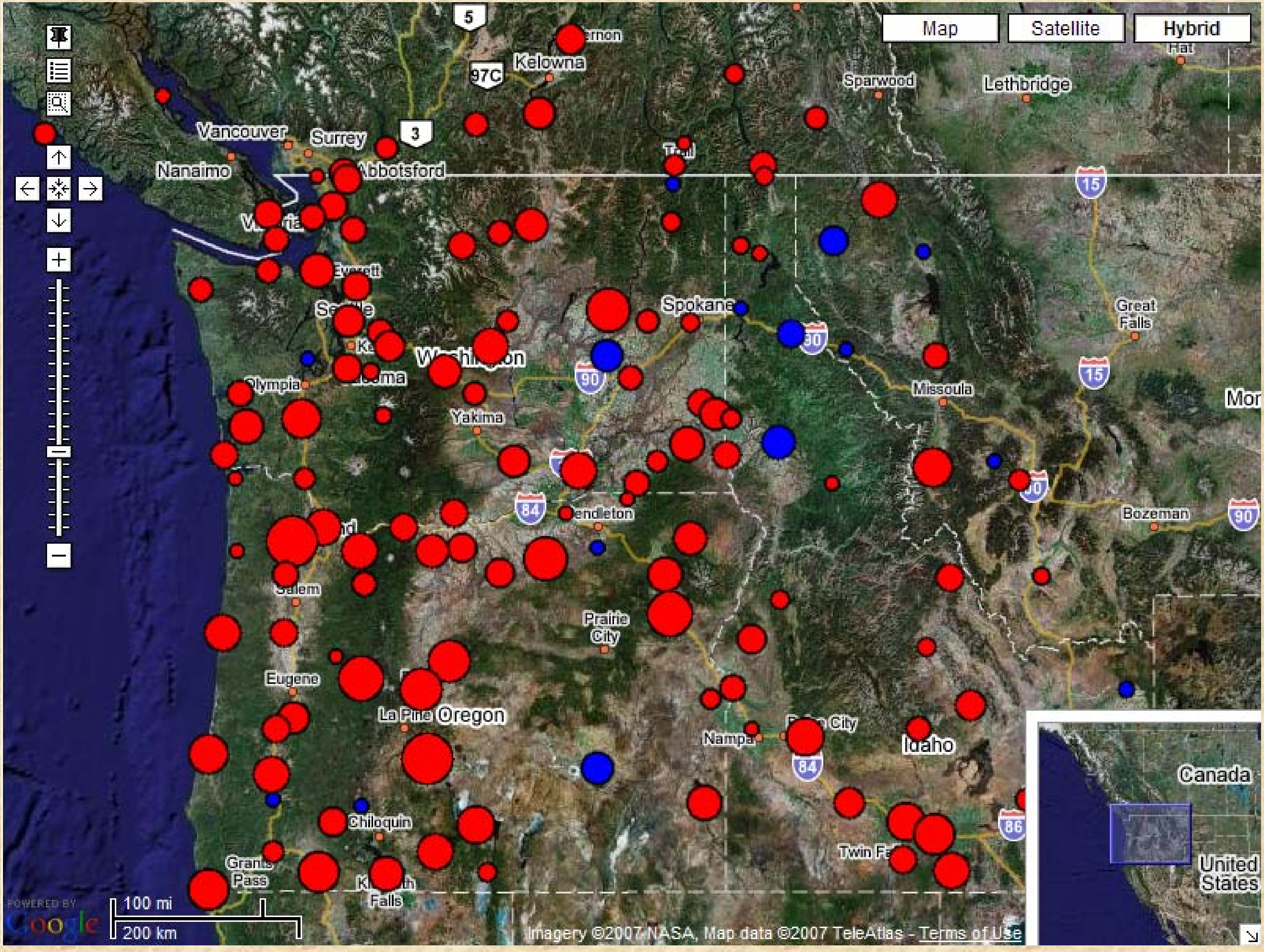
Winter Max Temperature Trend Analysis: 1915-2003



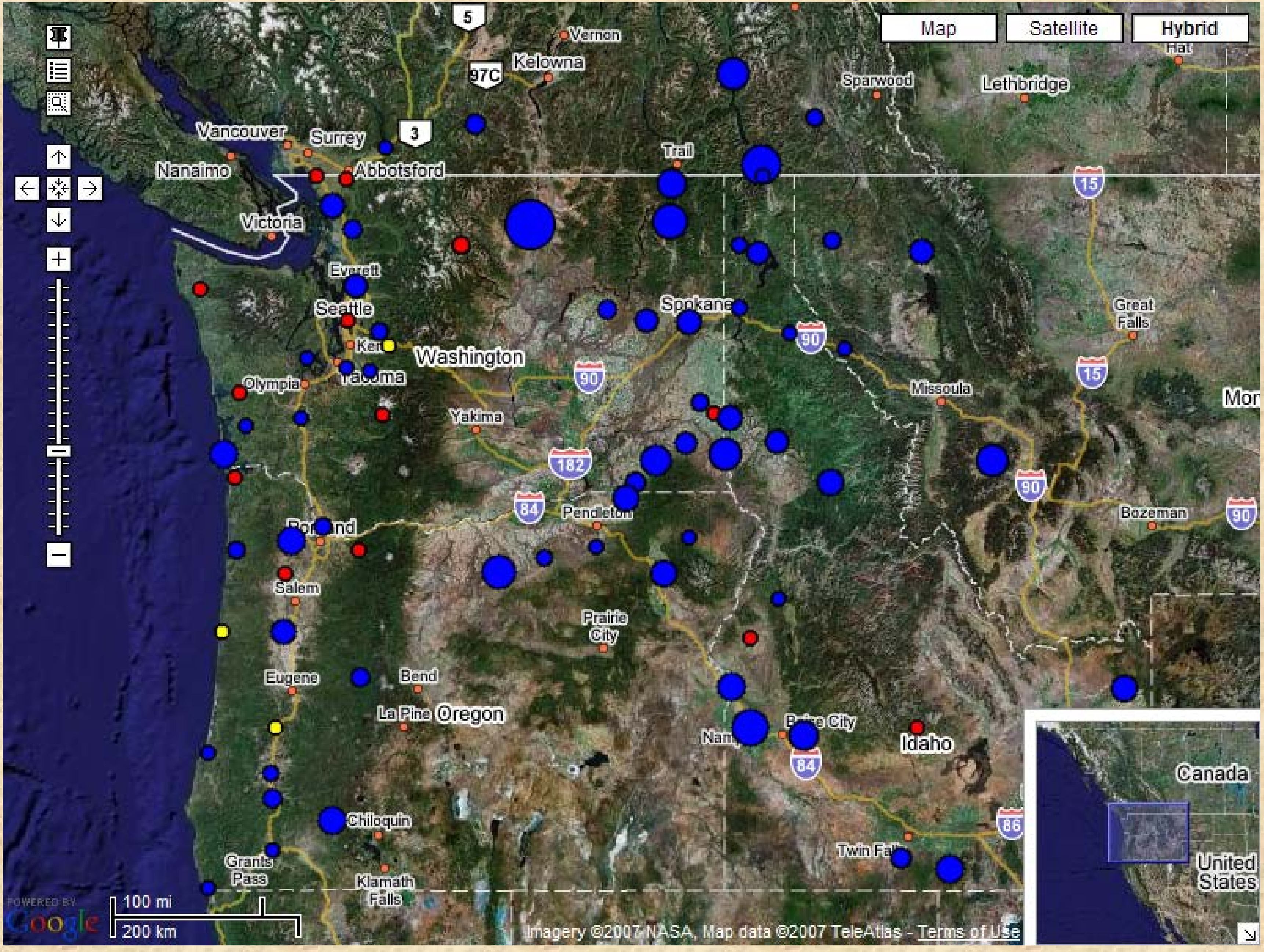
Winter Min Temperature Trend Analysis: 1915-2003



Summer Max Temperature Trend Analysis: 1915-2003

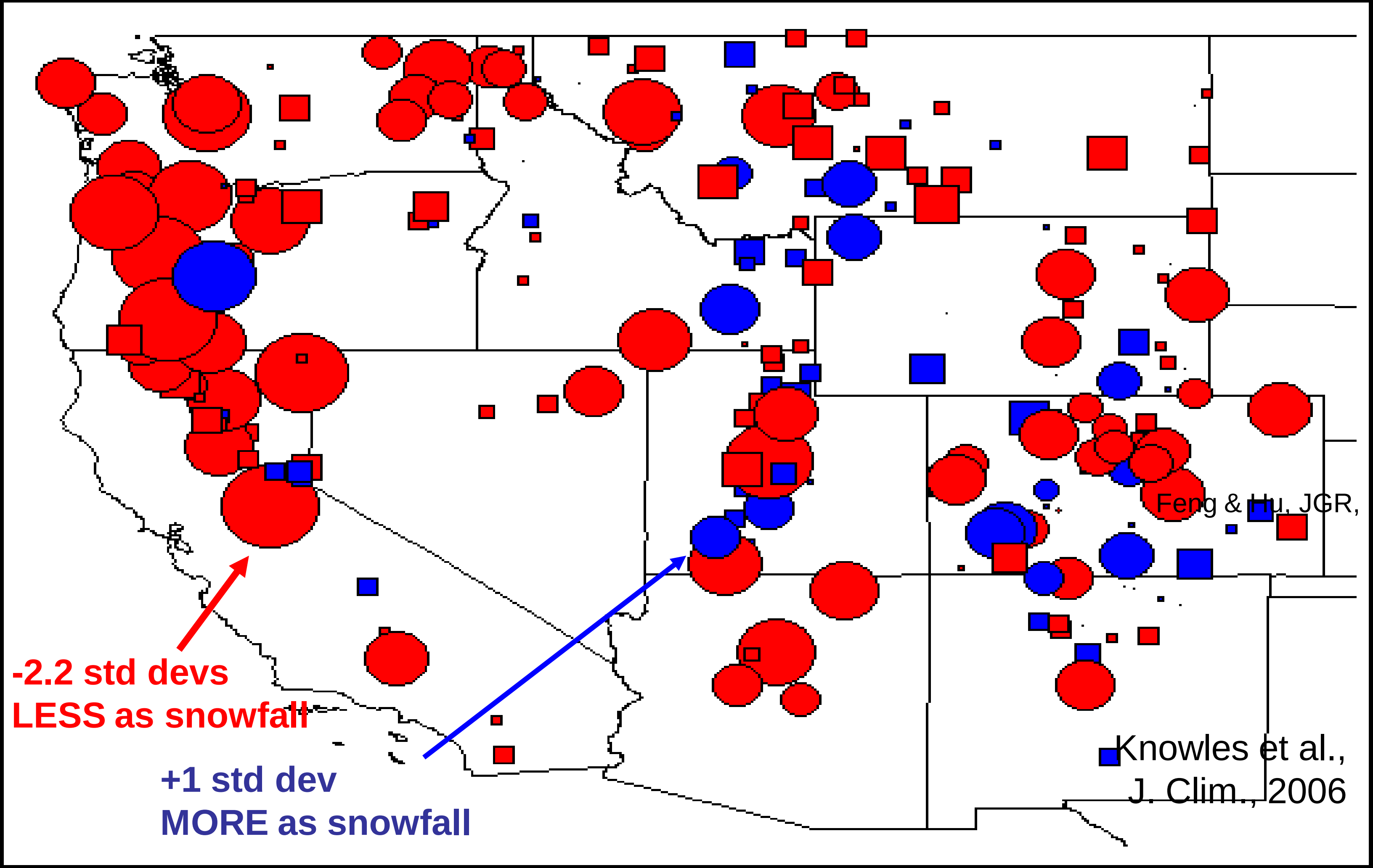


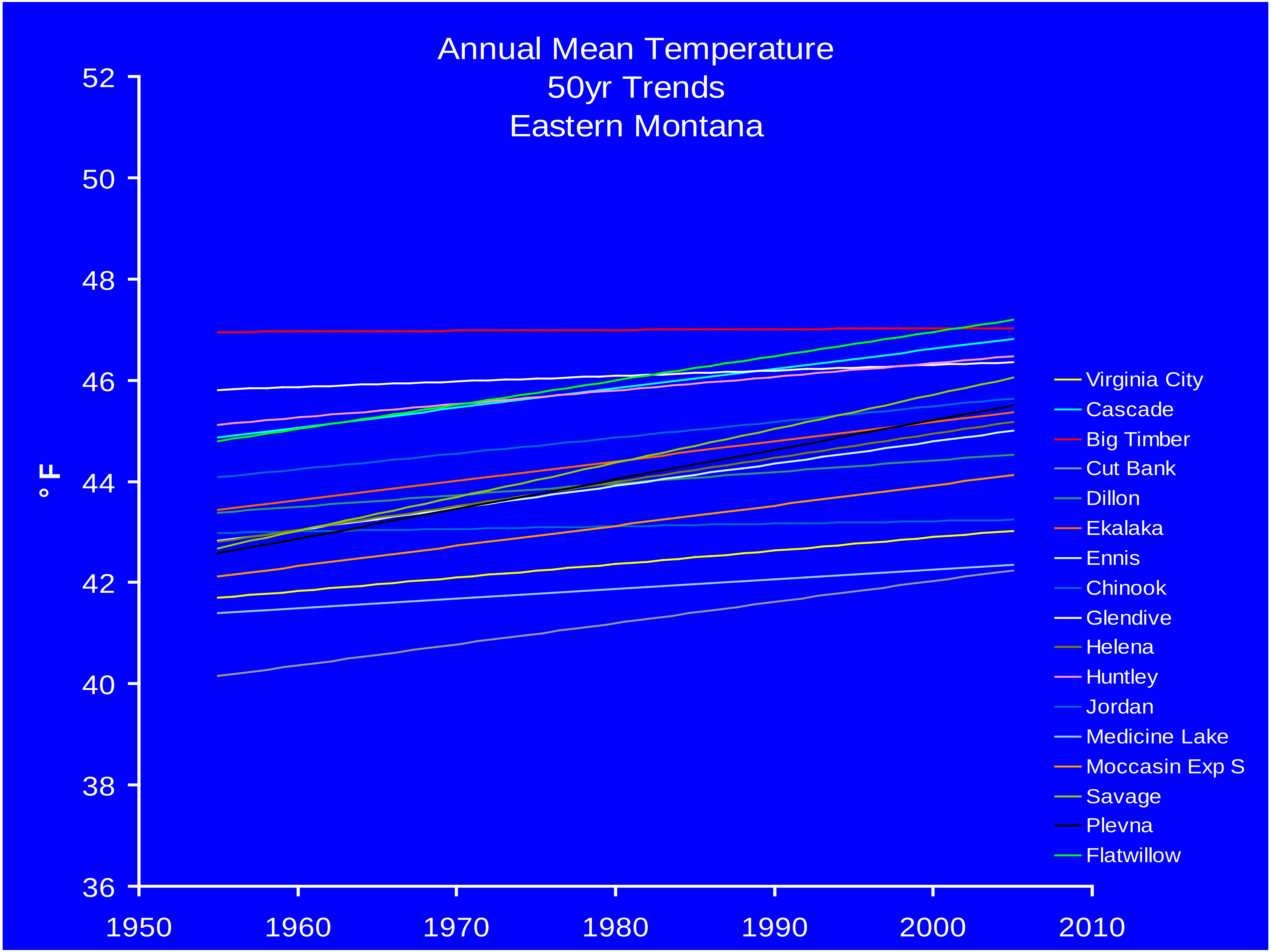
Annual Precipitation Trend Analysis: 1915-2003

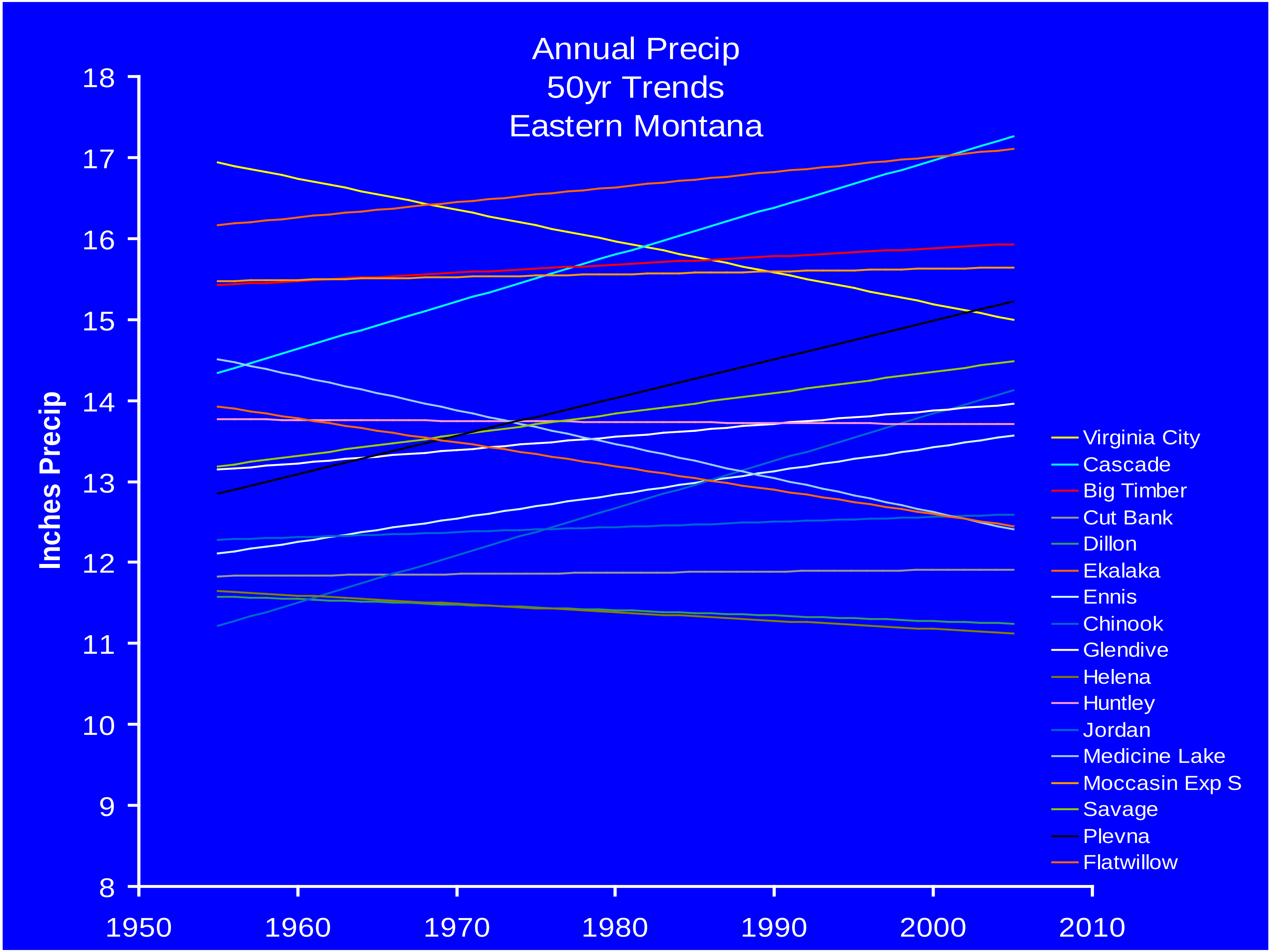


This recent warming already has driven significant hydroclimatic changes.

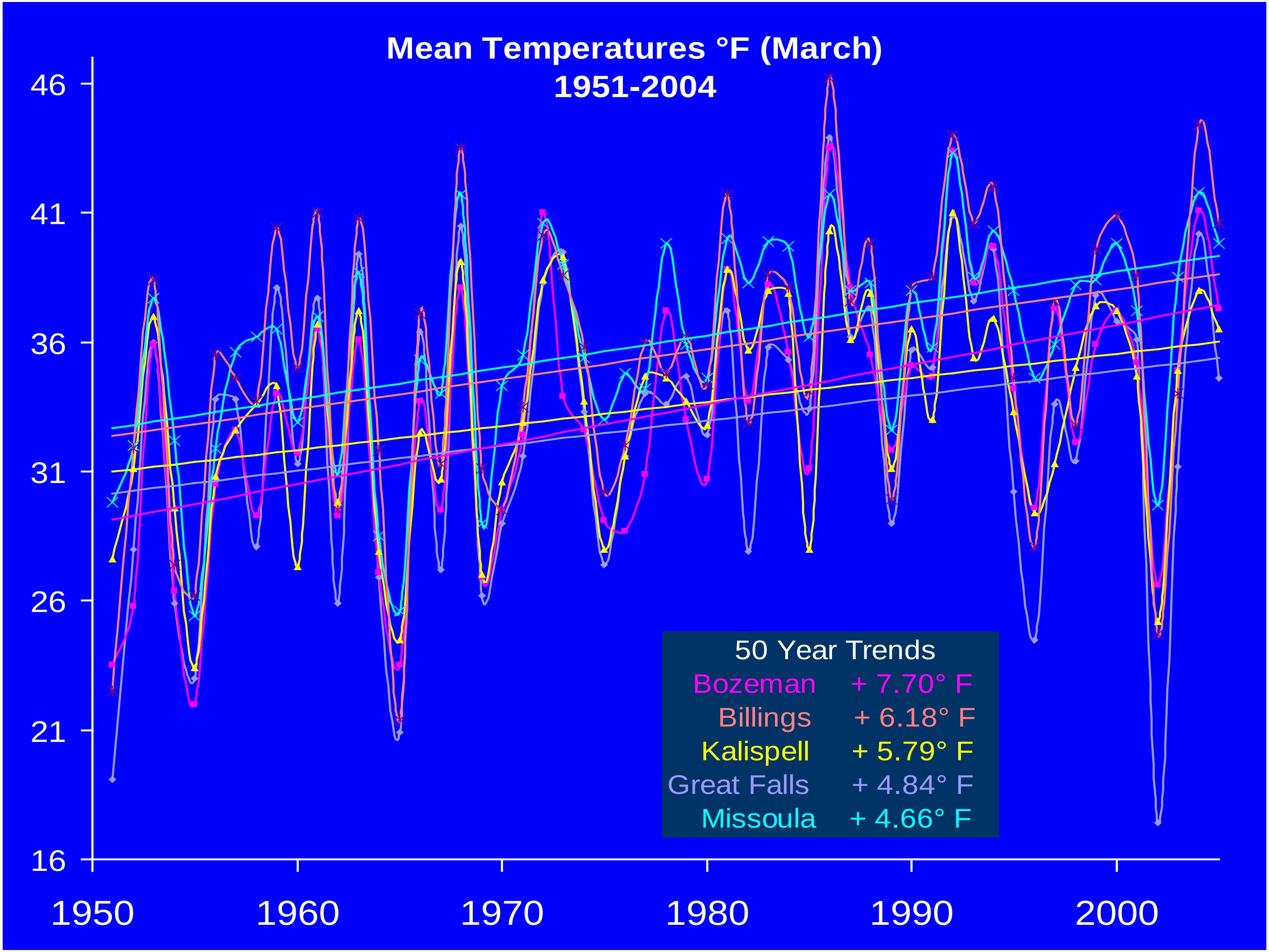
--> Less snow/more rain



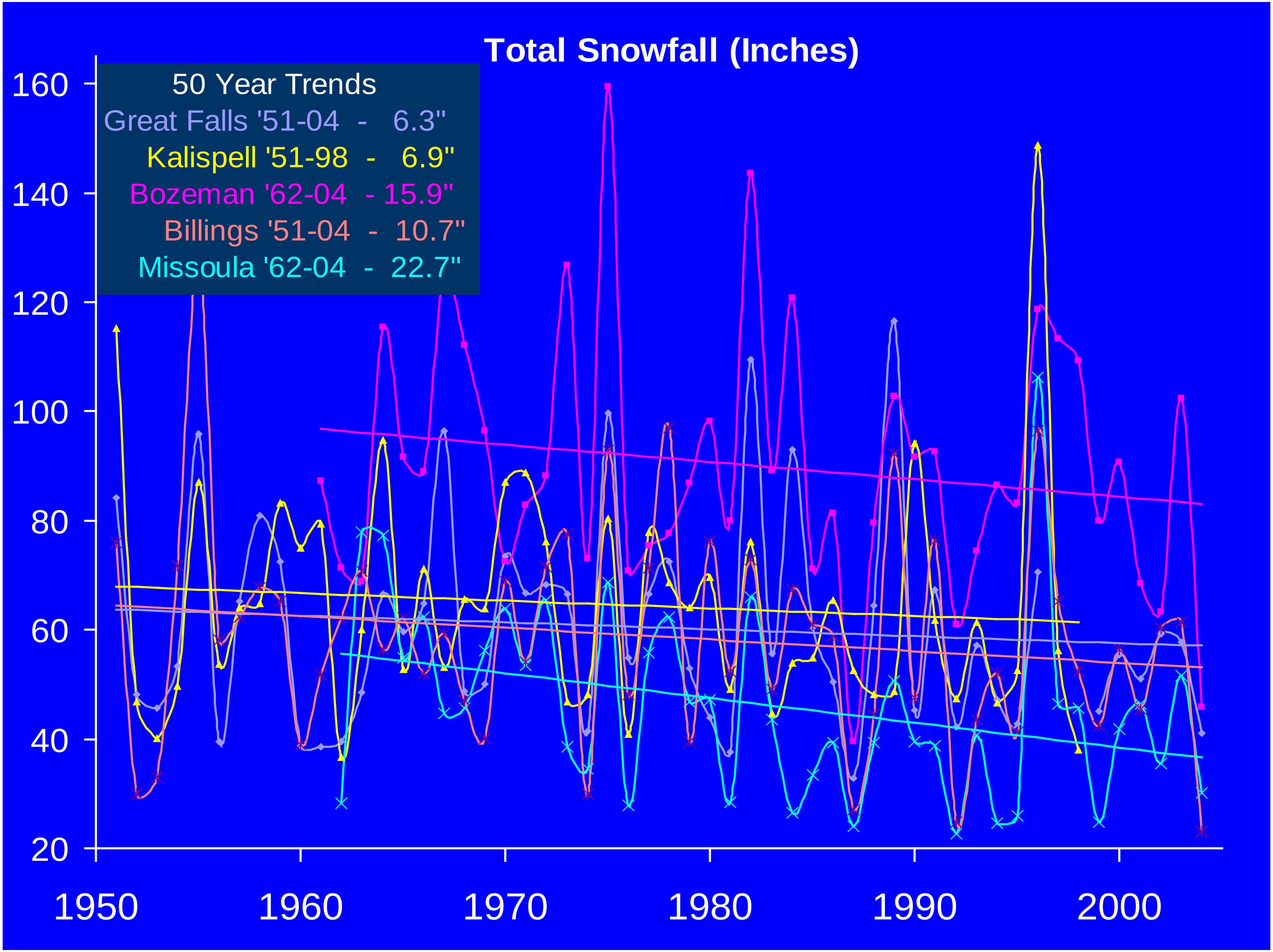

Annual Mean Temperature
50yr Trends
Eastern Montana
°F
52
50
48
46
44
42
40
38
36
1950
1960
1970
1980
1990
2000
2010
Virginia City
Cascade
Big Timber
Cut Bank
Dillon
Ekalaka
Ennis
Chinook
Glendive
Helena
Huntley
Jordan
Medicine Lake
Moccasin Exp S
Savage
Plevna
Flatwillow



Annual Precip
50yr Trends
Eastern Montana
Inches Precip
18
17
16
15
14
13
12
11
10
9
8
1950
1960
1970
1980
1990
2000
2010
Virginia City
Cascade
Big Timber
Cut Bank
Dillon
Ekalaka
Ennis
Chinook
Glendive
Helena
Huntley
Jordan
Medicine Lake
Moccasin Exp S
Savage
Plevna
Flatwillow

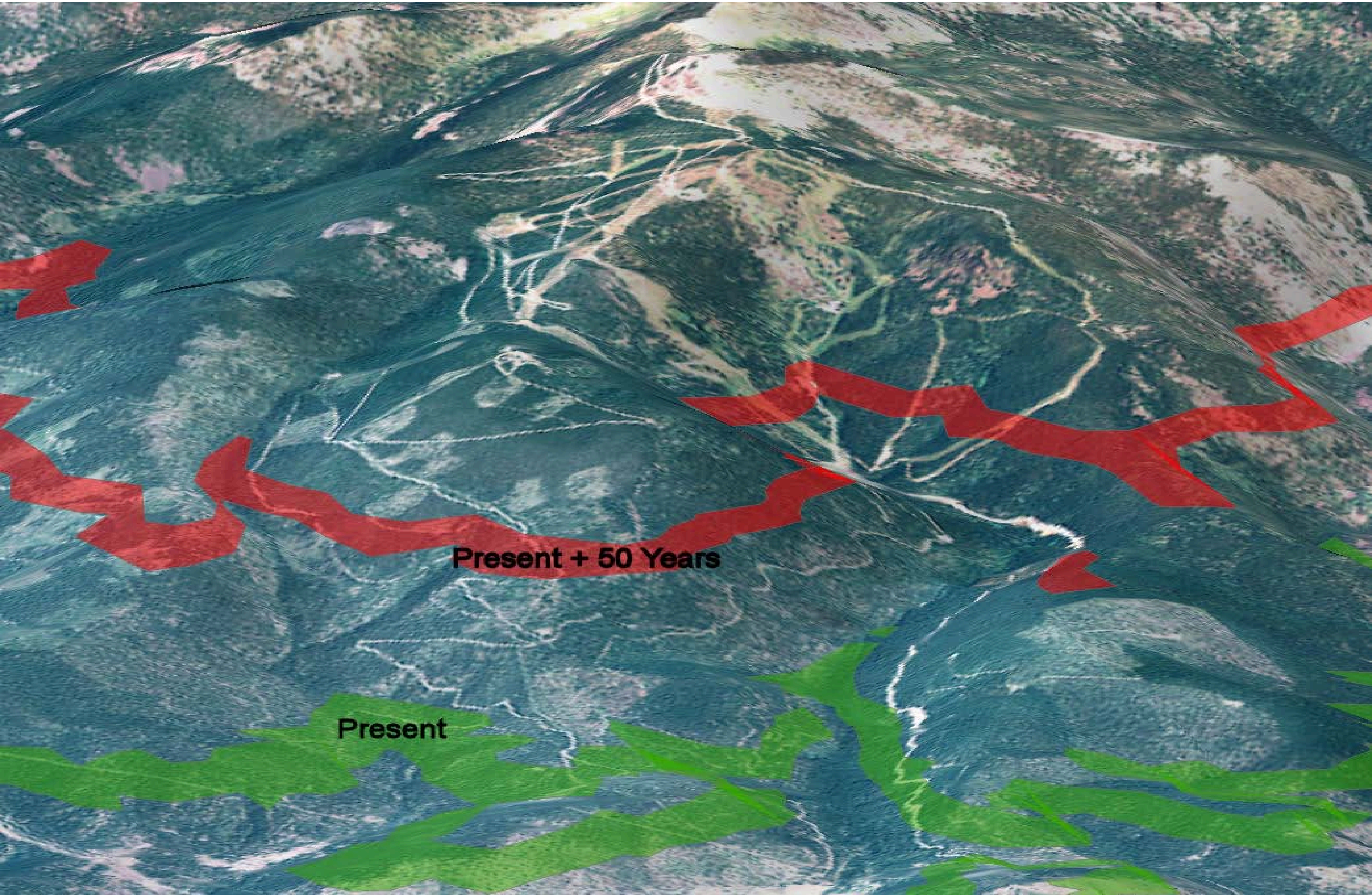


Mean Temperatures °F (March)
1951-2004
46
41
36
31
26
21
16
1950
1960
1970
1980
1990
2000
50 Year Trends
Bozeman + 7.70° F
Billings + 6.18° F
Kalispell + 5.79° F
Great Falls + 4.84° F
Missoula + 4.66° F



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

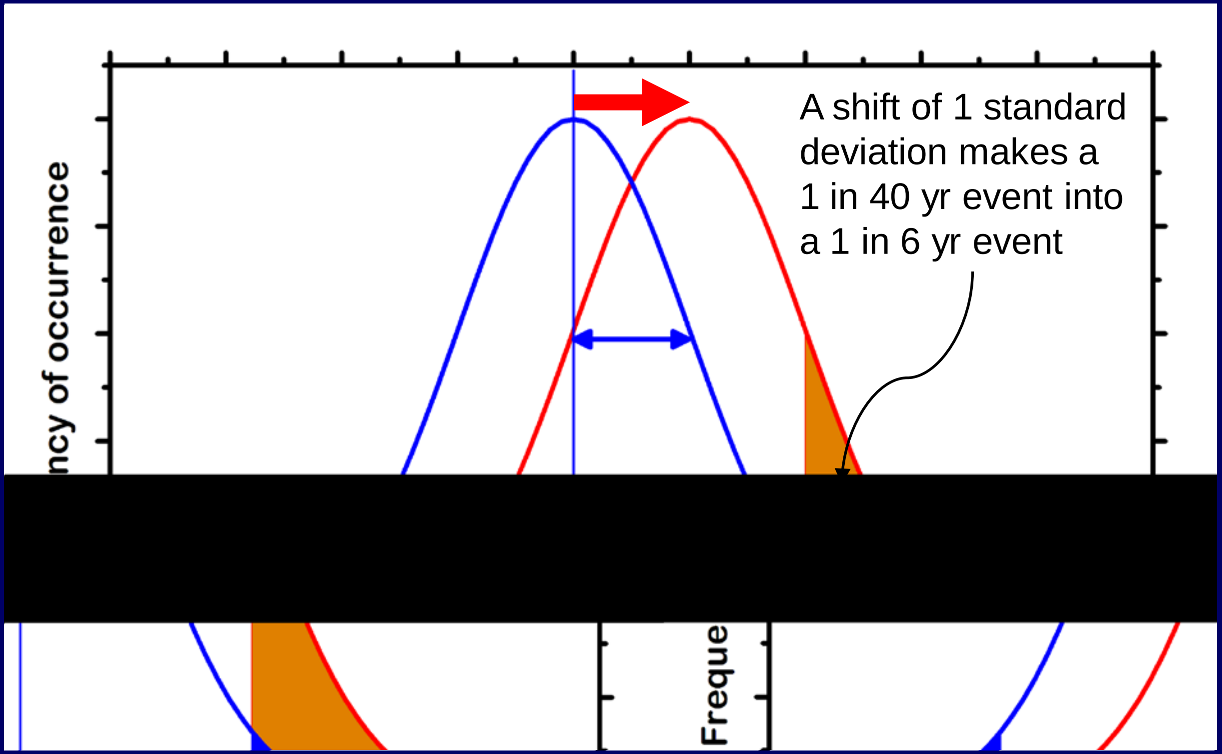
MARCH SNOWLEVEL AT SNOWBOWL 2005, 2055



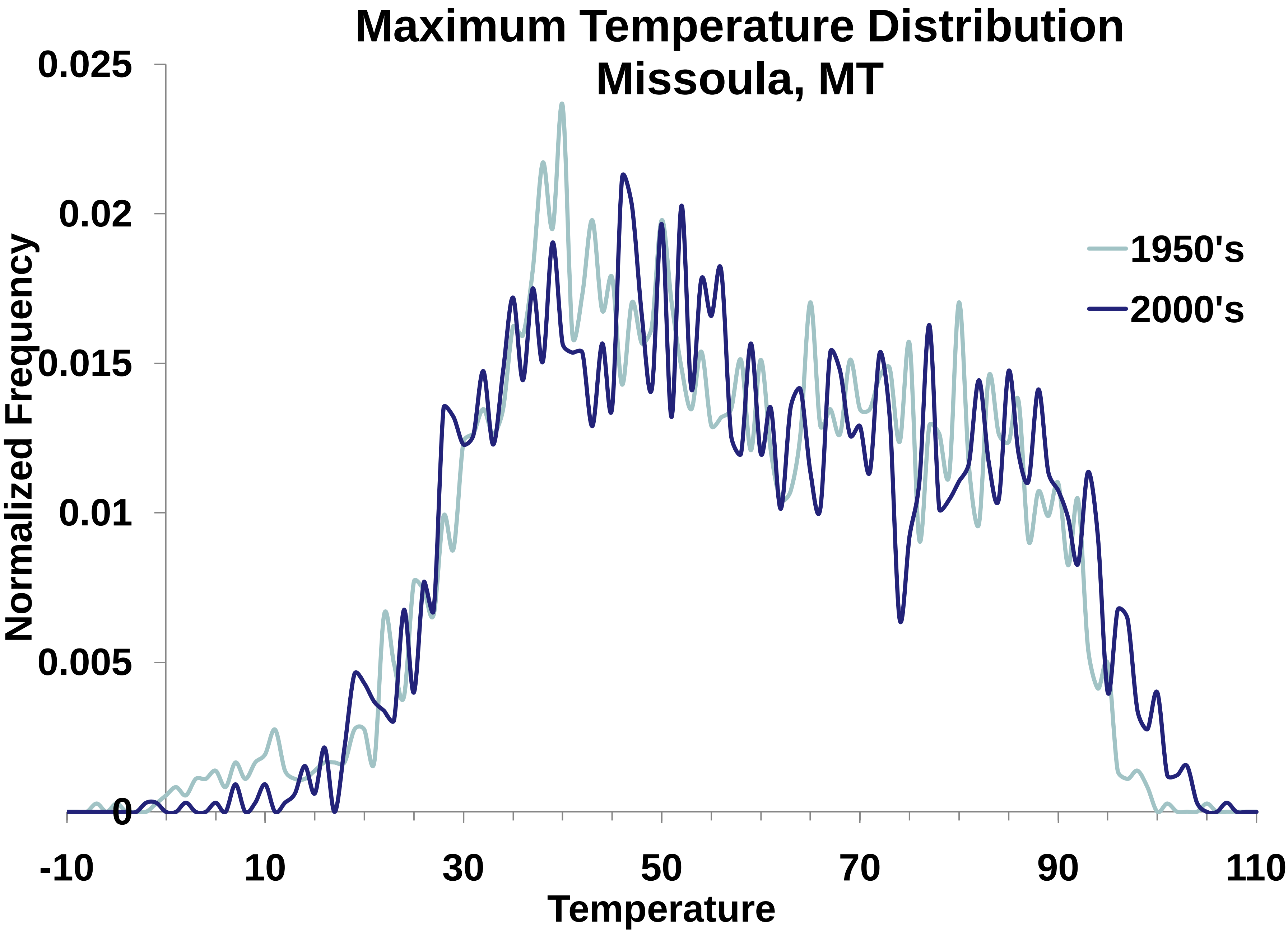
Calculus of extremes

The distribution of weather events around the climatic average often follows a ‘bell-shaped’ curve.

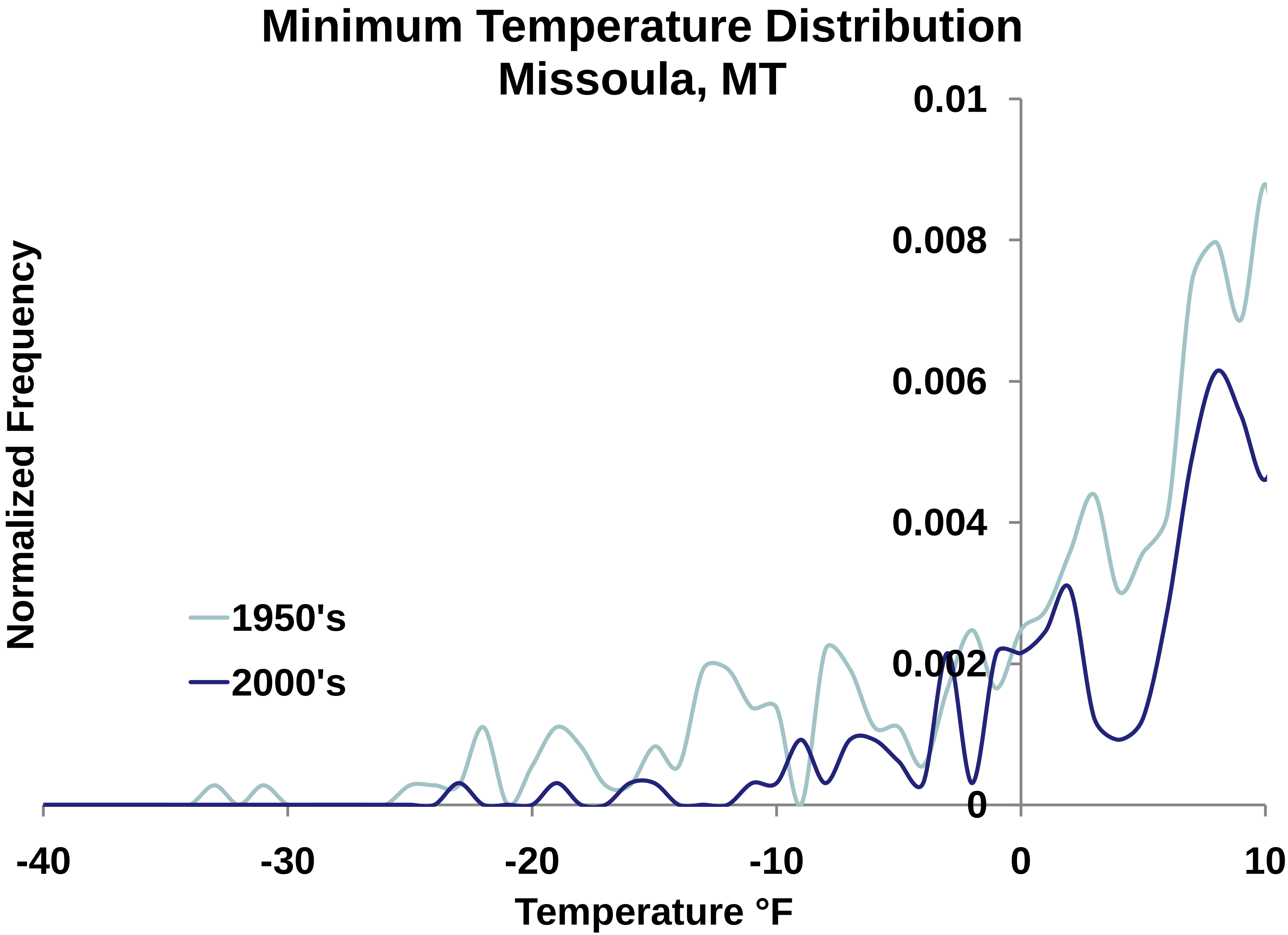
Climate change can involve change in the average, or the spread around the average (standard deviation), or both.



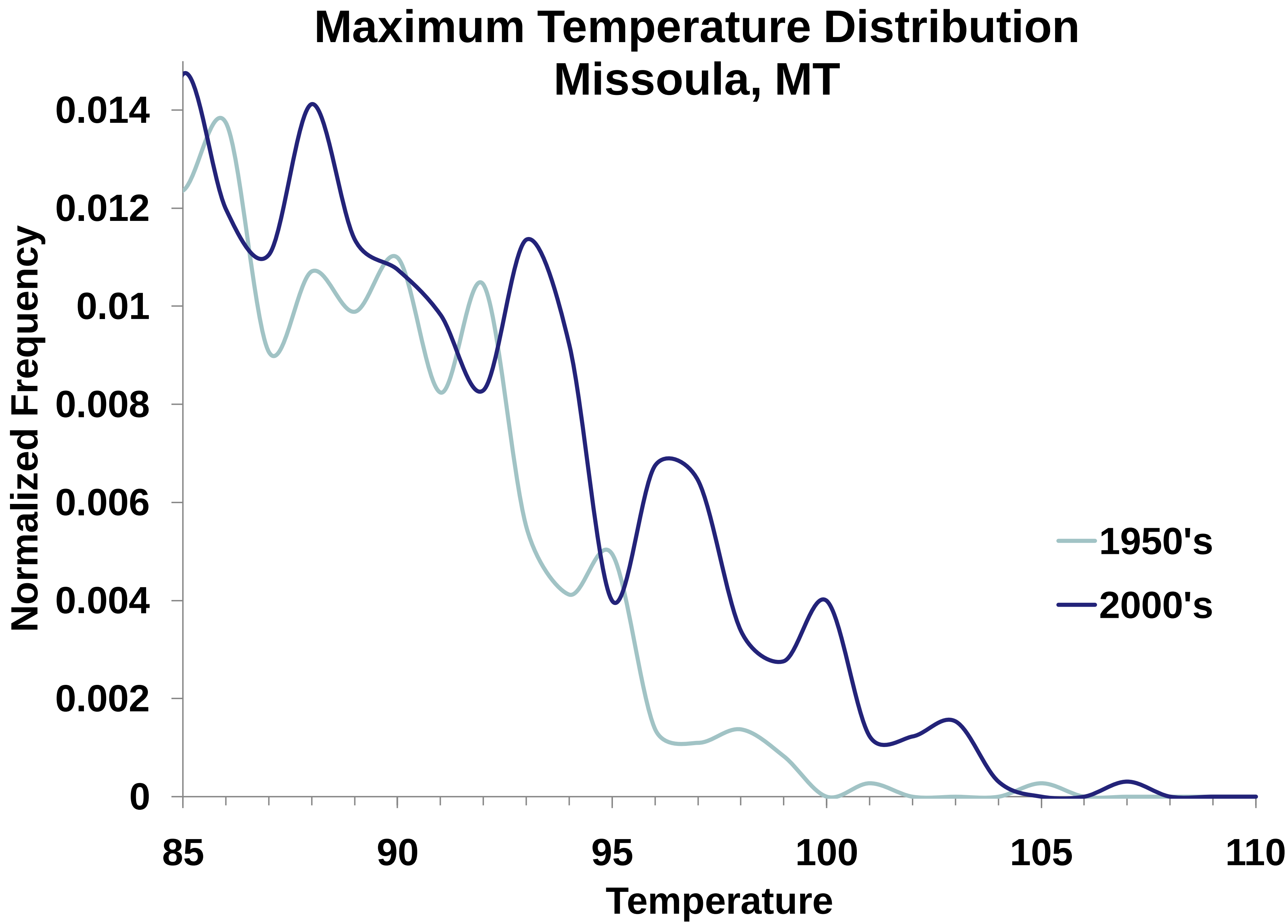
A shift in the distribution of temperatures has a much larger relative effect at the extremes than near the mean.



Maximum Temperature Distribution
Missoula, MT
0.025
0.02
0.015
0.01
0.005
0
Normalized Frequency
-10
10
30
50
70
90
110
Temperature
1950's
2000's



Minimum Temperature Distribution
Missoula, MT
Normalized Frequency
0.01
0.008
0.006
0.004
0.002
0
-40
-30
-20
-10
0
10
Temperature °F
1950's
2000's

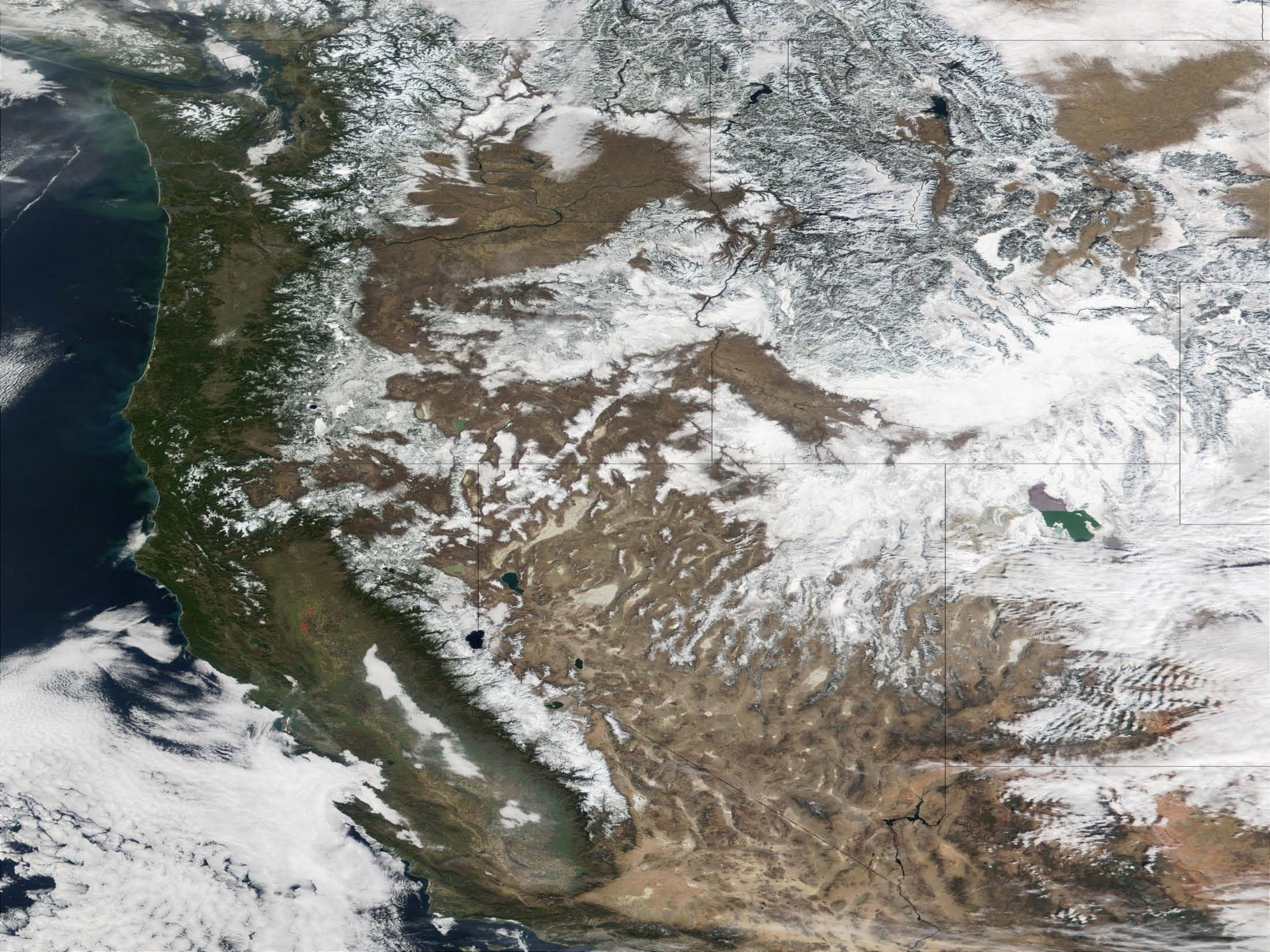

Maximum Temperature Distribution
Missoula, MT
Normalized Frequency
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
85
90
95
100
105
110
Temperature
1950's
2000's

Missoula July 07 Records

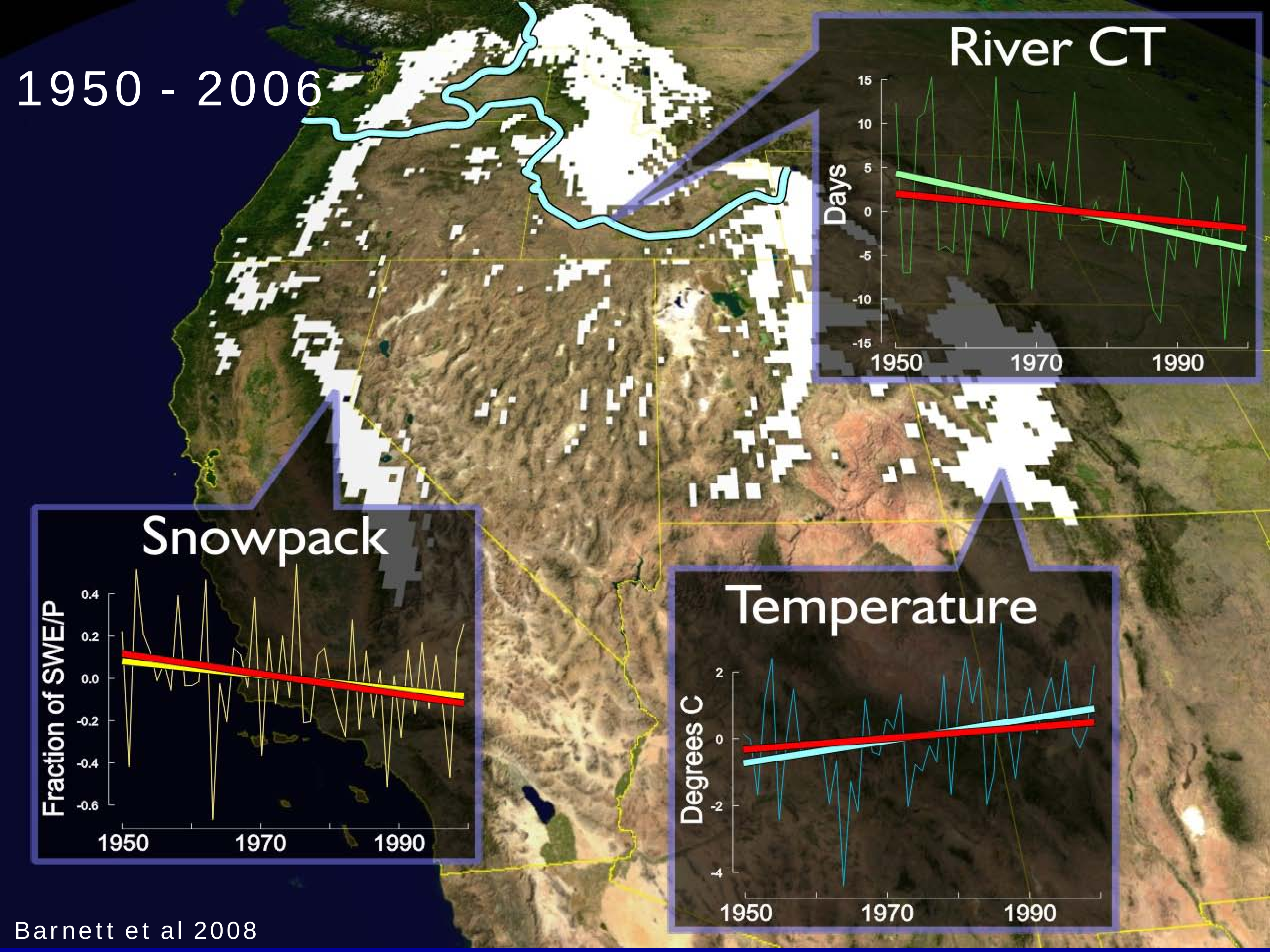
- Hottest Temperature Ever – 107
- Warmest Night Ever – 71
- Average Temp – 78.1 – 11.2 F above average
  - Breaks the old record by 3.3F
- Most number of 100 F days – 11
  - Old record – 6 in 1936
- Most number of nights 60F and above – 18
  - Old record – 10 in 1985
- Driest July on record at Missoula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

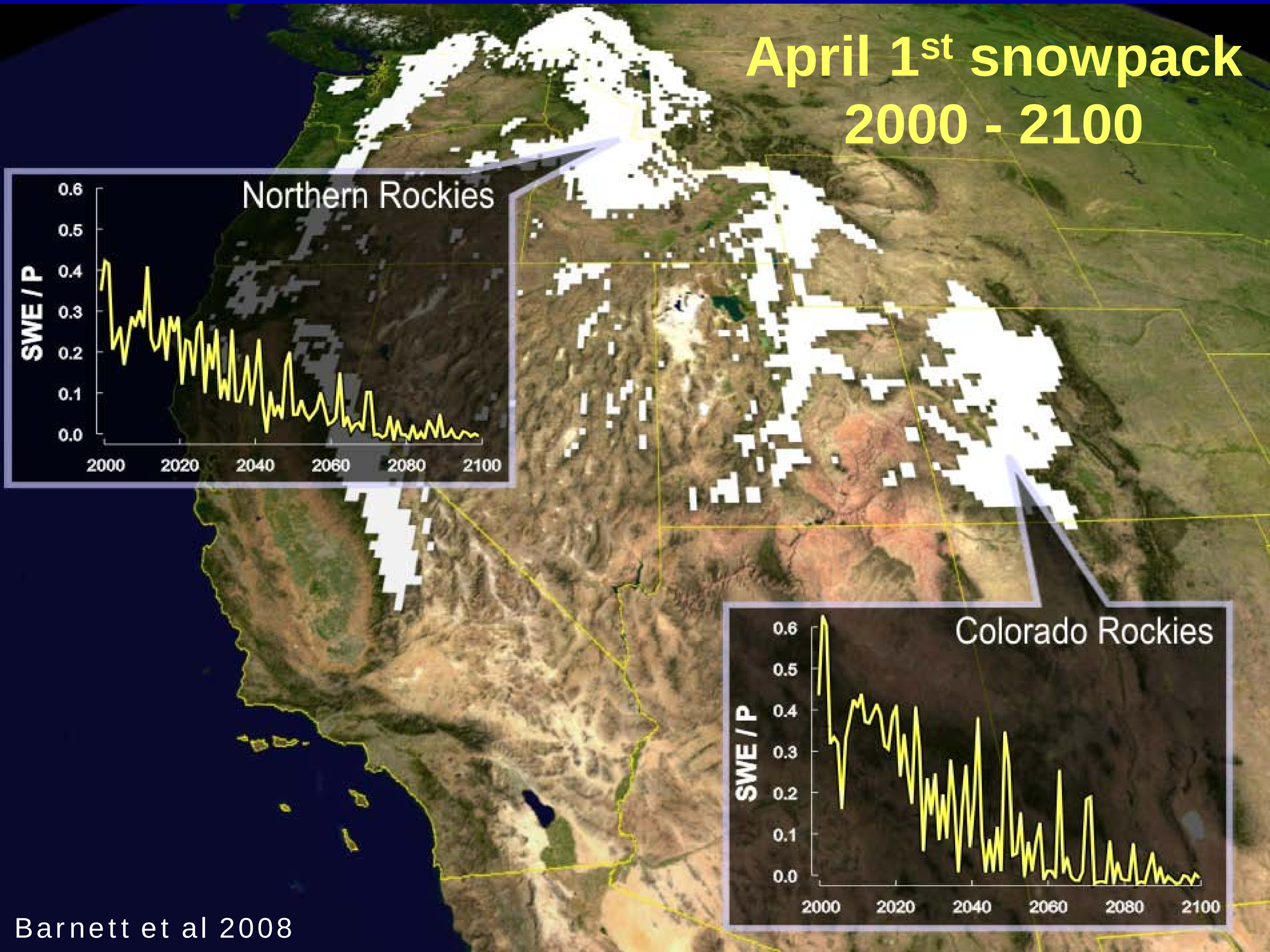
From Gene Petrescu, NWS, Missoula

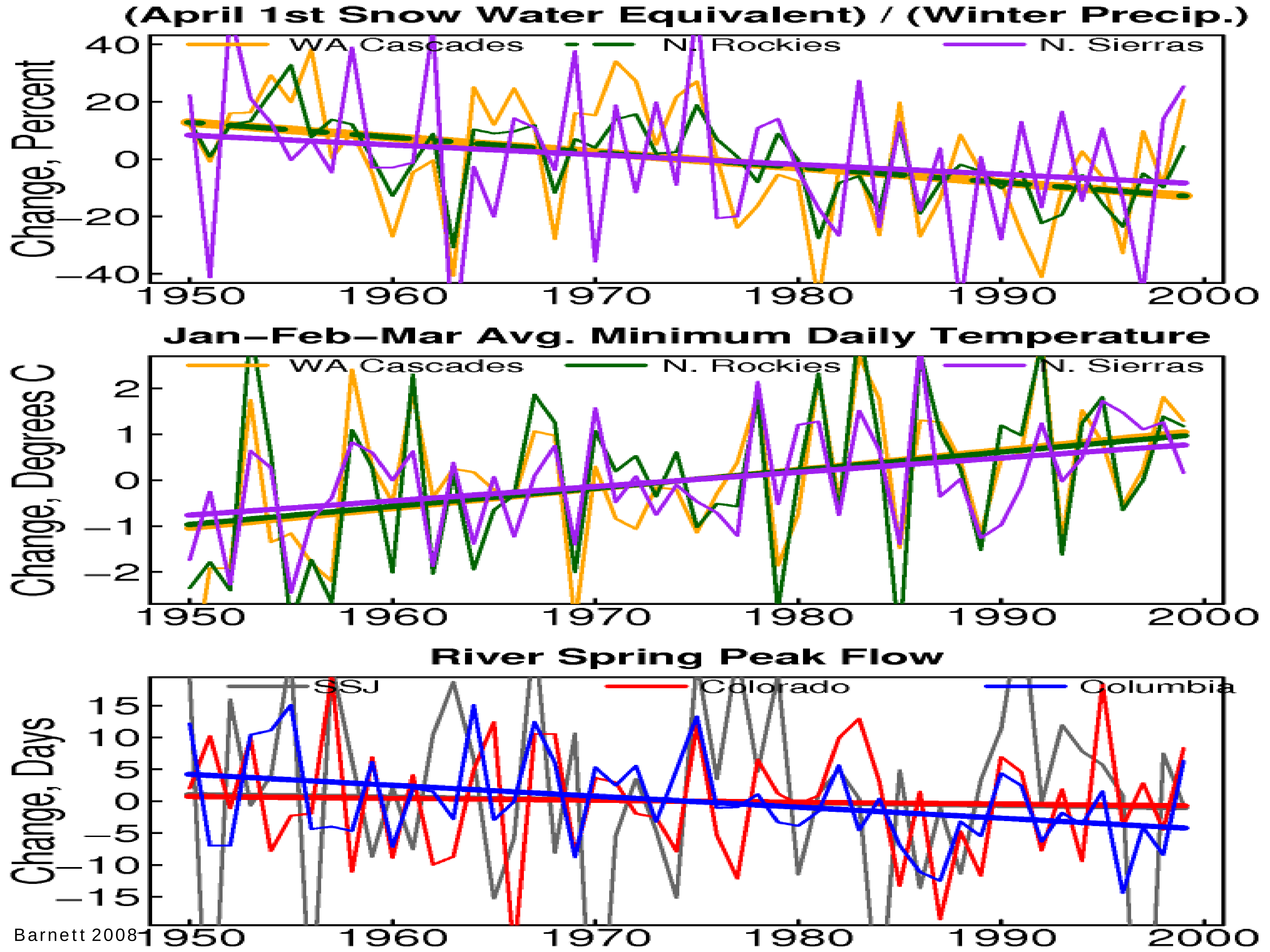
THIS WILL BE A NORMAL JULY IN 2050!!



March 4 2007, 7,000ft, North-slope Bitterroot Mtns, Montana

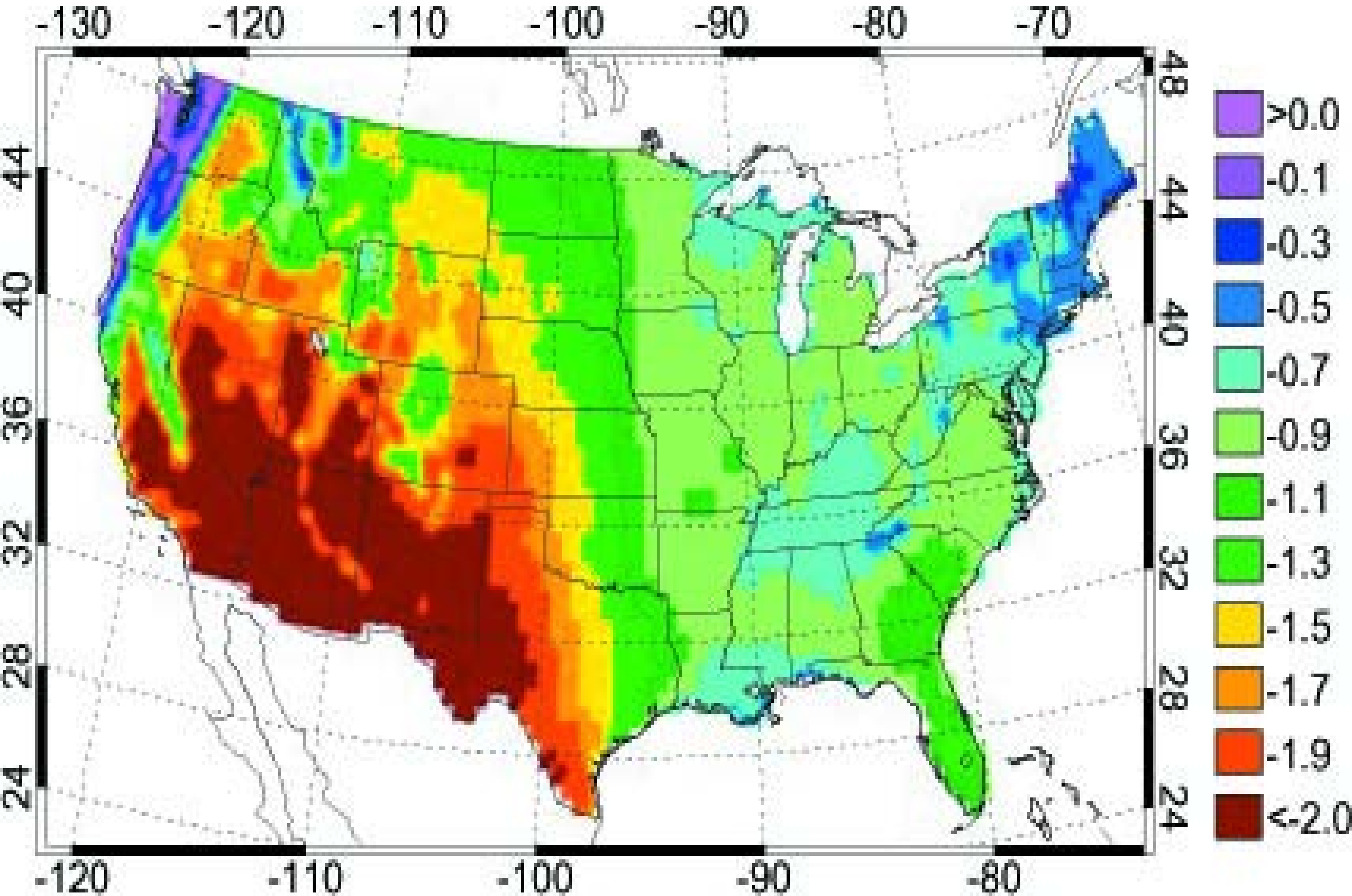

1950 - 2006
River CT
Days
15
10
5
0
-5
-10
-15
1950
1970
1990
Snowpack
Fraction of SWE/P
0.4
0.2
0.0
-0.2
-0.4
-0.6
1950
1970
1990
Temperature
Degrees C
2
0
-2
-4
1950
1970
1990
Barnett et al 2008


April 1st snowpack
2000 - 2100
Northern Rockies
SWE / P
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2000
2020
2040
2060
2080
2100
Colorado Rockies
SWE / P
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2000
2020
2040
2060
2080
2100
Barnett et al 2008

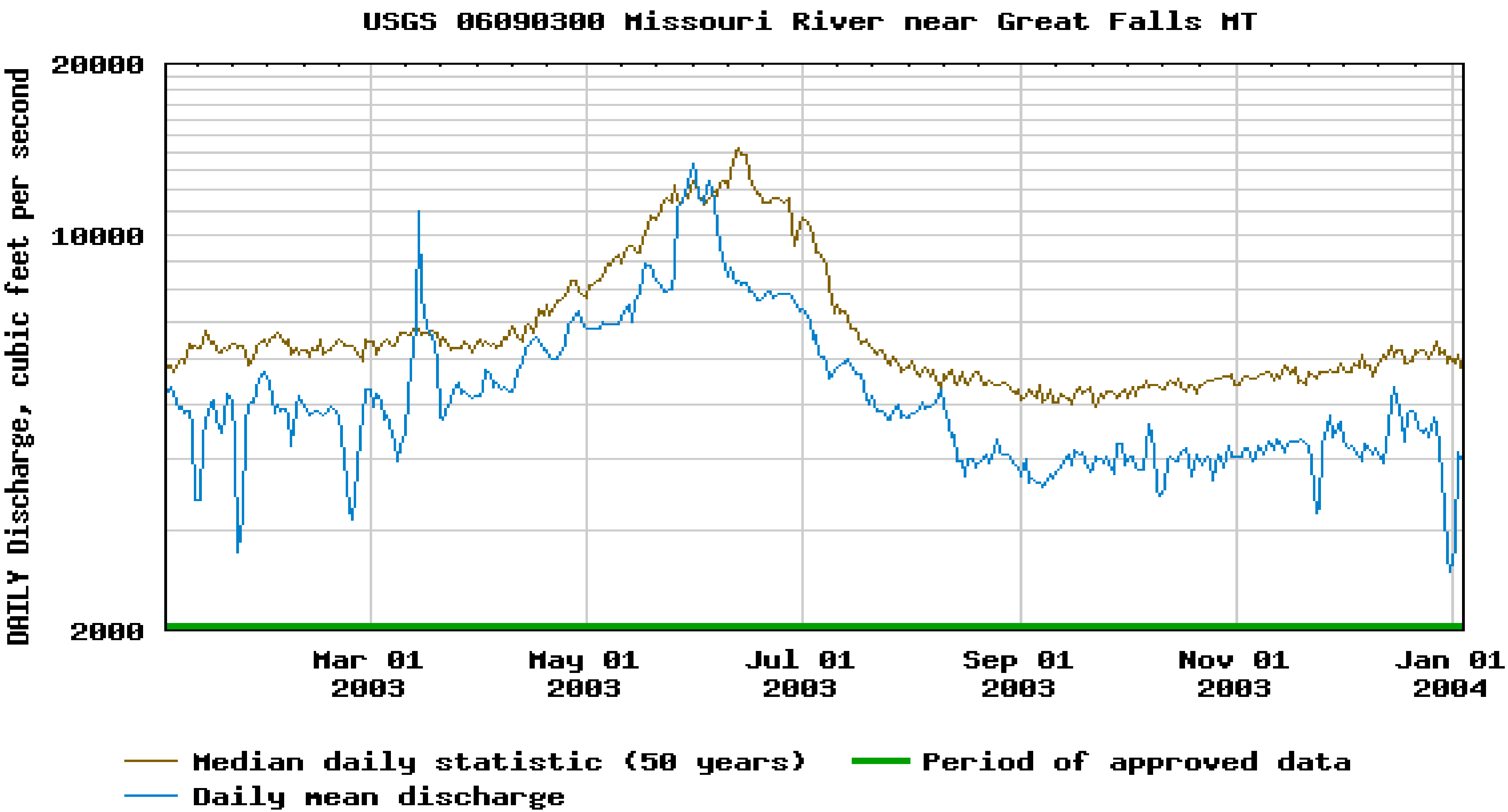


(April 1st Snow Water Equivalent) / (Winter Precip.)
WA Cascades
N. Rockies
N. Sierras
Change, Percent
40
20
0
−20
−40
1950
1960
1970
1980
1990
2000
Jan−Feb−Mar Avg. Minimum Daily Temperature
WA Cascades
N. Rockies
N. Sierras
Change, Degrees C
2
1
0
−1
−2
1950
1960
1970
1980
1990
2000
River Spring Peak Flow
SSJ
Colorado
Columbia
Change, Days
15
10
5
0
−5
−10
−15
1950
1960
1970
1980
1990
2000
Barnett 2008

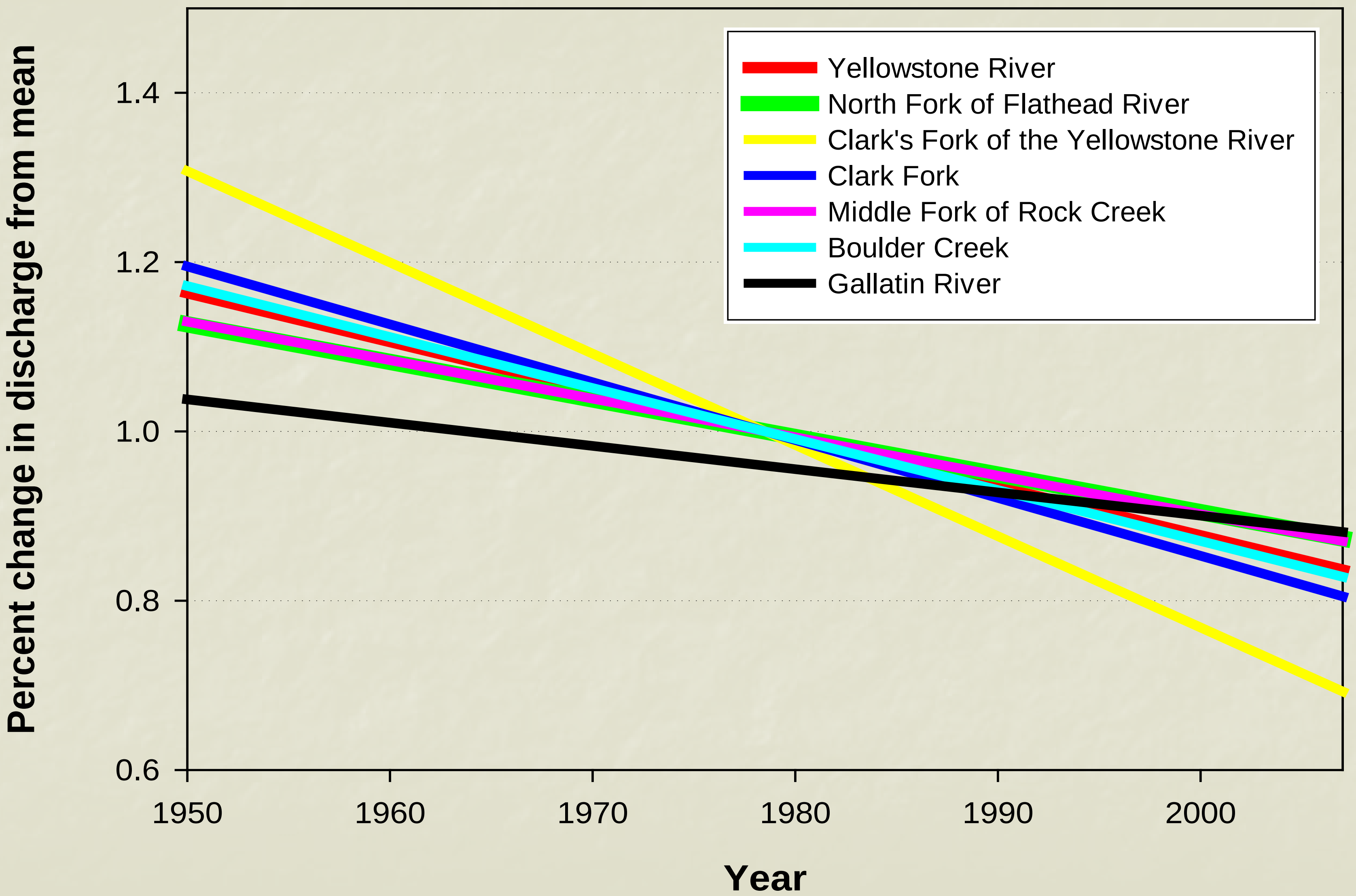
Geographic Variation in Annual Water Balance
(Precip - *Potential* ET, meters per year)

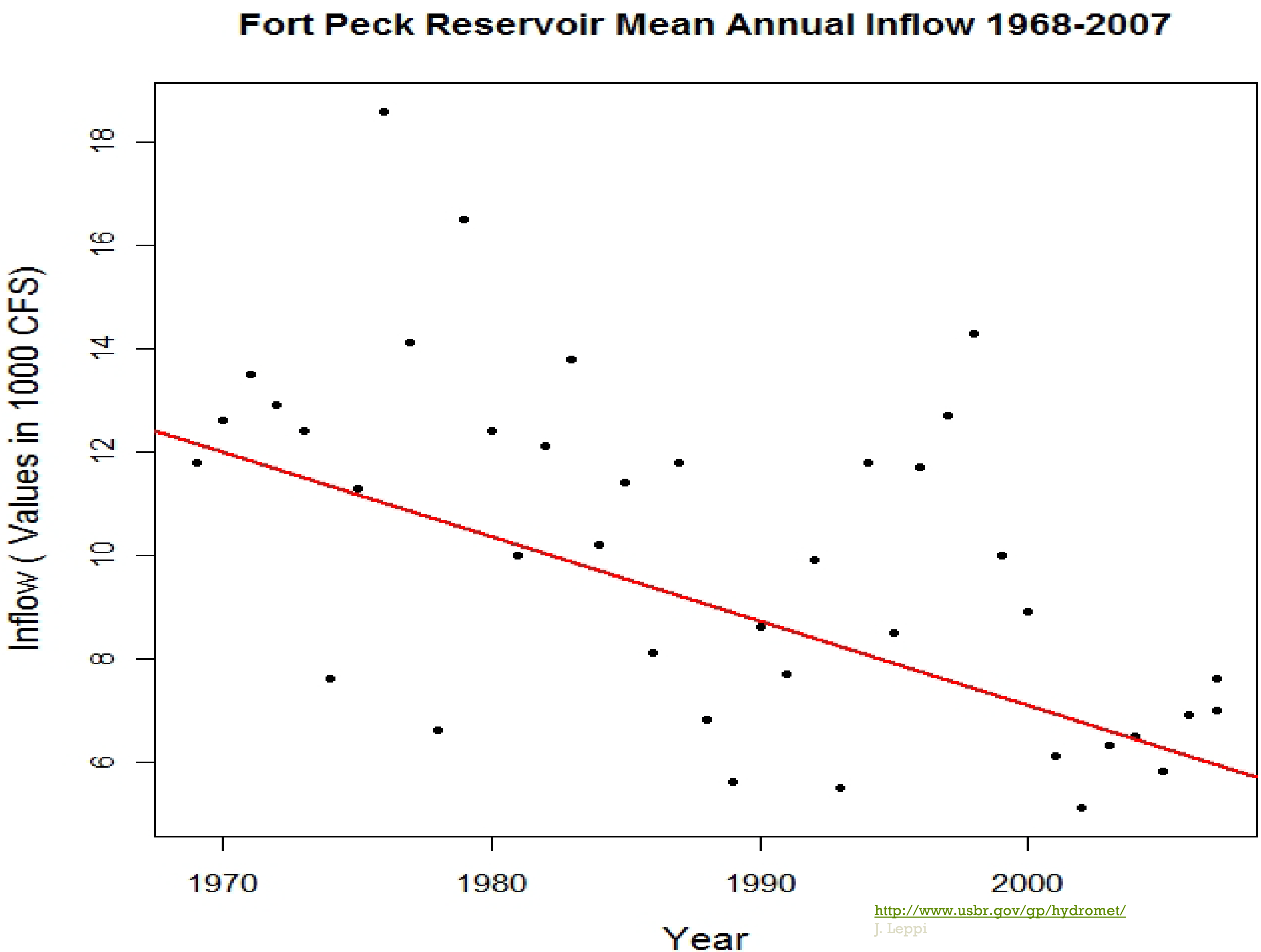


Montana's Streamflow is decreasing and peaking earlier



Montana Mean August stream Discharge 1950-2007



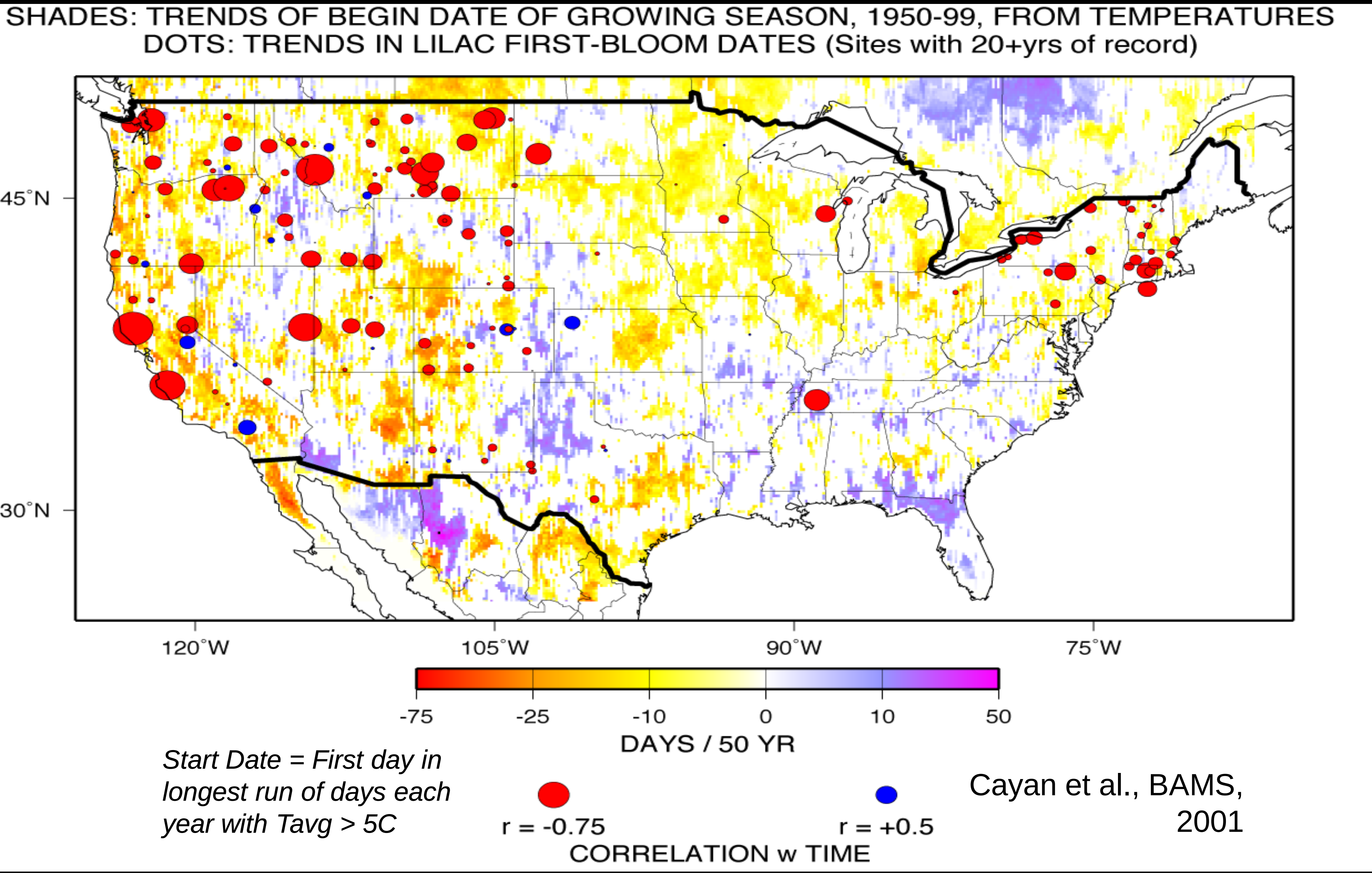


http://www.usbr.gov/gp/hydromet/

J. Leppi

ECOSYSTEM RESPONSES

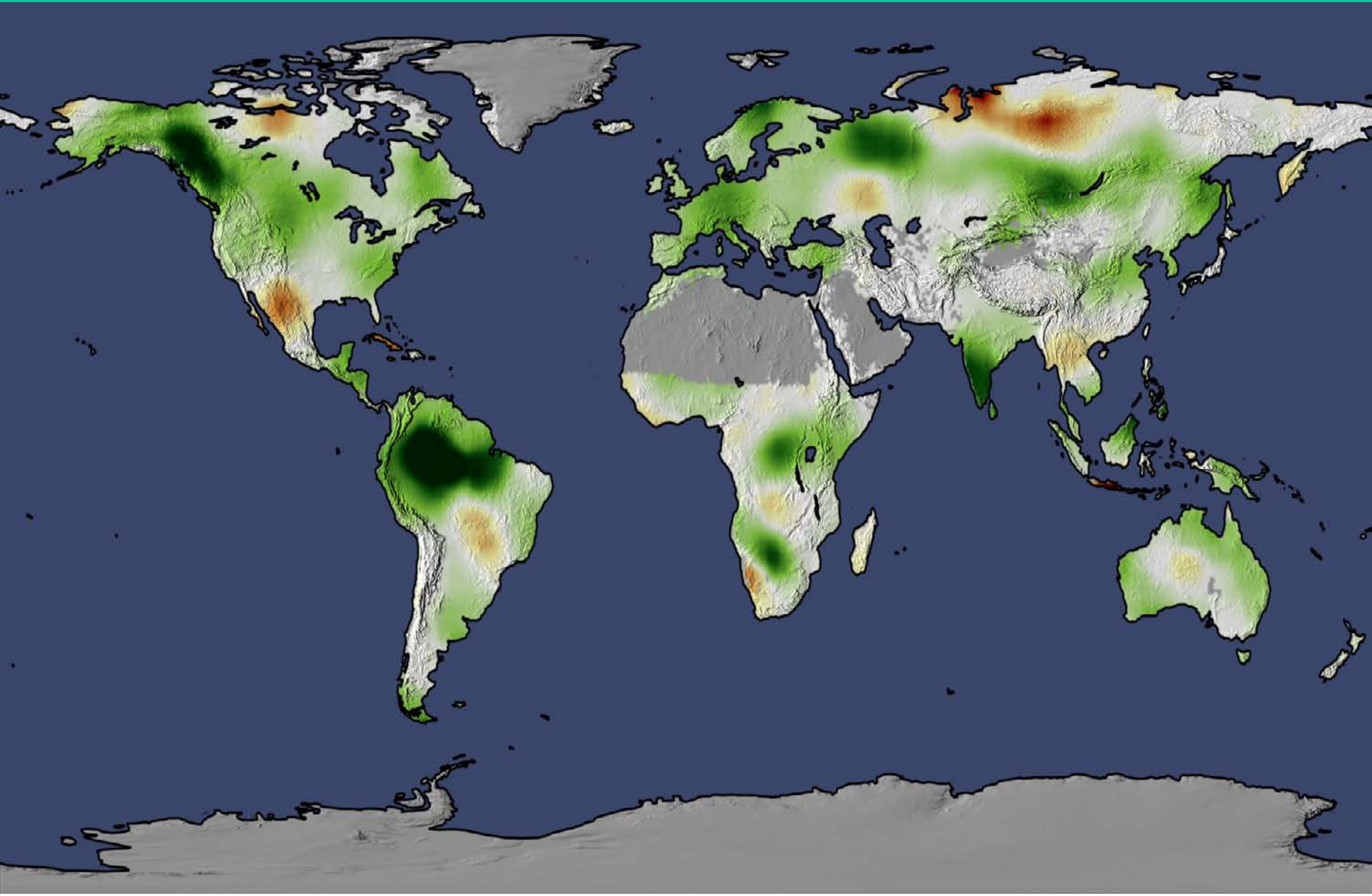
The warming has lengthened growing seasons and hastened green-up dates.



Start Date = First day in longest run of days each year with Tavg > 5C

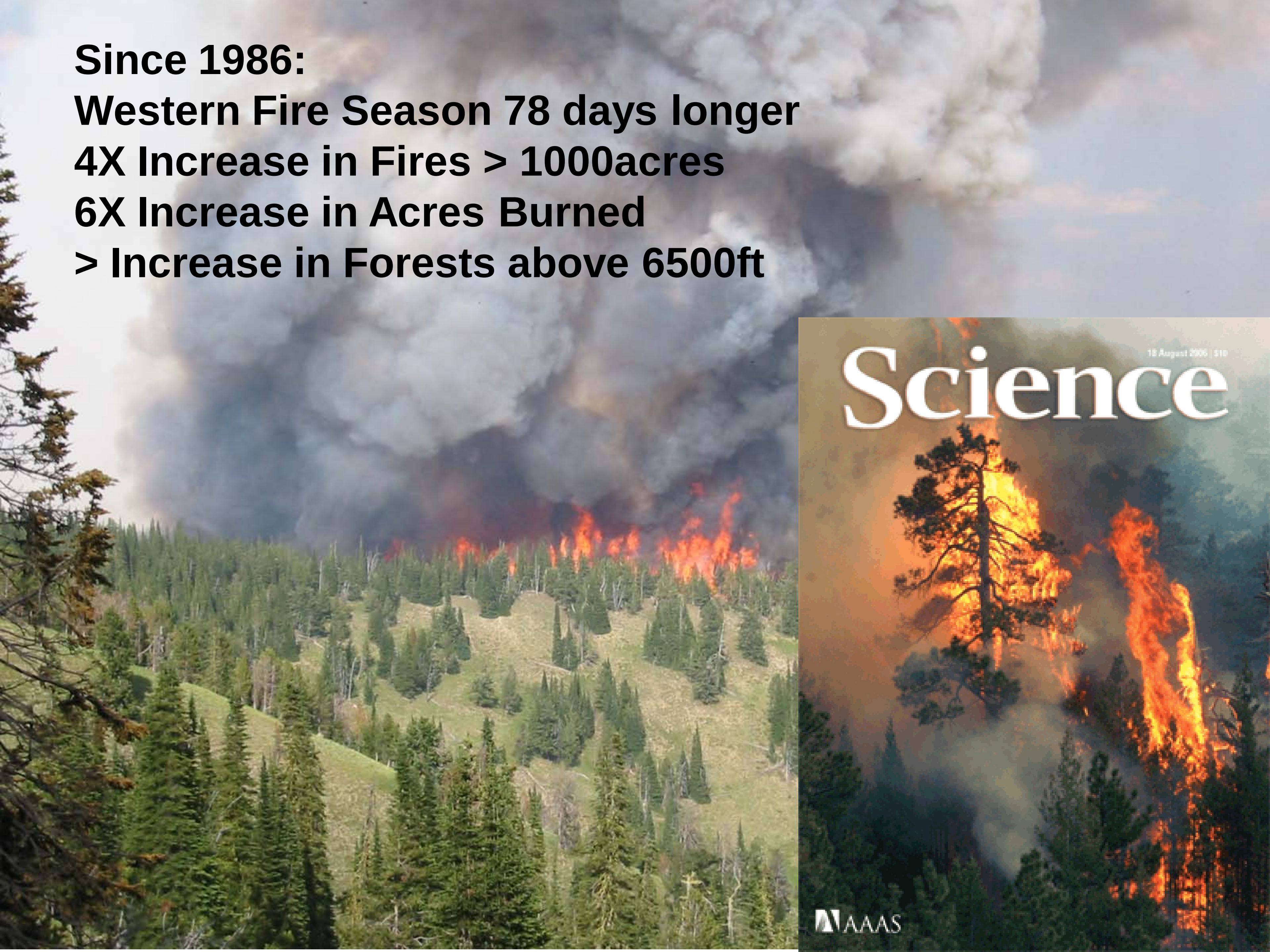
Cayan et al., BAMS, 2001

Change in Terrestrial NPP from 1982 to 1999.

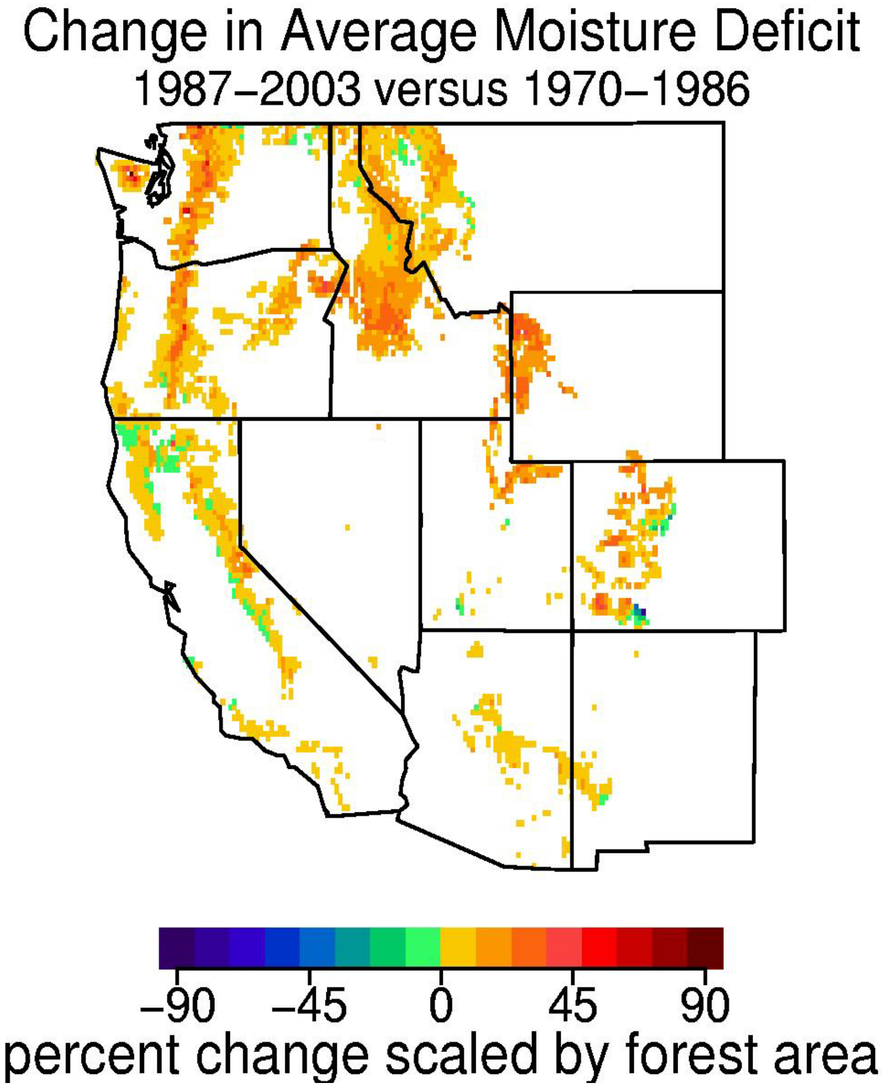


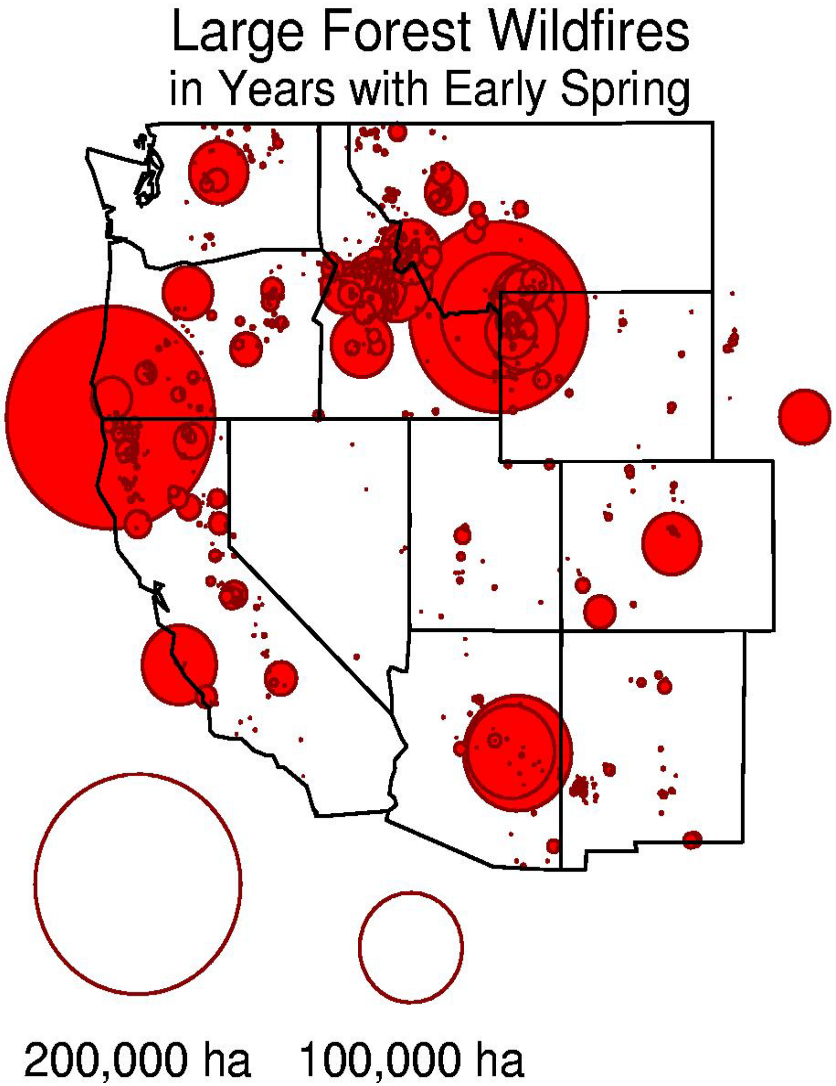
Nemani et al., Science June 6th 2003

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
Science
AAAS

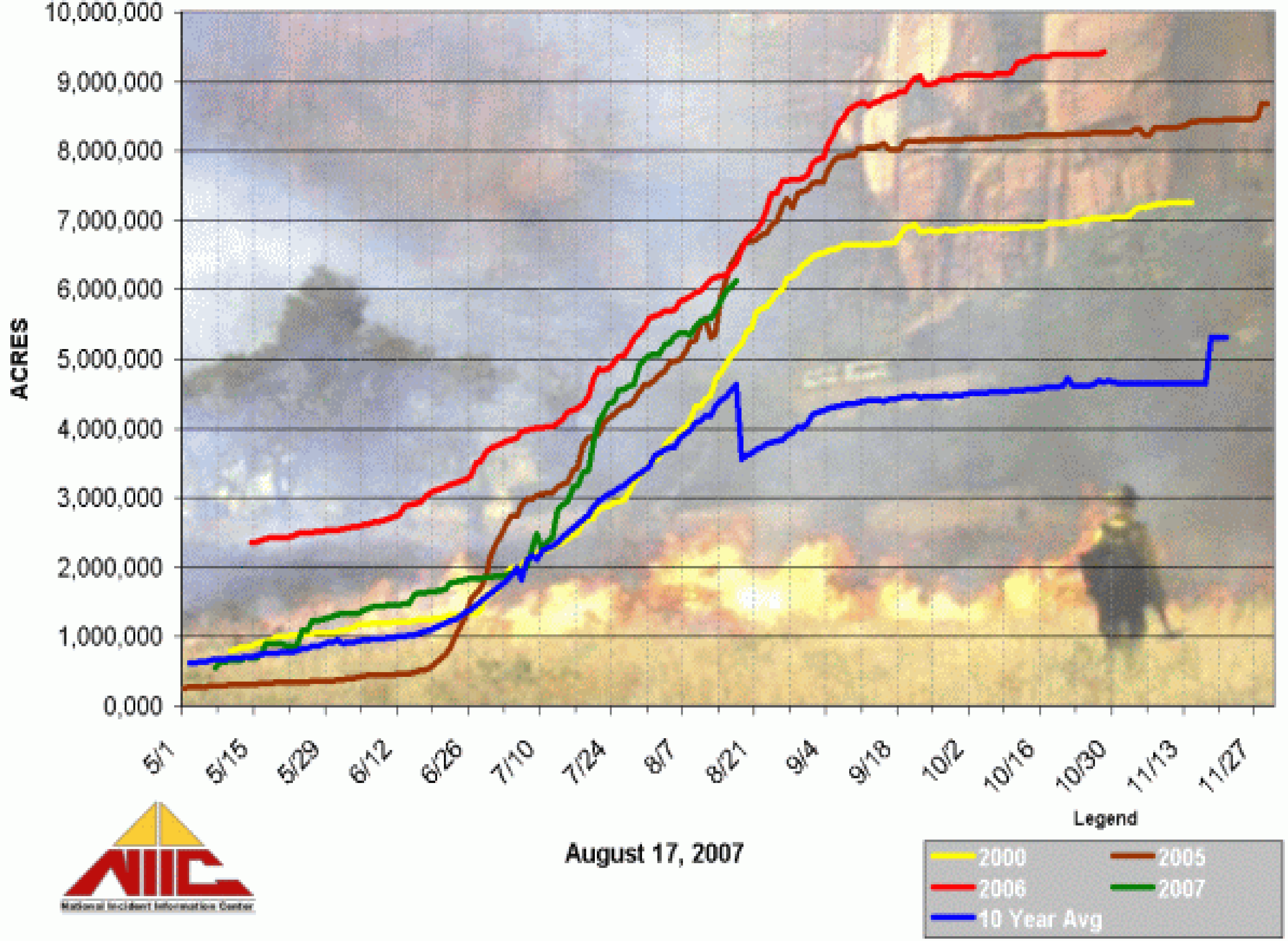
Wildfires accelerate 1970 – 2003 with early snowmelt, longer, drier summers





Westerling et al Science 2006, Running, Science 2006

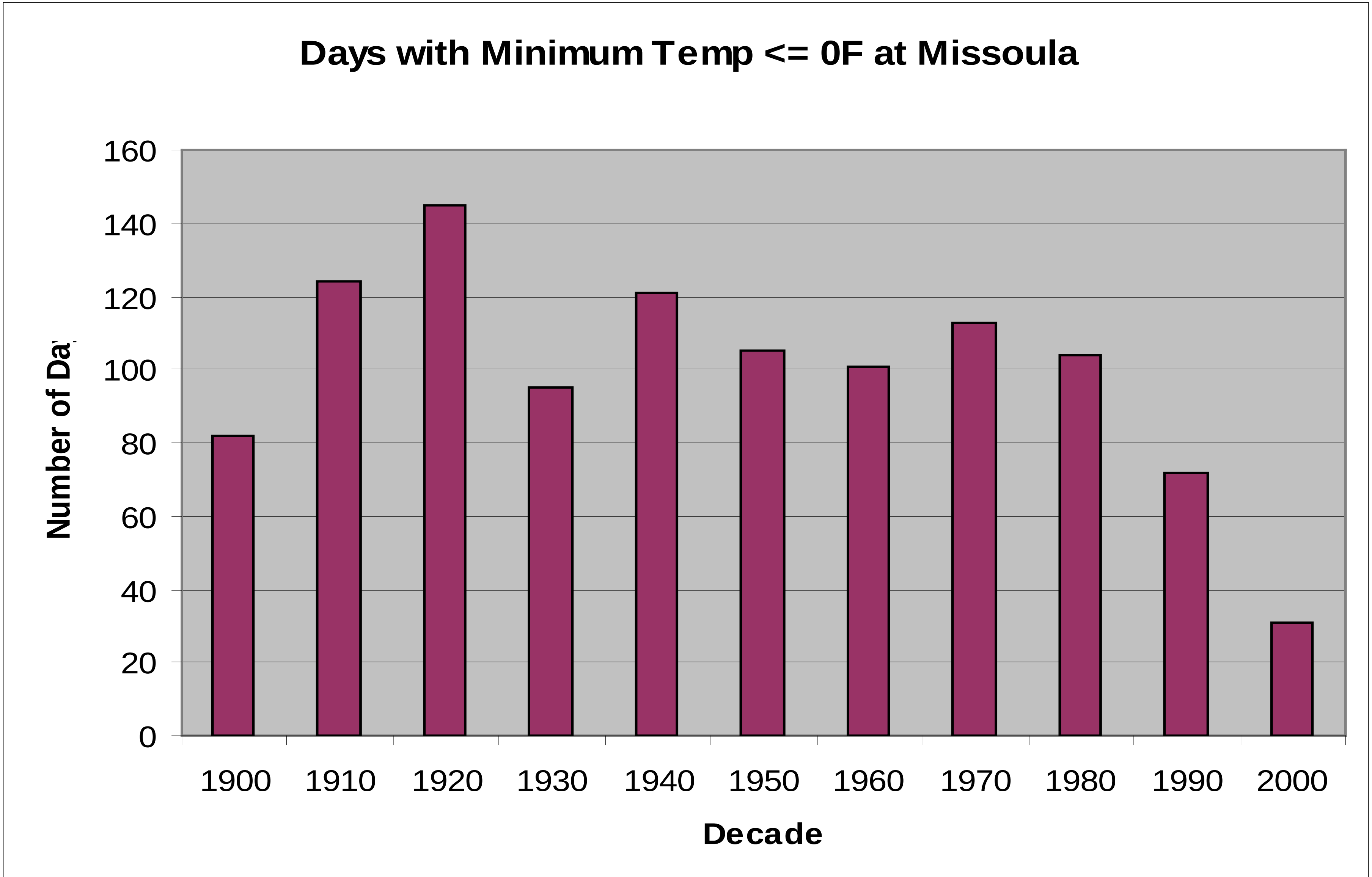
WILDLAND ACRES BURNED 2007



August 17, 2007

National Incident Information Center

DAYS/Decade <0degF



From Gene Petrescu, NWS, Missoula

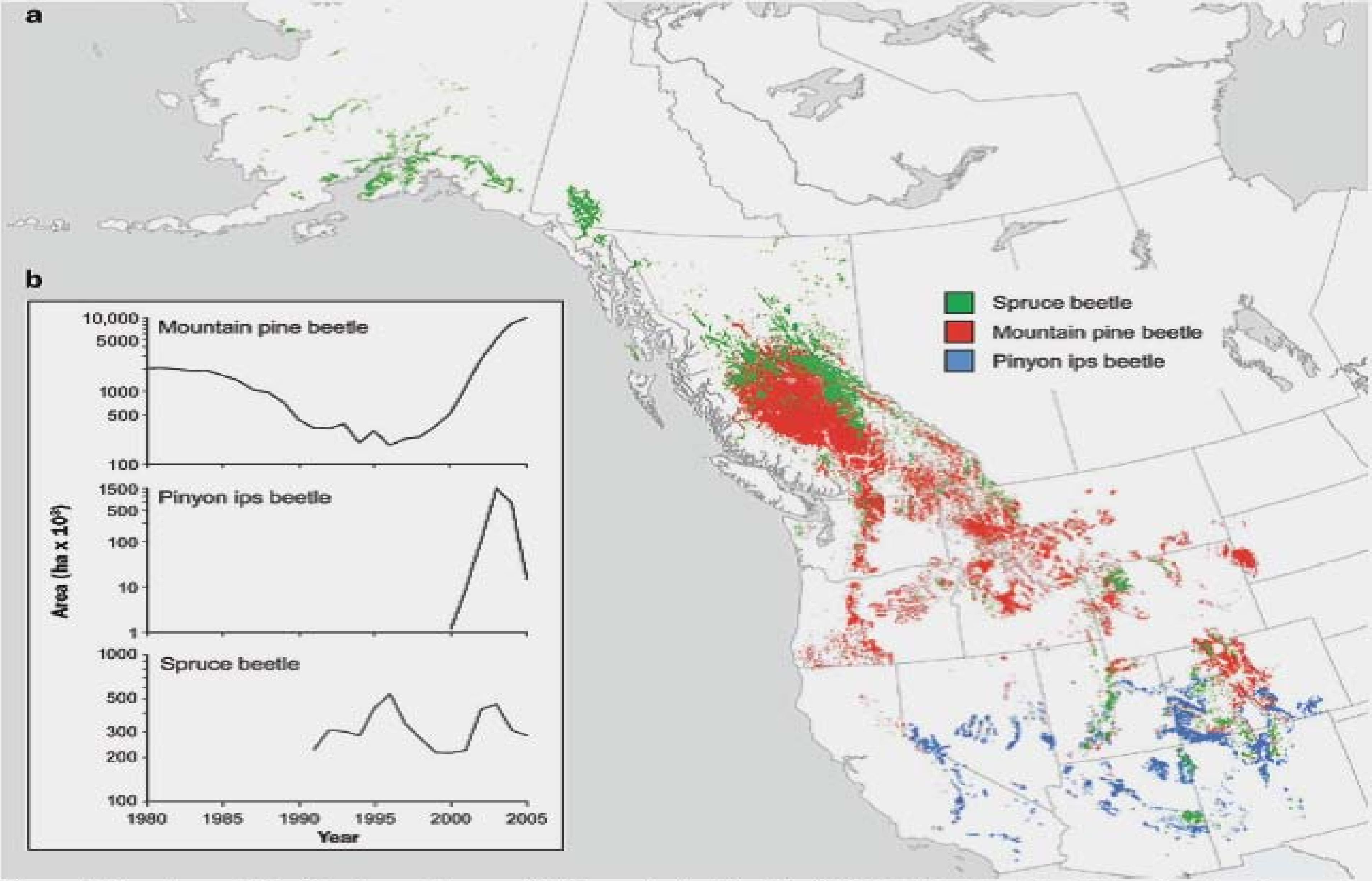


Figure 1. Recent mortality of major western conifer biomes to bark beetles. (a) Map of western North America showing regions of major eruptions by three species. (b) Sizes of conifer biome area affected by these three species over time. Data are from the Canadian Forest Service, the British Columbia Ministry of Forests and Range, and the US Forest Service.

Raffa et al Bioscience 2008.

Whitebark Pine Dubois WY Aug 08

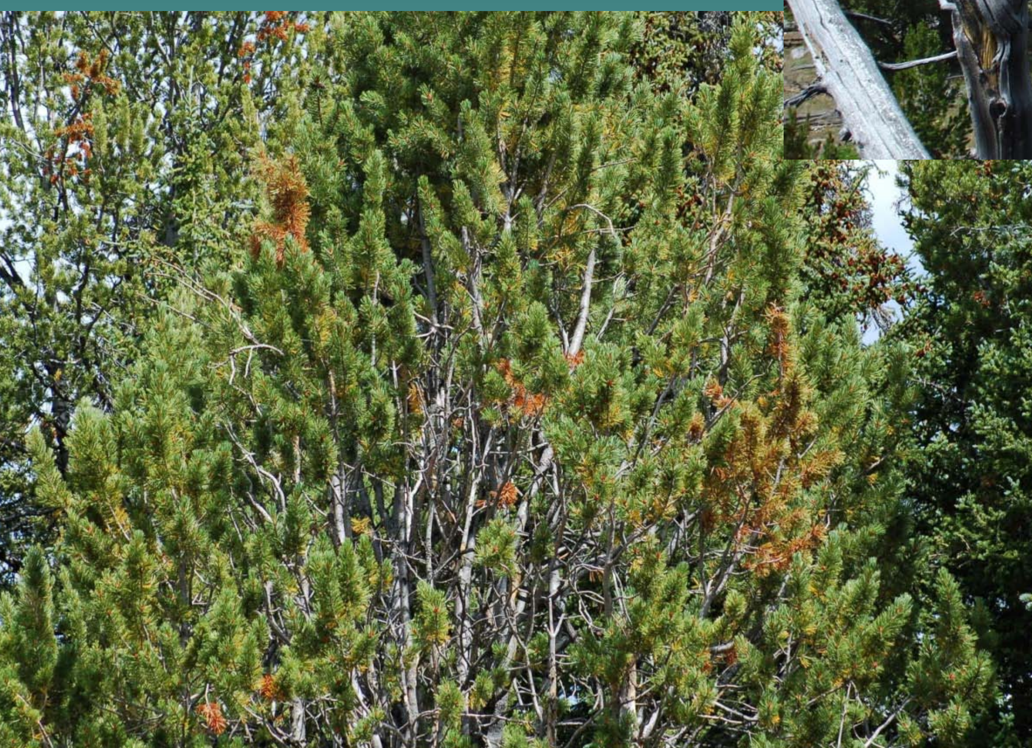
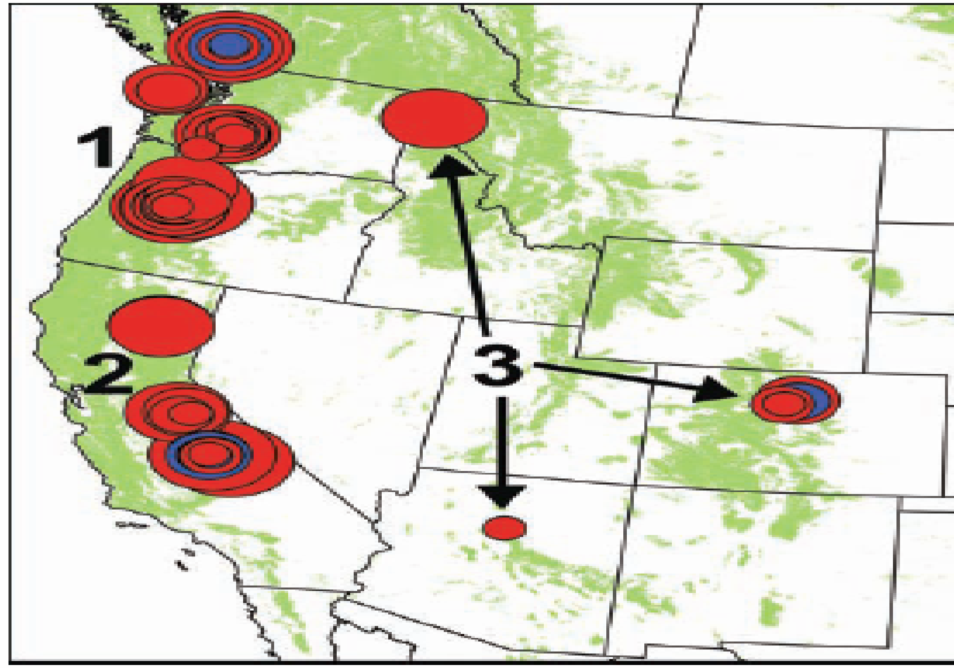


Fig. 1. Locations of the 76 forest plots in the western United States and southwestern British Columbia. Red and blue symbols indicate, respectively, plots with increasing or decreasing mortality rates. Symbol size corresponds to annual fractional change in mortality rate (smallest symbol, <0.025 year^{-1}; largest symbol, >0.100 year^{-1}; the three intermediate symbol sizes are scaled in increments of 0.025 year^{-1}). Numerals indicate groups of plots used in analyses by region: (1) Pacific Northwest, (2) California, and (3) interior. Forest cover is shown in green.



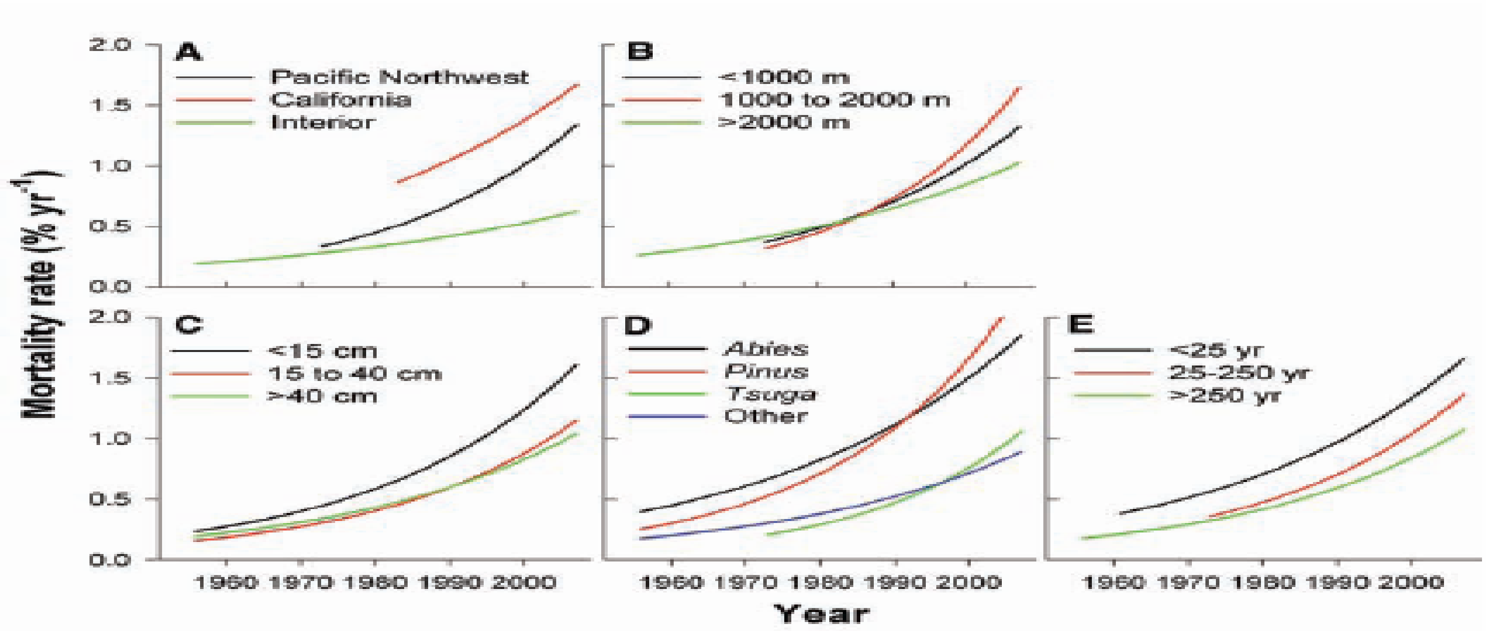
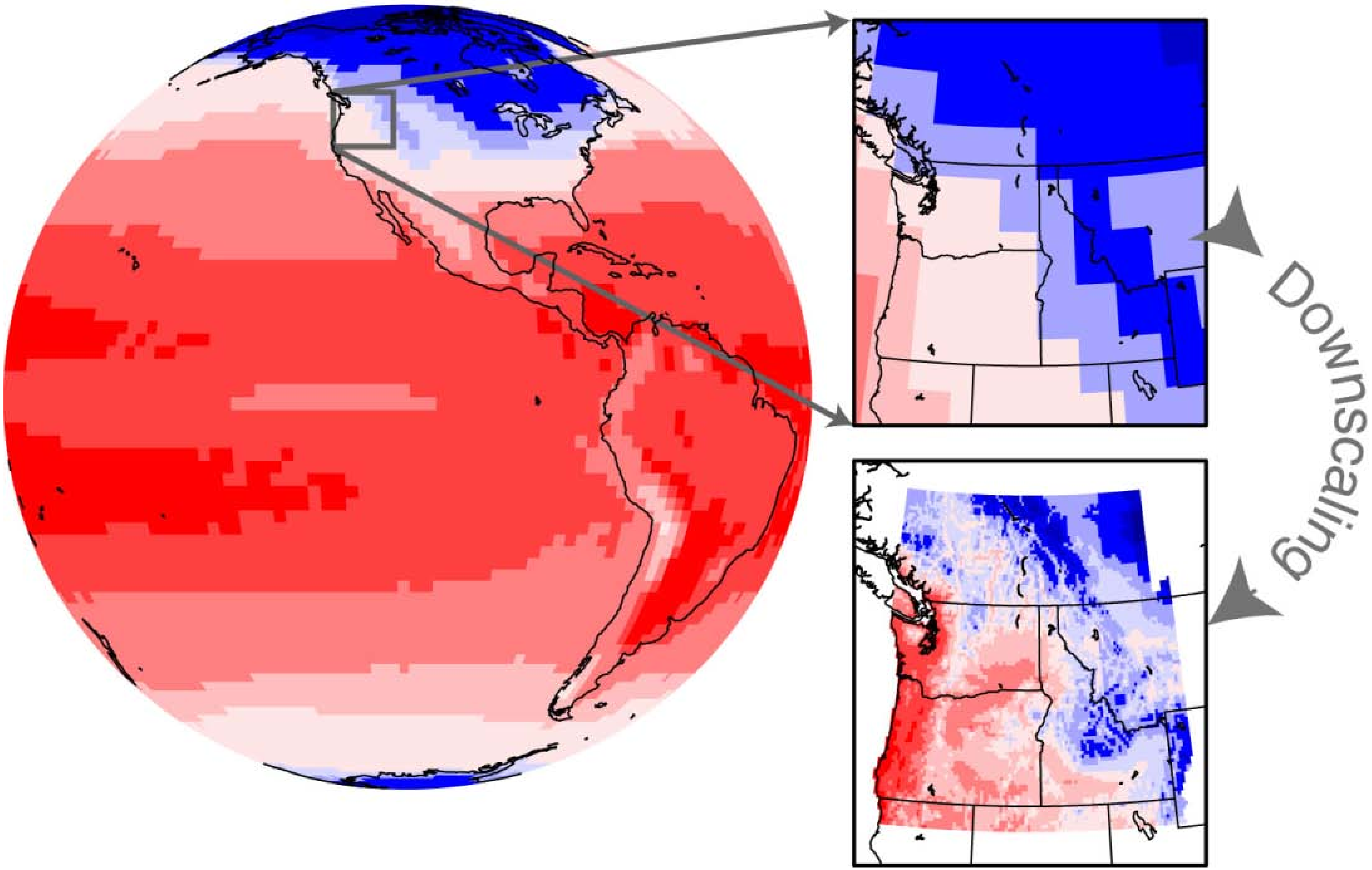


Fig. 2. *Modeled trends in tree mortality rates for* **(A)** regions, **(B)** elevational class, **(C)** stem diameter class, **(D)** genus, and **(E)** historical fire return interval class.

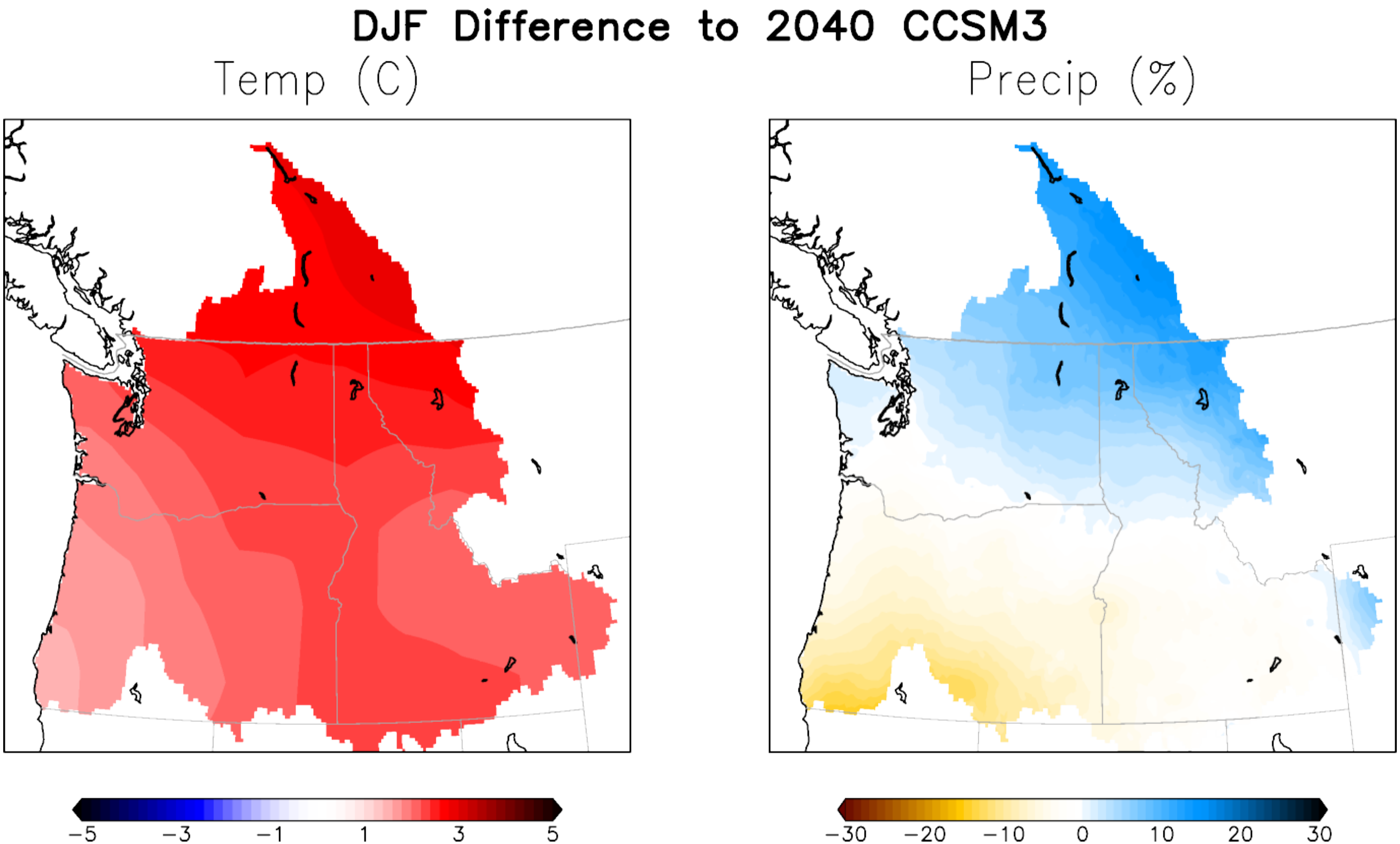
Van Mantgem et al Science 2009

Downscaling global models for regional studies

Global Climate Model Air Temperature

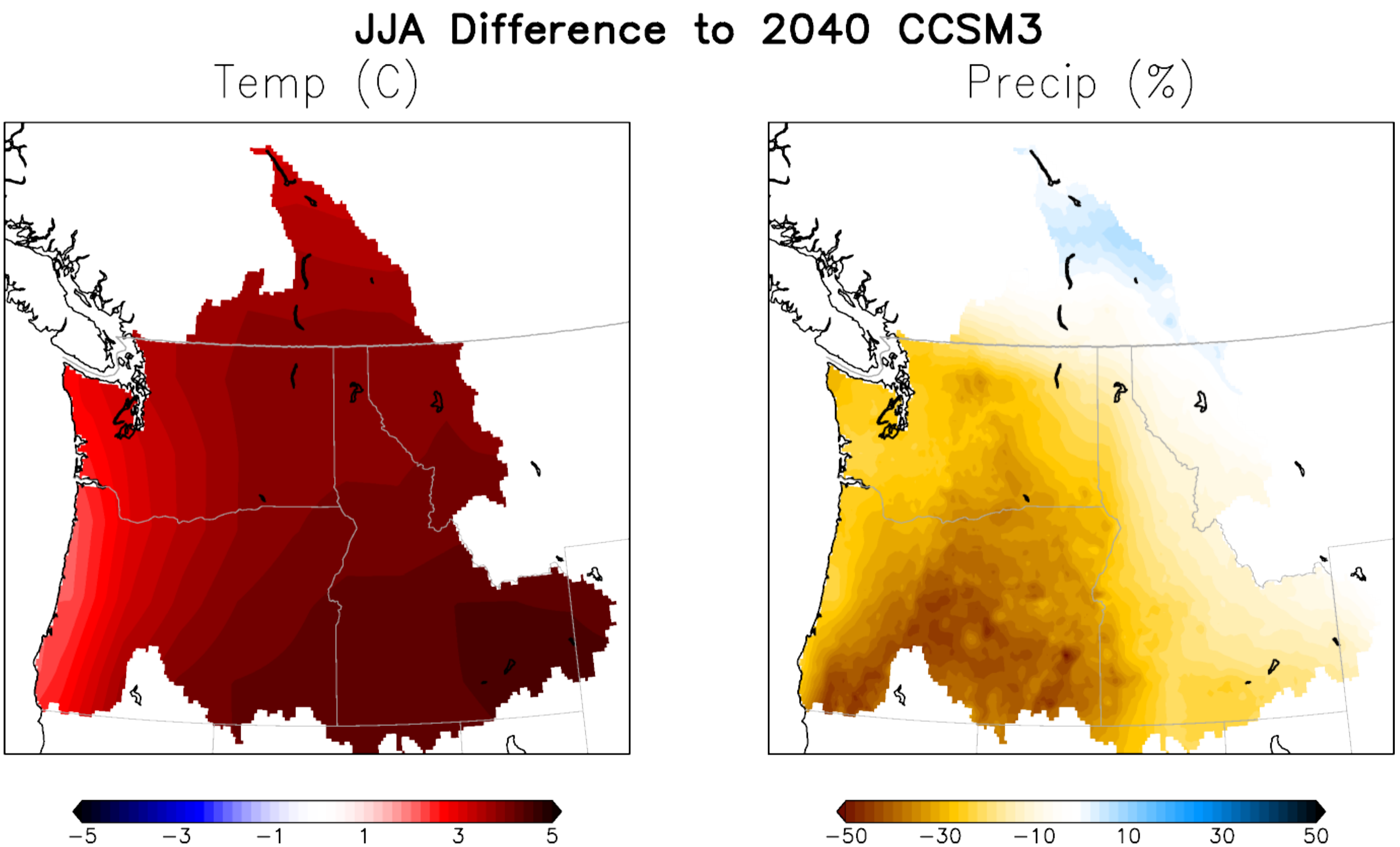


Downscaling -- Winter



CLIMATE IMPACTS GROUP

Downscaling -- Summer



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

40% Increase in Summer Evaporative Demand!!

Water Management
Recreation versus Agriculture

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

Montana Ecosystem Responses To Climate Trends

Water balance and
Disturbance dynamics
Will be more important than
pure temperature responses