Western Regional Climate Center

Colorado River Basin Climate Variability and Change: Background, Tools and Activities

Kelly Redmond

Deputy Director / Regional Climatologist
Western Regional Climate Center
Desert Research Institute
Reno Nevada

Colorado River Commission of Nevada
Technical Workshop: An Introduction to Water Supply and Climate-related Forecasting and Monitoring Tools
Las Vegas Nevada
5 December 2008

Potential external sources of climate change

Human

Greenhouse gasses
- Carbon dioxide
- Methane
- Nitrous oxide
- Ozone
- Chloroflourocarbons

Aerosols
- Radiative effects (the flow of radiant energy)
- Microphysics effects (how clouds form and how they work)

Land use / land cover changes
- Changes in albedo
- Changes in water vapor
- Changes in vegetative influence / participation in energy and mass flows

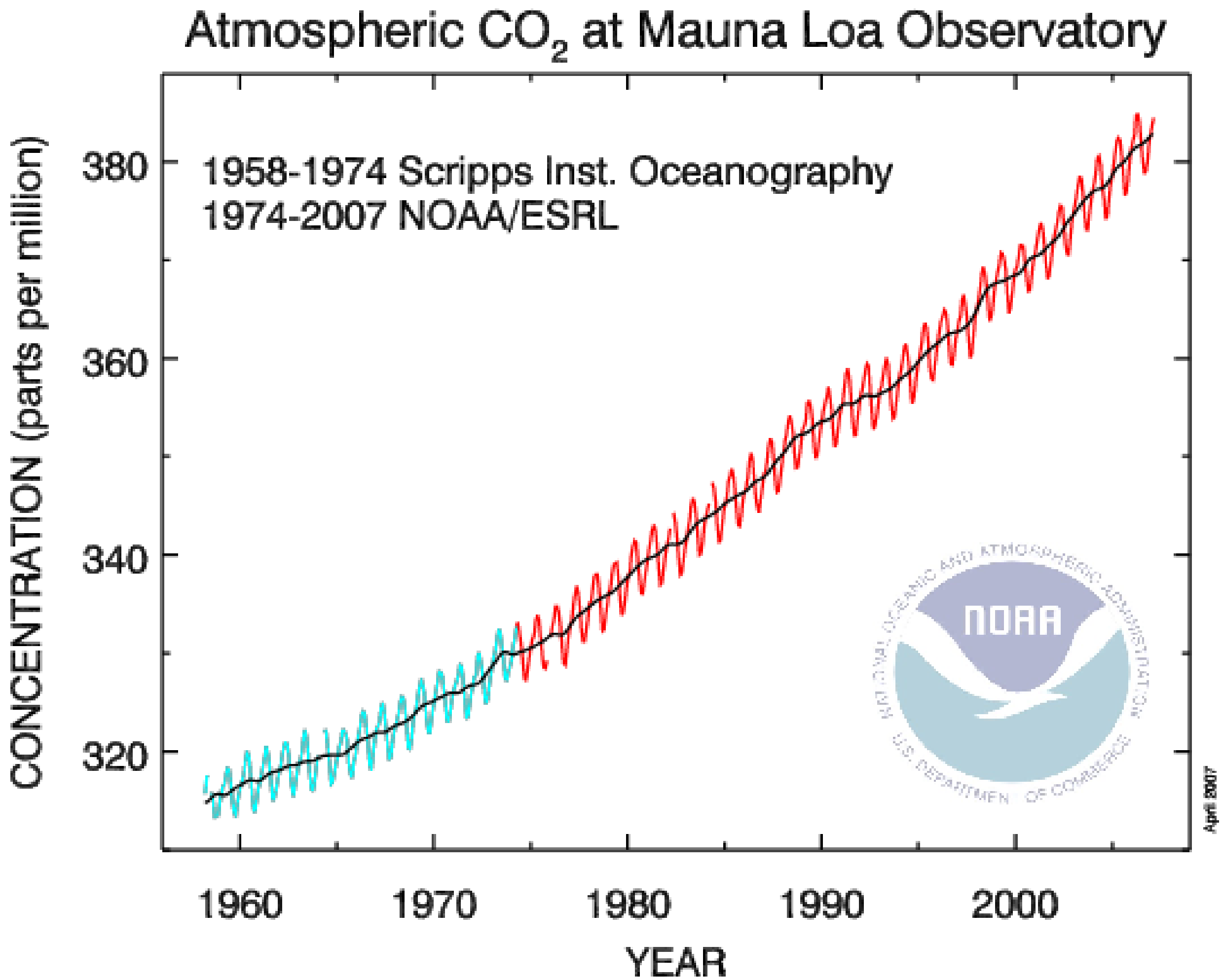
Natural

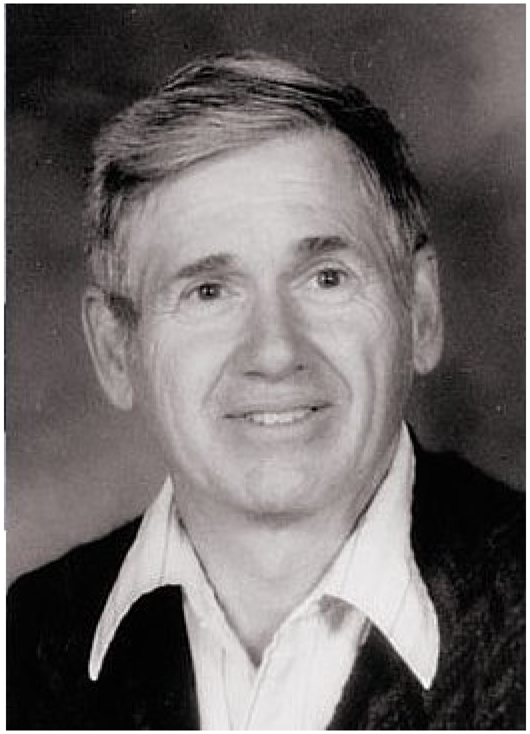
Astronomical radiation forcing

Solar variations

Volcanoes

Dave Keeling, Scripps





1928 April 20 - 2005 June 20

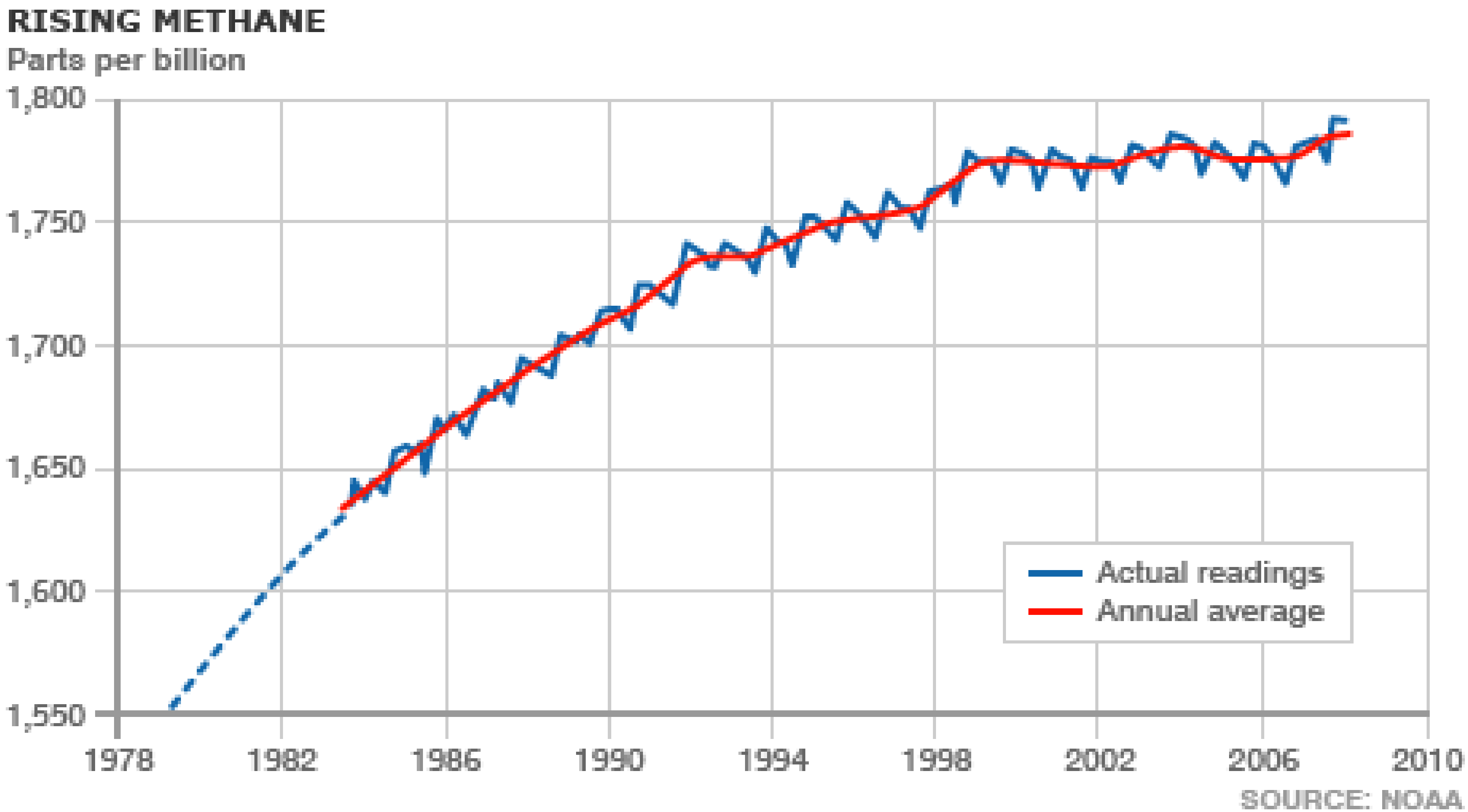
1959: 316 ppmv

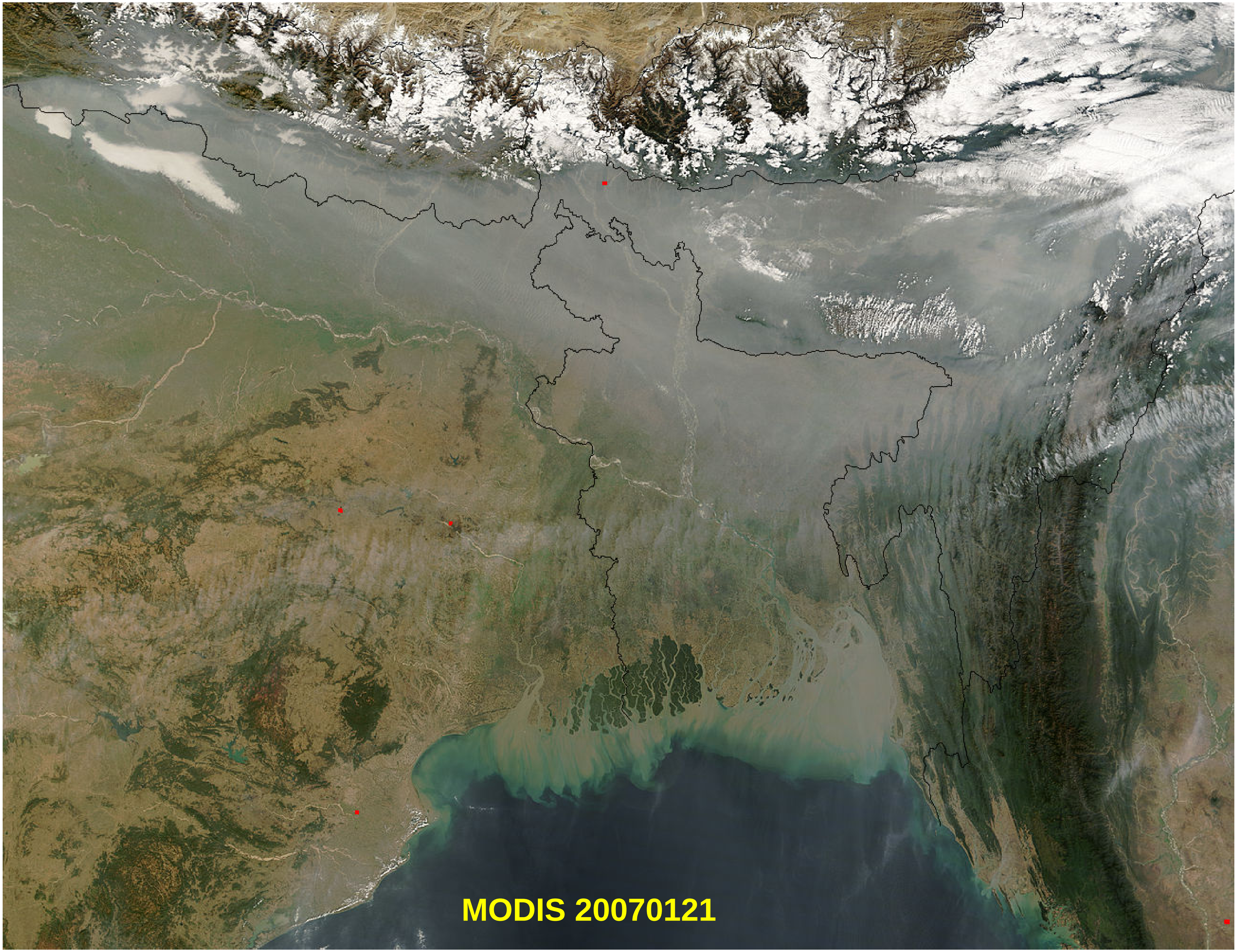
+20.8 %

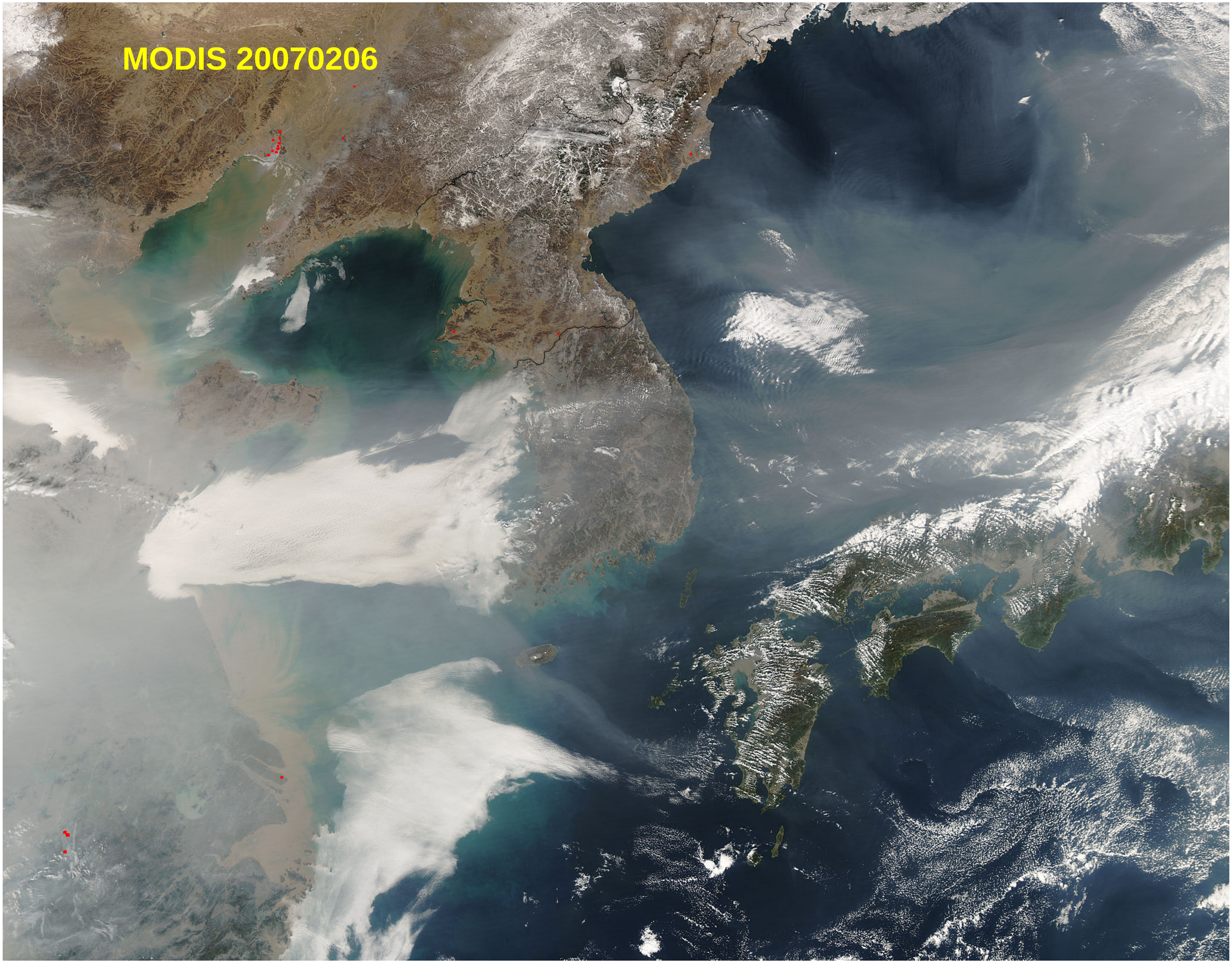
2006: 381.85 ppmv
2007: 383.5 est
March 2007

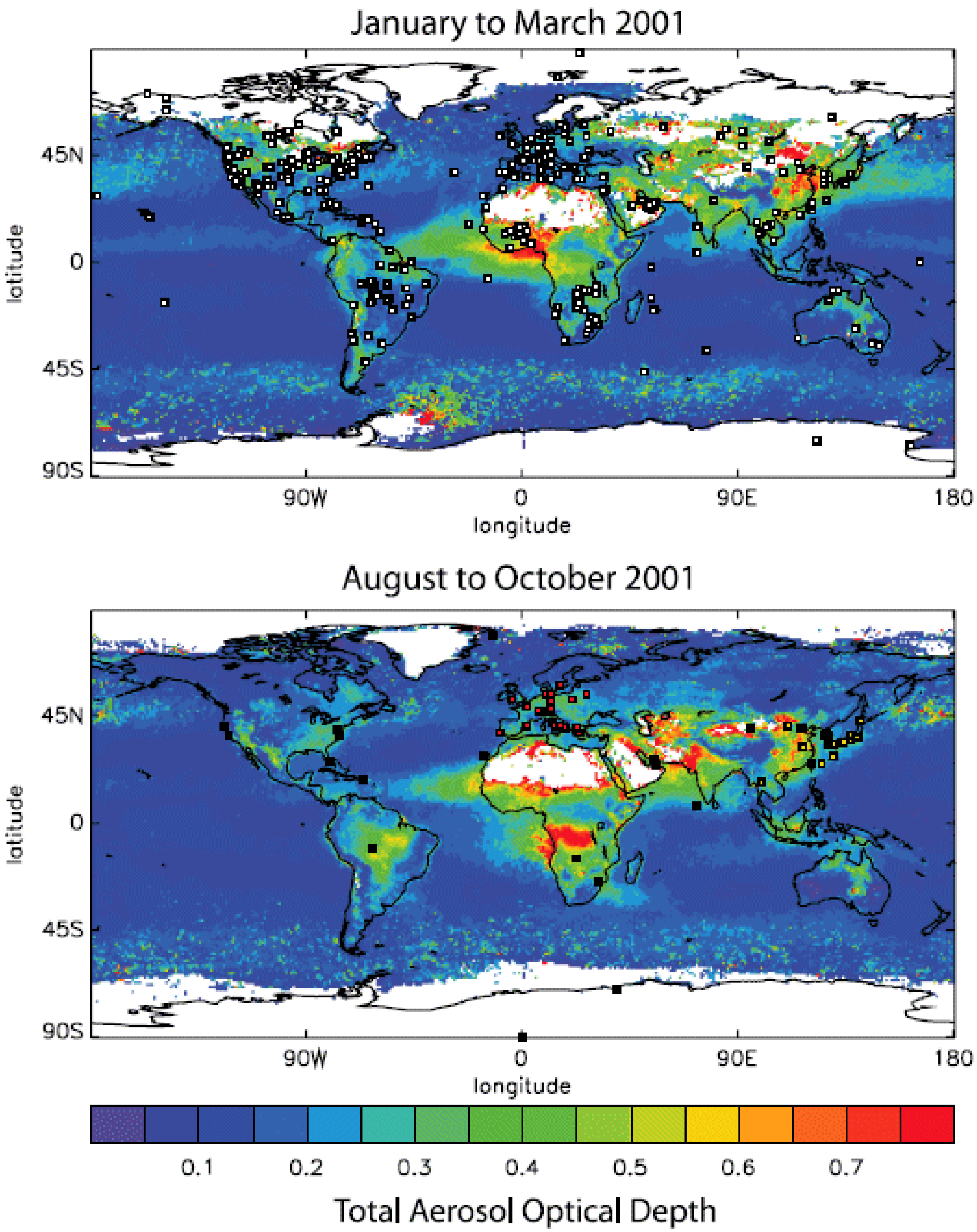
Photo: AGU, Emelio Segre Visual Archives

Atmospheric Methane: Resumption of its Rise???
Methane is 23 times more potent as a greenhouse gas than CO2




MODIS 20070121


MODIS 20070206



Pollution is a global atmospheric concern

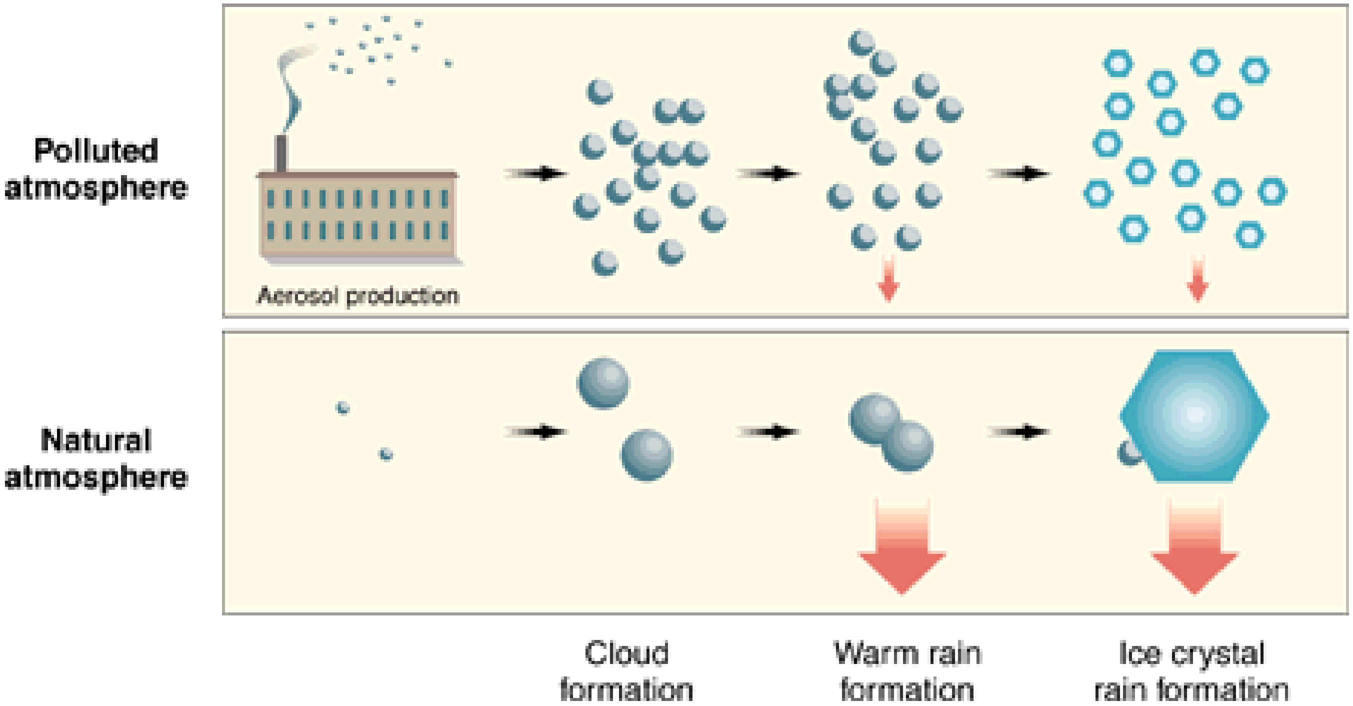
Obviously for health reasons

But, also,

Aerosols have effects on

Temperature
And
Precipitation

Also note:
Aerosols are unequally distributed around the earth



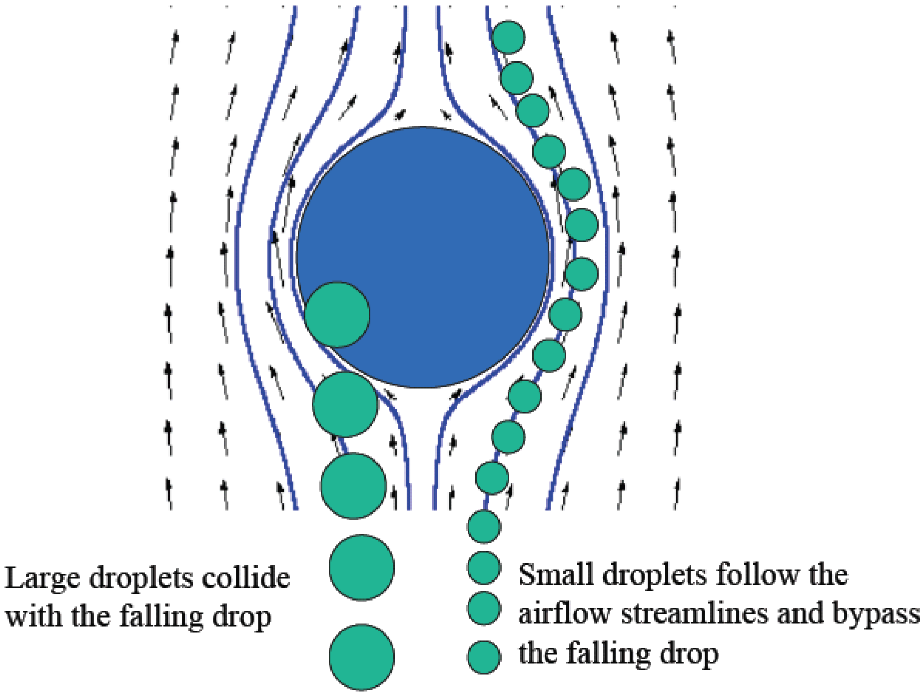
Owen B. Toon

How Pollution Suppresses Rain

Science Magazine,

10 March 2000

287 (5459), 1763-1765



Daniel Rosenfeld

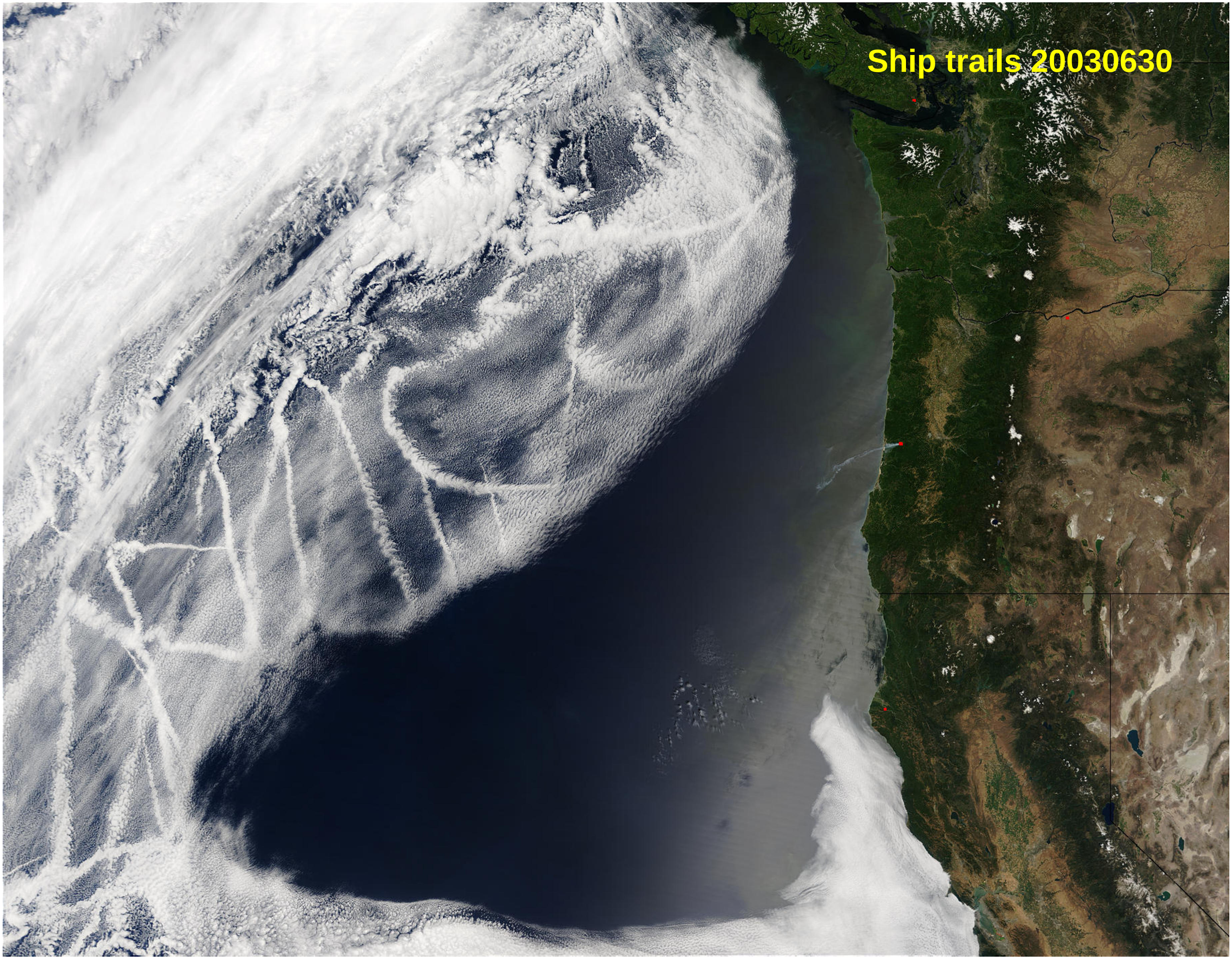
Aerosols Suppressing Precipitation in the Central Sierra: Results of the 2006 Winter Field Campaign

14 Sep 2006. California Climate Change Research Conference.

Suppression of Rain and Snow by Industrial and Urban Air Pollution. Science, 2000, March 10, 287, 1793-1796.


30 August 2007

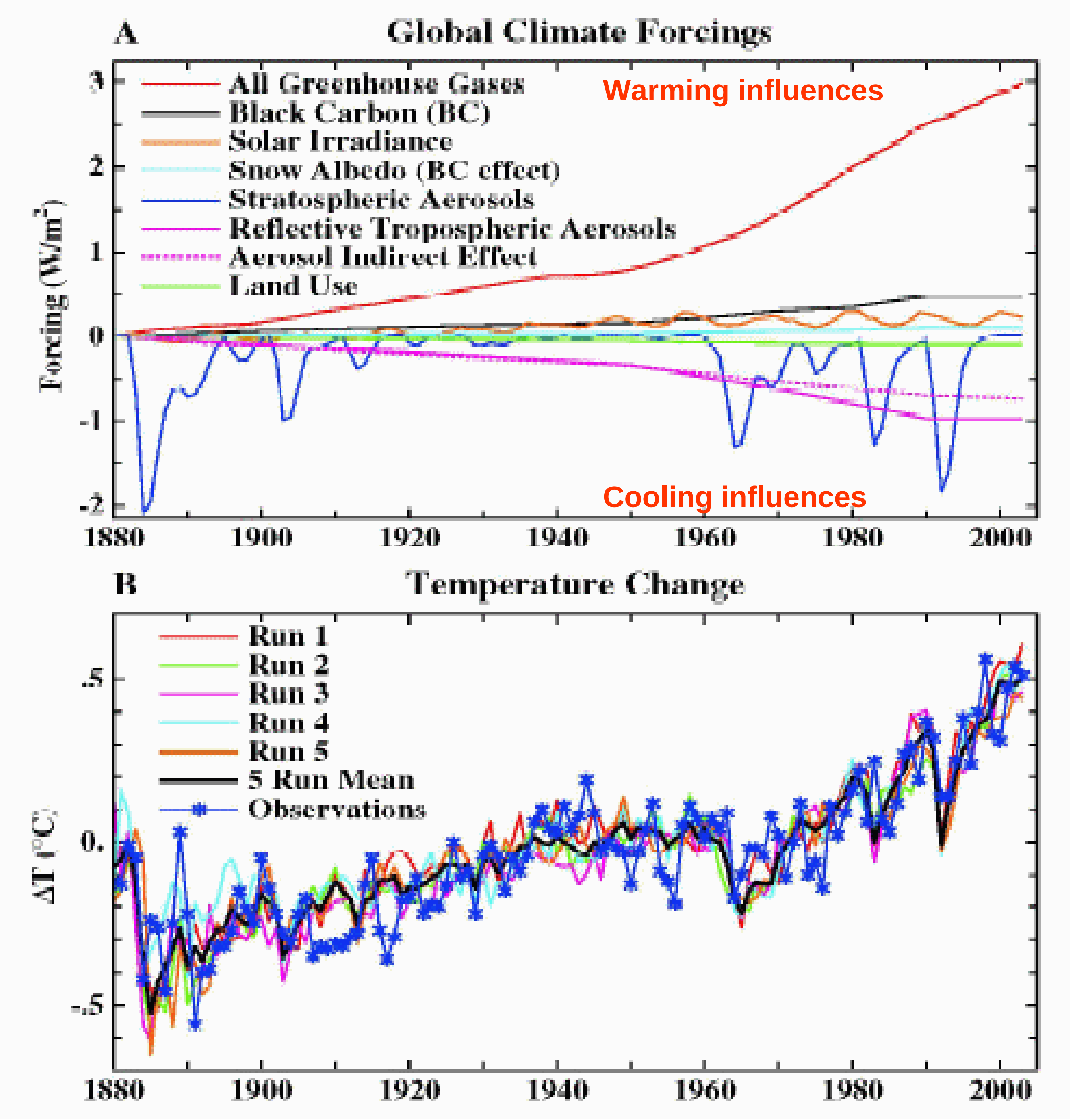

30 August 2007


Ship trails 20030630

History of

Atmospheric

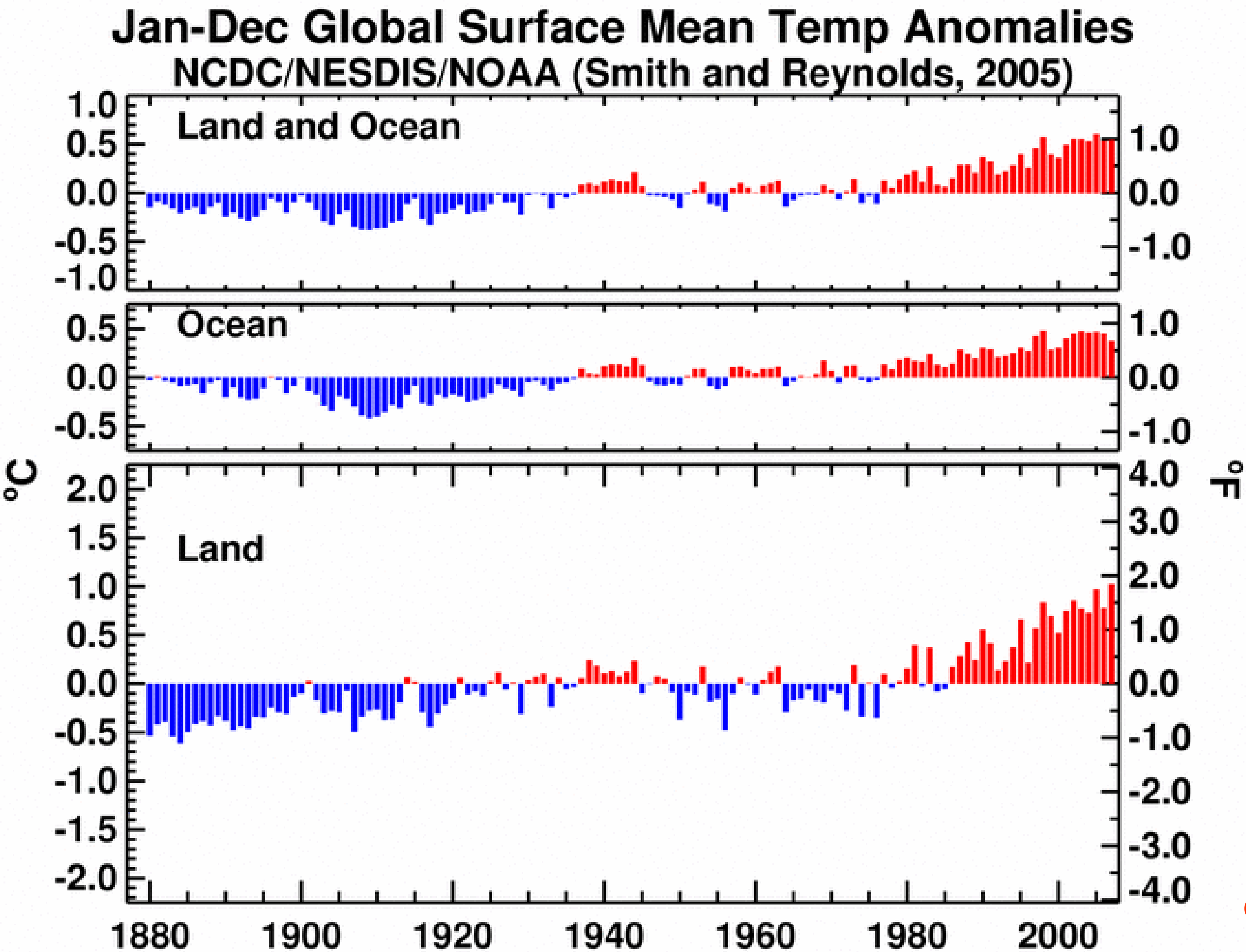
Forcings



Simulated and Observed Temperatures

(Global Mean)

Hansen et al, 2005. Earth's energy imbalance: Confirmation and implications. *Science,* 308, 1431.



Annual

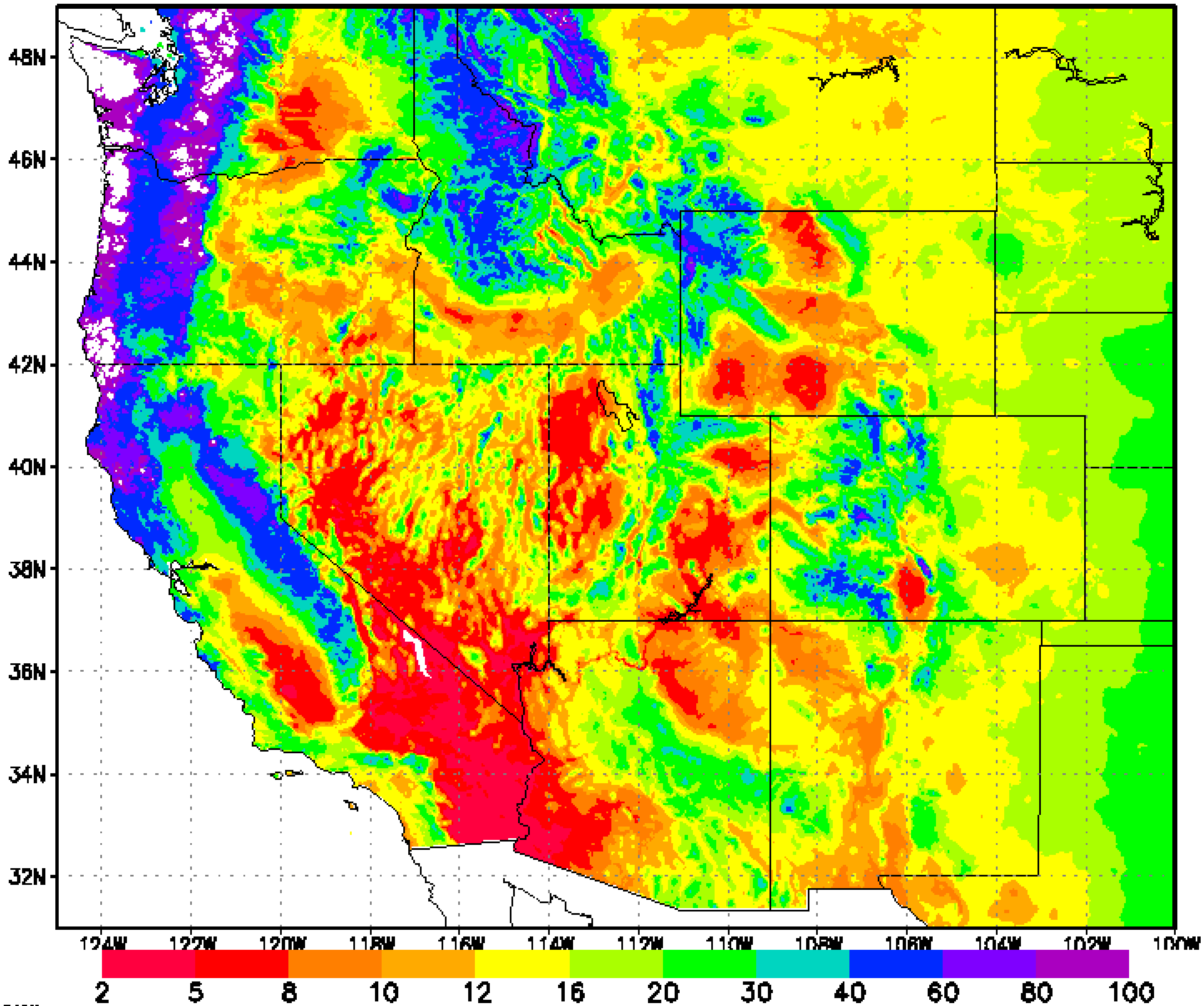
Jan-Dec

thru 2007

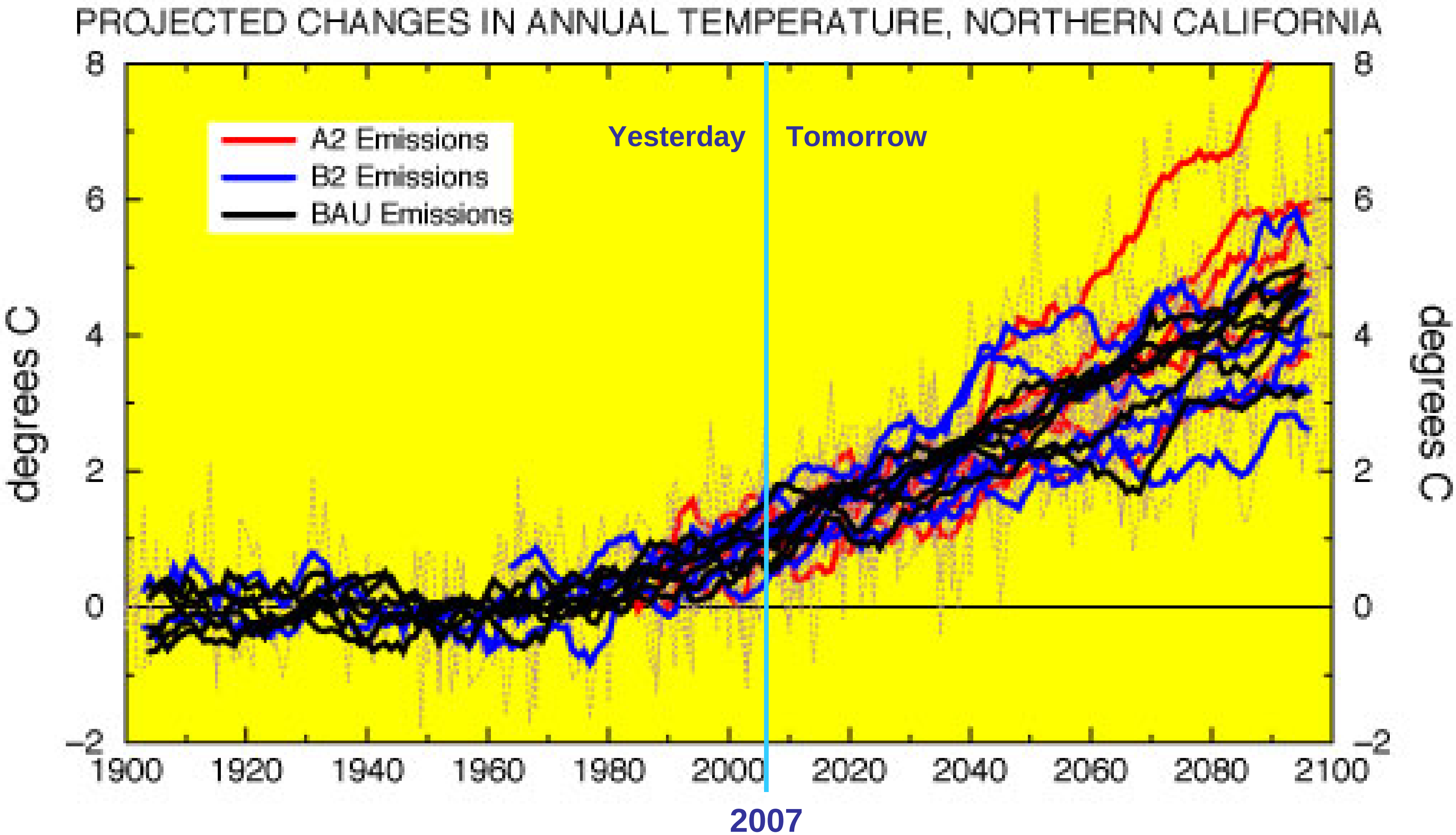
NOAA

National Climatic Data Center

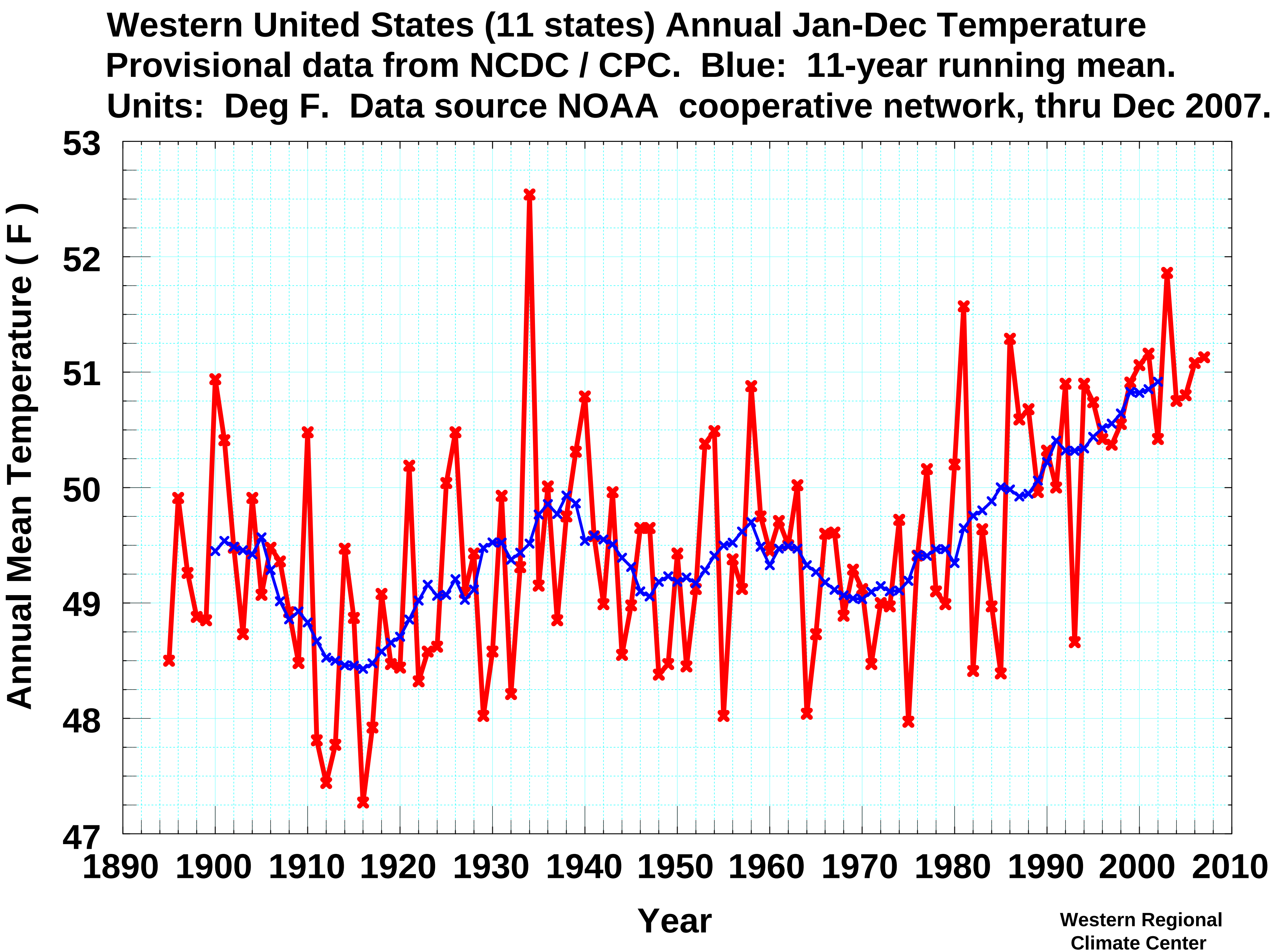
Annual Precipitation (inches)
1961-90 Average (PRISM OSU/WRCC)

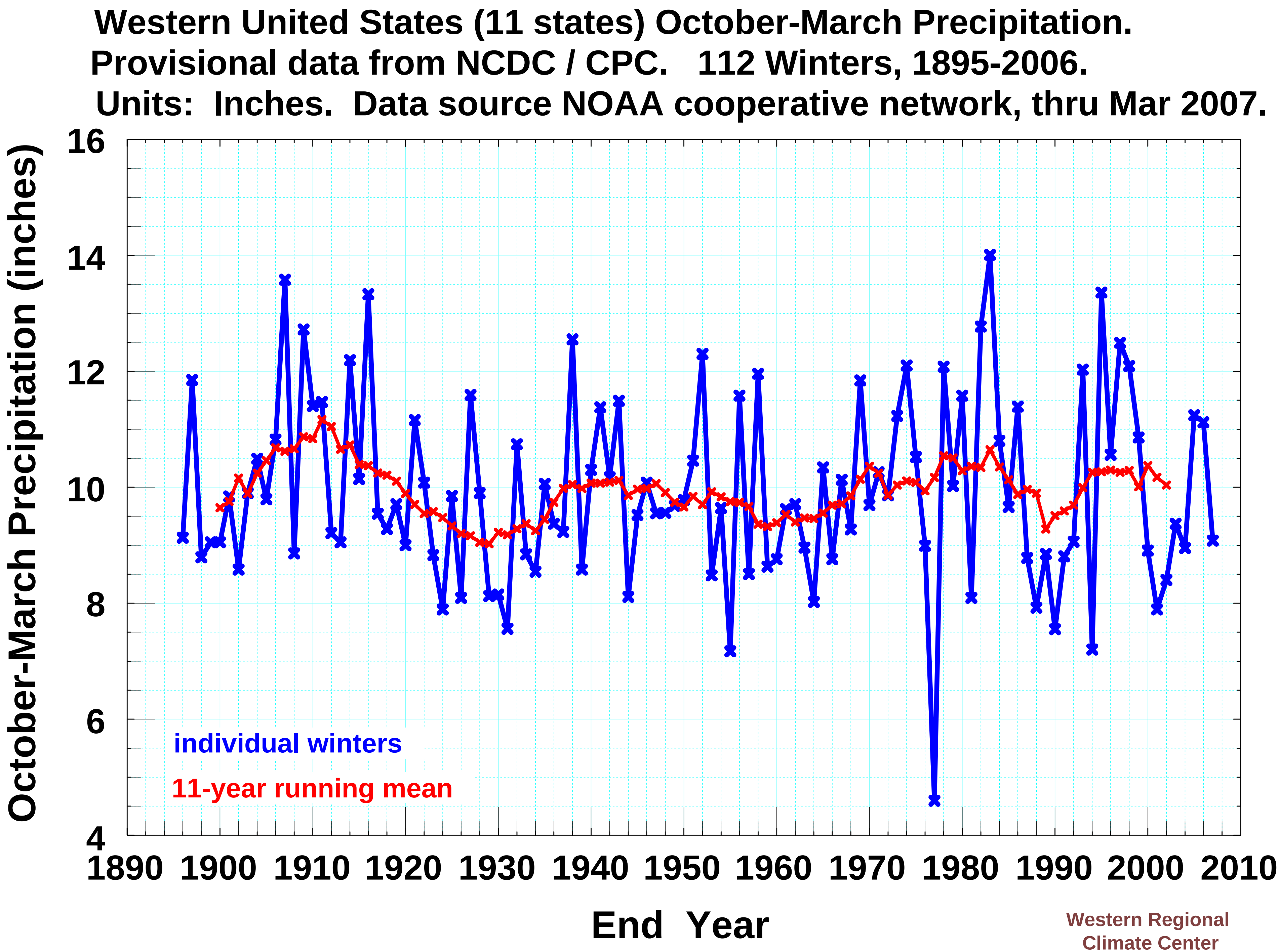


Courtesy of Mike Dettinger, USGS / Scripps.



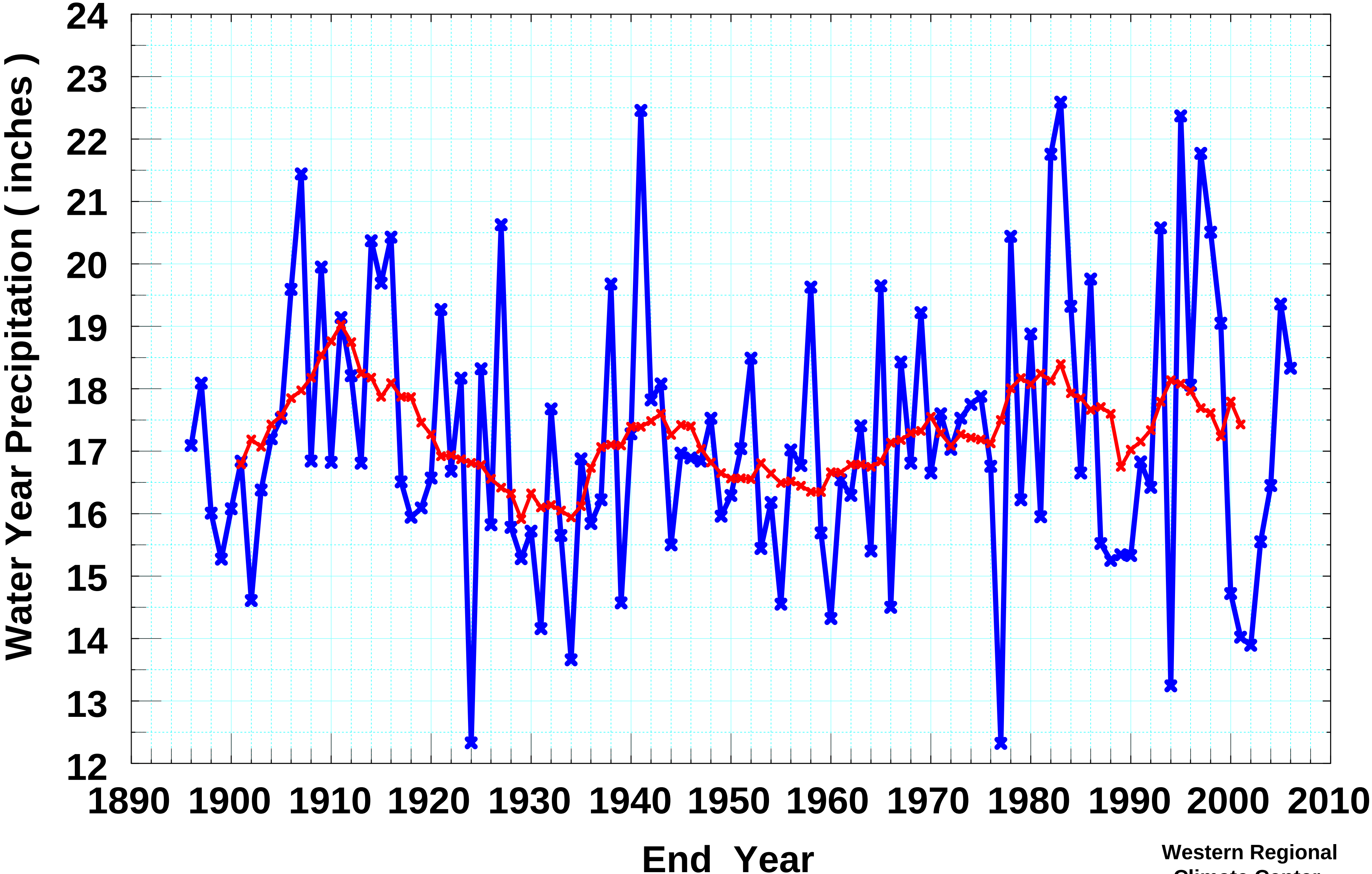
Dettinger MD. 2005. From climate change spaghetti to climate-change distributions for 21st Century California. San Francisco Estuary and Watershed Science. Vol. 3, Issue 1, (March 2005), Article 4. http://repositories.cdlib.org/jmie/sfews/vol3/iss1/art4


Western United States (11 states) Annual Jan-Dec Temperature
Provisional data from NCDC / CPC. Blue: 11-year running mean.
Units: Deg F. Data source NOAA cooperative network, thru Dec 2007.
Annual Mean Temperature (F)
53
52
51
50
49
48
47
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year
Western Regional
Climate Center

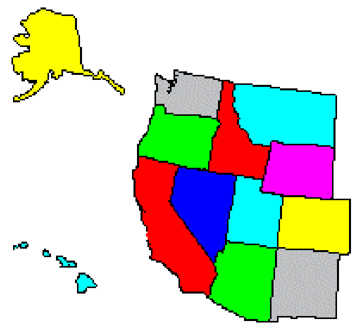


Western United States (11 states) October-March Precipitation.
Provisional data from NCDC / CPC. 112 Winters, 1895-2006.
Units: Inches. Data source NOAA cooperative network, thru Mar 2007.
October-March Precipitation (inches)
16
14
12
10
8
6
4
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
End Year
individual winters
11-year running mean
Western Regional
Climate Center

Western United States (11 states) Water Year (Oct-Sep) Precipitation.
Provisional data from NCDC / CPC. Blue: 11-year running mean.
Units: Inches. Data source NOAA cooperative network, thru Nov 2006.



Western Regional
Climate Center



Western Regional Climate Center

Historical Climate Information
Western U.S. Historical Summaries; Precipitation Maps; Station Inventories; Wind and Evaporation Data; Coastal Water Table; State Narratives; Station Descriptions; Anomalies.

Current Observations, Forecasts and Monitoring
Nat'l Weather Service Current and Past 24-hour Reports; Snotel; Climate Prediction Center Outlooks; Satellite and Radar Imagery; SPI; Anomalies; Divisional Climate Plots;

WRCC Projects
El Nino & La Nina; CEMP; WET; BLM RAWS; Yucca Mtn; Current Weather Plots; NSOE; Snotel; California Climate Data Archive; Photo Gallery; Webcam.

More Climate Information
Solar Radiation; Sunrise/Sunset Information (USNO); WGA data and information; Nat'l Climatic Data Center; Climate Prediction Center; CEFA; Nat'l Drought Mitigation Center.

Educational and Travel Pages
Terms; More about Weather and Climate - for teachers and kids! Climate for resorts and Nat'l parks around the West.

About the WRCC
Staff; Funding; Overview of WRCC; DRI Home Page; INTERNAL.

WRCC Supports a Three-Partner National Climate Services Program - the Partners Include:
National Climatic Data Center (NCDC), Regional Climate Centers (RCC's), and State Climate Offices.

Address:
WRCC
2215 Raggio Parkway
Reno, NV 89512
(775) 674-7010 - phone
(775) 674-7016 - fax

wrcc@dri.edu

Western Regional Climate Center

WRCC Projects

Community Environmental Monitoring Program (CEMP)
Data Monitoring Stations surrounding the NV test site.

Wind Energy Assesment for Nevada
Nevada Wind Study Towers.

RAWS Data (Remote Automated Weather Stations)
Summaries, Graphs, and other products for RAWS.

Current Weather Data Plots
Current Data Plots

Photo Galley of the Western States:
Landscapes; Sunrise, Sunset and Lunar; and Misc.

El Nino/La Nina and the Western US, Alaska and Hawaii
Information regarding El Nino and La Nina.

Yucca Mountain Climate Data Project
Climate Data from Yucca Mountain, Nevada.

Naval Air Warfare Center (NAWC) Pt. Mugu stations
Stations operated by the Naval Air Warfare Center. Pt. Mugu Handar stations.

Reno Area Weather Network
Reno Area weather/climate summaries

CoCoRaHS - Community Collaborative Rain, Hail and Snow Network

ACIS - Applied Climate Information System

Washoe Evapotranspiration Project (WET)
Weather Stations that Monitor Evapotranspiration Rates.

NSOE - Anemometer Loan Program
Wind Resource Potential in Nevada

Snotel Data
Listings, Narratives, Maps and Station Conditions

National Parks RAWS page
RAWS Projects in the National Parks

Current Webcam View from DRI-NNSC
View from the WRCC office

California Climate Data Archive
California Climate Information and Data (Scripps and CEC)

Nevada Test Site /NOAA/ARL/SORD/ MEDA Data Project
Climate Data from Nevada Test Site.

California Climate Tracker
Tracking Climate Variability and Change for the state of California.

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Tracking Climate Variability and Change for the state of Nevada.
NEW

Westmap Climate Project
The Western Climate Mapping Initiative.
NEW

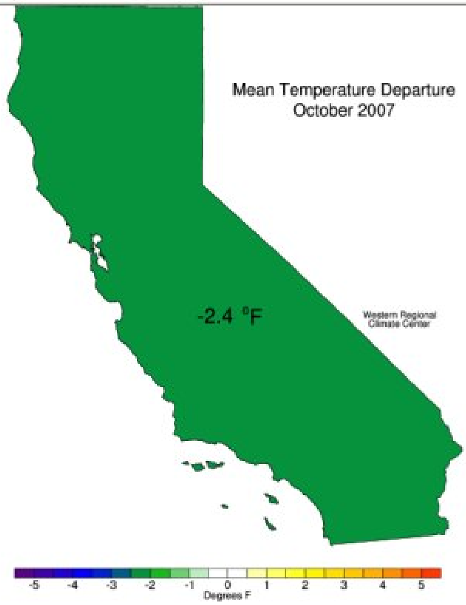
WxCoder
Data entry system for NWS COOP Observers.

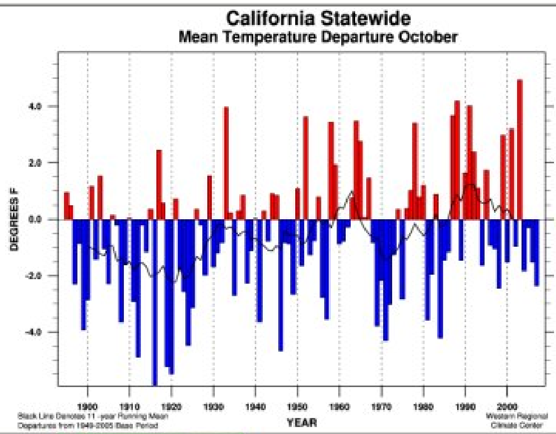
California Climate Tracker

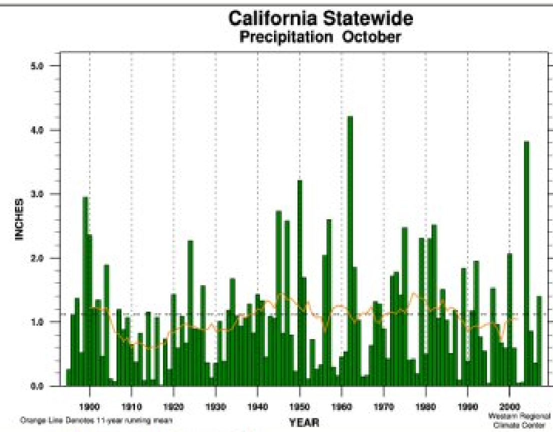
Tracking Climate Variability and Change for the State

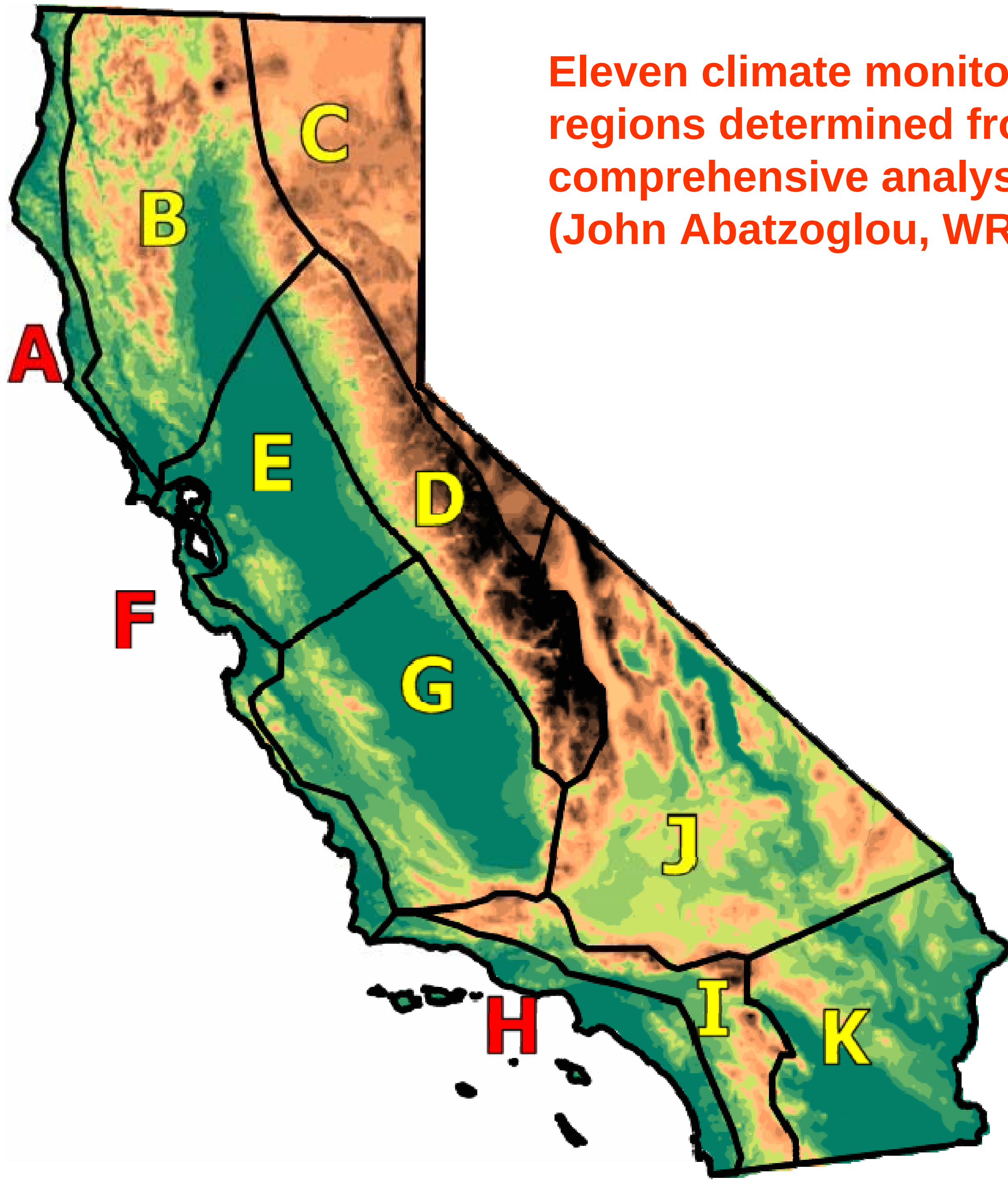
Climate Products Frames Version

OCTOBER 2007

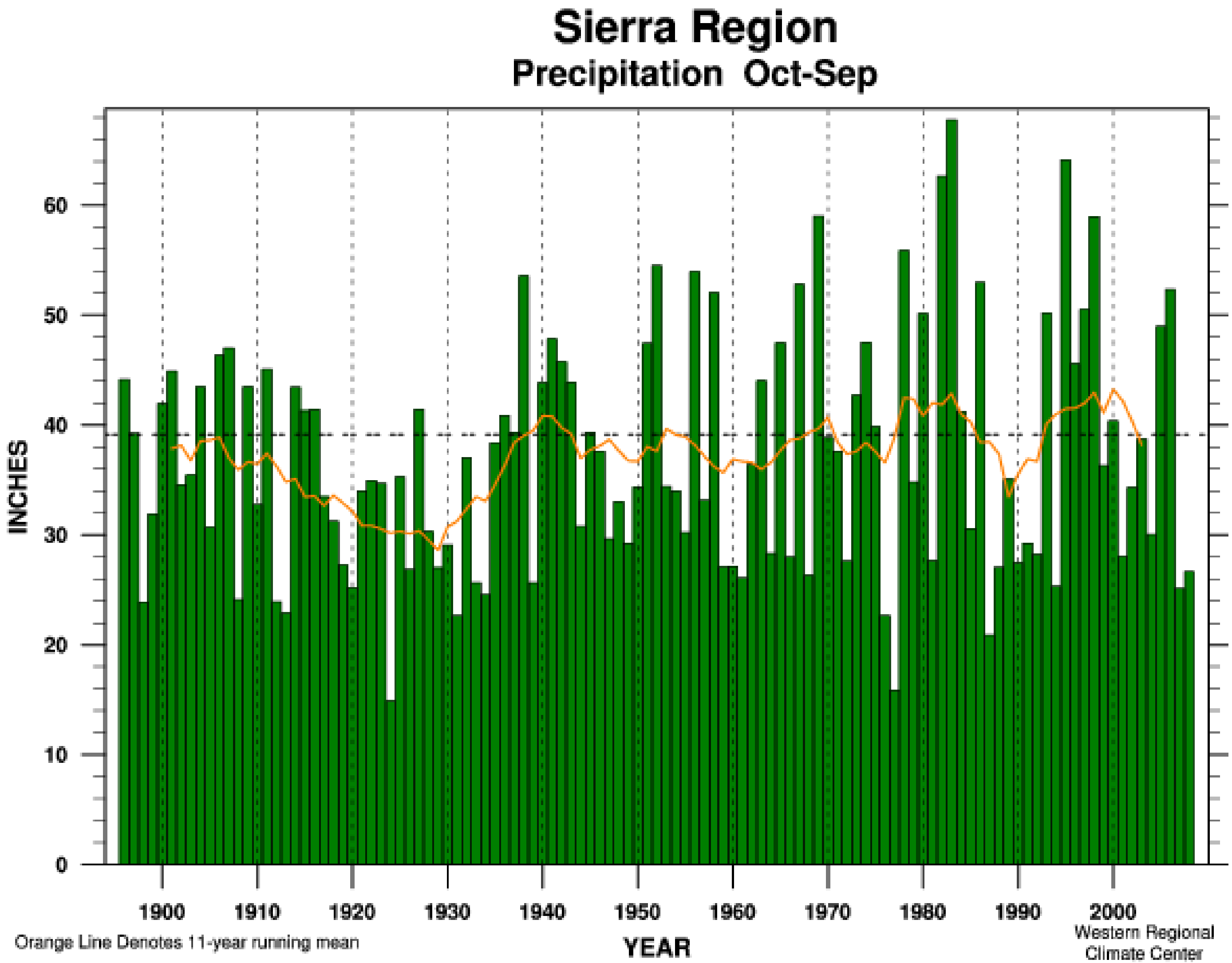








Eleven climate monitoring regions determined from a comprehensive analysis. (John Abatzoglou, WRCC)



Linear Trend 1895-present		+ 4.79 ± 6.10 in.	(+ 12 ± 15%) per 100 yr		
Linear Trend 1949-present		+ 0.25 ± 19.07 in.	(+ 0 ± 48%) per 100 yr		
Linear Trend 1975-present		- 0.92 ± 52.68 in.	(- 2 ± 134%) per 100 yr		
Wettest Year		67.79 in. (173%)	in 1983	MEAN	39.15 in.
Driest Year		14.89 in. (38%)	in 1924	STDEV	12.33 in.
Oct-Sep	2008	26.66 in. (68%)		RANK	18 of 113

Sierra Nevada Winter-Centered 12-Month Oct-Sep Water Year Precipitation

Thru Sep 2008

Western Regional Climate Center

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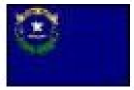
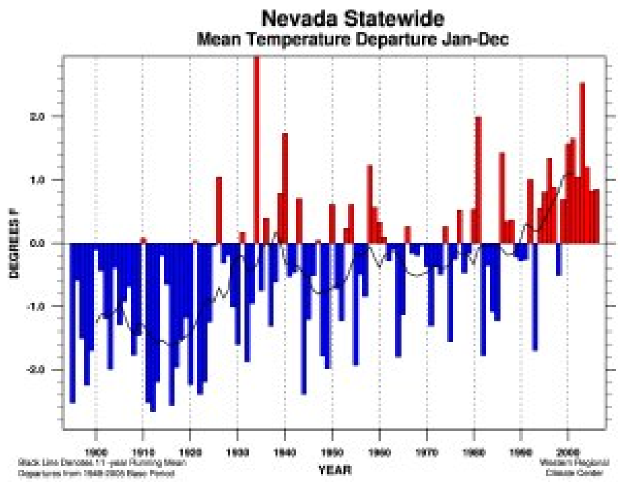
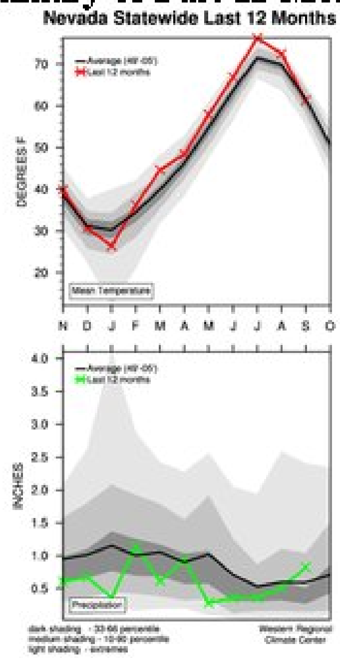
Select from the Menu to the Right



Time Series



Summary of Past 12 Months



Nevada Climate Tracker

Time Series

Select Variable

Select Time Period

Select

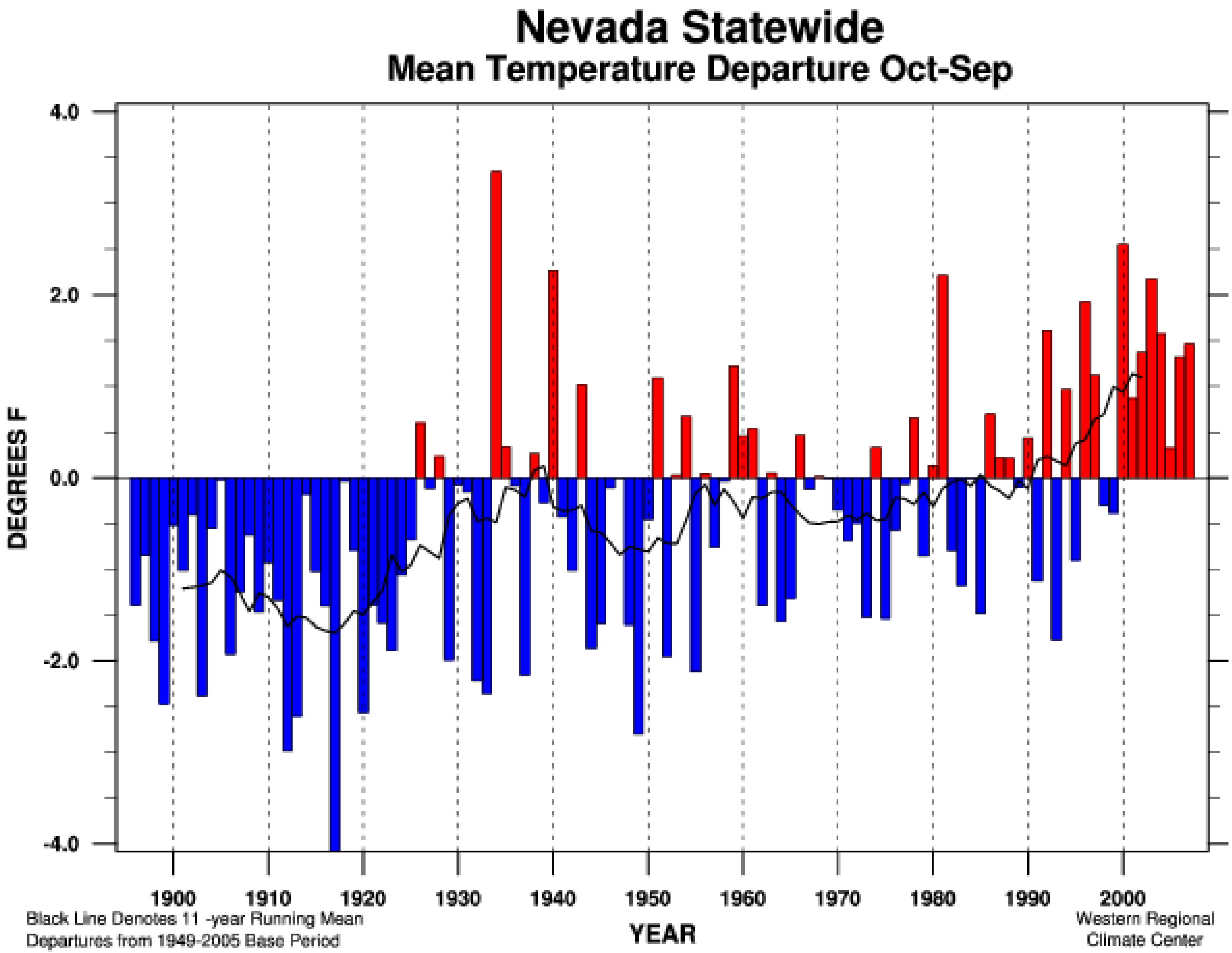
Summary of Past 12 Months

Plot Time Series
List Entire History
More Info

Return to the WRCC

Western Regional Climate Center

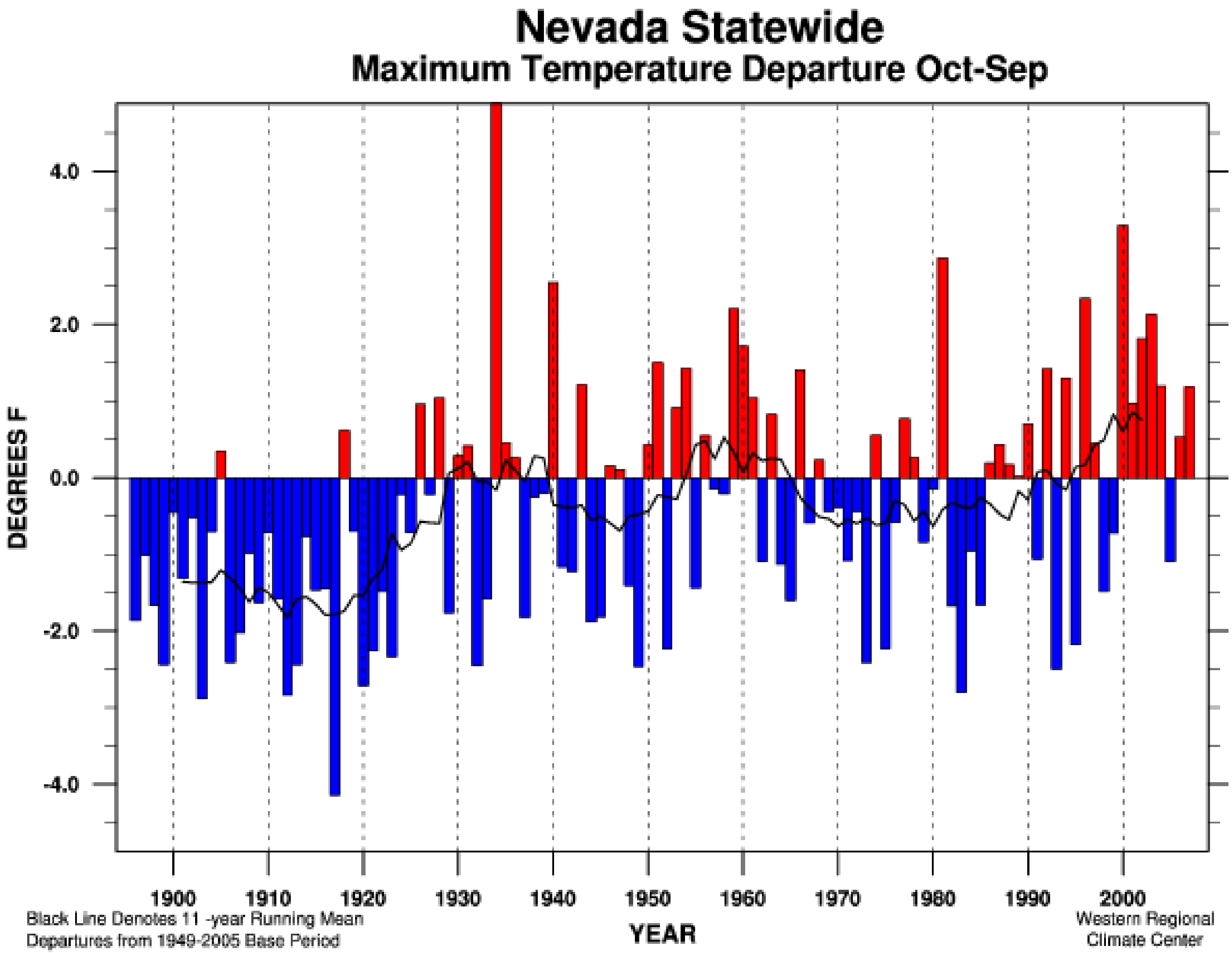
Powered by ACIS
NOAA Regional Climate Centers



Through
Sep 2007

PRISM values
not yet available
after June 2008

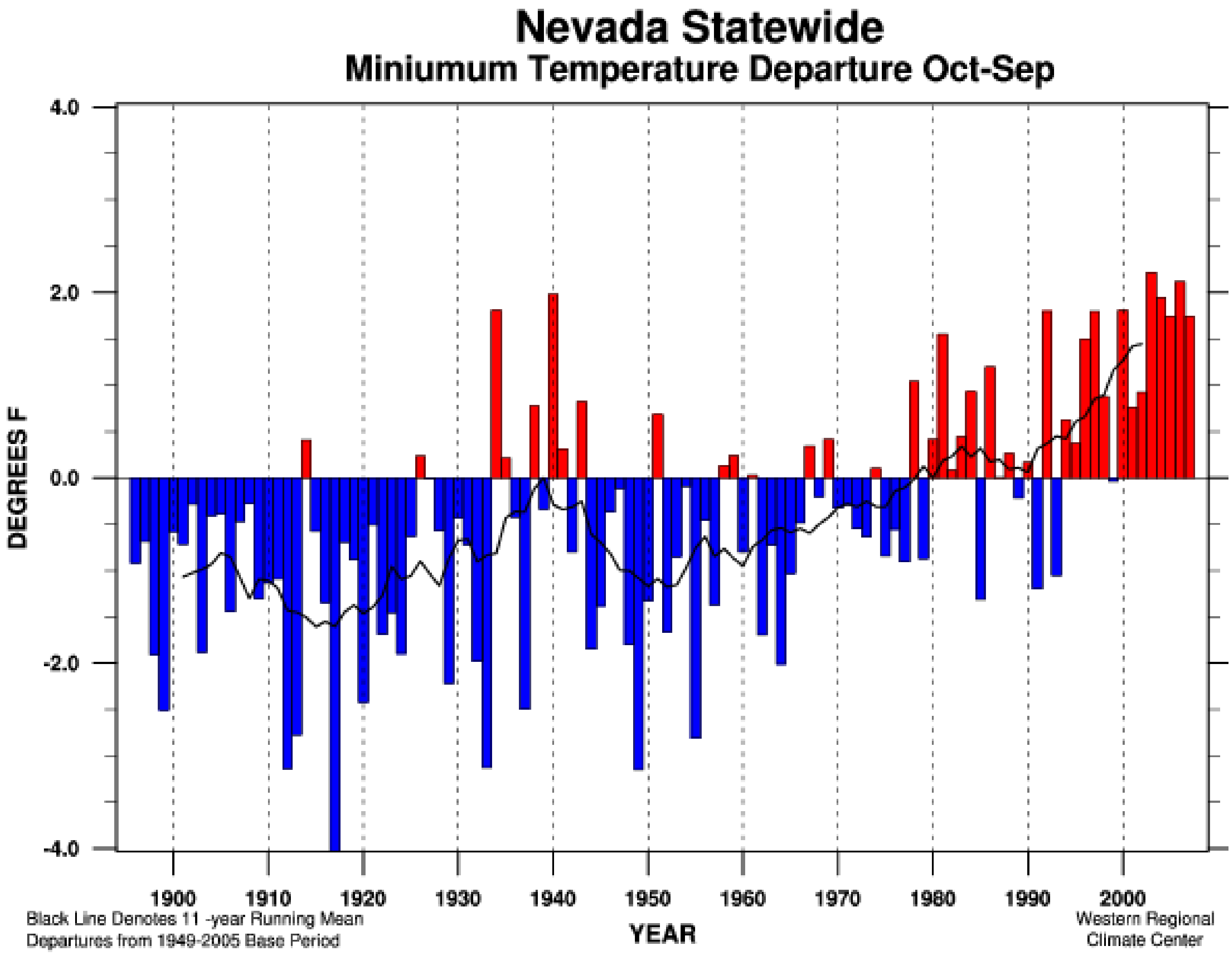
Linear Trend 1895-present		+ 1.94 ± 0.65 °F/100yr	
Linear Trend 1949-present		+ 2.67 ± 1.60 °F/100yr	
Linear Trend 1975-present		+ 5.54 ± 4.05 °F/100yr	
Warmest Year		52.8 °F (+ 3.3 °F) in 1934	MEAN 49.4 °F
Coldest Year		45.3 °F (- 4.1 °F) in 1917	STDEV 1.11 °F
Oct-Sep	2007	50.9 °F (+ 1.5 °F)	RANK 104 of 112



Linear Trend 1895-present		+ 1.72 ± 0.82 °F/100yr		
Linear Trend 1949-present		+ 0.82 ± 2.24 °F/100yr		
Linear Trend 1975-present		+ 4.66 ± 5.80 °F/100yr		
Warmest Year		68.9 °F (+ 4.9 °F) in 1934	MEAN	64.0 °F
Coldest Year		59.9 °F (- 4.1 °F) in 1917	STDEV	1.42 °F
Oct-Sep	2007	65.2 °F (+ 1.2 °F)	RANK	96 of 112

Through Sep 2007

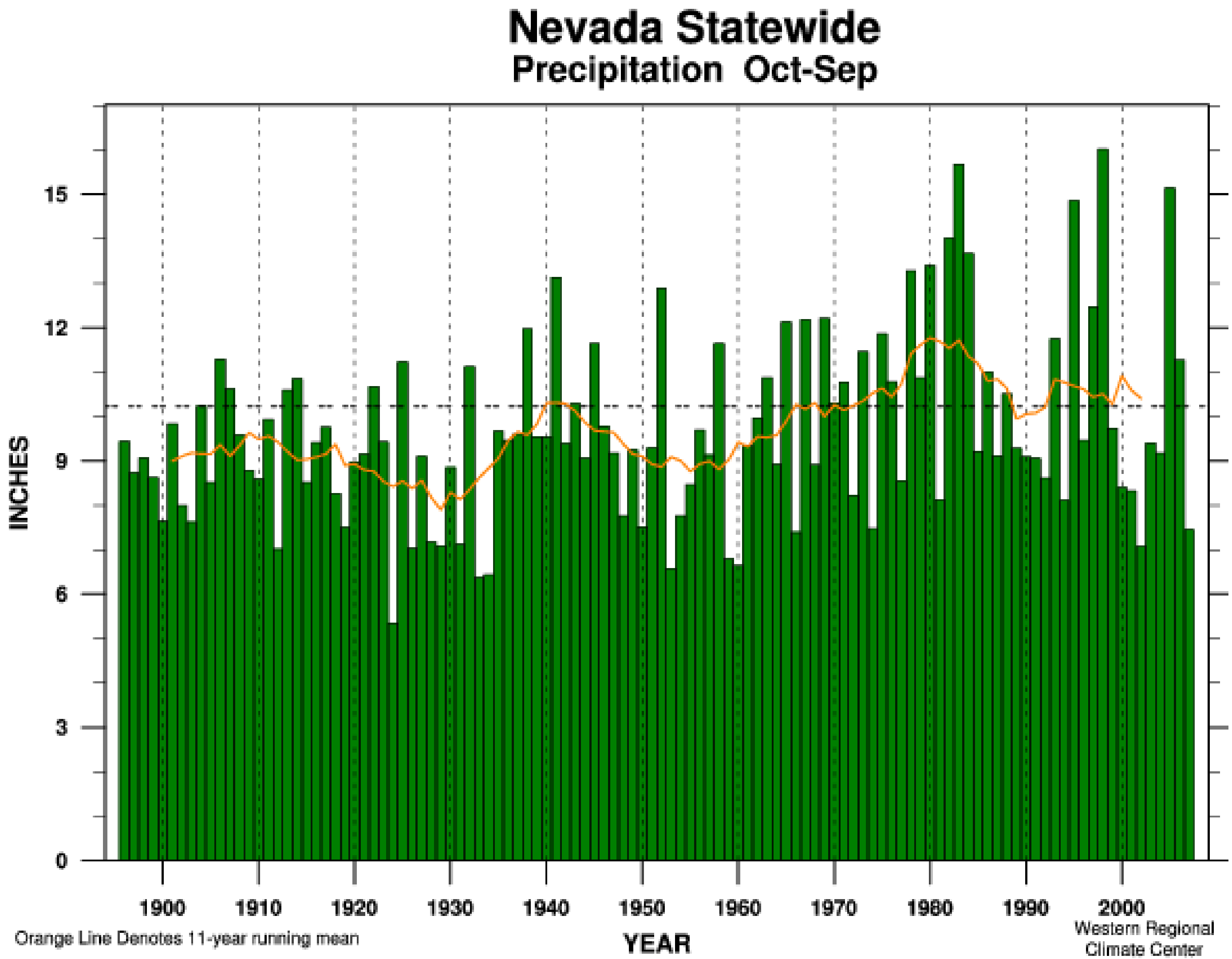
PRISM values not yet available after June 2008



Linear Trend 1895-present		+ 2.16 ± 0.61°F/100yr	
Linear Trend 1949-present		+ 4.51 ± 1.32°F/100yr	
Linear Trend 1975-present		+ 6.43 ± 3.36°F/100yr	
Warmest Year		37.0 °F (+ 2.2 °F) in 2003	MEAN 34.8 °F
Coldest Year		30.7 °F (- 4.0 °F) in 1917	STDEV 1.13 °F
Oct-Sep	2007	36.5 °F (+ 1.7 °F)	RANK 104 of 112

Through Sep 2007

PRISM values not yet available after June 2008

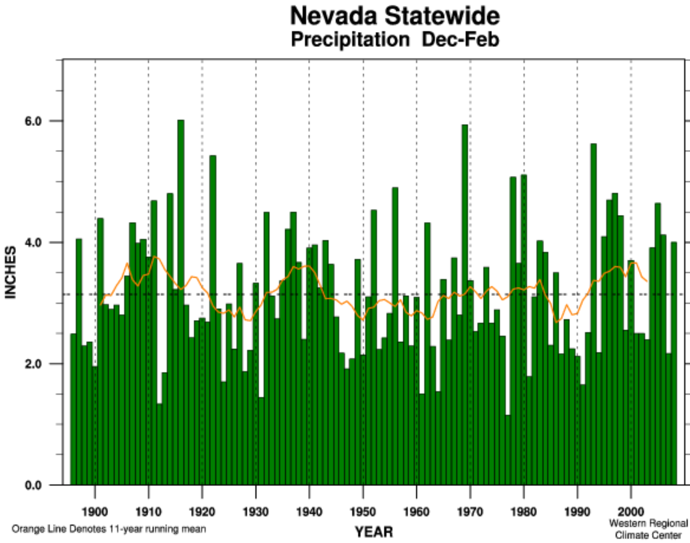


Linear Trend 1895-present		+ 1.93 ± 1.14 in.	(+ 18 ± 11%) per 100 yr		
Linear Trend 1949-present		+ 2.75 ± 3.66 in.	(+ 26 ± 35%) per 100 yr		
Linear Trend 1975-present		- 5.17 ± 9.98 in.	(- 50 ± 97%) per 100 yr		
Wettest Year		16.02 in. (156%)	in 1998	MEAN	10.22 in.
Driest Year		5.34 in. (52%)	in 1924	STDEV	2.35 in.
Oct-Sep	2007	7.45 in. (72%)		RANK	14 of 112

Through Sep 2007

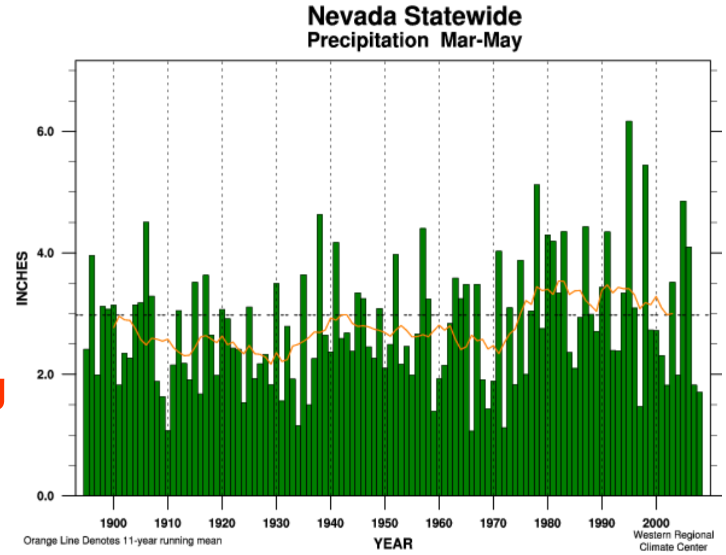
PRISM values not yet available after June 2008

Winter



Linear Trend 1895-present	+ 0.09 ± 0.60 in.	(+ 2 ± 19%) per 100 yr	
Linear Trend 1949-present	+ 0.98 ± 1.68 in.	(+ 31 ± 53%) per 100 yr	
Linear Trend 1975-present	+ 1.64 ± 4.37 in.	(+ 52 ± 138%) per 100 yr	
Wettest Year	6.02 in. (191%) in 1916	MEAN	3.15 in.
Driest Year	1.15 in. (36%) in 1977	STDEV	1.11 in.
Dec-Feb 2008	4.00 in. (127%)	RANK	87 of 113

Spring

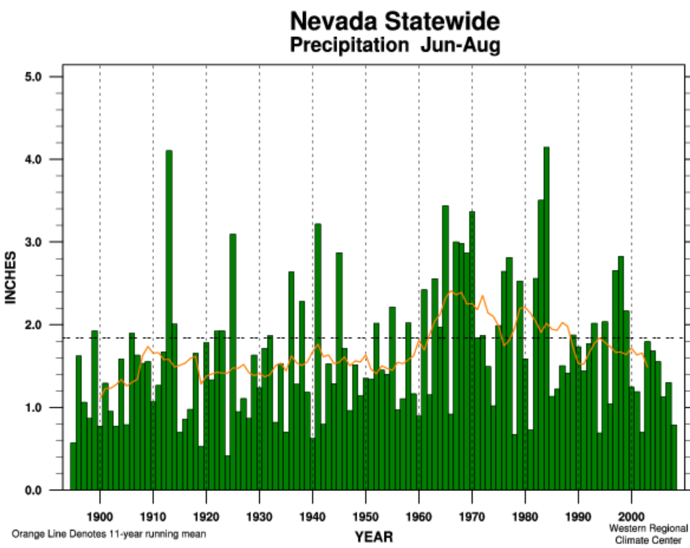


Linear Trend 1895-present	+ 0.60 ± 0.54 in.	(+ 20 ± 18%) per 100 yr	
Linear Trend 1949-present	+ 1.04 ± 1.64 in.	(+ 34 ± 55%) per 100 yr	
Linear Trend 1975-present	- 2.24 ± 4.13 in.	(- 75 ± 138%) per 100 yr	
Wettest Year	6.17 in. (207%) in 1995	MEAN	2.97 in.
Driest Year	1.07 in. (36%) in 1910	STDEV	1.11 in.
Mar-May 2008	1.70 in. (57%)	RANK	13 of 114

Through June 2008

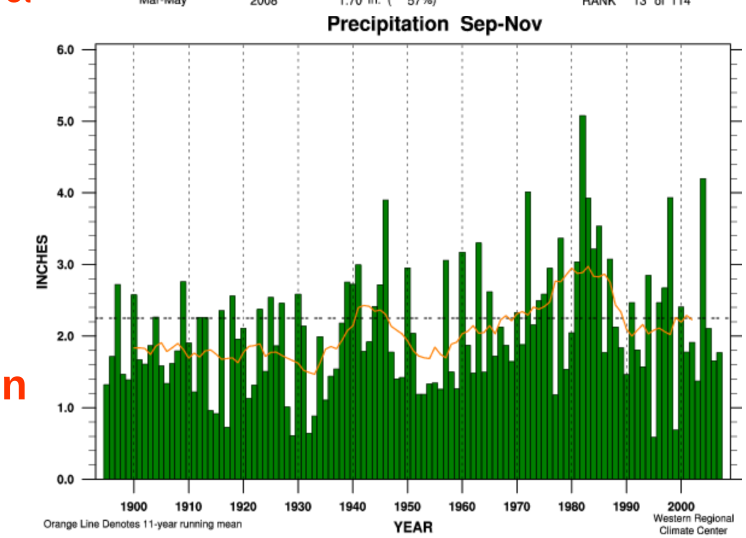
Later PRISM values not yet available

Summer



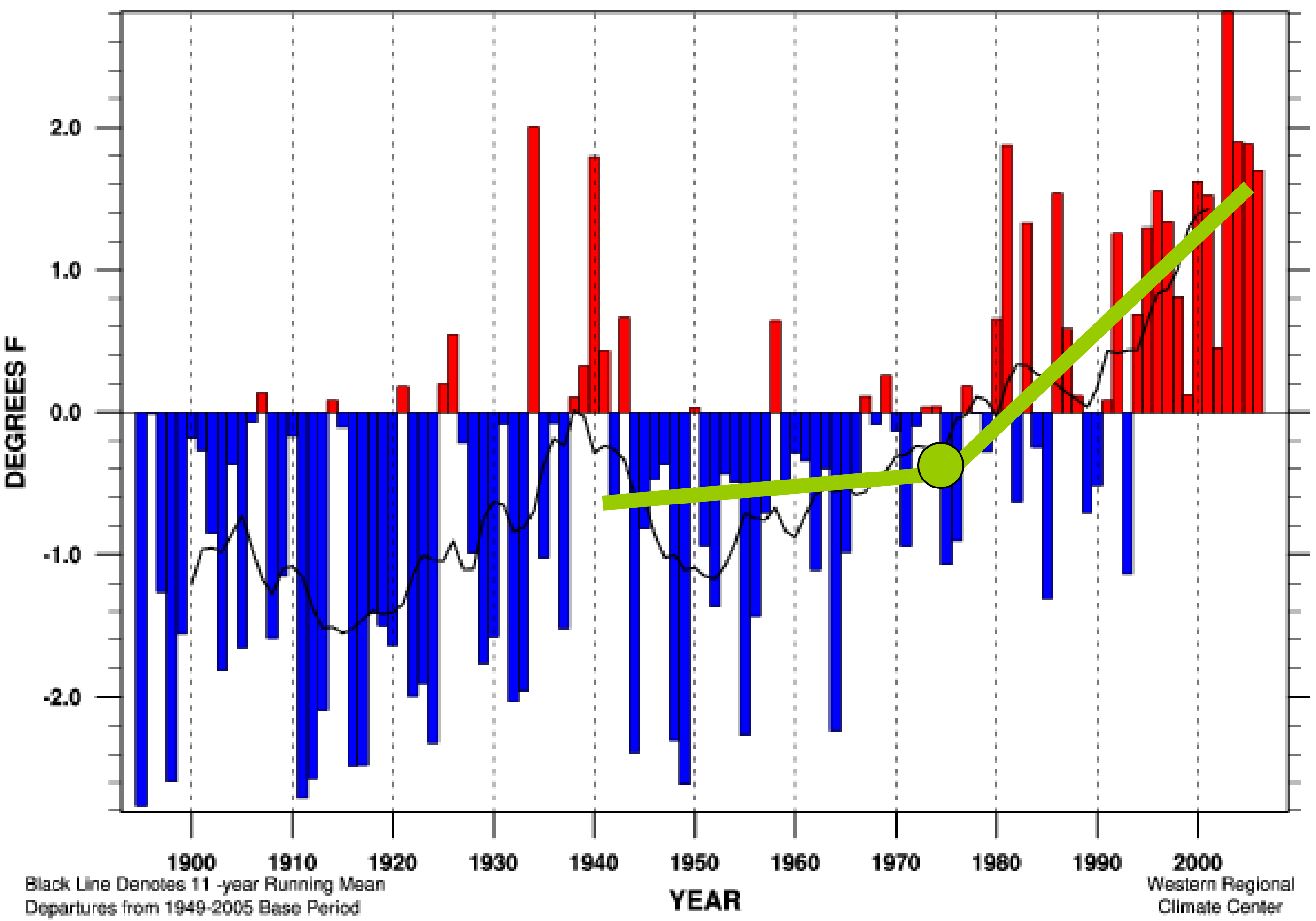
Linear Trend 1895-present	+ 0.48 ± 0.43 in.	(+ 26 ± 23%) per 100 yr	
Linear Trend 1949-present	- 0.39 ± 1.20 in.	(- 21 ± 65%) per 100 yr	
Linear Trend 1975-present	- 2.81 ± 2.79 in.	(-152 ± 151%) per 100 yr	
Wettest Year	4.14 in. (225%) in 1984	MEAN	1.84 in.
Driest Year	0.41 in. (22%) in 1924	STDEV	0.81 in.
Jun-Aug 2008	0.79 in. (42%)	RANK	13 of 114

Autumn

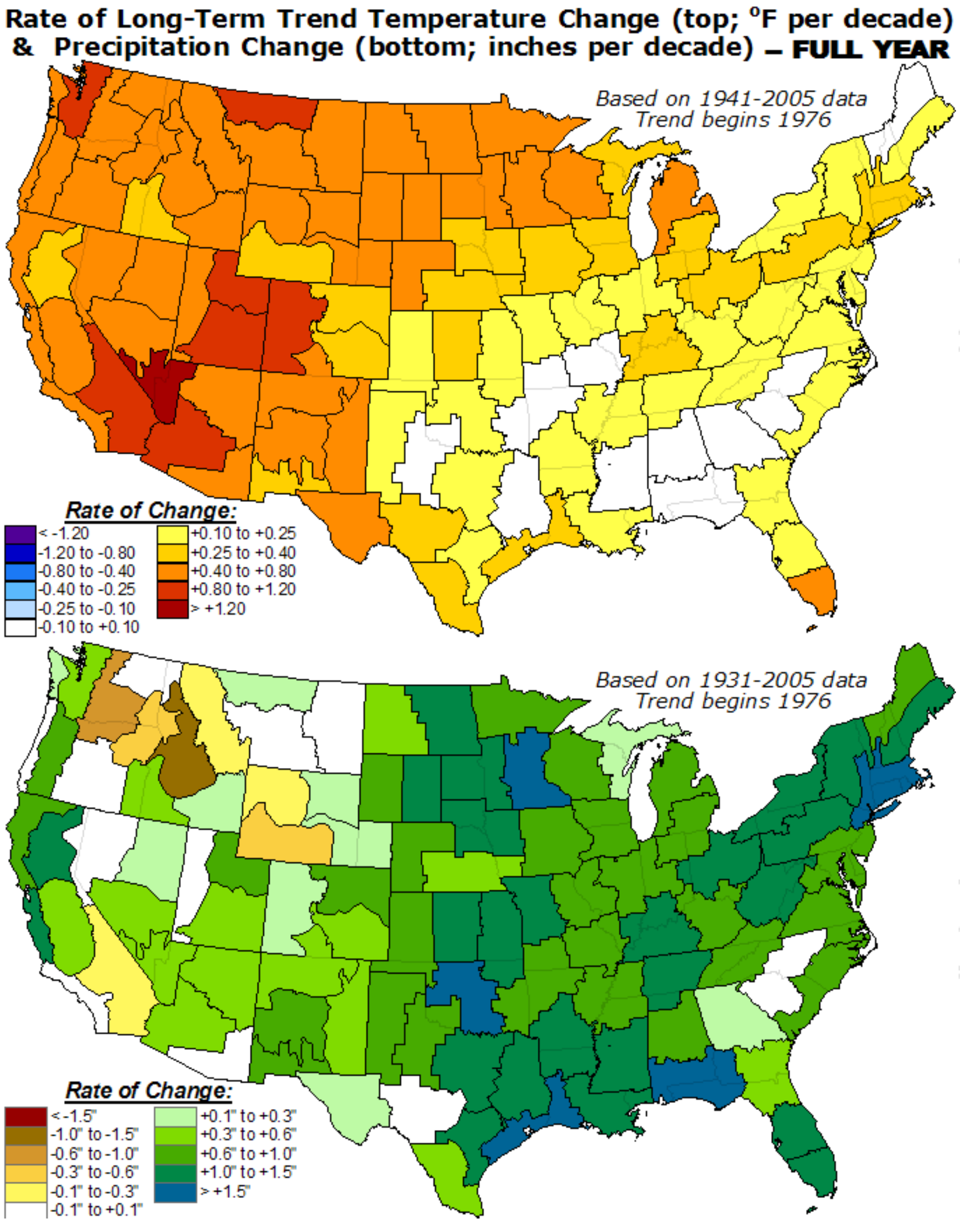


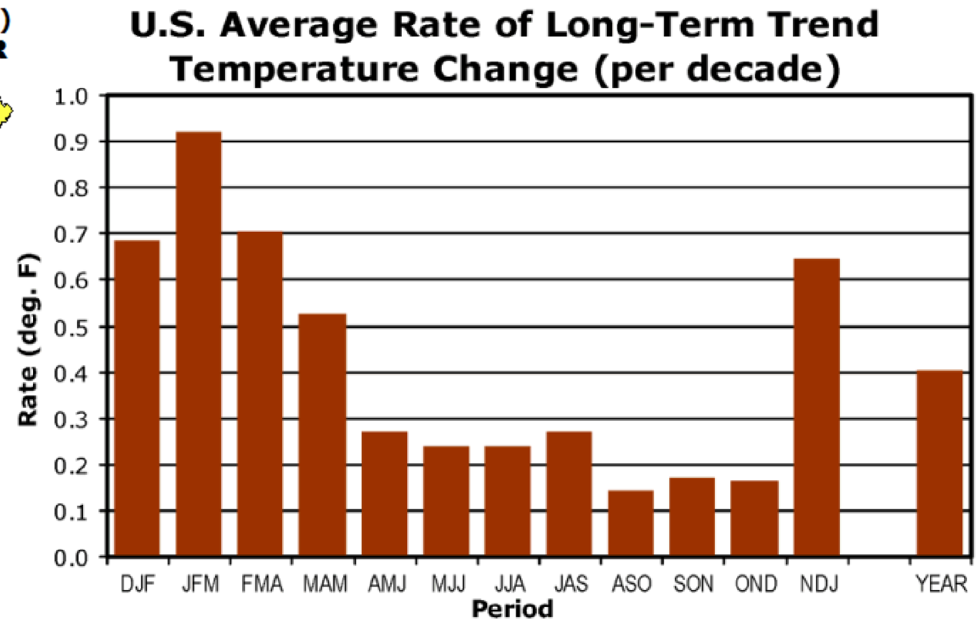
Linear Trend 1895-present	+ 0.67 ± 0.46 in.	(+ 29 ± 20%) per 100 yr	
Linear Trend 1949-present	+ 0.74 ± 1.41 in.	(+ 32 ± 62%) per 100 yr	
Linear Trend 1975-present	- 2.64 ± 3.74 in.	(-117 ± 166%) per 100 yr	
Wettest Year	5.08 in. (225%) in 1982	MEAN	2.25 in.
Driest Year	0.59 in. (26%) in 1995	STDEV	0.94 in.
Sep-Nov 2007	1.77 in. (78%)	RANK	46 of 113

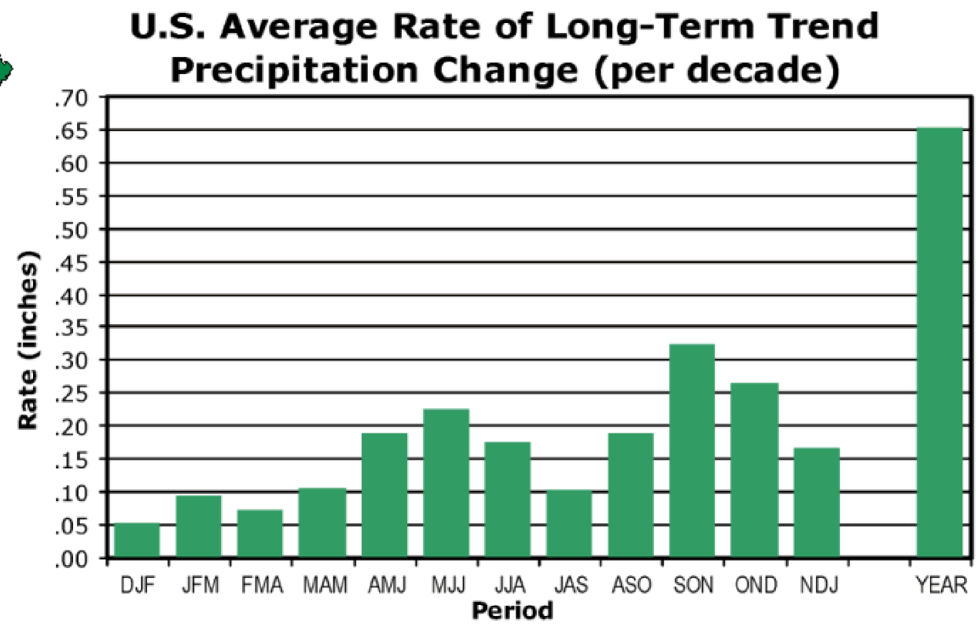
Nevada Statewide
Miniumum Temperature Departure Jan-Dec



Linear Trend 1895-present		+ 2.15 ± 0.59 °F/100yr	
Linear Trend 1949-present		+ 4.68 ± 1.29 °F/100yr	
Linear Trend 1975-present		+ 6.77 ± 3.30 °F/100yr	
Warmest Year		37.5 °F (+ 2.8 °F) in 2003	MEAN 34.7 °F
Coldest Year		32.0 °F (- 2.7 °F) in 1895	STDEV 1.24 °F
Jan-Dec	2006	36.4 °F (+ 1.7 °F)	RANK 106 of 112

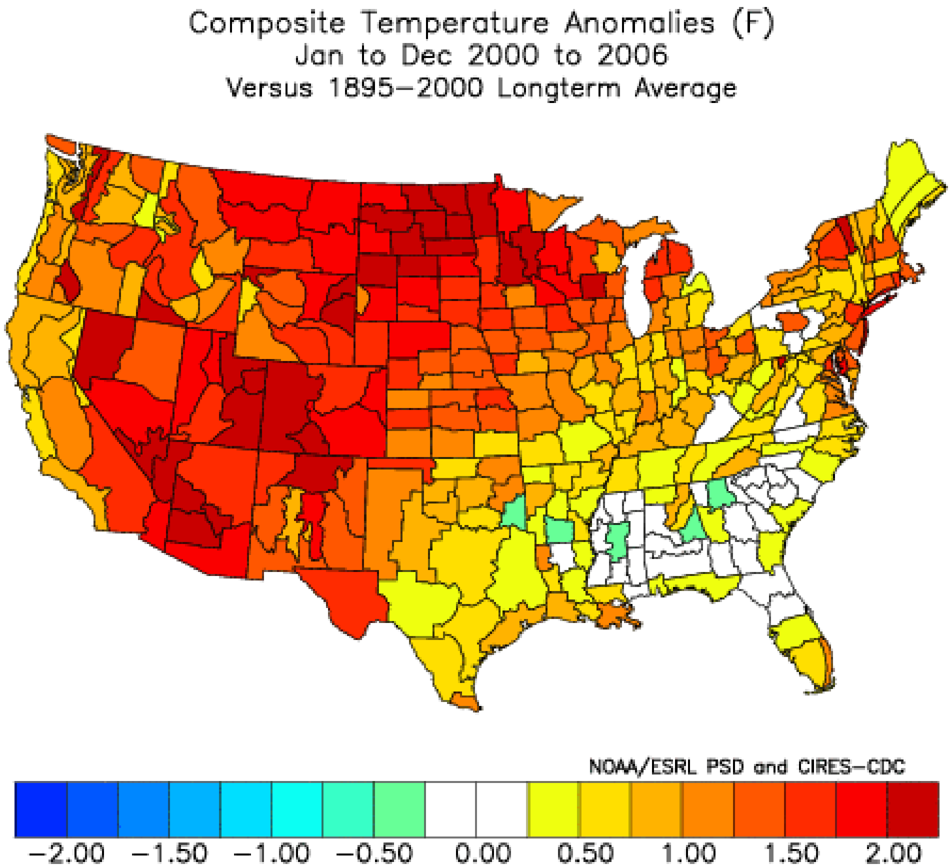


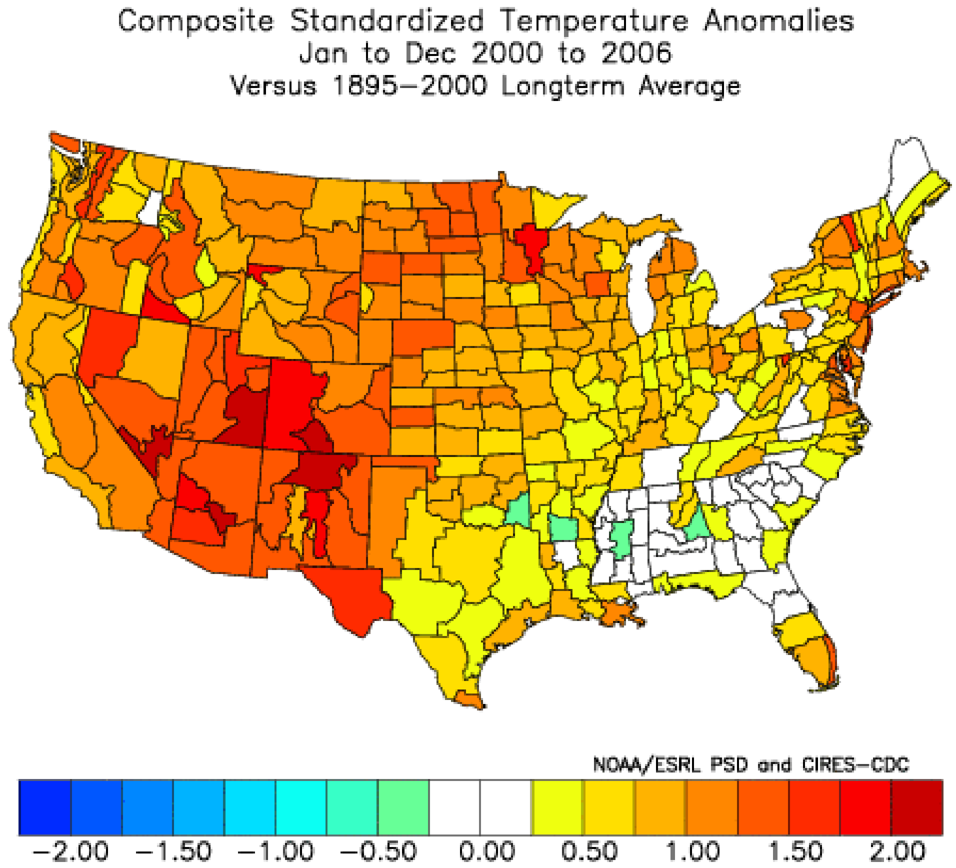




30 Year Trend 1976-Present

Annual Mean Temperatures, 2000-2006.
Departures from 1895-2000 Mean.

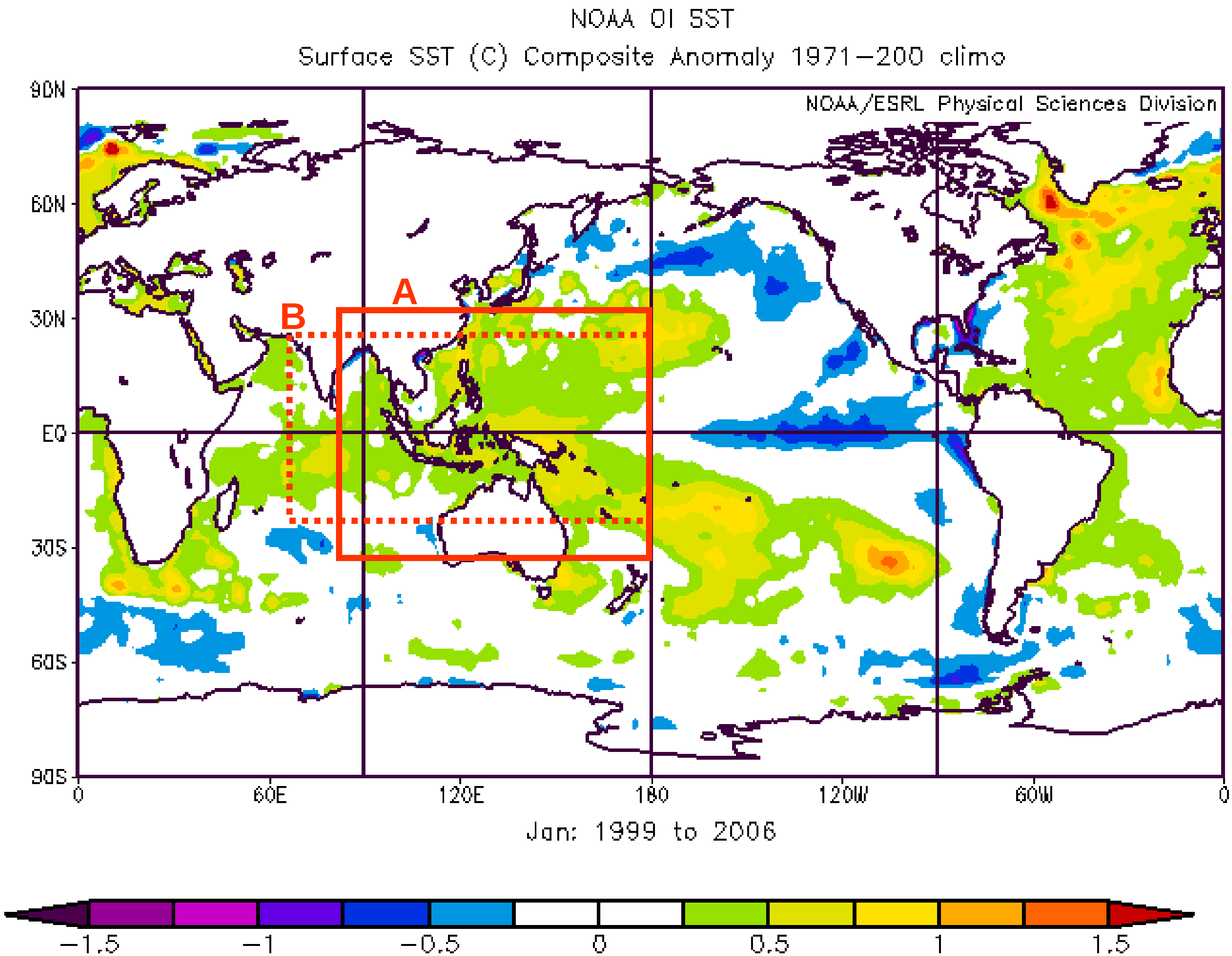


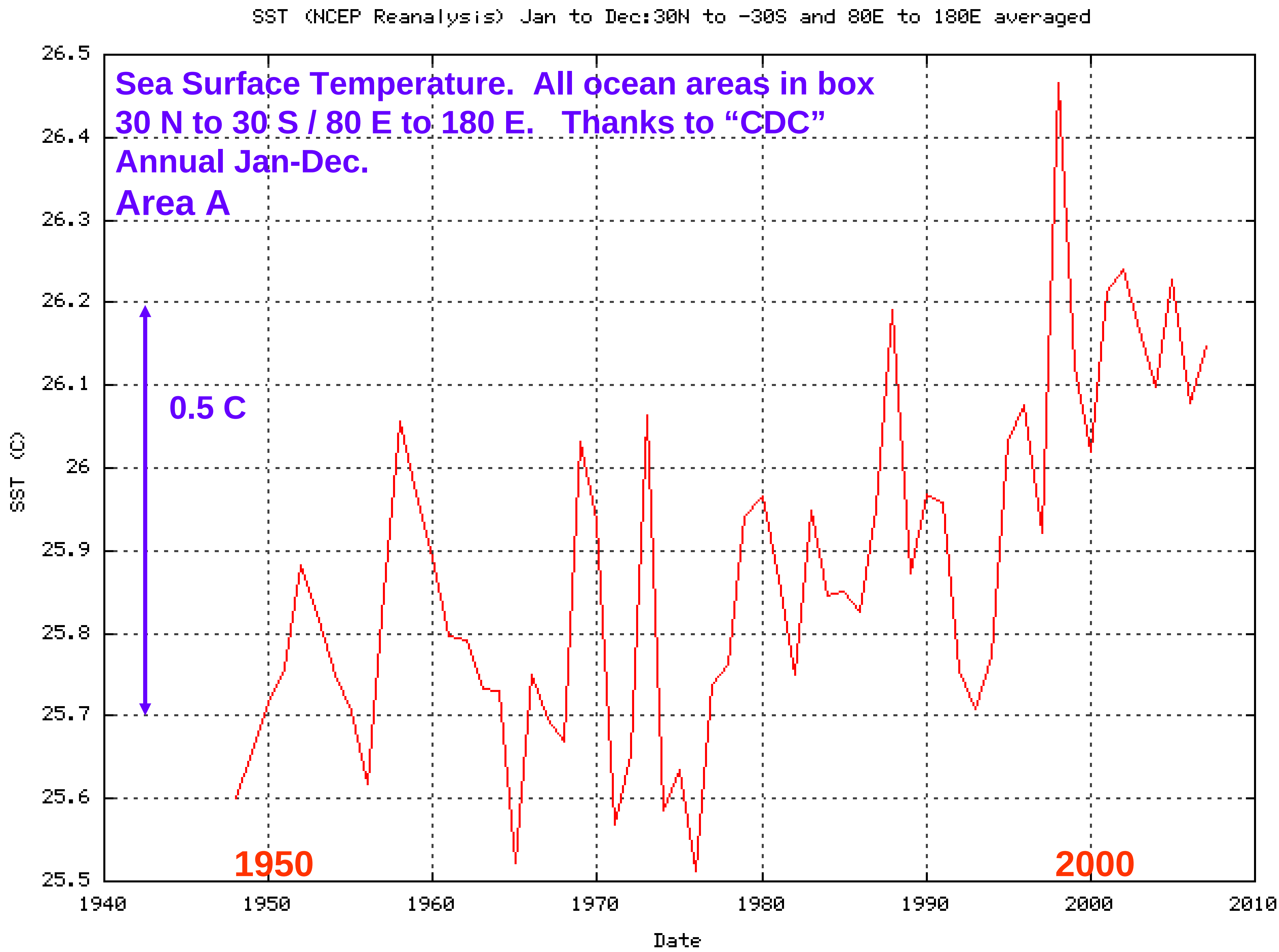


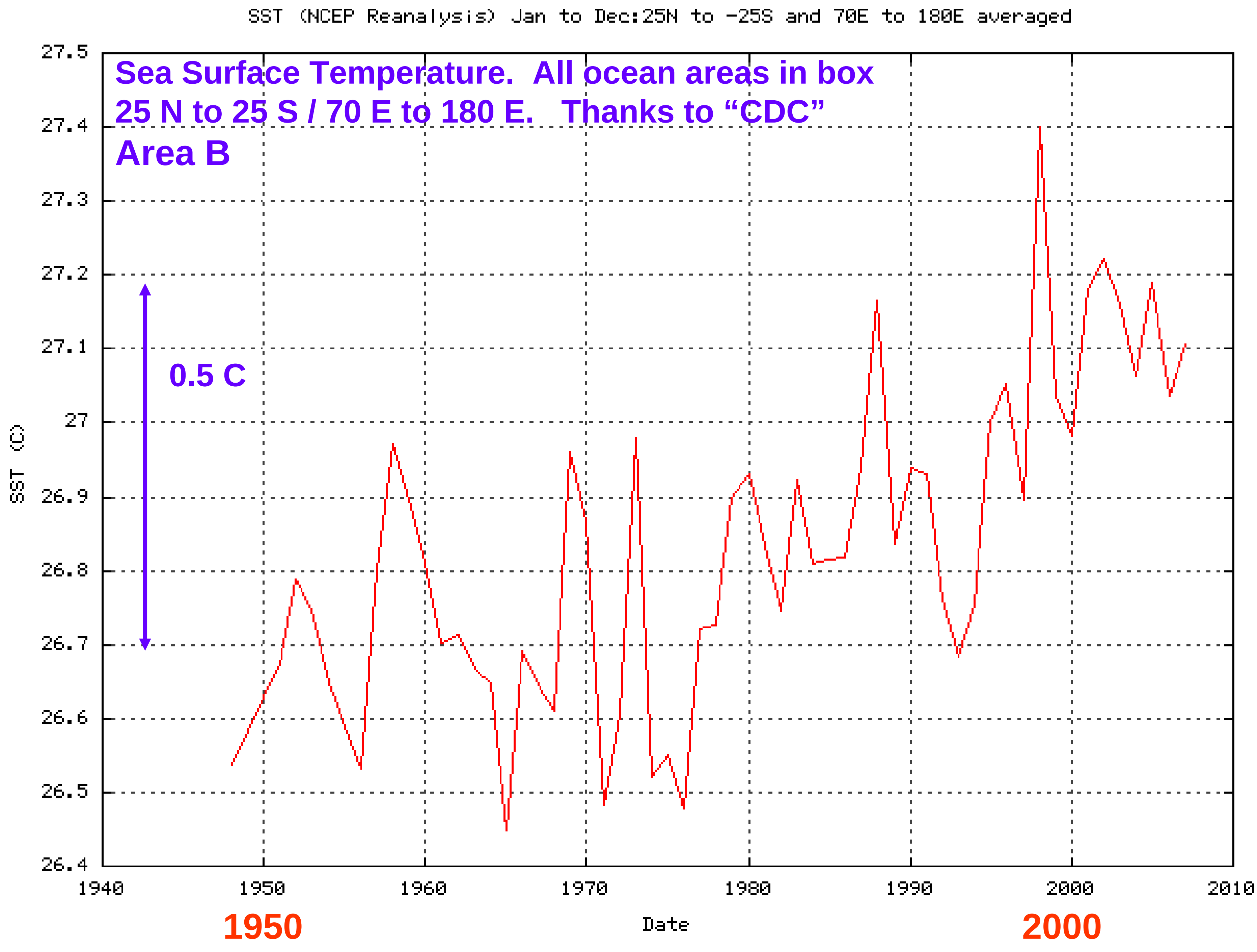
Non-standardized. Units: Degrees F. **Normalized (standard deviations).**

The West dominates recent U.S. warming.

SST Departure from Climatology, Annual Jan-Dec, for 8 years 1999-2006.

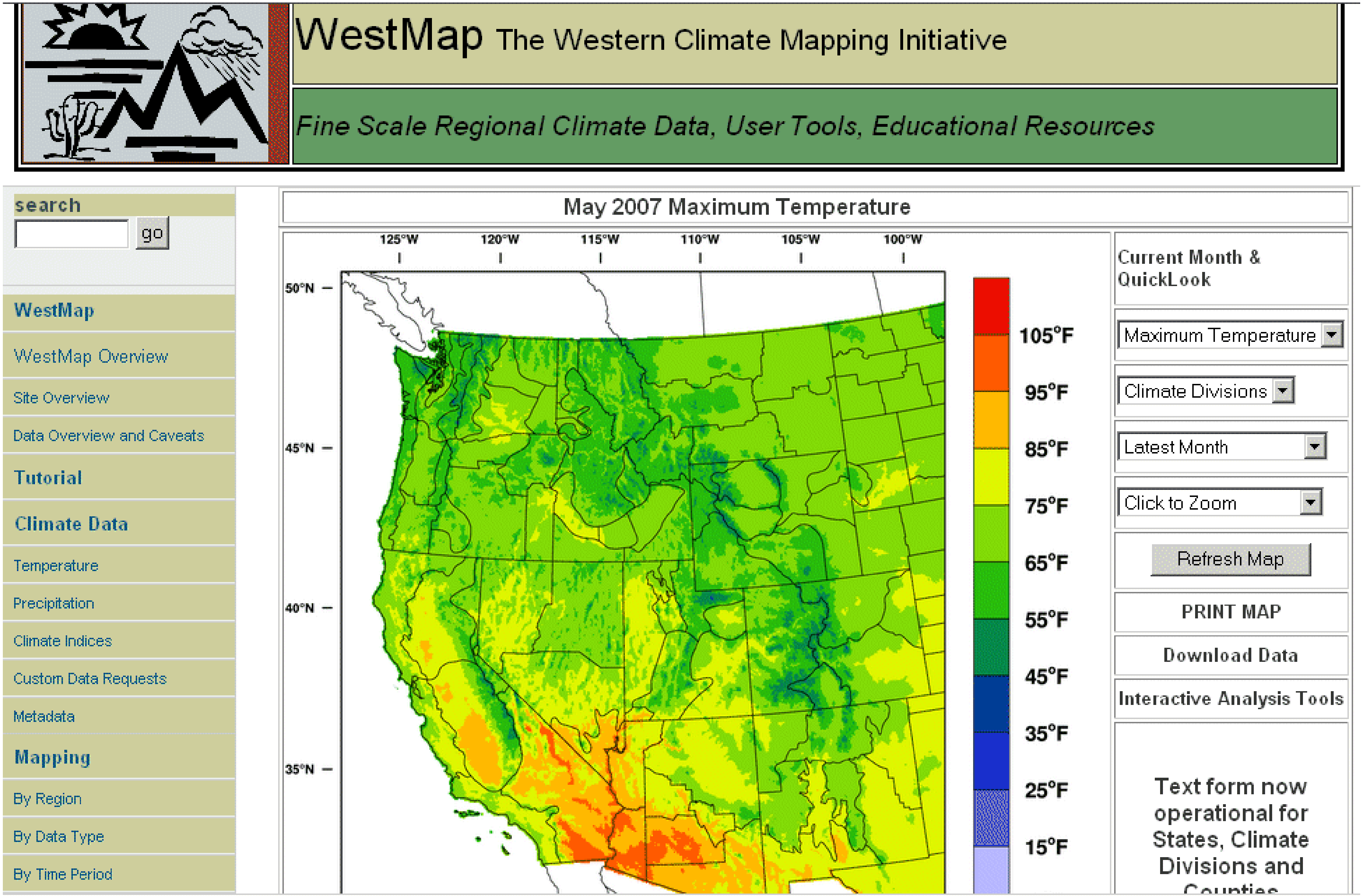



SST (NCEP Reanalysis) Jan to Dec:30N to -30S and 80E to 180E averaged
Sea Surface Temperature. All ocean areas in box
30 N to 30 S / 80 E to 180 E. Thanks to "CDC"
Annual Jan-Dec.
Area A
0.5 C
1950
2000
26.5
26.4
26.3
26.2
26.1
26
25.9
25.8
25.7
25.6
25.5
SST (C)
1940
1950
1960
1970
1980
1990
2000
2010
Date


SST (NCEP Reanalysis) Jan to Dec:25N to -25S and 70E to 180E averaged
Sea Surface Temperature. All ocean areas in box
25 N to 25 S / 70 E to 180 E. Thanks to "CDC"
Area B
0.5 C
SST (C)
27.5
27.4
27.3
27.2
27.1
27
26.9
26.8
26.7
26.6
26.5
26.4
1940
1950
1960
1970
1980
1990
2000
2010
Date
1950
2000

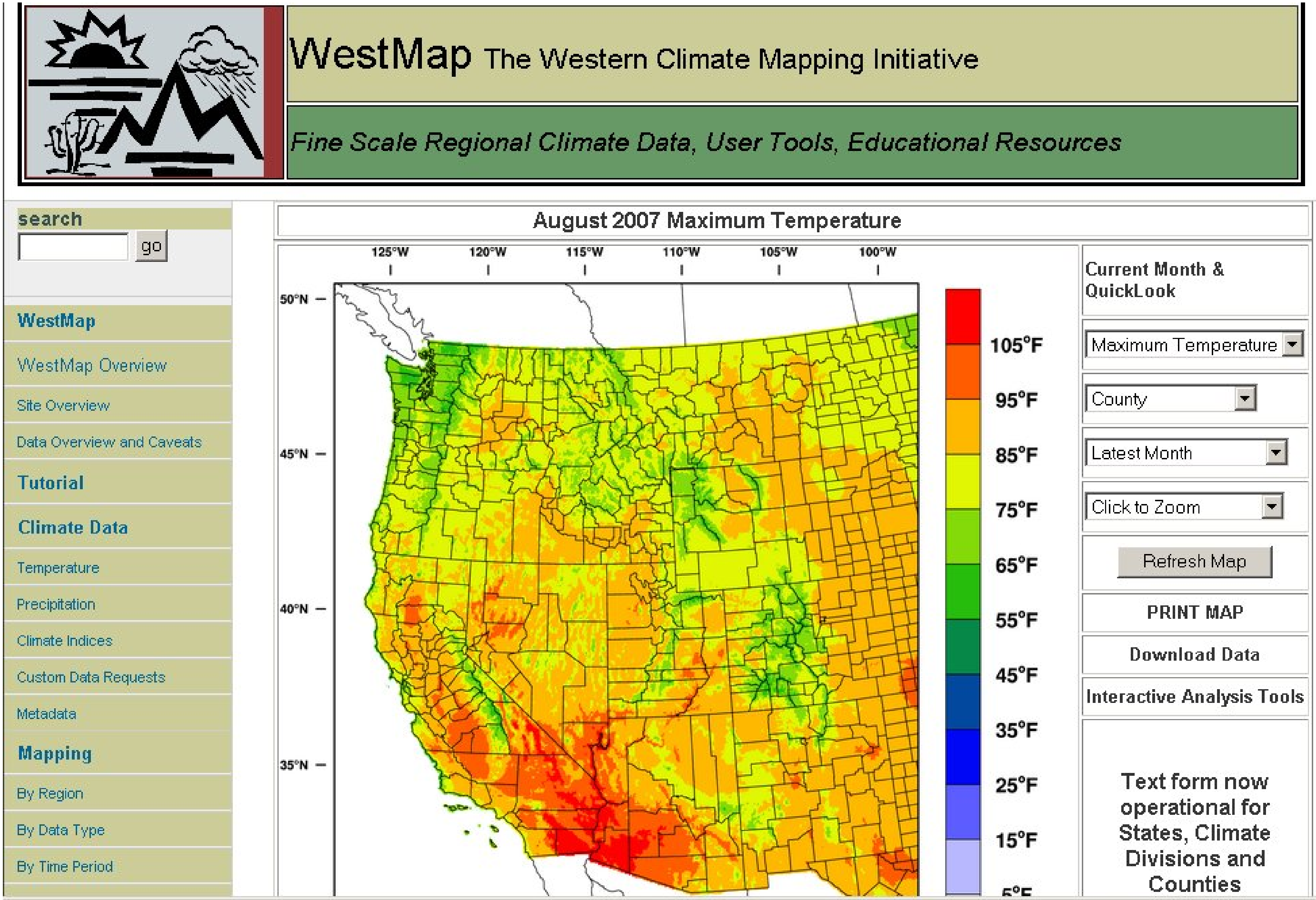
Westmap: U Arizona, DRI/WRCC, OSU NOAA – NCTP …CLIMAS/WRCC/CAP

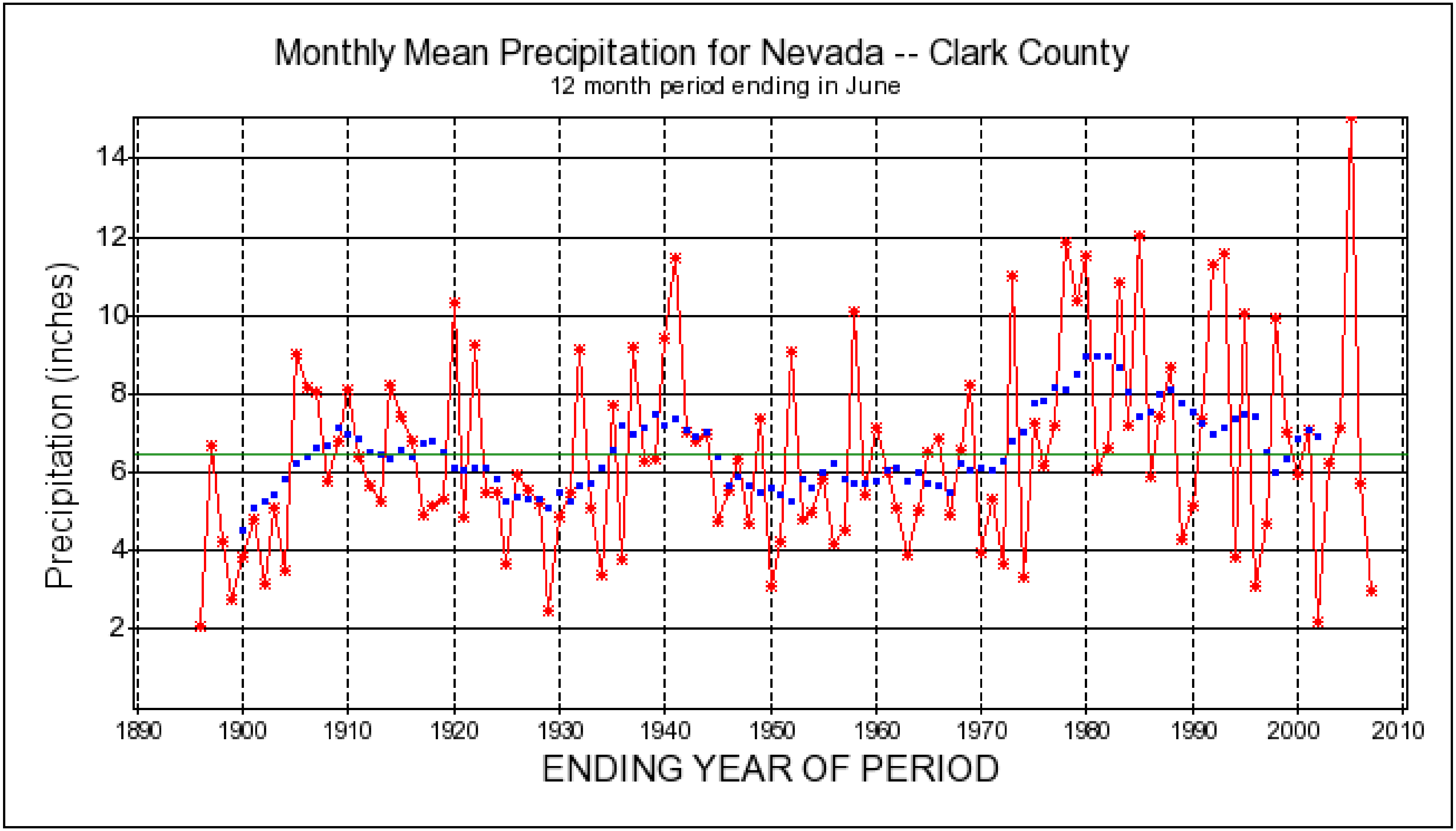
Can be expanded to cover additional states www.wrcc.dri.edu/PROJECTS.html



States, counties, hydro basins, climate divisions, grid squares, stakeholder pixels

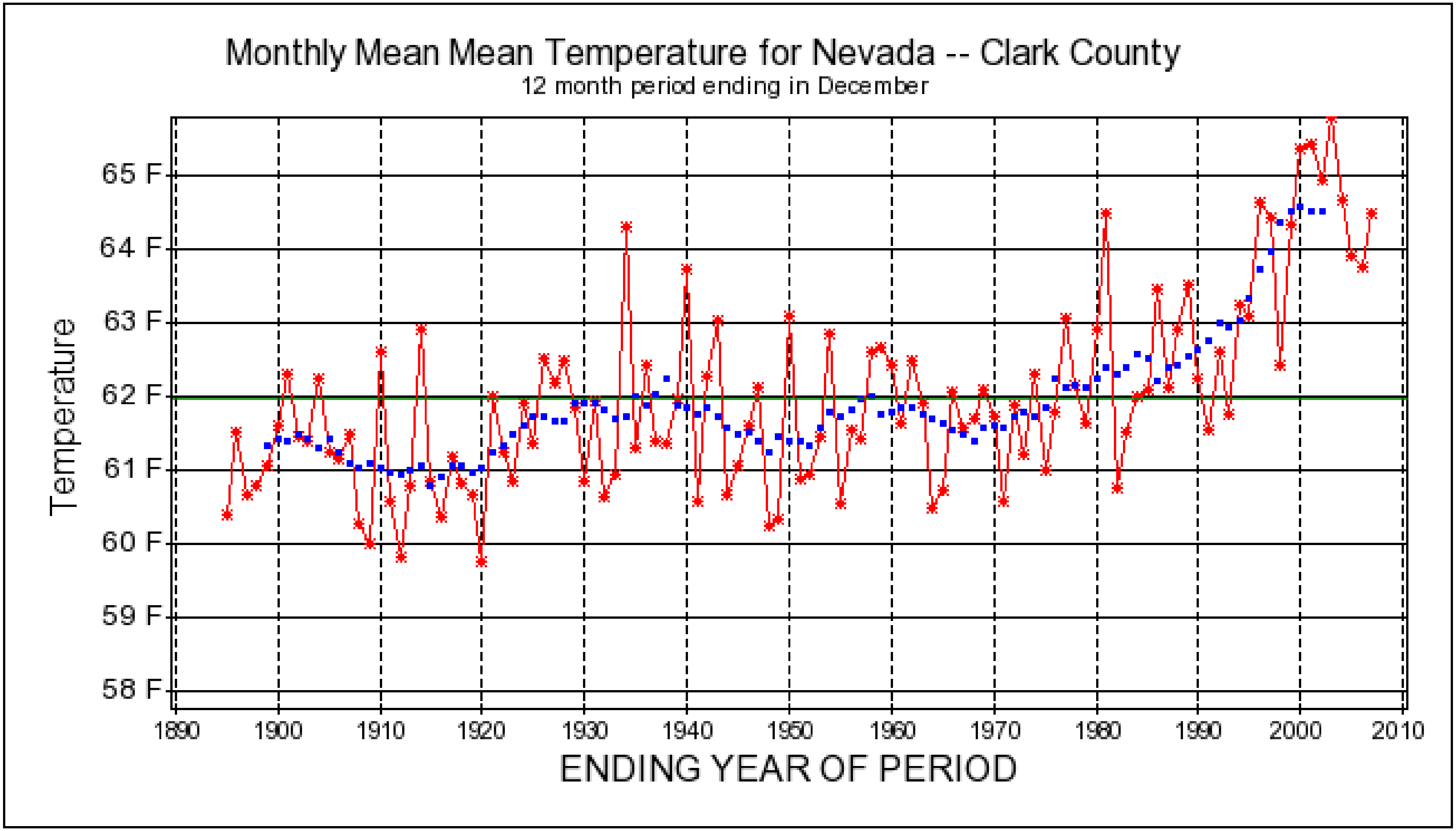
Uses 4 km (maybe soon 2 km) PRISM Monthly Time Series 1895 - last month





12-Month Period Ending in June	
AVERAGE	6.431
MEDIAN	5.980
MINIMUM	2.070
MAXIMUM	15.100
SKEWNESS	0.833
COEFF OF VAR	0.381
SIGMA (RMS)	6.888
NUMBER OBS	112.000

July-June 12-month Precipitation
Clark County, Nevada
With
10-Year Running Mean
Based on PRISM analysis

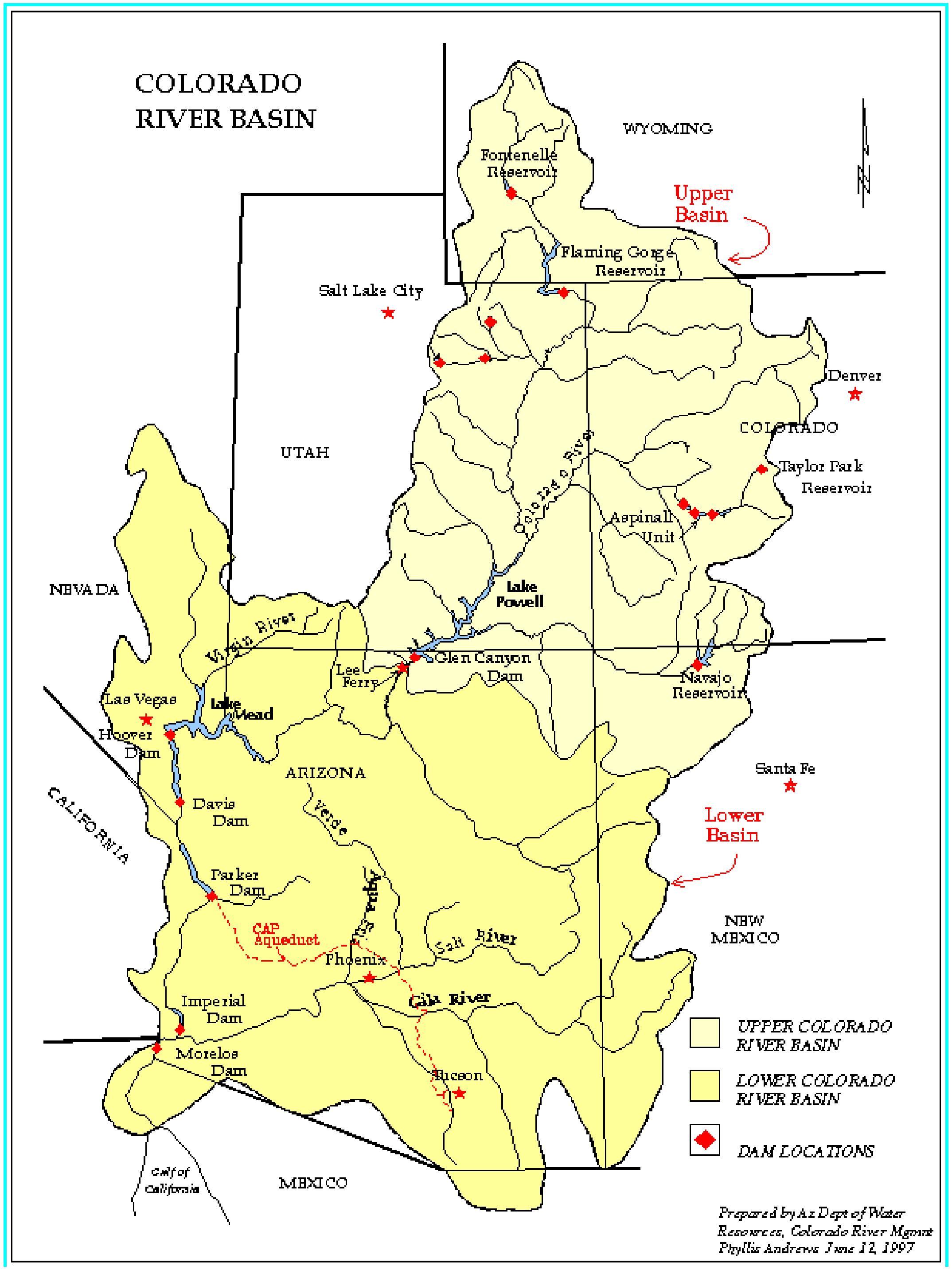


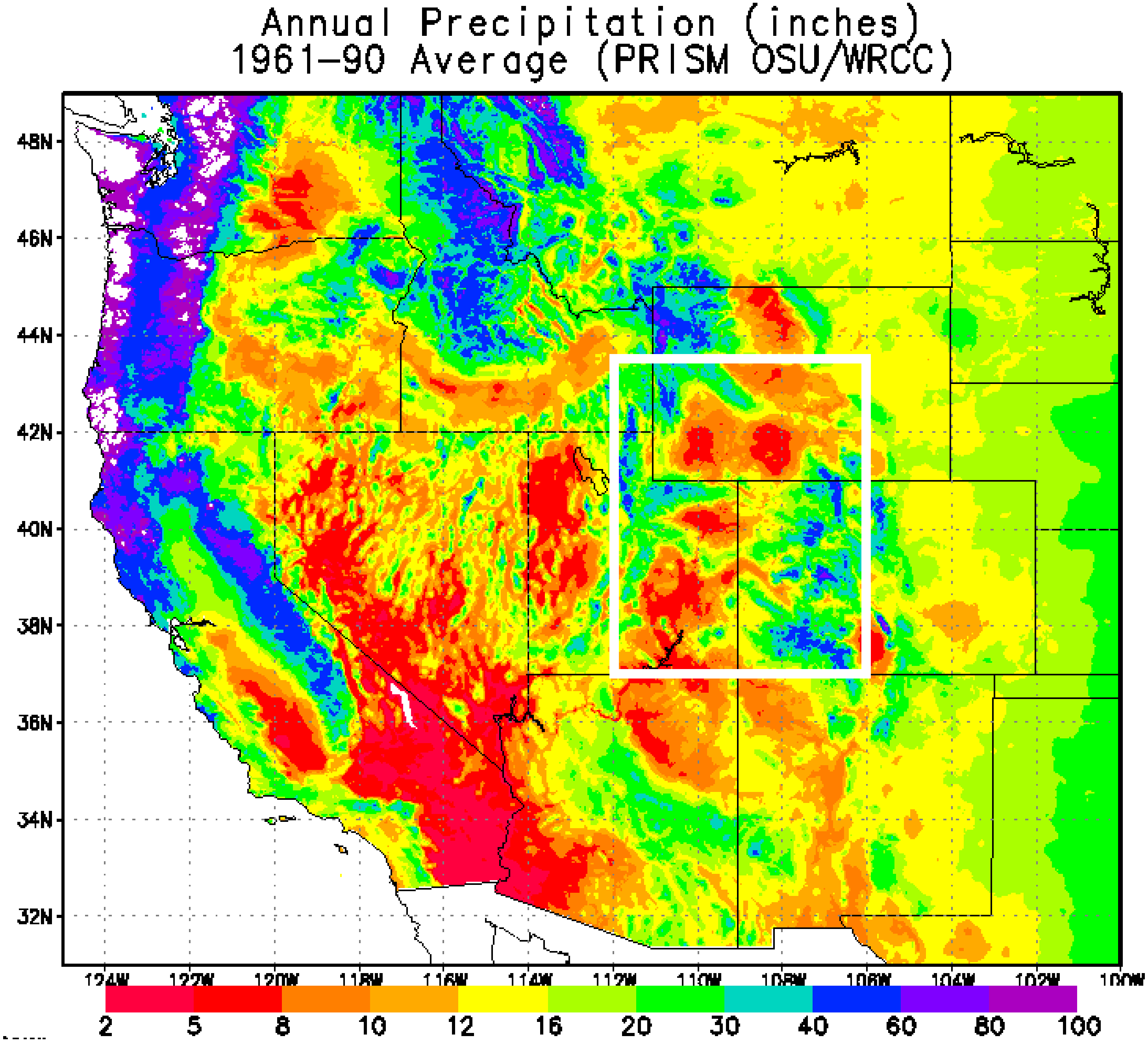

```
12-Month Period Ending in December
AVERAGE         61.986
MEDIAN          61.767
MINIMUM         59.775
MAXIMUM         65.825
SKEWNESS         0.917
COEFF OF VAR     0.020
SIGMA (RMS)     62.000
NUMBER OBS     113.000
```

Jan-Dec 12-month Temperature
Clark County, Nevada
With
10-Year Running Mean
Based on PRISM analysis

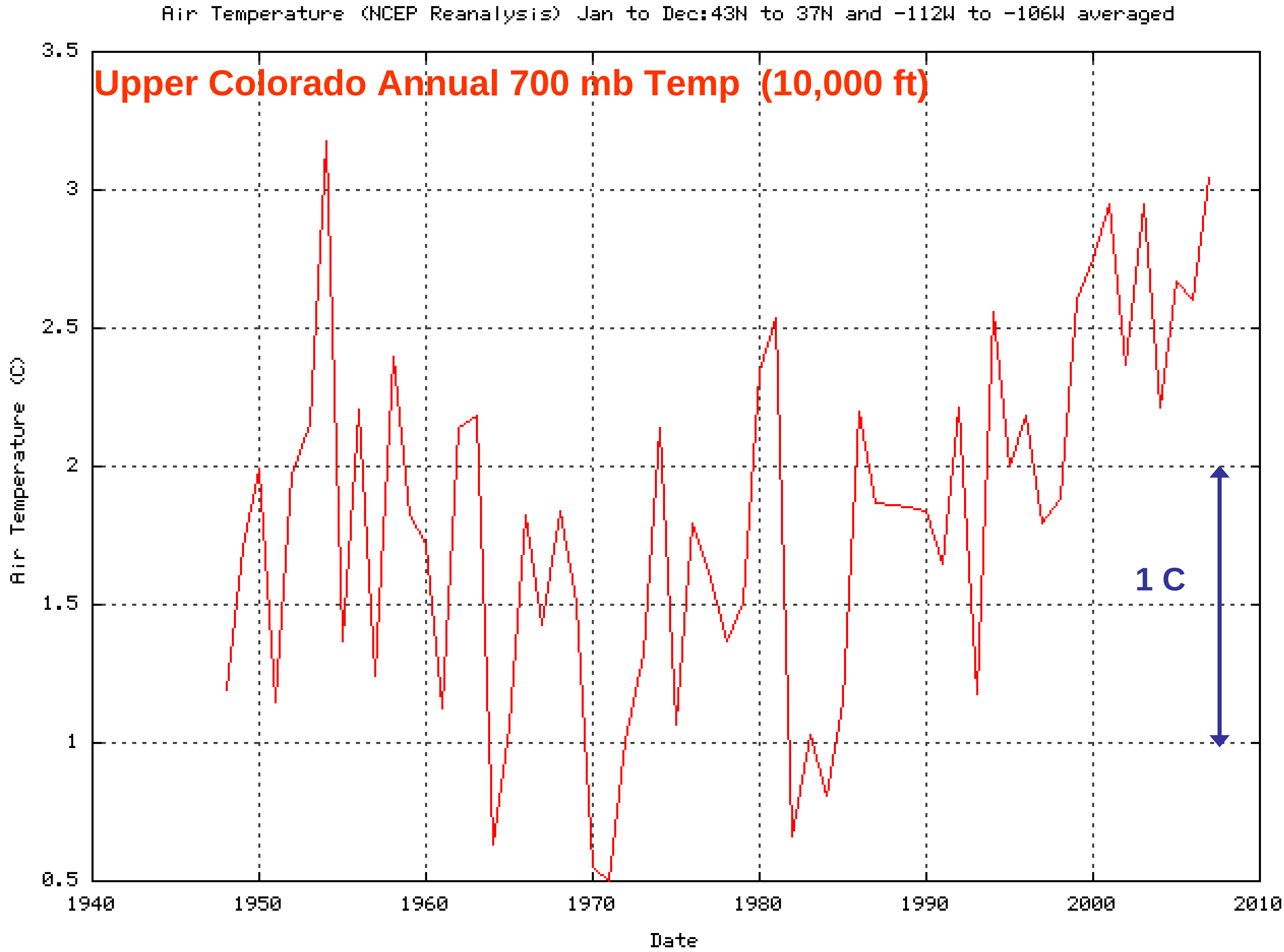
Western United States Warming Climate Evidence

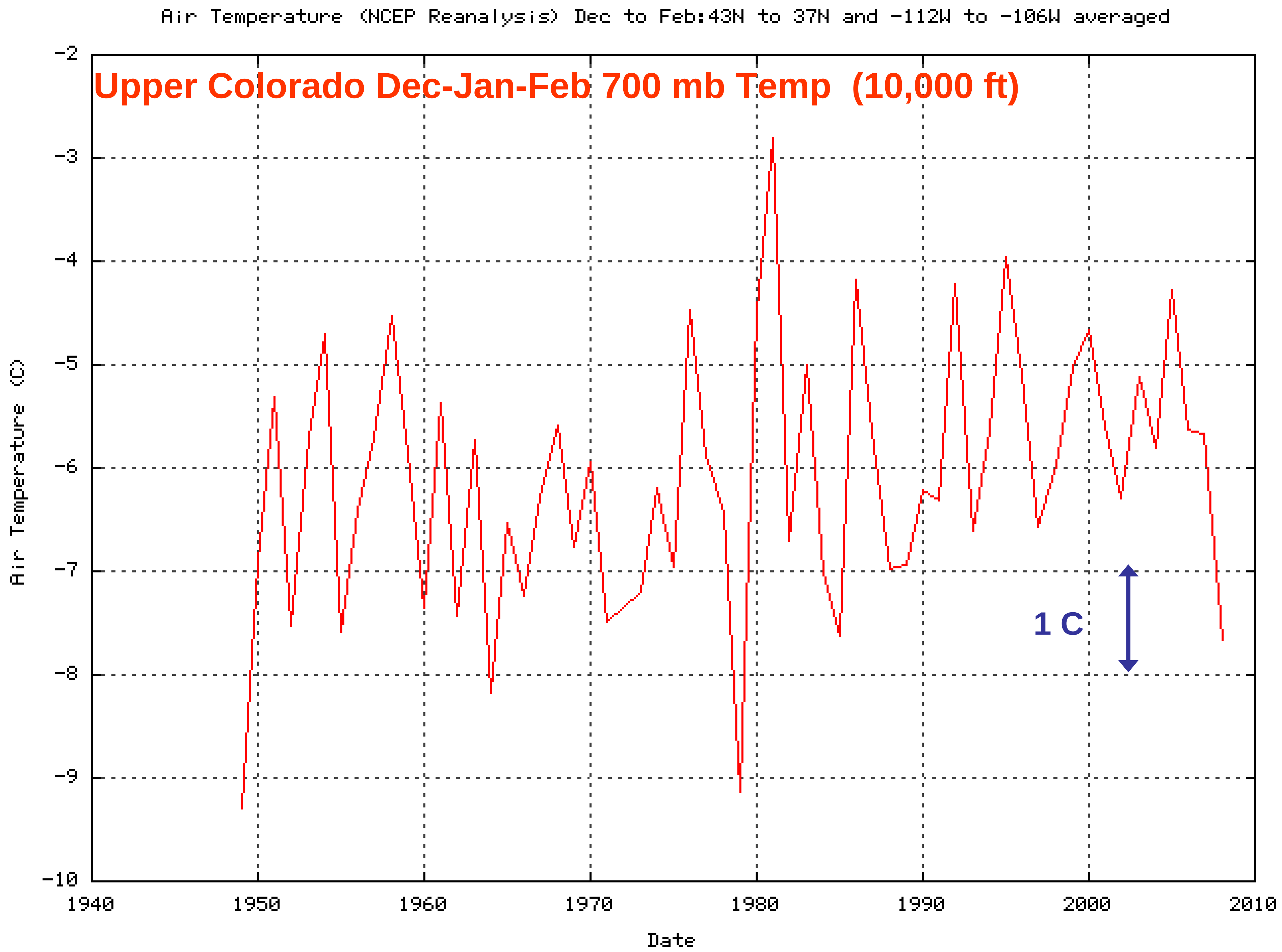
1. Warming - thermometers (NOAA coop surface data network)
2. Warming - thermometers (NOAA upper air data network)
3. Warming - thermometers (subsurface, western boreholes)
4. Snowpack decrease in spring months (Snotel network)
5. More rain / less snow in winter months (NOAA coop network)
6. Earlier snowmelt runoff pulse (date shift, USGS stream gage network)
7. Earlier blooming of lilacs and honeysuckles (phenology networks)
8. Mountain glacier recession and mass loss
9. Upward movement of plant / animal habitat zones
10. Warmer river and lake temperatures

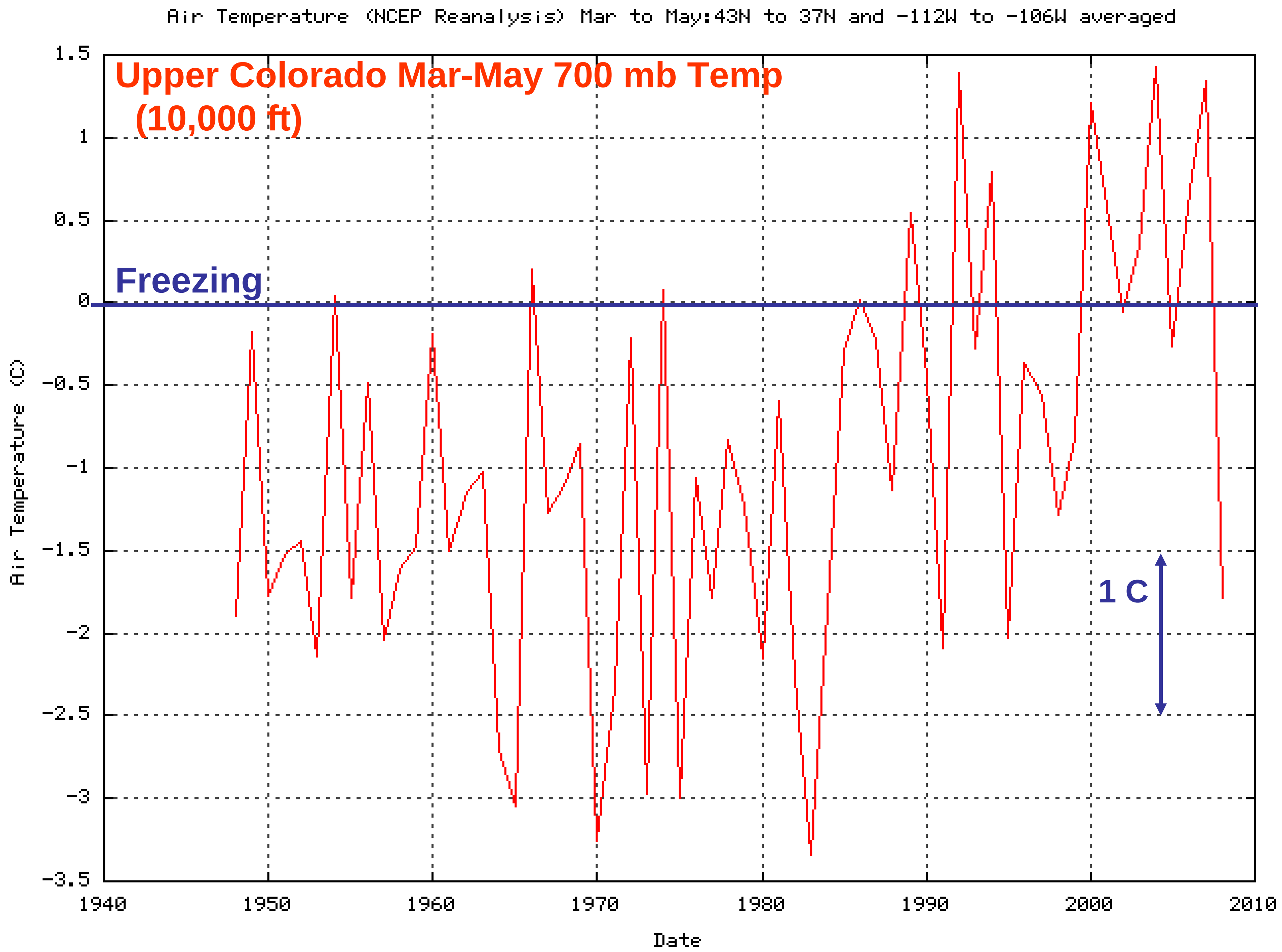

COLORADO RIVER BASIN
WYOMING
Fontenelle Reservoir
Upper Basin
Flaming Gorge Reservoir
Salt Lake City
Denver
COLORADO
Taylor Park Reservoir
UTAH
Colorado River
Aspinall Unit
Lake Powell
NEVADA
Virgin River
Glen Canyon Dam
Lee Ferry
Navajo Reservoir
Las Vegas
Lake Mead
Hoover Dam
ARIZONA
Santa Fe
Lower Basin
CALIFORNIA
Davis Dam
Verde
Parker Dam
NEW MEXICO
CAP Aqueduct
Salt River
Phoenix
Gila River
Imperial Dam
Morelos Dam
Tucson
UPPER COLORADO RIVER BASIN
LOWER COLORADO RIVER BASIN
DAM LOCATIONS
Gulf of California
MEXICO
Prepared by Az Dept of Water Resources, Colorado River Mgmt
Phyllis Andrews June 12, 1997

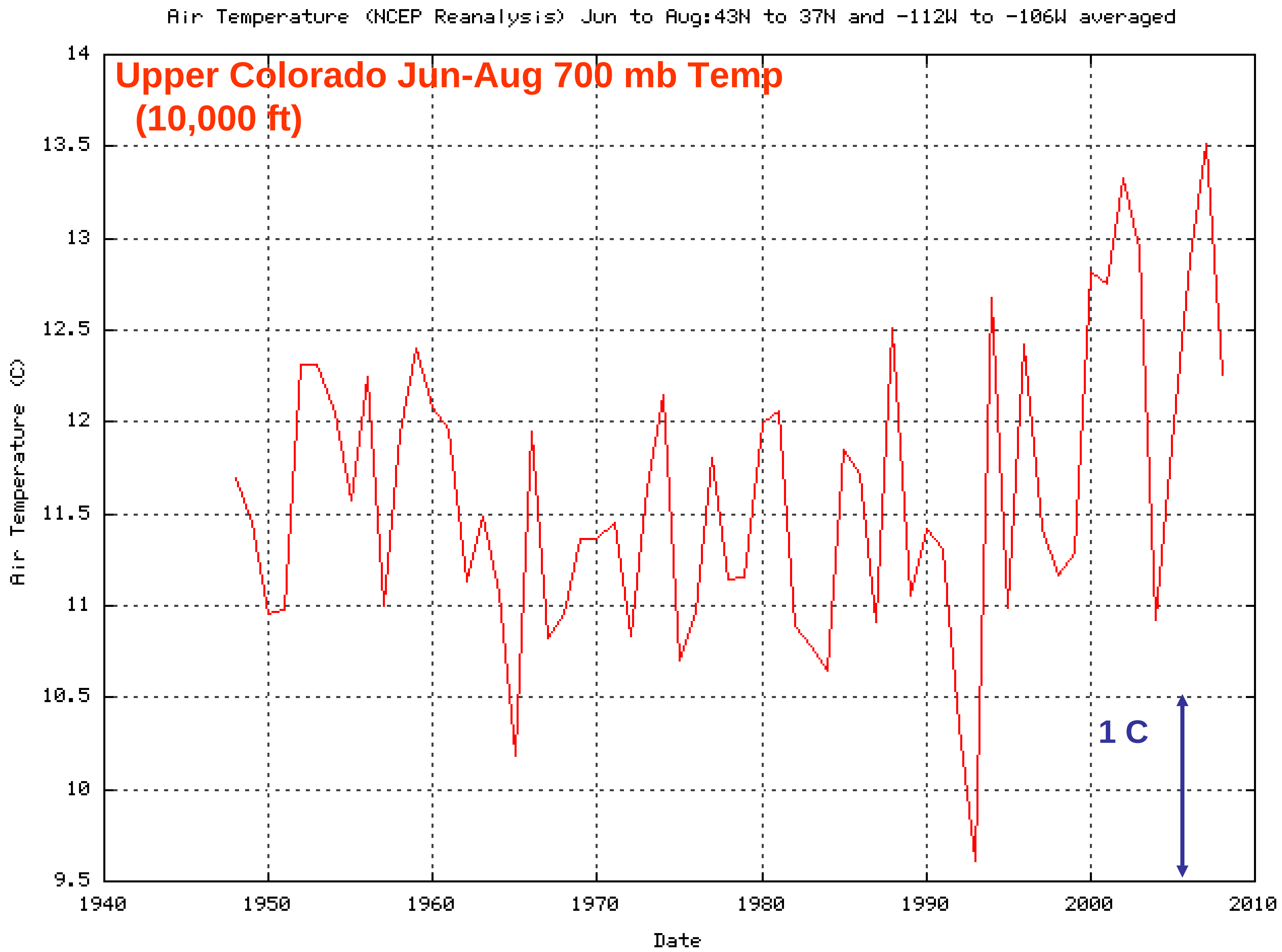


Annual Precipitation (inches)
1961–90 Average (PRISM OSU/WRCC)
48N
46N
44N
42N
40N
38N
36N
34N
32N
124W
122W
120W
118W
116W
114W
112W
110W
108W
106W
104W
102W
100W
2
5
8
10
12
16
20
30
40
60
80
100

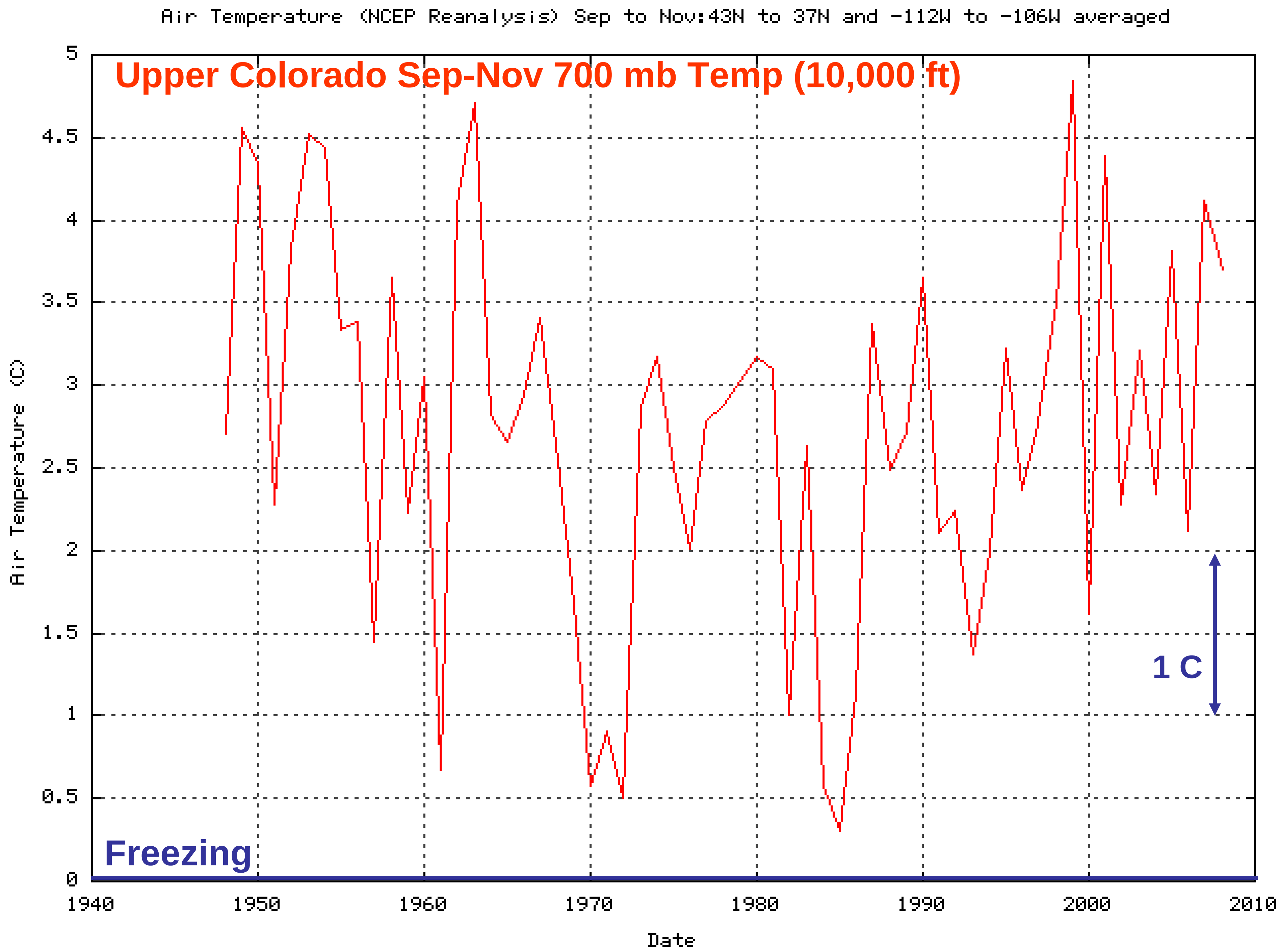

Air Temperature (NCEP Reanalysis) Jan to Dec:43N to 37N and -112W to -106W averaged
Upper Colorado Annual 700 mb Temp (10,000 ft)
1 C
Air Temperature (C)
Date
3.5
3
2.5
2
1.5
1
0.5
1940
1950
1960
1970
1980
1990
2000
2010


Air Temperature (NCEP Reanalysis) Dec to Feb:43N to 37N and -112W to -106W averaged
Upper Colorado Dec-Jan-Feb 700 mb Temp (10,000 ft)
1 C
Air Temperature (C)
Date
-2
-3
-4
-5
-6
-7
-8
-9
-10
1940
1950
1960
1970
1980
1990
2000
2010

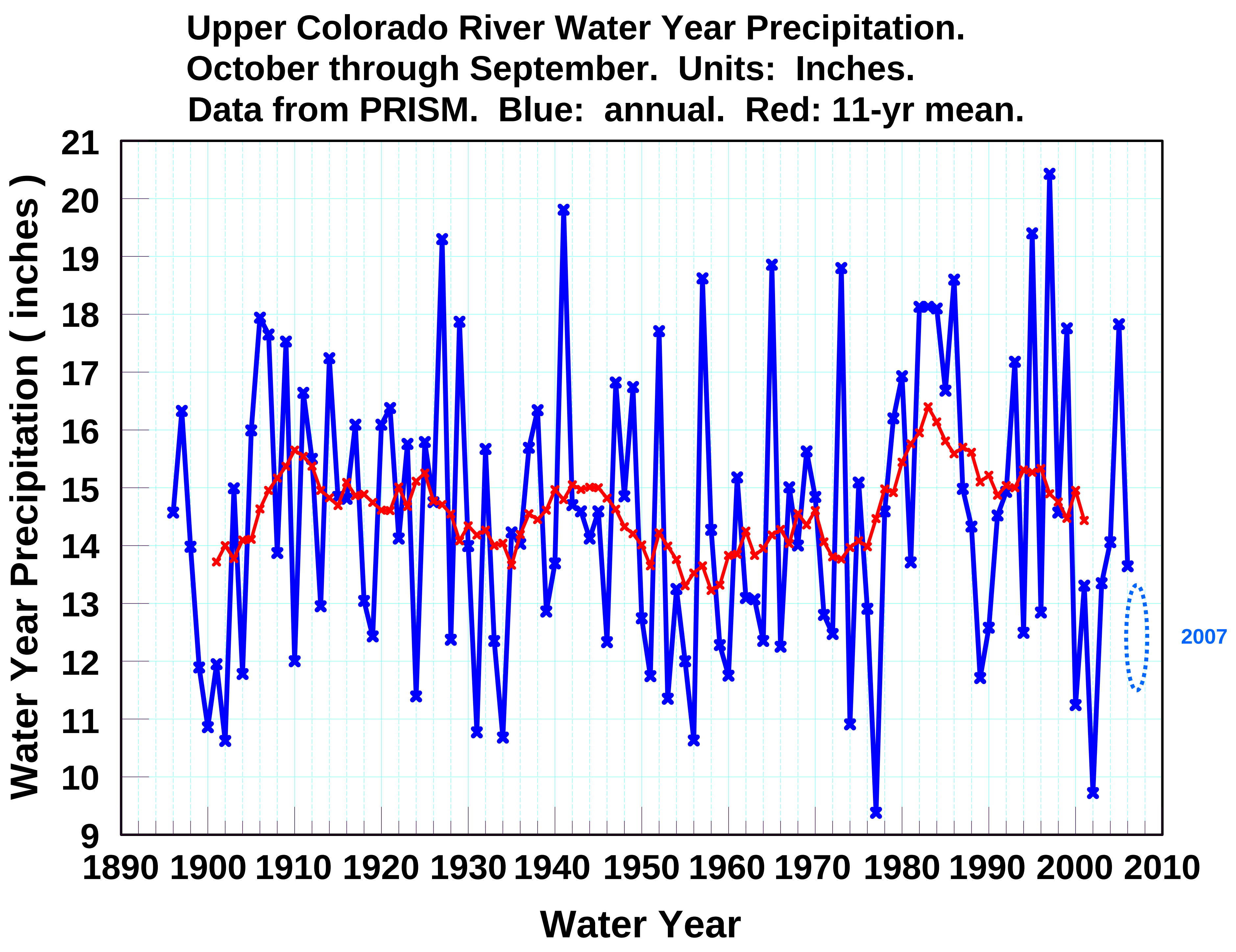

Air Temperature (NCEP Reanalysis) Mar to May:43N to 37N and -112W to -106W averaged
Upper Colorado Mar-May 700 mb Temp
(10,000 ft)
Freezing
1 C
Air Temperature (C)
Date
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
1940
1950
1960
1970
1980
1990
2000
2010

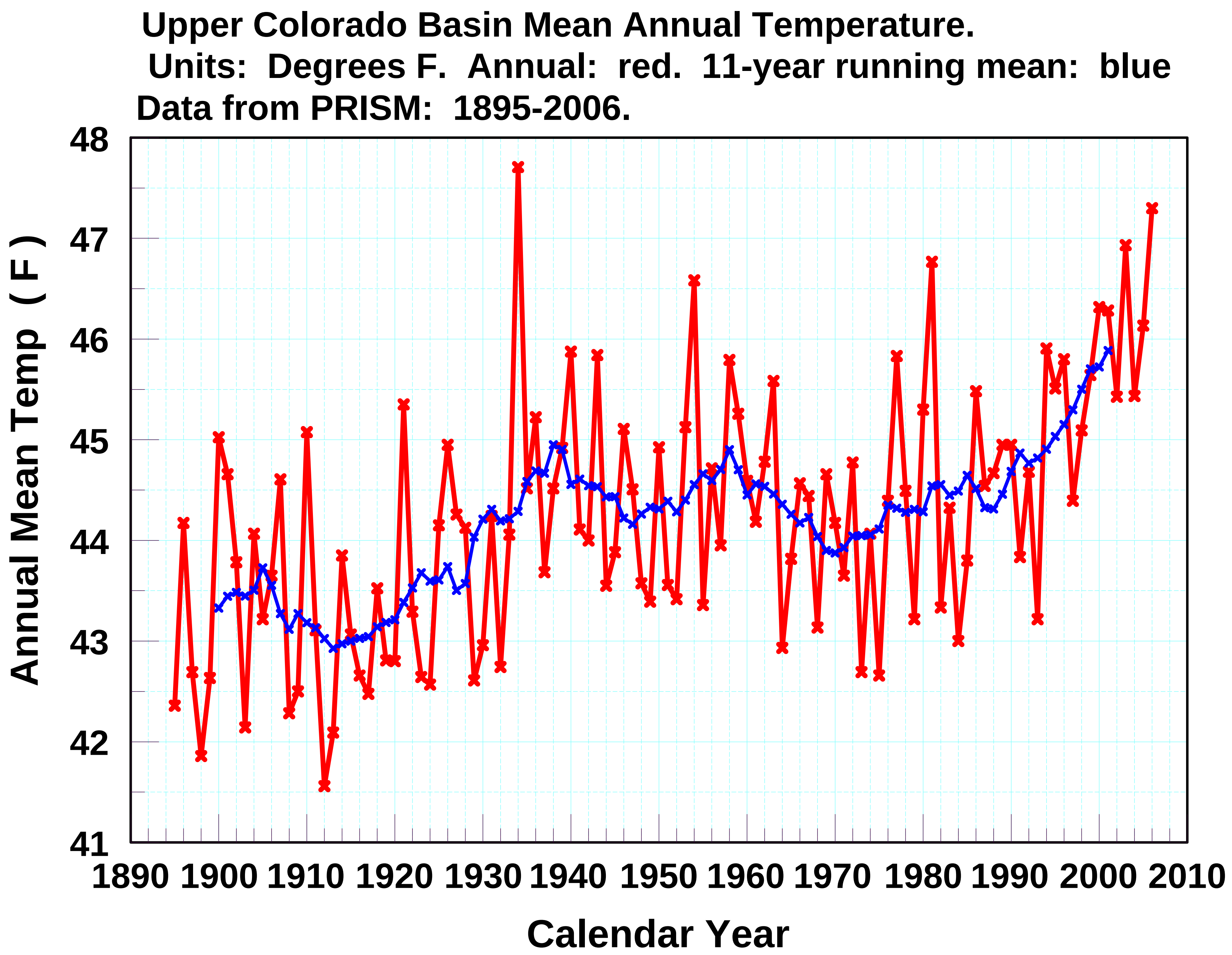


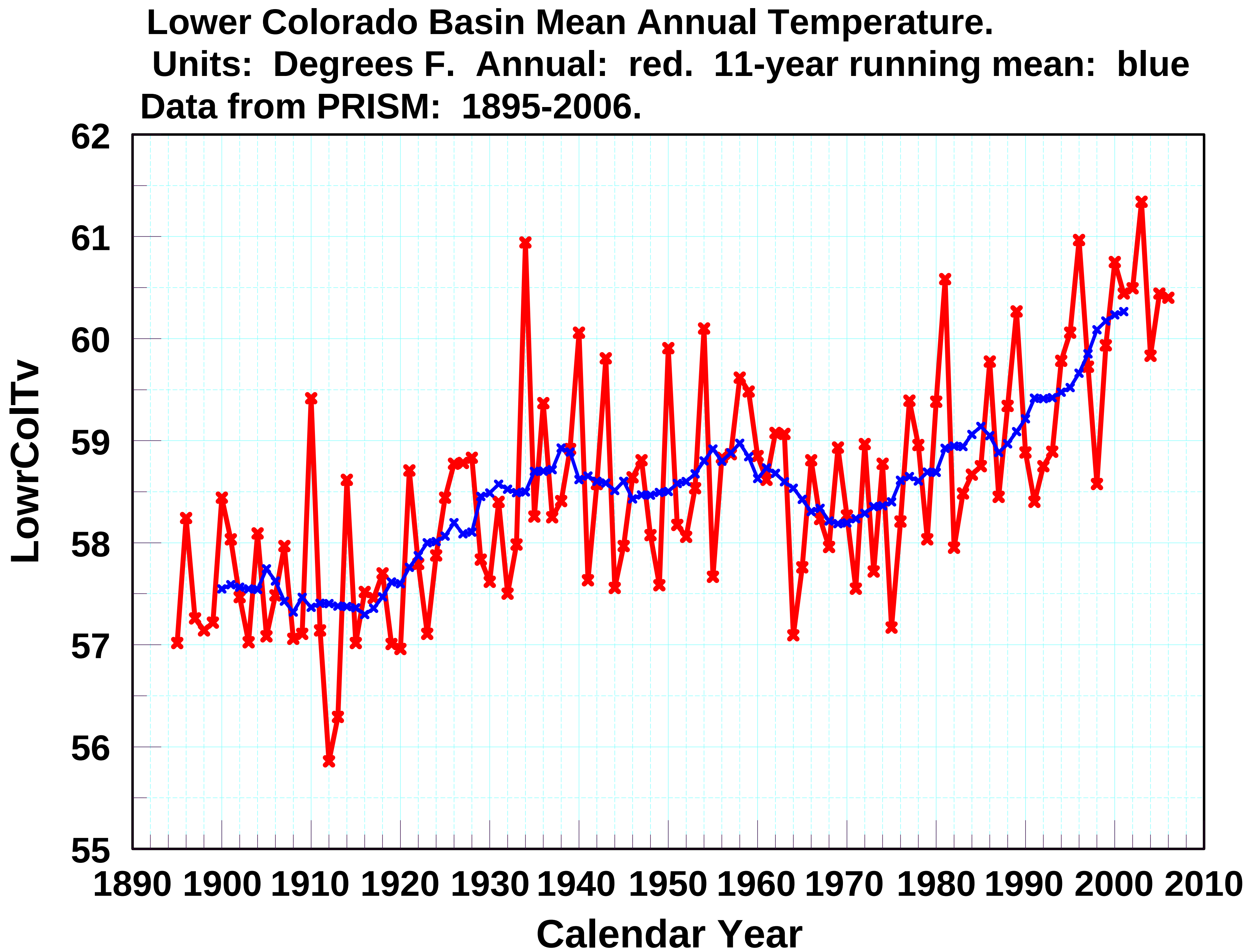
Air Temperature (NCEP Reanalysis) Jun to Aug:43N to 37N and -112W to -106W averaged
Upper Colorado Jun-Aug 700 mb Temp
(10,000 ft)
1 C
Air Temperature (C)
14
13.5
13
12.5
12
11.5
11
10.5
10
9.5
1940
1950
1960
1970
1980
1990
2000
2010
Date



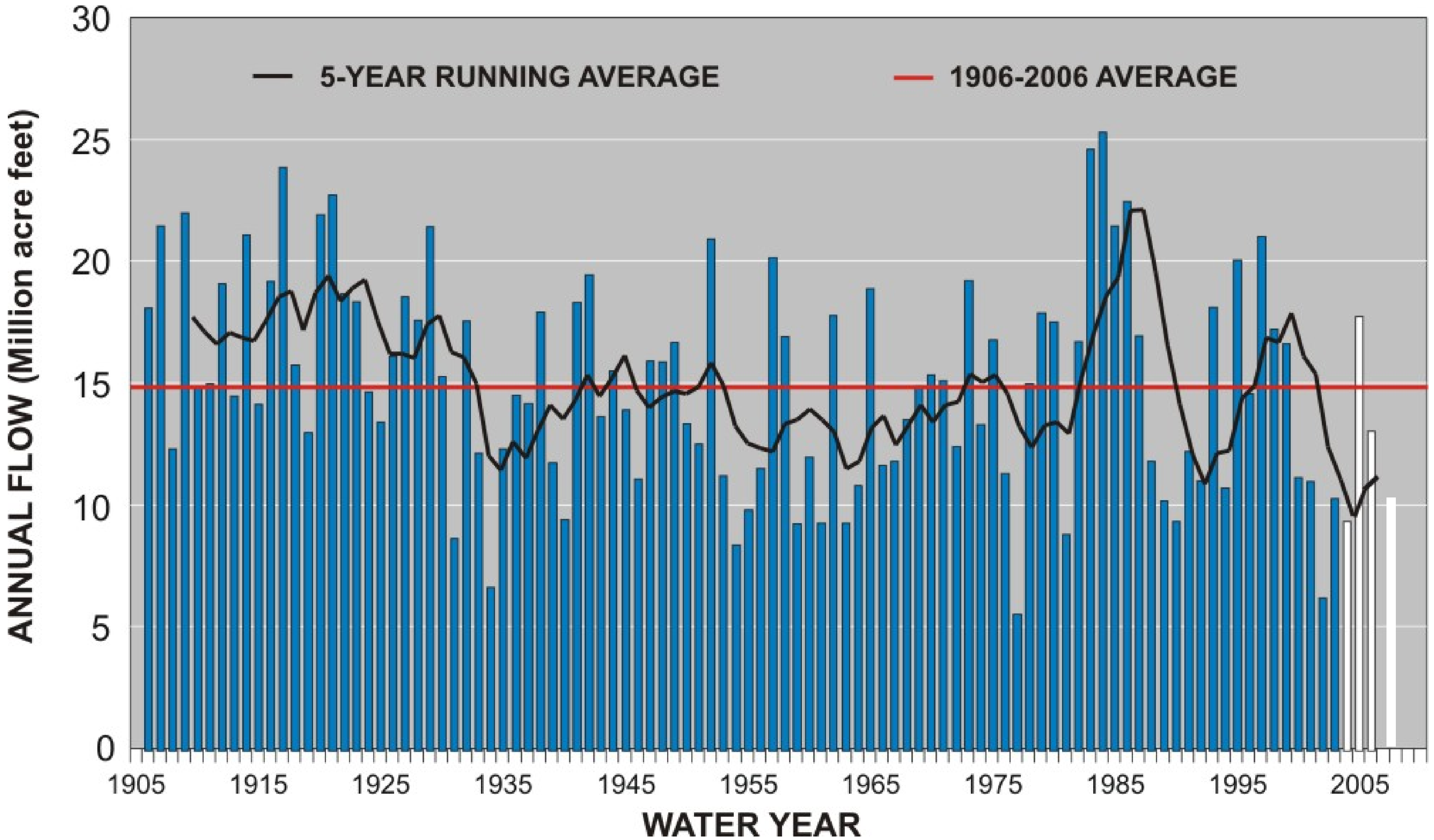
Air Temperature (NCEP Reanalysis) Sep to Nov:43N to 37N and -112W to -106W averaged
Upper Colorado Sep-Nov 700 mb Temp (10,000 ft)
Air Temperature (C)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1 C
Freezing
1940
1950
1960
1970
1980
1990
2000
2010
Date


Upper Colorado River Water Year Precipitation.
October through September. Units: Inches.
Data from PRISM. Blue: annual. Red: 11-yr mean.
Water Year Precipitation (inches)
21
20
19
18
17
16
15
14
13
12
11
10
9
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Water Year
2007

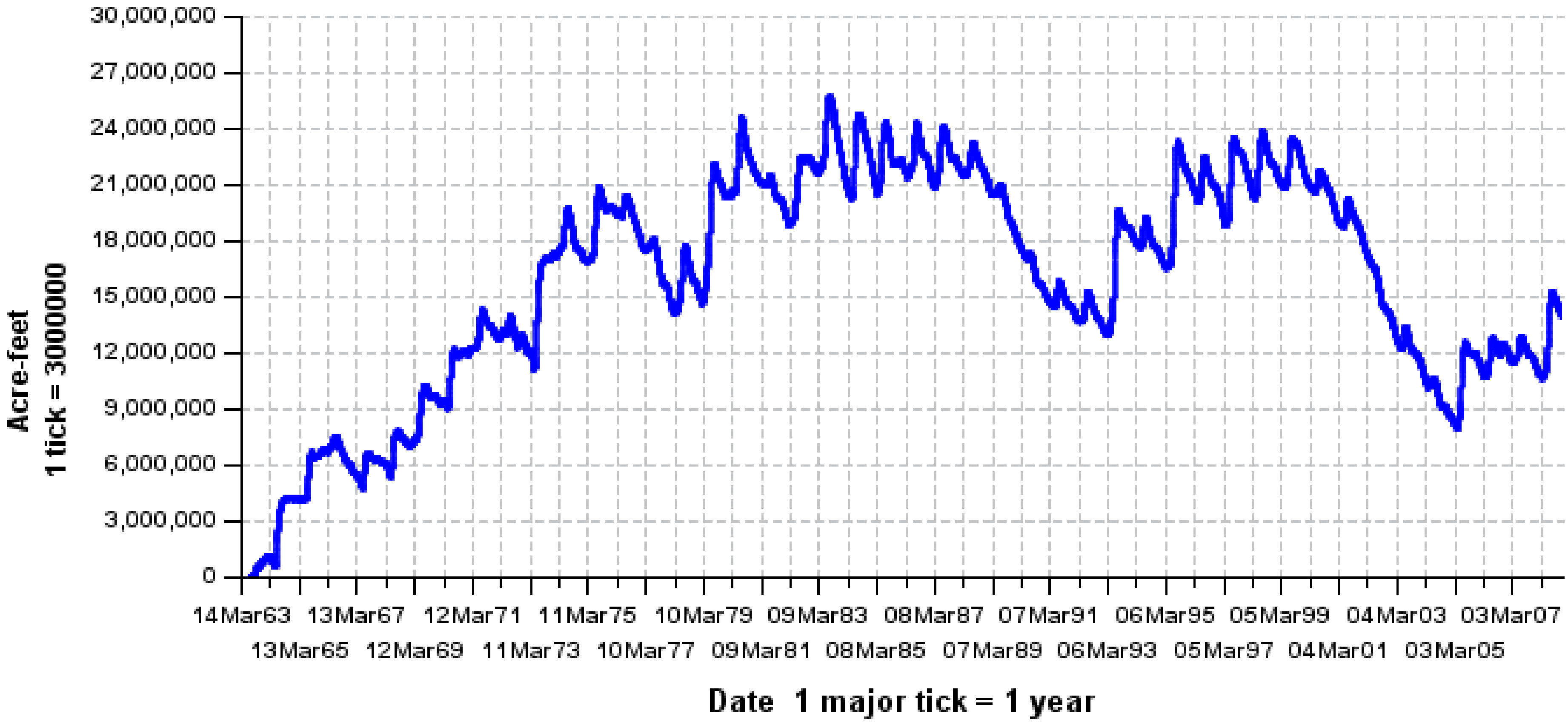

Upper Colorado Basin Mean Annual Temperature.
Units: Degrees F. Annual: red. 11-year running mean: blue
Data from PRISM: 1895-2006.
Annual Mean Temp (F)
48
47
46
45
44
43
42
41
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Calendar Year


Lower Colorado Basin Mean Annual Temperature.
Units: Degrees F. Annual: red. 11-year running mean: blue
Data from PRISM: 1895-2006.
62
61
60
59
58
57
56
55
LowrColTv
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Calendar Year

Reconstructed natural flow at Lees Ferry. Water Years 1906-2006. White: preliminary estimates.
Running mean plotted at end of 5-year period.
WY 2006-07 estimate (Aug 07) approx 69 percent



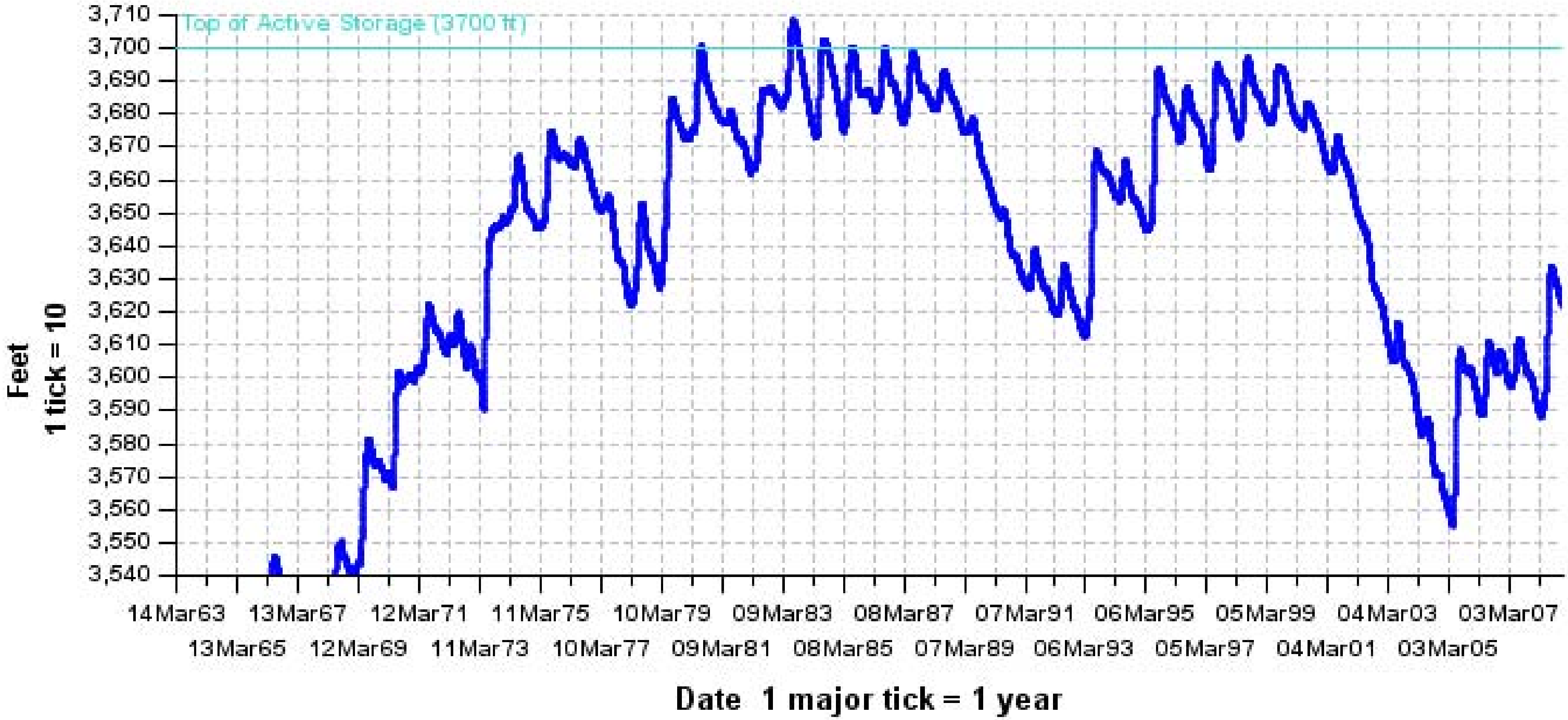
Lake Powell Storage Through December 02, 2008



Colorado River Storage
2008 Sep 30: 59.3 %

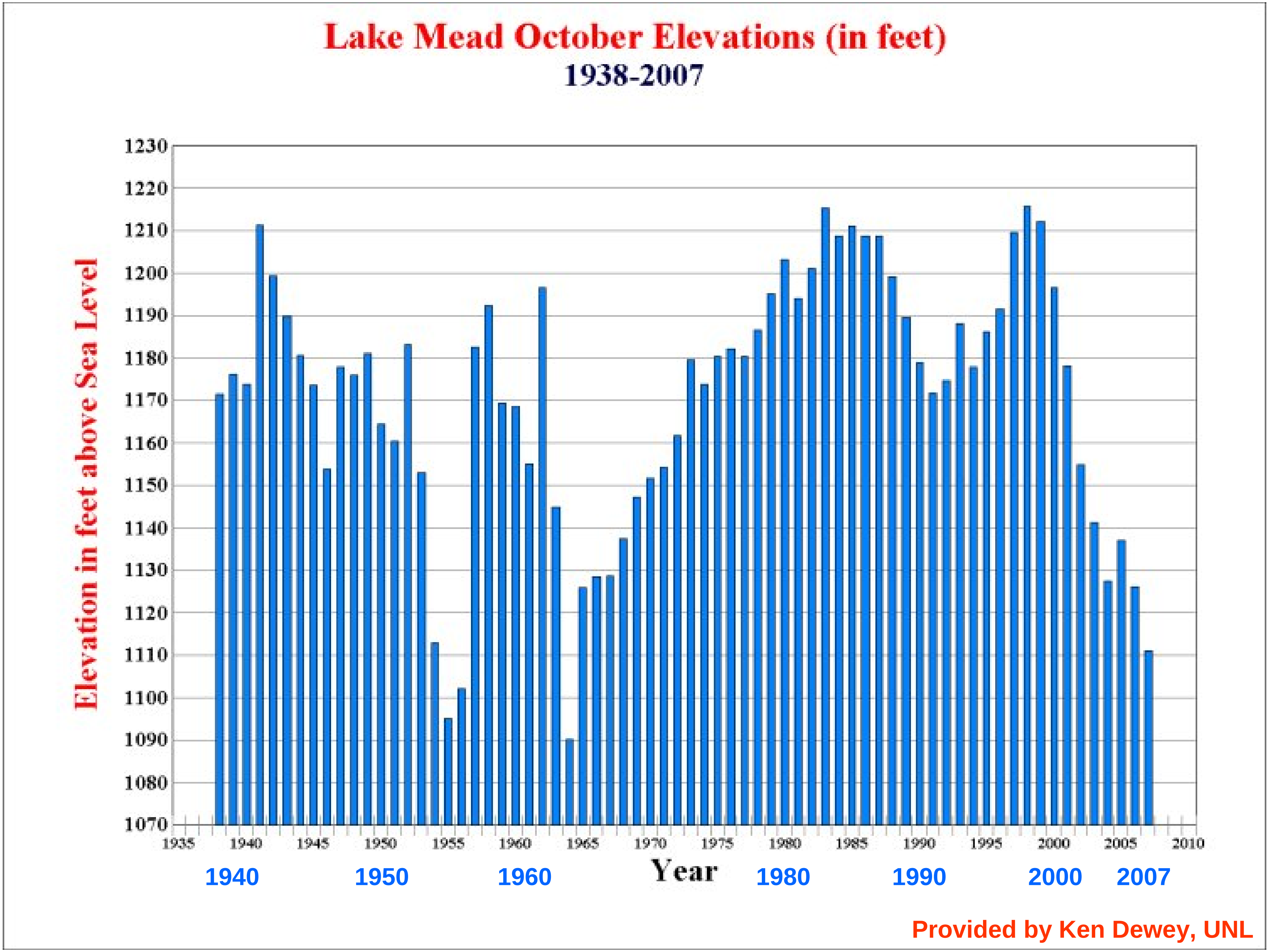
Currently 57.3 % full
Minimum: 33 % full on April 8, 2005

Lake Powell Elevation Through December 02, 2008



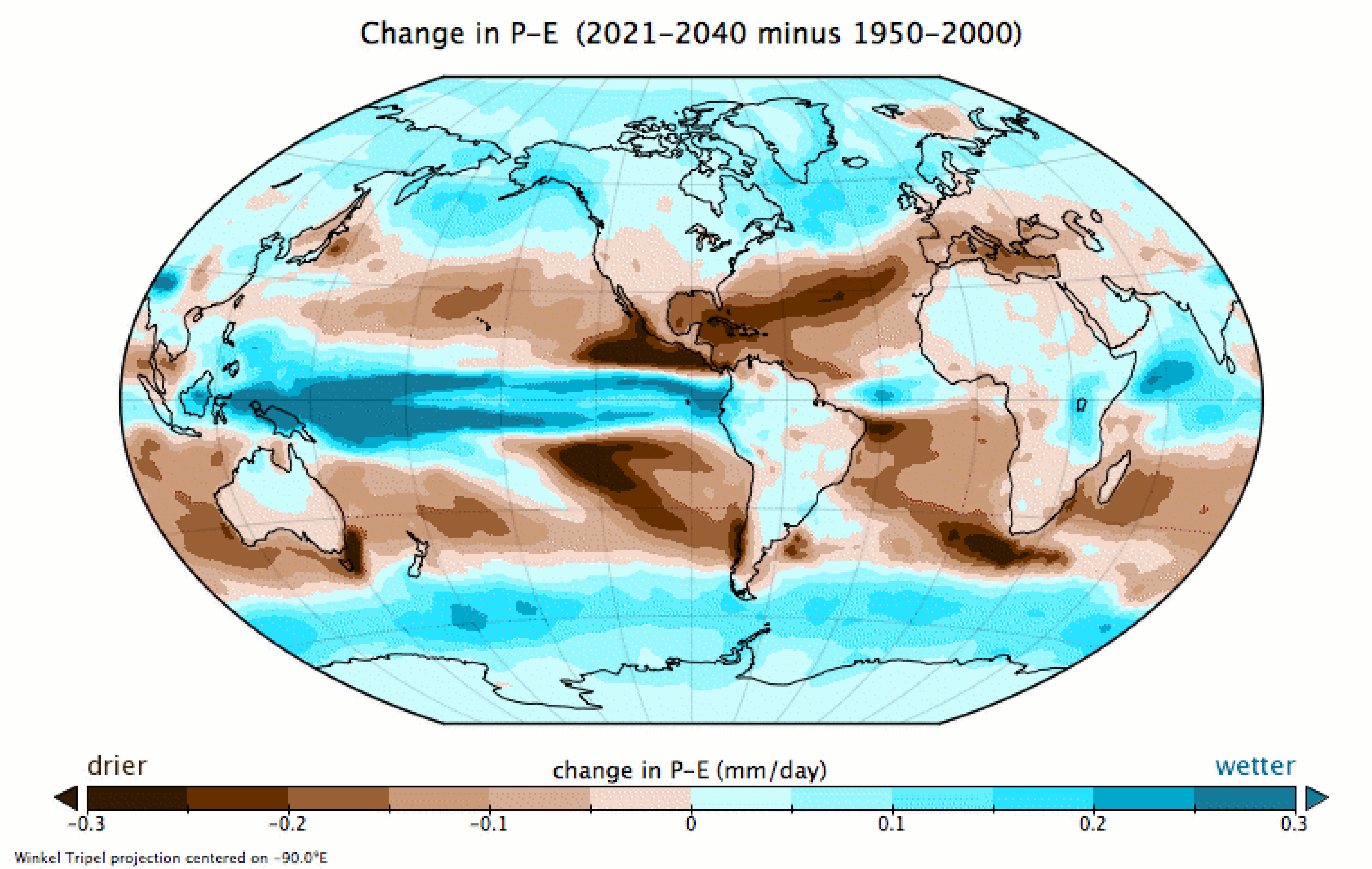
Water level on November 01, 2007 was 3621.66 ft, -88.34 ft below full.
Minimum level on April 8, 2005 was 3555 ft, -145 ft below full.

Source: www.usbr.gov/uc/water/index.html


Lake Mead October Elevations (in feet)
1938-2007
Elevation in feet above Sea Level
Year
1940
1950
1960
1980
1990
2000
2007
Provided by Ken Dewey, UNL

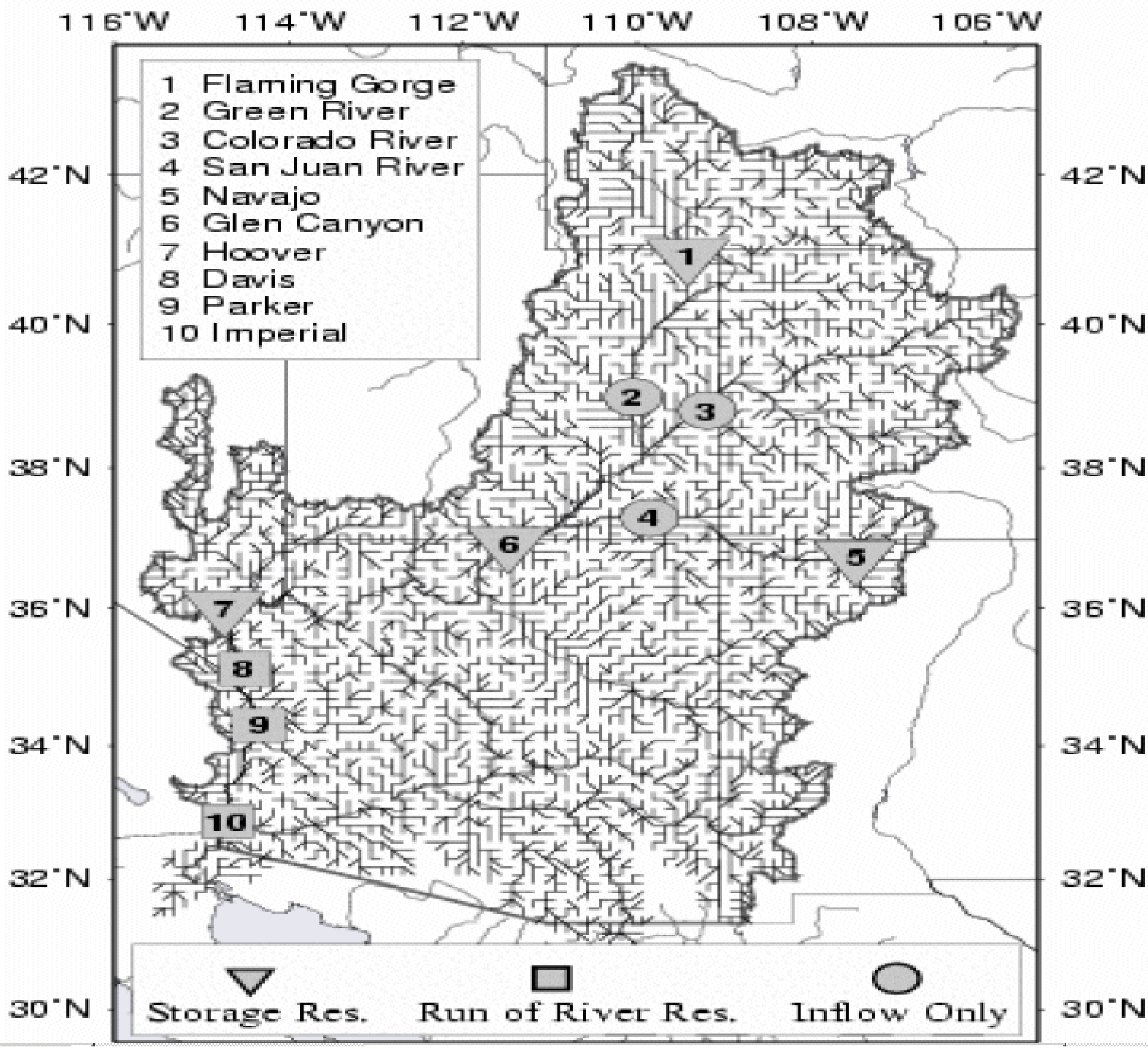
Lake Mead, October 2007

Photo by Ken Dewey



Seager et al, 2007. Average of 19 climate models. Figure by Naomi Naik.

www.ldeo.columbia.edu/res/div/ocp/drought/science.shtml

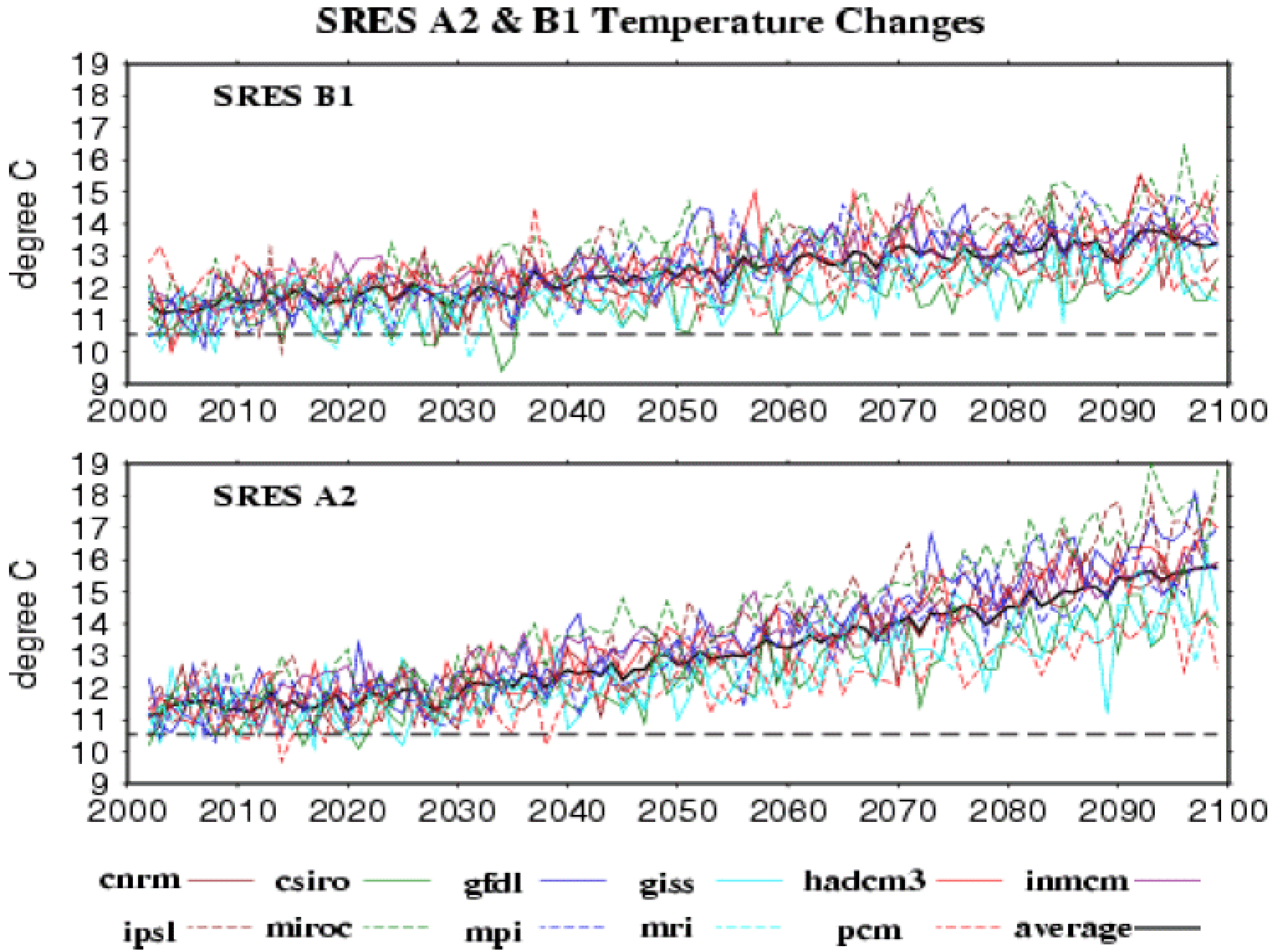


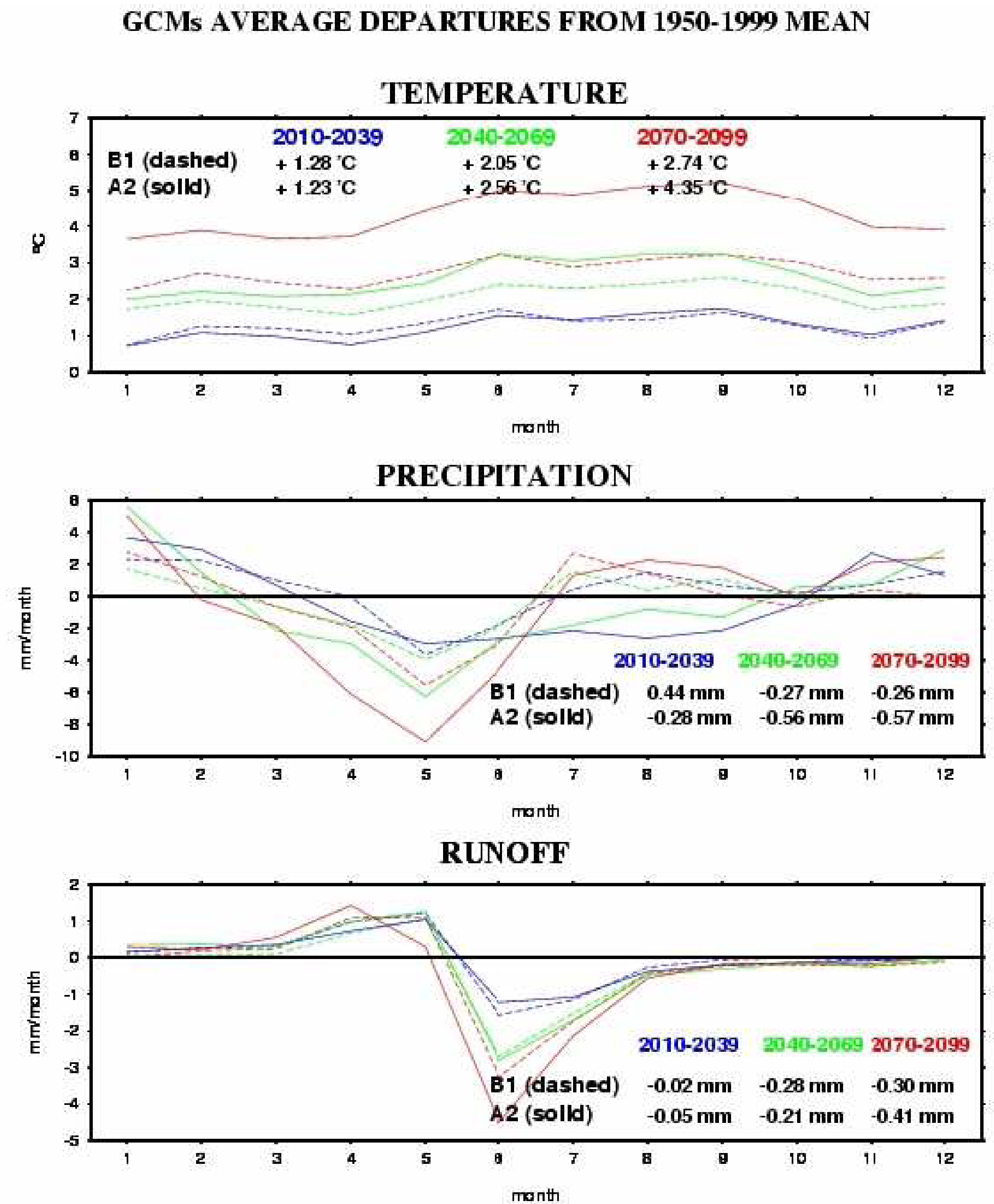
VIC
Variable Infiltration Capacity Representation

Colorado River Basin

From Christensen and Lettenmaier, Hyrology and Earth System Sciences, 2007

11 Models, 2 CO2 Scenarios, Colorado River Basin (from Christensen and Lettenmaier, HESS, 2007)





11-Model Consensus
2 Scenarios

Colorado River Basin

By Month

3 Future Periods

From Christensen and Lettenmaier, Hydrology and Earth System Sciences, 2007. Online journal.

PER 1: 2010-2039 **PER 2: 2040-2069** **PER 3: 2070-2099**

Flow at Lees Ferry

Table 2. Annual average precipitation, evaporation, and runoff (in mm/year), runoff ratio, and basin average temperature (°C).

Scenario, Per	Precip. (percent change relative to historic)	Evap. (percent change relative to historic)	Runoff (percent change relative to historic)	Runoff Ratio (percent change relative to historic)	Temp (°C relative to historic)
HISTORIC	354 mm/yr.	309 mm/yr.	45.2 mm/yr.	12.8 %	10.5 °C
B1 / PER 1	360 (+1%)	315 (+2%)	45.0 (0%)	12.5 (-2%)	11.8 (+ 1.3°C)
B1 / PER 2	351 (-1%)	310 (0%)	41.8 (-7%)	11.9 (-7%)	12.6 (+ 2.1°C)
B1 / PER 3	351 (-1%)	309 (0%)	41.6 (-8%)	11.8 (-8%)	13.2 (+ 2.7°C)
A2 / PER 1	351 (-1%)	307 (-1%)	44.6 (-1%)	12.7 (-1%)	11.8 (+ 1.2°C)
A2 / PER 2	348 (-2%)	305 (-1%)	42.7 (-6%)	12.2 (-5%)	13.1 (+ 2.6°C)
A2 / PER 3	347 (-2%)	306 (-1%)	40.3 (-11%)	11.6 (-10%)	14.9 (+ 4.4°C)

Niklas Christensen and Dennis Lettenmaier, A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River basin. Hydrology and Earth System Sciences, Hydrology and Earth System Sciences, 2007, online journal: http://www.hydro.washington.edu/SurfaceWaterGroup/Publications/hessd-2006-0147-tx.pdf

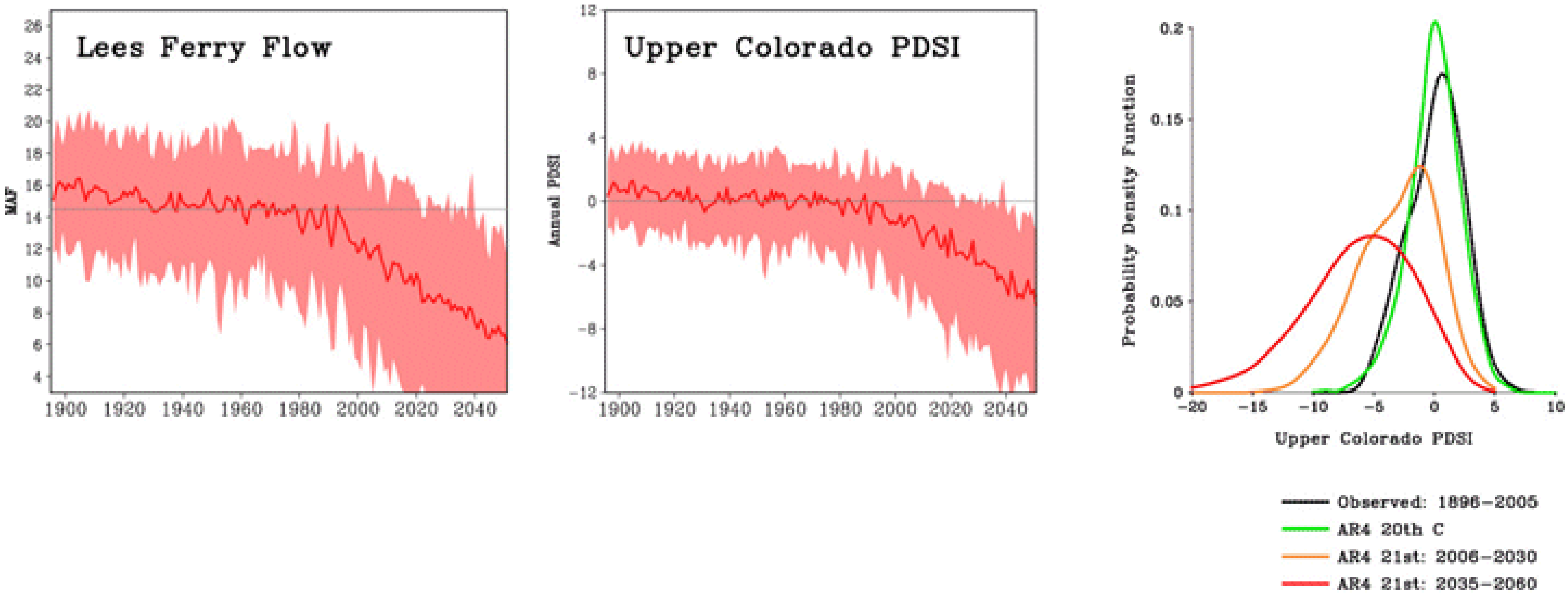
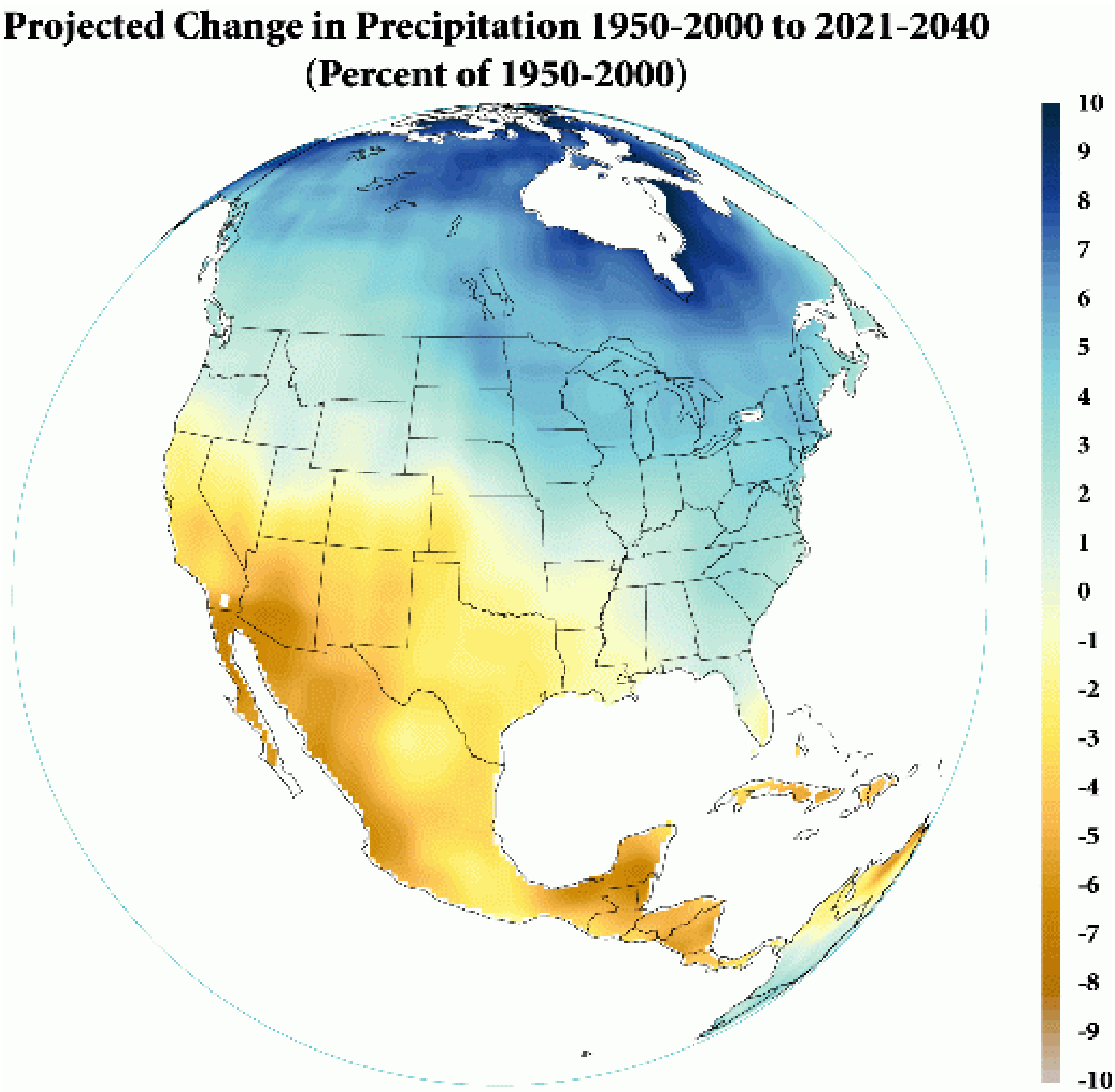


Plate B. The 1895-2050 Lees Ferry annual streamflow (left, macf) derived from the AR4 simulations of PDSI (middle) using the downscaling formula that relates observed Lees Ferry flow to observed PDSI during the 20th Century. The dark red curve denotes the 42-run average, and the cloud describes the 10%-90% range of individual simulations. The right panel summarizes the probability distribution function of PDSI averaged over the Upper Colorado Drainage Basin for individual years of observations 1895-2005 (black), for the 42-models for 1895-2005 (green), and for the 42-model projections of the average PDSI during 2006-2030 (orange) and 2035-2060 (red). Note that the models produce a realistic range of PDSI drought events during the 20th Century, and for the future they produce surface moisture conditions that denote progressive aridification and severe drought conditions.

Marty Hoerling and Jon Eischeid, Past Peak Water in the Southwest, SW Hydrology, 2007 Jan/Feb.



~23 years from now

Average of 19 climate models. 2007.

Figure by Gabriel Vecchi.

www.ldeo.columbia.edu/res/div/ocp/drought/science.shtml

R. Seager, M.F. Ting, I.M. Held, Y. Kushnir, J. Lu, G. Vecchi, H.-P. Huang, N. Harnik, A. Leetmaa, N.-C. Lau, C. Li, J. Velez, N. Naik, 2007. Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America. *Science*, DOI: 10.1126/science.1139601

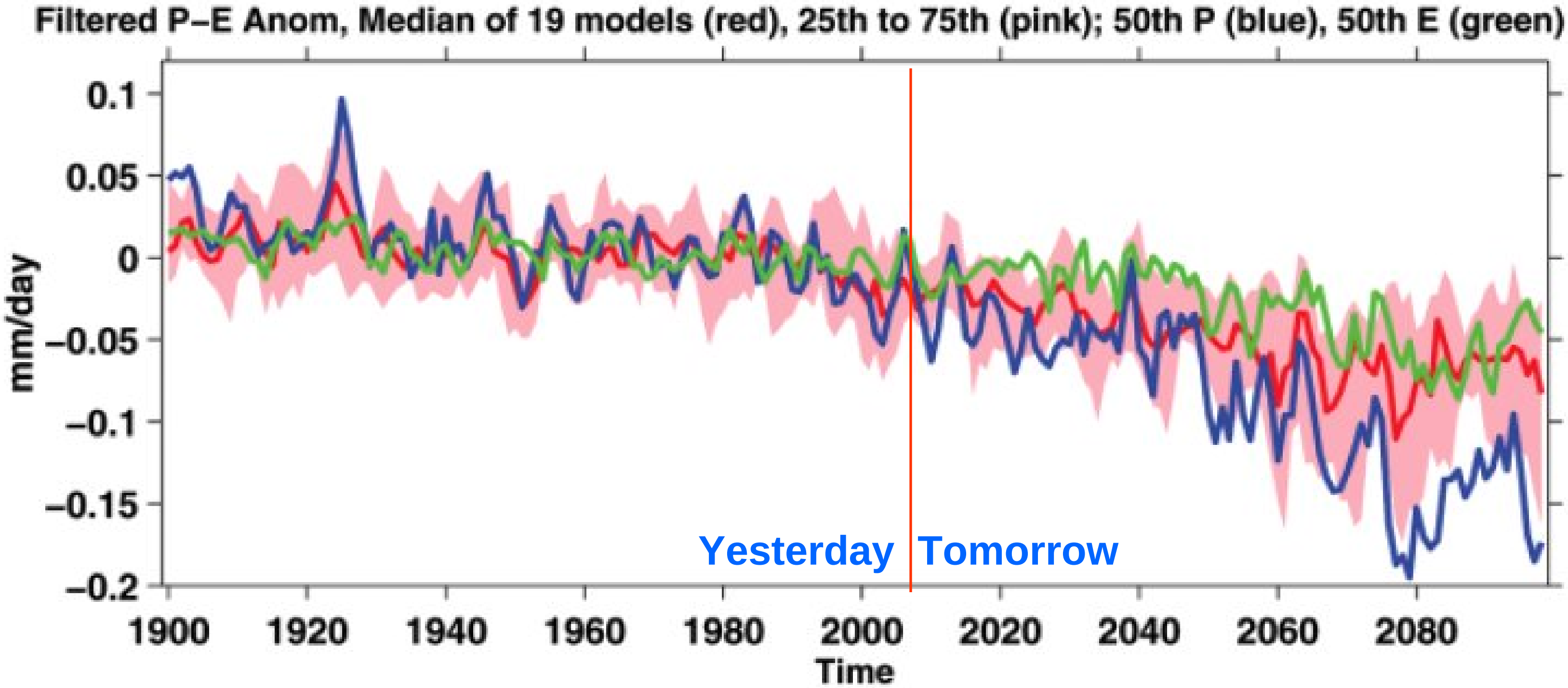


Fig. 1. Modeled changes in annual mean precipitation minus evaporation over the American Southwest (125°W to 95°W and 25°N to 40°N, land areas only), averaged over ensemble members for each of the 19 models. The historical period used known and estimated climate forcings, and the projections used the SResA1B emissions scenario. The median (red line) and 25th and 75th percentiles (pink shading) of the $P - E$ distribution among the 19 models are shown, as are the ensemble medians of P (blue line) and E (green line) for the period common to all models (1900–2098). Anomalies (Anom) for each model are relative to that model's climatology from 1950–2000. Results have been 6-year low-pass Butterworth-filtered to emphasize low-frequency variability that is of most consequence for water resources. The model ensemble mean $P - E$ in this region is around 0.3 mm/day.

Seager et al, 2007.