A Perspective on Applied Water Resources Research for Use by Decision Makers: The Case of Drought in Semiarid North America

Water resources in developing countries:
Planning and management in a climate change scenario
27 April – 8 May 2009

Gregg Garfin
Deputy Director for Science Translation and Outreach

INSTITUTE FOR ENVIRONMENT AND SOCIETY
THE UNIVERSITY OF ARIZONA

CLIMAS
Climate Assessment Project for the Southwest

RISA
Regional Integrated Sciences and Assessments
Building Bridges Between Climate Sciences and Society

The work presented here is a synthesis of the work of many excellent scientists.

Where Are We?

Recent Drought in Semiarid North America

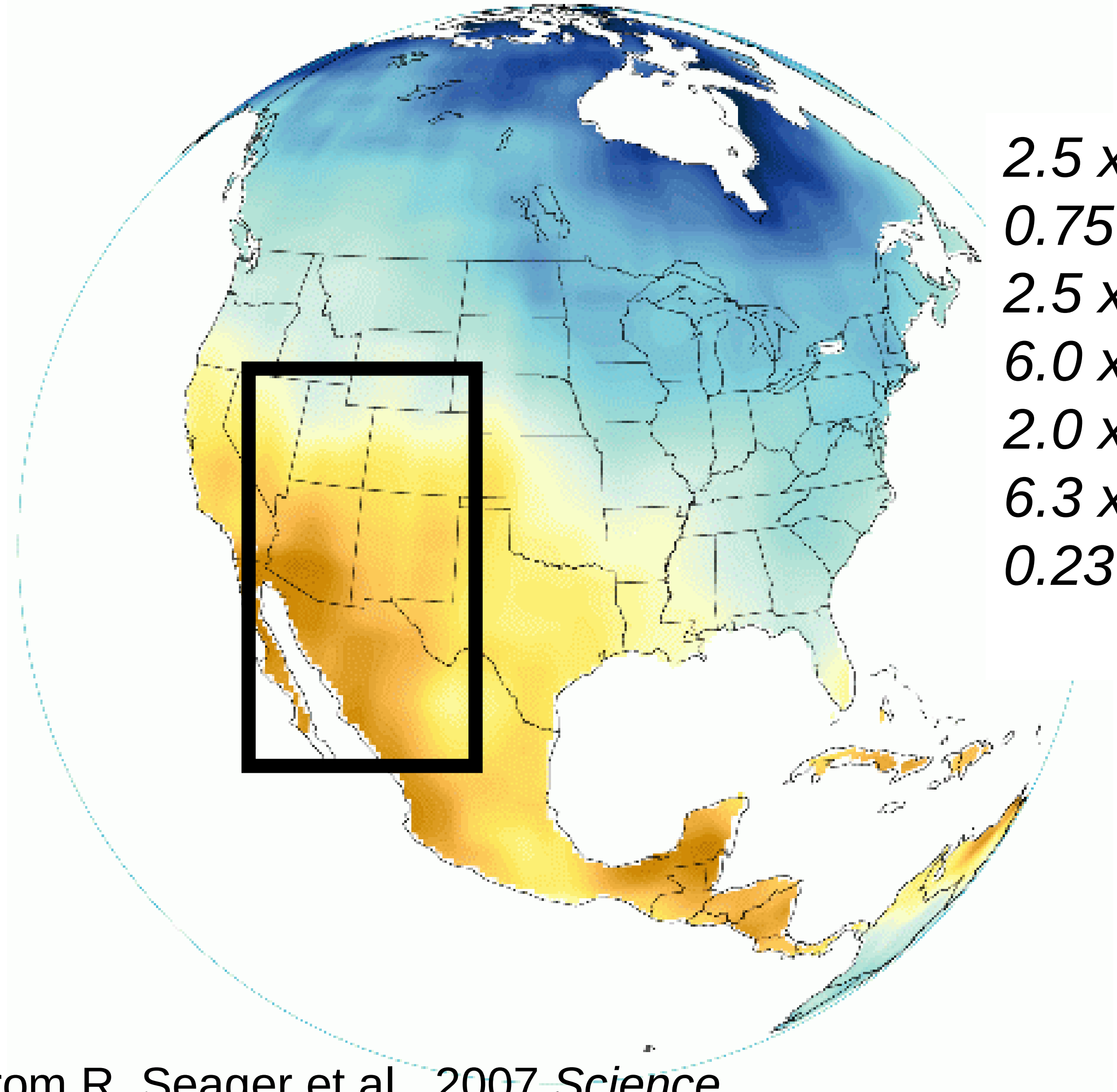
Components of Risk Management

RISK = Hazard x Vulnerability

(natural event) (social factors)

Adapted from Don Wilhite, National Drought Mitigation Center

Semiarid North America



2.5 x Pakistan
0.75 x Argentina
2.5 x Chile
6.0 x Viet Nam
2.0 x Nigeria
6.3 x Italy
0.23 x China

Figure from R. Seager et al., 2007 *Science*

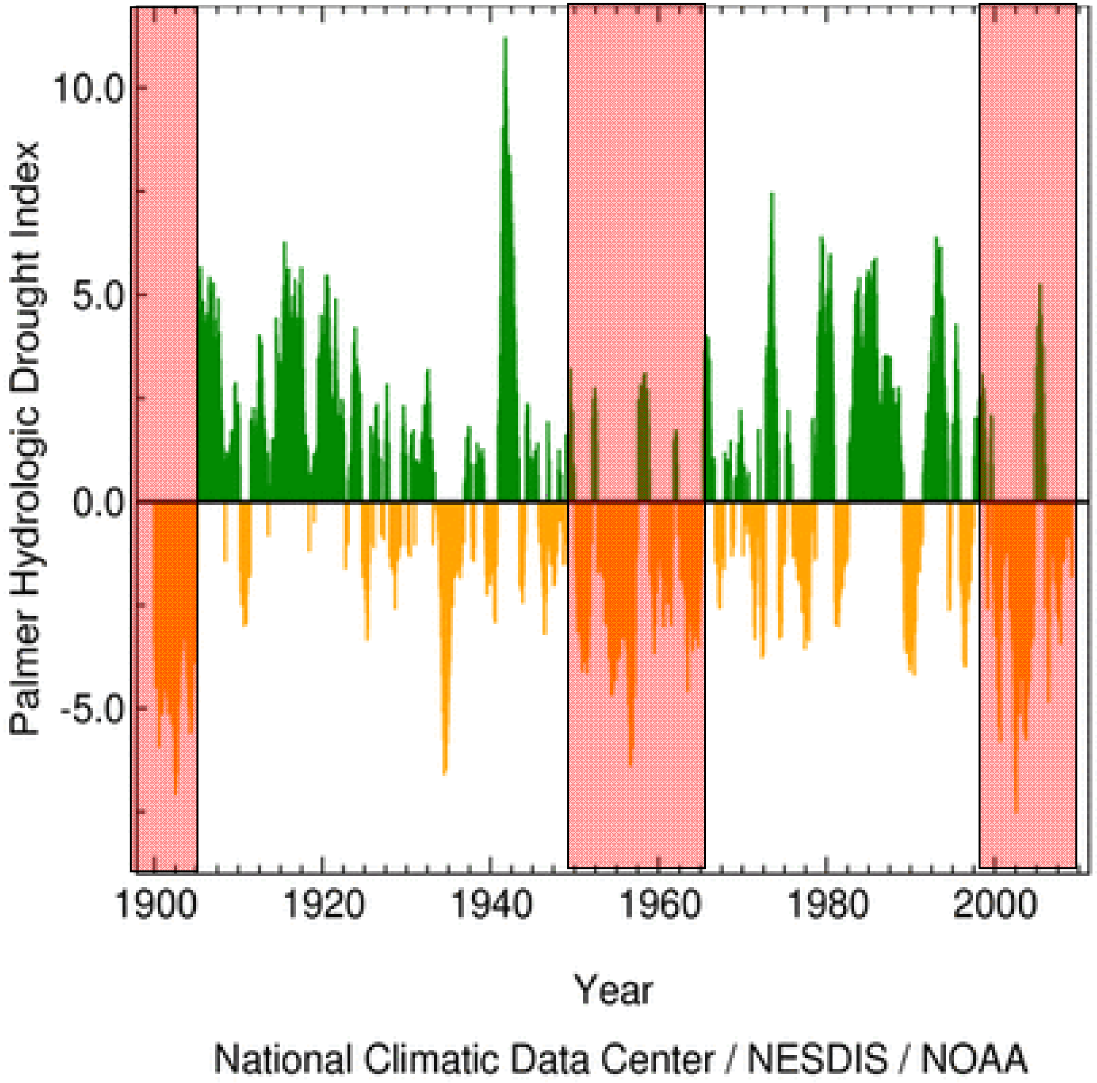
Lake Powell's decline
J. Dohrenwend, USGS

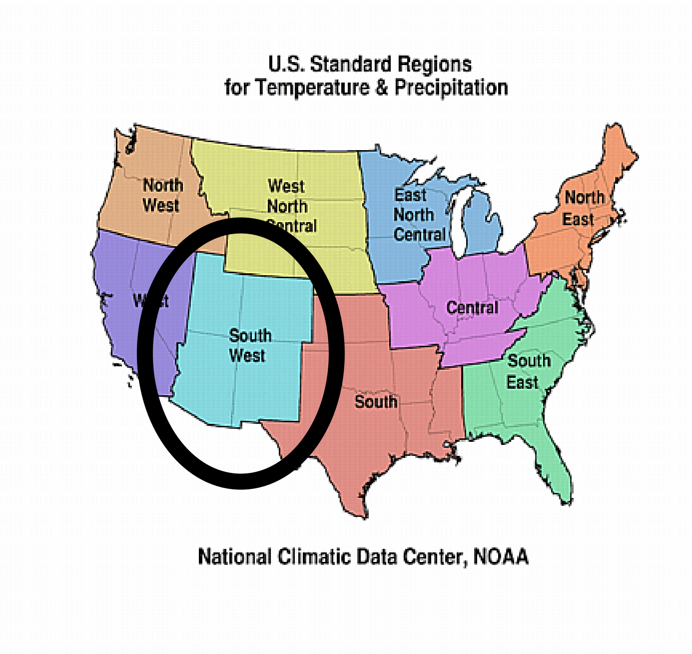
2003 Southern California Wildfires
New York Times

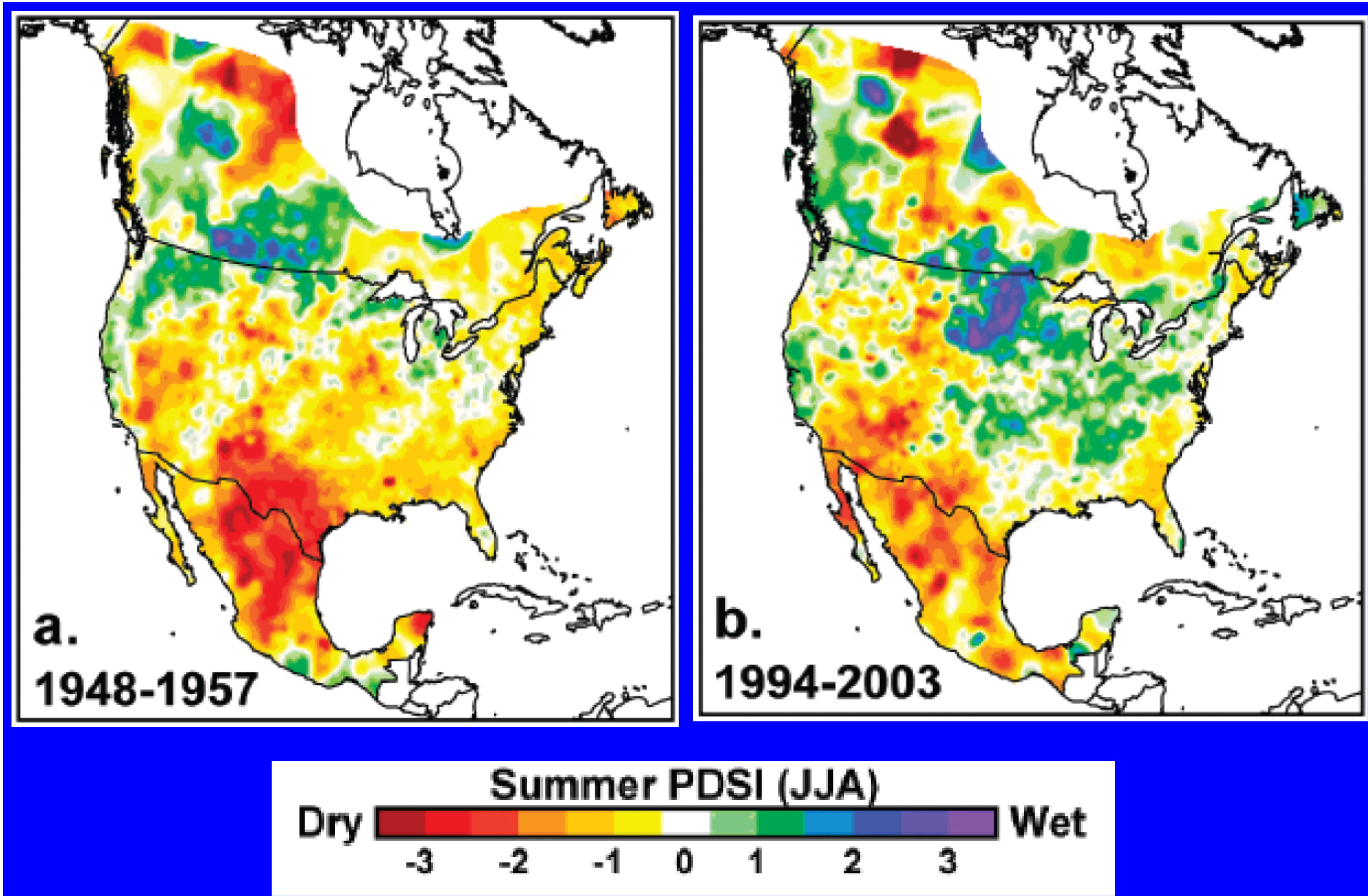
Southwest U.S. forest die-off
T. Degomez, UA Cooperative Extension

2002
Soil desiccation
Arizona Daily Star

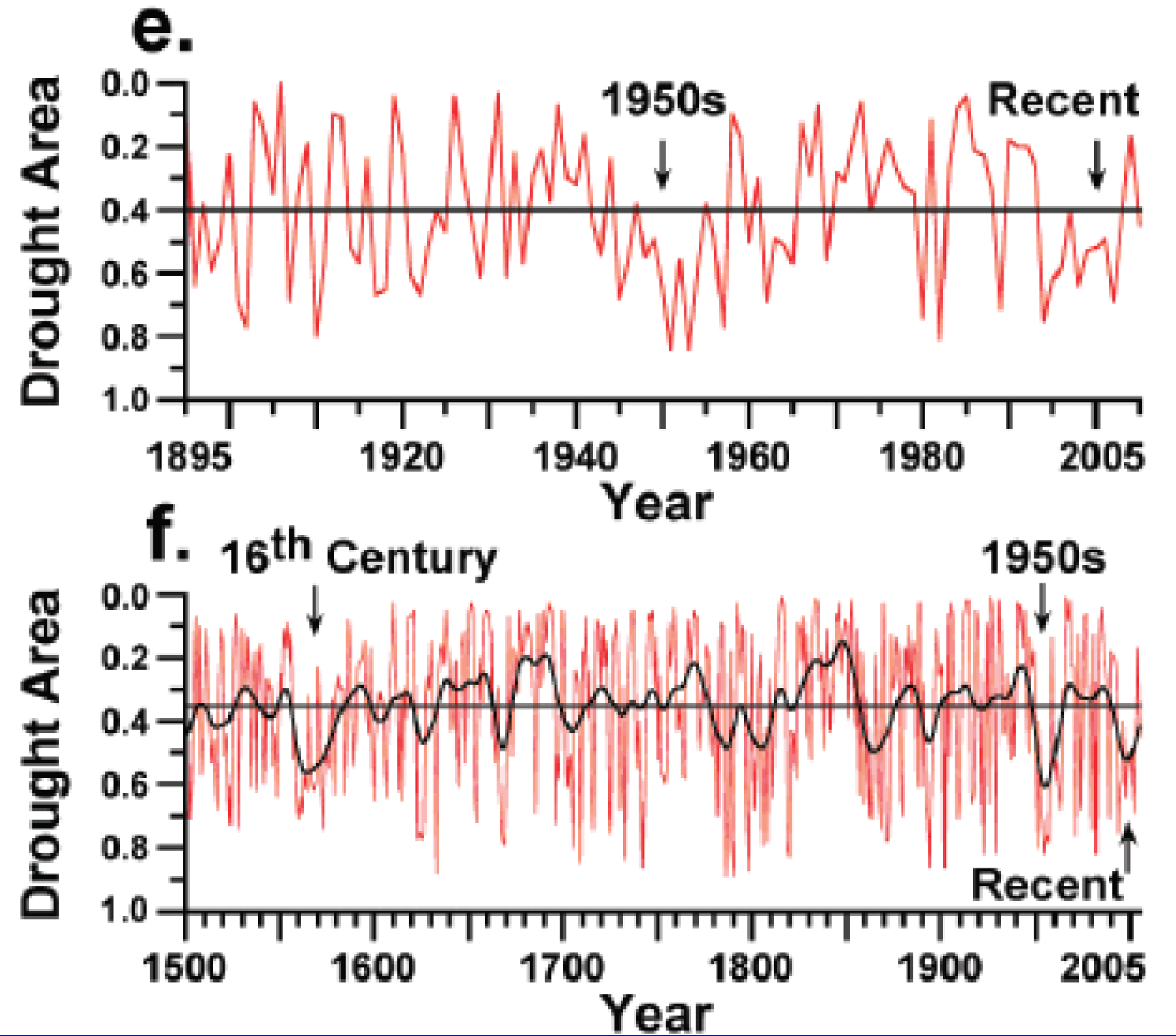
Southwest Region
Palmer Hydrologic Drought Index
January 1900-March 2009



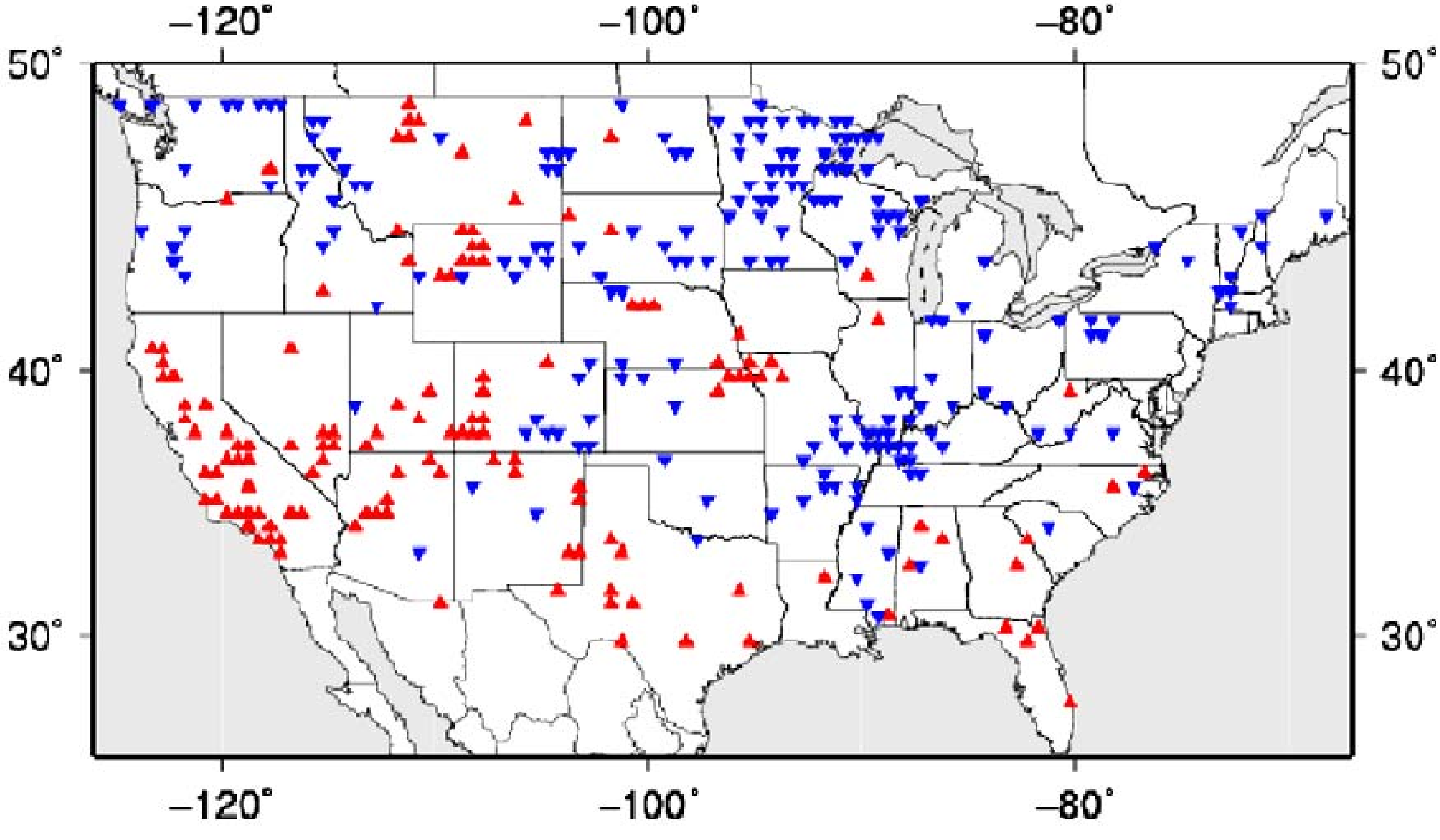




Stahle et al. 2009 *EOS*



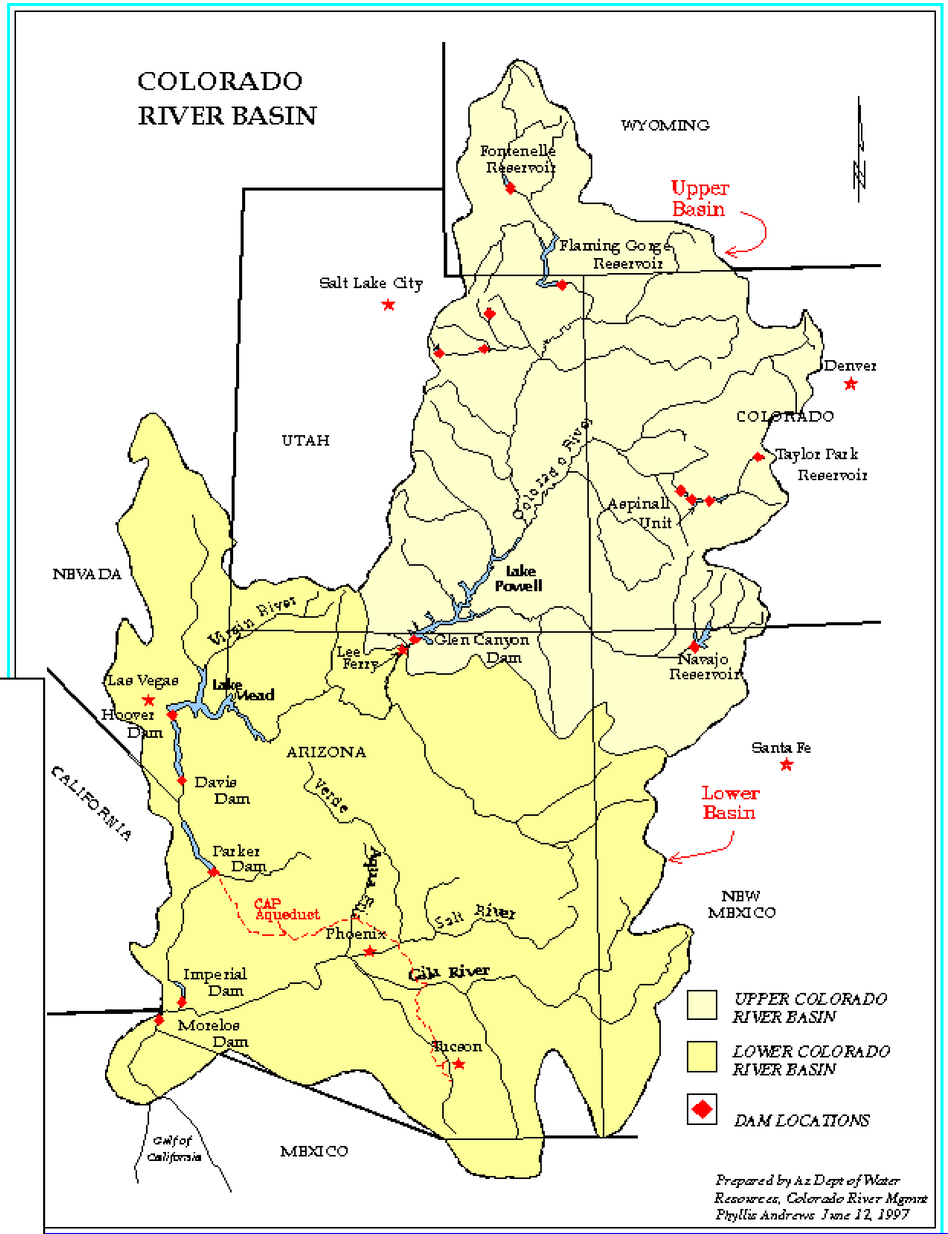
Stahle et al. 2009 *EOS*

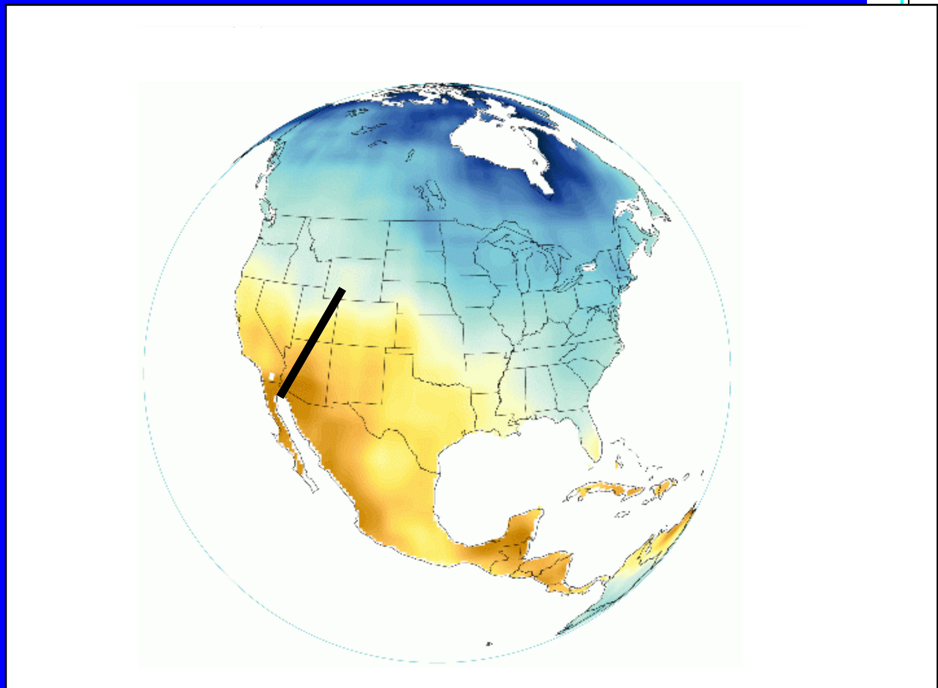


Trends in Drought Severity (< 20th %ile) – 1915-2003

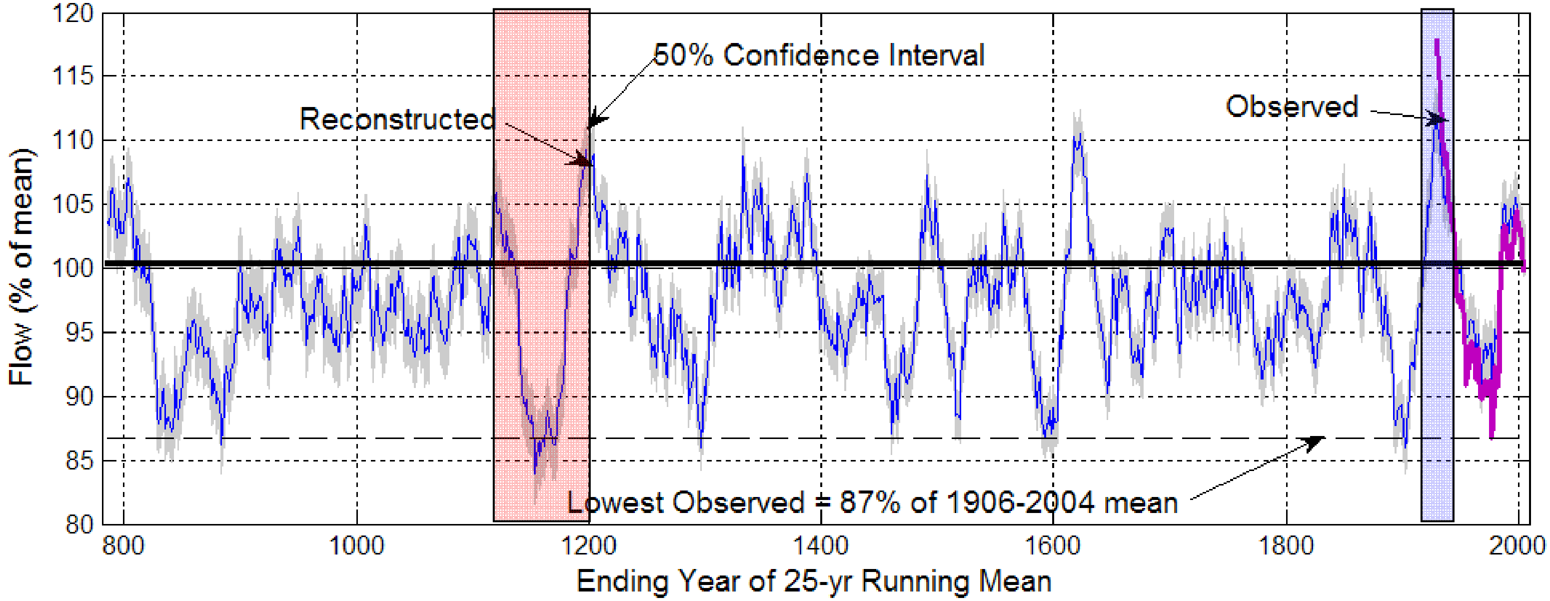
Andreadis and Lettenmaier, 2006 *Geophysical Research Letters*

Colorado River Basin





Colorado River Flow, 762-2005



Dave Meko, UA Laboratory of Tree-Ring Research

How Did We Get Here?

Climate of Semiarid North America

Precipitation Seasonality

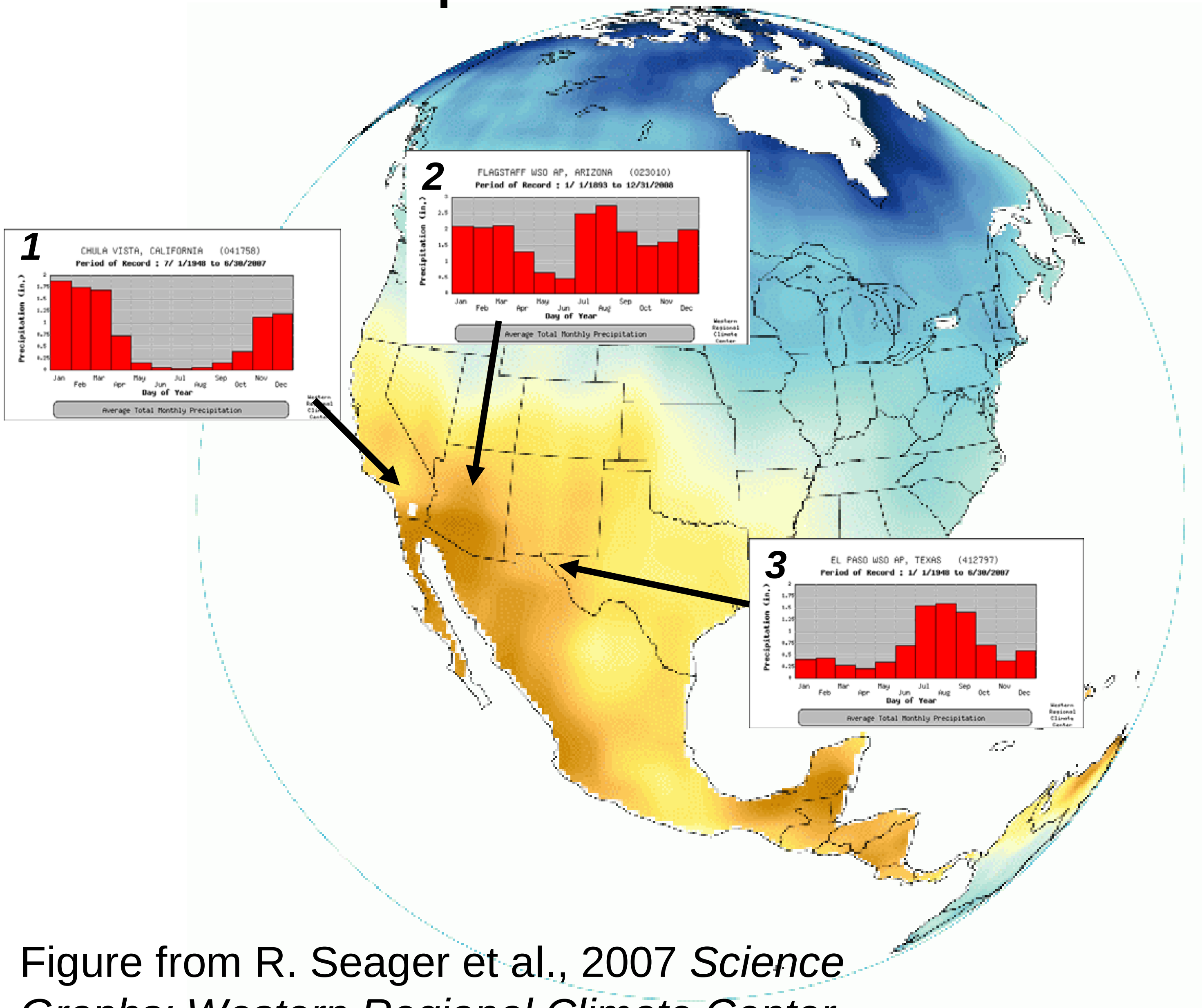
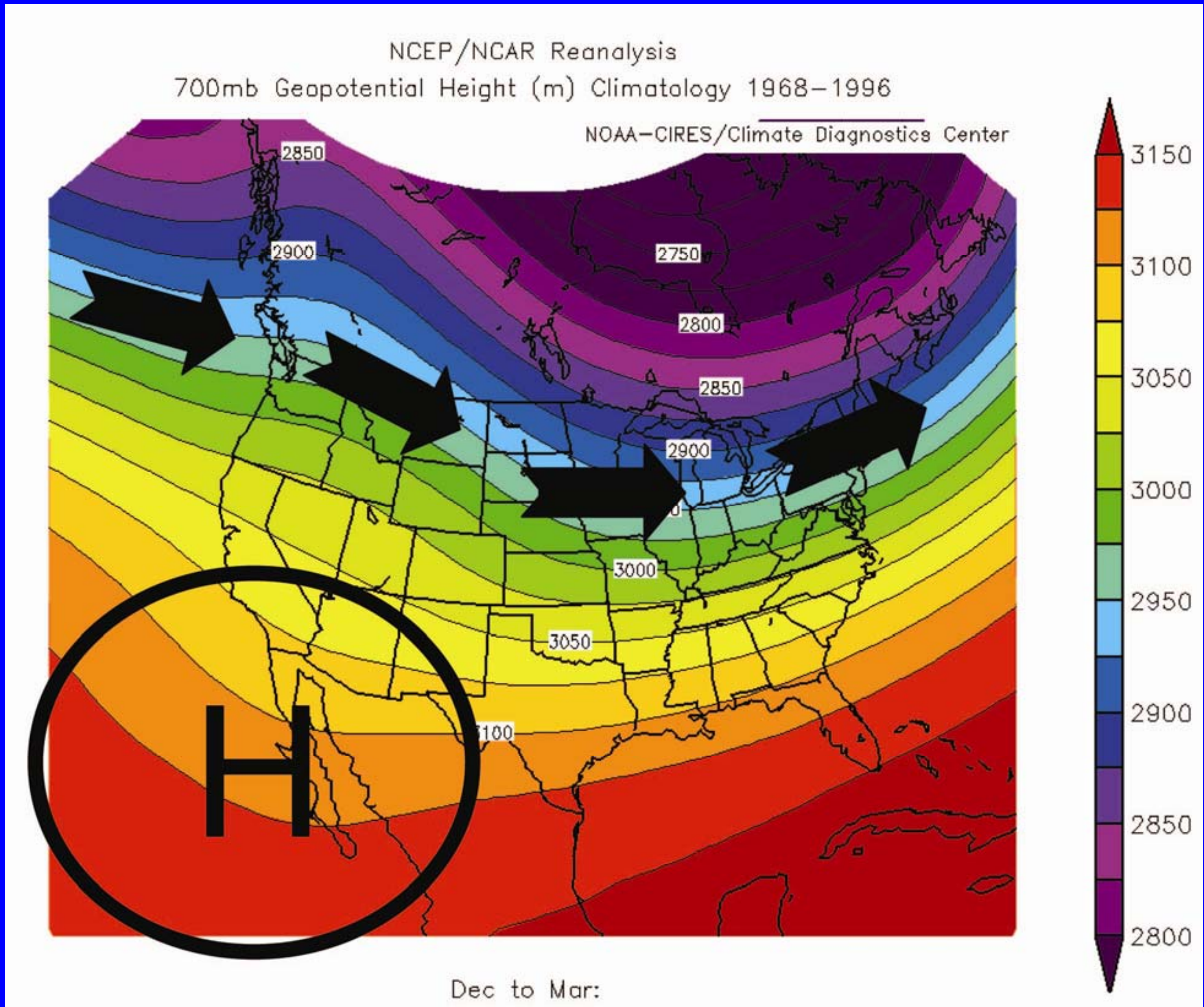


Figure from R. Seager et al., 2007 *Science*

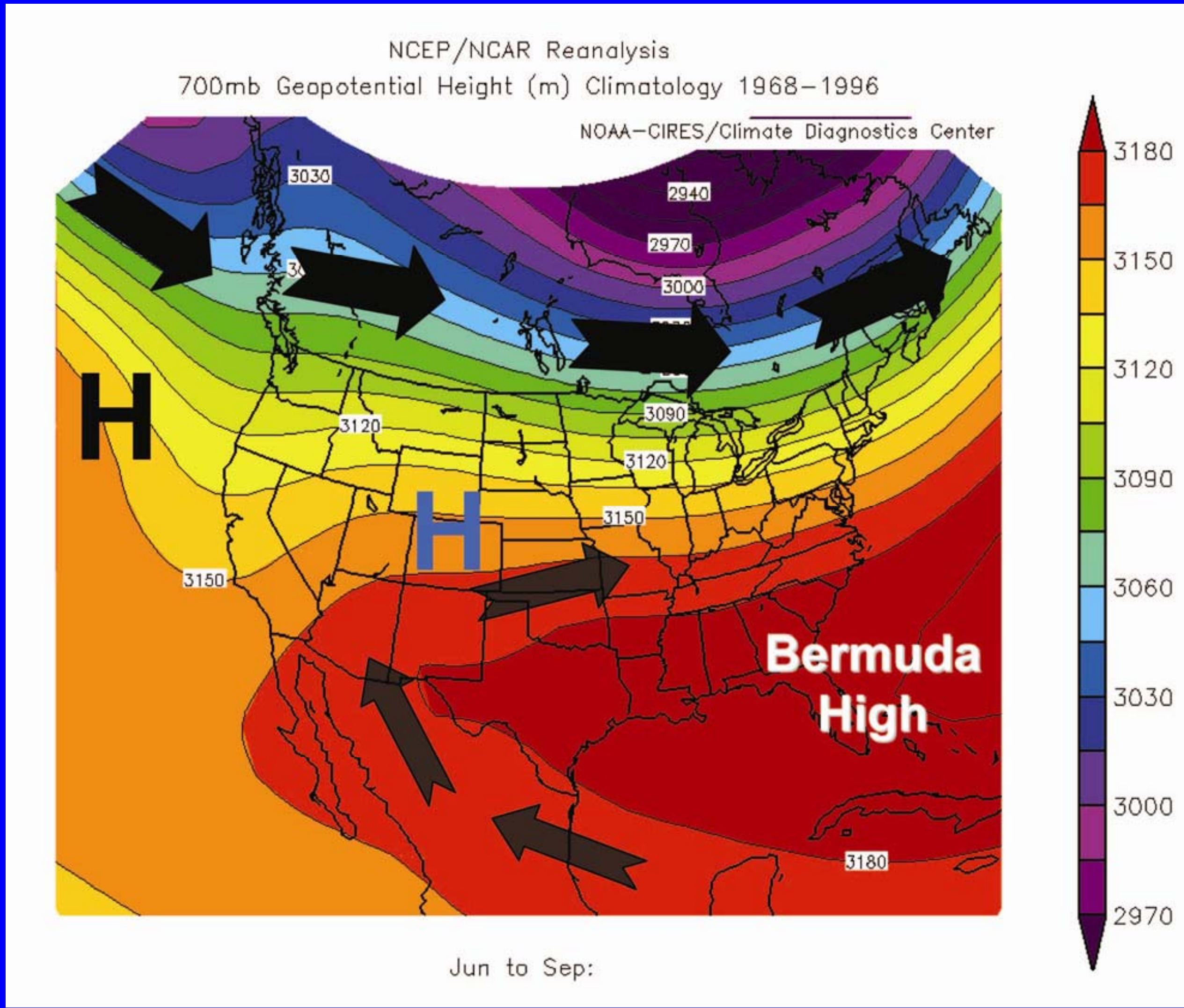
Graphs: Western Regional Climate Center

Atmospheric Circulation: Winter



Mike Crimmins, University of Arizona

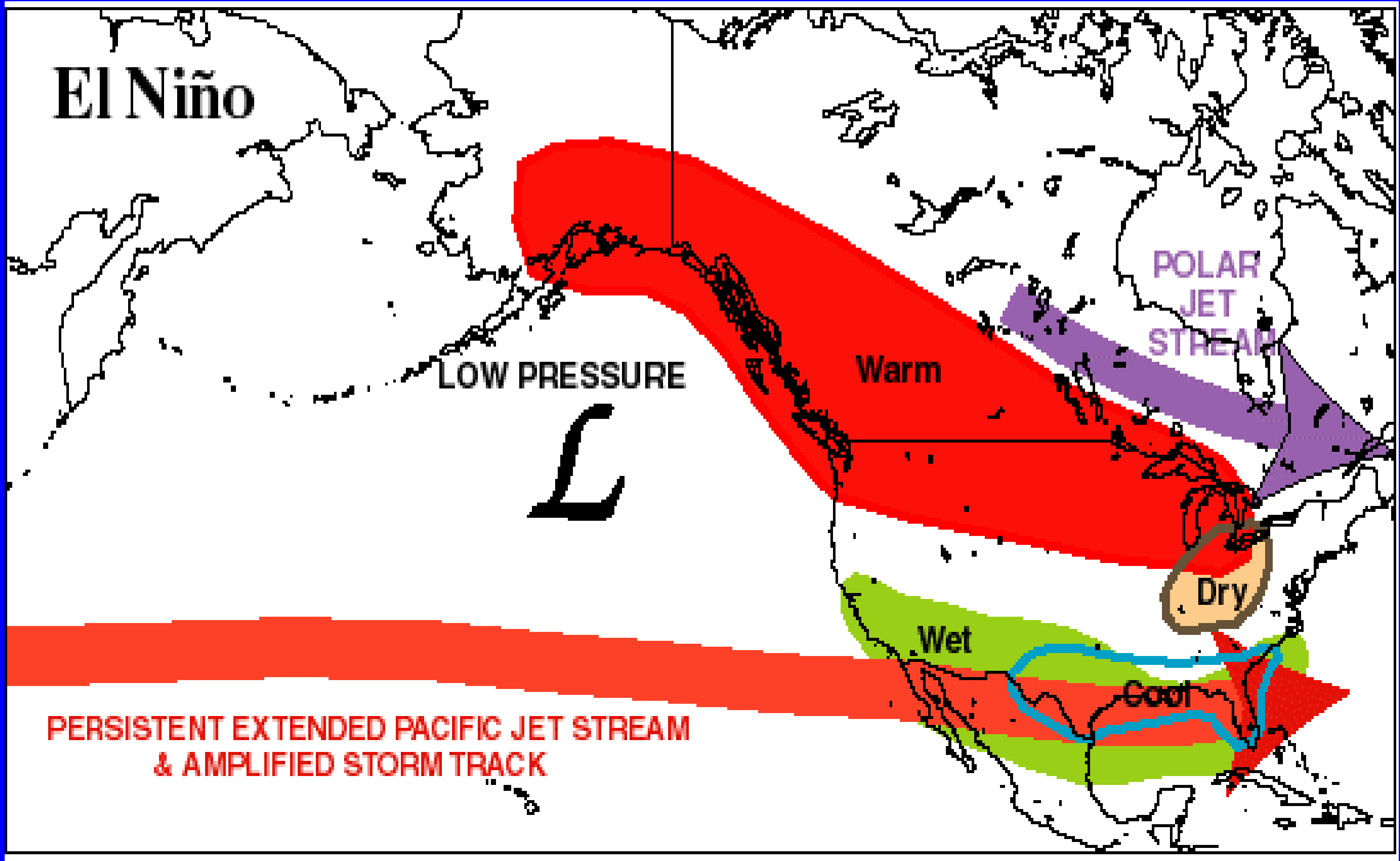
Atmospheric Circulation: Summer



Mike Crimmins, University of Arizona

El Niño: Winter Effects U.S.

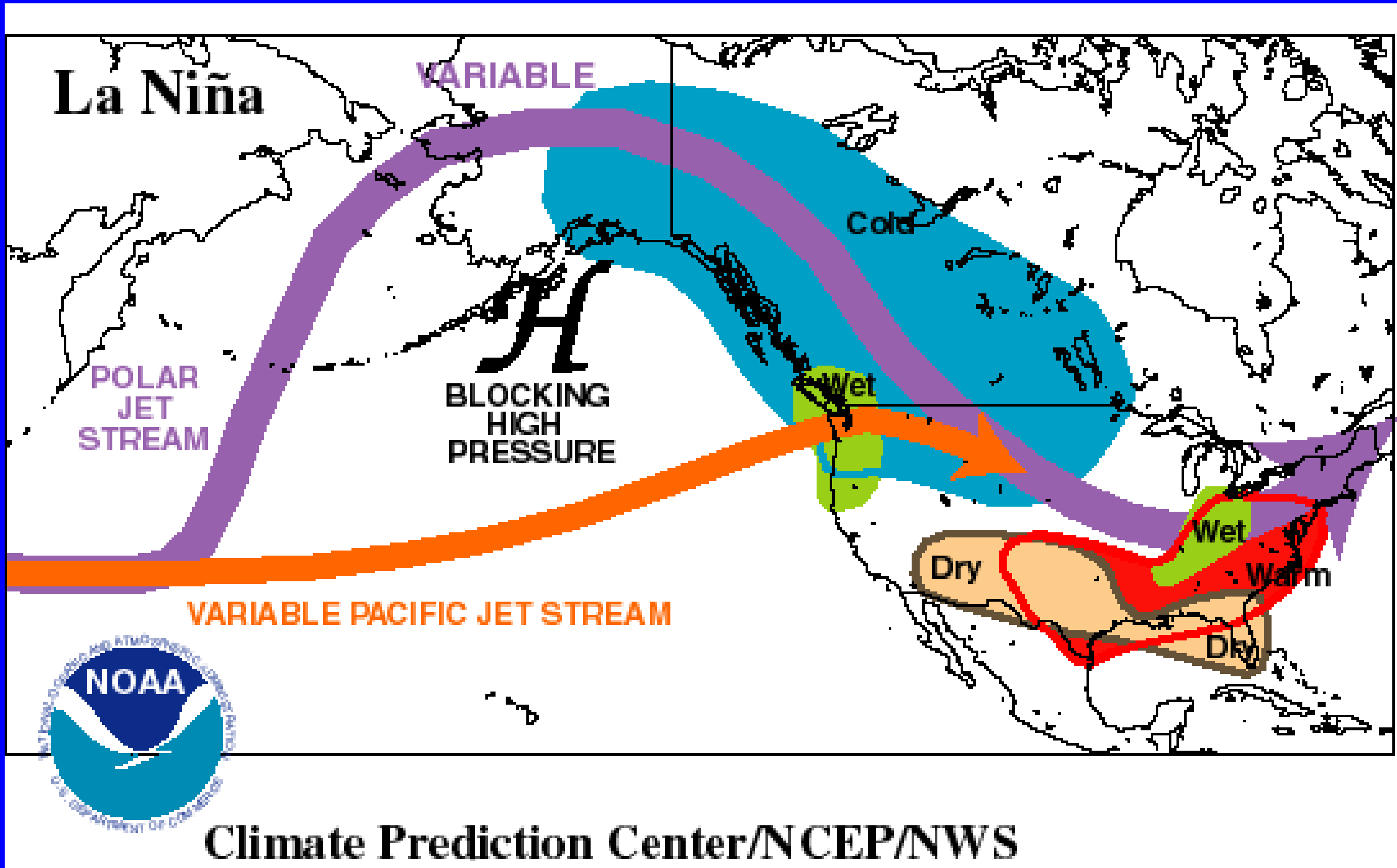
- **Wet winter, dry summer**



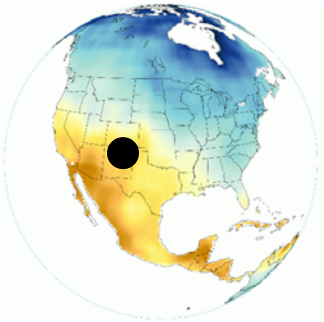
Source: NOAA Climate Prediction Center
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/winter25%25.gif

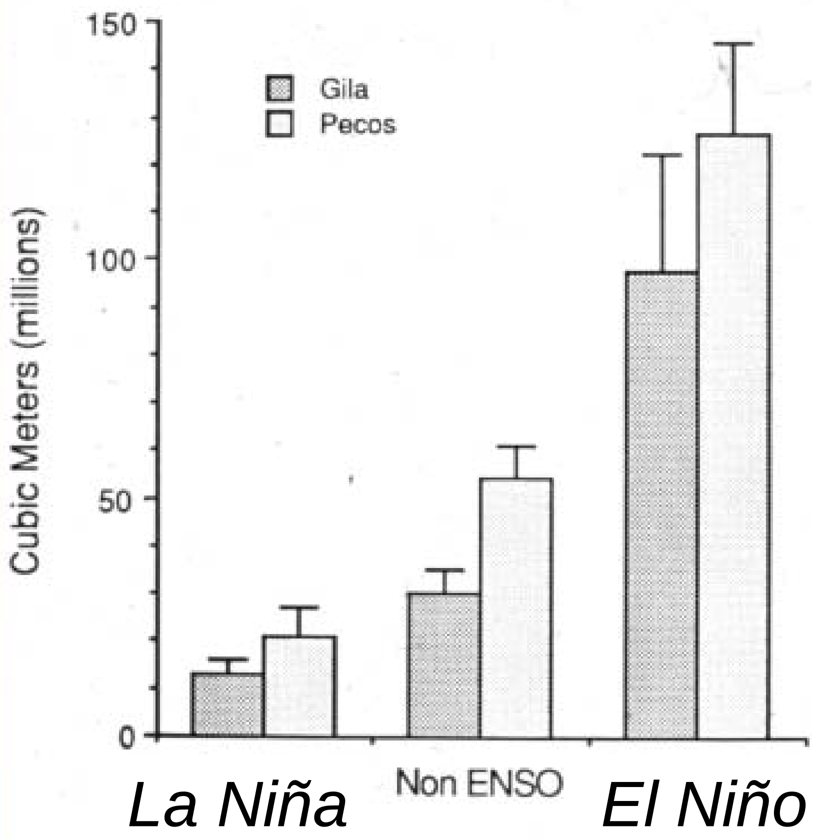
La Niña: Winter Effects U.S.

- **Dry winter, Wet summer**



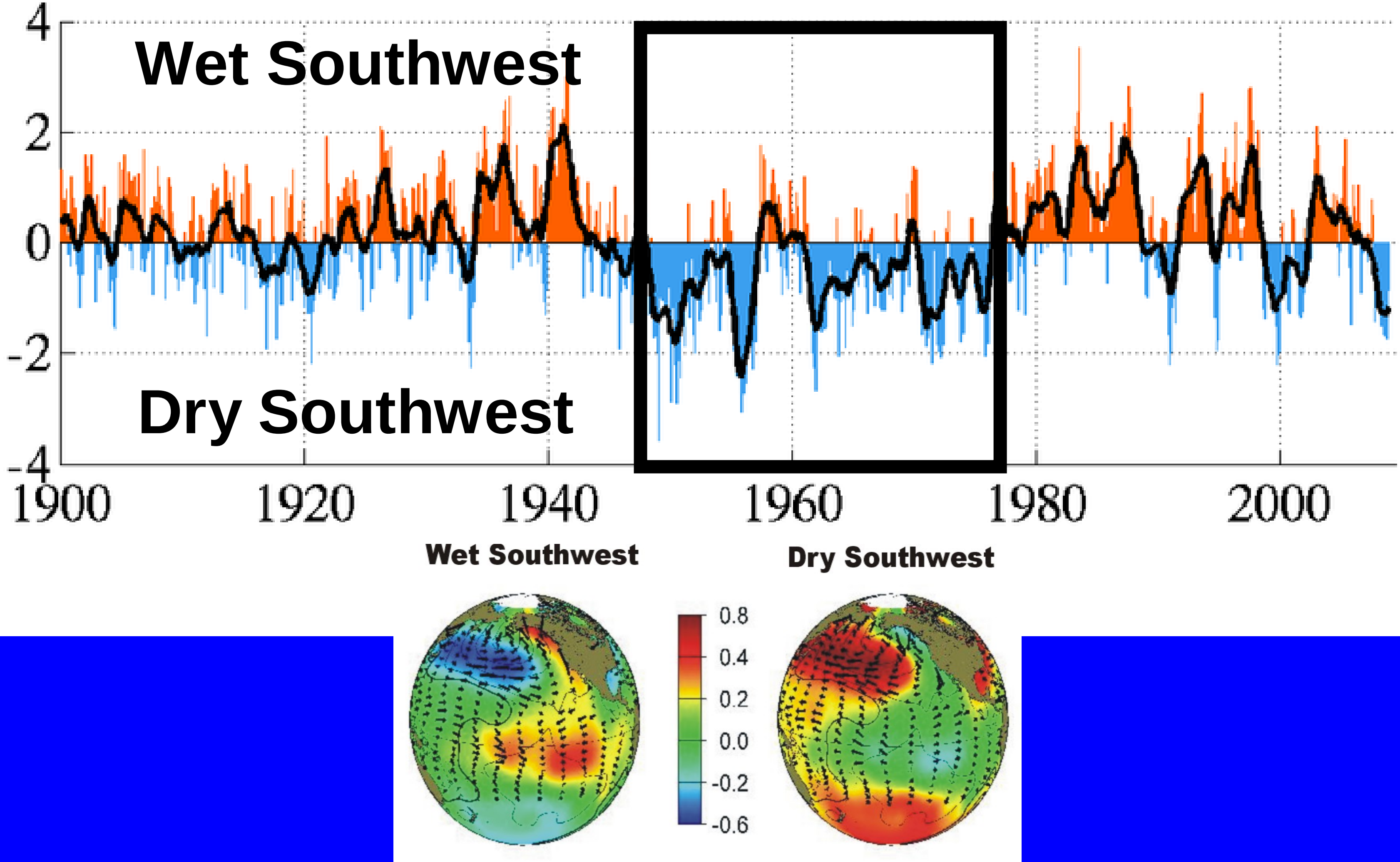
Source: NOAA Climate Prediction Center
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/winter25%25.gif





Manuel Molles, University of New Mexico

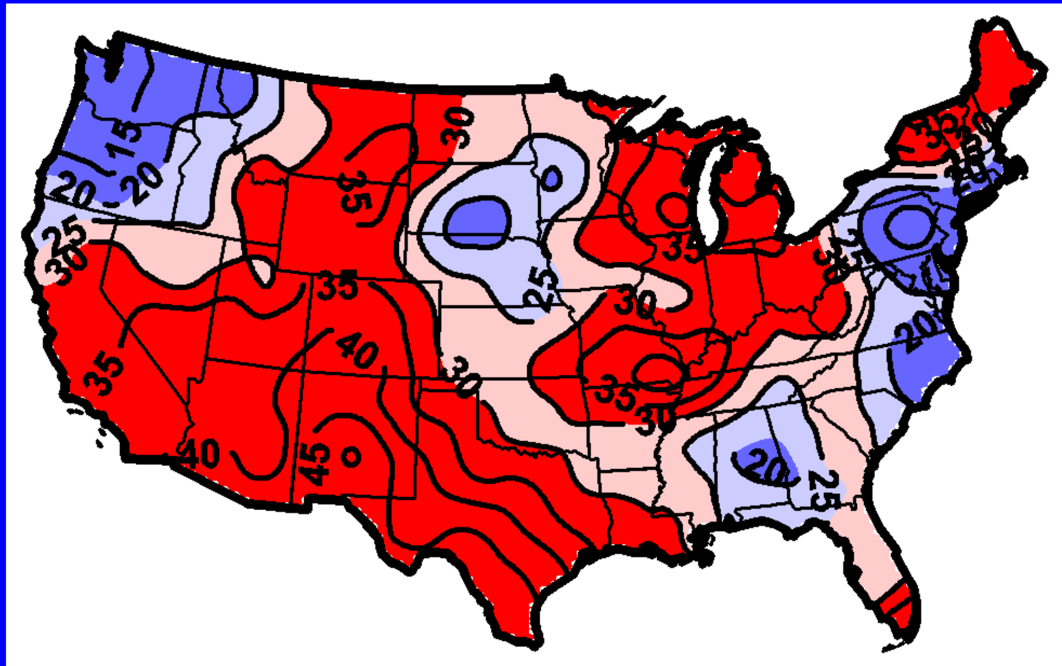
Pacific Decadal Variability - PDO



Joint Institute for the Study of the Atmosphere and Ocean
http://jisao.washington.edu/pdo/

PDO negative + AMO positive

Drought Frequency % (25 = expected)



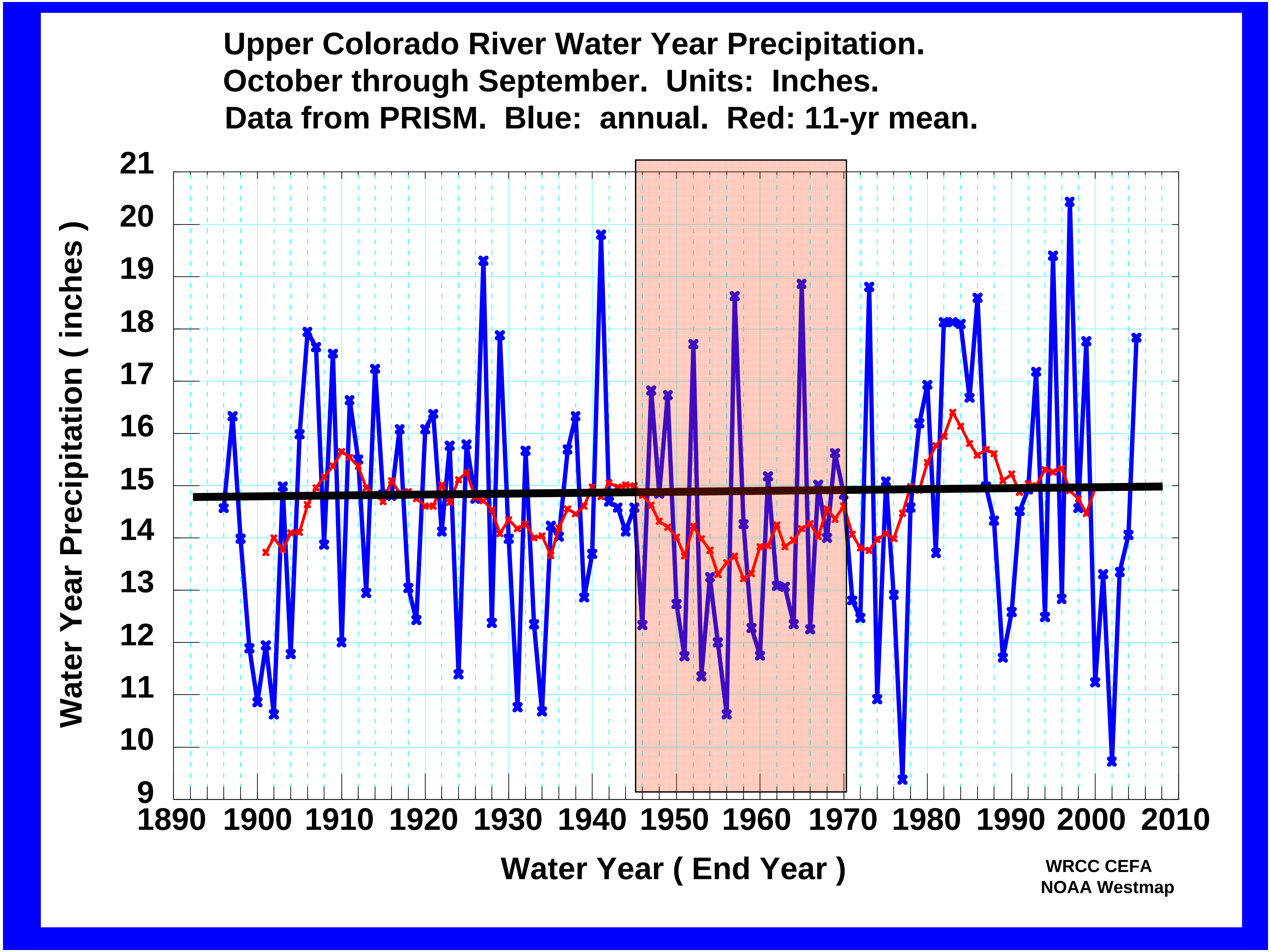
high drought frequency

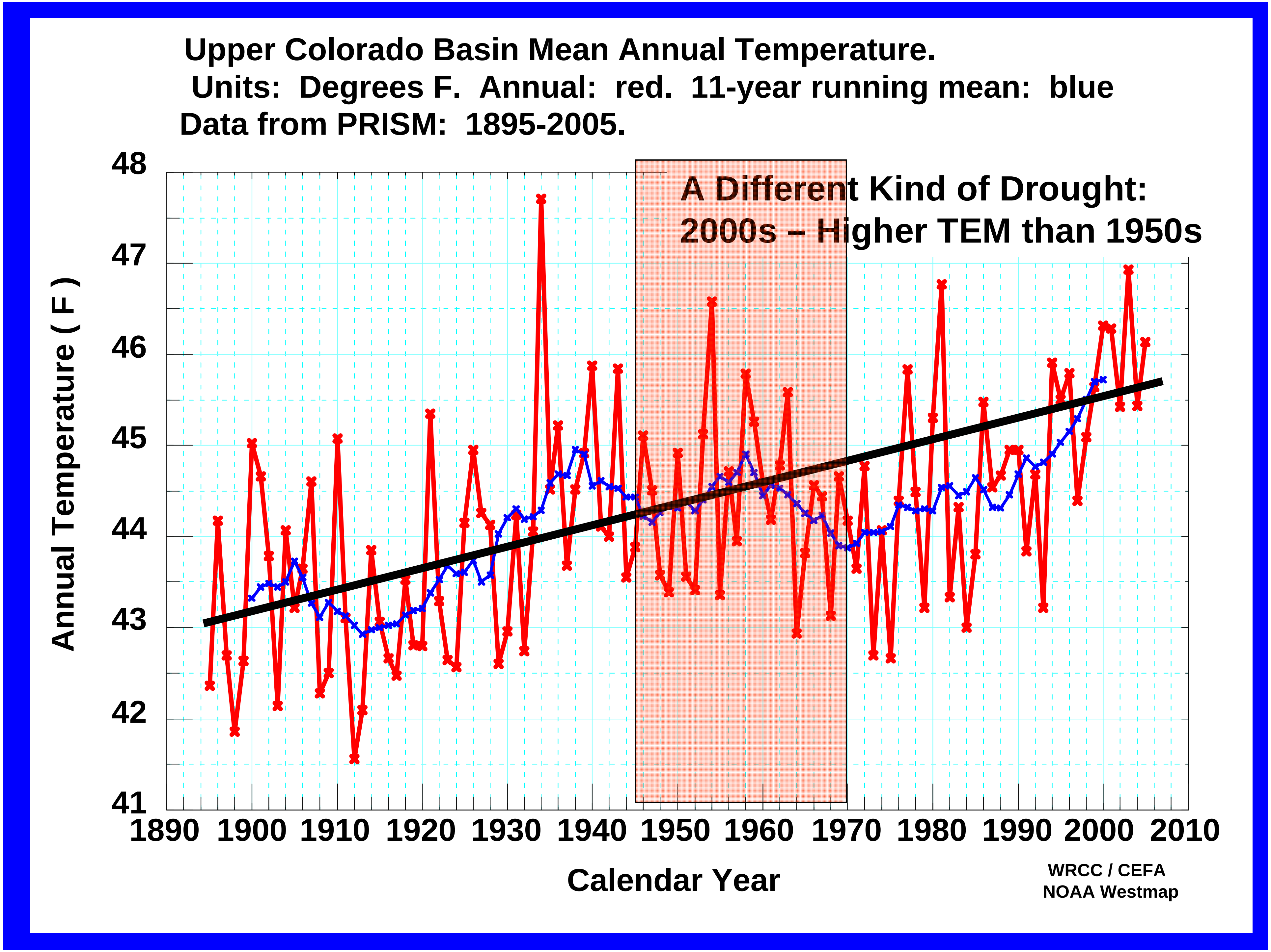
low drought frequency

McCabe et al., 2004 Proceedings of the National Academy of Sciences

How Did We Get Here?

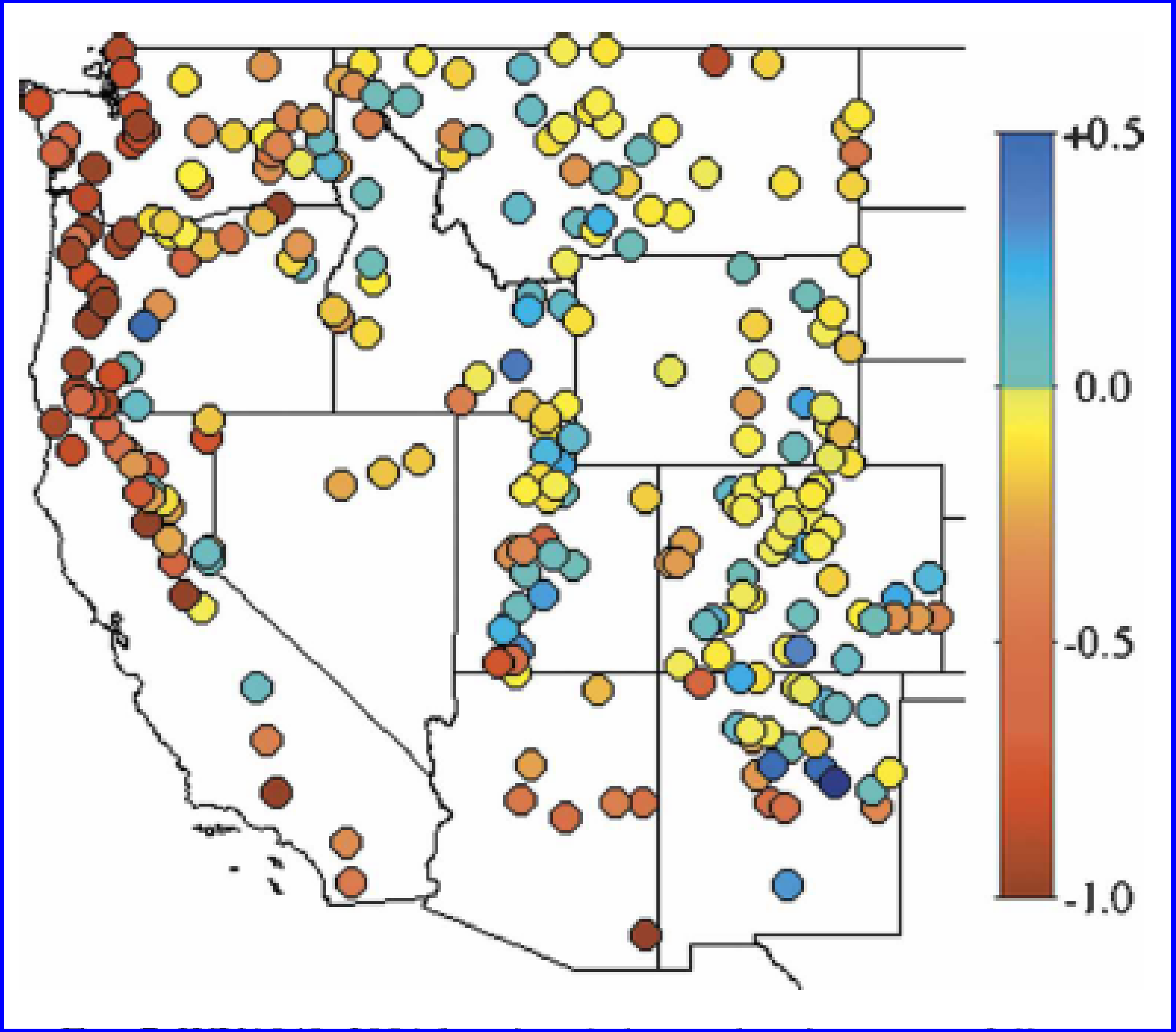
"Global Change Type Drought"


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 (End Year)
WRCC CEFA
NOAA Westmap



Upper Colorado Basin Mean Annual Temperature.
Units: Degrees F. Annual: red. 11-year running mean: blue
Data from PRISM: 1895-2005.
A Different Kind of Drought:
2000s – Higher TEM than 1950s
Annual Temperature (F)
48
47
46
45
44
43
42
41
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Calendar Year
WRCC / CEFA
NOAA Westmap

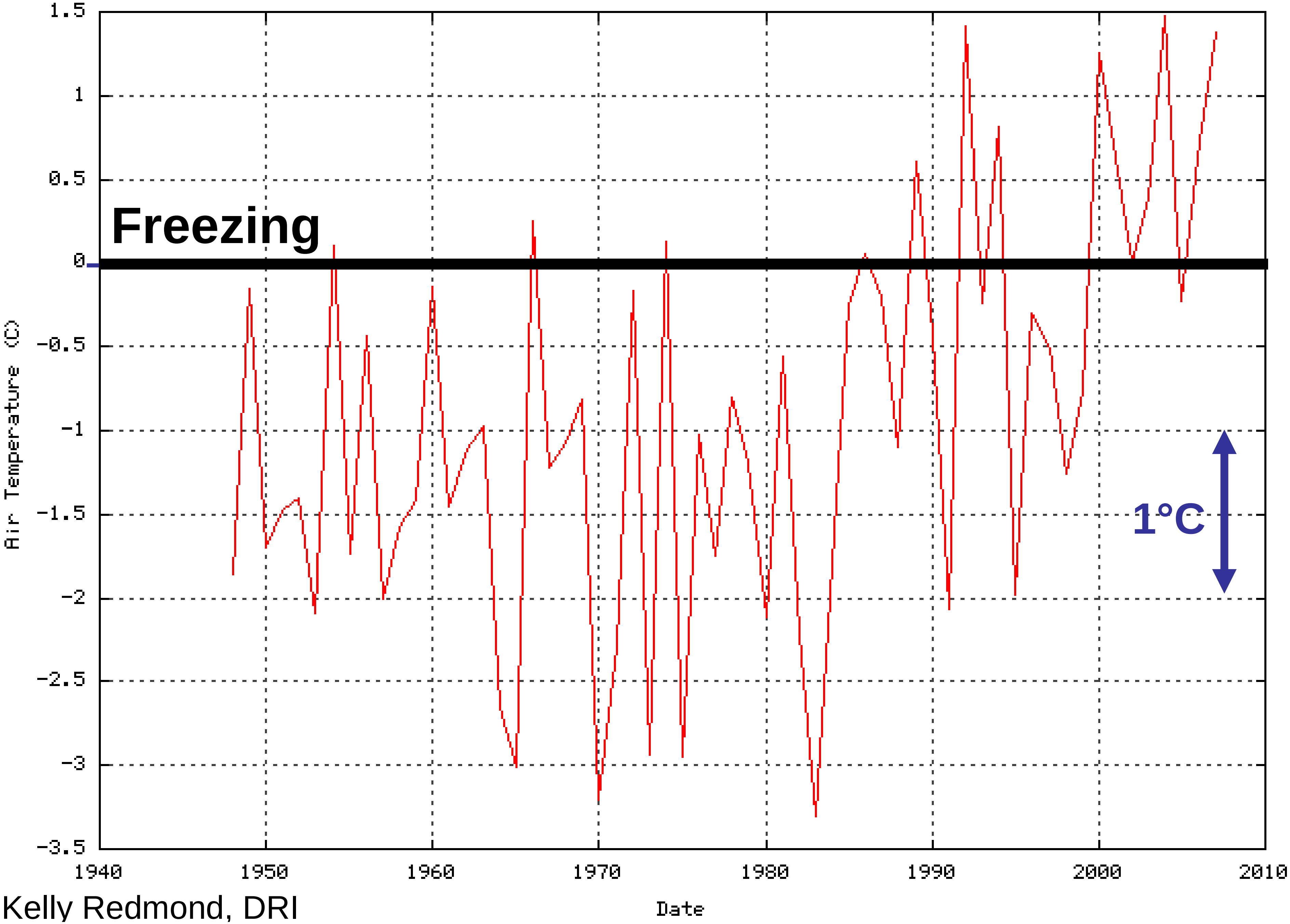
Winter Trends: Less Snow, More Rain



Strongest at elevations <2,300 m and in March

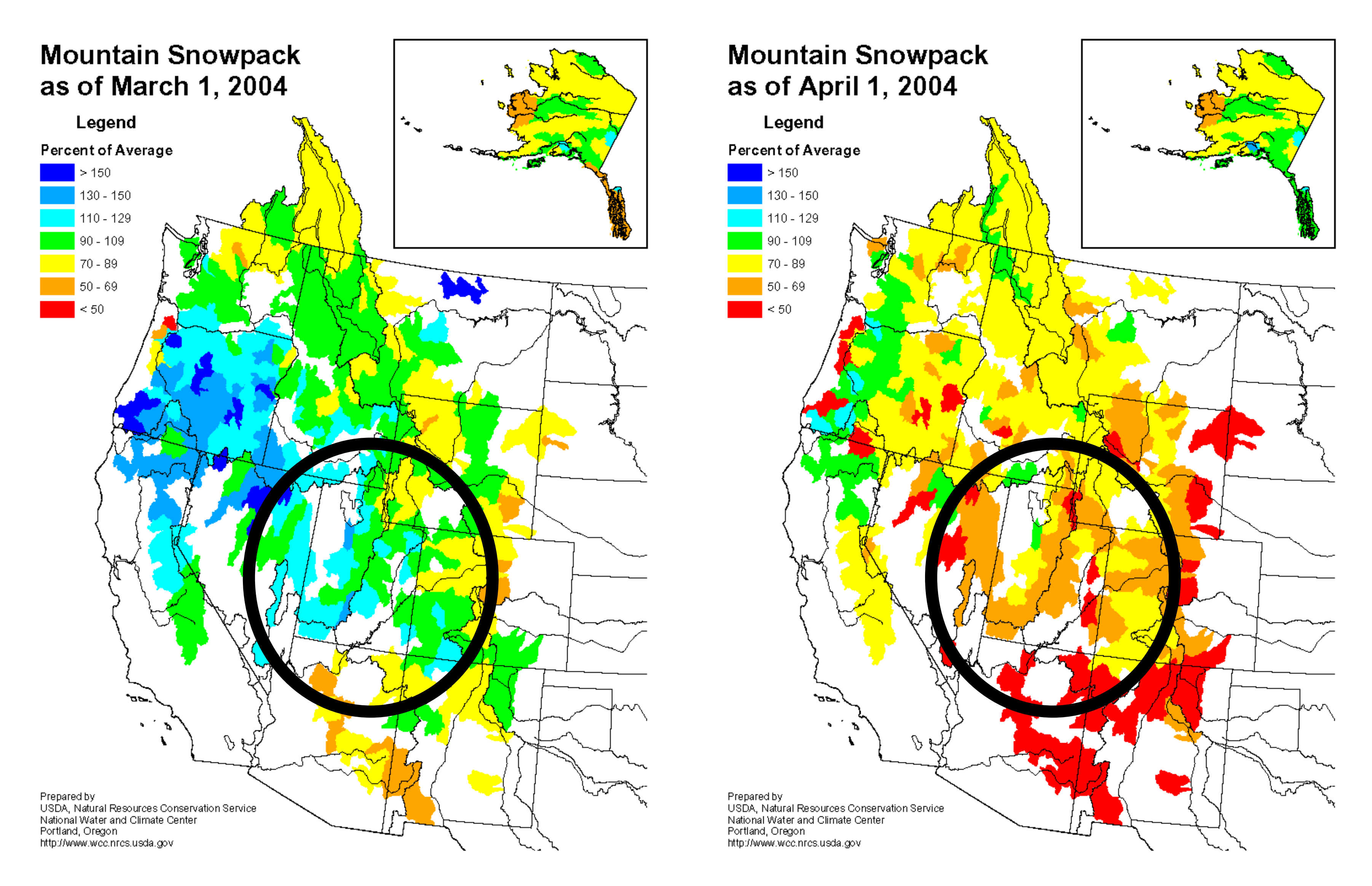
Knowles, et. al, 2006 Journal of Climate

Upper Colorado River Basin **Mar-May** 700 mb Temperature (3,000 m)



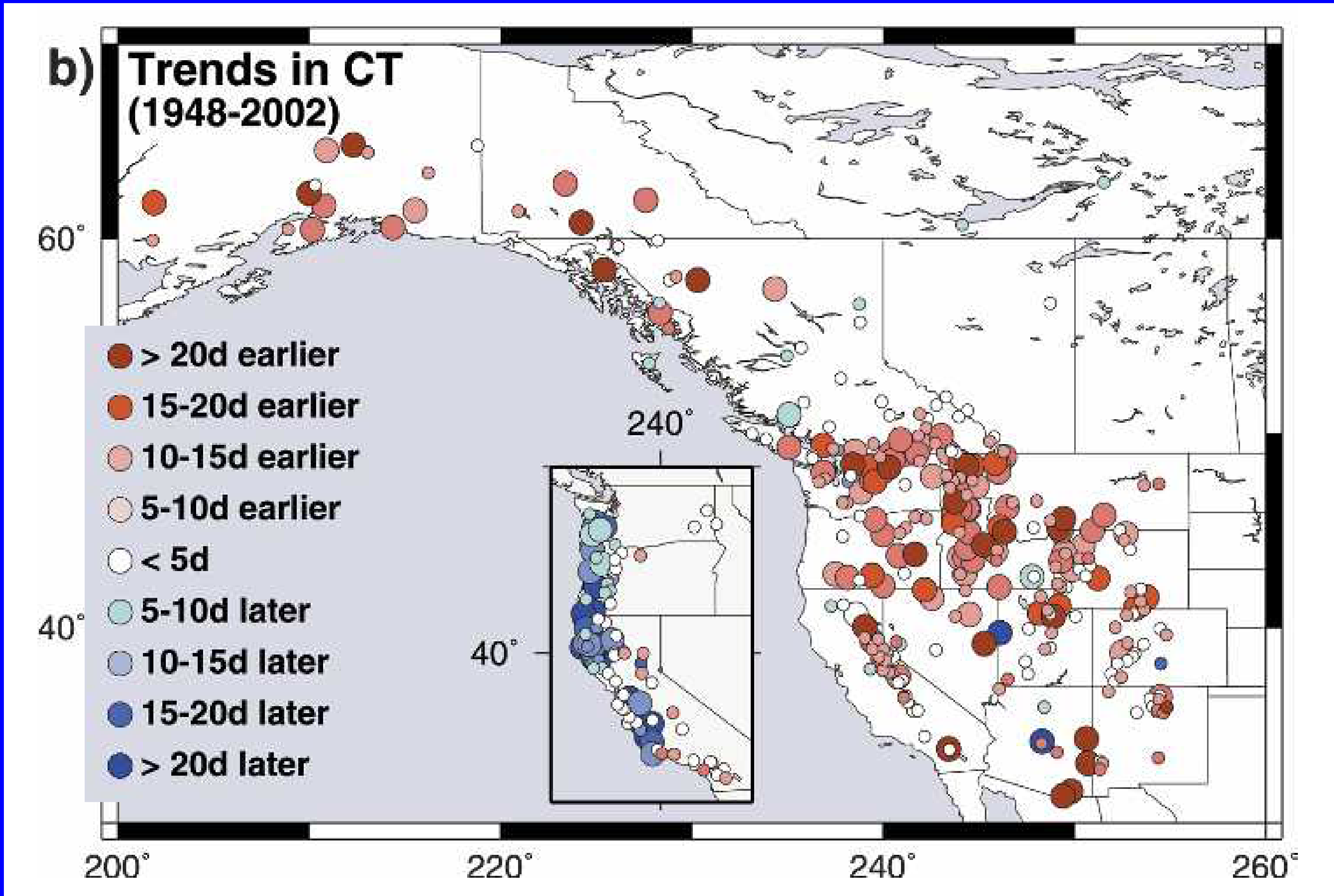
Kelly Redmond, DRI

Dramatic Warming Episodes

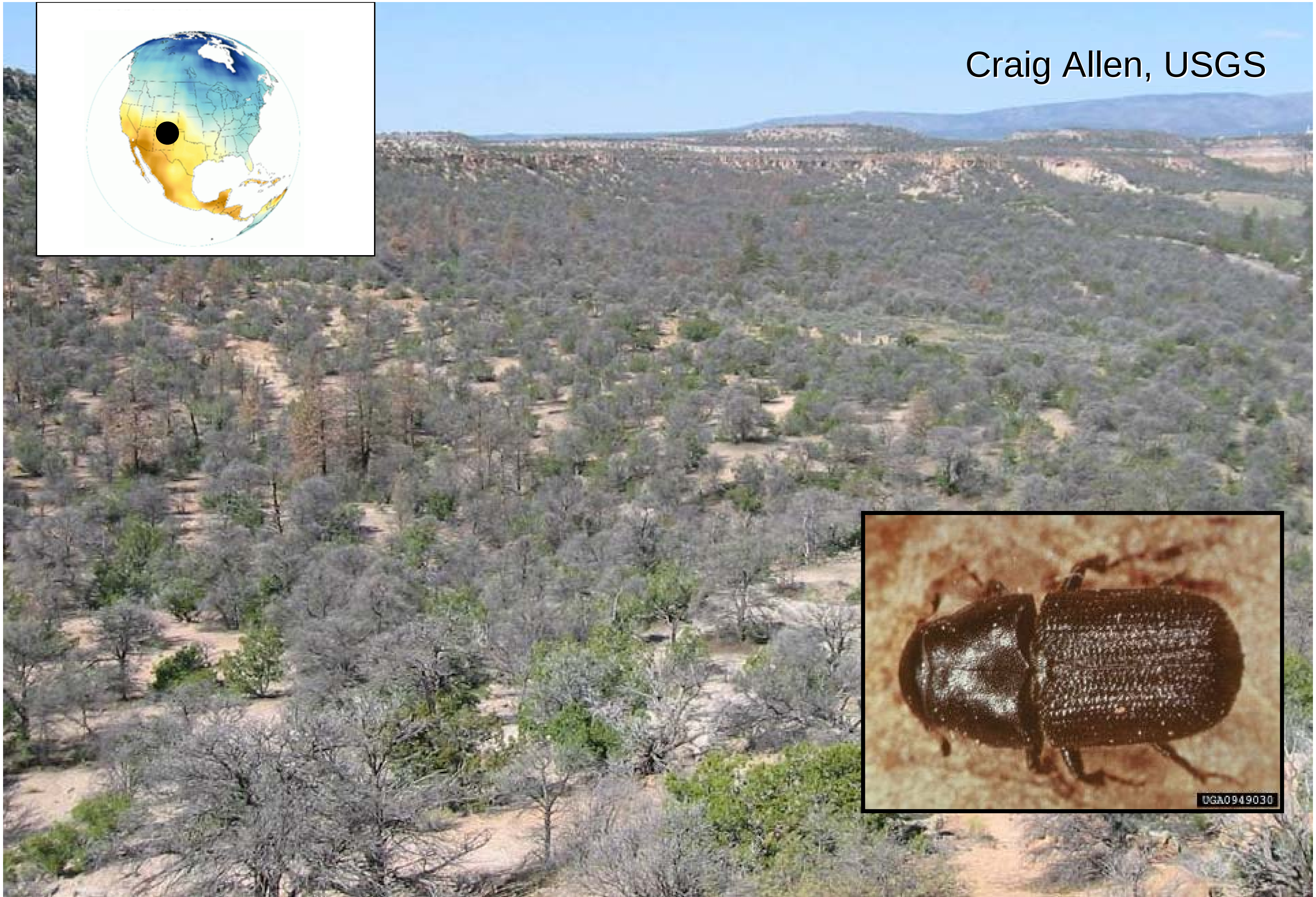


Losses of 30-60% SWE

Observed Changes in Snowmelt Runoff

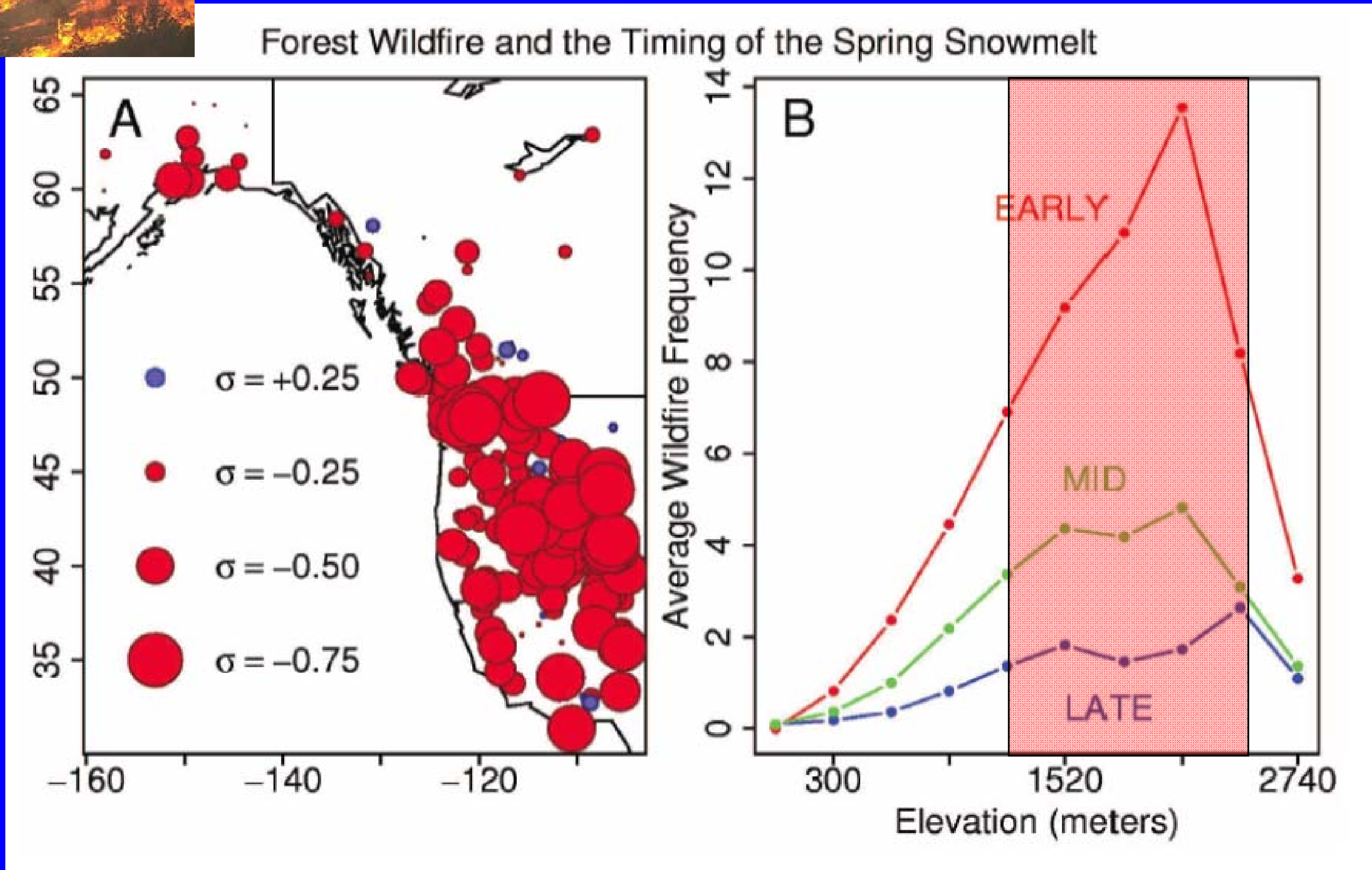


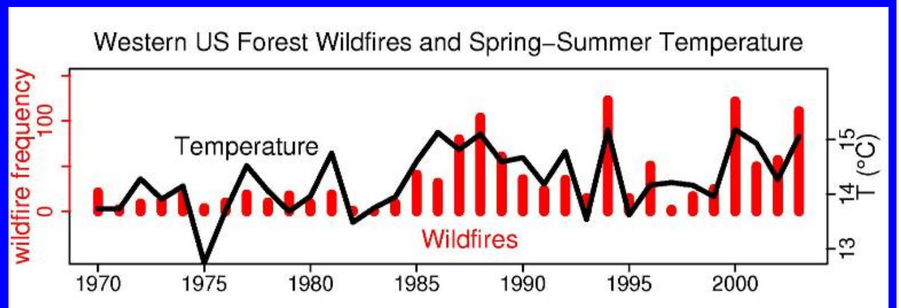
Stewart et al. 2005 Journal of Climate



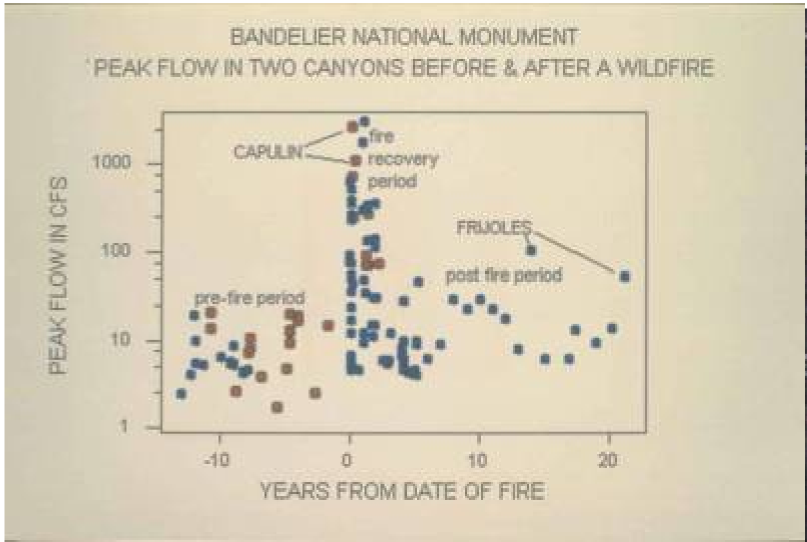
Big, fast ecological change…

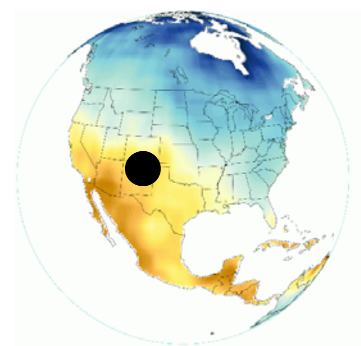
Jemez Mts., May 2004





Westerling et al., 2006 *Science*



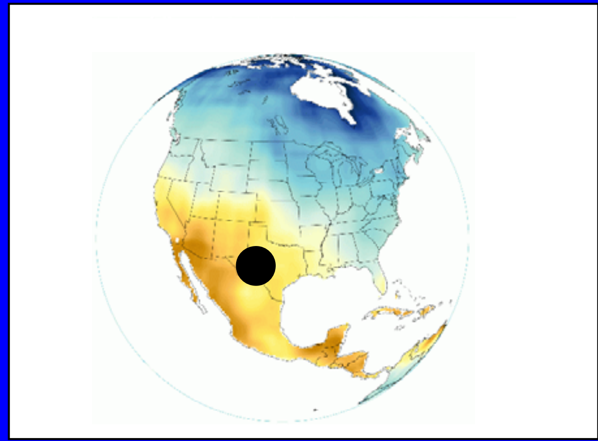


100-fold increases in runoff and erosion.

July 2001, Cerro Grande Fire area

2006 TX and OK: 1.6 million hectares

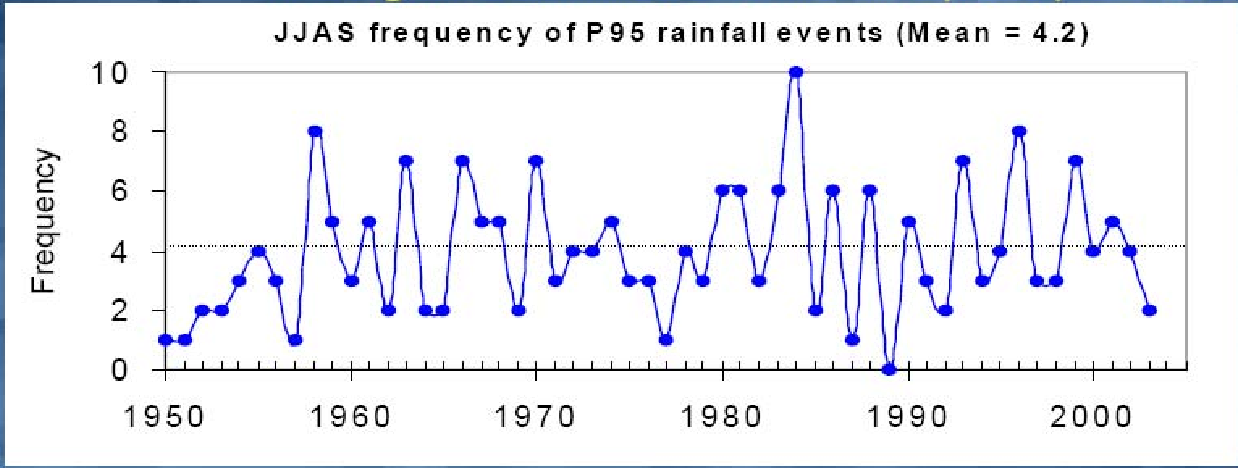
Increased ***wind*** and water erosion risk



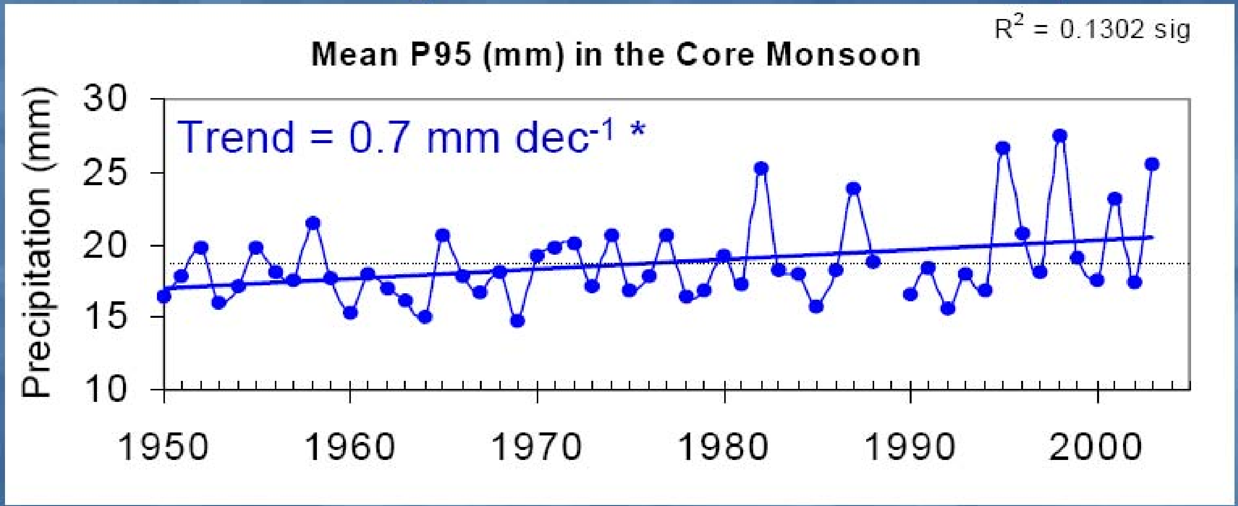
Craig Allen, USGS

Interannual variability of P95 rainfall events

No significant trend in the frequency of P95

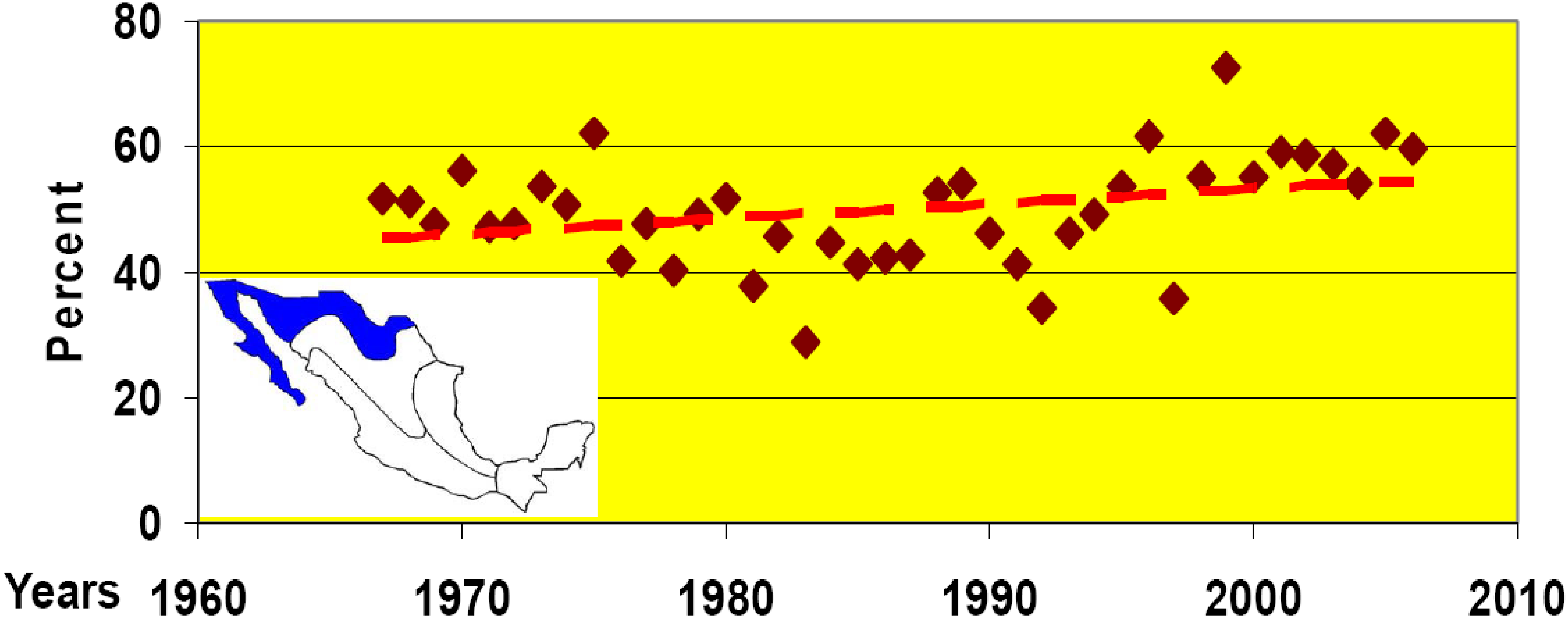


Significant trend in the intensity of P95



Cavazos, 2007 CLIVAR 10th Annual Meeting

Northern Mexico, fraction of strings of dry days longer than 60 days



Red dashed line: linear trend (9.4% per 40 years)

P. Groisman et al. 2007, NEESPI/LCLUC Science Team Meeting, Urumqi, China

Monsoon & Tropical Storms

La Paz, BCS

Alamos, Sonora

Courtesy of N. Piñeda

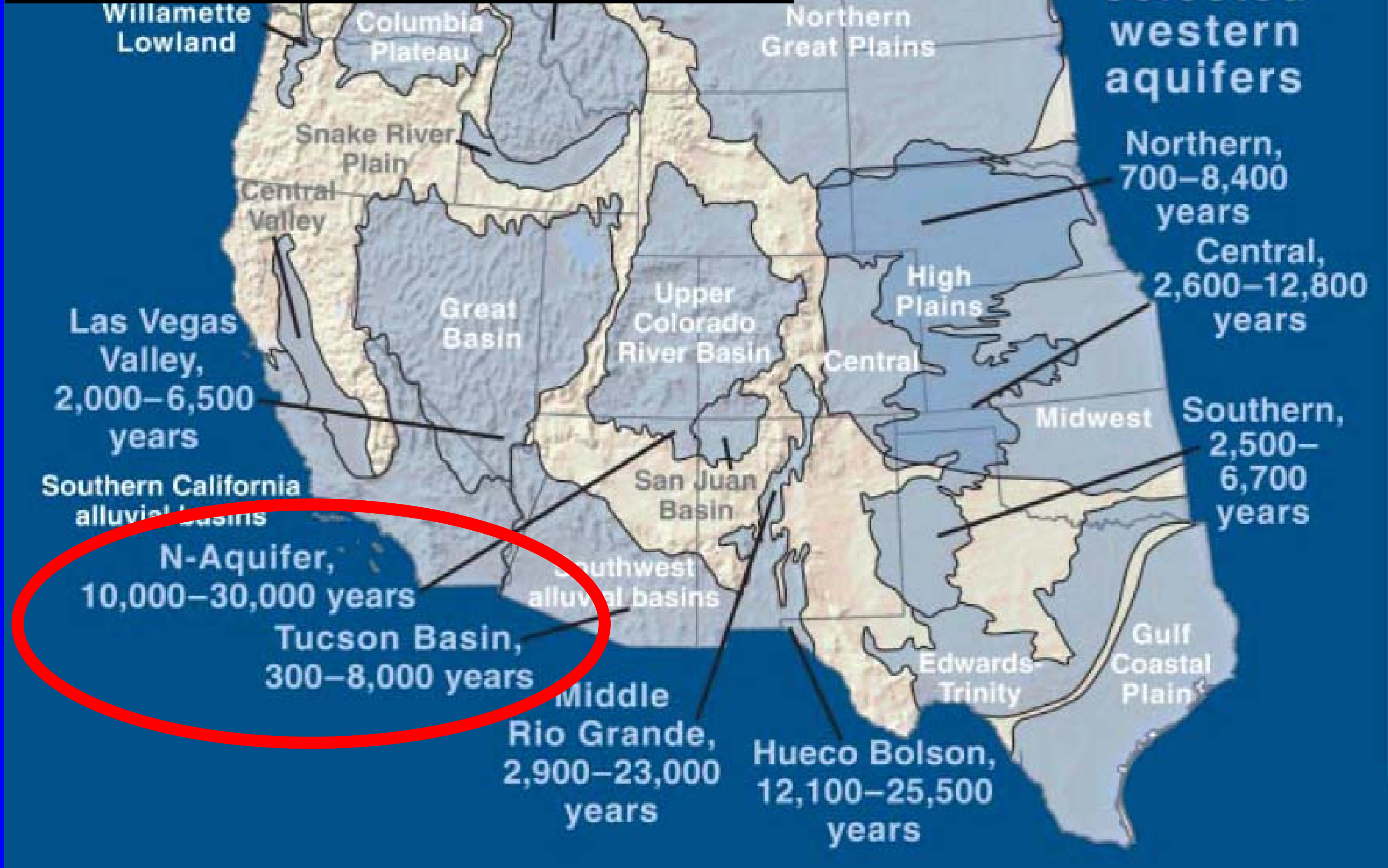
Precipitation is important, of course!

But, temperature is also a hydrologic variable.

How Did We Get Here?

Land and Water Management Practices

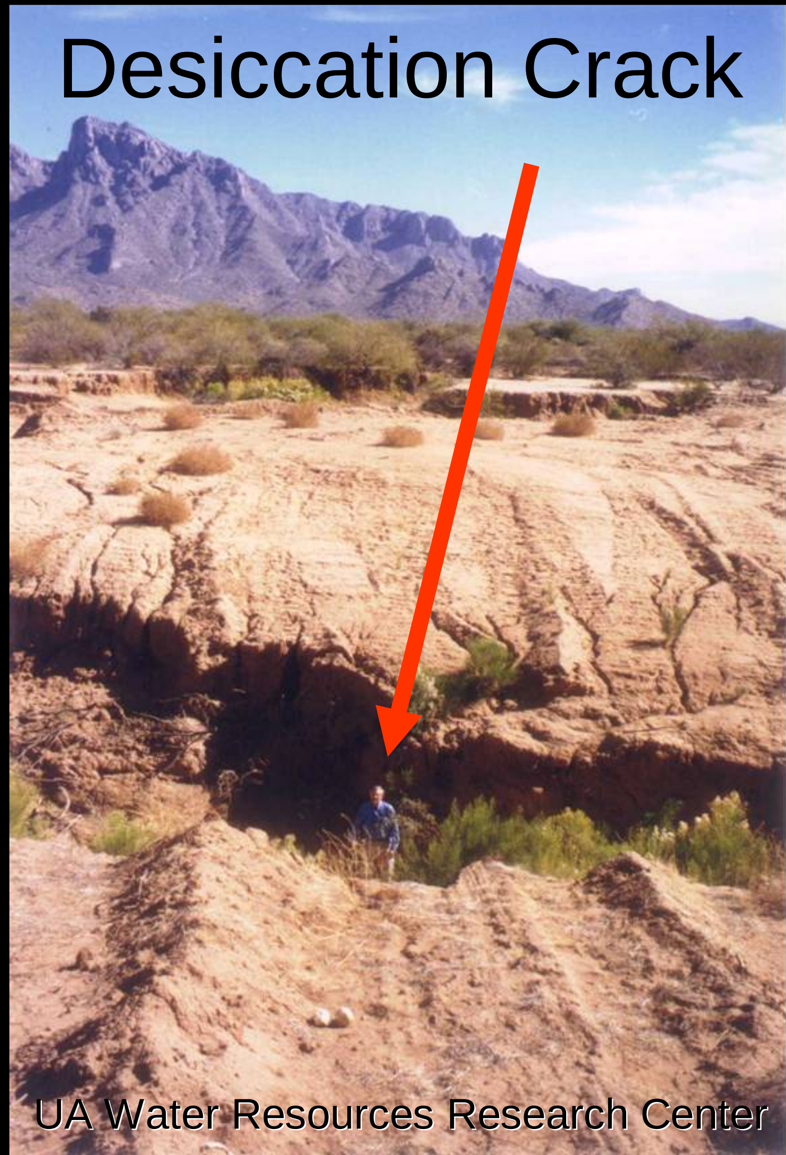
GW: 40-60%



Slide courtesy of Mark Anderson, USGS

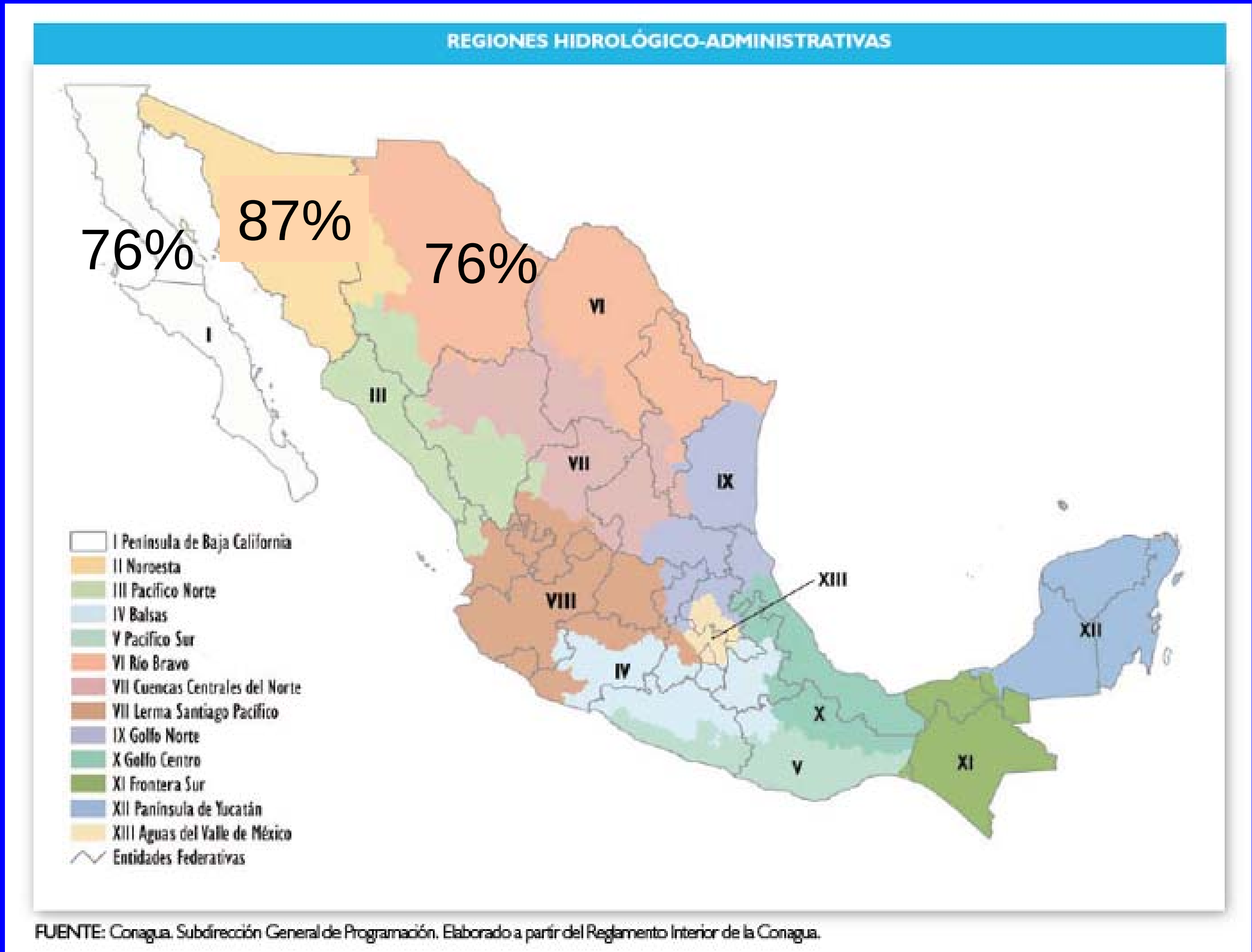
Subsidence from Overpumping

Anderson and Woolsey, 2005 USGS



UA Water Resources Research Center

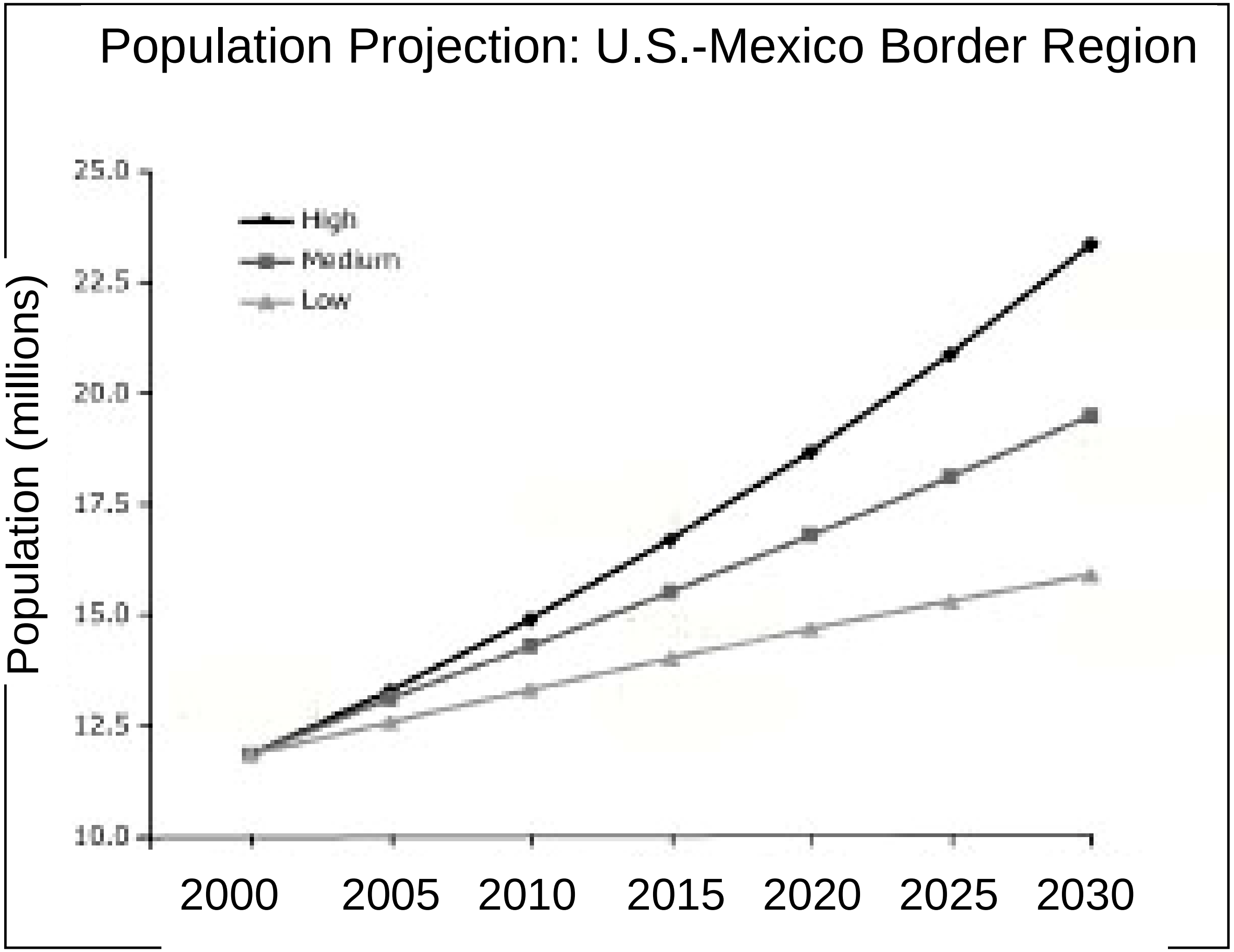
Water Stress



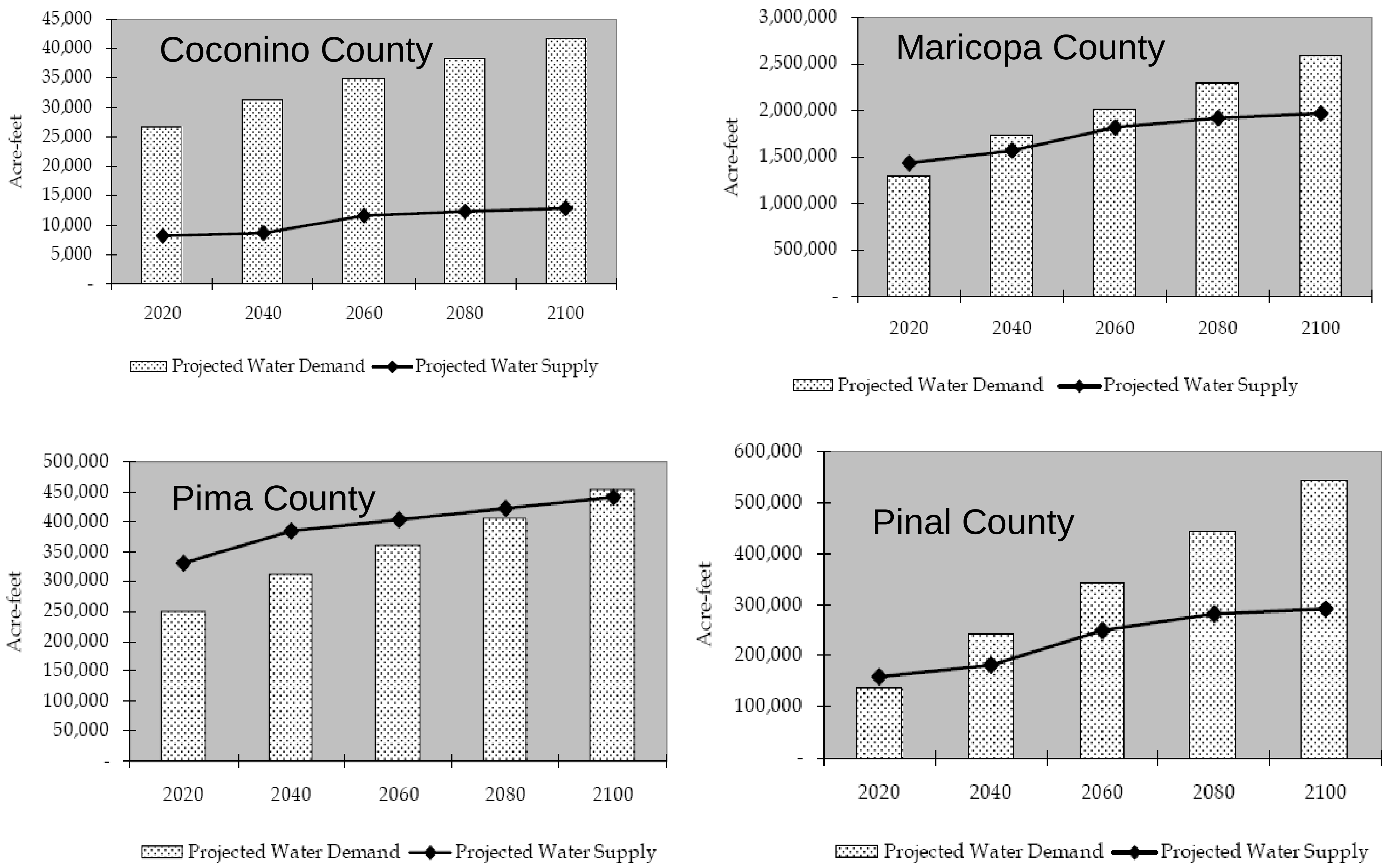
Original Source: CONAGUA

M. Wilder, UA Center for Latin American Studies & CLIMAS

Context: Population



Robert Varady, UA Udall Center for Studies in Public Policy



Coconino County
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
-
Acre-feet
2020
2040
2060
2080
2100
Projected Water Demand
Projected Water Supply
Maricopa County
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
-
Acre-feet
2020
2040
2060
2080
2100
Projected Water Demand
Projected Water Supply
Pima County
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
-
Acre-feet
2020
2040
2060
2080
2100
Projected Water Demand
Projected Water Supply
Pinal County
600,000
500,000
400,000
300,000
200,000
100,000
-
Acre-feet
2020
2040
2060
2080
2100
Projected Water Demand
Projected Water Supply

Colorado River Delta

The delta covers less than one tenth of its original expanse.

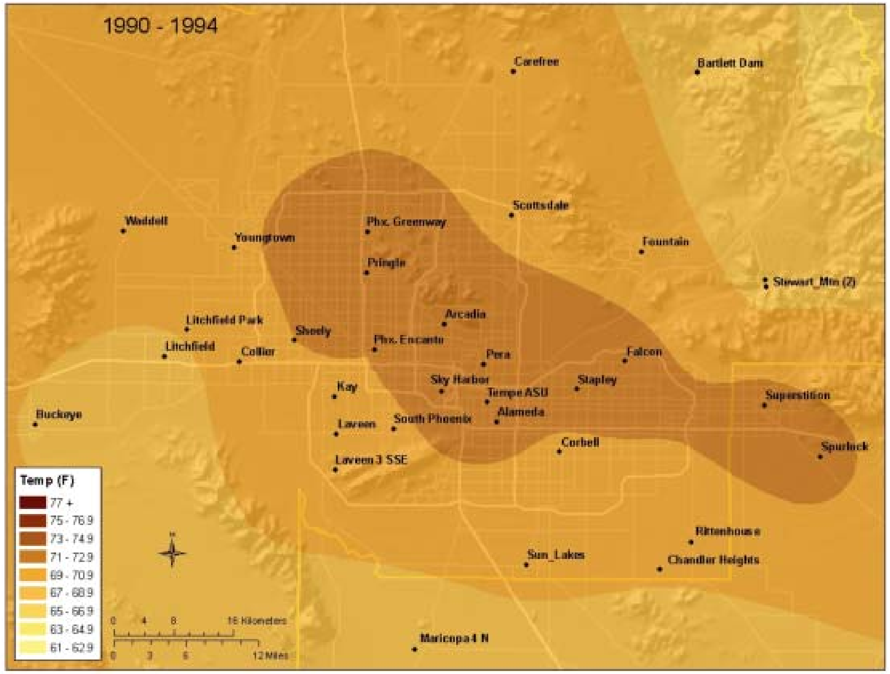
The delta's upper reaches has been converted to irrigated farmland.

The formerly vegetated lower reaches are now barren salt flats.

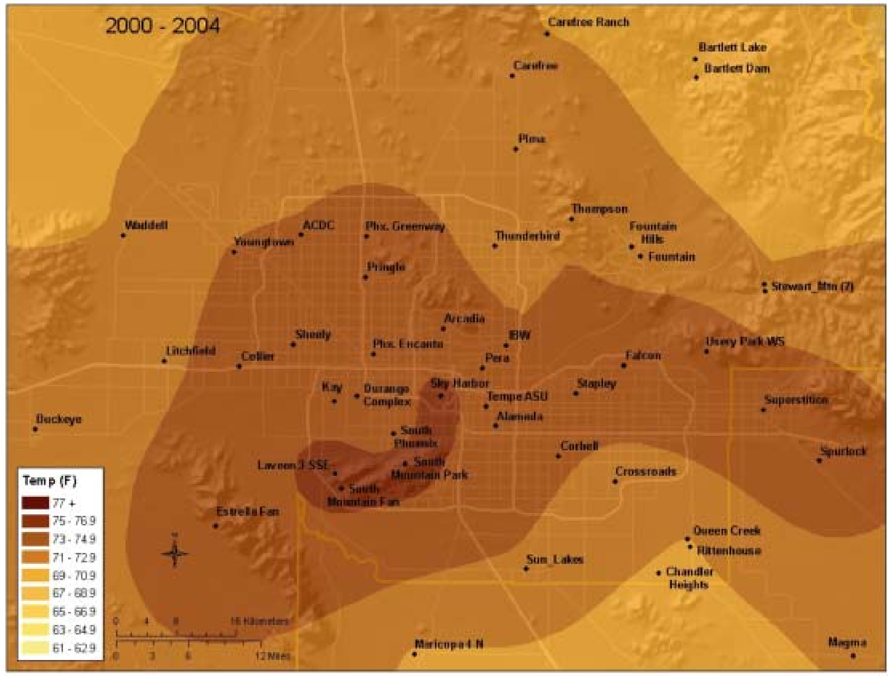
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=4732

Urban Heat Island: Phoenix, AZ

June Min TEM 1990-94

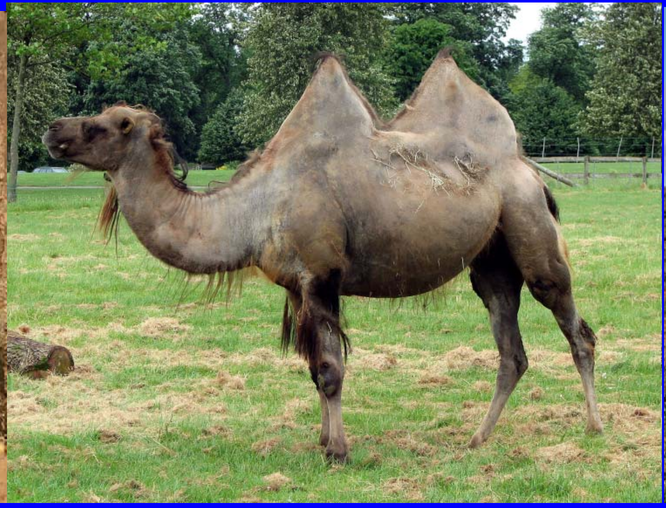


June Min TEM 2000-04

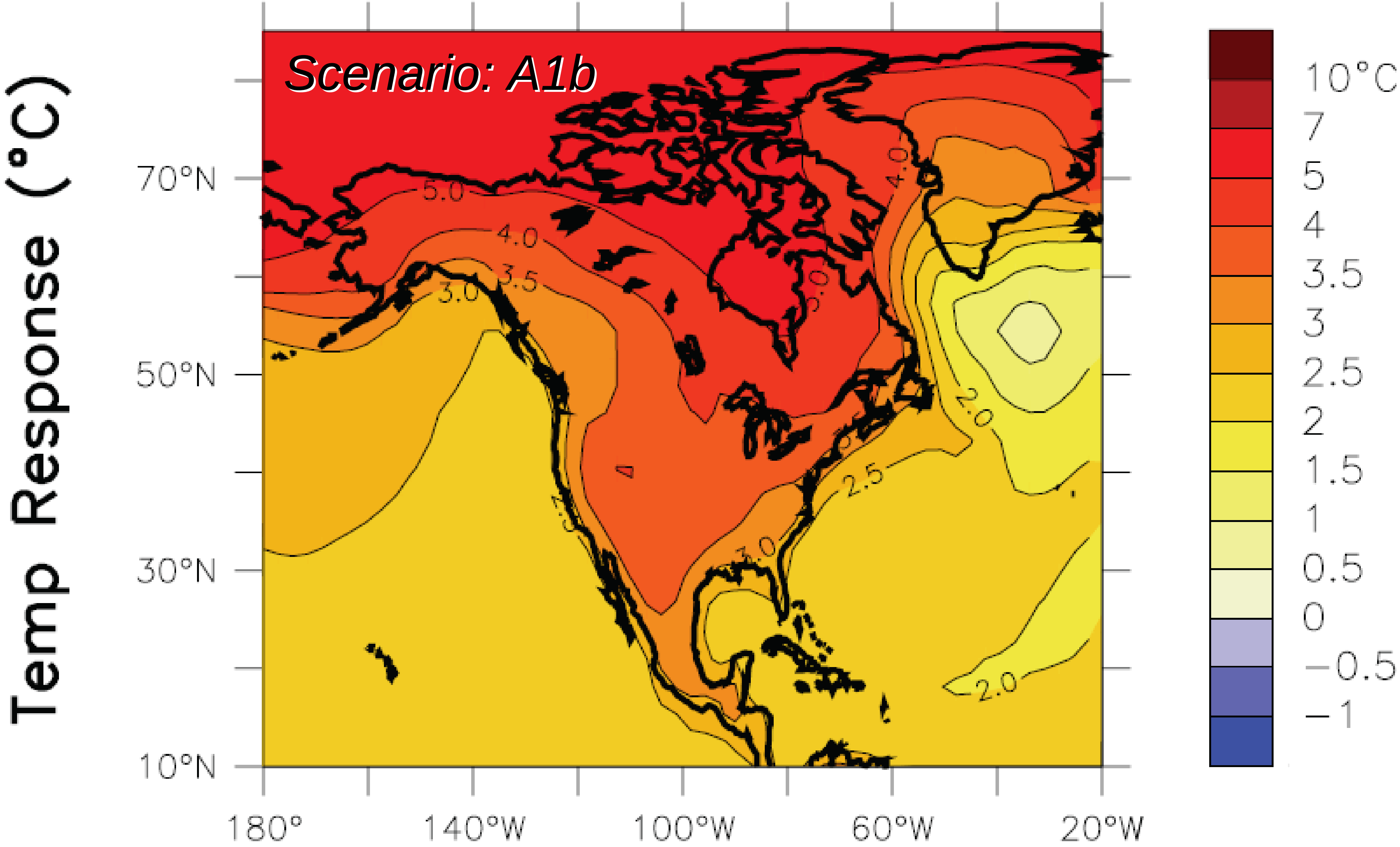


Brazel et al., 2007 *Climate Research*

Climate Change Projections

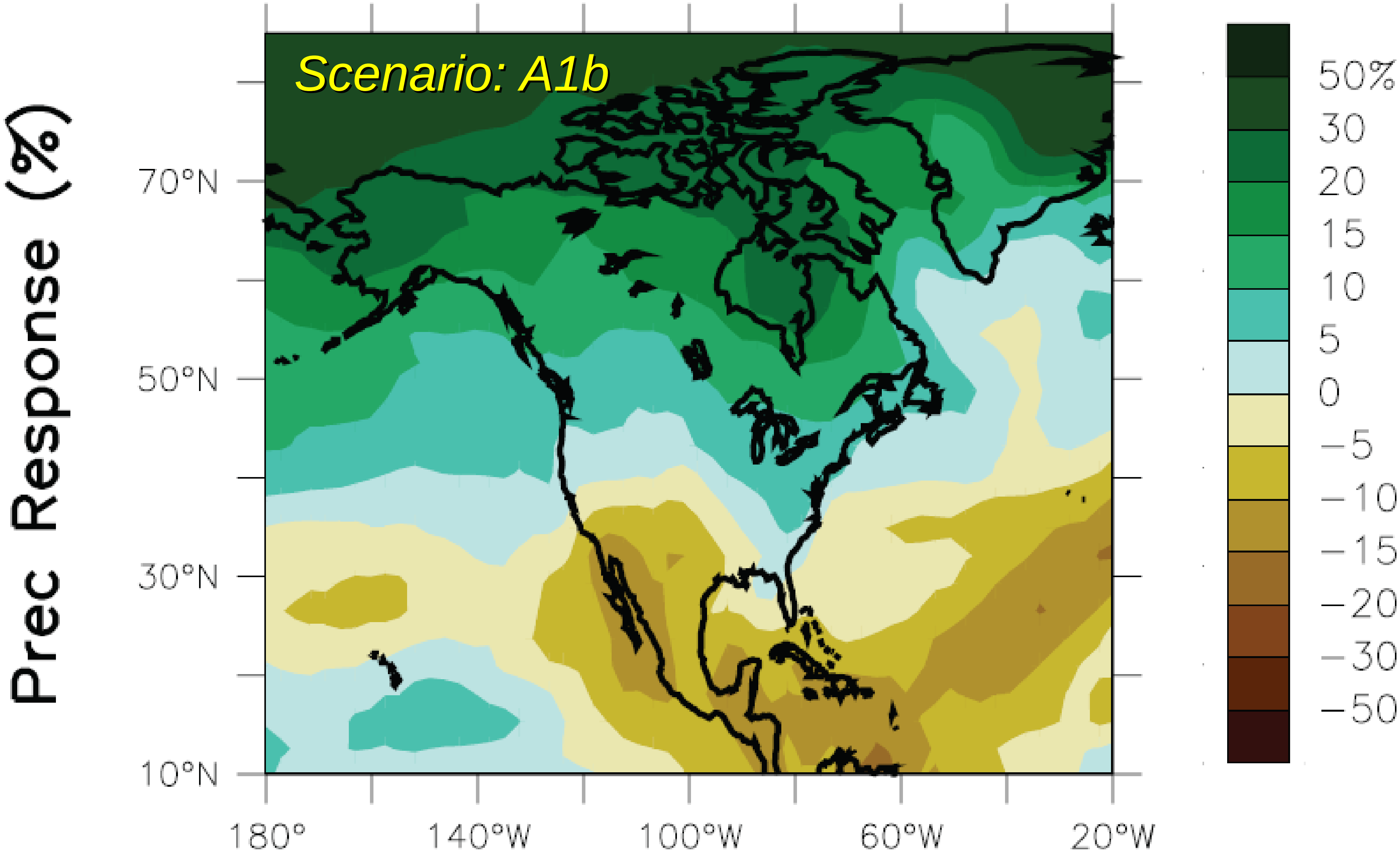




Annual Temperature: End of 21st Century



IPCC 4th Assessment: Working Group I, Chapter 11, Regional Projections

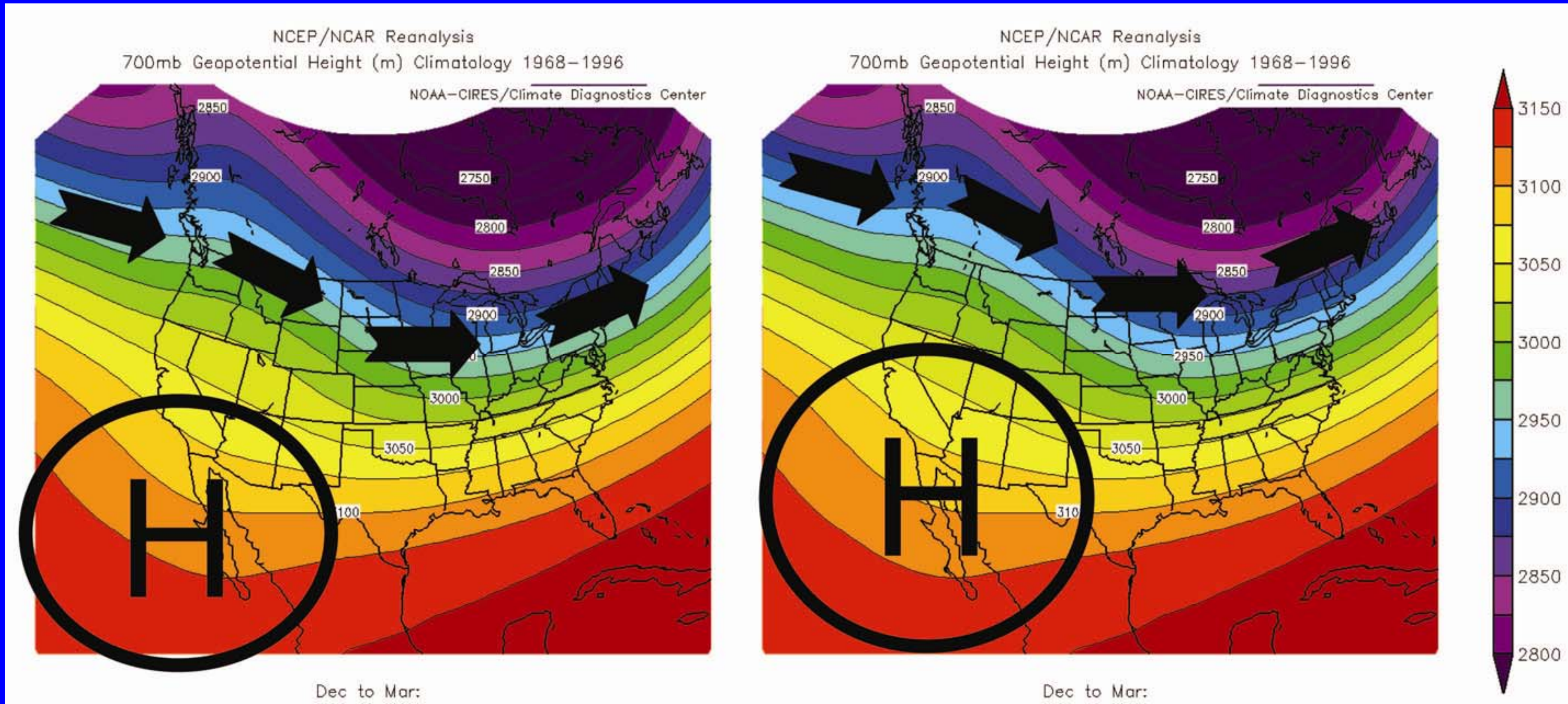
Annual Precipitation: End of 21st Century



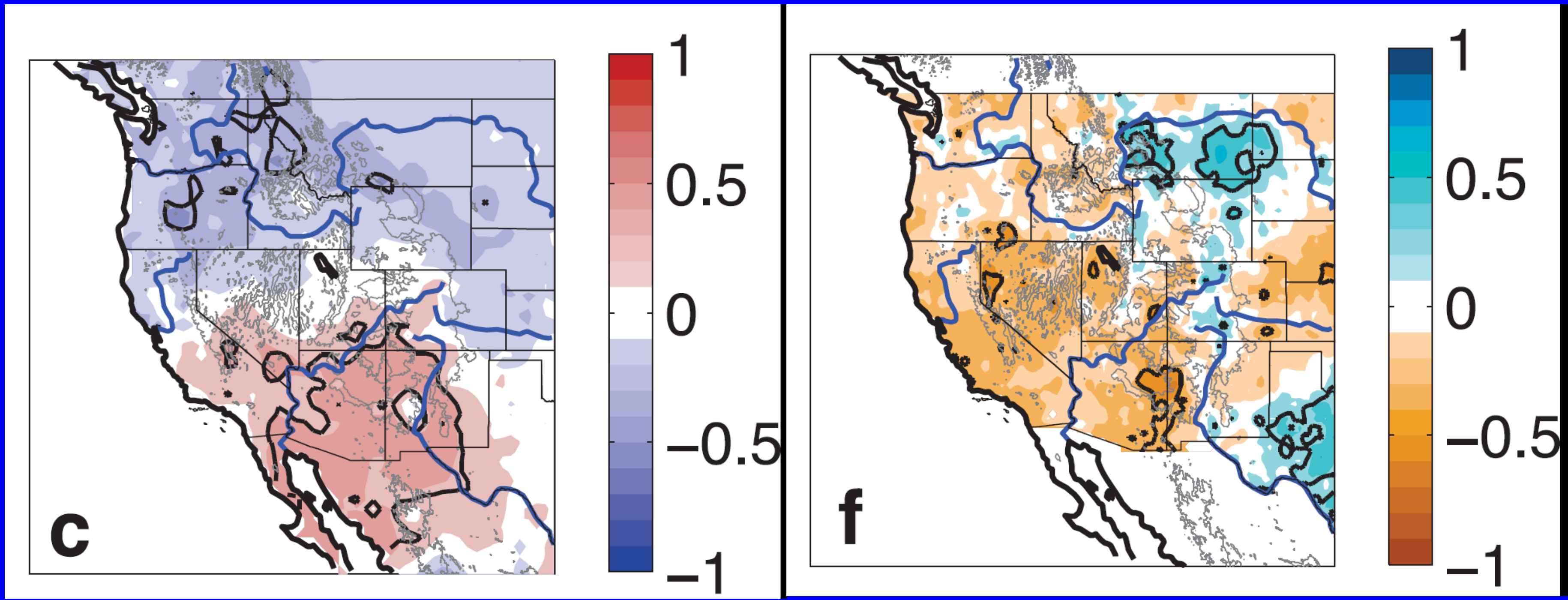
IPCC 4th Assessment: Working Group I, Chapter 11, Regional Projections

Average Winter Jet Stream

Climate Change Winter Jet Stream



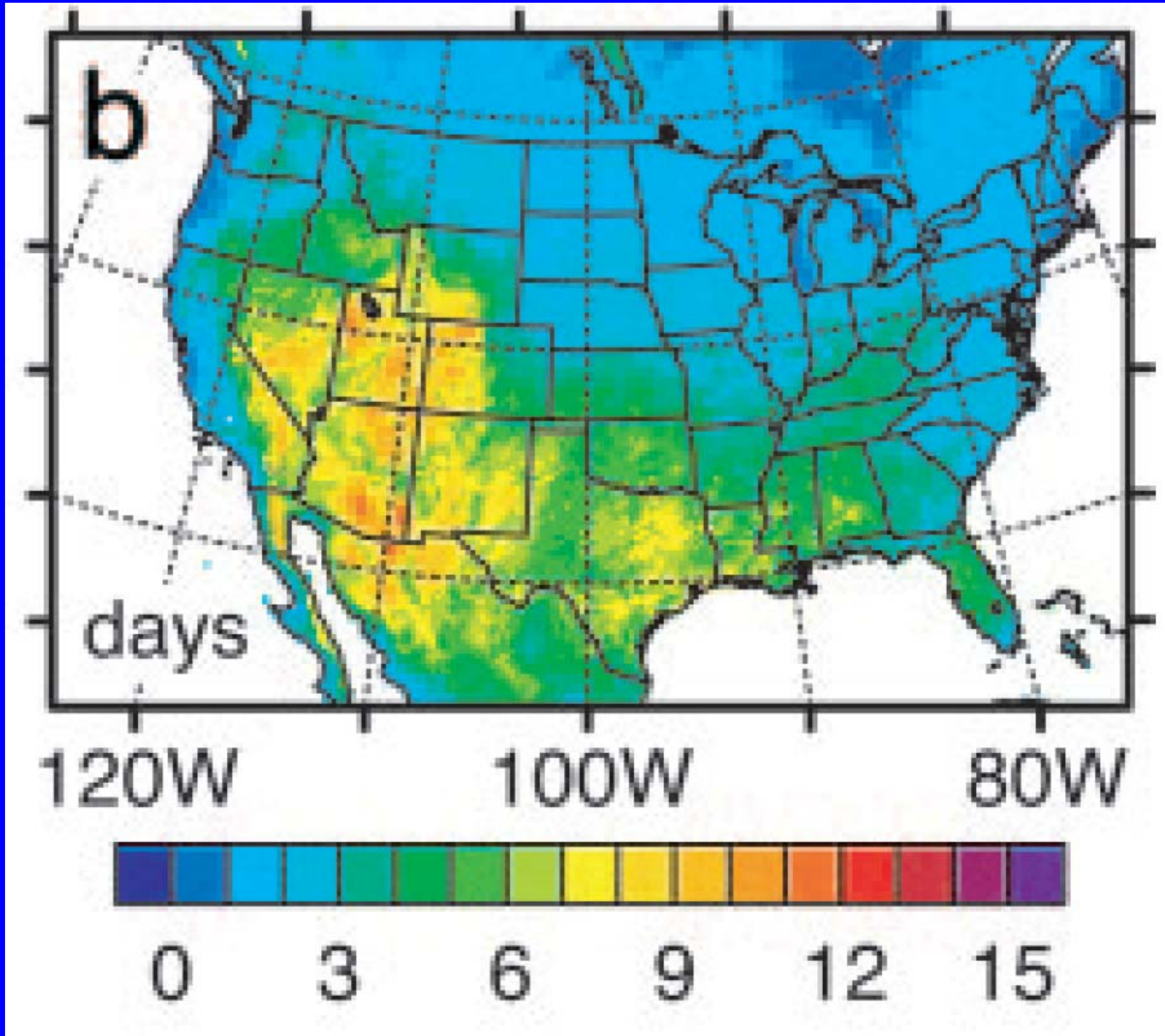
Mike Crimmins, University of Arizona



March is key month

What happens to El Niño?

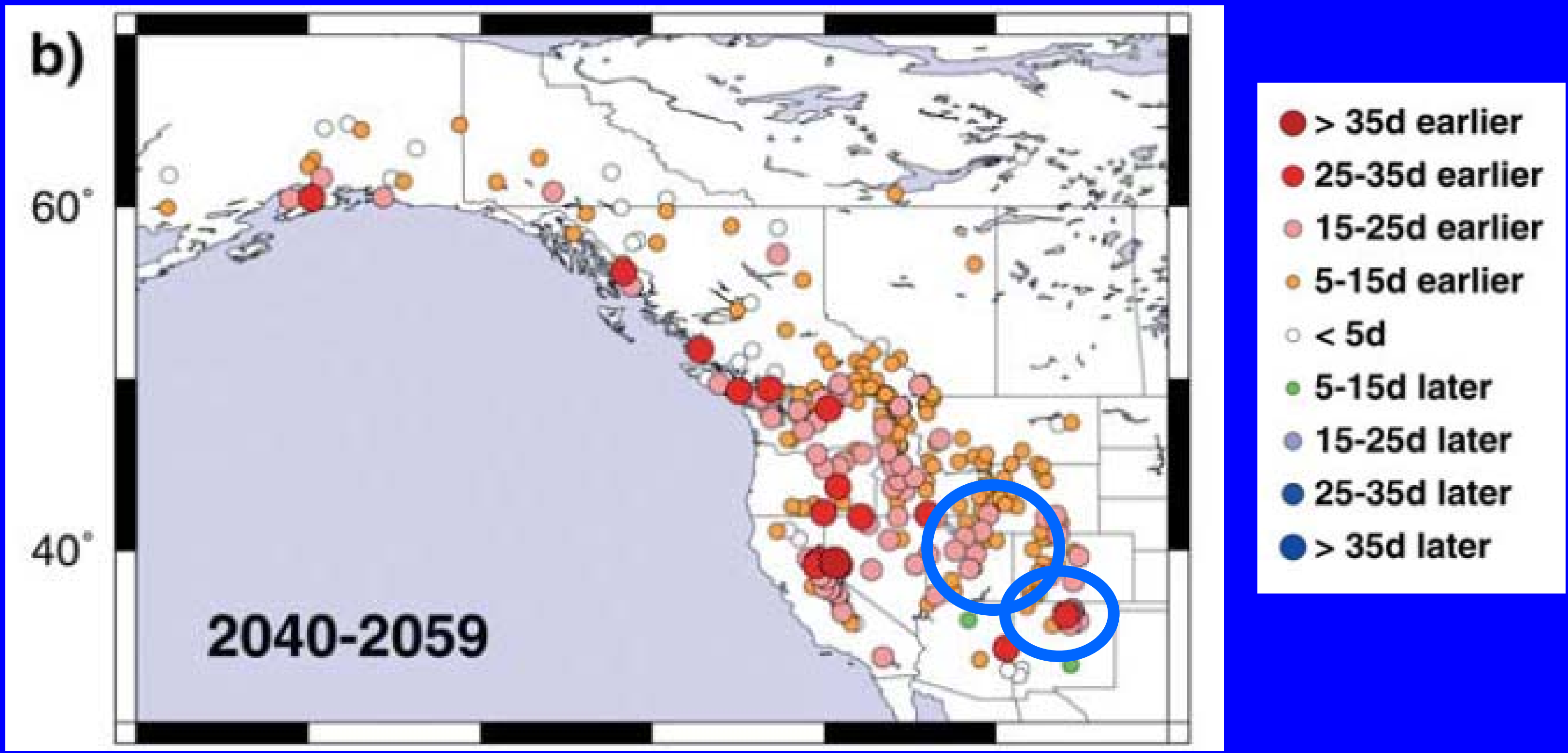
McAfee and Russell, 2008 – *Geophysical Research Letters*



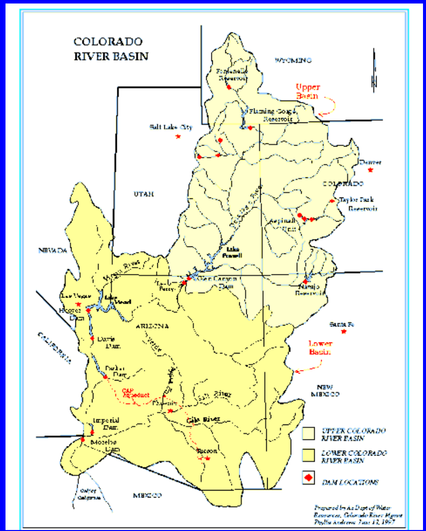
Longer Heat Waves

Diffenbaugh et al., 2005
Proceedings of the National Academy of Science

Earlier Peak Streamflow



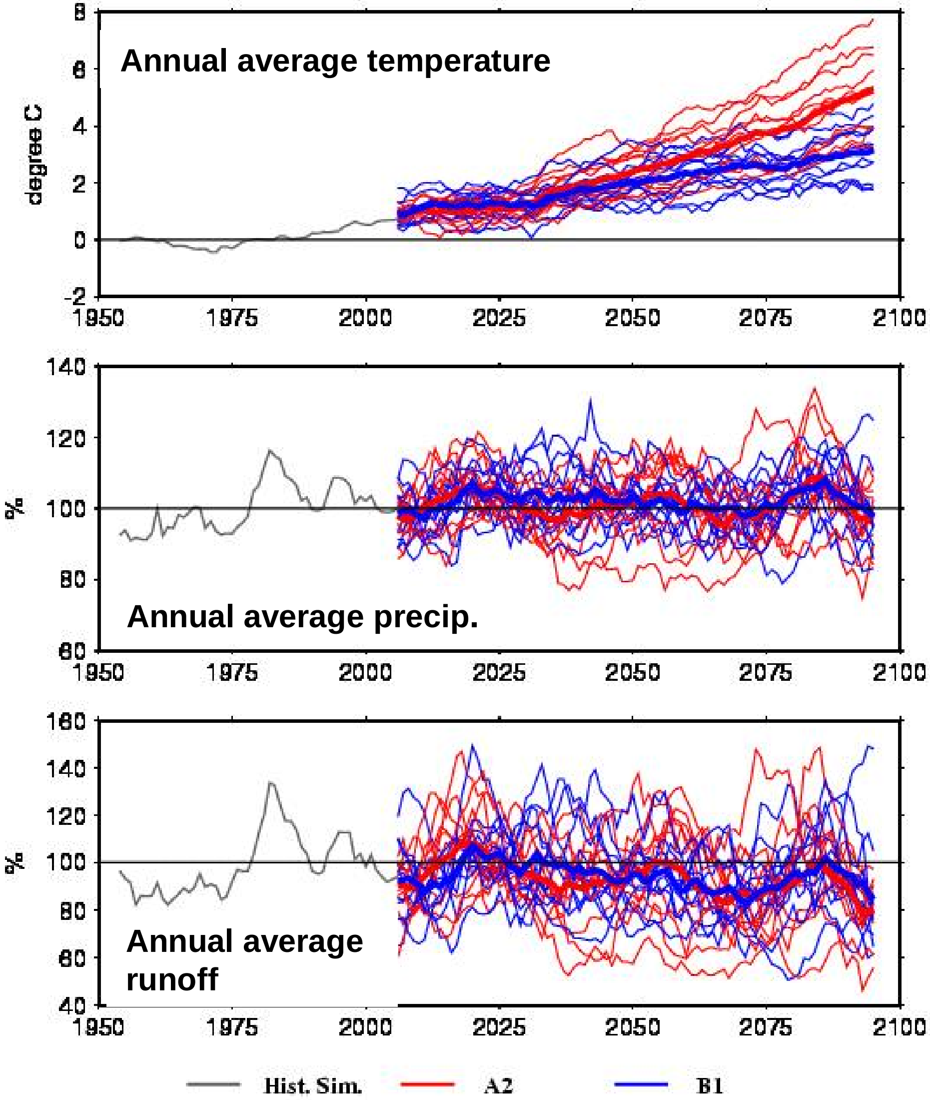
From: Stewart et al., 2004 *Climatic Change*



6-7% Decrease in runoff, 2040-2069
8-11% Decrease in runoff, 2070-2099
Decreases in hydropower
Treaty implications

11 models and 2 emissions scenarios downscaled to the Colorado River Basin

9-year running means expressed as departures from 1950-1999 means



Christensen & Lettenmaier, 2006

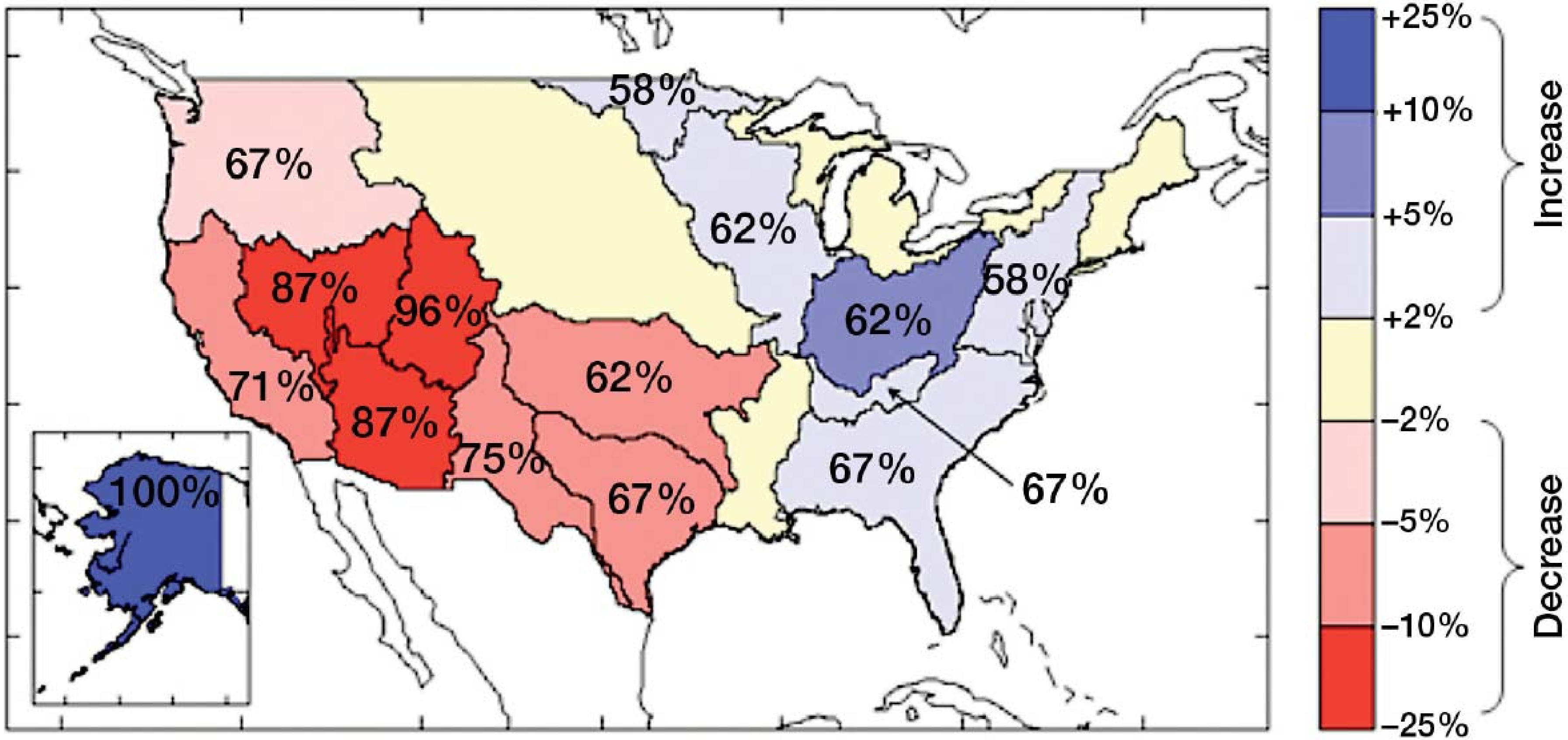


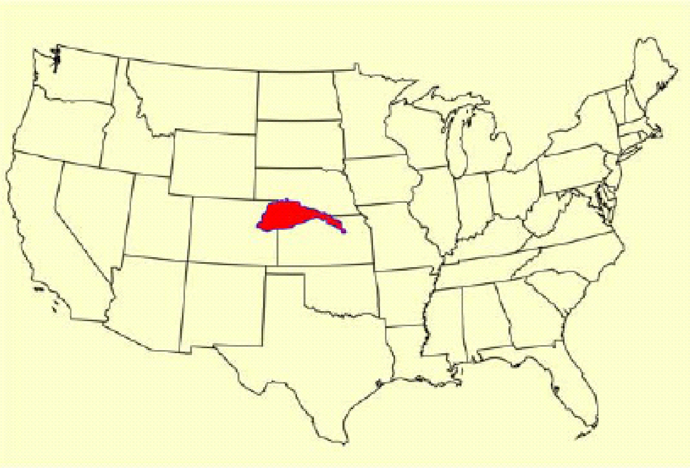
Figure 4.10 *Median changes in runoff interpolated to USGS water resources regions from Milly et al. (2005) from 24 pairs of GCM simulations for 2041-2060 relative to 1901-1970. Percentages are fraction of 24 runs for which differences had same sign as the 24-run median. Results replotted from Milly et al. (2005) by Dr. P.C.D. Milly, USGS.*

CCSP SAP 4.3 – www.climatescience.gov

Aquifer storage/baseflow change ratios

Republican River Basin:

3% depletion of groundwater storage led to 50% decline in baseflow



S. Earman, Scripps

(Data from Alley, 2005)

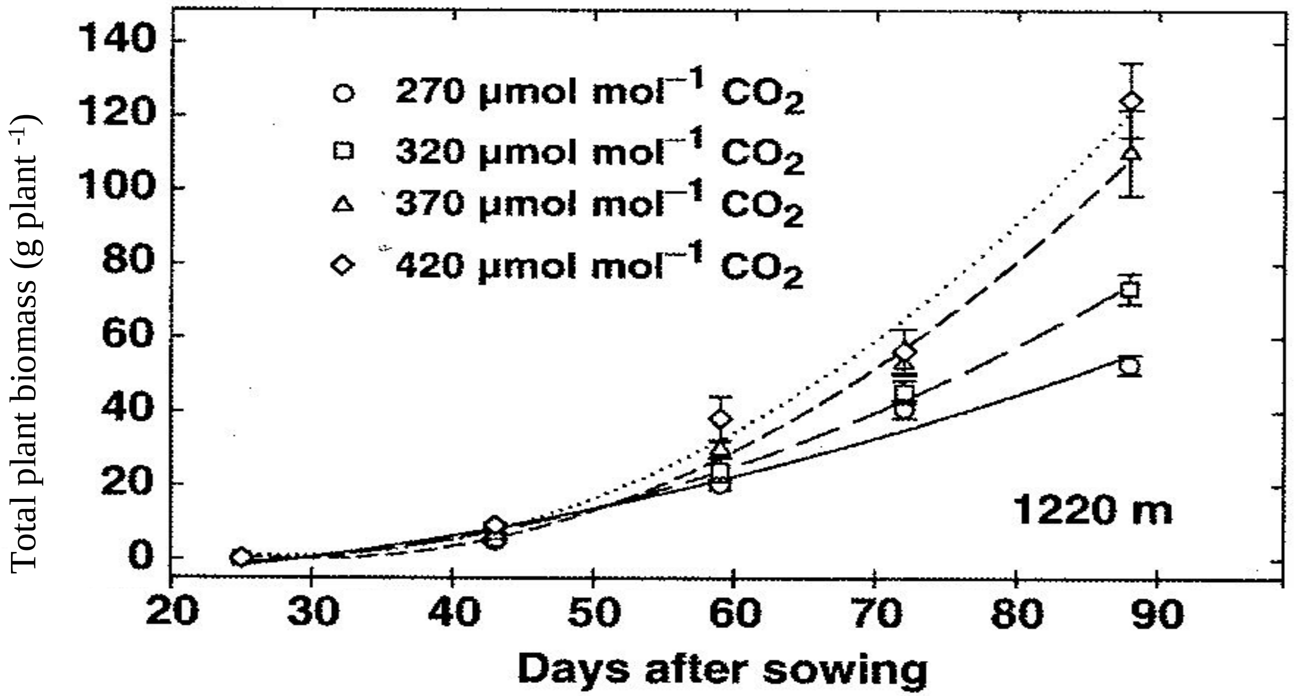
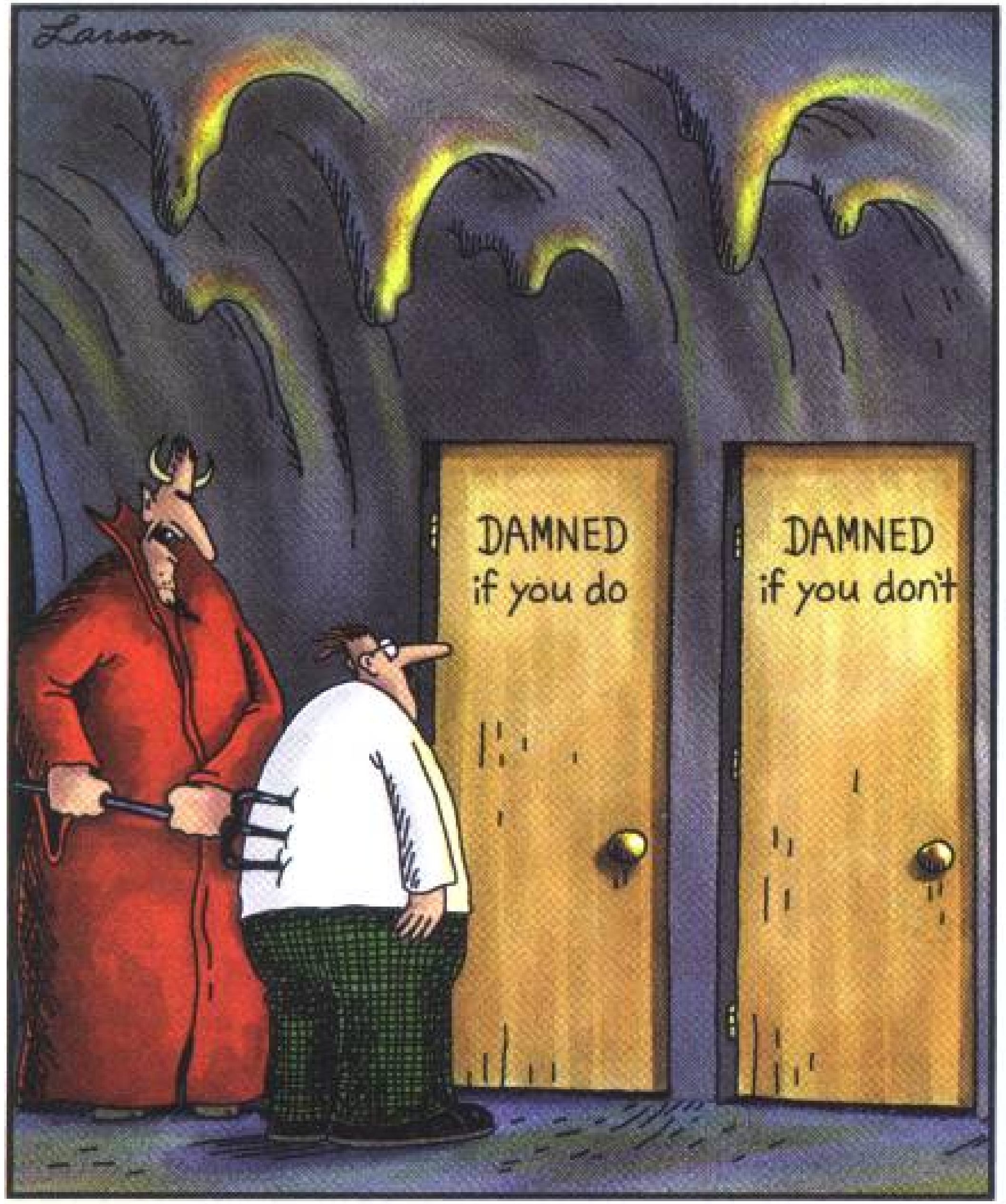


Fig. 1 Total biomass of cheatgrass (*Bromus tectorum* g per plant) over time (days after sowing, DAS) as a function of increasing [CO_2] for three populations collected at different elevations in northern Nevada. Significant [CO_2] differences were observed after 59 DAS. Bars are ± SE.

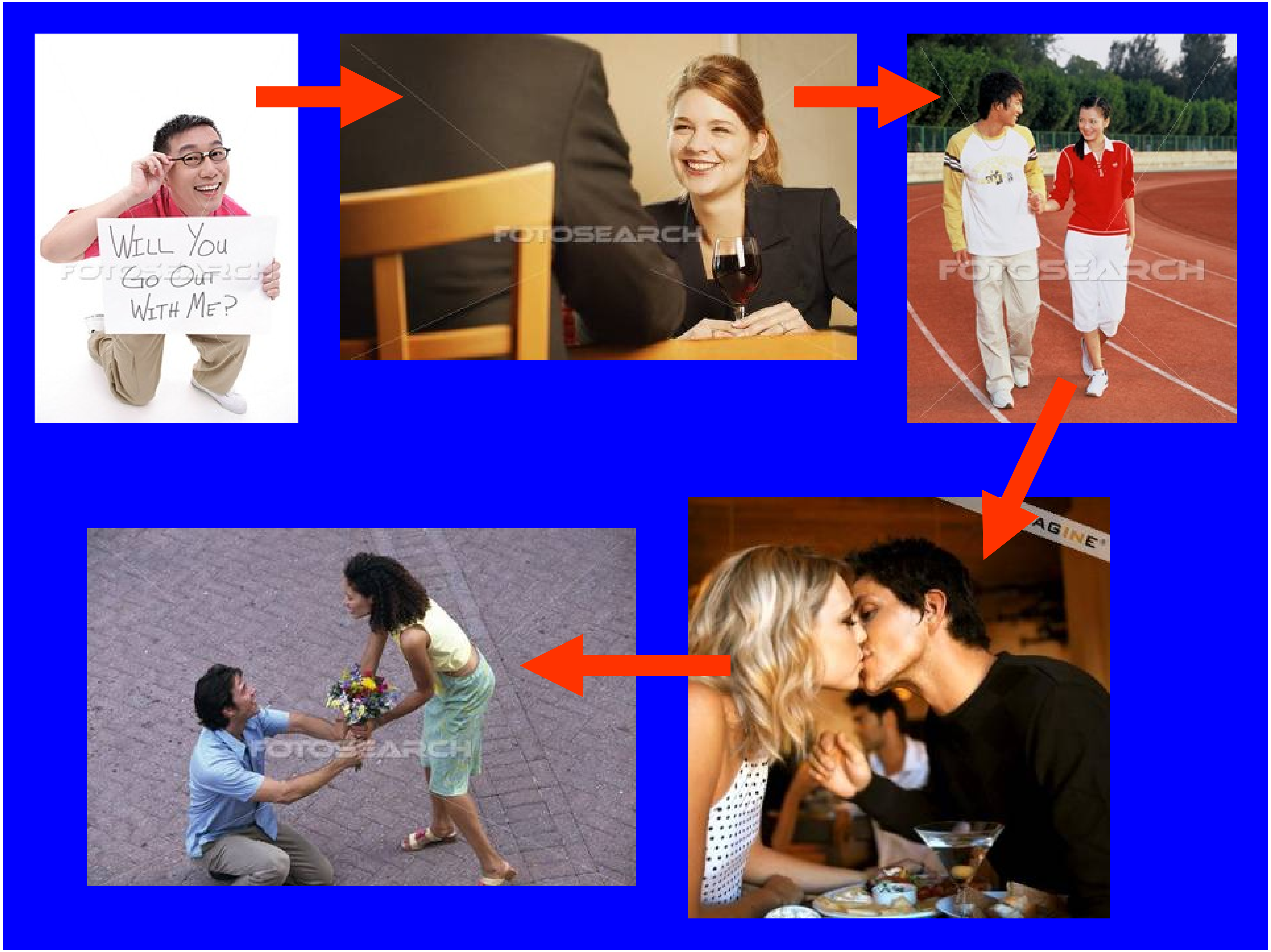
Ziska, Reeves and Blank, 2005. The impact of recent increases in atomospheric CO_2 on biomass production and vegetative retention of cheatgrass (*Bromus tectorum*): implications for fire disturbance. *Global Change Biology* 11: 1325-1332.

Decision Makers' Needs and Applications of Hydrological Modeling

What options do managers have?



"C'mon, c'mon—it's either one or the other."

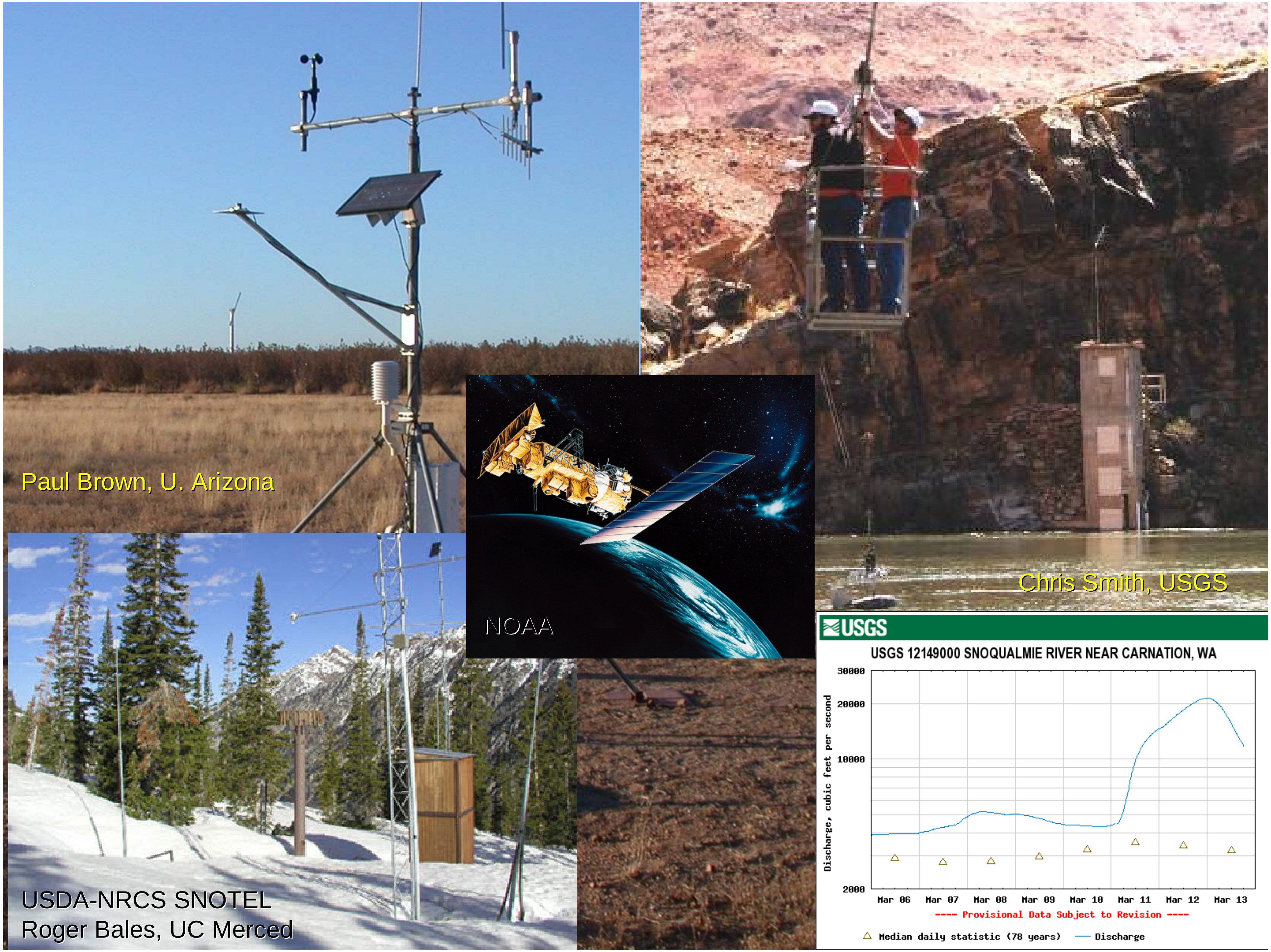

WILL YOU GO OUT WITH ME?

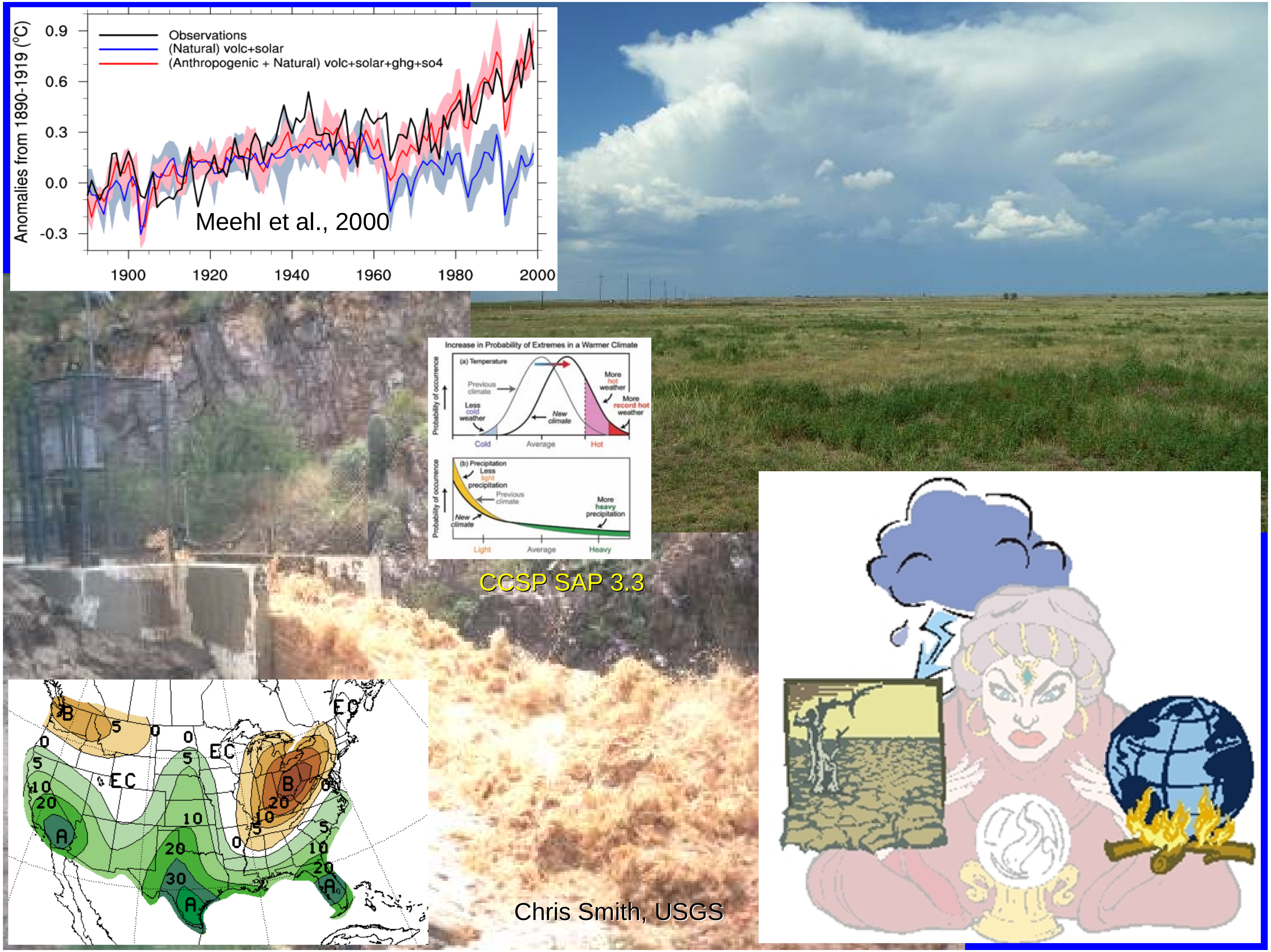
What We Heard

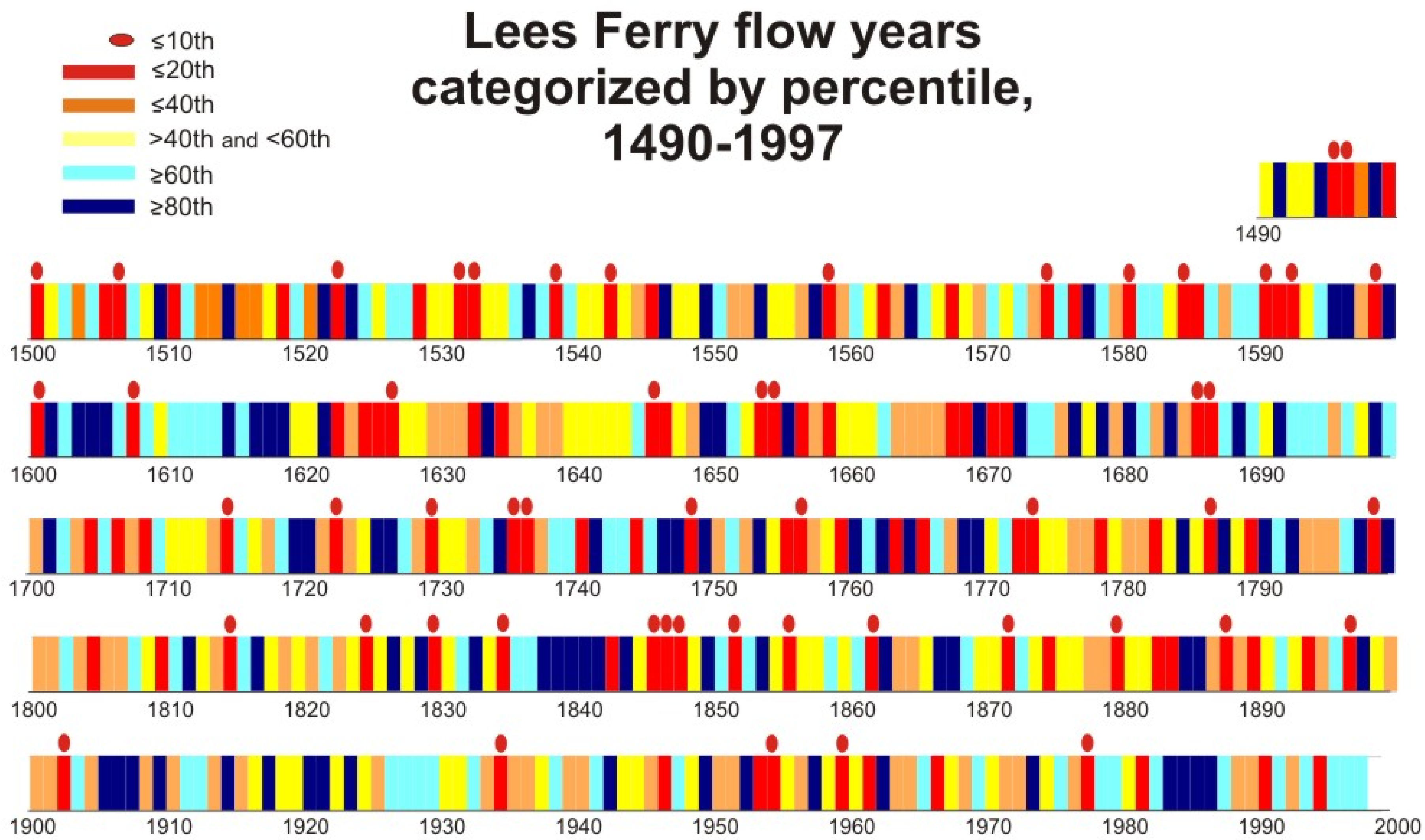
- **Monitoring**
- **Climate prediction**
- **Engineering**
- **Energy-water nexus**
- **Decision support**

Workshop on
Climate Change
Agenda
Adaptation for Water Managers

http://azwaterinstitute.org/workshops.html

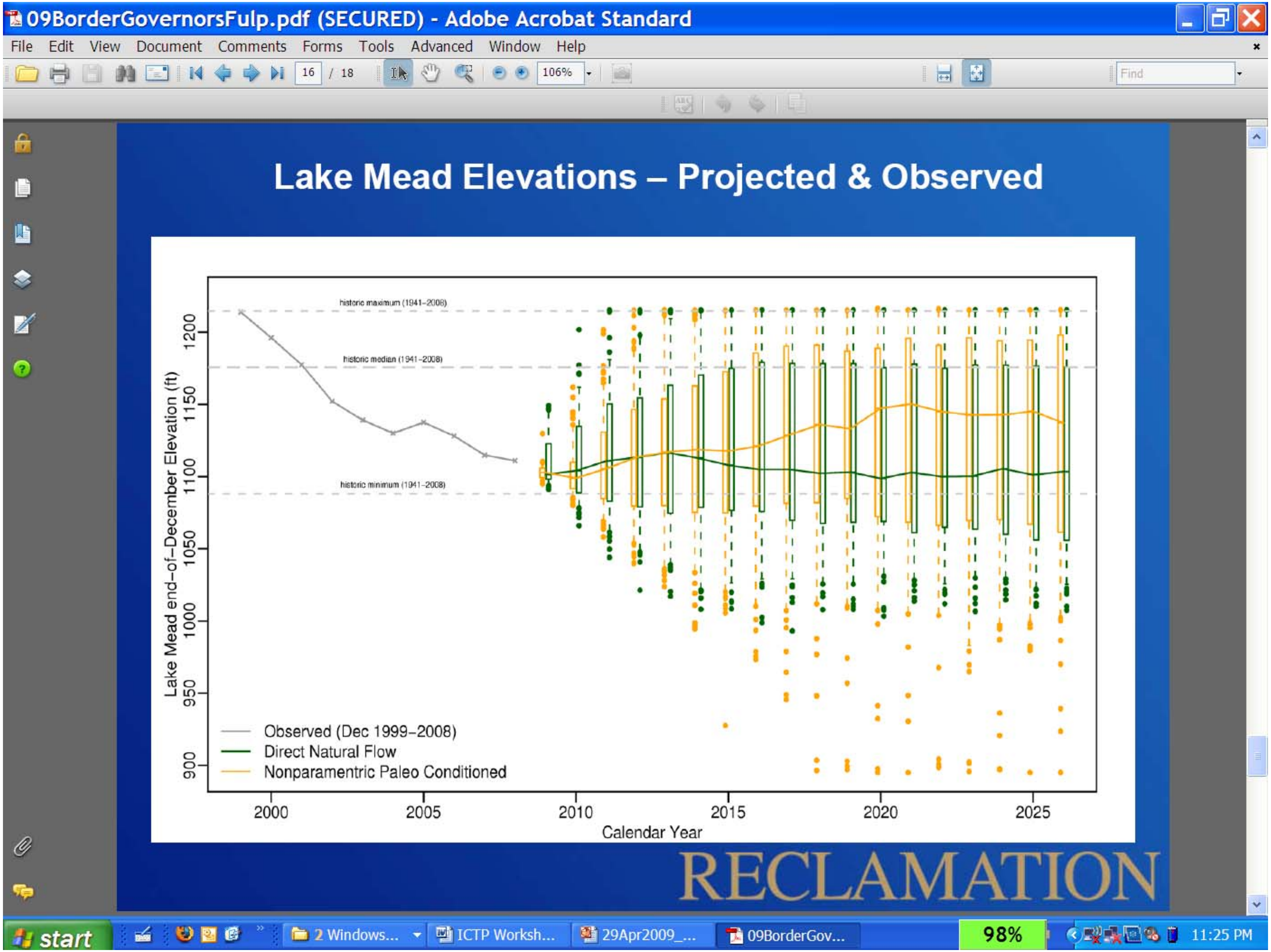

Paul Brown, U. Arizona
Chris Smith, USGS
NOAA
USDA-NRCS SNOTEL
Roger Bales, UC Merced
USGS
USGS 12149000 SNOQUALMIE RIVER NEAR CARNATION, WA
Discharge, cubic feet per second
30000
20000
10000
2000
Mar 06
Mar 07
Mar 08
Mar 09
Mar 10
Mar 11
Mar 12
Mar 13
---- Provisional Data Subject to Revision ----
Median daily statistic (78 years)
Discharge

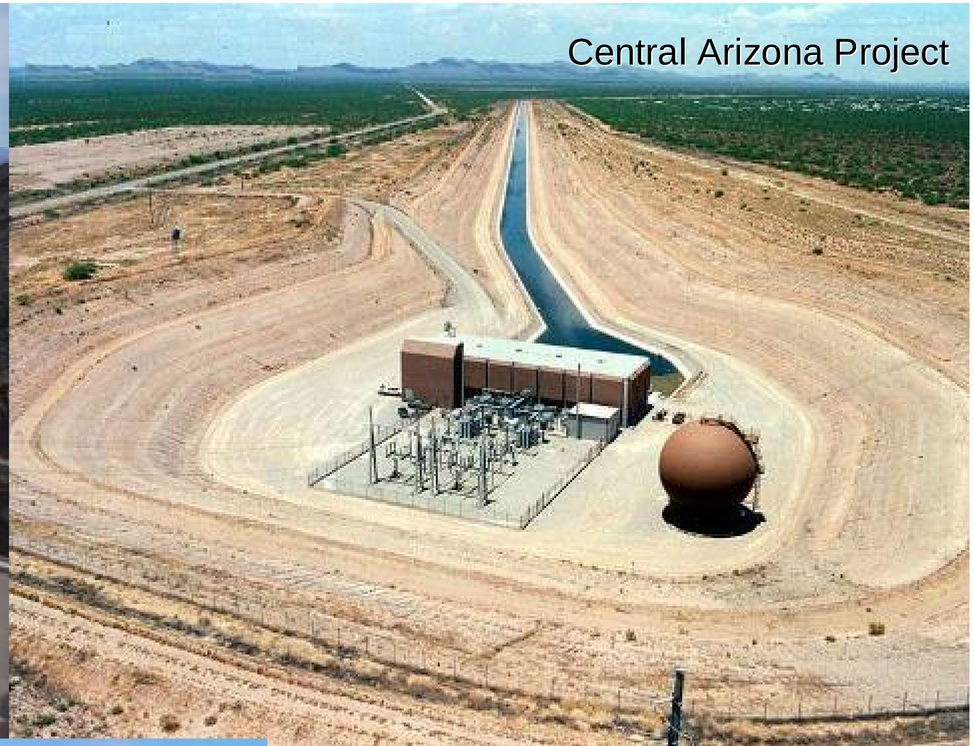

Observations
(Natural) volc+solar
(Anthropogenic + Natural) volc+solar+ghg+so4
Anomalies from 1890-1919 (°C)
0.9
0.6
0.3
0.0
-0.3
1900
1920
1940
1960
1980
2000
Meehl et al., 2000
Increase in Probability of Extremes in a Warmer Climate
(a) Temperature
Previous climate
Less cold weather
New climate
More hot weather
More record hot weather
Probability of occurrence
Cold
Average
Hot
(b) Precipitation
Less light precipitation
Previous climate
New climate
More heavy precipitation
Light
Average
Heavy
CCSP SAP 3.3
Chris Smith, USGS
B
5
0
EC
10
20
30
A



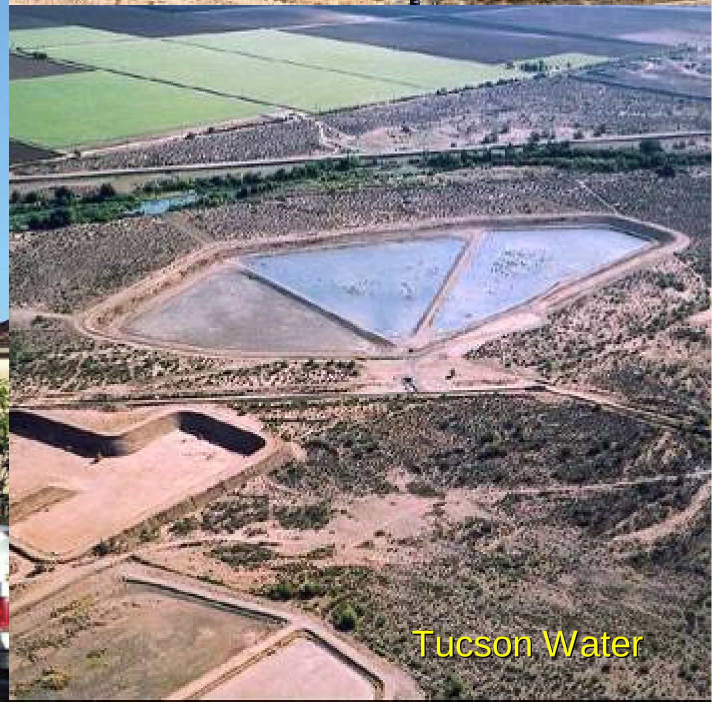
The sequences of years and the distribution of extreme events or runs of wet or dry years is variable from century to century.

Connie Woodhouse, University of Arizona


09BorderGovernorsFulp.pdf (SECURED) - Adobe Acrobat Standard
File Edit View Document Comments Forms Tools Advanced Window Help
16 / 18
106%
Find
Lake Mead Elevations – Projected & Observed
historic maximum (1941–2008)
historic median (1941–2008)
historic minimum (1941–2008)
Lake Mead end–of–December Elevation (ft)
900
950
1000
1050
1100
1150
1200
Observed (Dec 1999–2008)
Direct Natural Flow
Nonparamentric Paleo Conditioned
2000
2005
2010
2015
2020
2025
Calendar Year
RECLAMATION
start
2 Windows...
ICTP Worksh...
29Apr2009_...
09BorderGov...
98%
11:25 PM


Central Arizona Project


ASCE

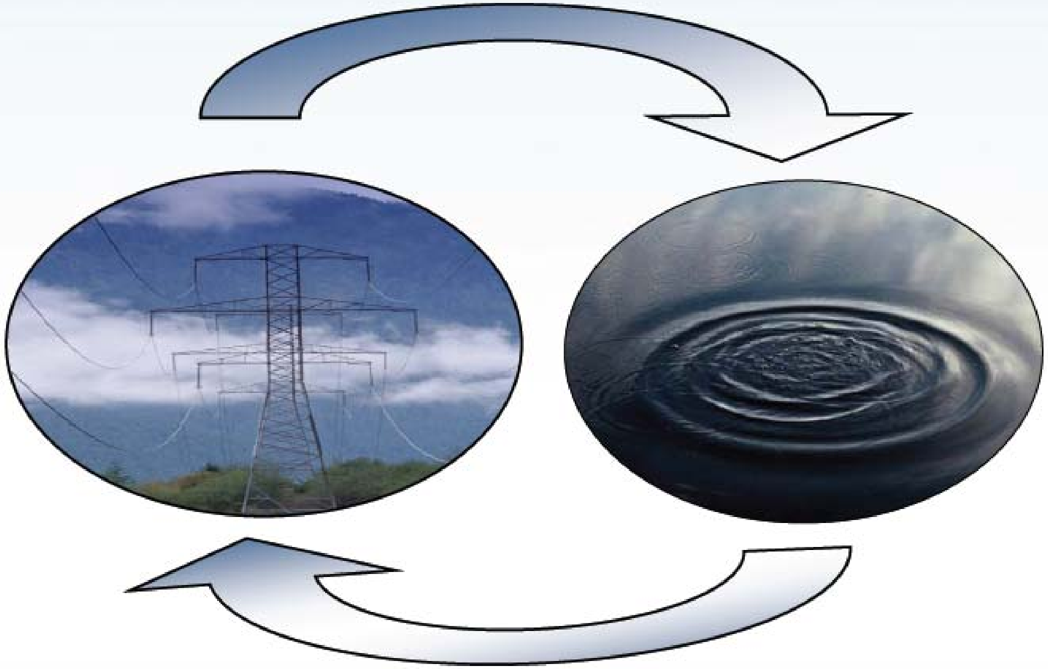

Tucson Water

Energy and Water are ... Inextricably linked

<u>Energy for Water</u> and <u>Water for Energy</u>

Energy and power production requires water:

- Thermoelectric cooling
- Hydropower
- Energy minerals extraction / mining
- Fuel Production (fossil fuels, H_2, biofuels/ethanol)
- Emission controls

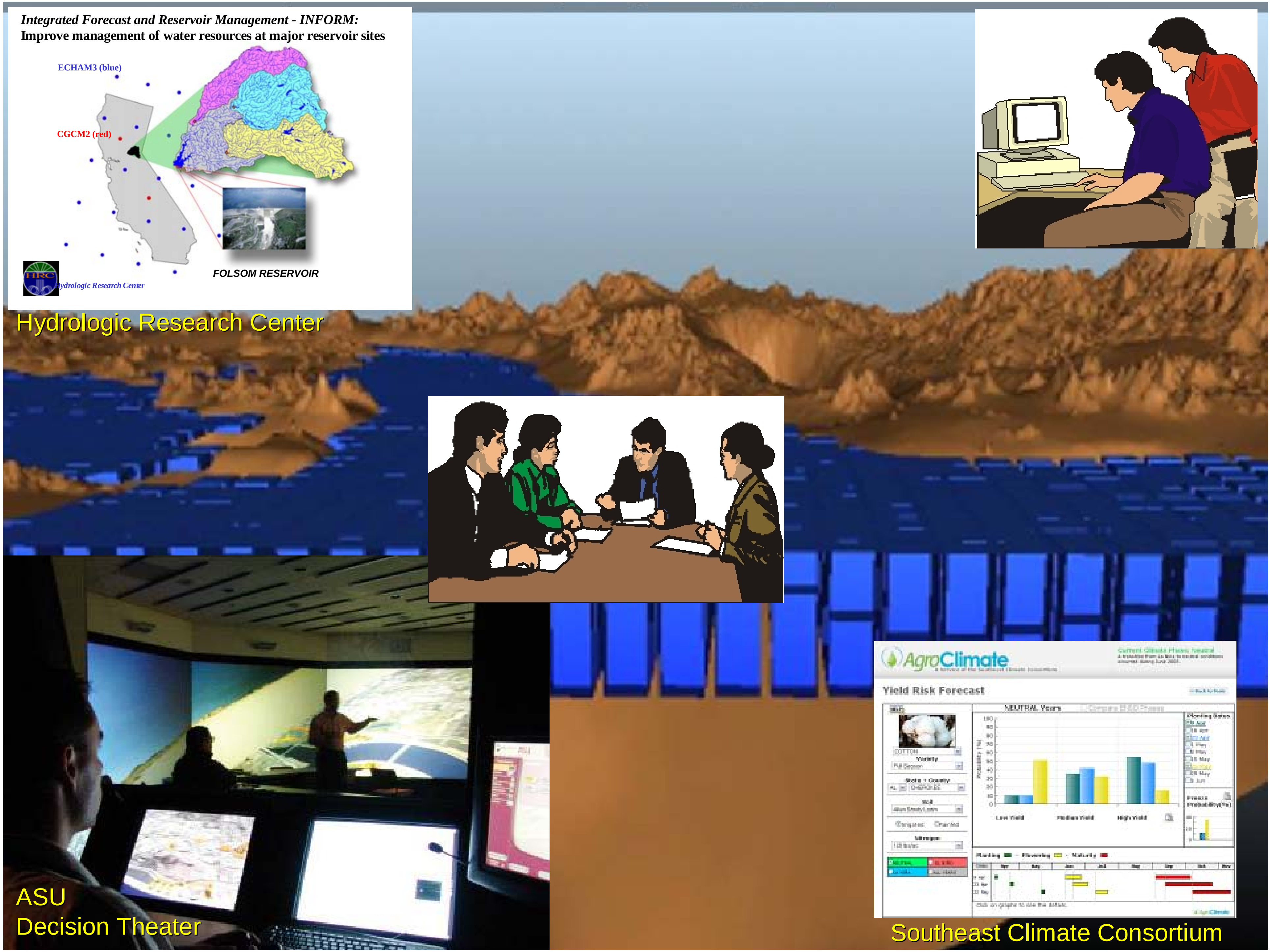


Water production, processing, distribution, and end-use requires energy:

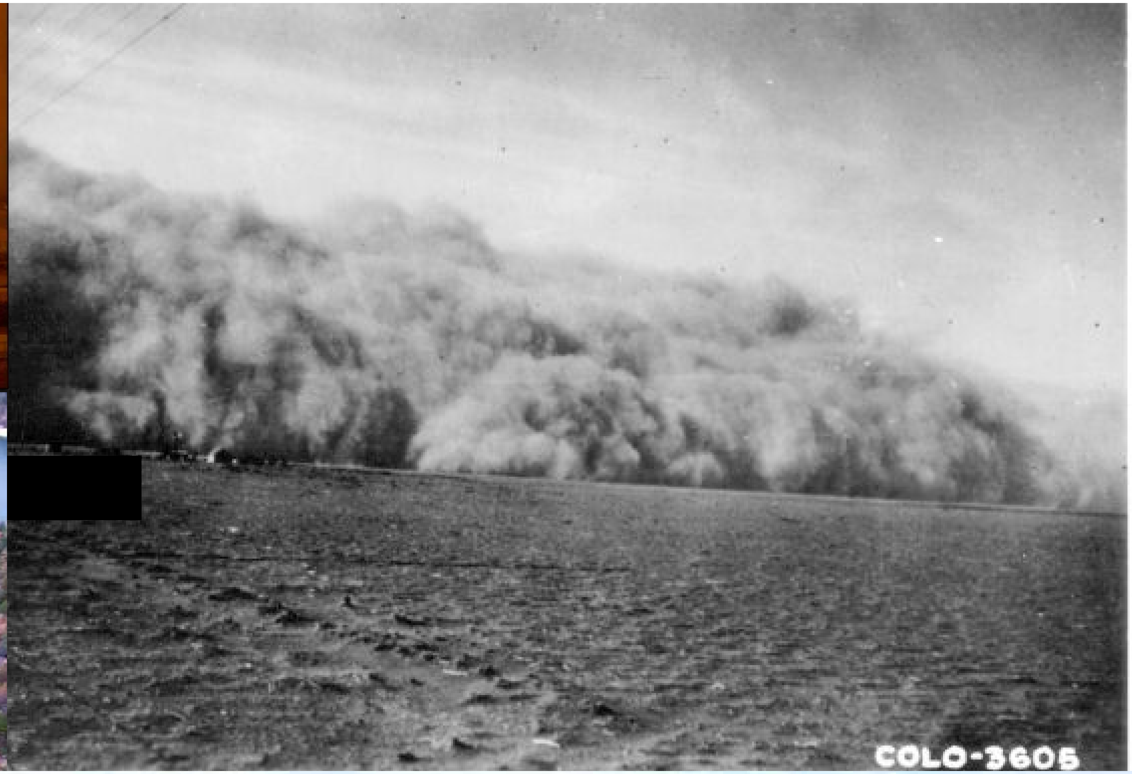
- Pumping
- Conveyance and Transport
- Treatment
- Use conditioning
- Surface and Ground water

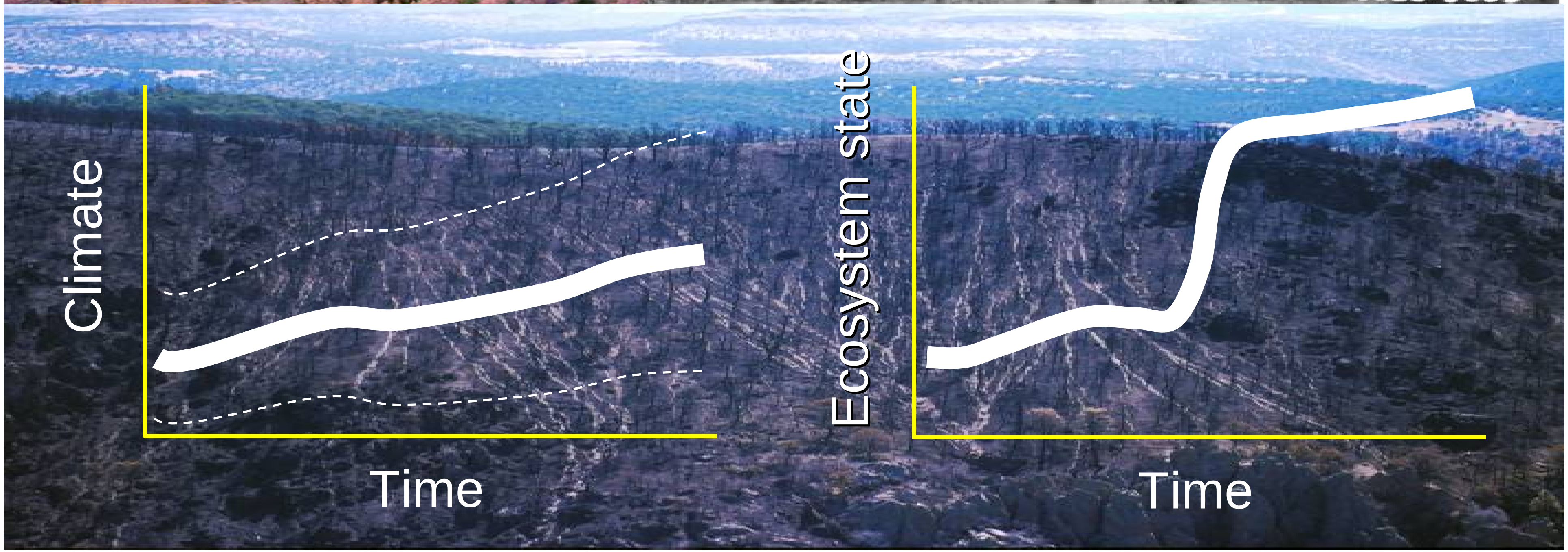
ENERGY and WATER

Mike Hightower, Sandia National Laboratory

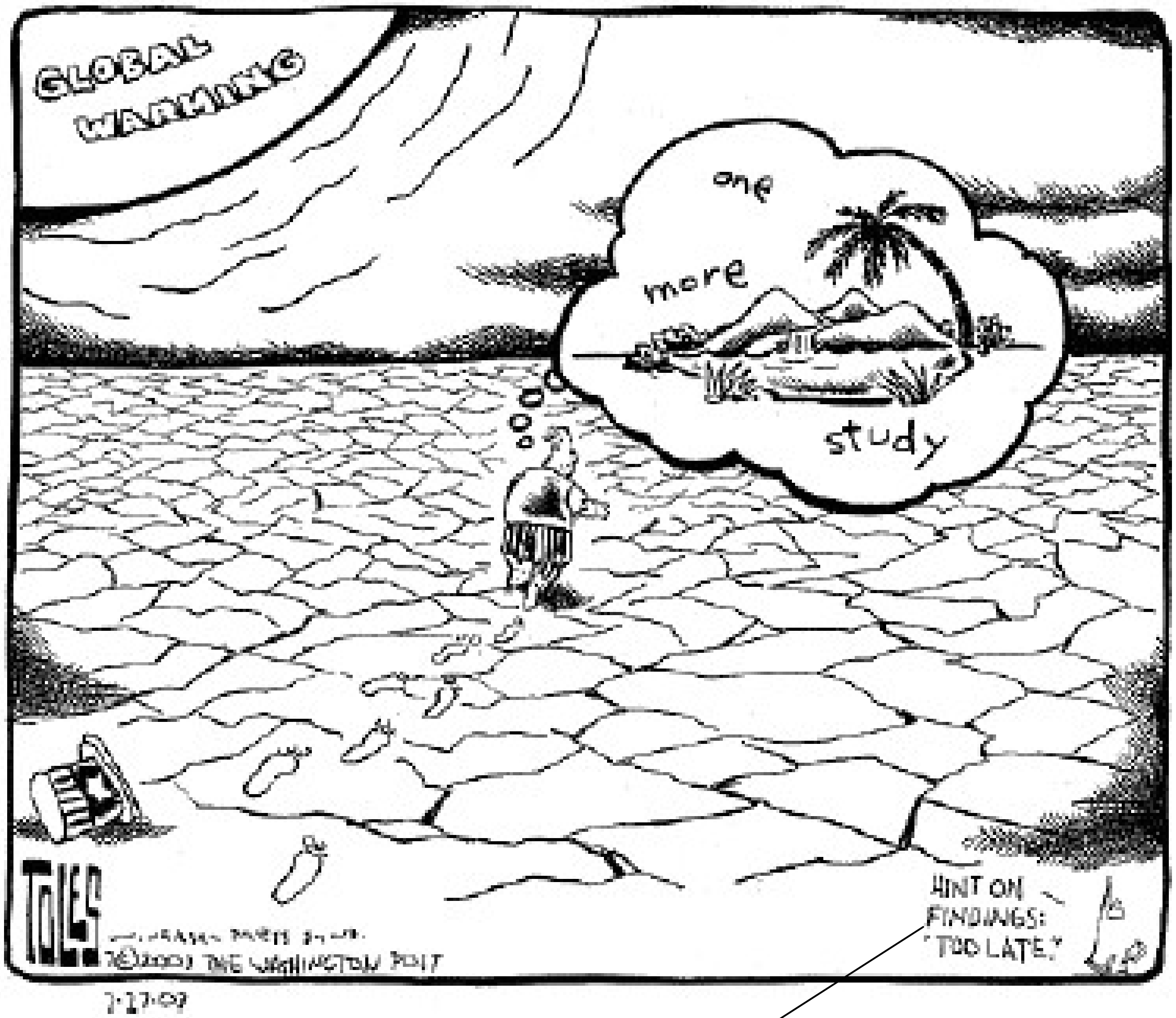


Integrated Forecast and Reservoir Management - INFORM:
Improve management of water resources at major reservoir sites
ECHAM3 (blue)
CGCM2 (red)
FOLSOM RESERVOIR
Hydrologic Research Center
Hydrologic Research Center
AgroClimate
Yield Risk Forecast
NEUTRAL Years
COTTON
Low Yield
Median Yield
High Yield
Click on graphs to see the details.
ASU
Decision Theater
Southeast Climate Consortium


COLO-3605


Climate
Time
Ecosystem state
Time

Summary and Opportunities for Applications of Hydrological Modeling



Hint on findings: “Too Late.”

Summary

- Semiarid North America will likely experience:
  - Increased temperature, longer heat waves
  - Greater water demand
  - Earlier snowmelt, earlier streamflow
  - Greater variability – drought, flood
  - Less reliable surface water supplies
  - More ecosystem disturbance and change
  - More evaporative stress

Summary

- **Opportunities for Hydrological Modelers:**
  - Improved integration of land surface changes
  - Estimates of runoff timing, hydrograph changes
  - Snowmelt and rain/snow fractional precipitation
  - Forecasting extremes: drought, flood, QPE
  - Interpolated precipitation, soil moisture, runoff
  - Integrated dynamic simulation modeling
    - Including social, economic, legal, ecosystem factors
  - Improved ET estimation
  - Groundwater–Surface water modeling
  - Working with decision makers

Gregg Garfin

Director for Science Translation and Outreach
Institute for Environment and Society
The University of Arizona

gmgarfin@email.arizona.edu
520-622-9016
www.ispe.arizona.edu

INSTITUTE FOR ENVIRONMENT AND SOCIETY
THE UNIVERSITY OF ARIZONA

CLIMAS
Climate Assessment Project for the Southwest

RISA
Regional Integrated Sciences and Assessments
Building Bridges Between Climate Sciences and Society