Glen Canyon Dam Adaptive Management Work Group
Agenda Item Information
August 29-30, 2007

Agenda Item

Climate Change Presentation

Action Requested

√ Information item only; we will answer questions but no action is requested.

Presenter

Dr. Roger Pulwarty, Physical Scientist, National Oceanic and Atmospheric Administration

Previous Action Taken

N/A

Relevant Science

N/A

Background Information

The Monitoring and Research Plan to Support the GCDAMP that was approved by that AMWG in December 2006 as a "working document" identifies the effects of climate change and drought as a critical research and monitoring need outside the Colorado River Ecosystem. The MRP states:

> "Long-term drought and climate change have significant implications for decisions about future water management and hydropower production in the Colorado River Basin and the conservation of natural resources in Grand Canyon. Run-off in 2000–4 in the upper Colorado River Basin was the lowest in the period of record; Lake Powell is currently (2007) less than 50% full…. Water managers increasingly need predictive capability for climate change and related drought forecasting over annual-to-decadal time spans. Continued climate change and long-term drought will have potentially significant implications for several identified strategies for the operation of GCD to attain a variety of GCDAMP goals (e.g., native fishes, sediment, cultural resources, and recreation).
>
> Under this research initiative, basin-scale climate studies will be conducted on how new emerging climate information could be used by water and other resource managers in the GCDAMP program. The specific focus will be on: (1) how climate forecast information could be used in decisions related to the operation of GCD and other Colorado River Storage Project operations, and (2) the role of climate variability and hydrological variance (upper basin runoff versus the flood frequency of major tributaries below GCD) in ecosystem responses and their relationship to operation of GCD. This study will be carried out in cooperation with the National Oceanic and Atmospheric Administration and the Bureau of Reclamation."

Dr. Roger Pulwarty of NOAA will present a summary of the latest scientific information concerning climate variability, climate change, and drought with emphasis on the Colorado River basin and the results of the recently released Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Dr.

Pulwarty will also present information on the National Integrated Drought Information System (NIDIS). The NIDIS Act of 2006 (PL 109-430) prescribes an interagency and interstate approach to drought monitoring, forecasting, and early warning. The goal of NIDIS is to improve the Nation's capacity to proactively manage drought-related risks, by providing those affected with the best available information and tools to assess the potential impacts of drought, and to better prepare for and mitigate the effects of drought. Major elements of NIDIS include:

- Consolidating physical, hydrological, and socio-economic data
- Integrating observation and monitoring networks
- Engaging stakeholders
- Developing simulation, risk assessment, and decision support tools
- Delivering standardized interactive products through the internet

Initial implementation of NIDIS will focus on several pilot regions including a specific pilot study evaluating water management issues associated with long-term (multi-year) drought in the Colorado River Basin.

Climate Change:The IPCC Fourth Assessment Report

What does it mean for the Colorado Basin?

National Integrated Drought Information System (NIDIS)

Roger S. Pulwarty

Physical Scientist and

Director, NIDIS Program

NOAA

Boulder CO

Western Water Assessment

NOAA-CIRES Climate Diagnostics Center

Colorado
University of Colorado at Boulder

The IPCC (as opposed to the UN Framework Convention) defines climate change as ***"any change in climate over time, whether due to natural variability or as a result of human activity"***

Structure of the IPCC 2007

WG1 - Climate Change: The Physical Science Basis

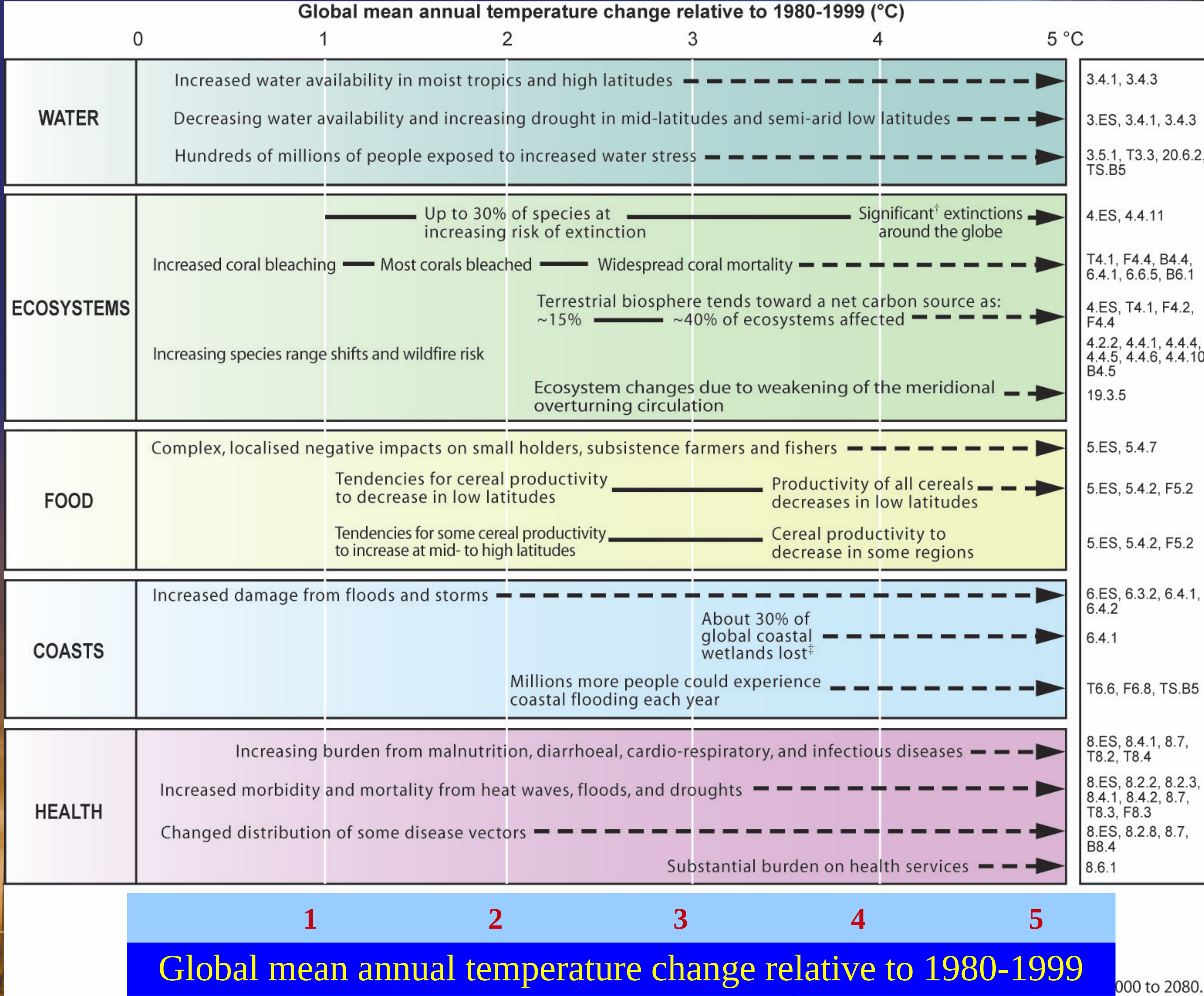
WG2 - Climate Change: Impacts, Adaptation and Vulnerability

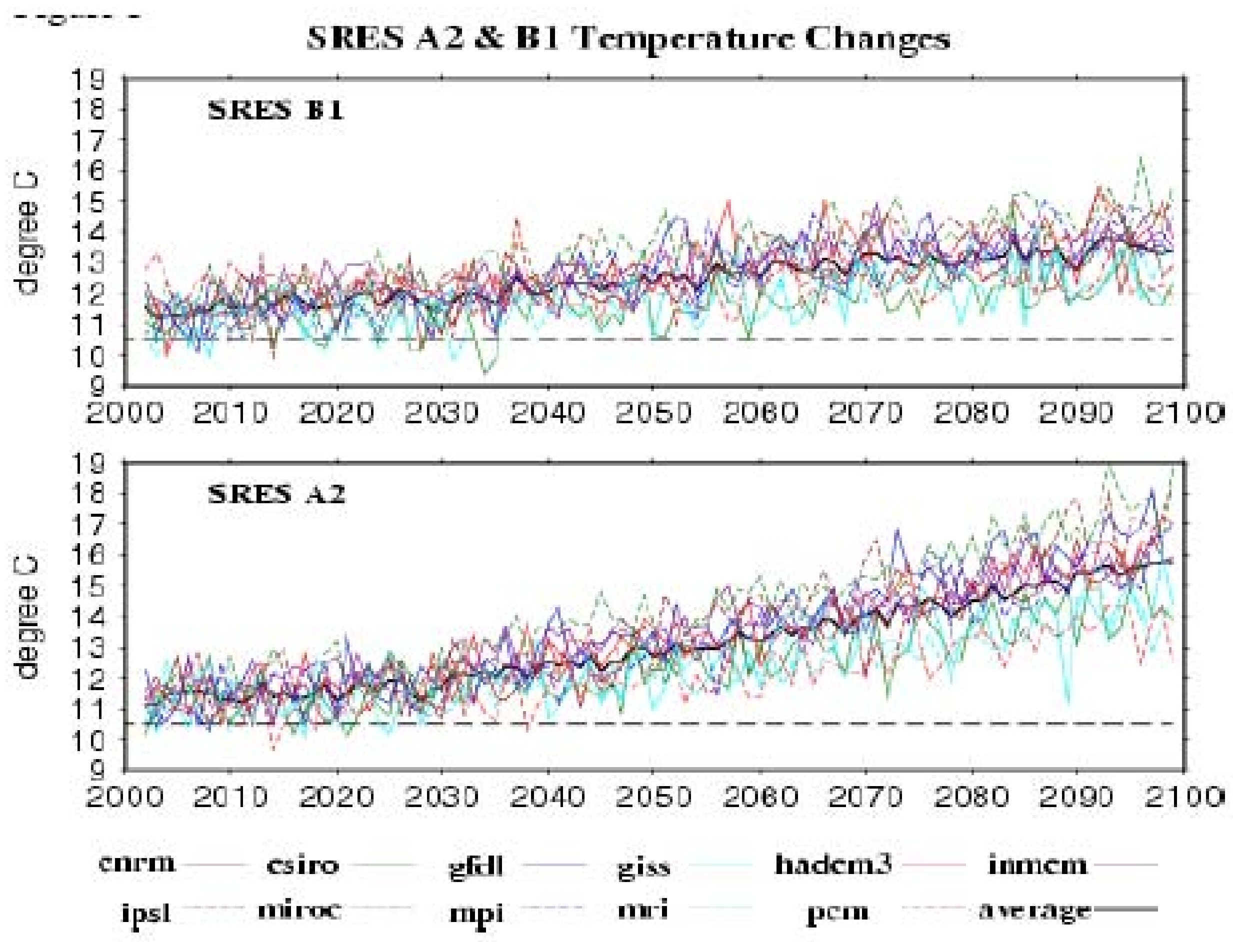
policy options, discount rates, emission scenarios,…..

Flowering dates, corals, coastal zone erosion Socio-economics

WG3: Mitigation of Climate Change

Three different working groups with quite distinct scientific purviews and required expertise. www.ipcc.ch

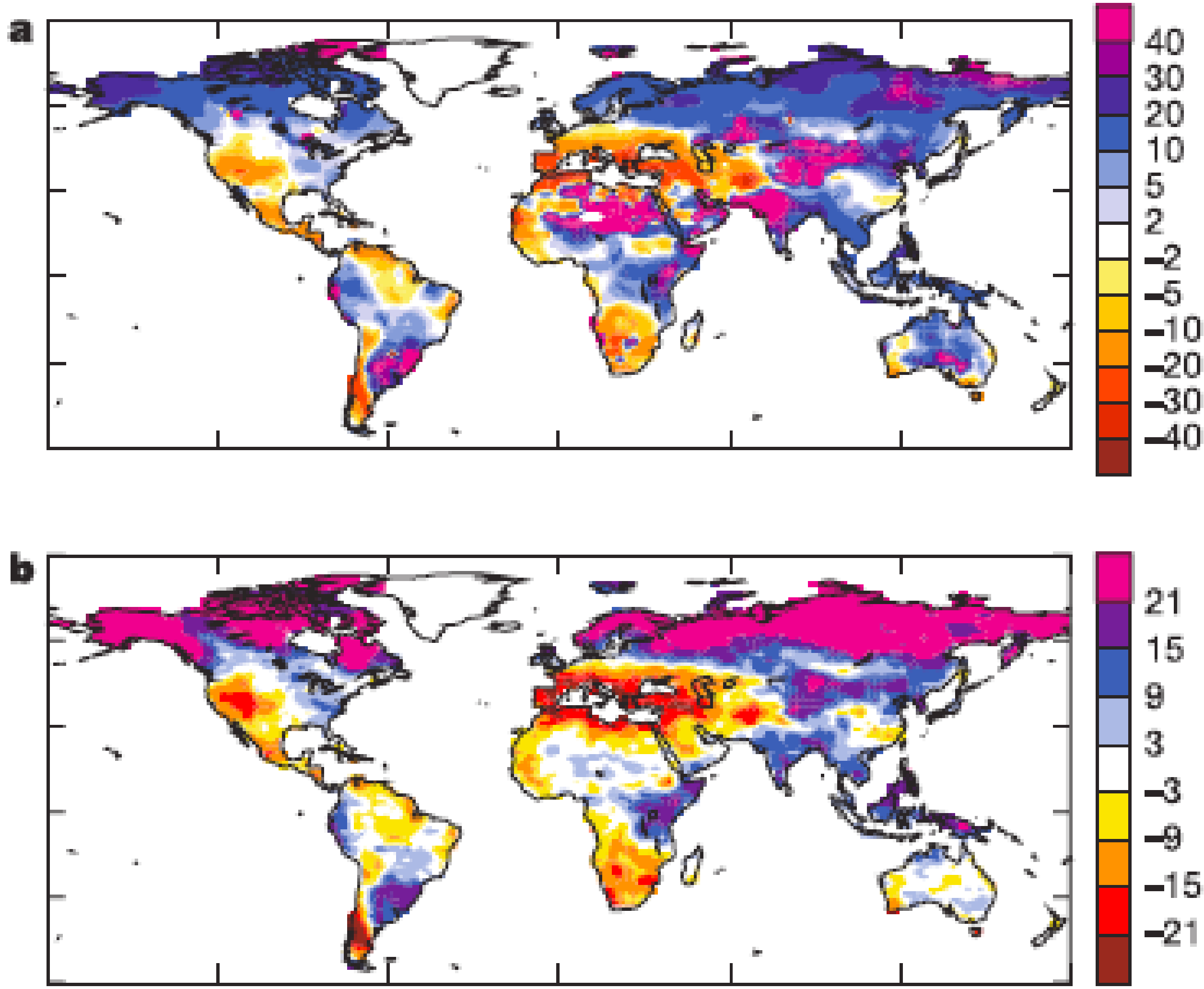

Global mean annual temperature change relative to 1980-1999 (°C)
0
1
2
3
4
5 °C
WATER
Increased water availability in moist tropics and high latitudes
3.4.1, 3.4.3
Decreasing water availability and increasing drought in mid-latitudes and semi-arid low latitudes
3.ES, 3.4.1, 3.4.3
Hundreds of millions of people exposed to increased water stress
3.5.1, T3.3, 20.6.2, TS.B5
ECOSYSTEMS
Up to 30% of species at increasing risk of extinction
Significant† extinctions around the globe
4.ES, 4.4.11
Increased coral bleaching
Most corals bleached
Widespread coral mortality
T4.1, F4.4, B4.4, 6.4.1, 6.6.5, B6.1
Terrestrial biosphere tends toward a net carbon source as:
~15%
~40% of ecosystems affected
4.ES, T4.1, F4.2, F4.4
Increasing species range shifts and wildfire risk
4.2.2, 4.4.1, 4.4.4, 4.4.5, 4.4.6, 4.4.10, B4.5
Ecosystem changes due to weakening of the meridional overturning circulation
19.3.5
FOOD
Complex, localised negative impacts on small holders, subsistence farmers and fishers
5.ES, 5.4.7
Tendencies for cereal productivity to decrease in low latitudes
Productivity of all cereals decreases in low latitudes
5.ES, 5.4.2, F5.2
Tendencies for some cereal productivity to increase at mid- to high latitudes
Cereal productivity to decrease in some regions
5.ES, 5.4.2, F5.2
COASTS
Increased damage from floods and storms
6.ES, 6.3.2, 6.4.1, 6.4.2
About 30% of global coastal wetlands lost‡
6.4.1
Millions more people could experience coastal flooding each year
T6.6, F6.8, TS.B5
HEALTH
Increasing burden from malnutrition, diarrhoeal, cardio-respiratory, and infectious diseases
8.ES, 8.4.1, 8.7, T8.2, T8.4
Increased morbidity and mortality from heat waves, floods, and droughts
8.ES, 8.2.2, 8.2.3, 8.4.1, 8.4.2, 8.7, T8.3, F8.3
Changed distribution of some disease vectors
8.ES, 8.2.8, 8.7, B8.4
Substantial burden on health services
8.6.1
1
2
3
4
5
Global mean annual temperature change relative to 1980-1999
000 to 2080.



SRES A2 & B1 Temperature Changes
SRES B1
SRES A2
degree C
19
18
17
16
15
14
13
12
11
10
9
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
cnrm
csiro
gfdl
giss
hadcm3
inmcm
ipsl
miroc
mpi
mri
pcm
average

Projections of Future Changes in Climate

- For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios.
- Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected.
- Earlier IPCC projections of 0.15 to 0.3 ^{o}C per decade can now be compared with observed values of 0.2 ^{o}C

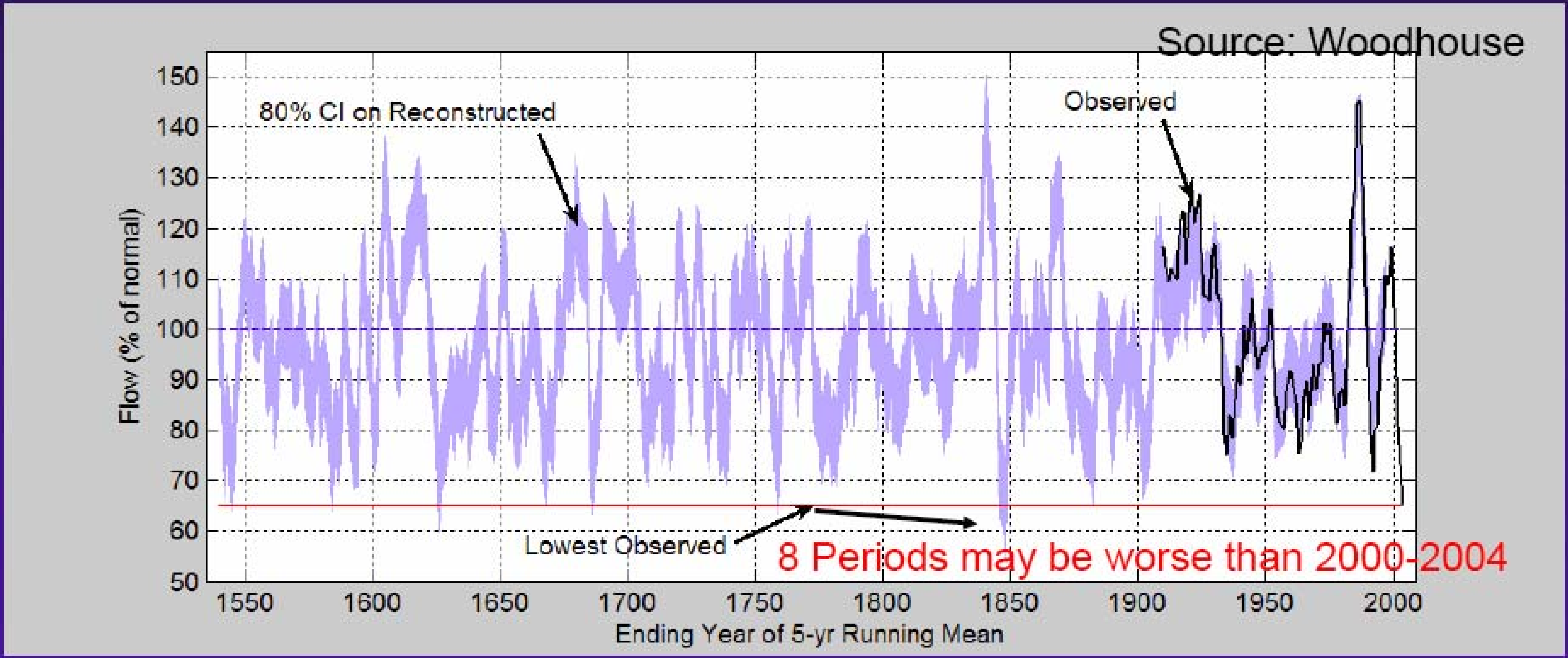


2041-2060

- Milly et al 2005
- IPCC 2007

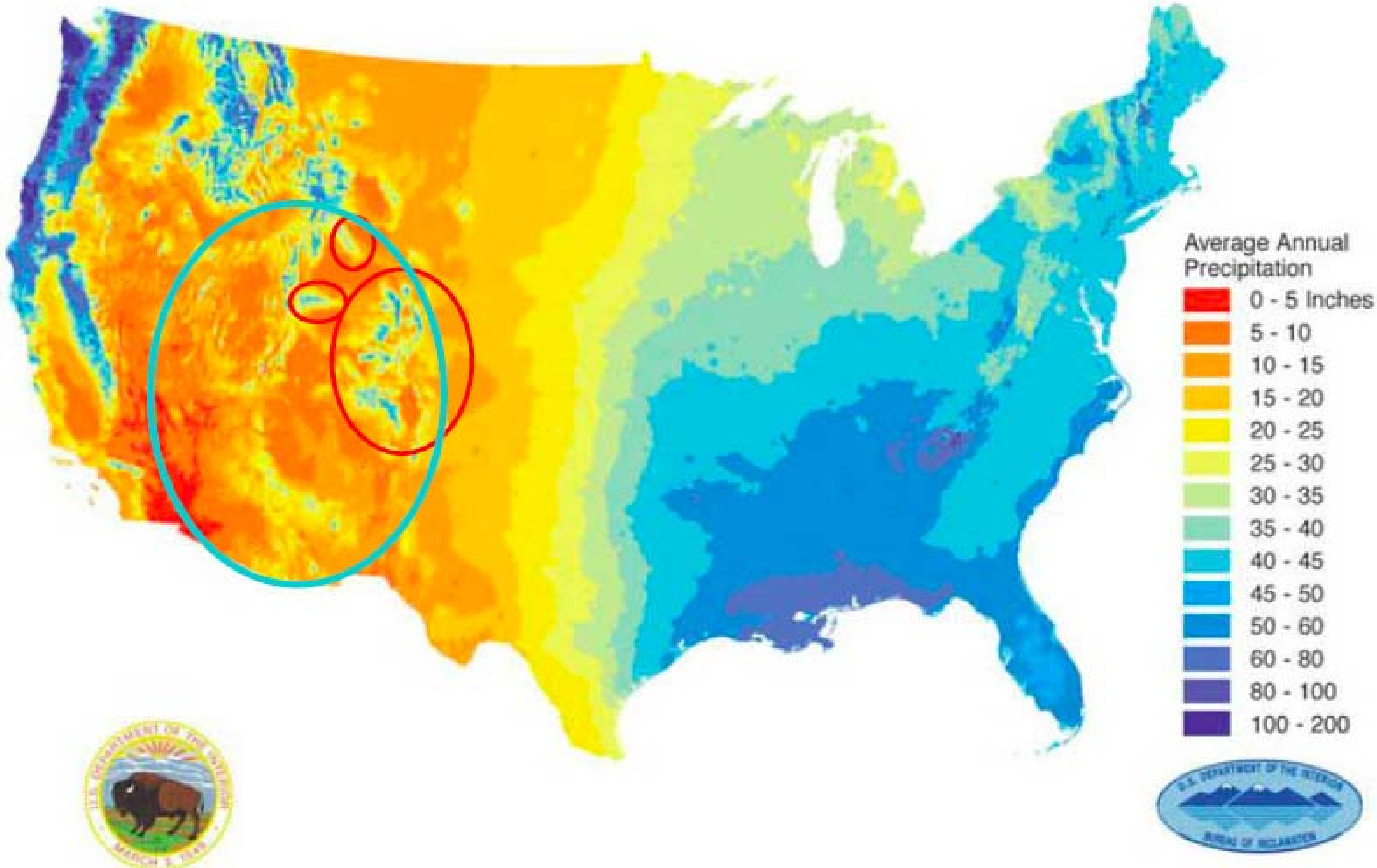
Lees Ferry Reconstruction, 1536-1997
5-Year Running Mean

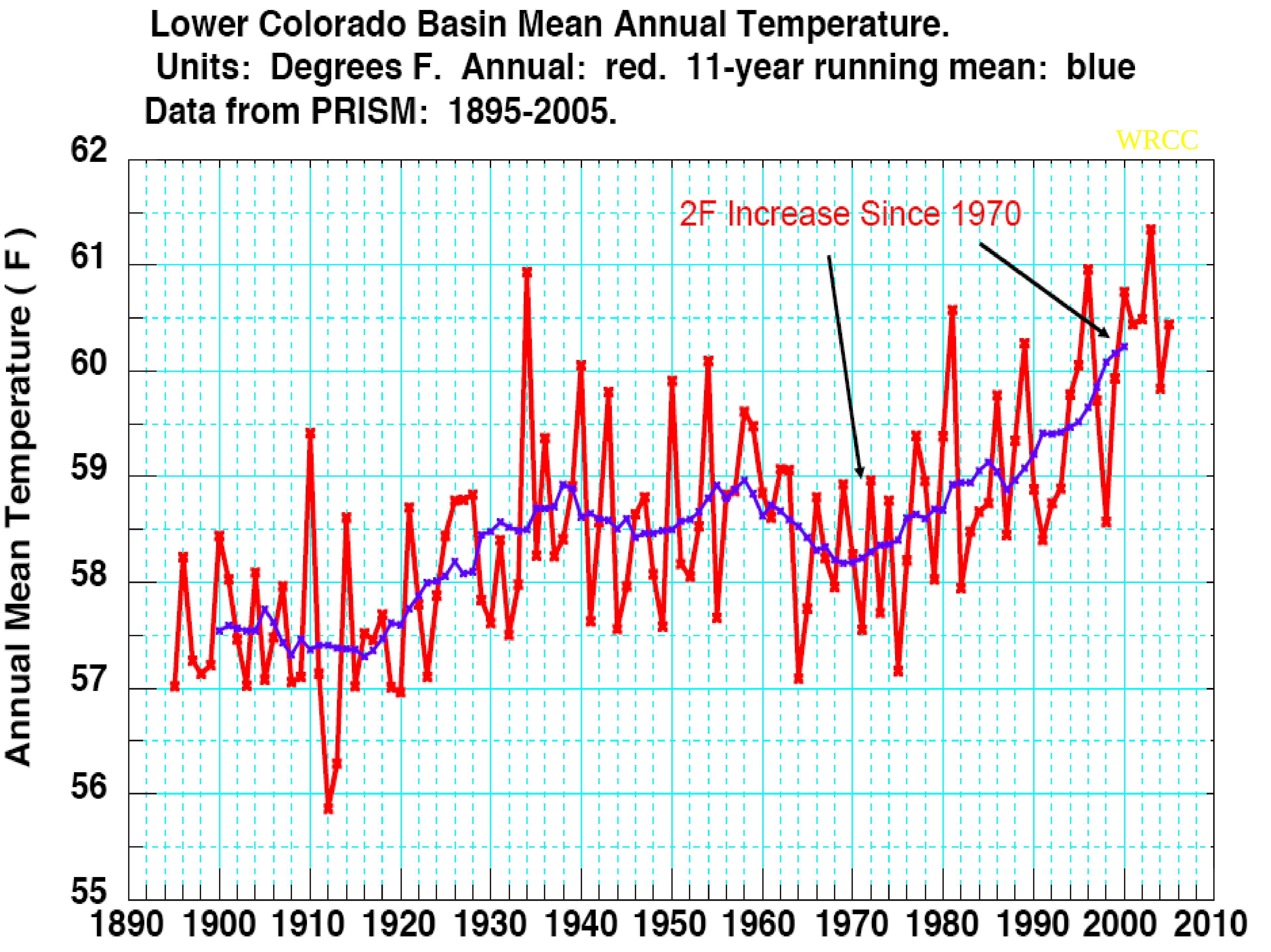
Assessing the 1999-2004 drought in a multi-century context

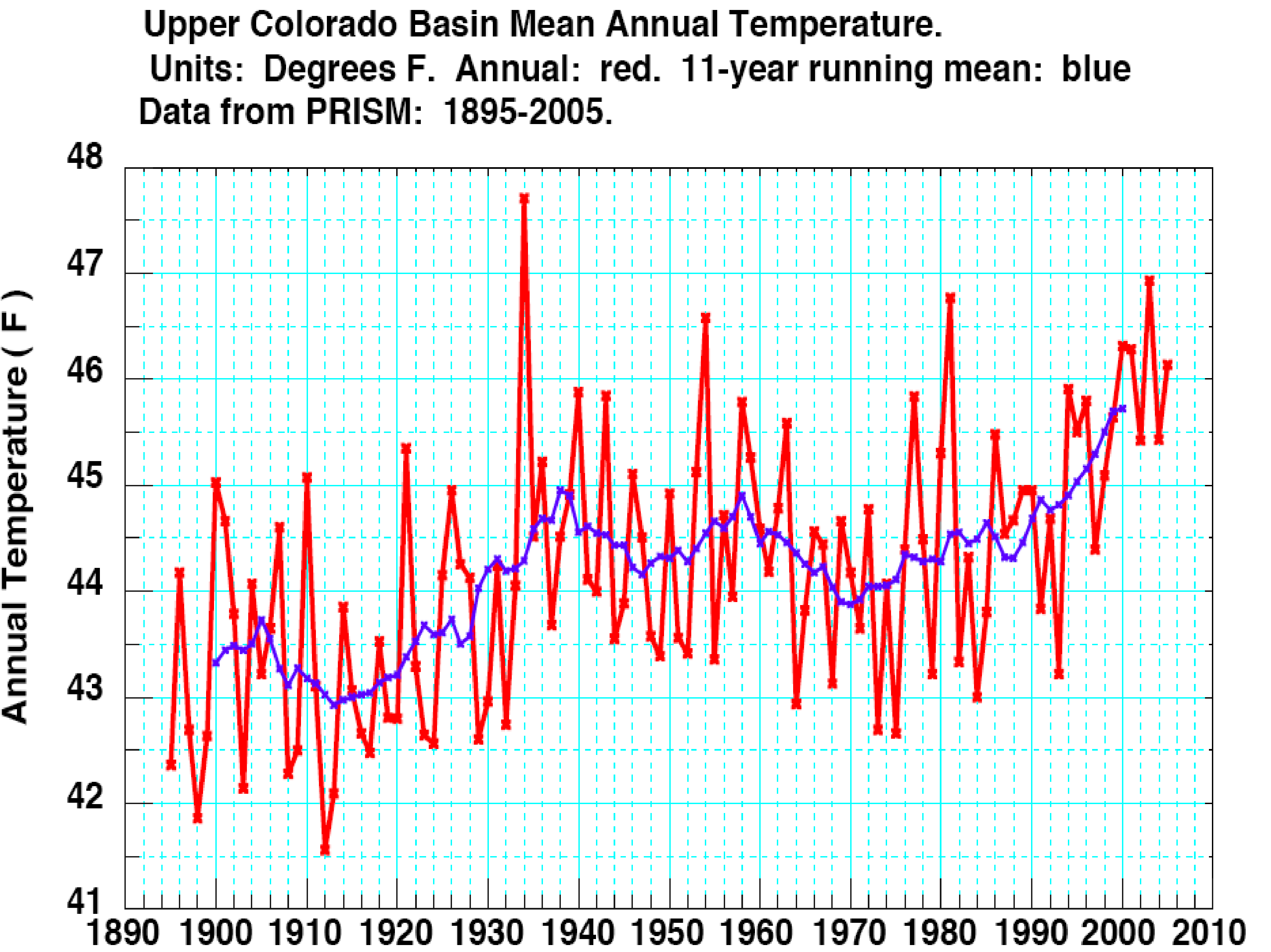


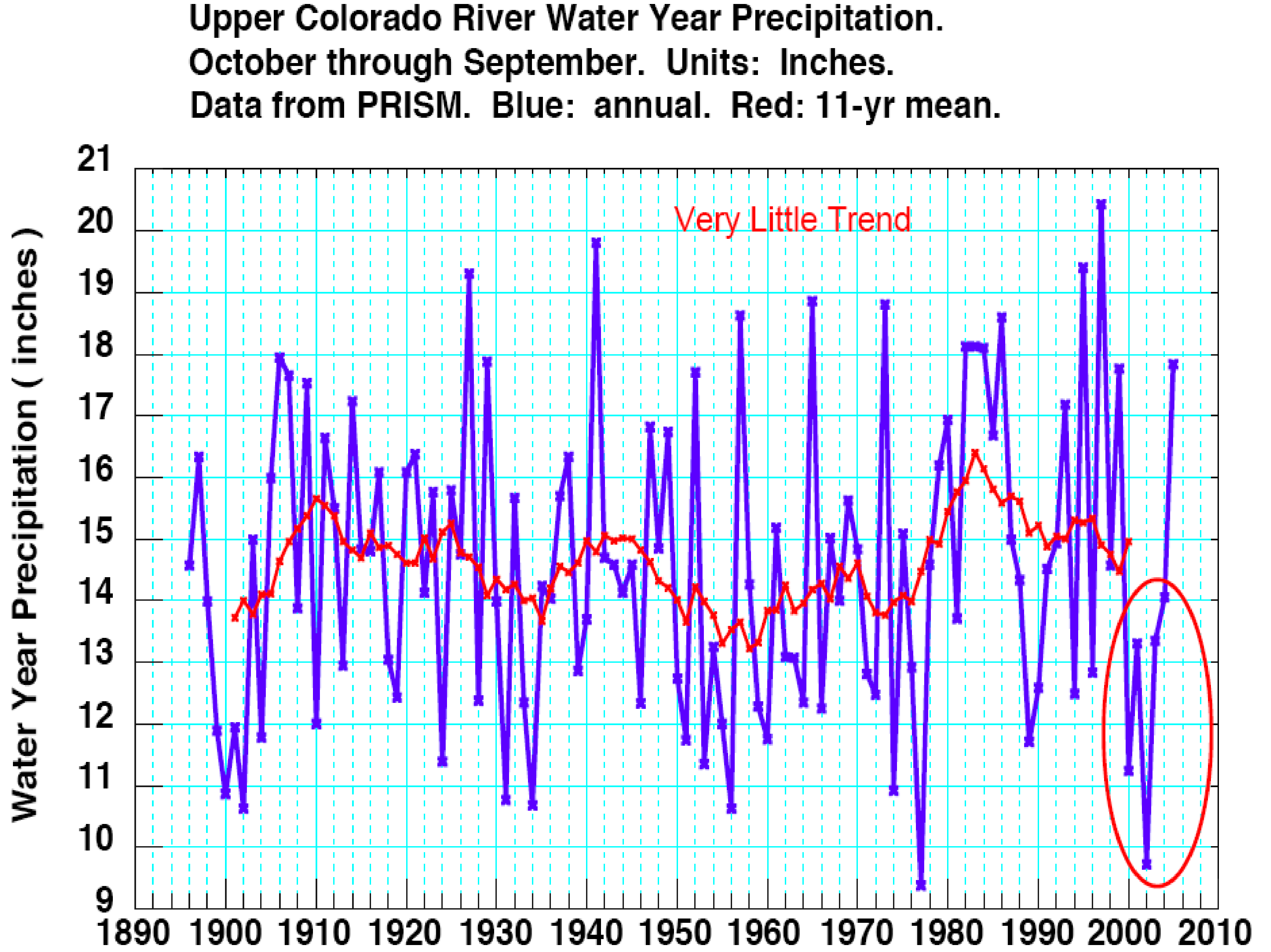
What's in the data?

Average Inches of Annual Precipitation in the United States 1961-1990



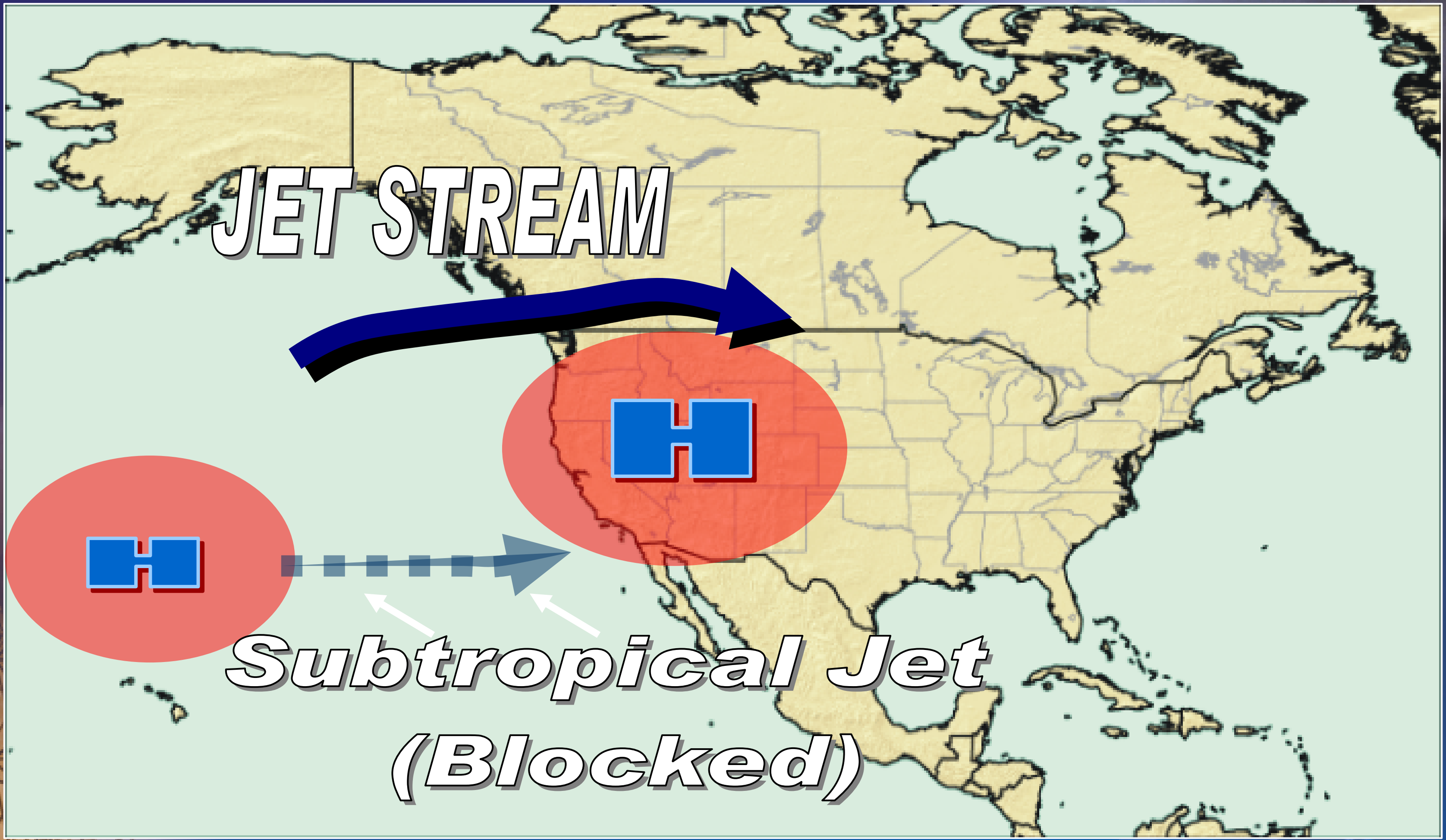

Lower Colorado Basin Mean Annual Temperature.
Units: Degrees F. Annual: red. 11-year running mean: blue
Data from PRISM: 1895-2005.
WRCC
2F Increase Since 1970
Annual Mean Temperature (F)
62
61
60
59
58
57
56
55
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010


Upper Colorado Basin Mean Annual Temperature.
Units: Degrees F. Annual: red. 11-year running mean: blue
Data from PRISM: 1895-2005.
Annual Temperature (F)
48
47
46
45
44
43
42
41
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

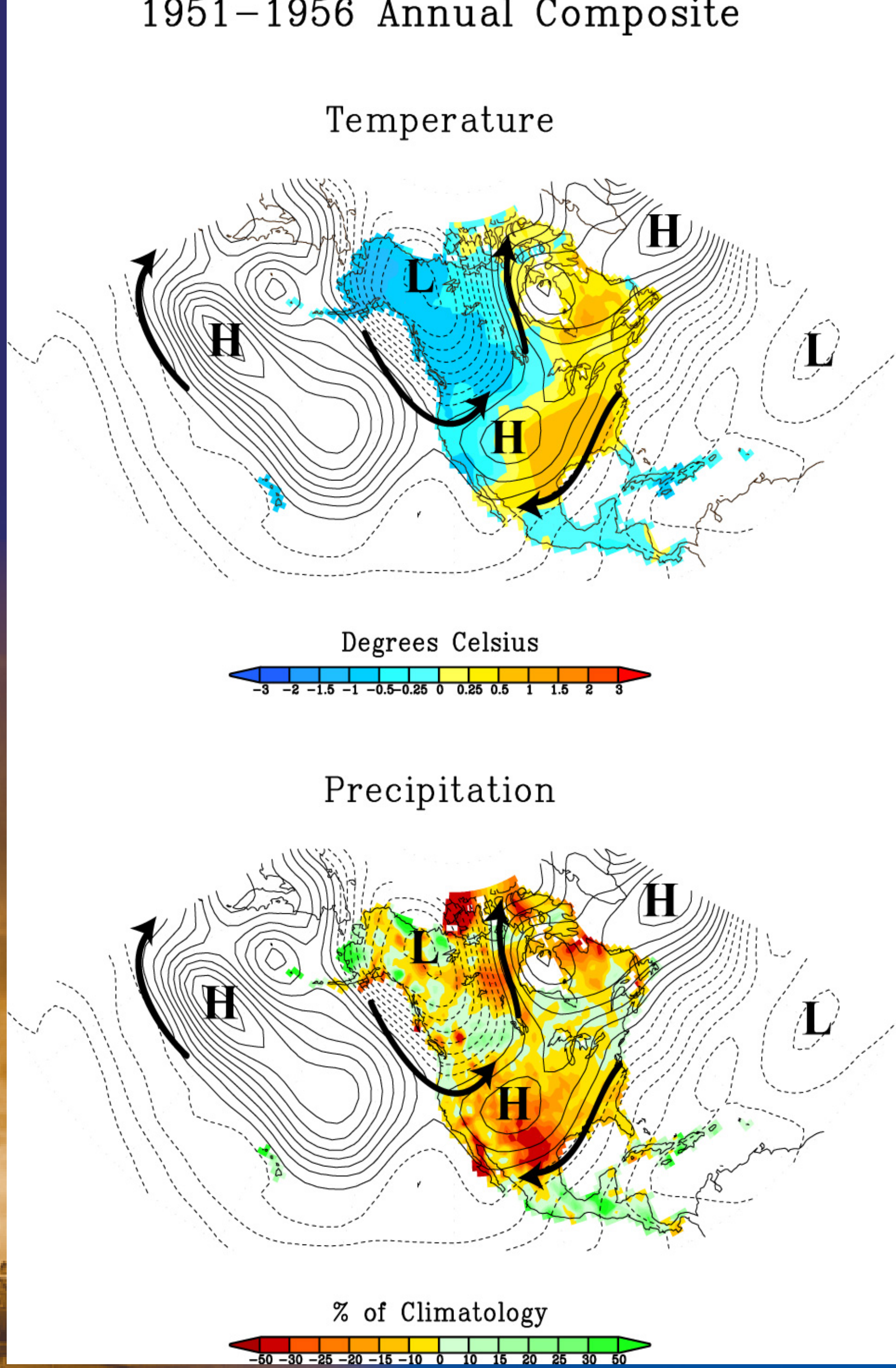

Upper Colorado River Water Year Precipitation.
October through September. Units: Inches.
Data from PRISM. Blue: annual. Red: 11-yr mean.
Very Little Trend
Water Year Precipitation (inches)
21
20
19
18
17
16
15
14
13
12
11
10
9
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

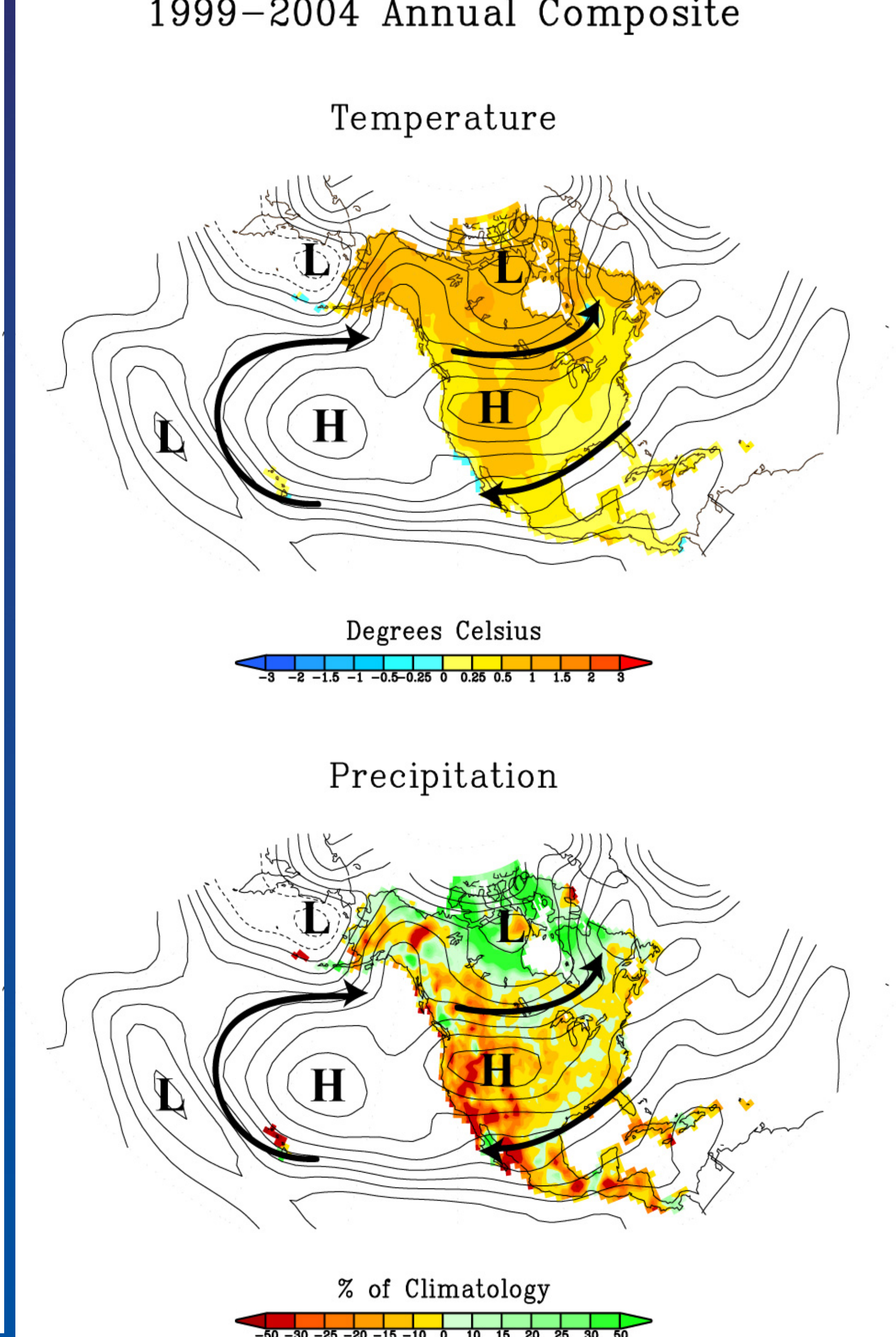
Western drought

Large-Scale Circulation Pattern During 1999-2003



During the multi-year drought in the West, abnormally high pressure over the Pacific and western states tended to block storms from penetrating the affected region..


1951–1956 Annual Composite
Temperature
H
L
H
L
H
Degrees Celsius
−3 −2 −1.5 −1 −0.5 −0.25 0 0.25 0.5 1 1.5 2 3
Precipitation
H
L
H
L
H
% of Climatology
−50 −30 −25 −20 −15 −10 0 10 15 20 25 30 50


1999–2004 Annual Composite
Temperature
L
L
L
H
H
Degrees Celsius
−3 −2 −1.5 −1 −0.5 −0.25 0 0.25 0.5 1 1.5 2 3
Precipitation
L
L
L
H
H
% of Climatology

2004 Snowpack Vanishing Act

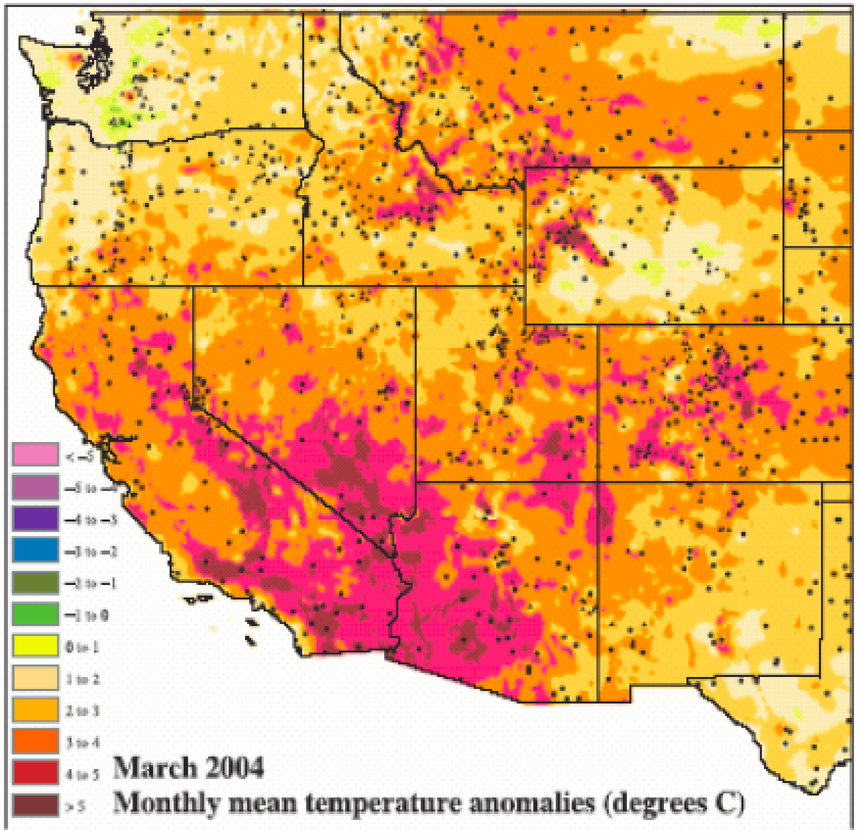
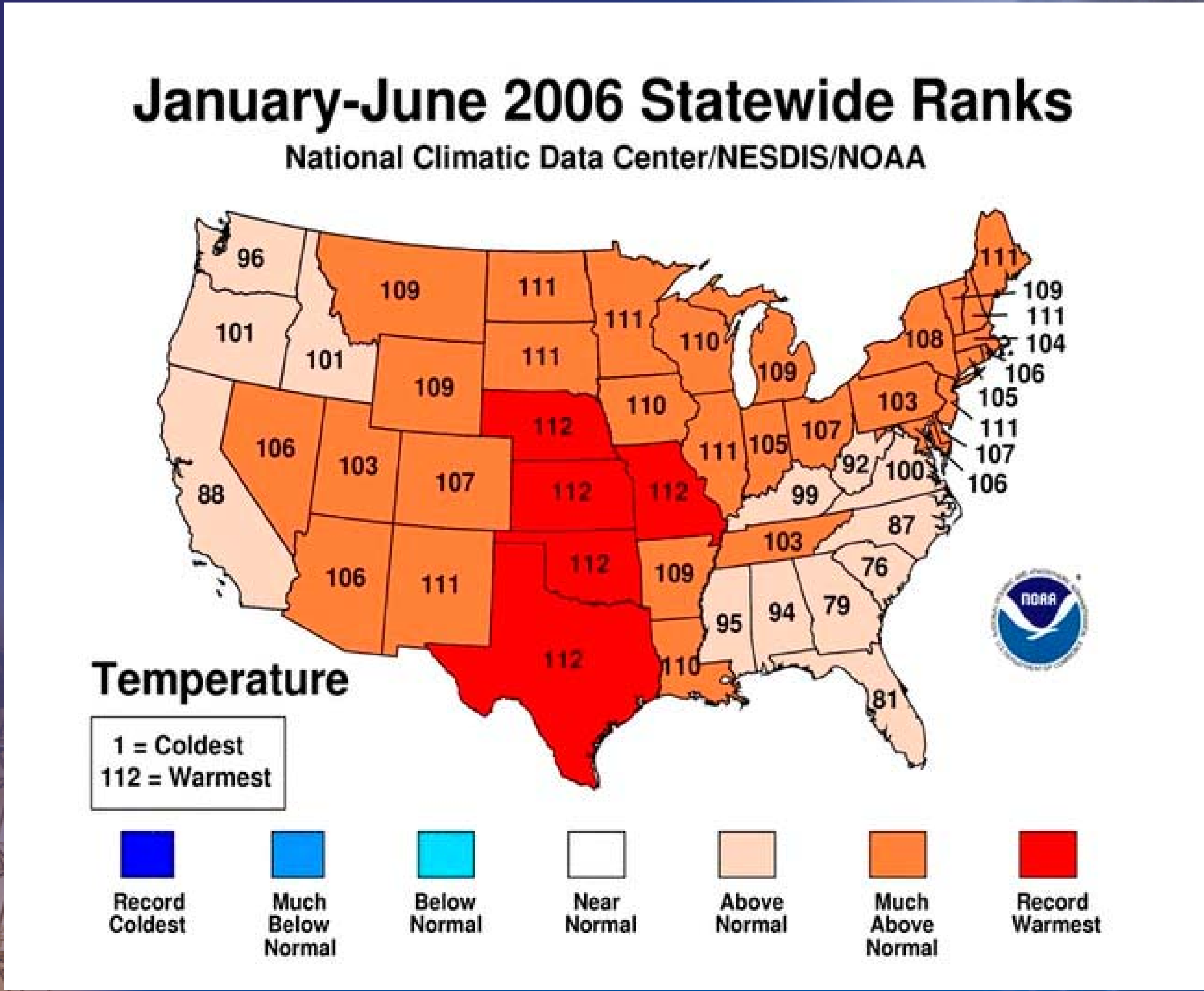


Fig. 1. March 2004 observed monthly mean temperature anomalies in degrees Celsius. NRCS SNOTEL sites are shown as triangles, and NWS sites are shown as circles. Contours are derived using the PRISM system (http://www.ocs.orst.edu/prism/).

Table 1. Summary of Mountain Snowpack (Snow Water Equivalent) Changes Between 1 March and 1 April 2004.

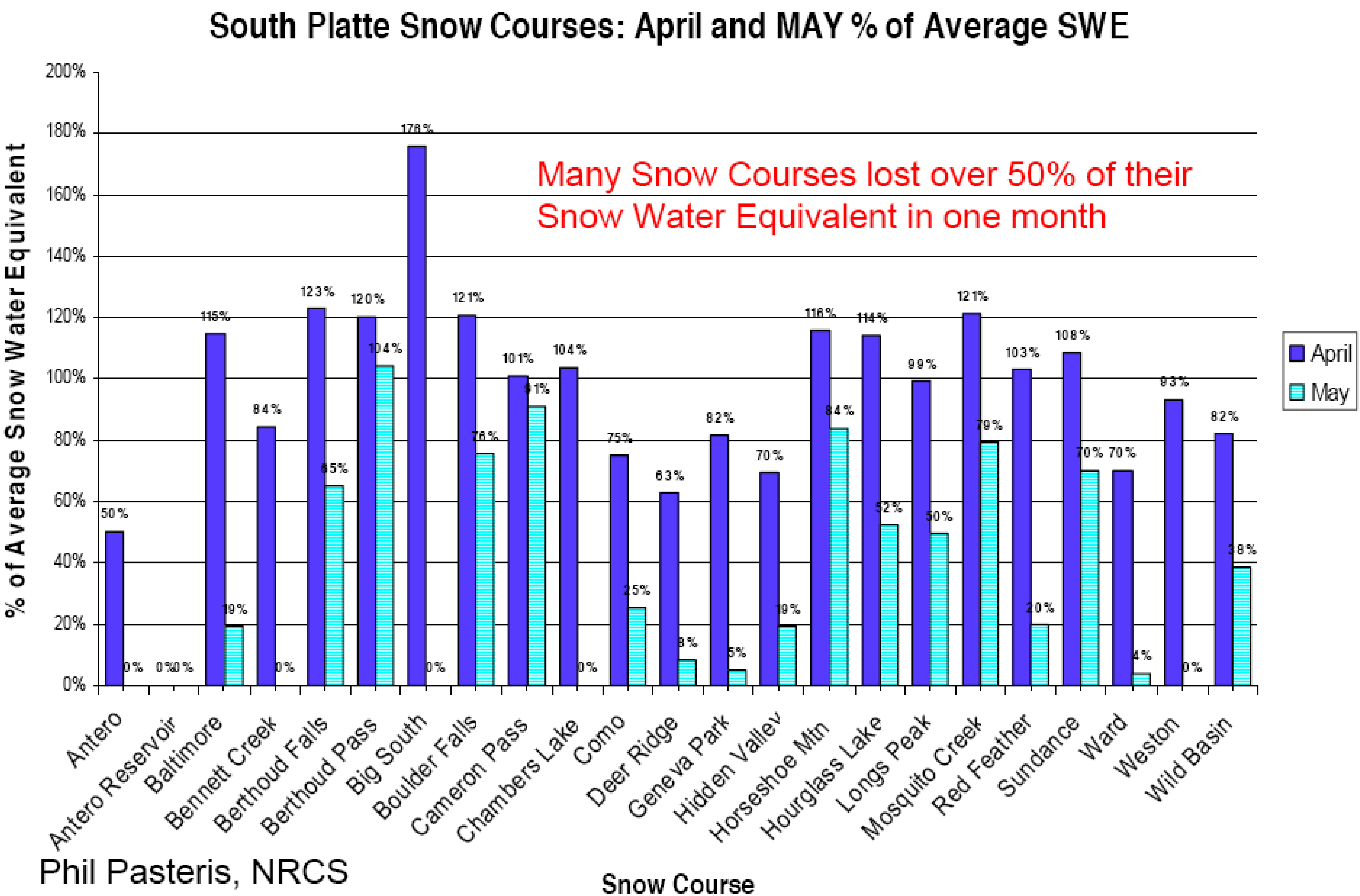
State/Area	*Statewide % of Average, 1 March 2004*	*Statewide % of Average, 1 April 2004*	*Statewide % of Average, Change*
Arizona	74	22	-51
Sierra/Tahoe	113	70	-35
Colorado	90	64	-26
Idaho	105	81	-25
Montana	93	78	-16
Nevada	118	64	-54
New Mexico	80	37	-43
Oregon	126	96	-30
Utah	109	70	-39
Washington	93	86	-7
Wyoming	91	71	-19

Rapid snowpack reduction. Record warmth and dryness combine in March 2004. (Pagano, Pasteris, Redmond, Dettinger, EOS)



How were runoff forecasts (and actual runoff) affected?

2006 Snowpack Vanishing Act



Phil Pasteris, NRCS

Water Resource input Change	*Examples from AR4 (IPCC Working Group)*
1 to 4 week earlier peak streamflow due to warming-driven snowmelt	US West and Canada *(WGI and II)*
↓ Proportion of precip falling as snow	Western Canada /prairies, US West *WG II, WG1)*
↓ Duration and extent of snow cover	most of North America *(WG1)*
↑ Annual precipitation	most of North America *(WG1)*
↓ Mountain snow water equivalent	Western North America *(WG1)*
↓ Annual precipitation	central Rockies, Southwest US *(WGII)*
↑ Frequency of heavy precipitation events	most of US *(WGII)*
↓ Runoff and streamflow	Colorado and Columbia River Basins *(WGII*
↑ Water temperature of lakes (0.1 to 1.5 C)	most of North America
↓ Glacial reach and glacial mass	US western mountains, *(WG1)*
↑ Dry days (timing between rainfall events)	most of North America (*WG1)*
↑ Periods of drought	Western US

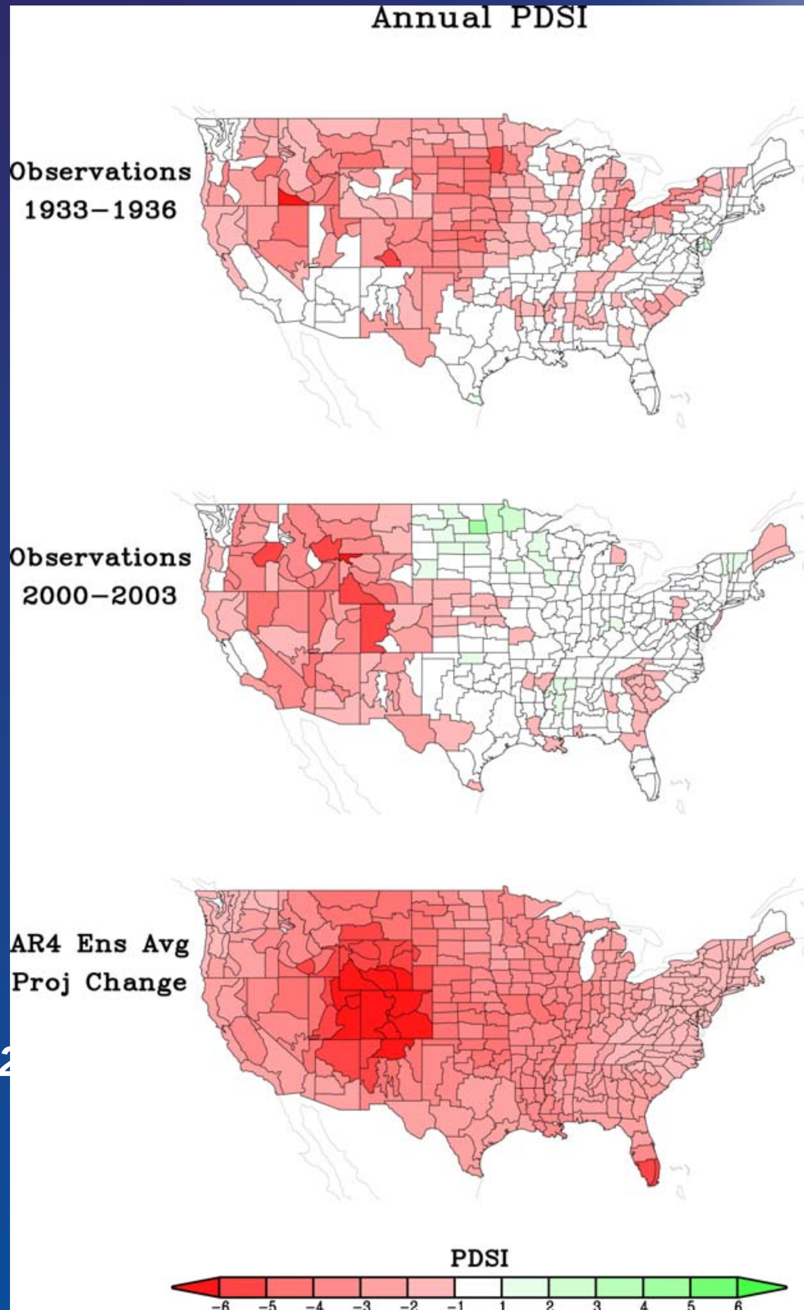
For droughts:

- **It is *very likely* that short-term severe droughts that have impacted North America during the past half-century are mostly due to atmospheric variability, in some cases amplified by local soil moisture conditions.**

- **It is *likely* that sea surface temperature anomalies have been important in forcing long-term severe droughts that have impacted North America during the past half-century.**

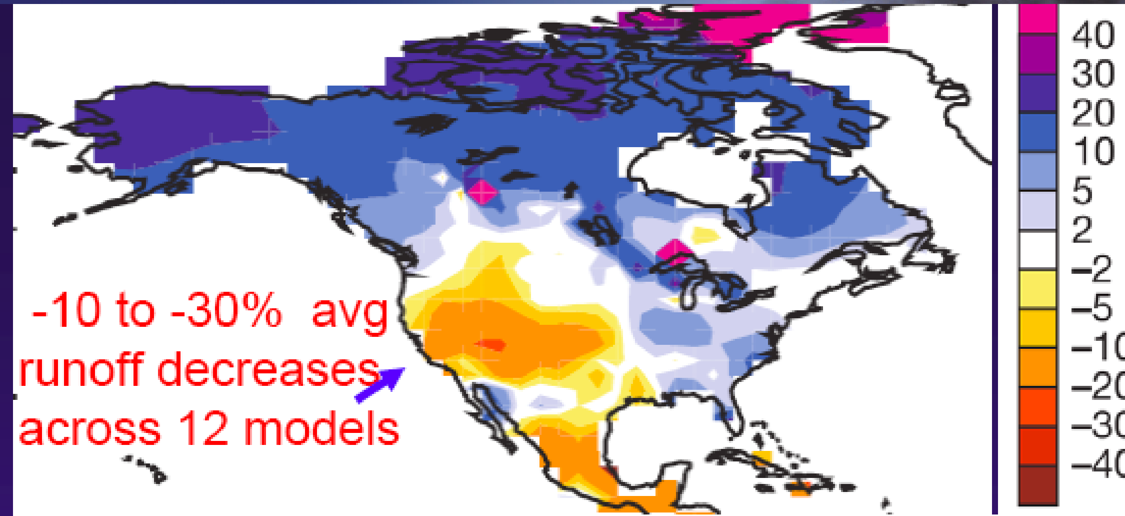
- **It is *likely* that anthropogenic warming has increased the severity of both short-term and long-term droughts over North America in recent decades.**

Drought @2050 vs Recent Historical Droughts

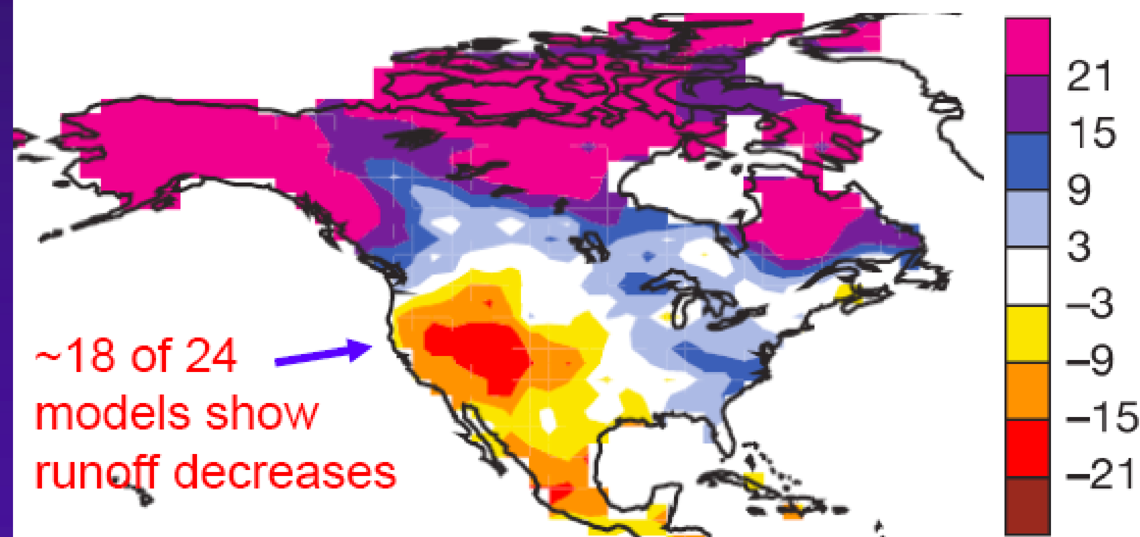


Current Thinking

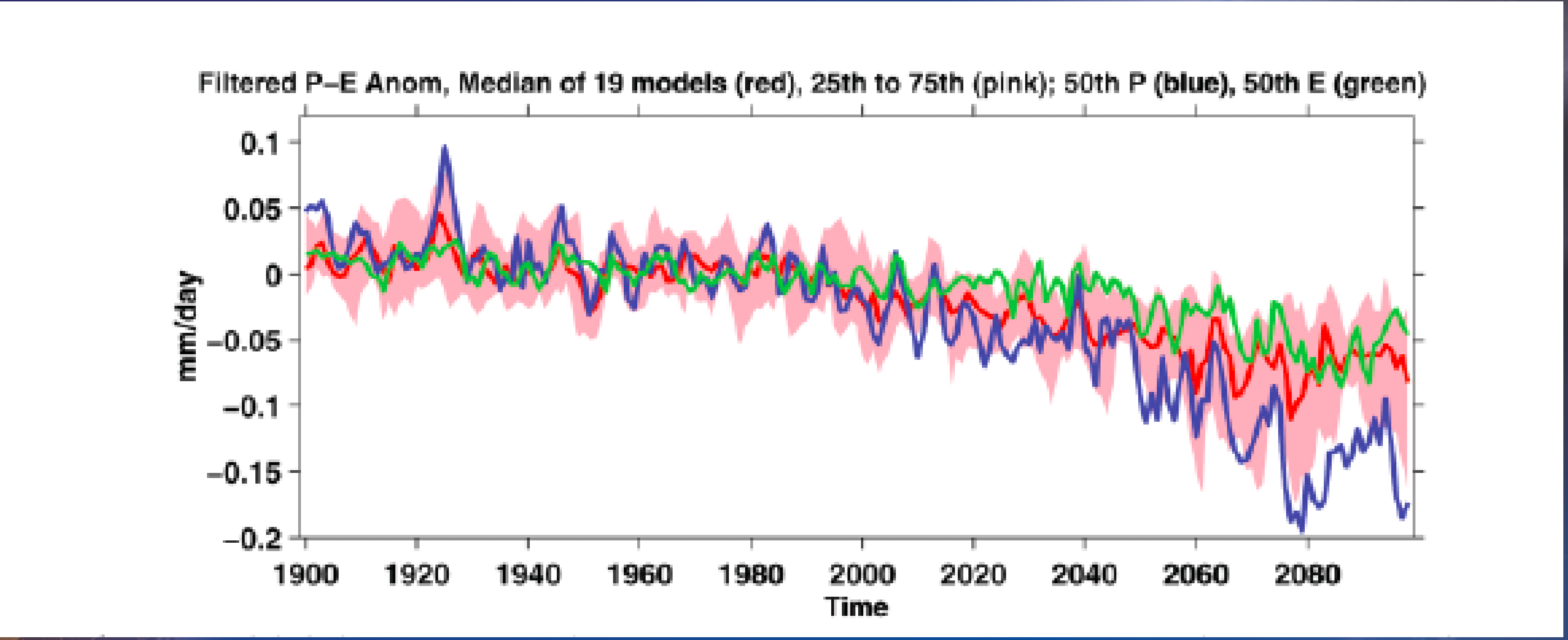
- PRELIMINARY Results -- lots of additional analysis required. Models are not predictions.
- 10 to 30% Less Runoff
- About ¾ of Models Agree
- Decreases in runoff due to temperature increases, perhaps small precipitation declines
- Dryness consistent with world-wide poleward movement of deserts from ~30 N/S Latitude



Relative Change in Runoff 2041 to 2060 relative to 1900-1970 Runoff from 12 Models



Number of Models Runs showing a positive change minus number showing negative change.



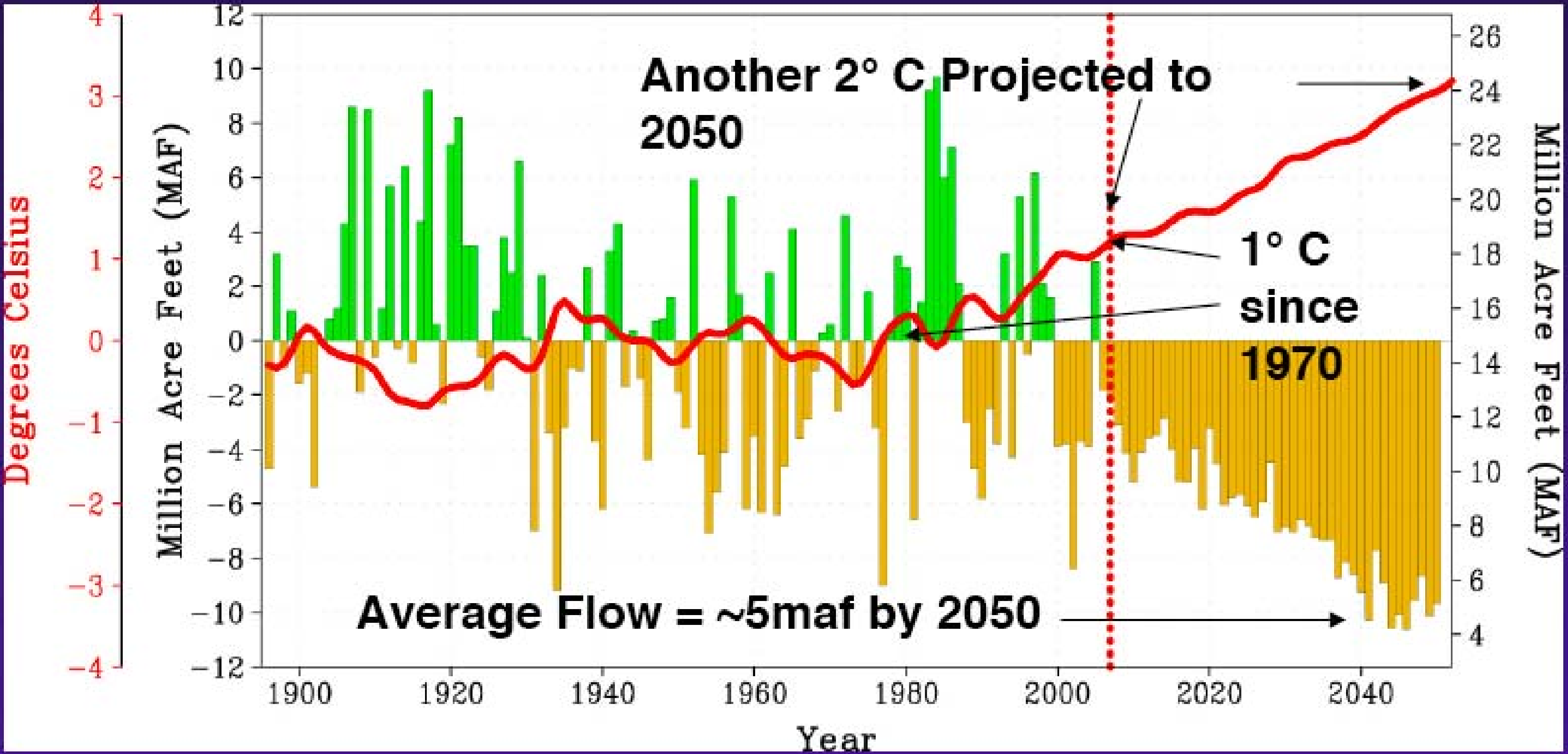
Western U.S. P-E 19 models 1900-2100

(Seager et al, 2007)

Period	Temperature Change	Precipitation Change	Storage Change
2010-2039	+1.8^{o}F	-3%	-36%
2040-2069	+3.1^{o}F	-6%	-32%
2079-2098	+3.6^{o}F	-3%	-40%

Annual average changes in the Colorado Basin for future climate periods (based on Christiansen et la 2004,2006)

Problems with the models



Another 2° C Projected to 2050
1° C since 1970
Average Flow = ~5maf by 2050
Degrees Celsius
Million Acre Feet (MAF)
Million Acre Feet (MAF)
Year
4
3
2
1
0
−1
−2
−3
−4
12
10
8
6
4
2
0
−2
−4
−6
−8
−10
−12
26
24
22
20
18
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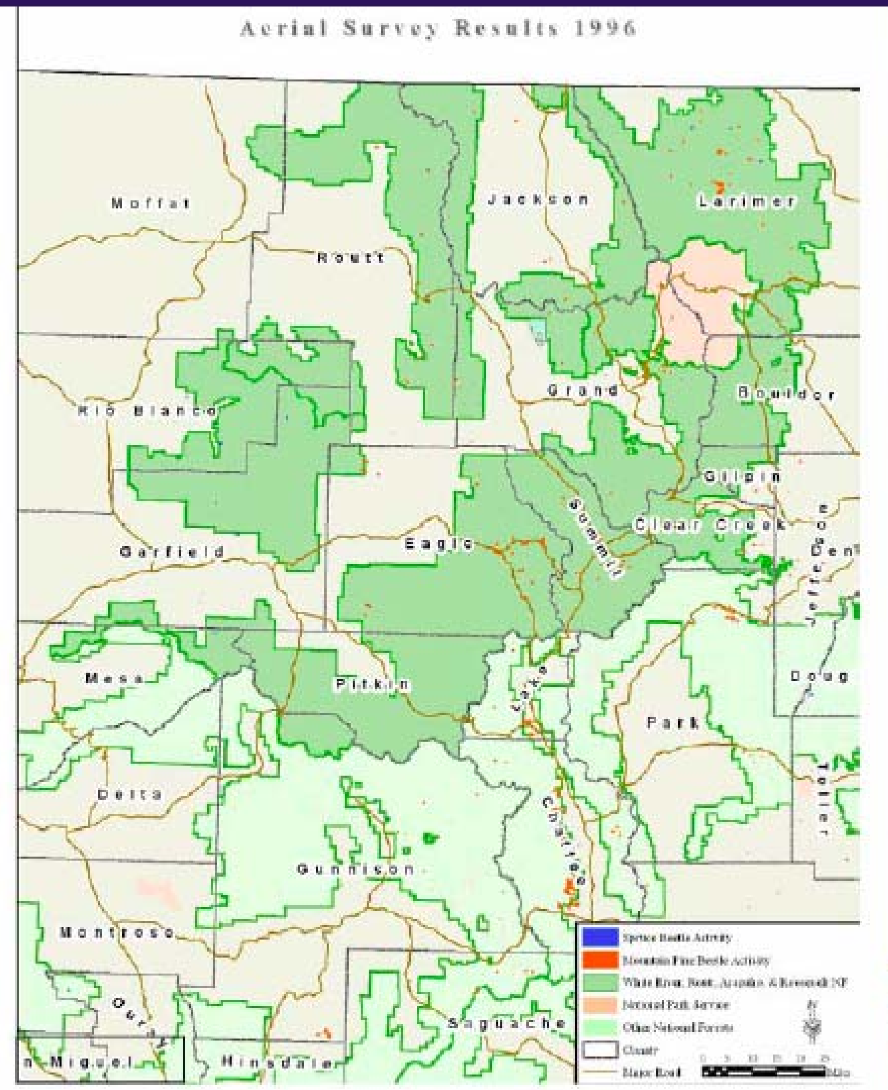
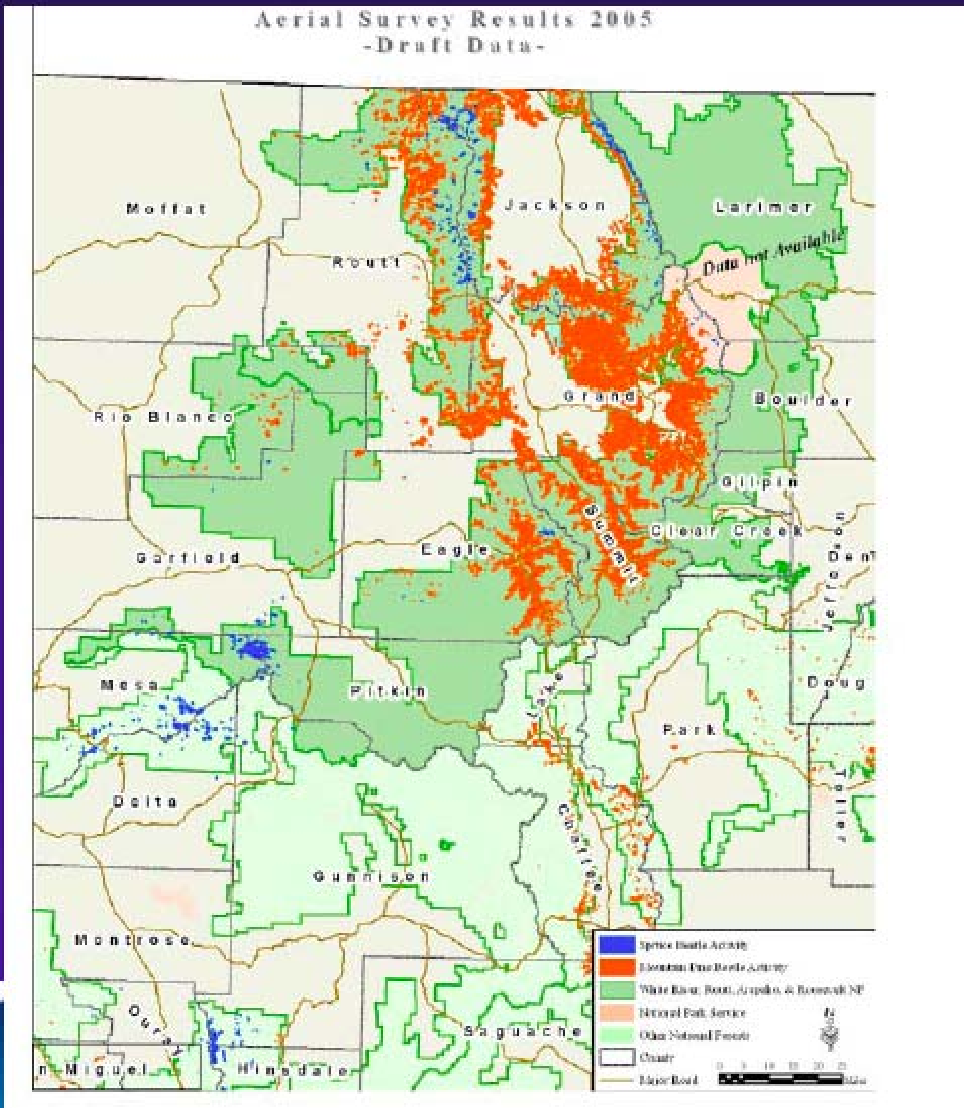
6
4
1900
1920
1940
1960
1980
2000
2020
2040

Wild Cards: Pine Beetles

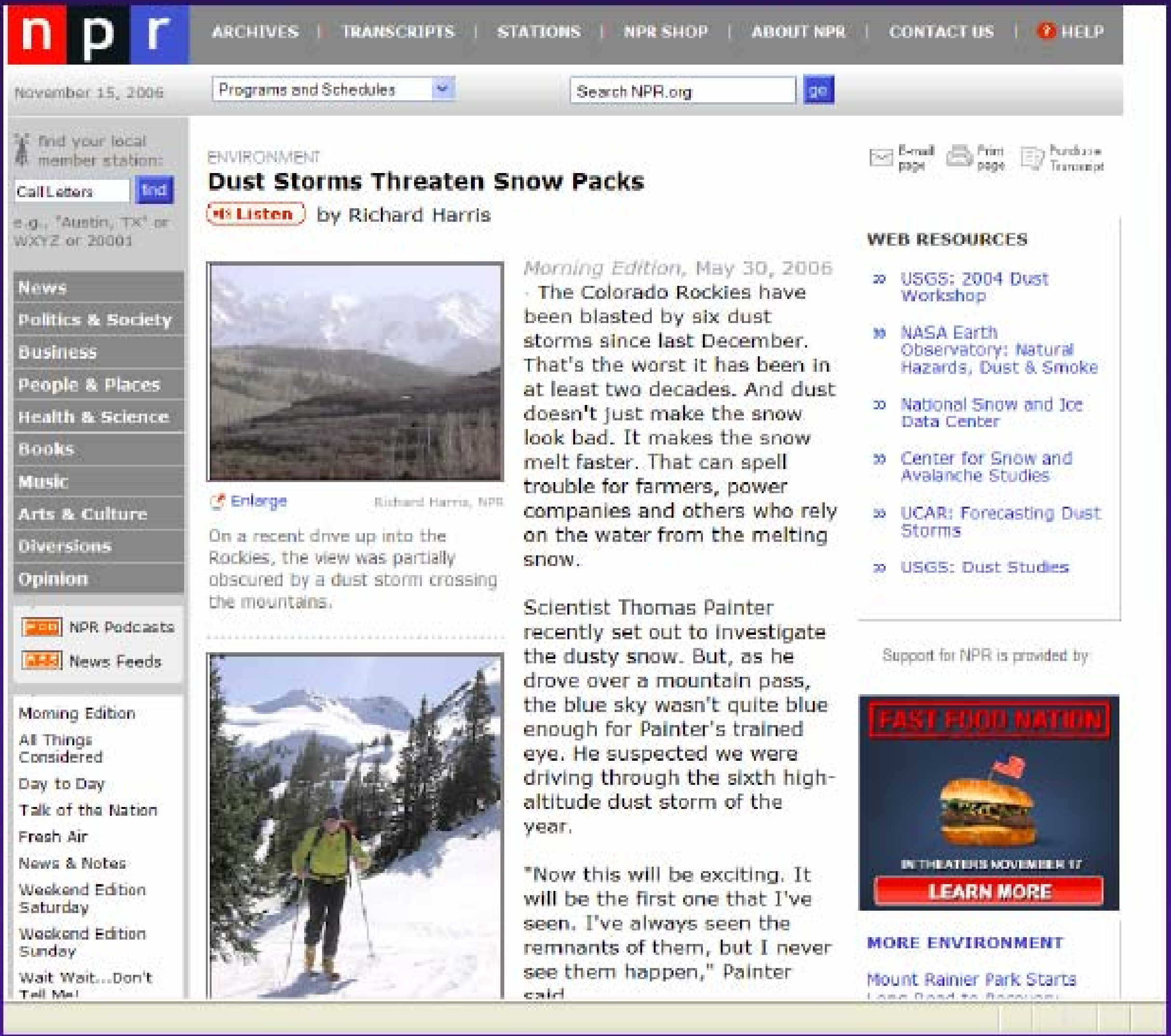




'Dust Storms Threaten Snowpacks'

Preliminary Findings:

- snow melt may occur up to 3 weeks earlier if significant dust
- strong connection with drought in Southwest



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Weekend Edition Sunday
Wait Wait...Don't Tell Me!

ENVIRONMENT

Dust Storms Threaten Snow Packs

Listen by Richard Harris

Enlarge Richard Harris, NPR

On a recent drive up into the Rockies, the view was partially obscured by a dust storm crossing the mountains.

Morning Edition, May 30, 2006 · The Colorado Rockies have been blasted by six dust storms since last December. That's the worst it has been in at least two decades. And dust doesn't just make the snow look bad. It makes the snow melt faster. That can spell trouble for farmers, power companies and others who rely on the water from the melting snow.

Scientist Thomas Painter recently set out to investigate the dusty snow. But, as he drove over a mountain pass, the blue sky wasn't quite blue enough for Painter's trained eye. He suspected we were driving through the sixth high-altitude dust storm of the year.

"Now this will be exciting. It will be the first one that I've seen. I've always seen the remnants of them, but I never see them happen," Painter said.

WEB RESOURCES

- USGS: 2004 Dust Workshop
- NASA Earth Observatory: Natural Hazards, Dust & Smoke
- National Snow and Ice Data Center
- Center for Snow and Avalanche Studies
- UCAR: Forecasting Dust Storms
- USGS: Dust Studies

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MORE ENVIRONMENT

Mount Rainier Park Starts

Regional climates (&trends)

VAR = GHG + Decadal + ENSO + Regional + Local + Noise

(not everything is greenhouse-related, nor will it ever be & don’t underestimate the “noise”=our (in-) ability to measure correctly)

We do NOT fully understand all of the above components of the climate system, leaving room for surprises!

- Warming in Western U.S clearly reflects the combined influence of natural variation, greenhouse gases, sulfate aerosols
- Tendency for models to project future warming with more droughts
- Evapotranspiration rates (ET) increased by 3-4 in. in the last 50 years
- April 1 SWE decreased 15-30% since 1950 particularly at low elevations
- Phenological changes

  Warmer nights may have enhanced wine quality in the West
- Increase length of growing season (by2 days/decade

Current models show little change in total precipitation

Drying trend from increases in temperature

By 2010-2039 year round temperatures are anticipated to be outside the range of normal variability

Most studies show future reductions in flow
Depending on the analysis this could mean *10%* or up to *50%* decrease (median around 17%)

If the models are correct, the levels of aridity may increase within a time frame of years to decades

- **Planning: depends on "stable" climate**
- **Small mountainous areas drive the runoff**

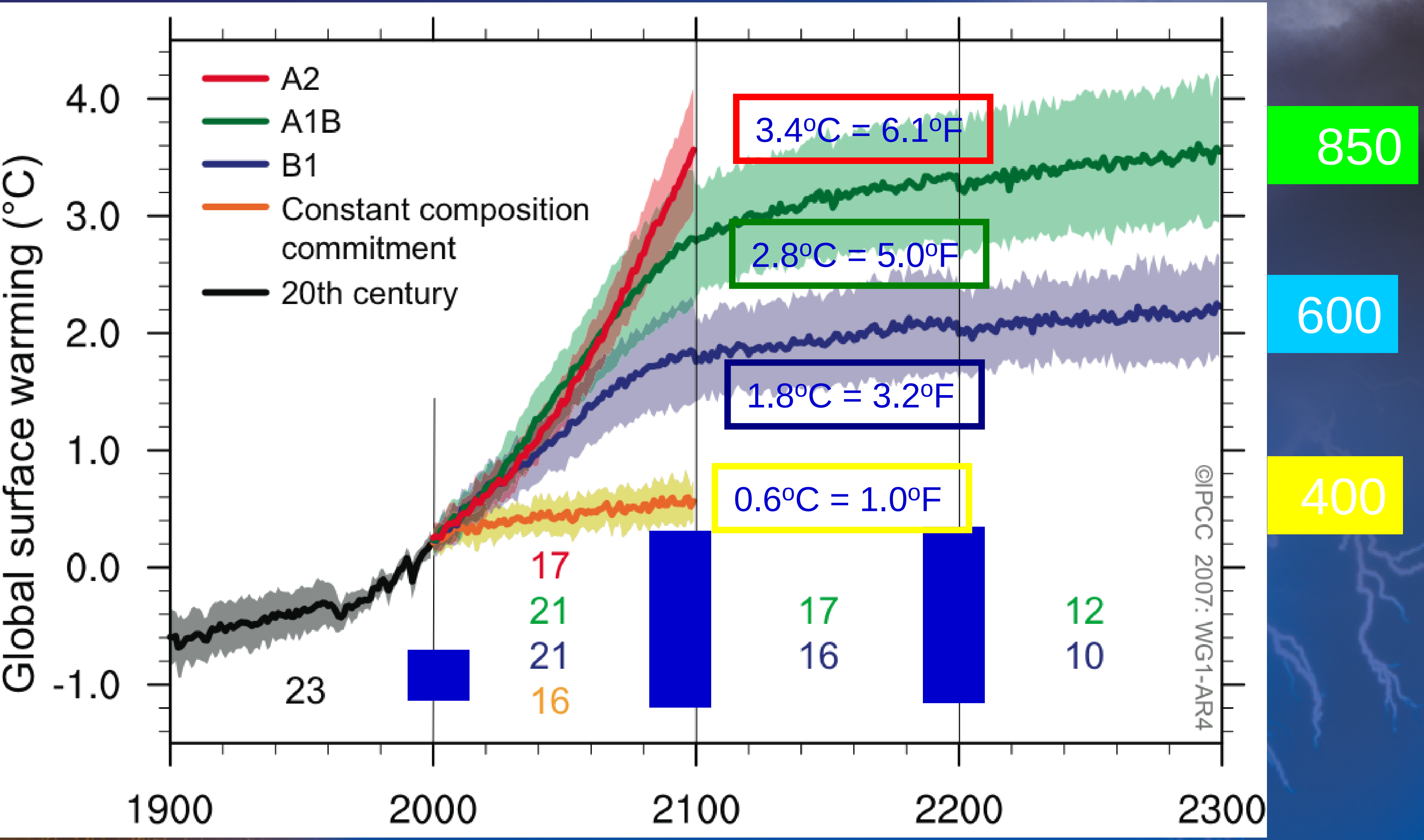
- **Paleo-record suggests that depending on the planning horizon "normal" might not exist**
- **Recent climate warmer esp. in Spring**
- **Snowmelt is occurring earlier and the proportion of precipitation occurring as rain is increasing**

  (note: late-summer early fall)

- **Most climate studies suggest that in the near future droughts may be more common in the Colorado Basin even if precipitation stays the same**

The Longer Term

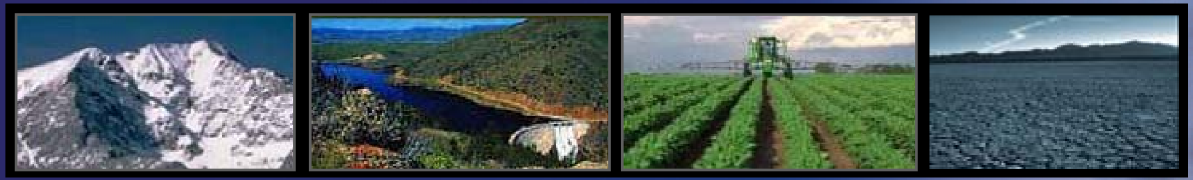
Warming will increase if GHGs increase. If GHGs were kept fixed at current levels, a committed 0.6°C of further warming would be expected by 2100. Higher emissions translate into more warming.



Committed change (change already in the climate system) requires effective adaptation

Collaborative framework between research and management

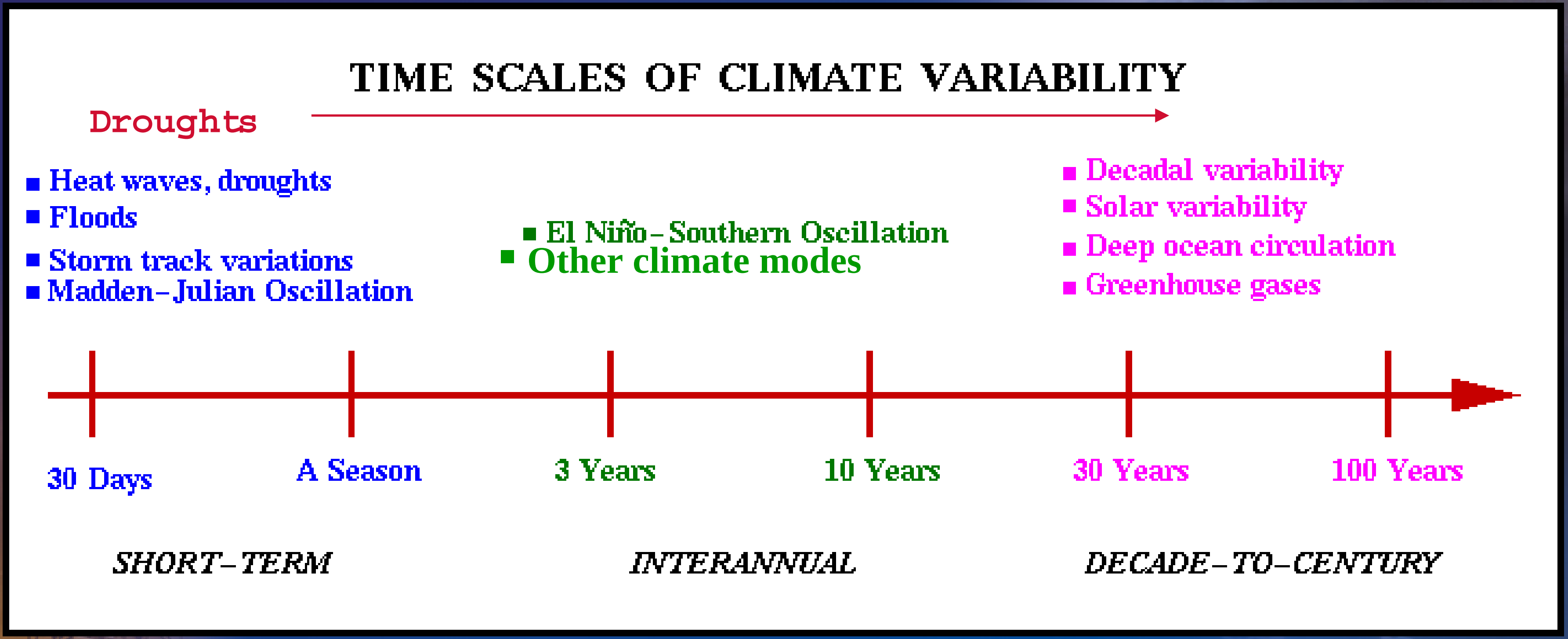
Information services for adaptation from short-term (next season) through climate changes (next 10-20 years)



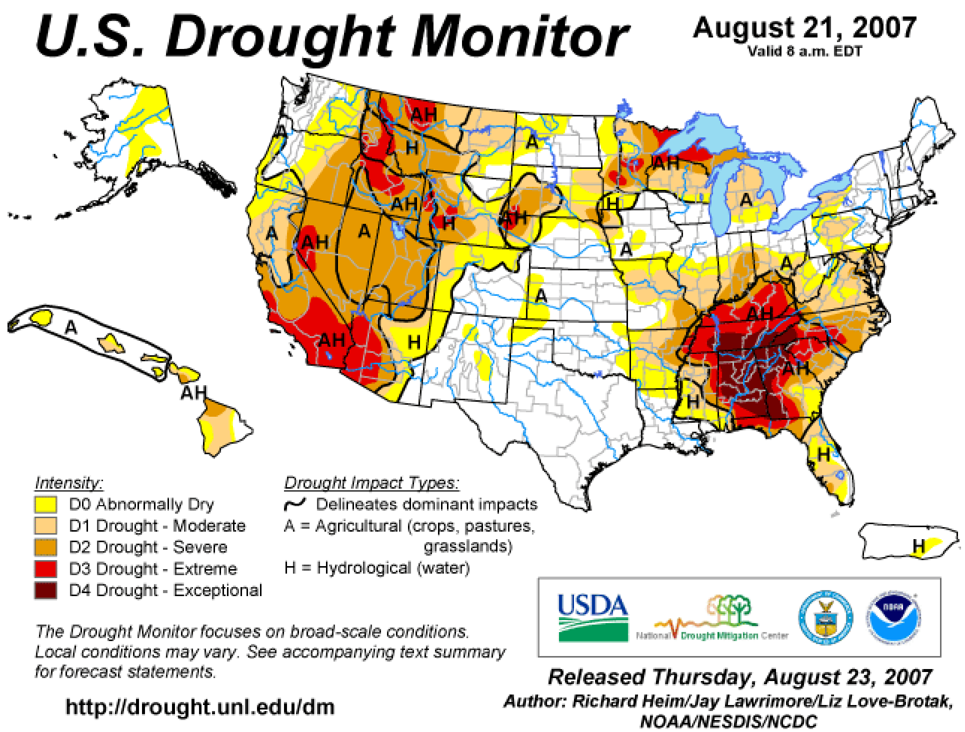
National Integrated Drought Information System

Fundamental Challenges of Drought

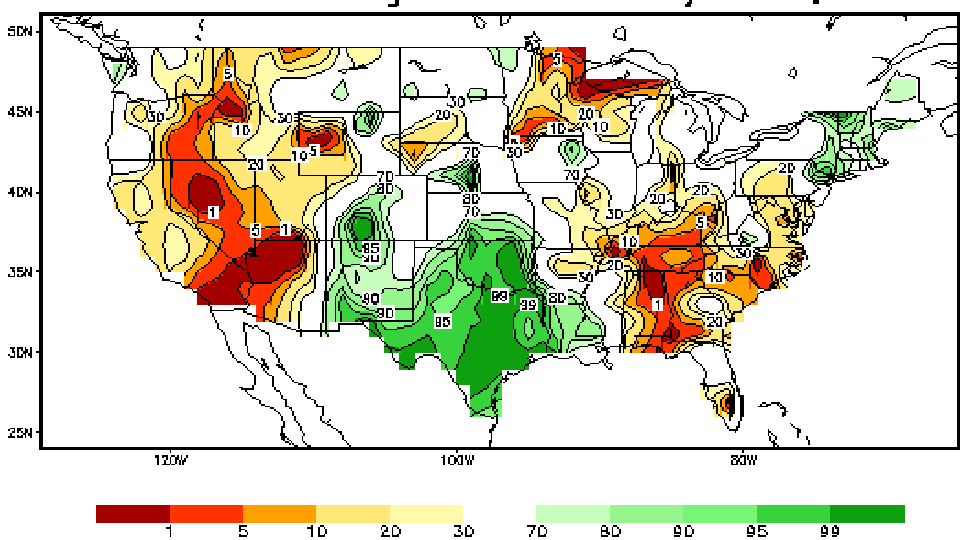
Diverse time scales



Droughts span an enormous range of time scales, from short-term “flash droughts” that can have major agricultural impacts to multi-year or even decadal droughts (1930s, 1950s, etc.) Paleoclimate evidence suggests that in the last 1000 years parts of the U.S. have experienced “mega-droughts” that persisted for decades.



Soil Moisture Ranking Percentile Last day of JUL, 2007

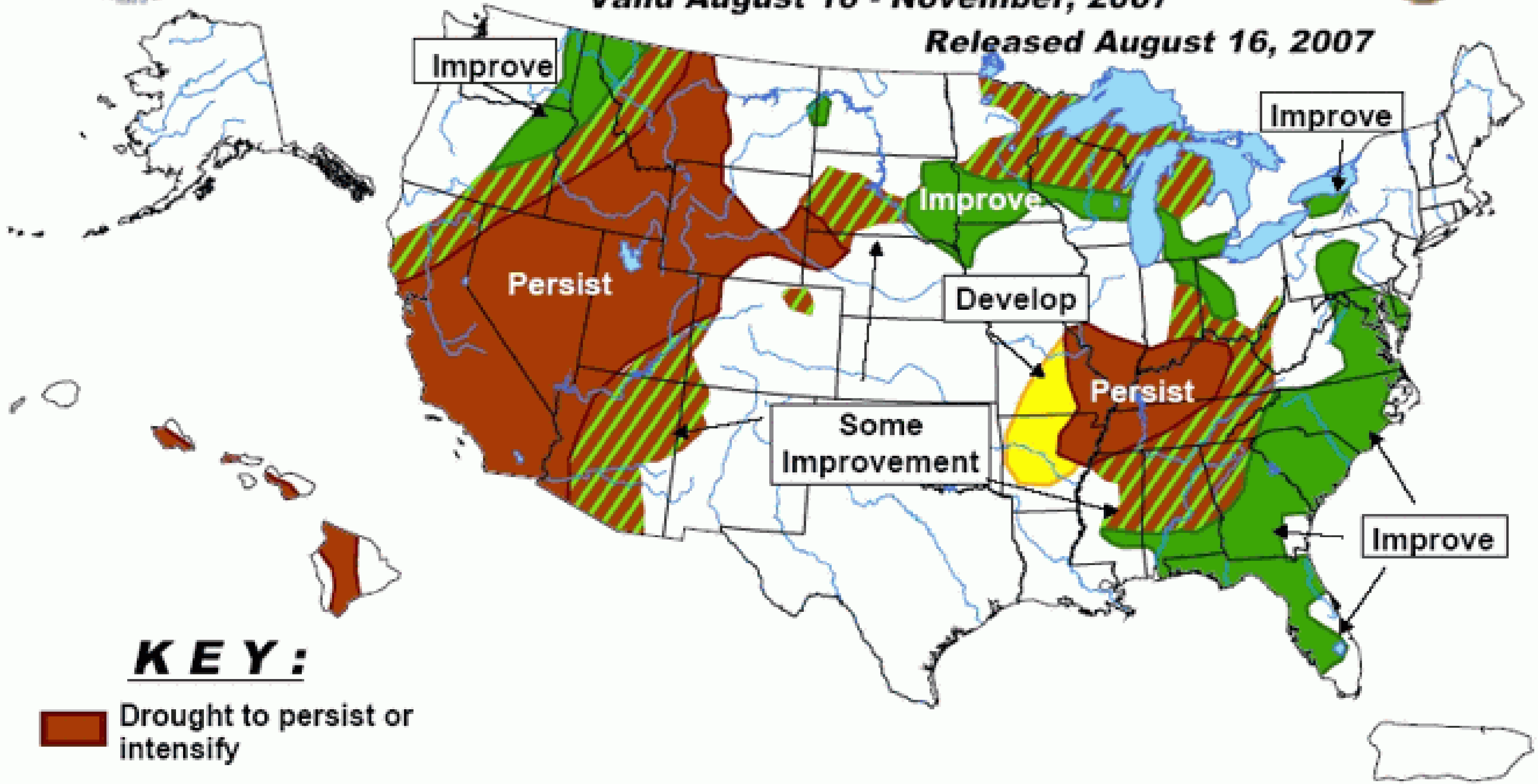


U.S. Seasonal Drought Outlook

Drought Tendency During the Valid Period

Valid August 16 - November, 2007

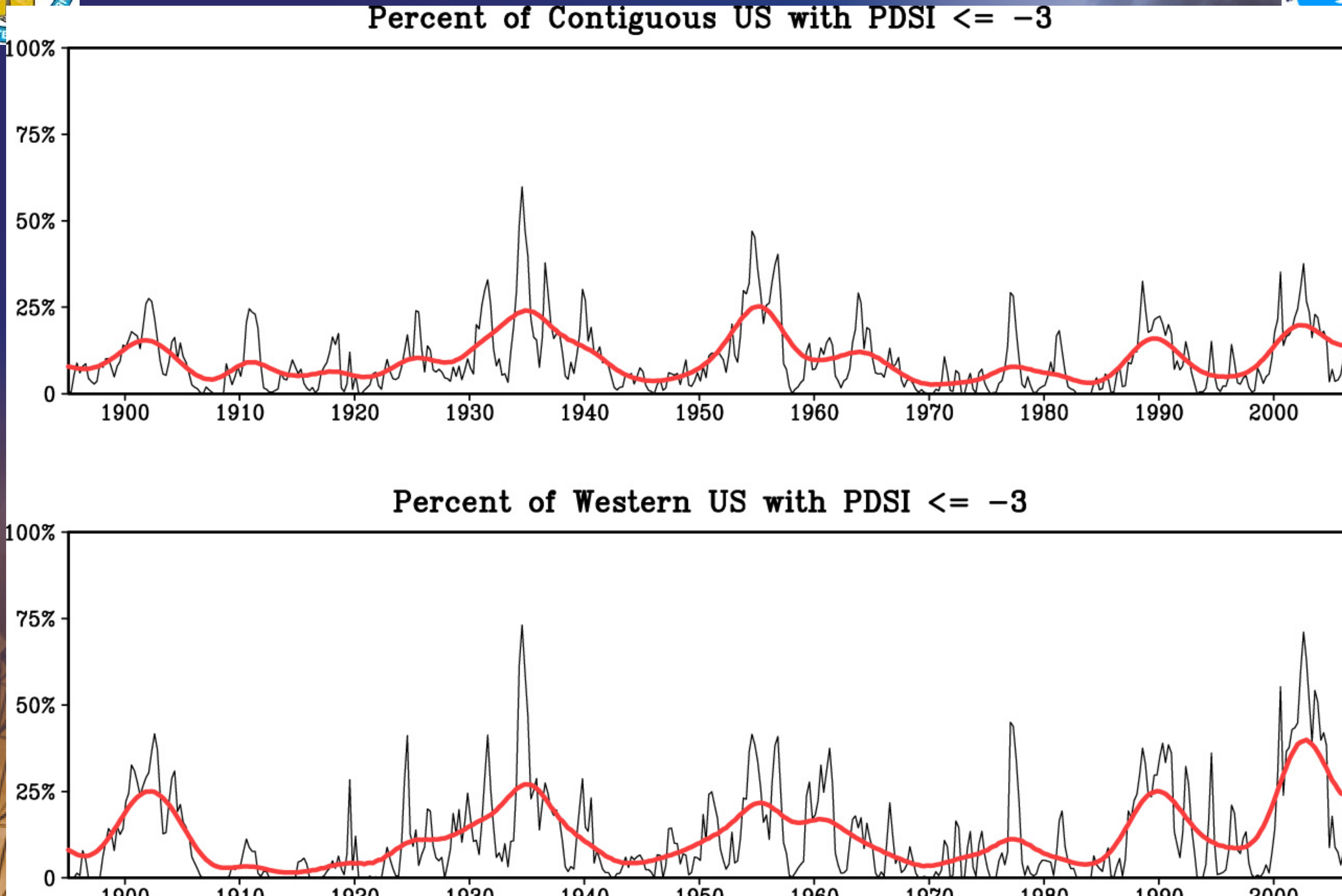
Released August 16, 2007



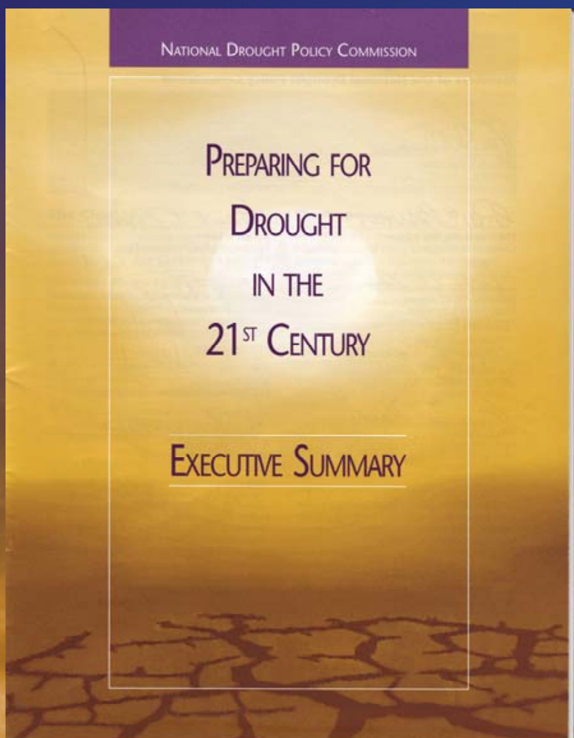
KEY:

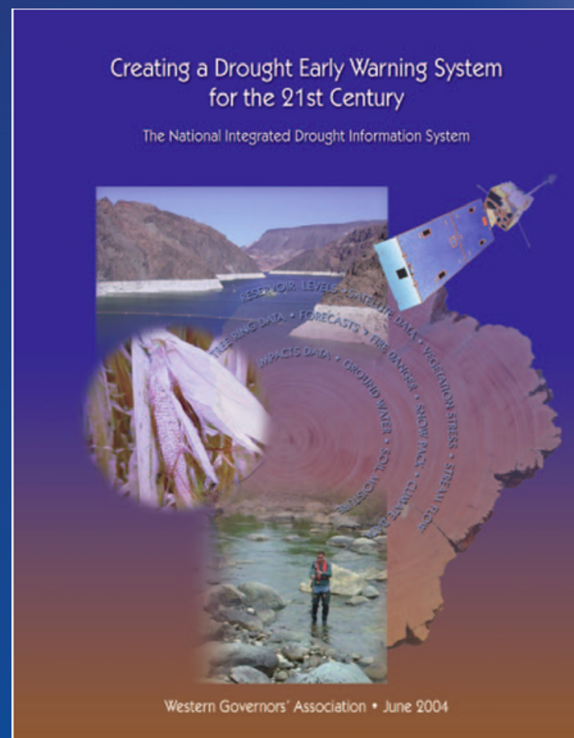
- Drought to persist or intensify
- Drought ongoing, some improvement
- Drought likely to improve, impacts ease
- Drought development likely

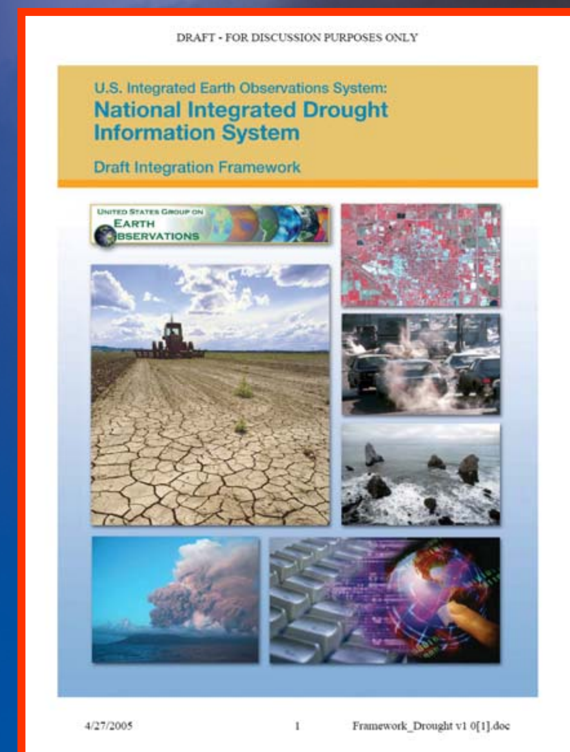
Depicts large-scale trends based on subjectively derived probabilities guided by short- and long-range statistical and dynamical forecasts. Short-term events -- such as individual storms -- cannot be accurately forecast more than a few days in advance. Use caution for applications -- such as crops -- that can be affected by such events. "Ongoing" drought areas are approximated from the Drought Monitor (D1 to D4 intensity). For weekly drought updates, see the latest U.S. Drought Monitor. NOTE: the green improvement areas imply at least a 1-category improvement in the Drought Monitor intensity levels, but do not necessarily imply drought elimination.


Percent of Contiguous US with PDSI <= -3
100%
75%
50%
25%
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Percent of Western US with PDSI <= -3
100%
75%
50%
25%
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

National Drought Policy Commission, Drought Policy Commission (2000), WGA (2004), USGEO (2006)







PL 109-430

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

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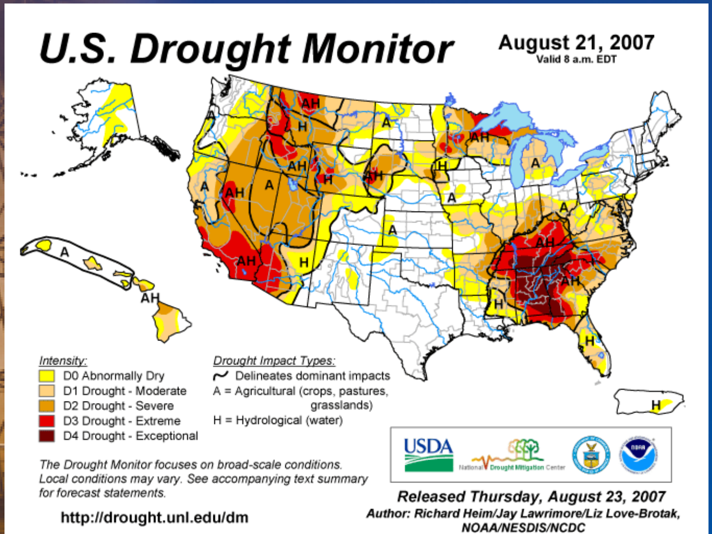
TIFF (Uncompressed) decompressor
are needed to see this picture.

Partnerships: State, Tribal, Local, Federal, Private: County and Regional/Watersheds

National Integrated Drought Information System

NIDIS: An integrated, interagency national drought monitoring and forecasting system that provides:

- **An** early warning system **for drought.**
- **Drought impact and risk scenarios.**
- **Resources for drought education and** mitigation**.**
- **An interactive, web-based** drought portal**.**
- **Improved** observational **capabilities.**



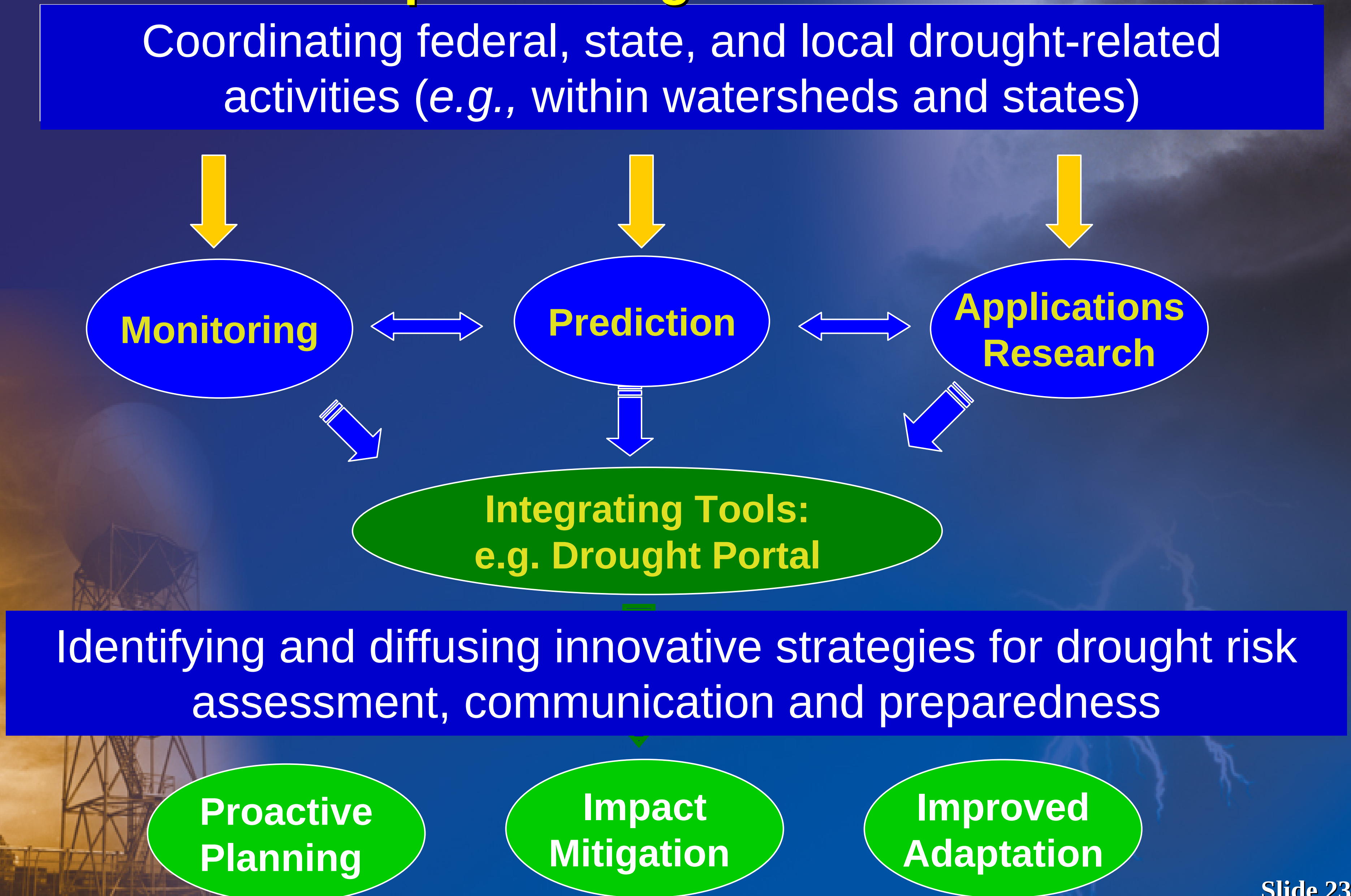
Existing Drought Product:
NIDIS will Provide Major Improvements


First Rule of Prototyping:
Think Big!
But, don’t start off by trying to
implement as big as we can think it!

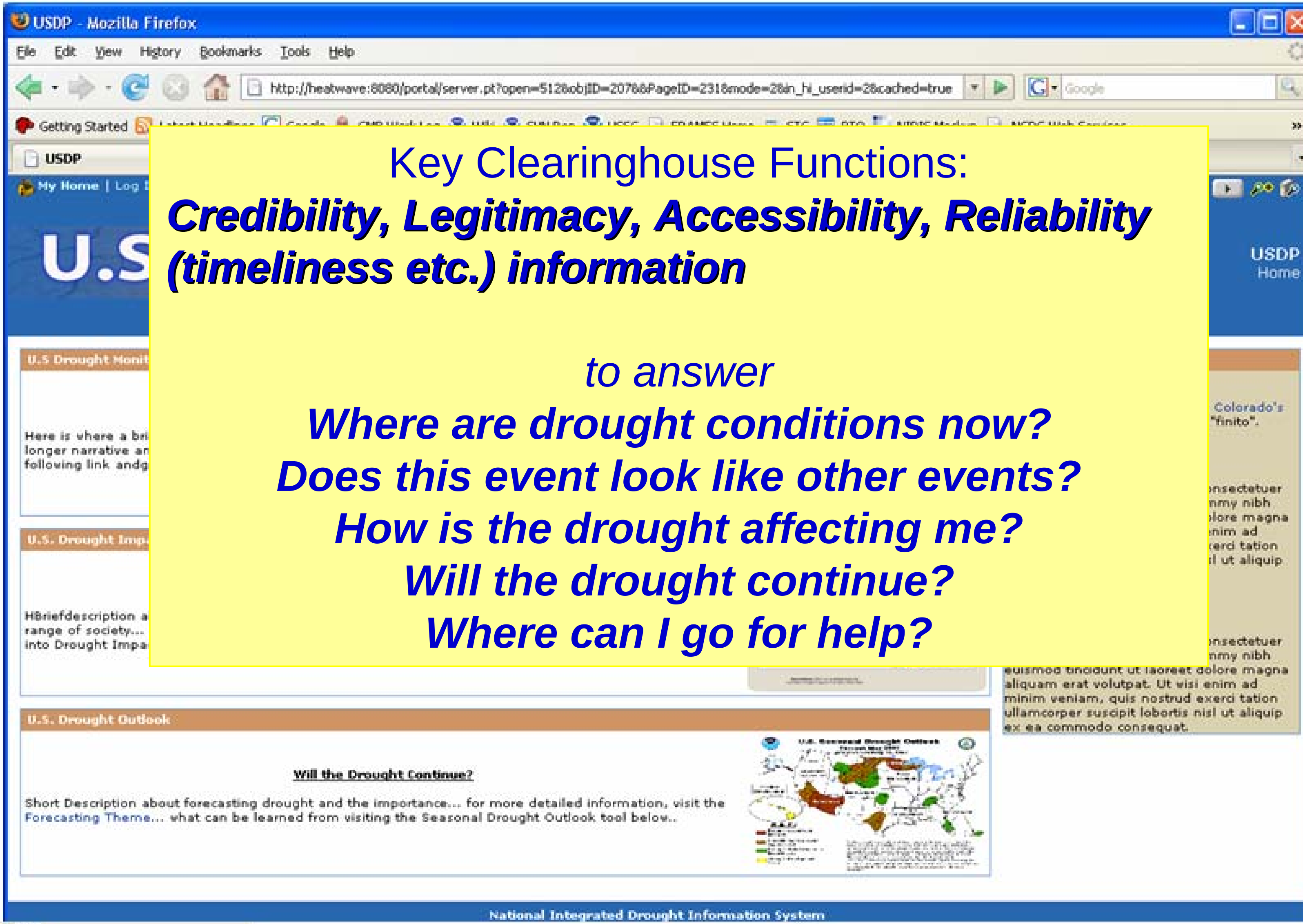
NIDIS Pilots

Timeline? Funding? Transferability?

NIDIS Process Model: Implementing NIDIS Pilots



Portal Home:



Key Clearinghouse Functions:

Credibility, Legitimacy, Accessibility, Reliability (timeliness etc.) information

to answer

Where are drought conditions now?

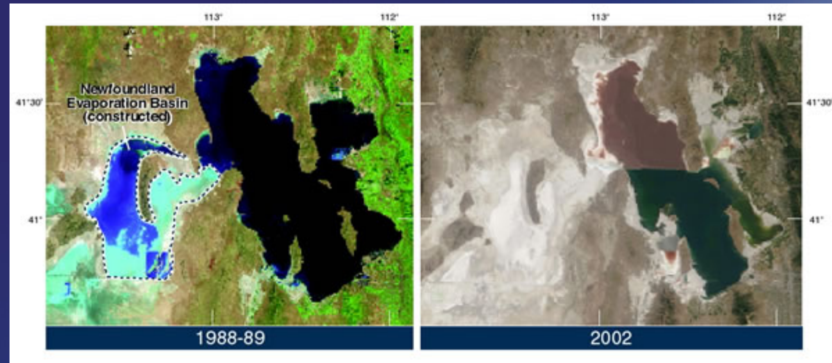
Does this event look like other events?

How is the drought affecting me?

Will the drought continue?

Where can I go for help?

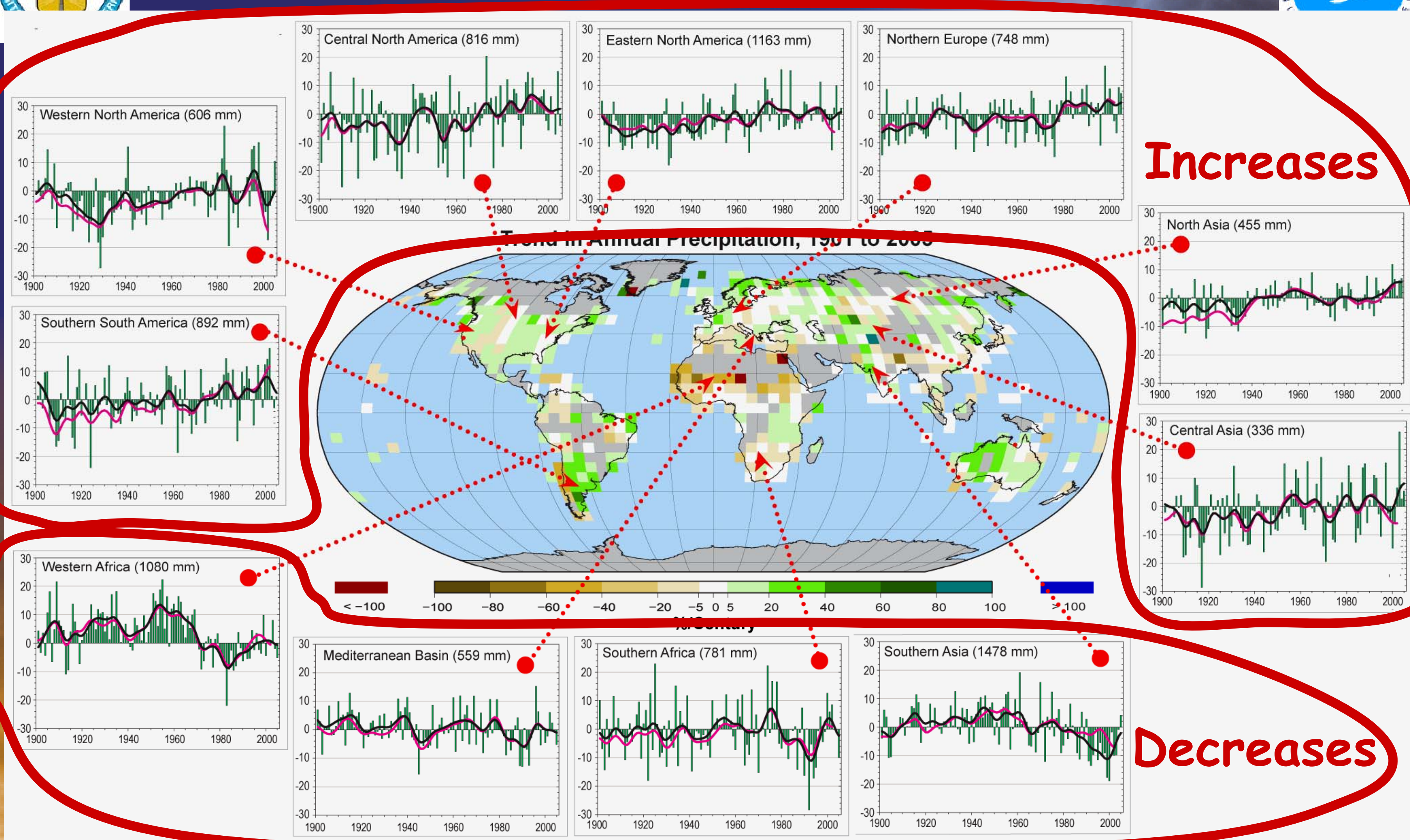
Opportunities?


Newfoundland Evaporation Basin (constructed)
1988-89
2002


I'm sure glad the hole isn't in our end . . .

End

Land precipitation is changing significantly over broad areas

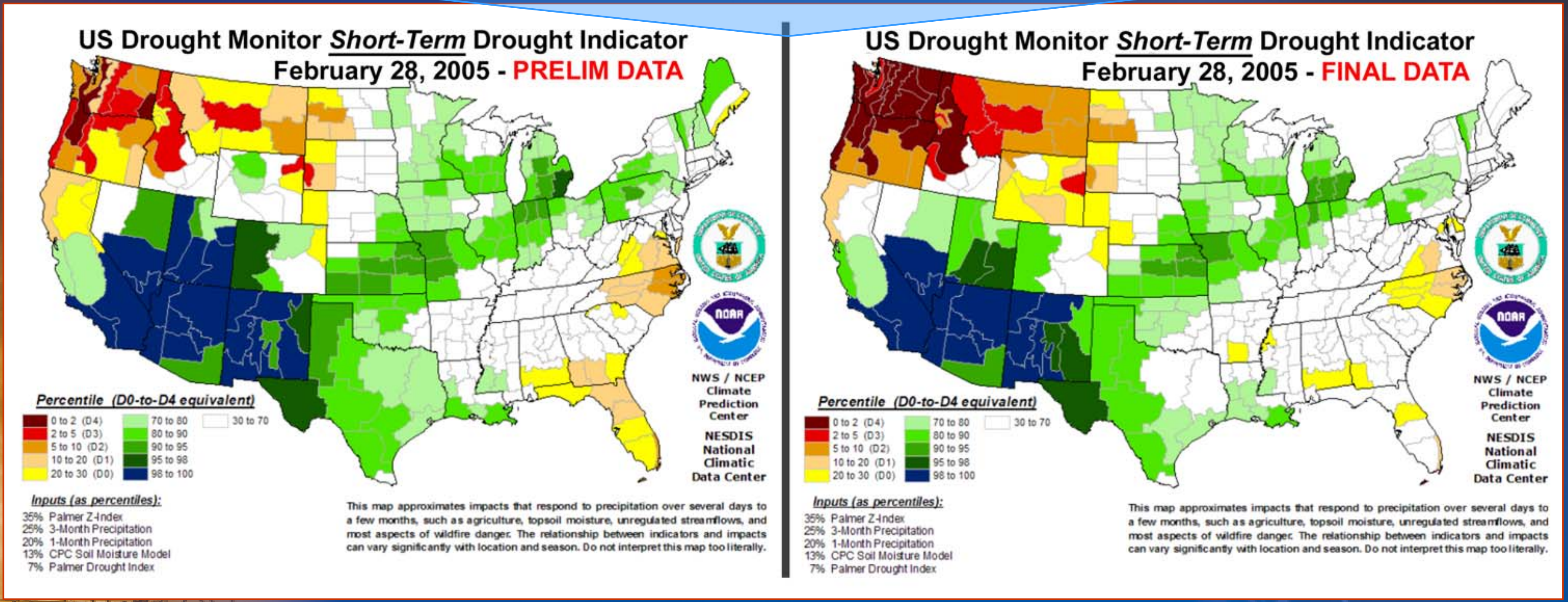


Smoothed annual anomalies for precipitation (%) over land from 1900 to 2005; other regions are dominated by variability.

Gaps in Adequate and Timely Observations

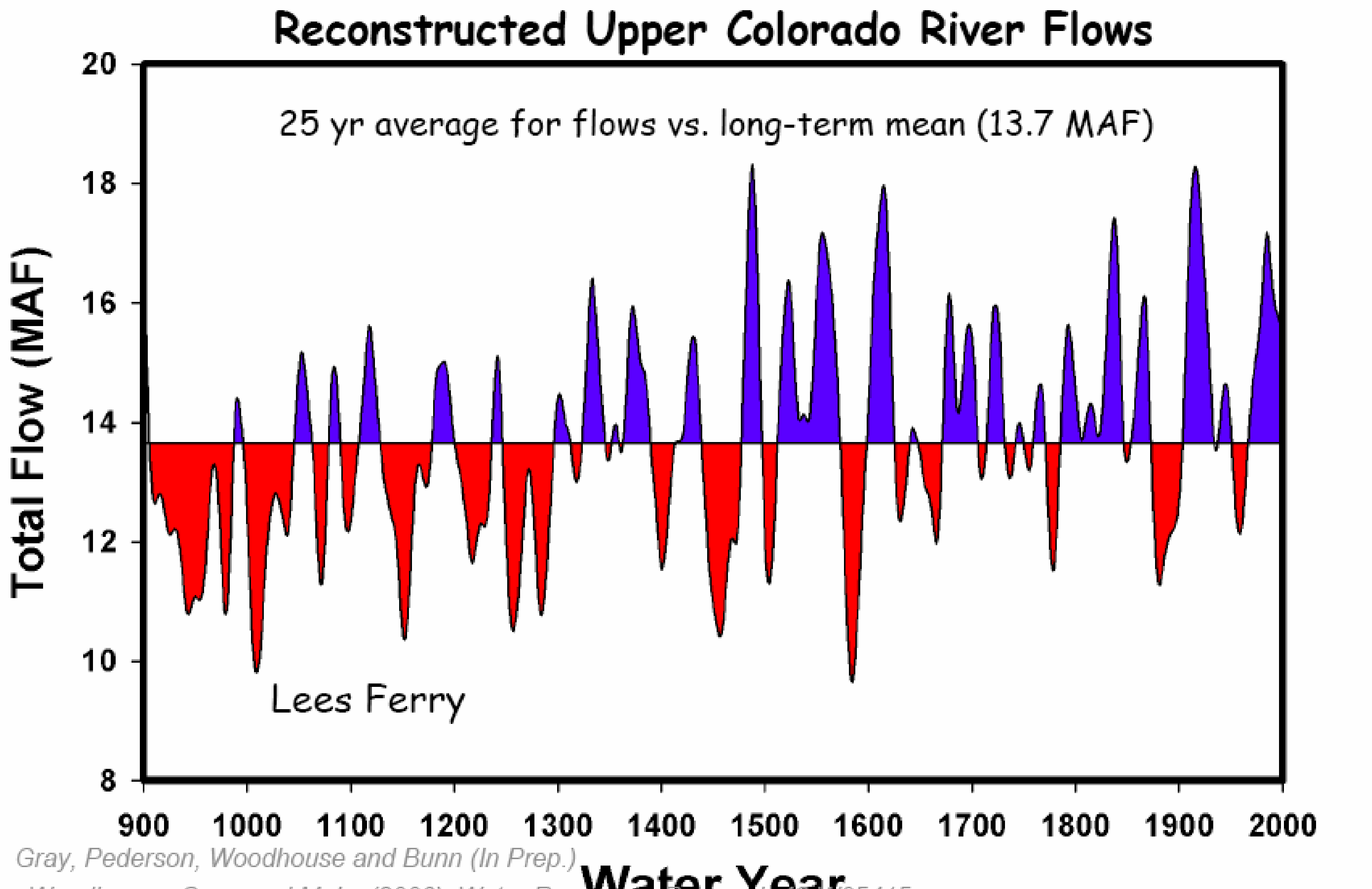
- Drought severity **can be significantly under-estimated or over-estimated due to** inadequate **drought observations.**
- **Poor estimation affects the Nation's ability to** Plan, Predict, Mitigate, and Respond.

Example Map Analysis Differences Due to Late Station Reporting



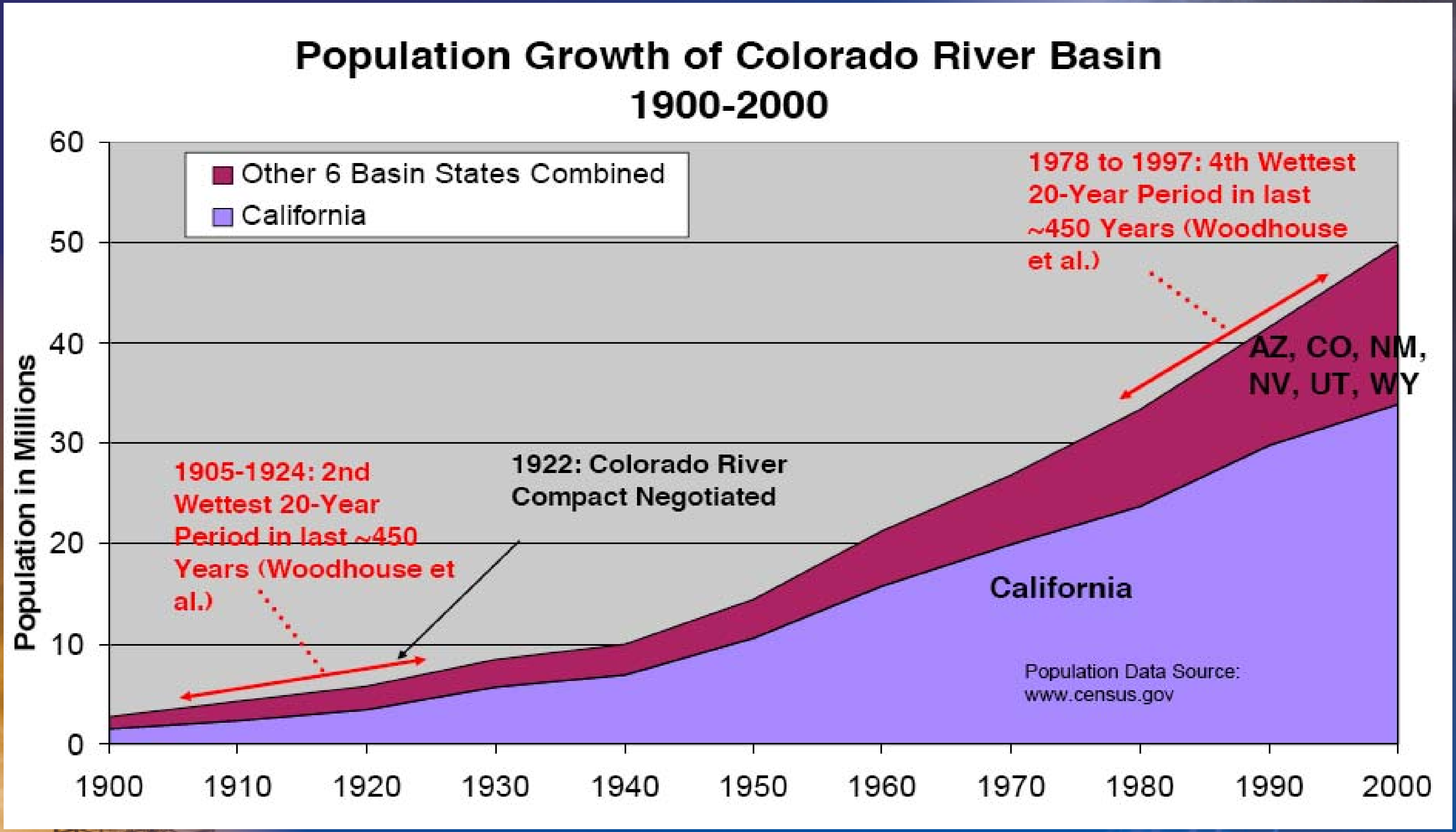
Period	Temperature Change	Precipitation Change	Storage Change	Hydropower Change
2010-2039	+1.8°F	-3%	-36%	-56%
2040-2069	+3.1°F	-6%	-32%	-45%
2079-2098	+3.6°F	-3%	-40%	-53%

Annual average changes in the Colorado Basin for future climate periods (based on Christiansen et la 2004)



Gray, Pederson, Woodhouse and Bunn (In Prep.)

Woodhouse, Gray, and Meko (2006). Water Resources Research 42:W05415


Population Growth of Colorado River Basin
1900-2000
Other 6 Basin States Combined
California
1978 to 1997: 4th Wettest 20-Year Period in last ~450 Years (Woodhouse et al.)
AZ, CO, NM, NV, UT, WY
1905-1924: 2nd Wettest 20-Year Period in last ~450 Years (Woodhouse et al.)
1922: Colorado River Compact Negotiated
California
Population Data Source: www.census.gov
Population in Millions
0
10
20
30
40
50
60
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000