Hydro-Climate of Arizona

JON SKINDLOV
Climatologist/Meteorologist
Salt River Project, Phoenix

NAU 2006 Field School in Water Science
for K-12 Educators
April 20, 2006

Delivering More Than Power.

Geography

Causes of Drought and Flood

The Historical Record

The Future of Water in Arizona

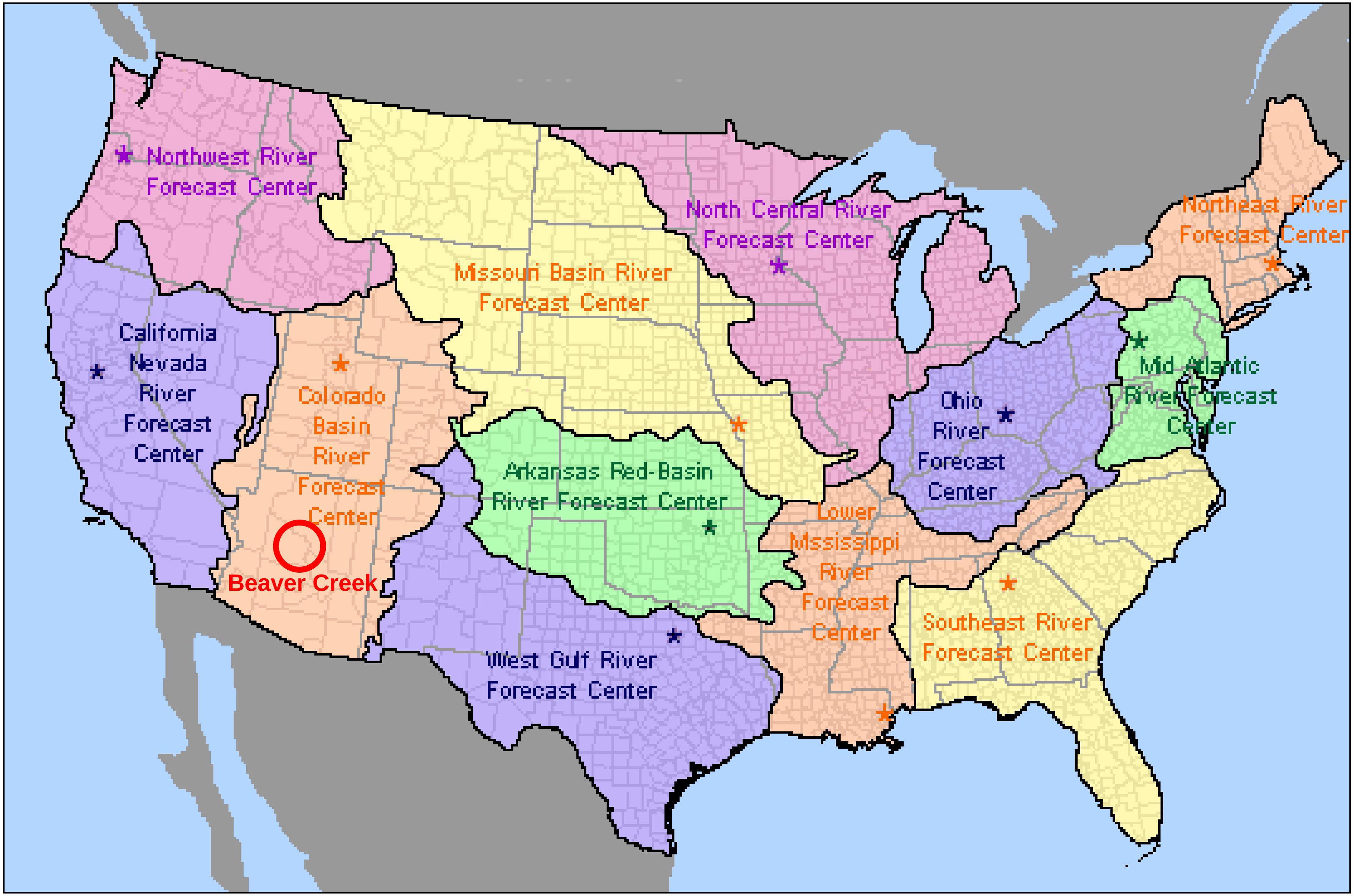
Salt River Project

- **Salt River Valley Water Users Association**
- **Established 1903**
- **A Federal reclamation project**
- **Private corporation**
- **Delivers almost 1 million acre-feet per year**

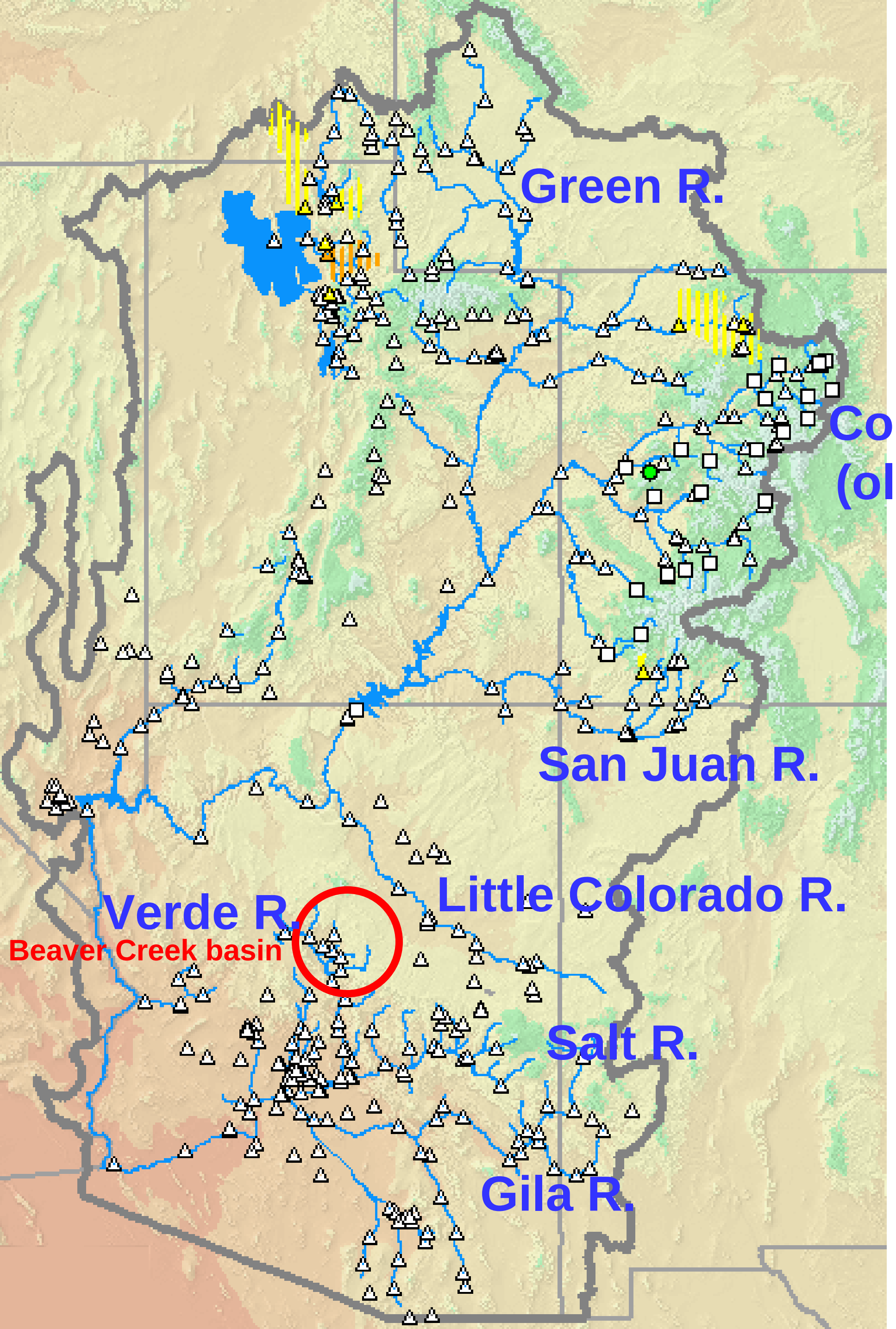
www.srpnet.com

- **SRP Agricultural Improvement and Power District**
- Established 1937 as a political subdivision of the state of Arizona
- 35,516 million kWh sold in FY05
- Over 850,000 customers in and around the Phoenix metro area

Geography



National Weather Service River Basins

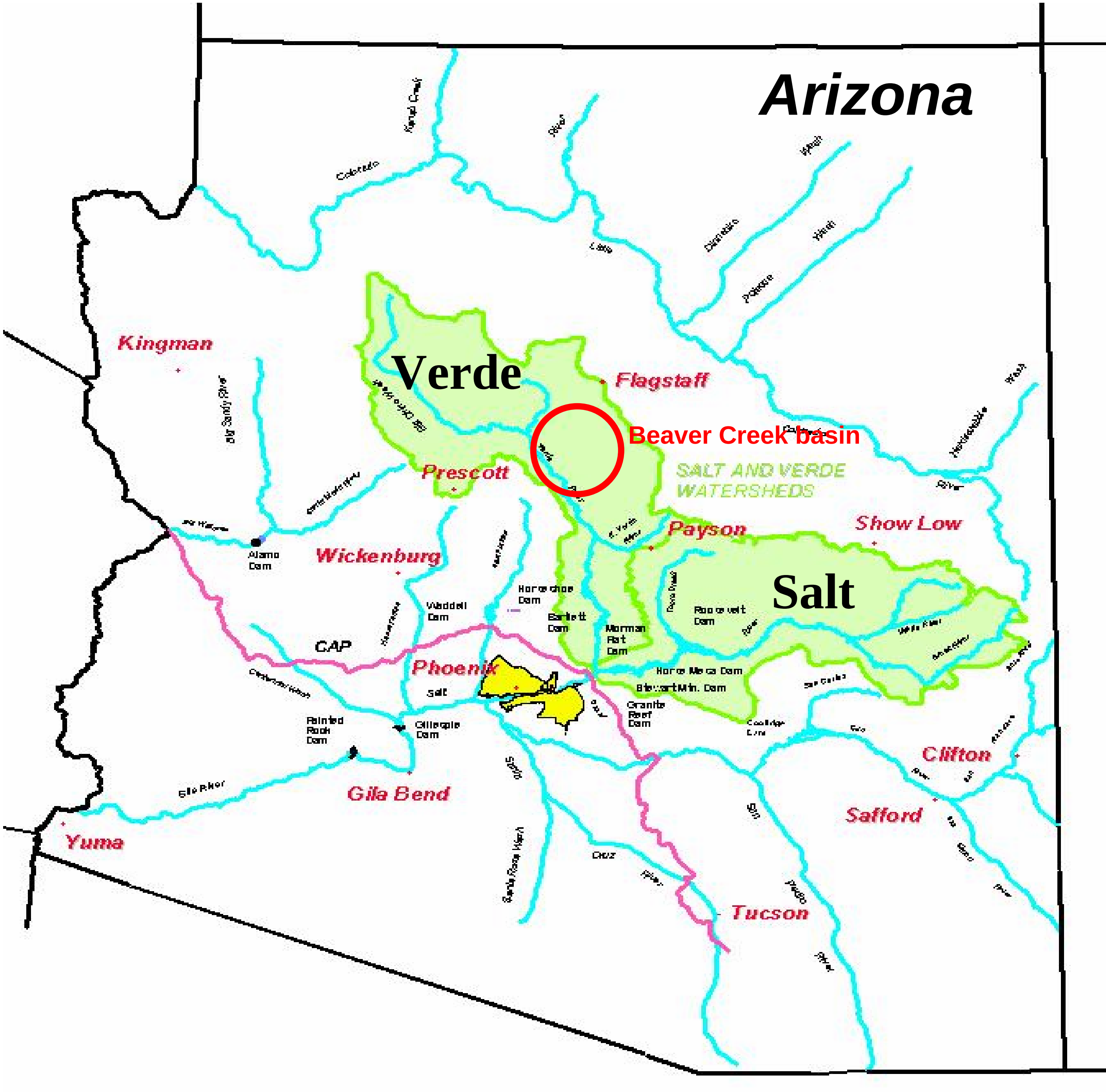


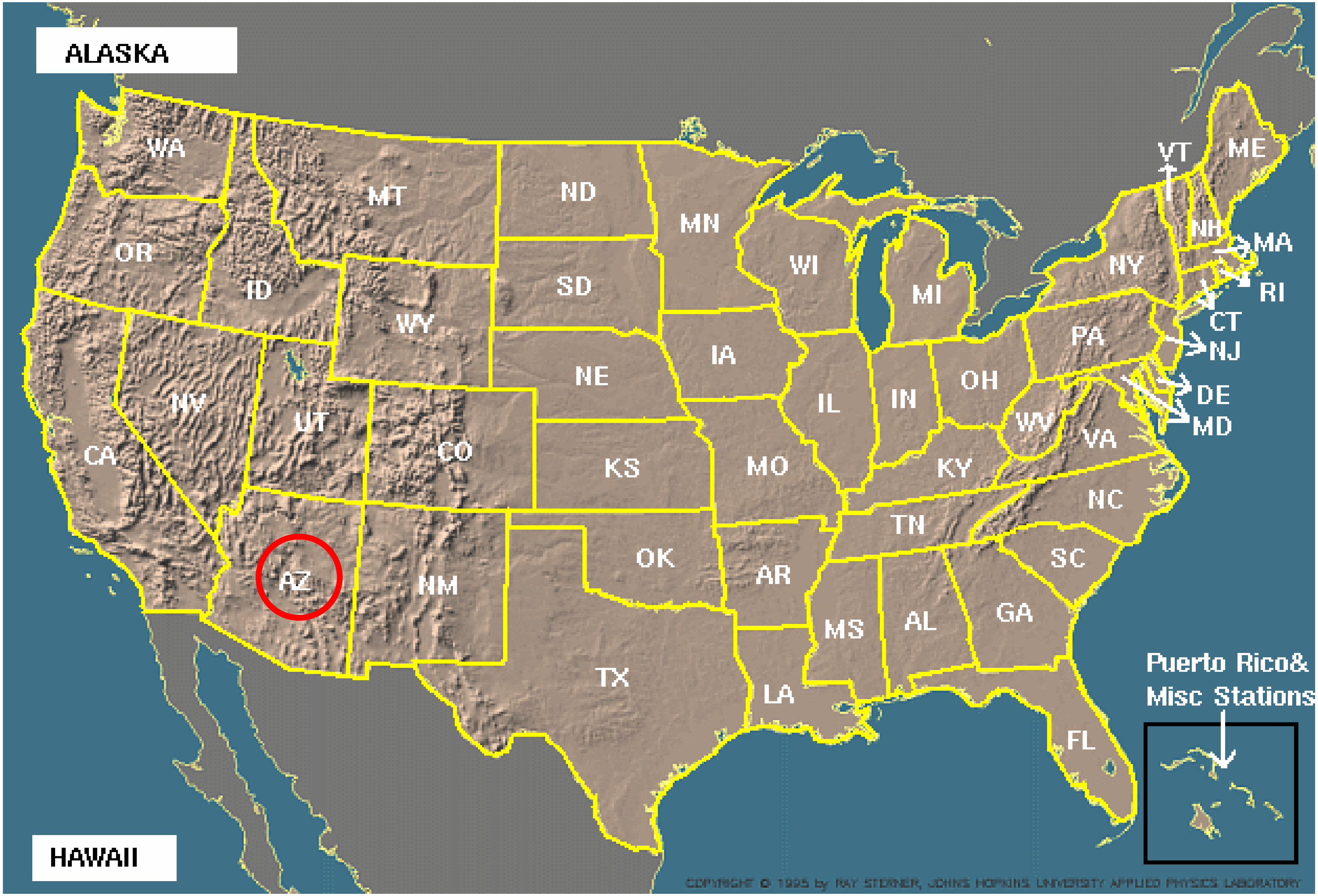
NWS

Colorado Basin River Forecast Center

area

http://www.cbrfc.noaa.gov/


Arizona
Verde
Salt
Beaver Creek basin
SALT AND VERDE WATERSHEDS
Kingman
Flagstaff
Prescott
Payson
Show Low
Wickenburg
Phoenix
CAP
Gila Bend
Yuma
Clifton
Safford
Tucson
Alamo Dam
Waddell Dam
Horseshoe Dam
Bartlett Dam
Roosevelt Dam
Horse Mesa Dam
Stewart Mtn. Dam
Granite Reef Dam
Gillespie Dam


ALASKA
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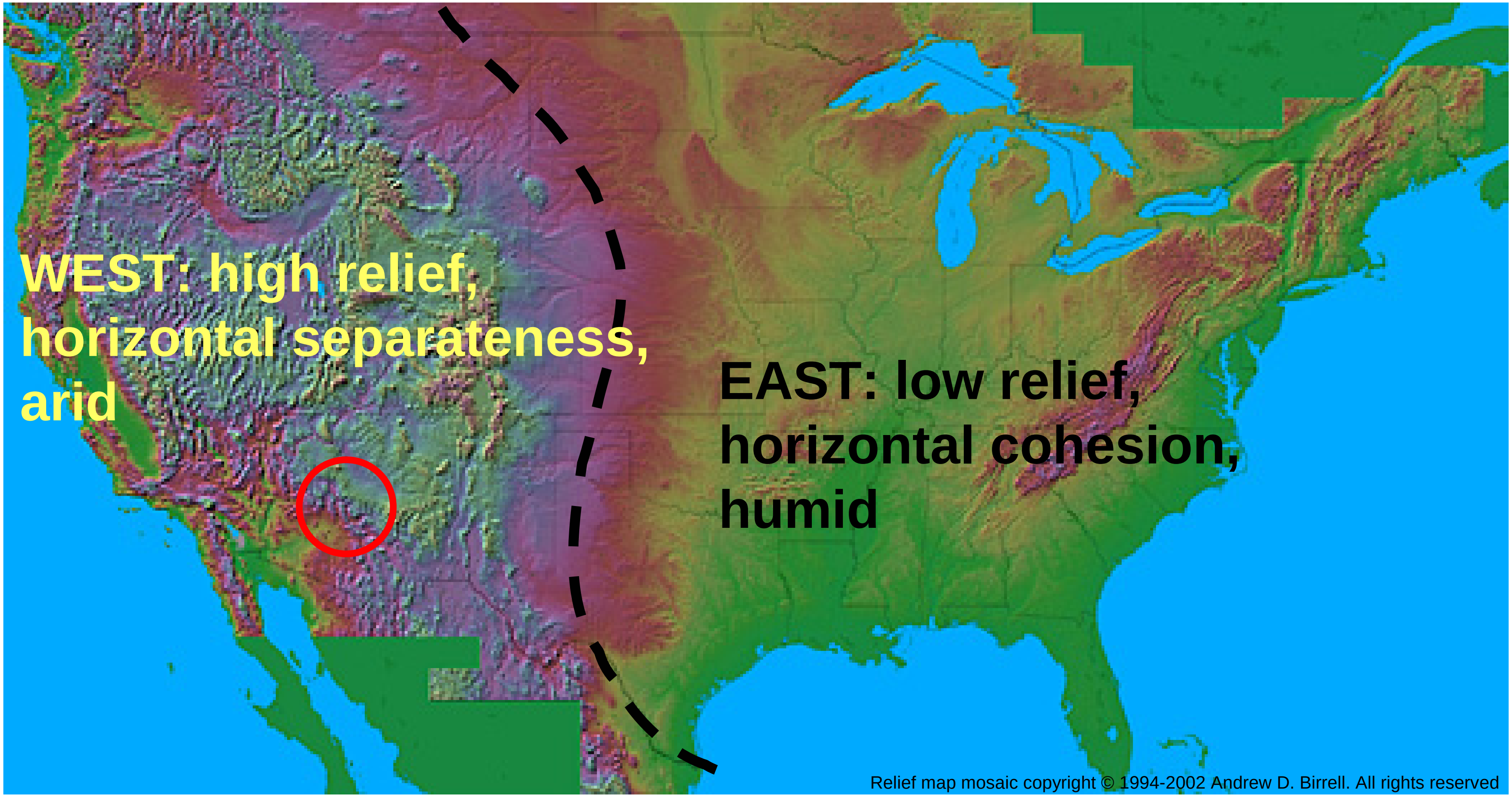
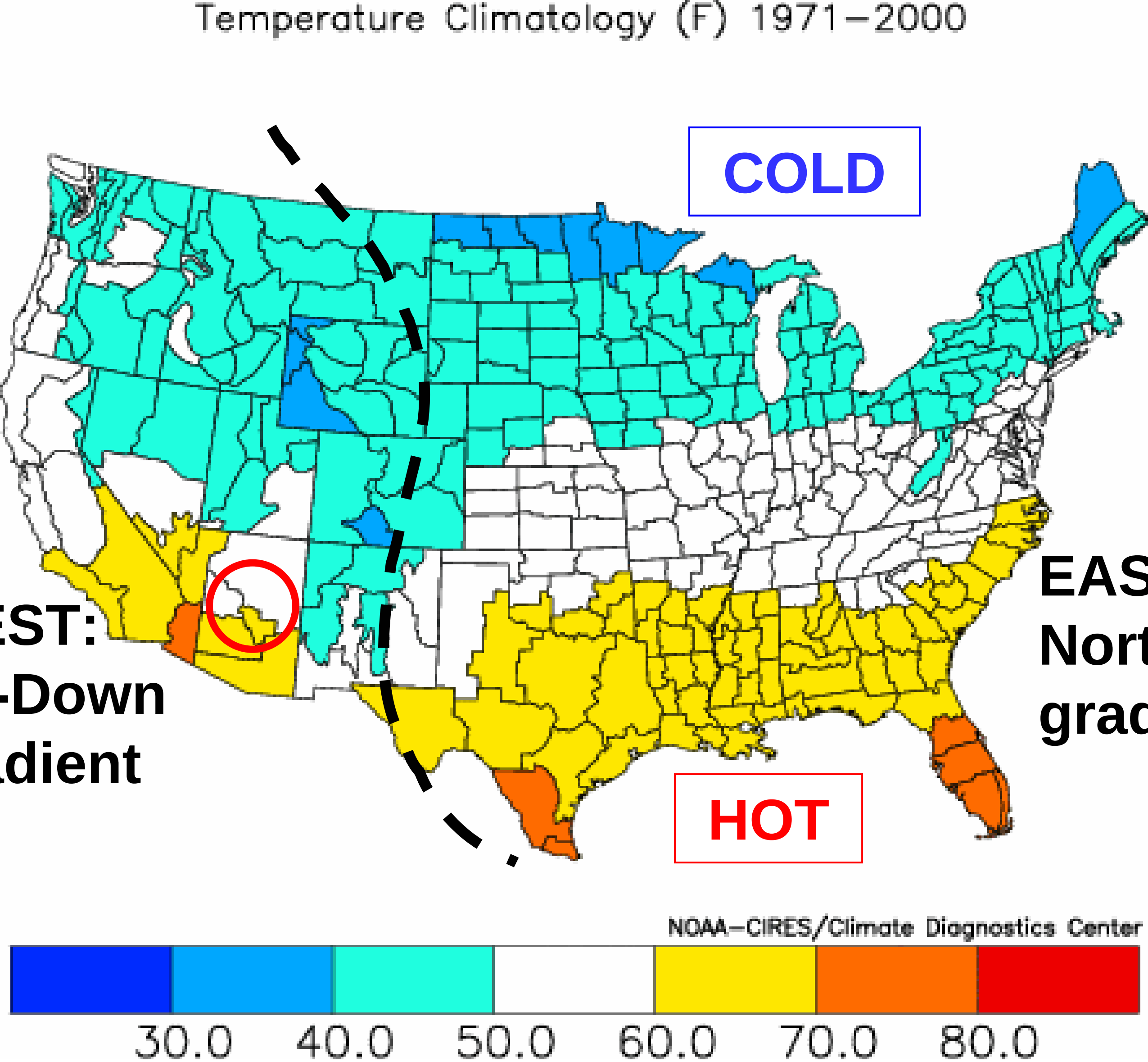


Climatic Differences



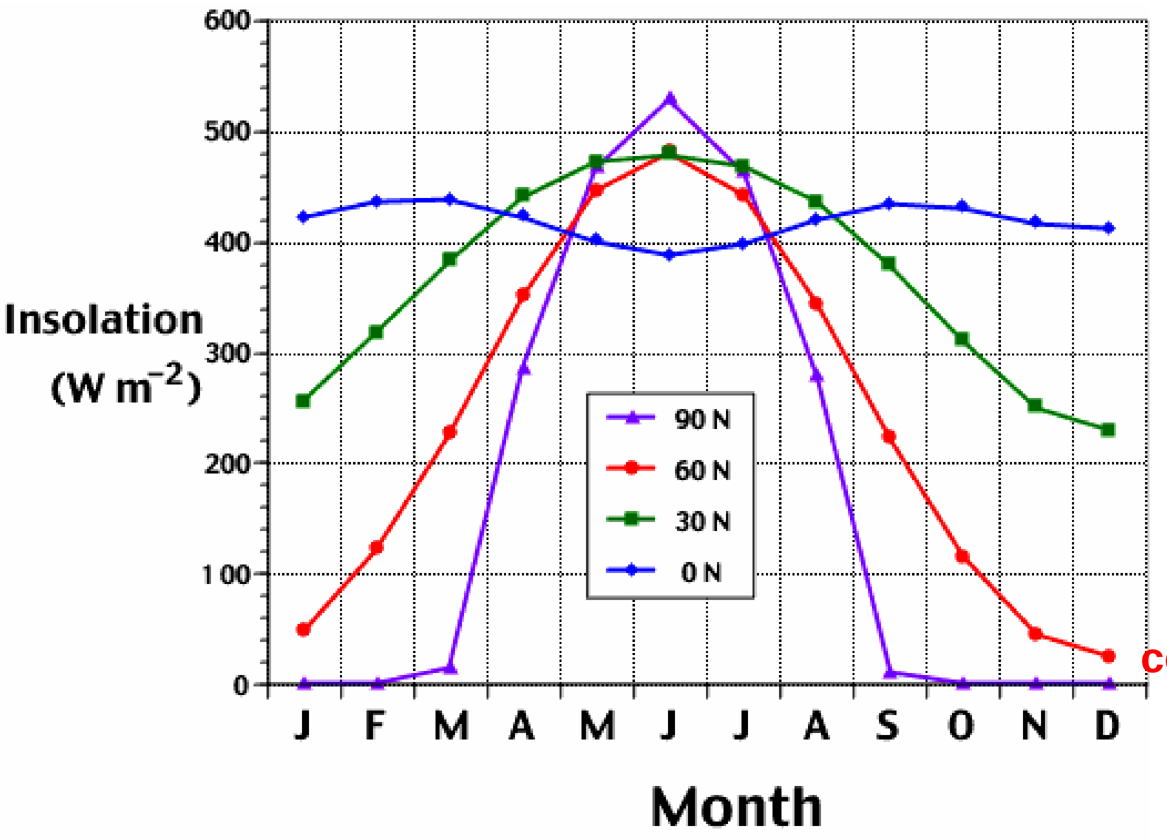
WEST:
Up-Down gradient

EAST:
North-South gradient

Annual Average Temperature, 1971-2000

http://www.cdc.noaa.gov

Monthly values of available **insolation** for the equator, 30, 60, and 90° North.



Arizona, Gulf Coast

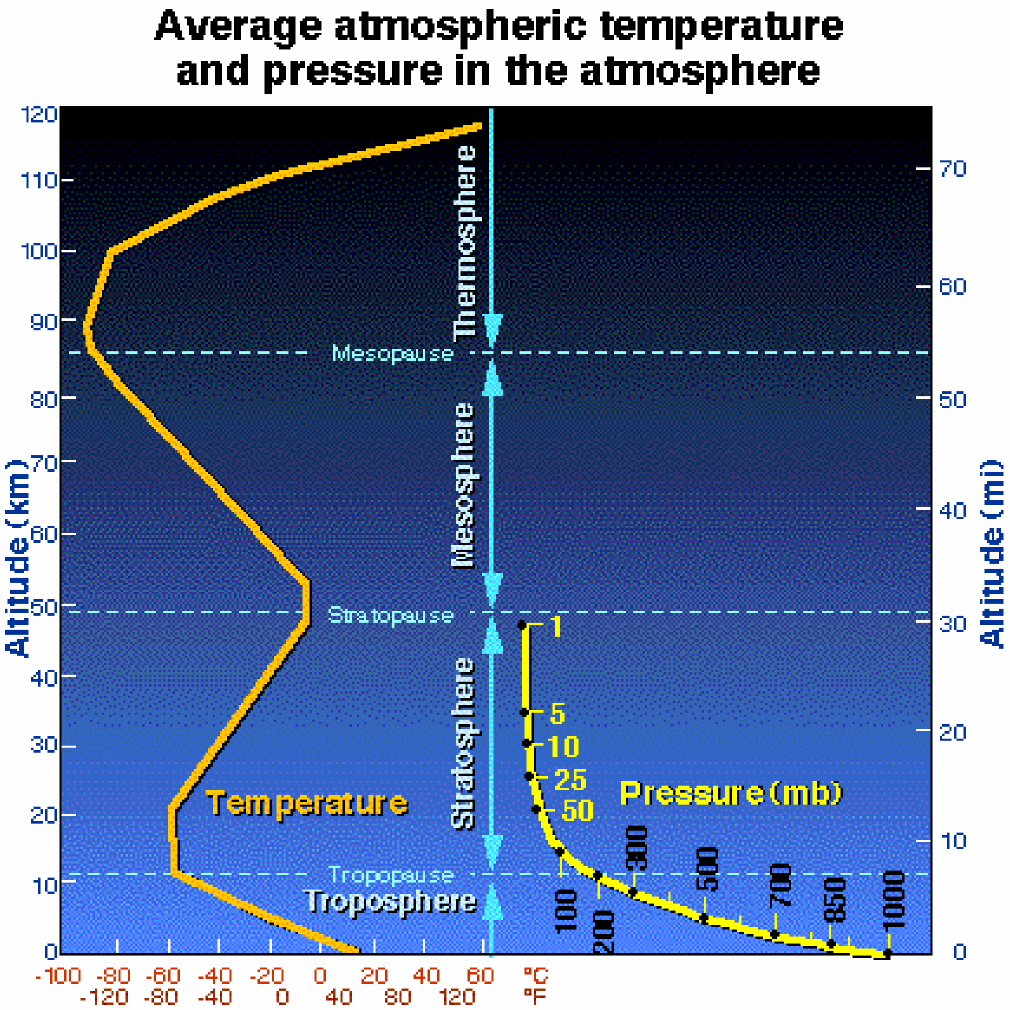
central Canada

INSOLATION (INcoming SOLar radiATION)

Direct or diffused shortwave solar radiation that is received in the Earth's atmosphere or at its surface.

PhysicalGeography.net

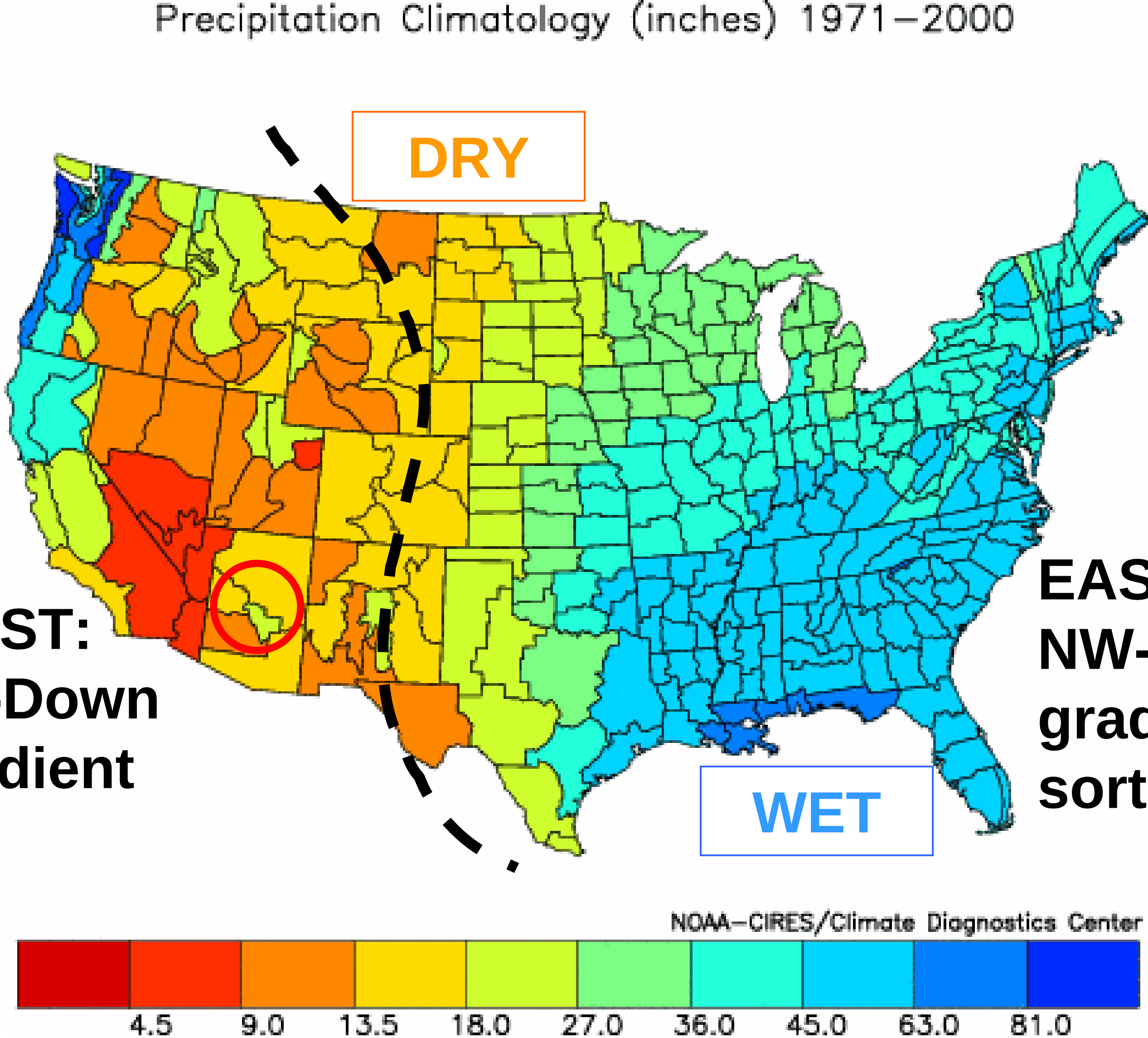
http://www.physicalgeography.net/home.html



Lapse Rate

Rate of change of temperature with height. In the troposphere, the lapse rate in **dry air** is about **5.5ºF per 1000 feet**. The **average lapse rate** with some moisture in the air is about **3.6ºF per 1000 feet**.

http://okfirst.ocs.ou.edu/train/meteorology/VertStructure2.html

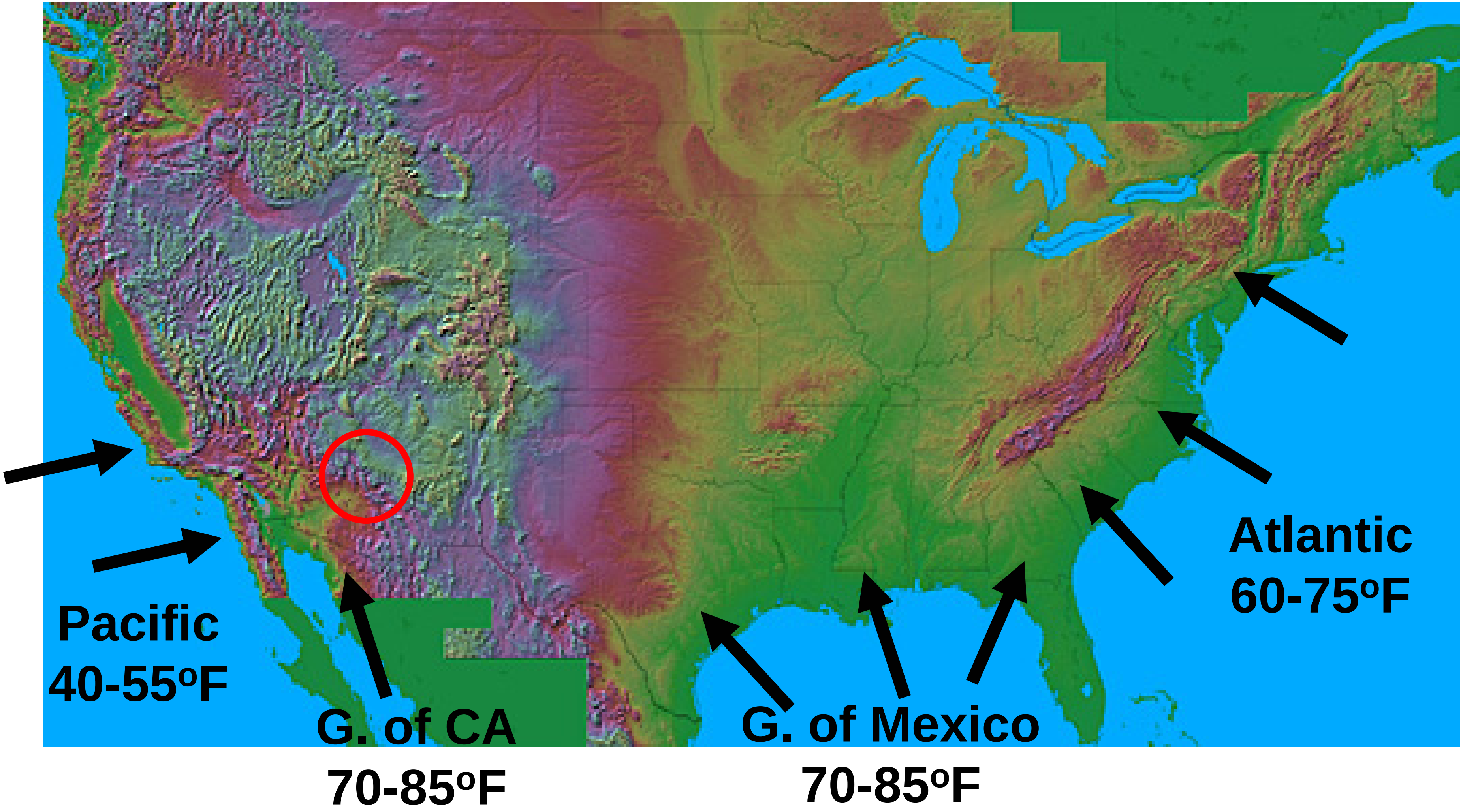


WEST:
Up-Down gradient

EAST:
NW-to-SE gradient… sort of

Annual Total Precipitation, 1971-2000

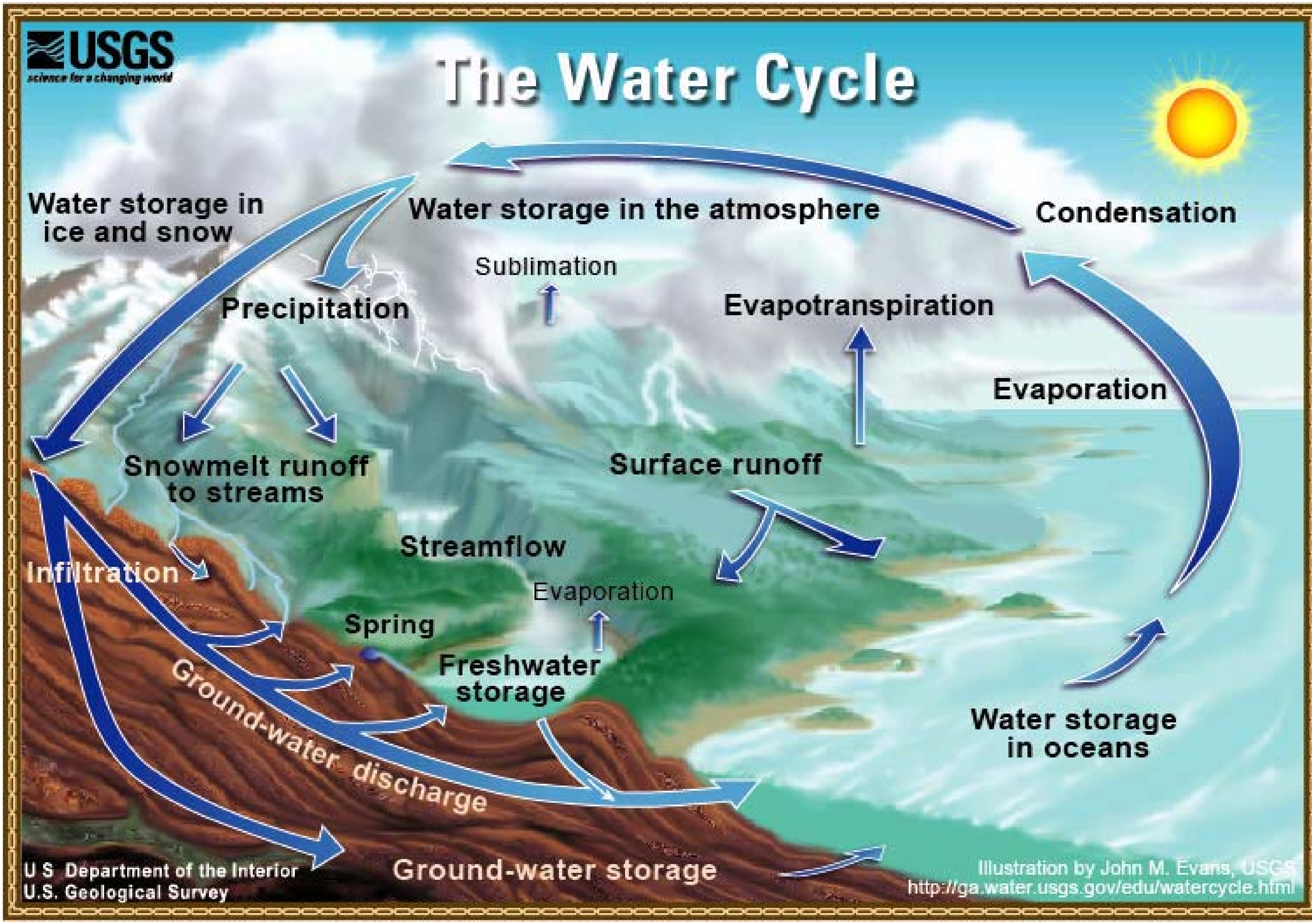
http://www.cdc.noaa.gov



Moisture Sources

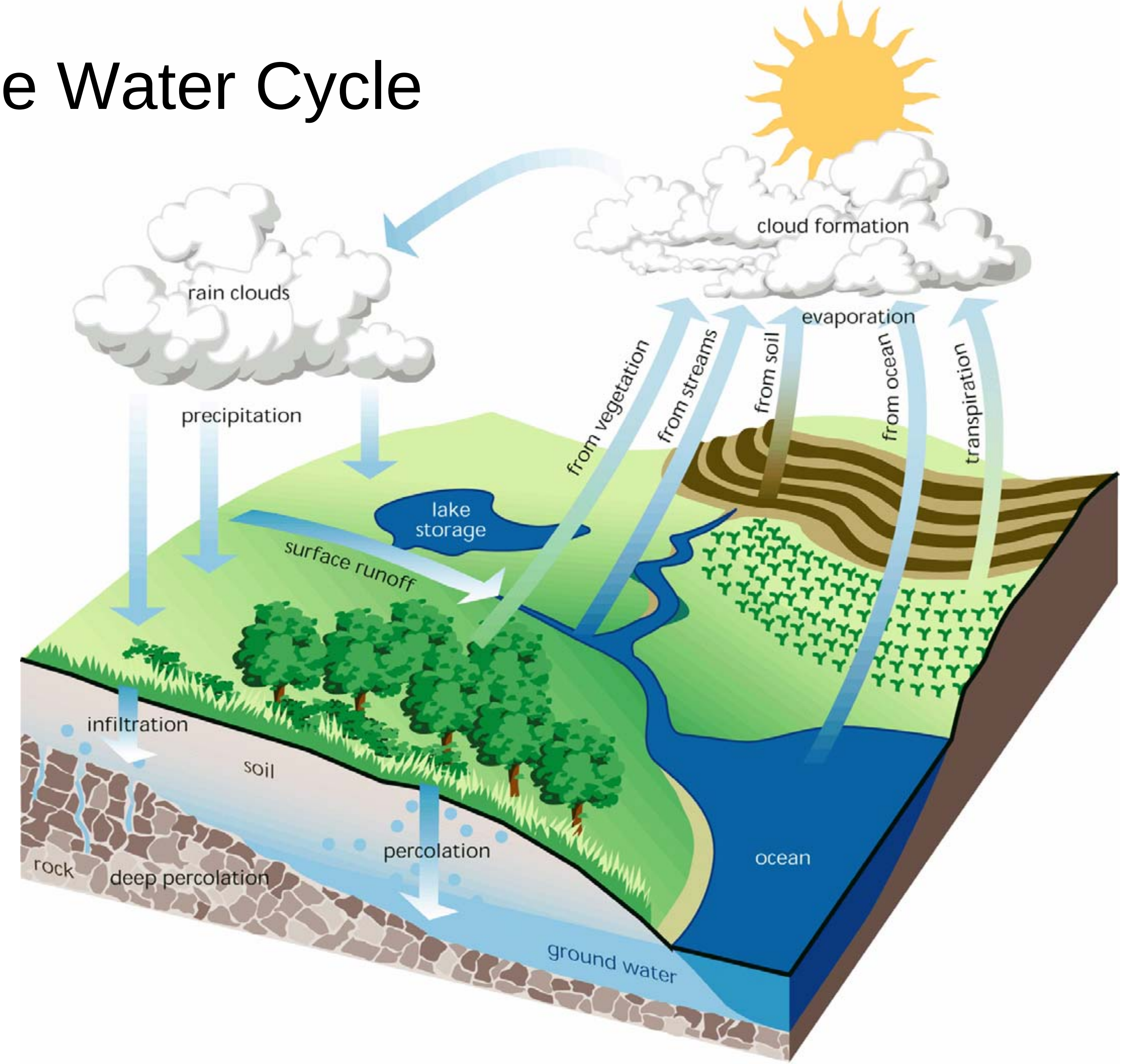
and associated sea surface temperature ranges

Causes of Drought and Flood

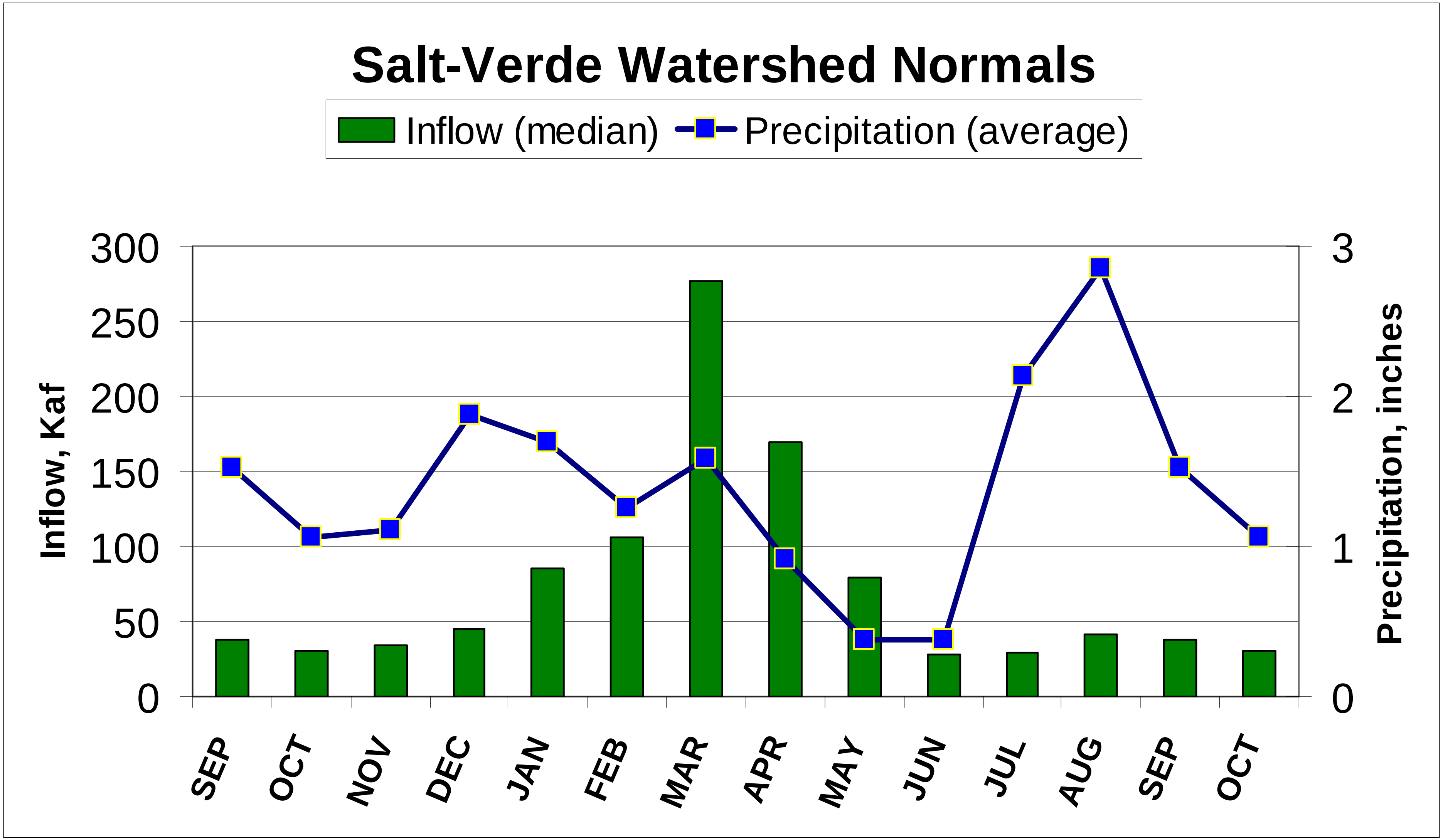


http://ga.water.usgs.gov/edu/watercycle.html

The Water Cycle



NAU Sustainable Water Resources Alliance http://www.cet.nau.edu/Projects/SWRA/research.html



WINTER:	SUMMER:
Precip. (Dec-Mar): 6.3 in	Precip. (Jul-Sep): 6.8 in
Runoff (Dec-May): 665 Kaf	Runoff (Jul-Sep): 120 Kaf

SRP Water Resource Operations: jas 04/2006

shed Normals

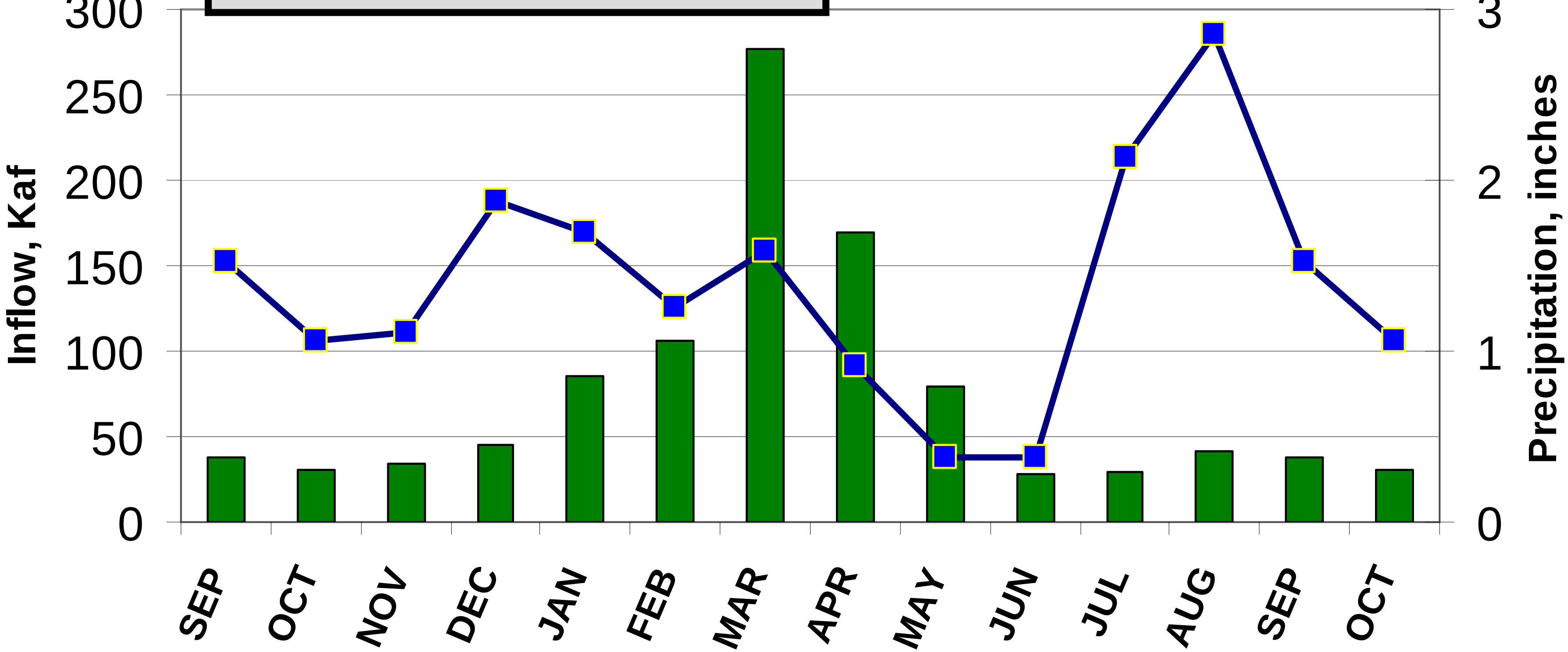
Precipitati

WINTER:

Precipitation (P) >> Evapotranspiration (ET)

SUMMER:

ET >> P



WINTER:

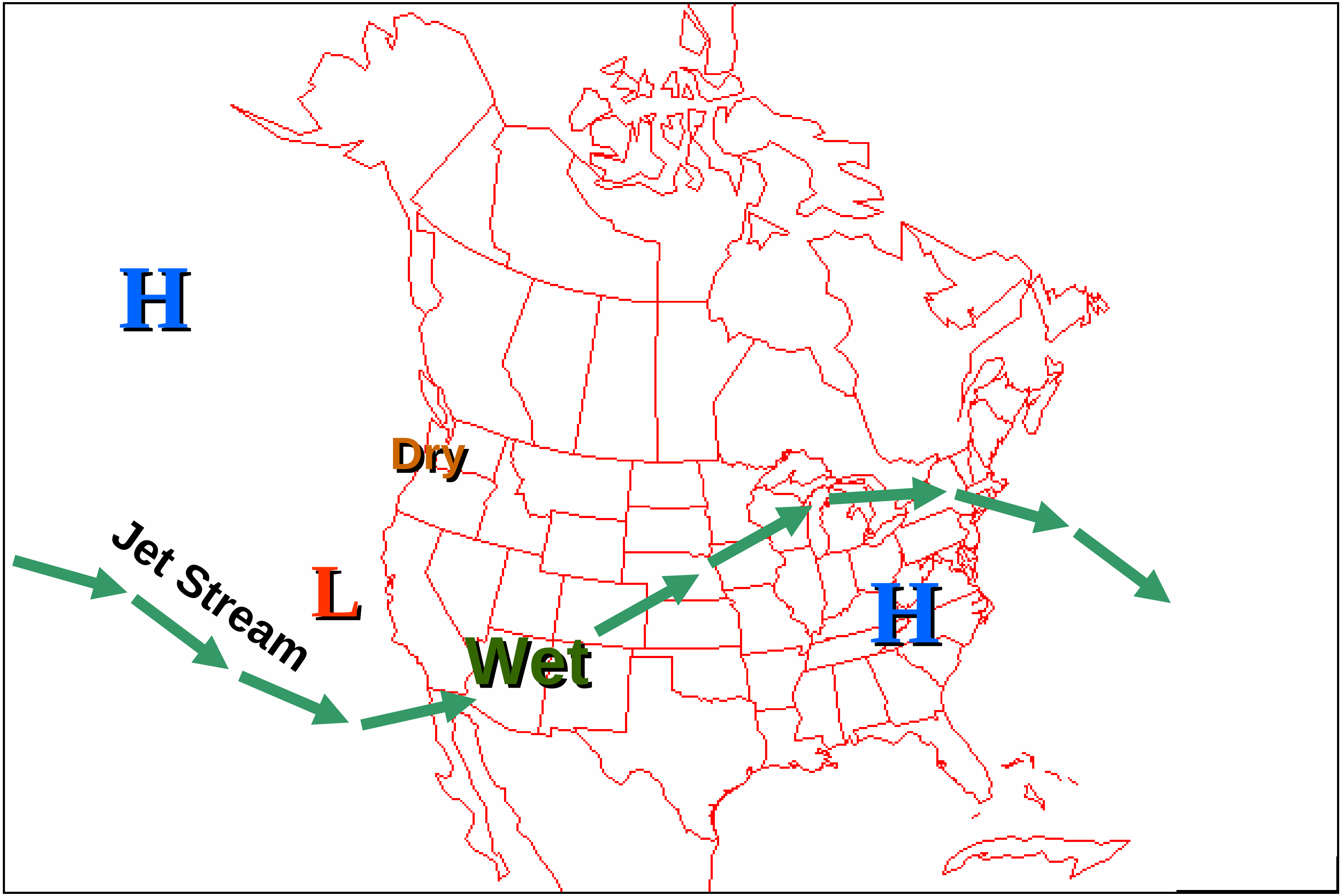
Precip. (Dec-Mar): <u>6.3</u> in

Runoff (Dec-May): <u>665</u> Kaf

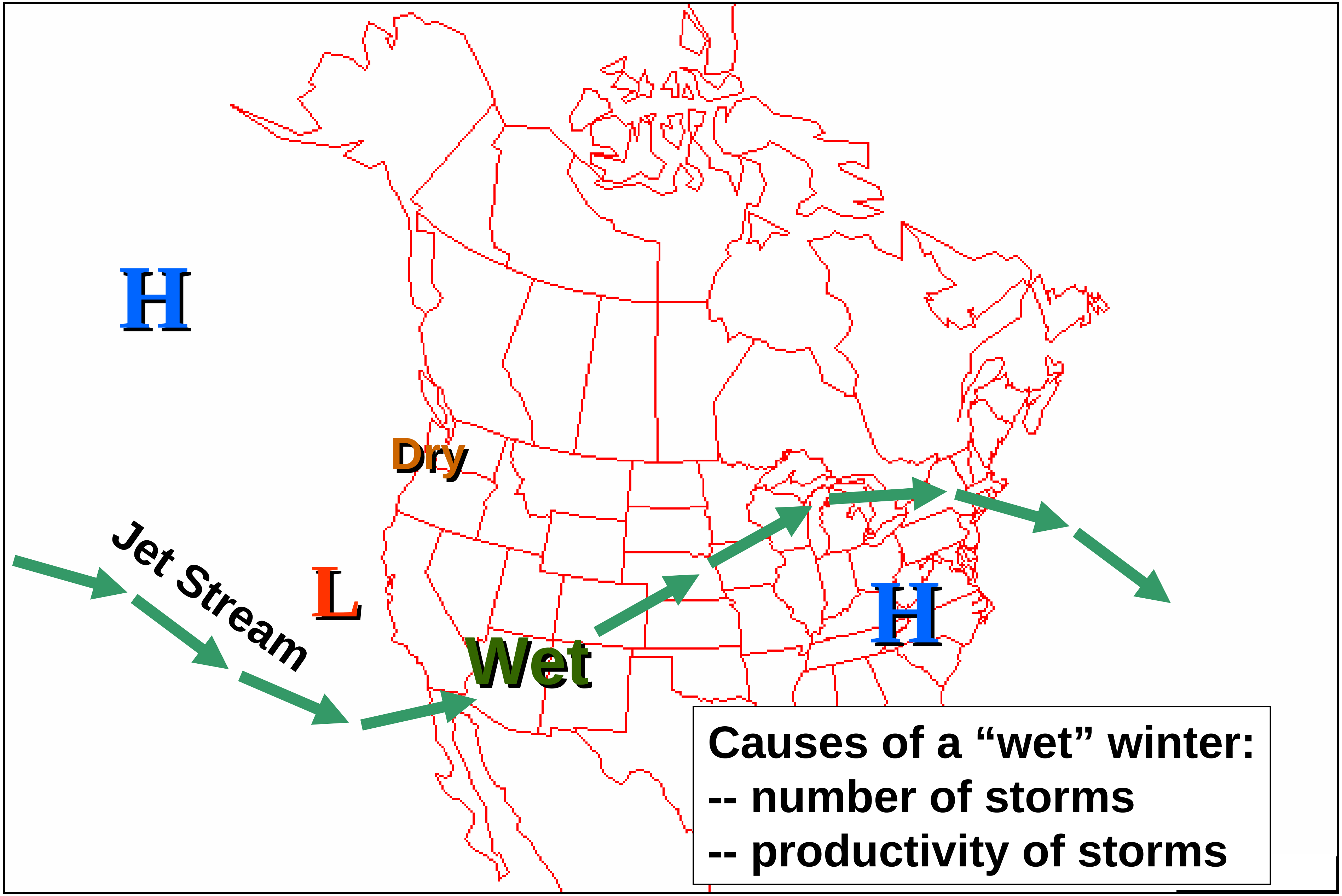
SUMMER:

Precip. (Jul-Sep): <u>6.8</u> in

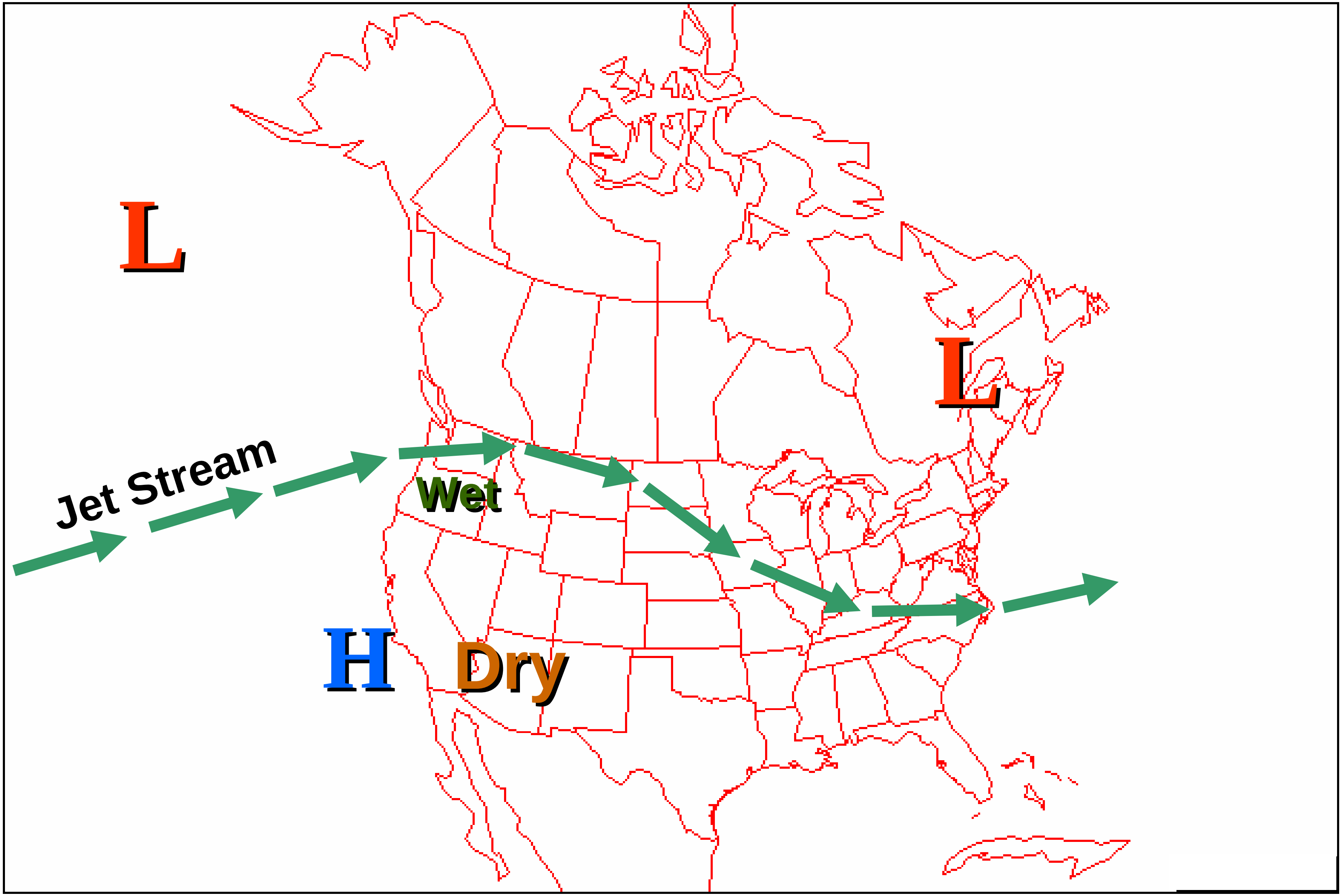
Runoff (Jul-Sep): <u>120</u> Kaf



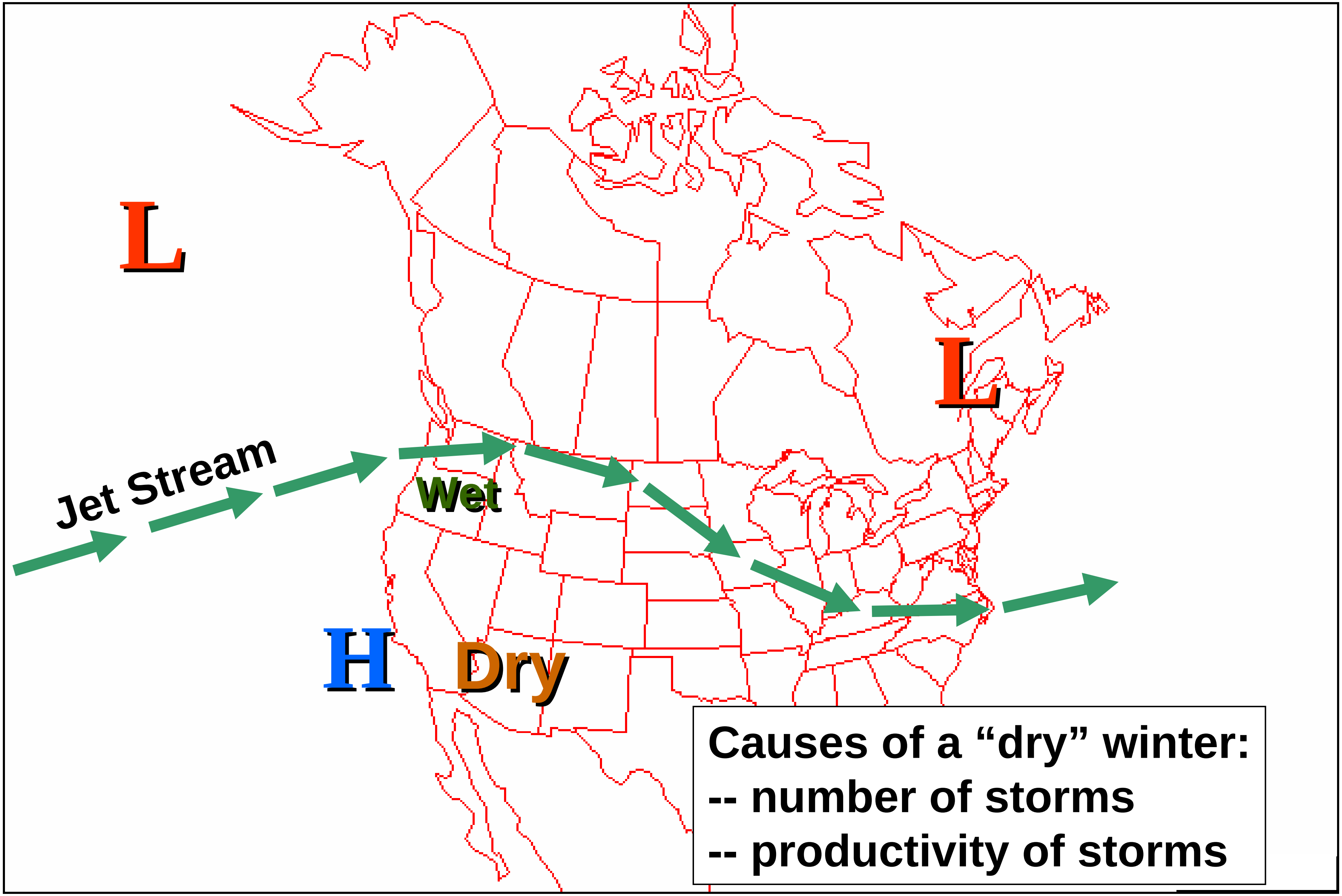
Winter Weather Patterns



Winter Weather Patterns



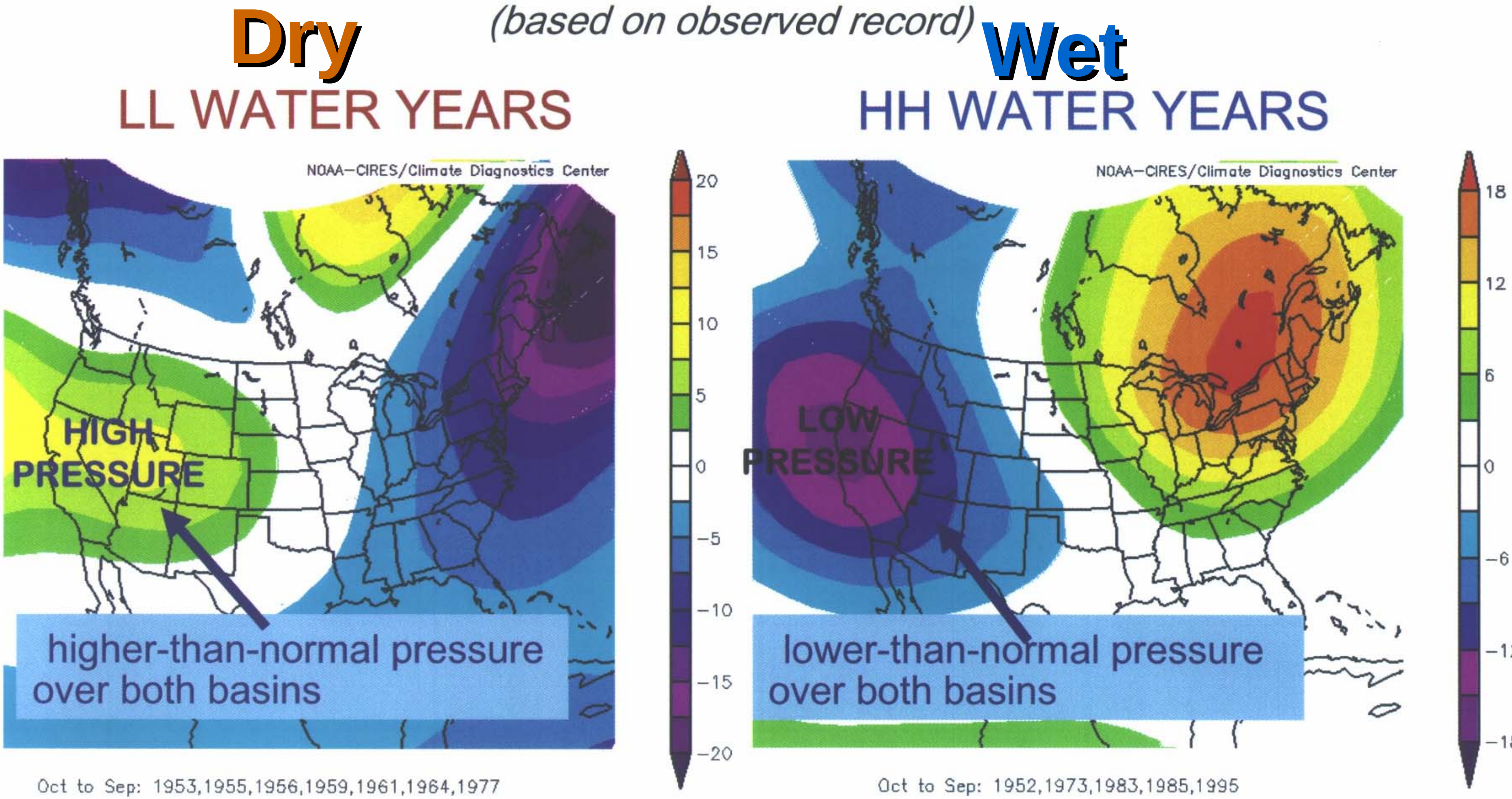
Winter Weather Patterns



Winter Weather Patterns

Atmospheric Circulation Anomalies

(based on observed record)



500 mb Geopotential Height (m) Composite Anomaly, Oct-Sep water year

http://fpcluster.ccit.arizona.edu/khirschboeck/srp.htm

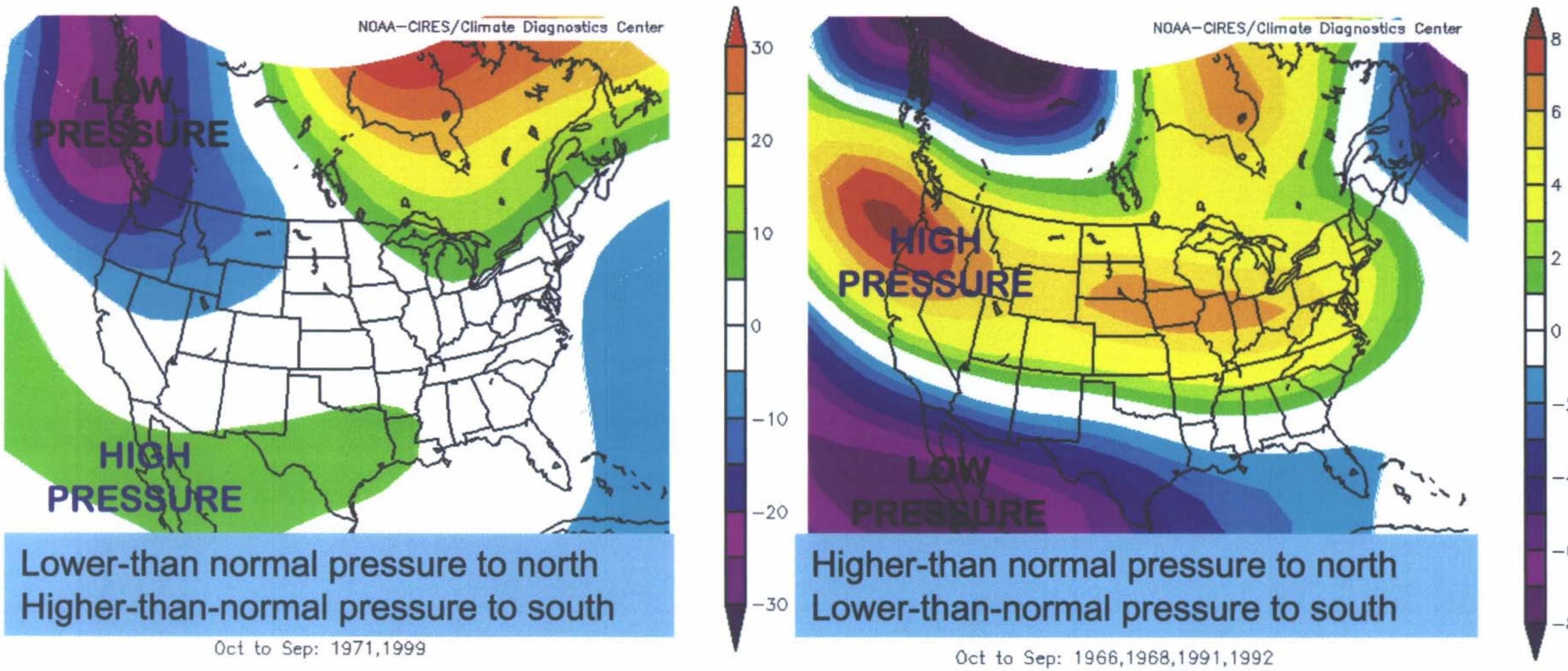
Atmospheric Circulation Anomalies for Observed Years with Streamflow in Opposite Direction

HL WATER YEARS

High flow in Upper Colorado
Low flow in Salt-Verde-Tonto

LH WATER YEARS

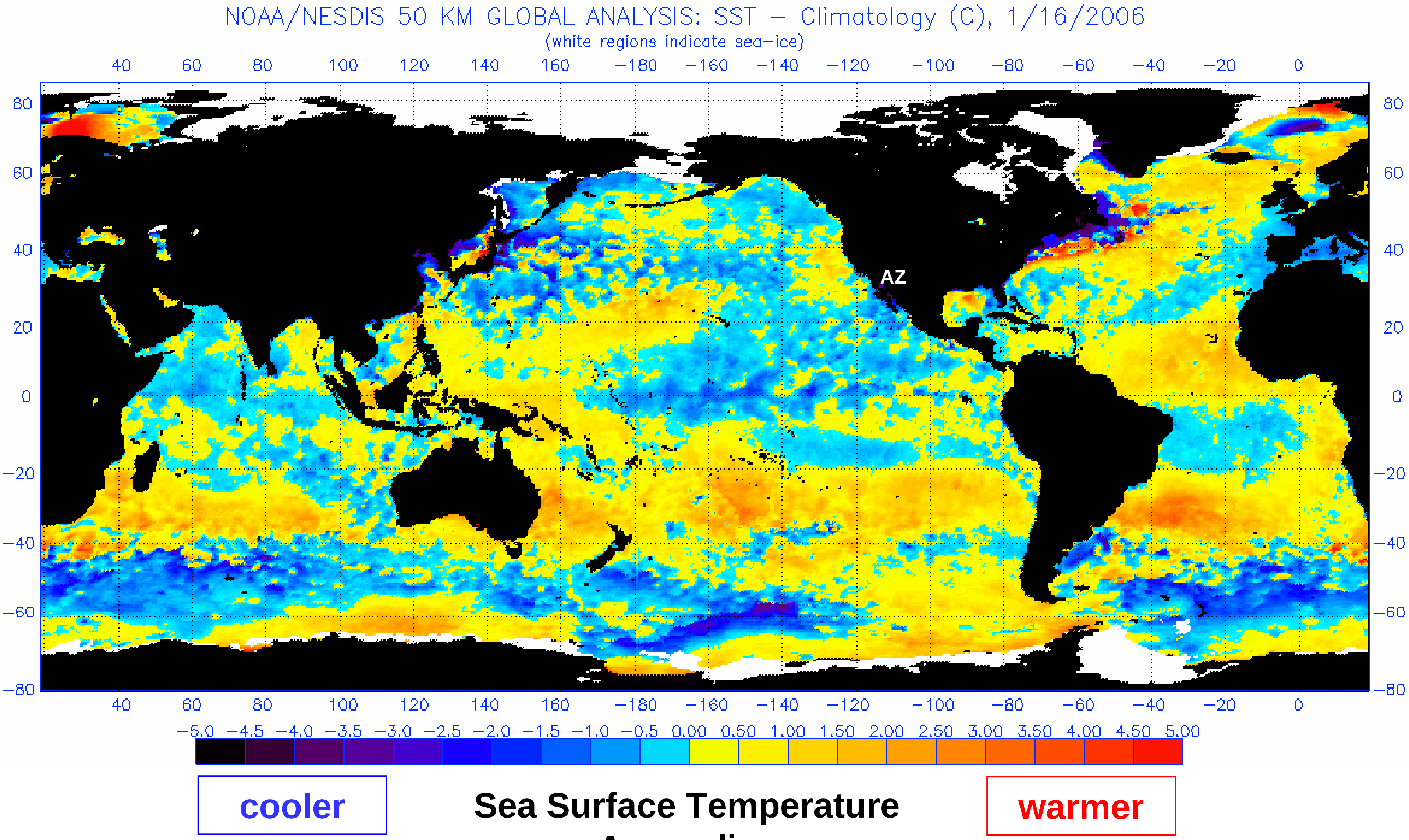
Low flow in Upper Colorado
High flow in Salt-Verde-Tonto



500 mb Geopotential Height (m) Composite Anomaly, Oct-Sep

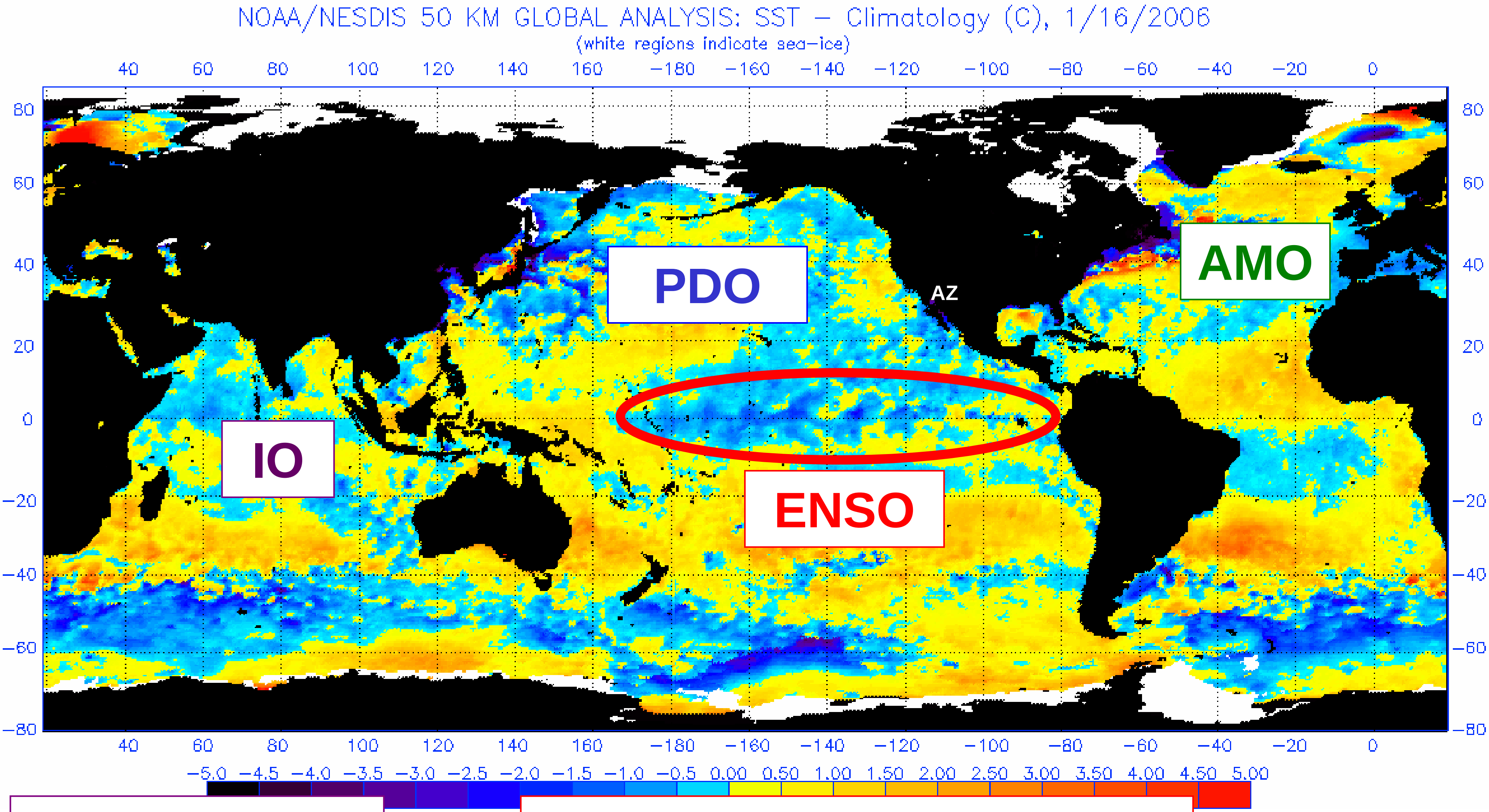
http://fpcluster.ccit.arizona.edu/khirschboeck/srp.htm

Influence of Ocean Surface Temperatures on Western U.S. Winter Precipitation



Sea Surface Temperature Anomalies

Influence of Ocean Surface Temperatures on Western U.S. Winter Precipitation



IO: Indian Ocean

ENSO: El Niño/Southern Oscillation

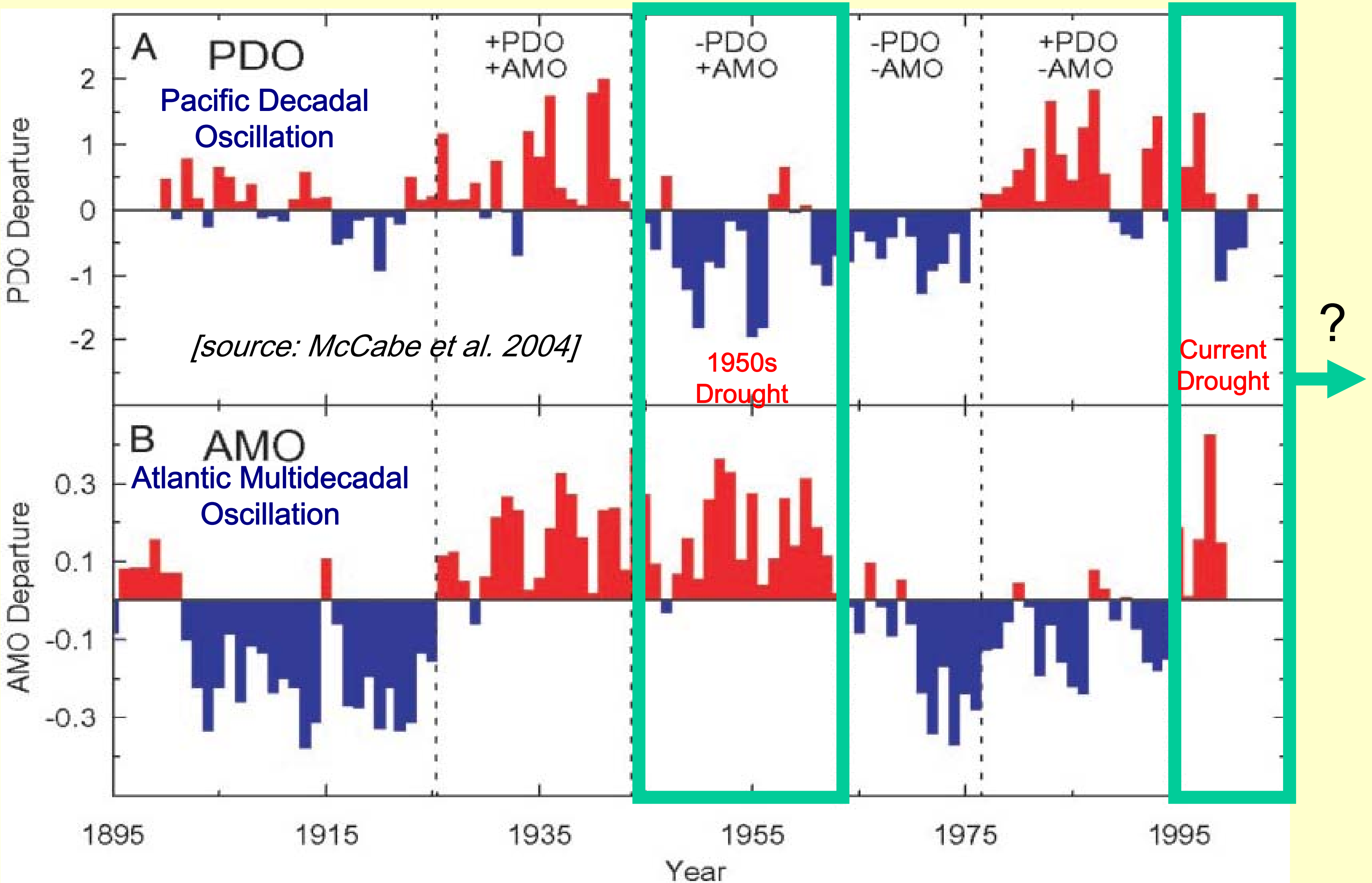
PDO: Pacific Decadal Oscillation

AMO: Atlantic Multi-decadal Oscillation

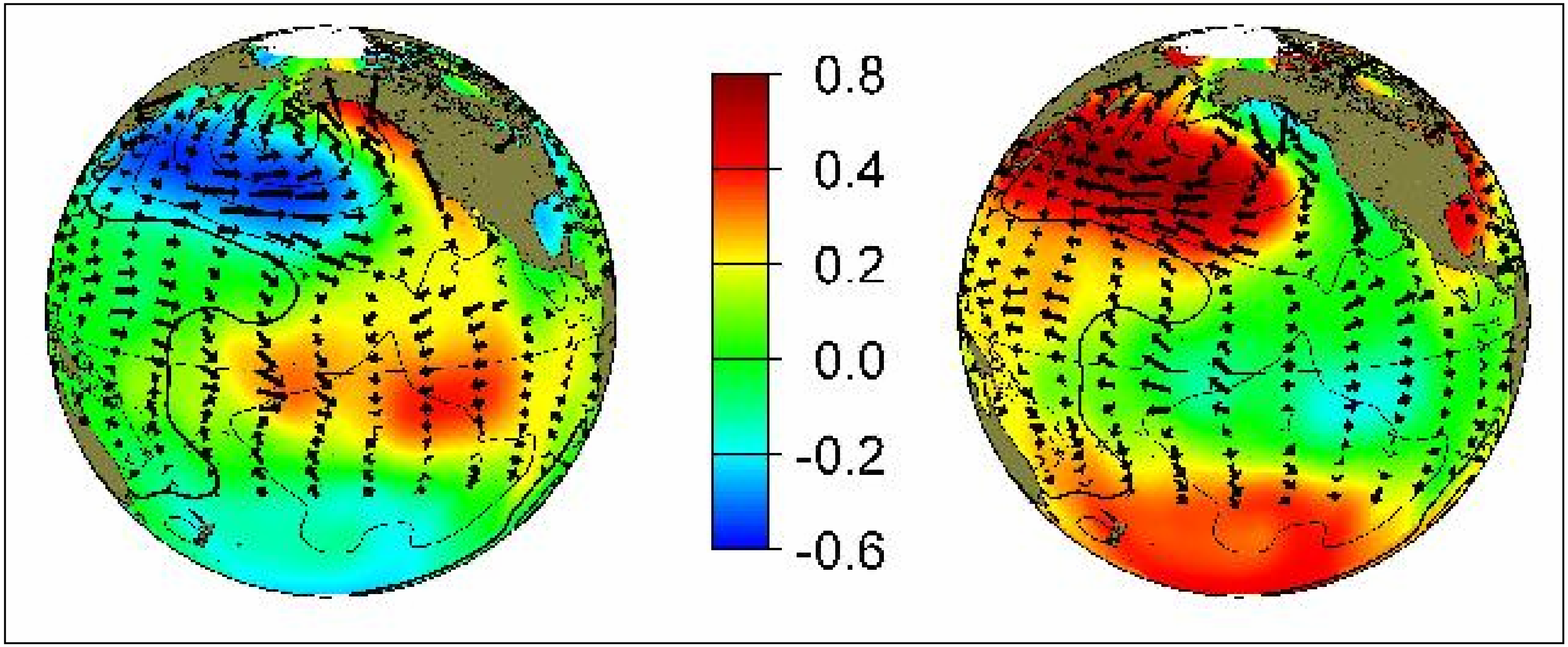
What are the ultimate drivers of these circulation anomalies?

One current hypothesis: Multi-decadal drought scenarios in western U.S. may be linked to North Pacific & North Atlantic Ocean SST Indices

– PDO (cool NE + tropical Pacific) and + AMO (warm North Atlantic)



Pacific Decadal Oscillation (PDO)



WARM (positive) phase

COOL (negative) phase

Image courtesy of Stephen Hare and Nathan Mantua, University of Washington, units are degrees Celsius

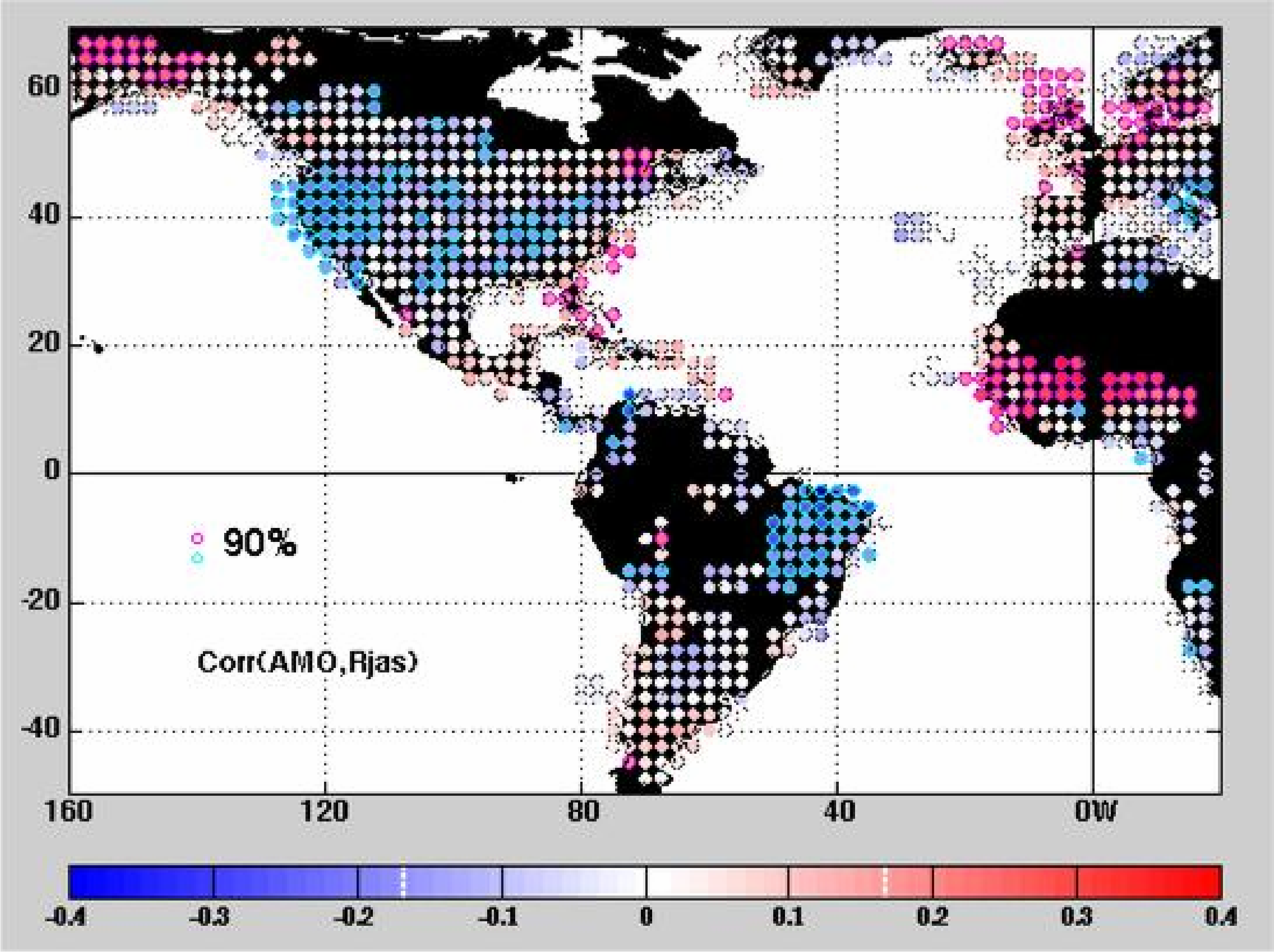
http://jisao.washington.edu/pdo/

Table 1: summary of North American climate anomalies associated with extreme phases of the PDO.

climate anomalies	Warm (+) Phase PDO	Cool (-) Phase PDO
Ocean surface temperatures in the northeastern and tropical Pacific	Above average	Below average
October-March northwestern North American air temperatures	above average	Below average
October-March Southeastern US air temperatures	below average	Above average
October-March southern US/Northern Mexico precipitation	Above average	Below average
October-March Northwestern North America and Great Lakes precipitation	Below average	Above average
Northwestern North American spring time snow pack	below average	Above average
Winter and spring time flood risk in the Pacific Northwest	Below average	Above average

http://www.atmos.washington.edu/~mantua/REPORTS/PDO/PDO_cs.htm

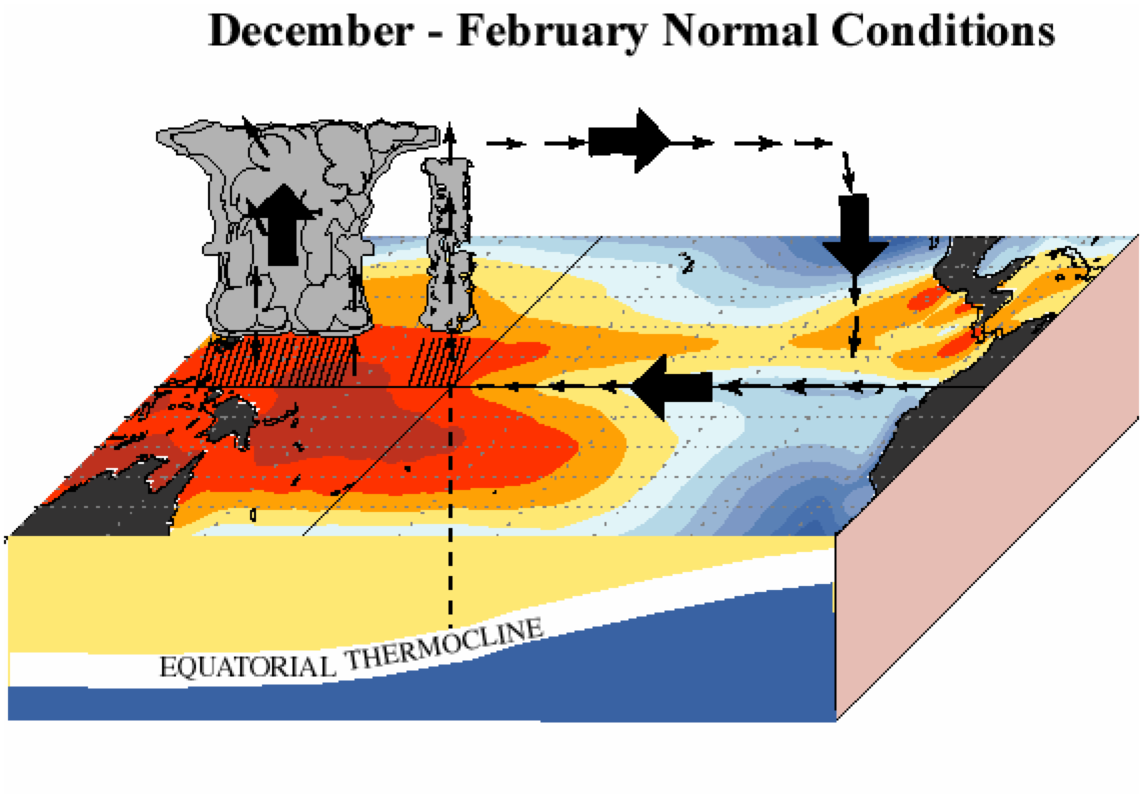
Atlantic Multidecadal Oscillation (AMO)



Red and blue colored dots represent positive and negative correlations of Northern Hemisphere summer rainfall with the AMO index. <u>When the AMO is positive (warm Atlantic) there is less rainfall over most of the United States</u> and northeastern South America, and more rainfall in southern Alaska, northern Europe, west Africa and Florida.

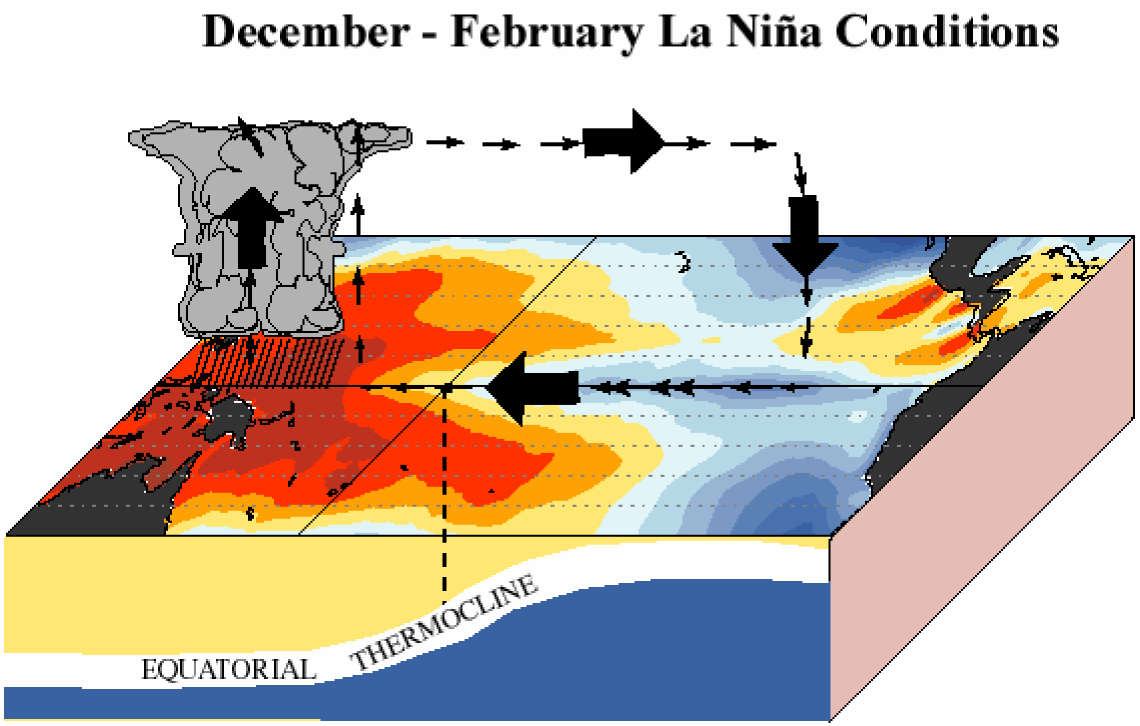
http://www.aoml.noaa.gov/phod/amo_faq.php

ENSO: El Niño/Southern Oscillation



http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml

ENSO: El Niño/Southern Oscillation



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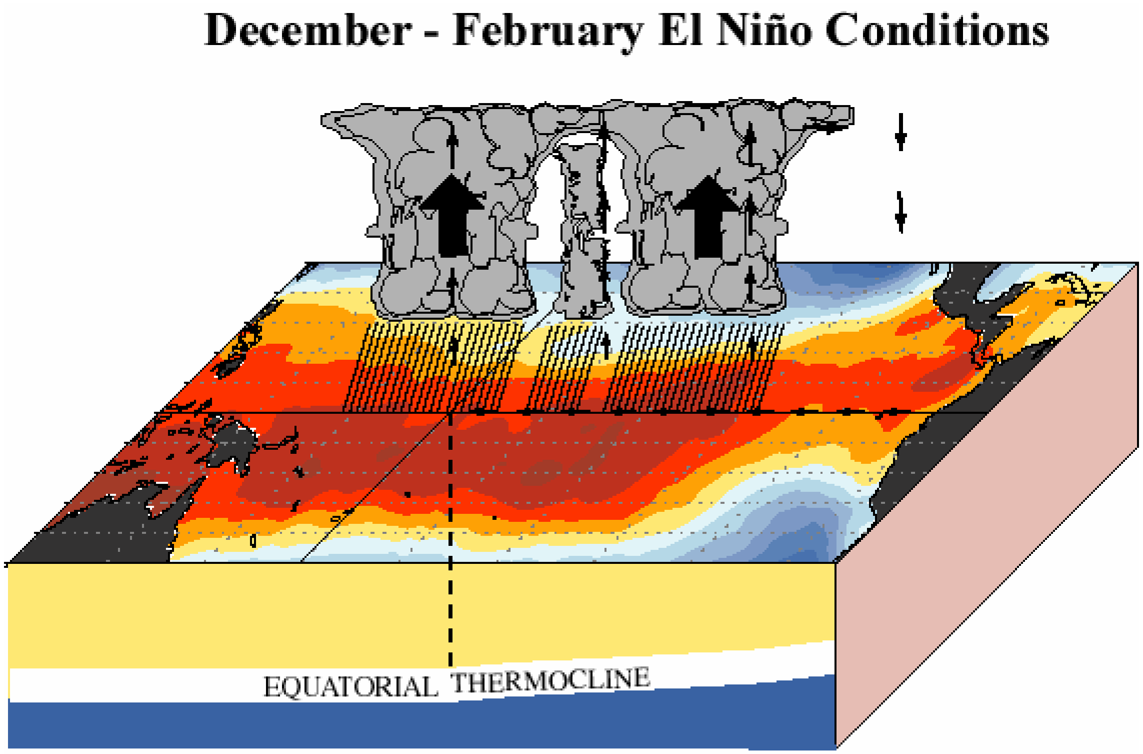
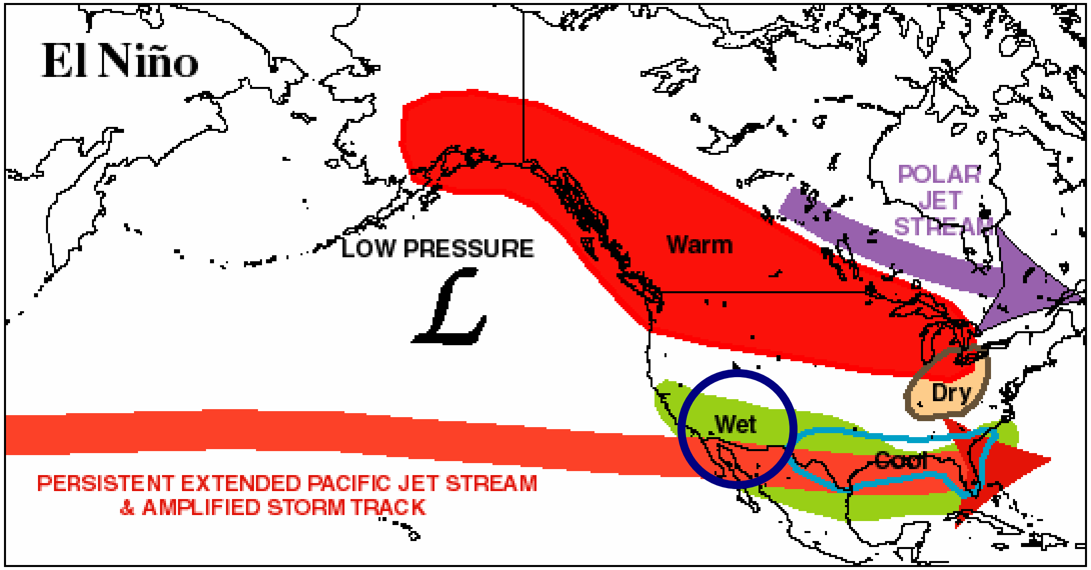
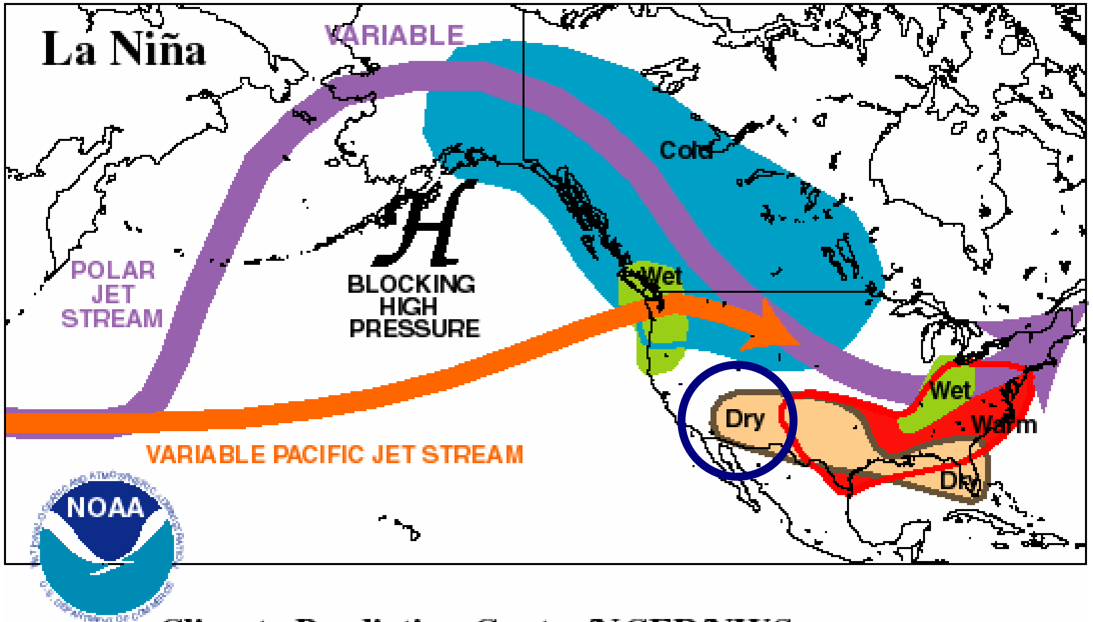


http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml

TYPICAL JANUARY-MARCH WEATHER ANOMALIES AND ATMOSPHERIC CIRCULATION DURING MODERATE TO STRONG EL NIÑO & LA NIÑA



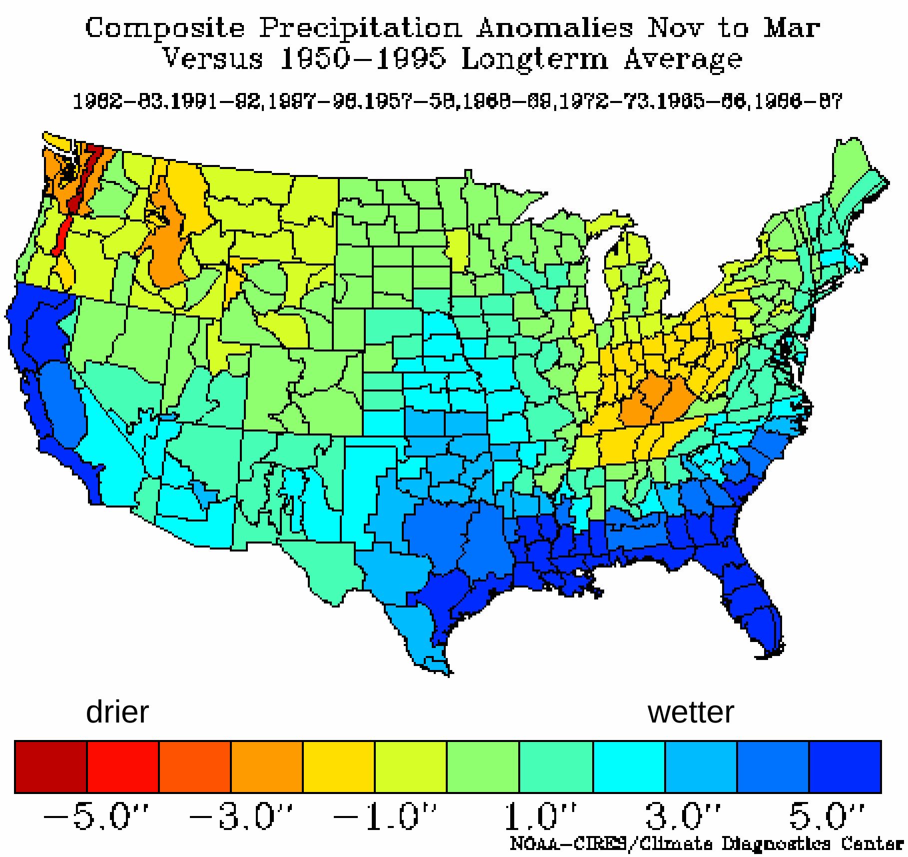
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/enso_cycle.shtml

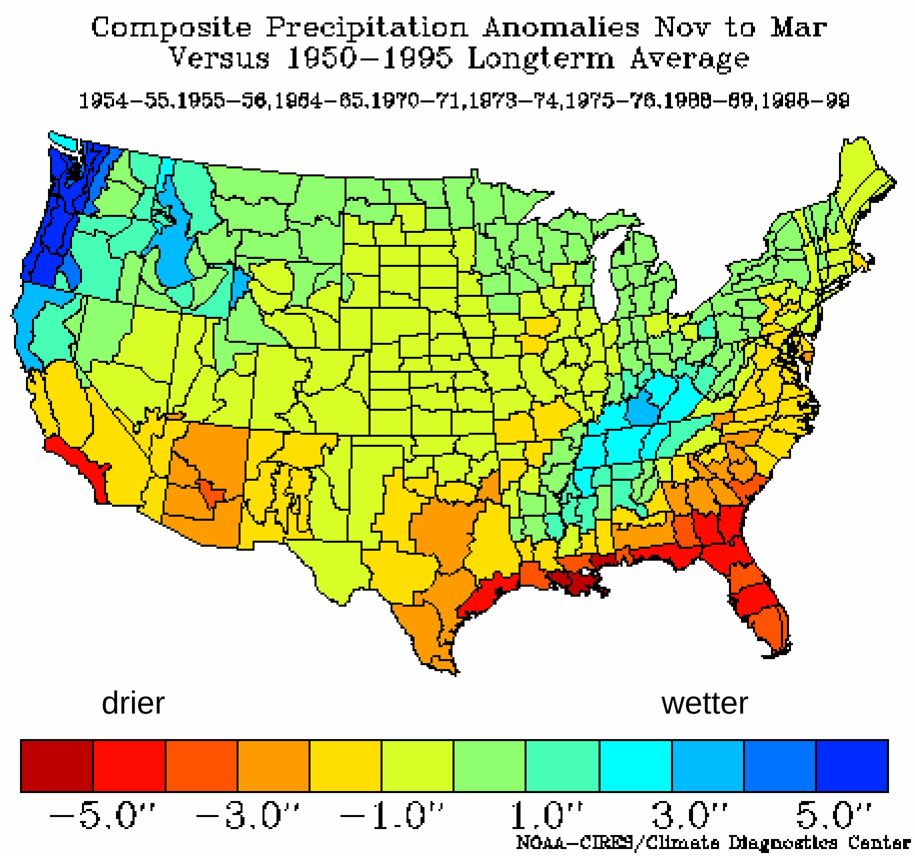


Climate Prediction Center/NCEP/NWS

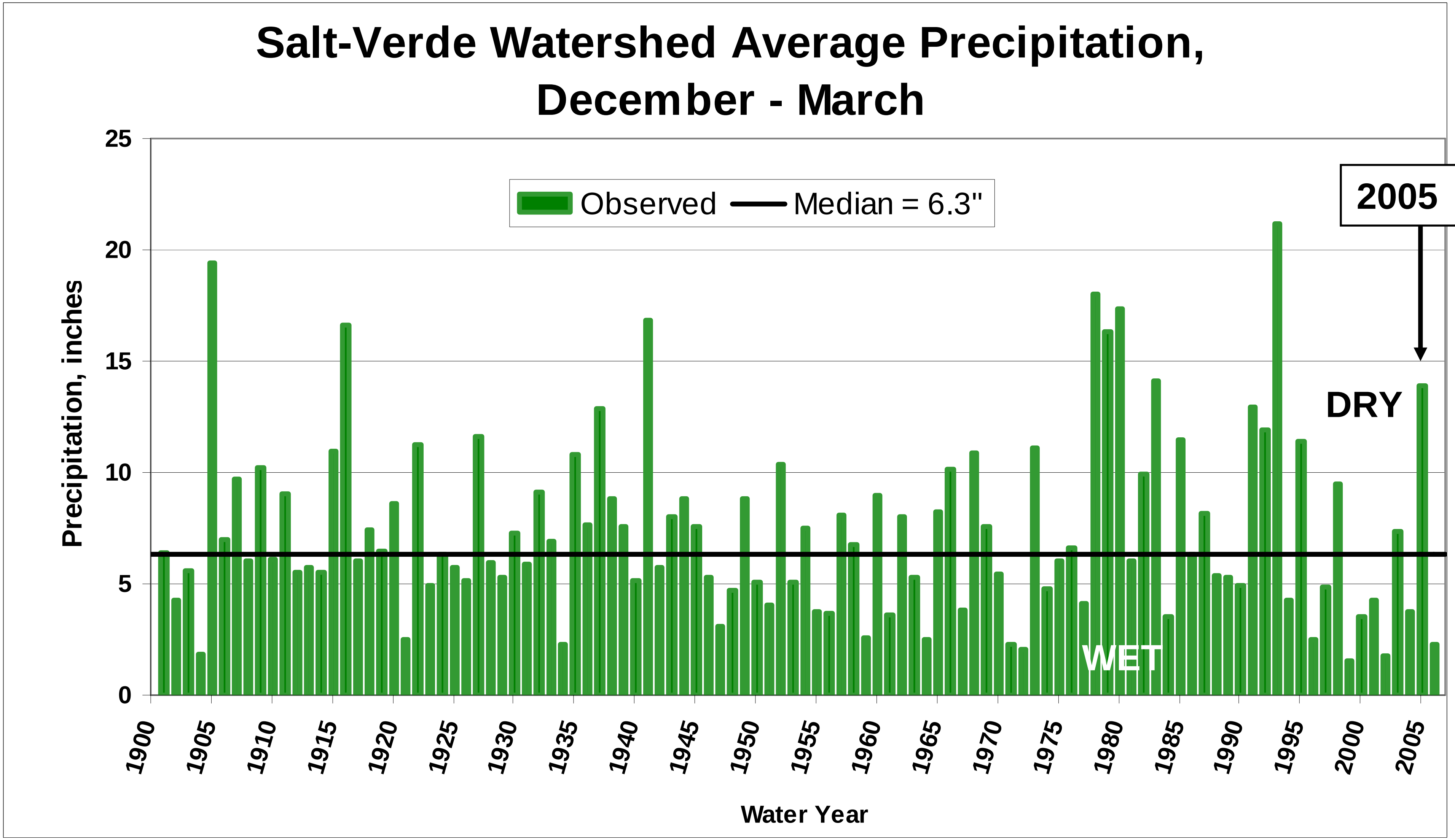
El Niño Precipitation Anomalies

La Niña Precipitation Anomalies

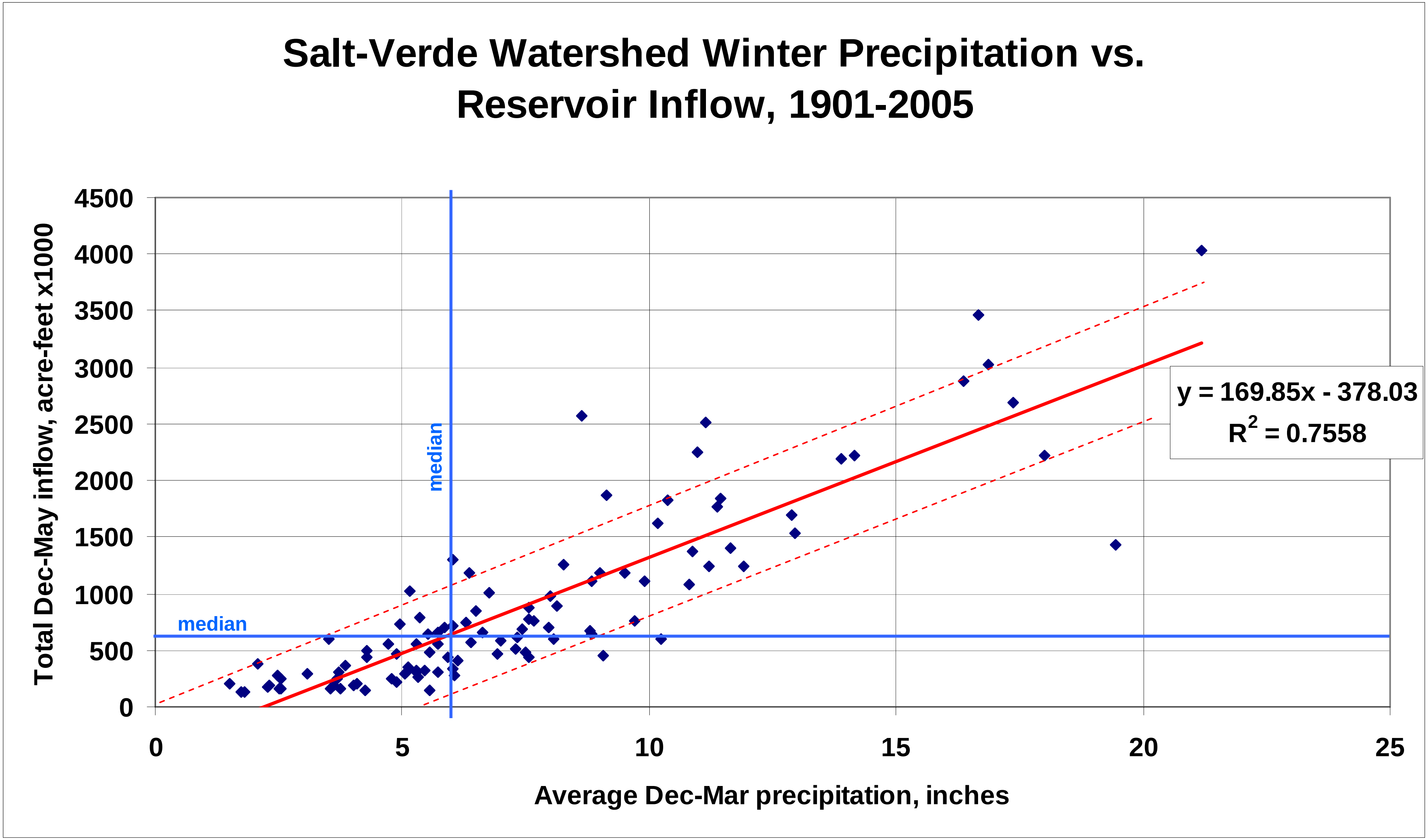




The Historical Record

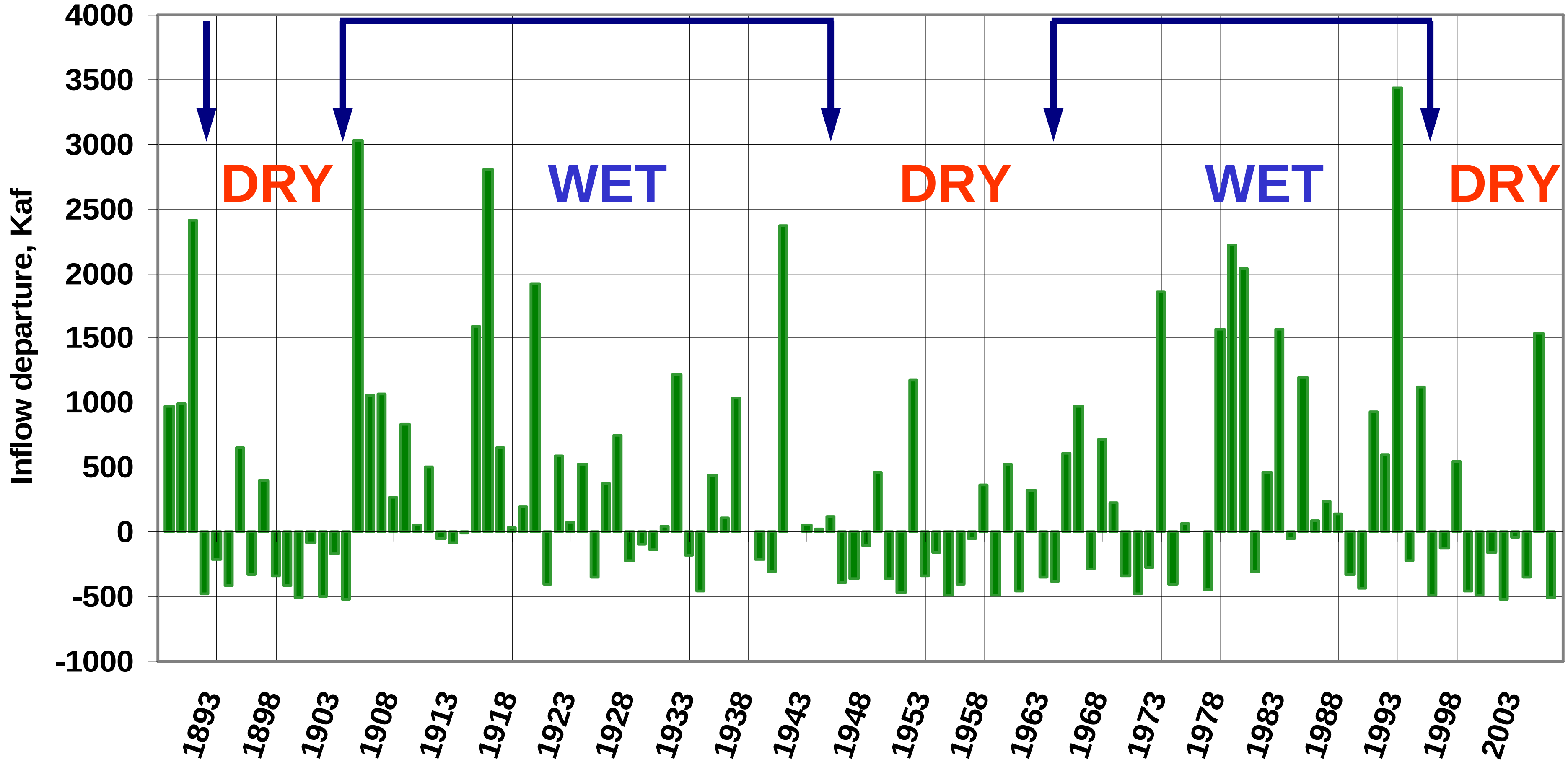


SRP Water Resource Operations: jas 04/2006



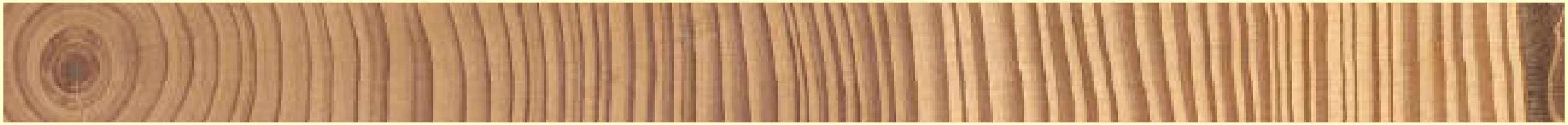
SRP Water Resource Operations: jas 04/2006

Salt+Tonto+Verde WINTER (Dec-May) INFLOW:
Departure from Median (651 Kaf)



1892-1904:	1905-45:	1946-64:	1965-95:	1996-2006:
2 wet,	**28** wet,	5 wet,	**19** wet,	2 wet,
11 dry	13 dry	**14** dry	12 dry	**9** dry

http://fpcluster.ccit.arizona.edu/khirschboeck/srp.htm



A Tree-Ring Based Assessment of Synchronous Extreme Streamflow Episodes in the Upper Colorado & Salt-Verde-Tonto River Basins

A Collaborative Project between The University of Arizona's Laboratory of Tree-Ring Research & The Salt River Project

2005

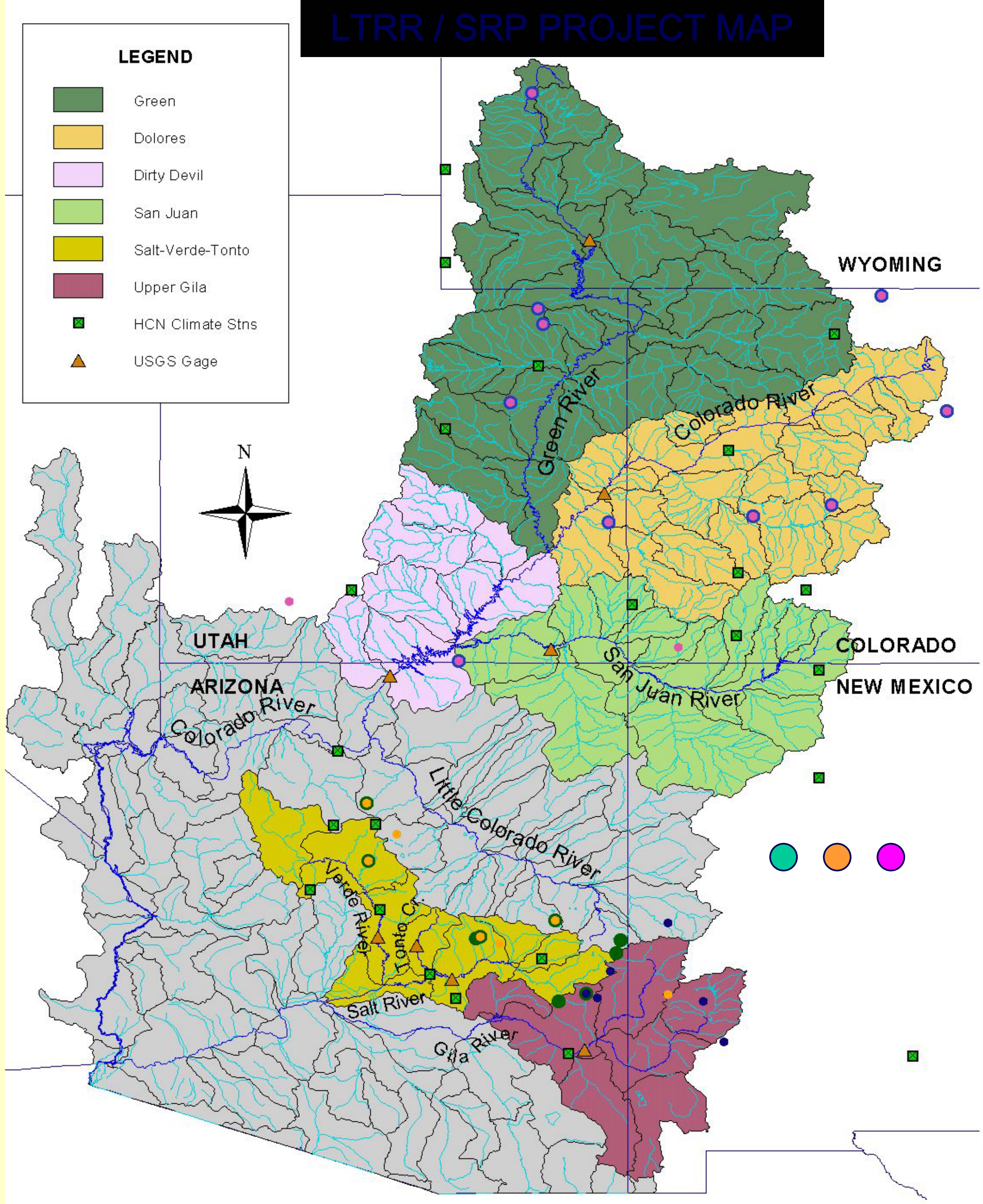
Prepared by **K.K. Hirschboeck** & **D.M. Meko**

THE UNIVERSITY OF ARIZONA.
The Laboratory of
Tree-Ring Research

SRP
Delivering more than power.

Project map showing:

- Tree-ring sites
- USGS gages
- Climate stations

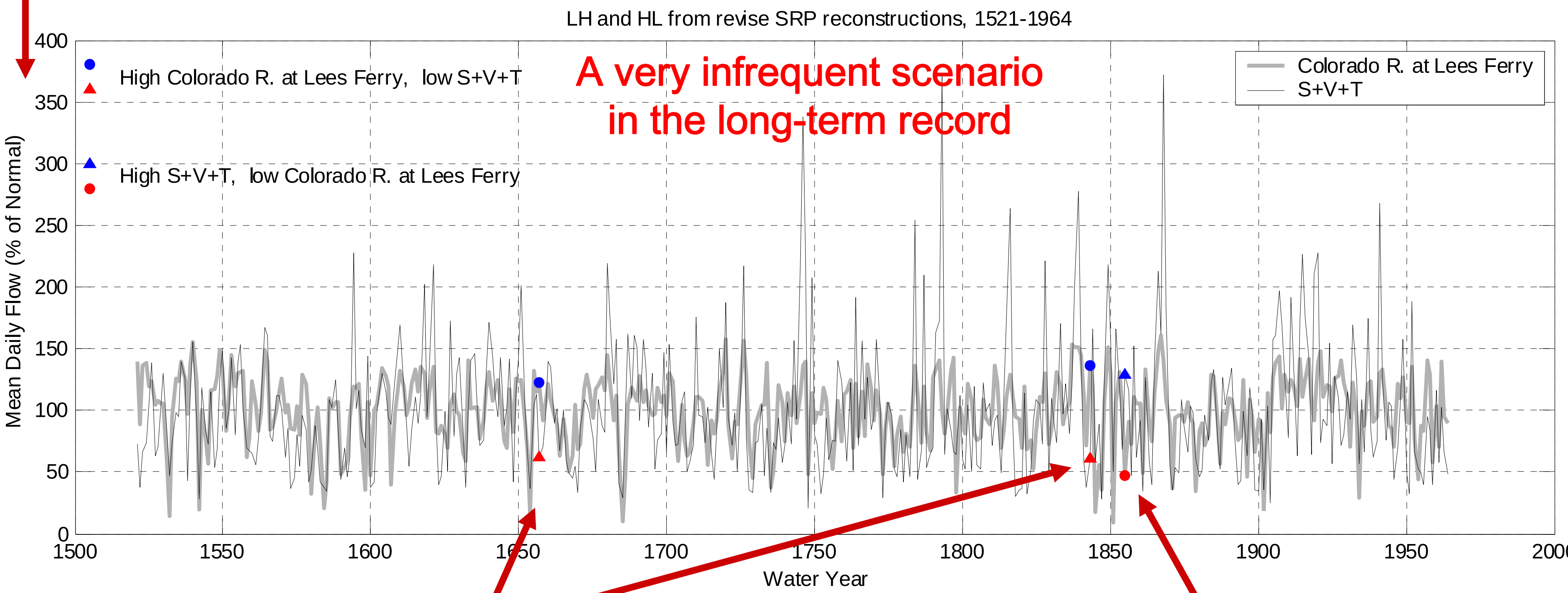


RESULTS: Synchronous extremes in the OPPOSITE direction:

(HIGH in one basin & LOW in the other)

% of normal flow used for comparison

Reconstructed flows: HL & LH events



HL = HIGH on Colo & LOW on SVT
(Years: 1657 & 1843)

LH = LOW on Colo & HIGH on SVT
(Year: 1855)

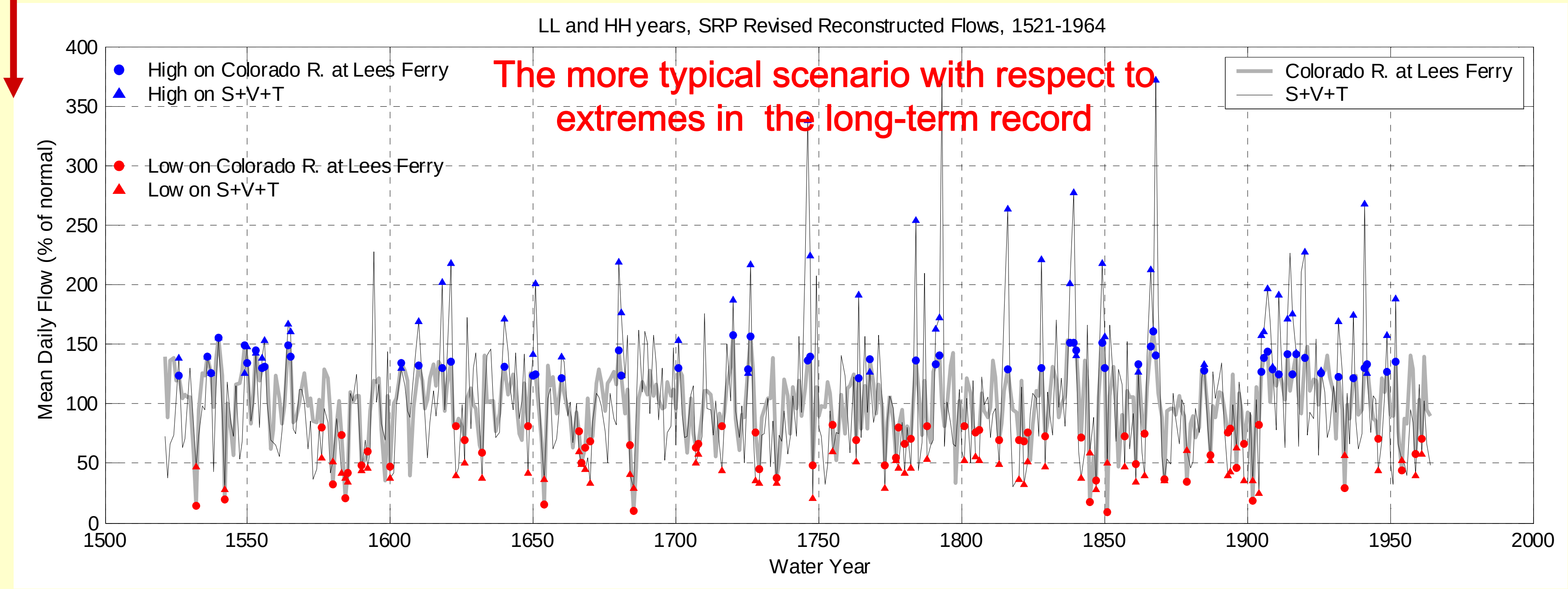
Probability (HL) = 2 / 444 = 0.0045

Probability (LH) = 1 / 444 = 0.0023

RESULTS: Synchronous extremes in the SAME direction:
(LOW or HIGH in BOTH BASINS)

% of normal flow used for comparison

Reconstructed flows: LL & HH events

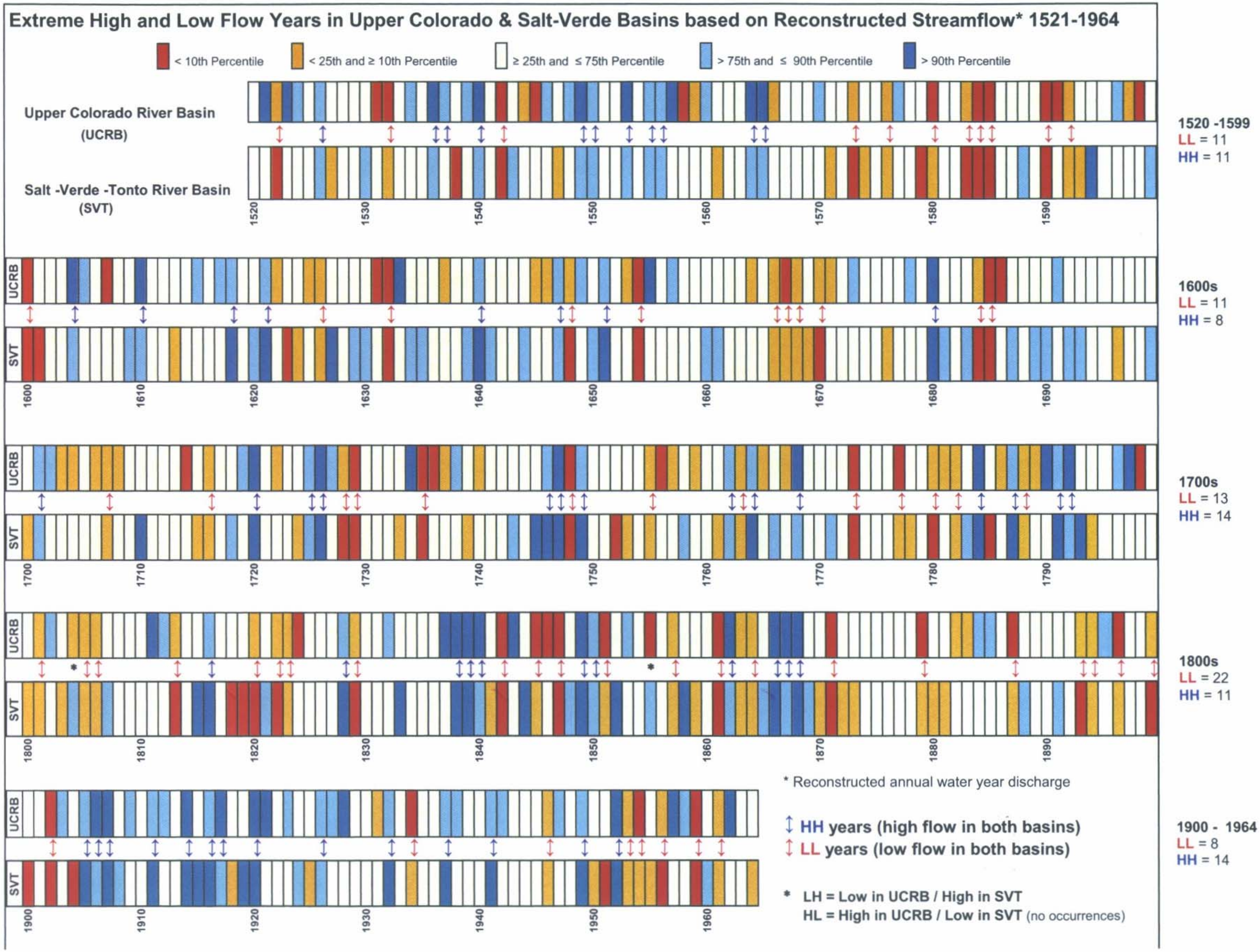


HH = HIGH on Colo & HIGH on SVT (blue symbols)

Probability (HH) = 60 / 444 = 0.135

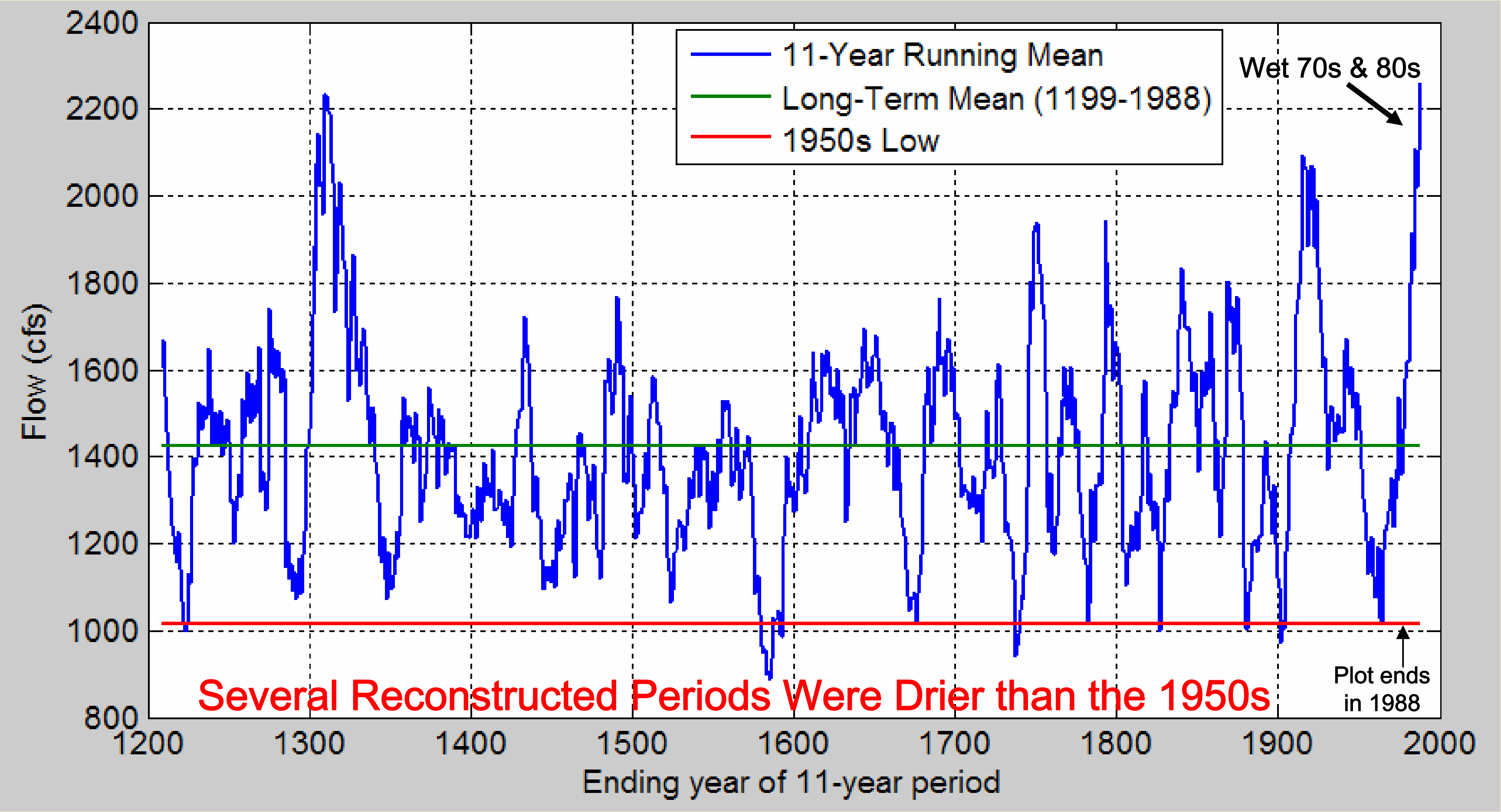
LL = LOW on Colo & LOW on SVT (red symbols)

Probability (LL) = 65 / 444 = 0.146



Extreme High and Low Flow Years in Upper Colorado & Salt-Verde Basins based on Reconstructed Streamflow* 1521-1964
< 10th Percentile
< 25th and ≥ 10th Percentile
≥ 25th and ≤ 75th Percentile
> 75th and ≤ 90th Percentile
> 90th Percentile
Upper Colorado River Basin (UCRB)
Salt -Verde -Tonto River Basin (SVT)
1520 -1599
LL = 11
HH = 11
1600s
LL = 11
HH = 8
1700s
LL = 13
HH = 14
1800s
LL = 22
HH = 11
1900 - 1964
LL = 8
HH = 14
UCRB
SVT
* Reconstructed annual water year discharge
HH years (high flow in both basins)
LL years (low flow in both basins)
* LH = Low in UCRB / High in SVT
HL = High in UCRB / Low in SVT (no occurrences)

Severity of Current Drought in Context of Reconstructed Record: Salt + Verde + Tonto Reconstruction



-- Current drought was about as severe as 1950s in terms of flows averaged over 11 years

-- 8 other droughts in tree-ring record were as severe as current drought

-- Late 1500s mega-drought was much more severe than current drought

Climatic Fluctuations, Drought, and Flow

in the Colorado River Basin

U.S. Department of the Interior

U.S. Geological Survey

USGS Fact Sheet 2004-3062

version 2

August 2004

http://pubs.usgs.gov/fs/2004/3062/

The Future of Water in Arizona

APRIL 3, 2006 www.time.com AOL Keyword: TIME

SPECIAL REPORT GLOBAL WARMING

TIME

BE WORRIED. BE VERY WORRIED.

Climate change isn't some vague future problem—it's already damaging the planet at an alarming pace. Here's how it affects you, your kids and their kids as well

EARTH AT THE TIPPING POINT

HOW IT THREATENS YOUR HEALTH

HOW CHINA & INDIA CAN HELP SAVE THE WORLD—OR DESTROY IT

THE CLIMATE CRUSADERS

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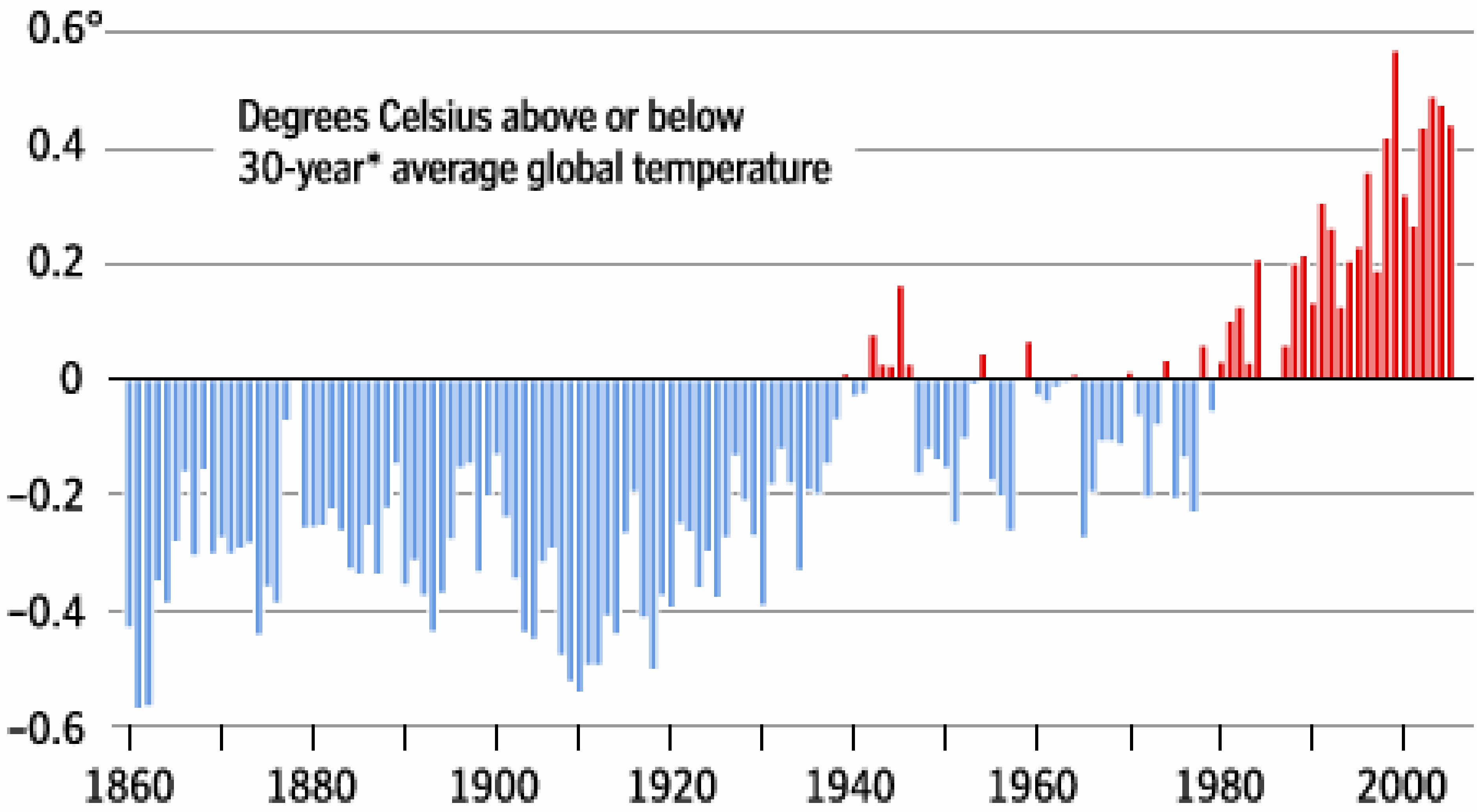
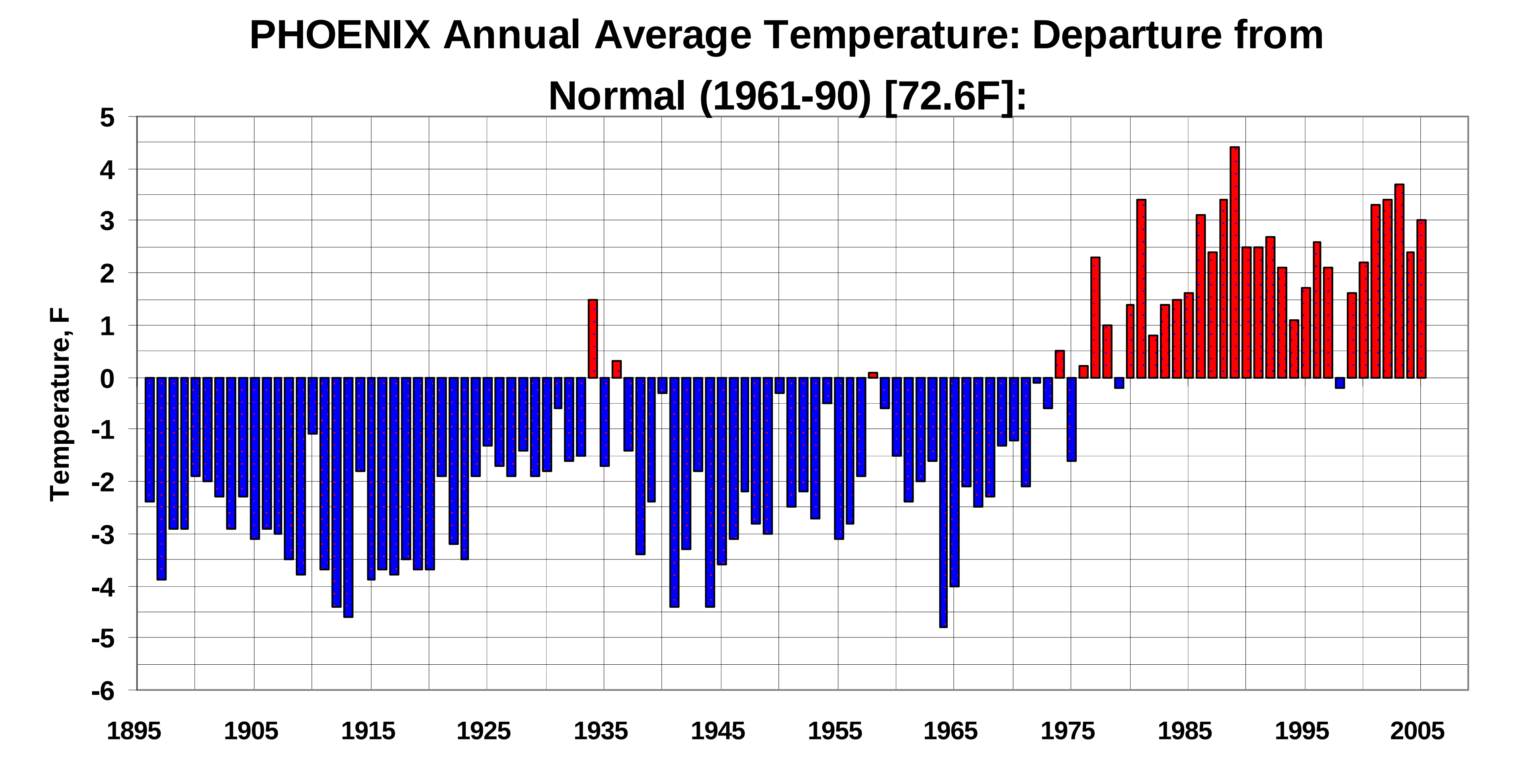
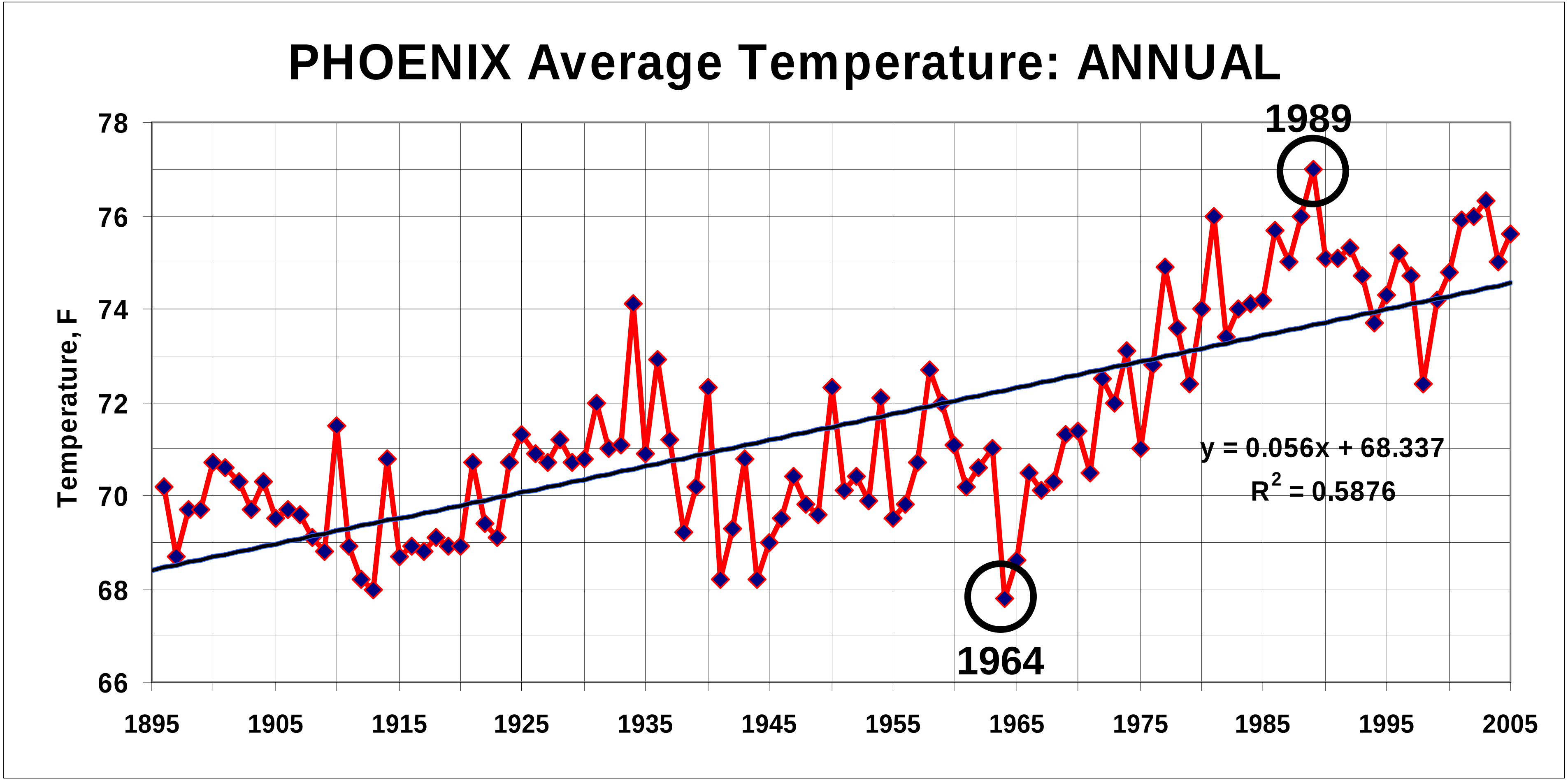
PRICE $3.95
THE NEW YORKER
DEC. 12, 2005



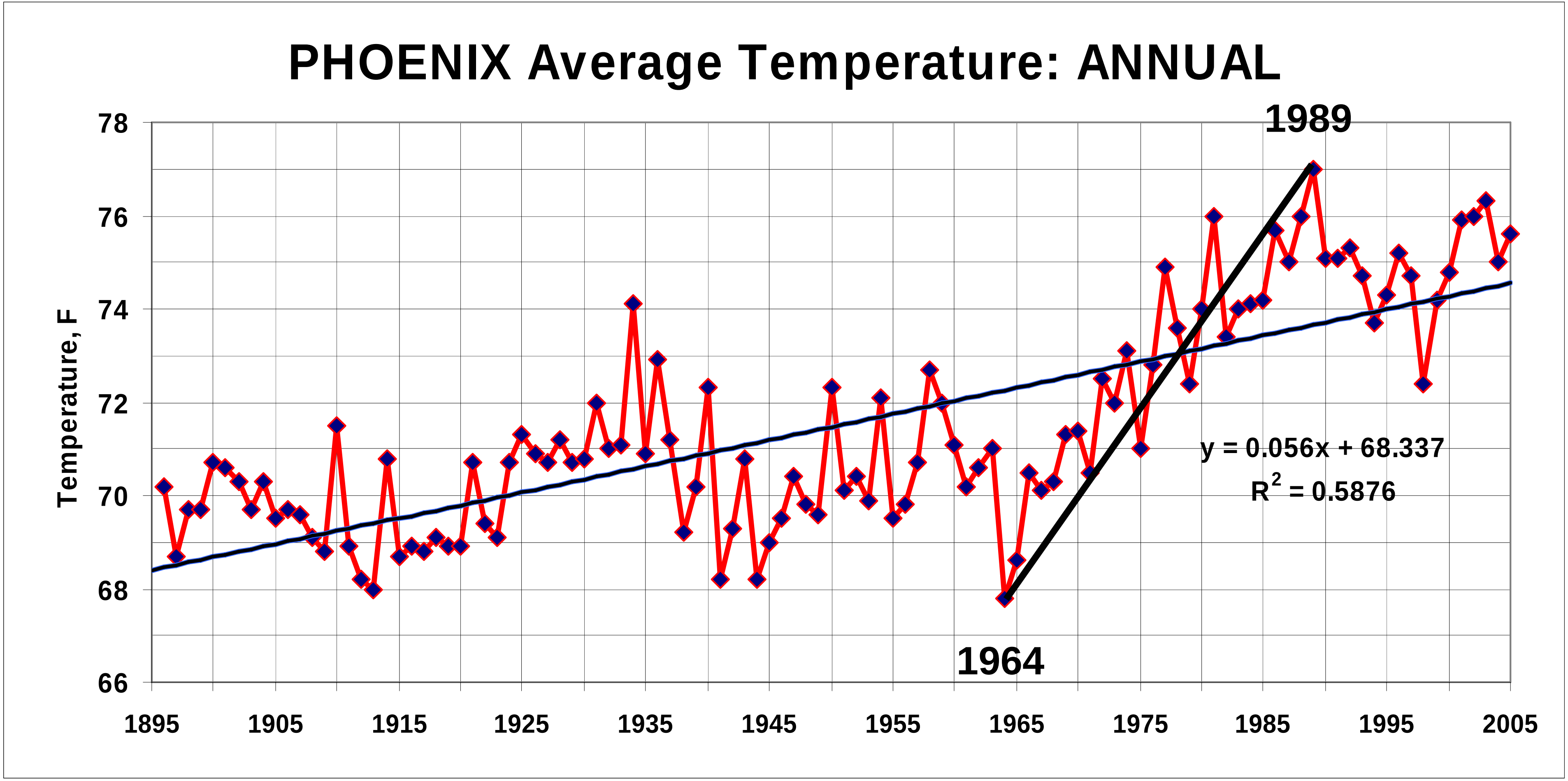
SOURCE: National Center for Atmospheric Research | *30-year period: 1961-1990 | The Washington Post, 13 Oct 2005



SRP Water Resource Operations: jas 04/2006



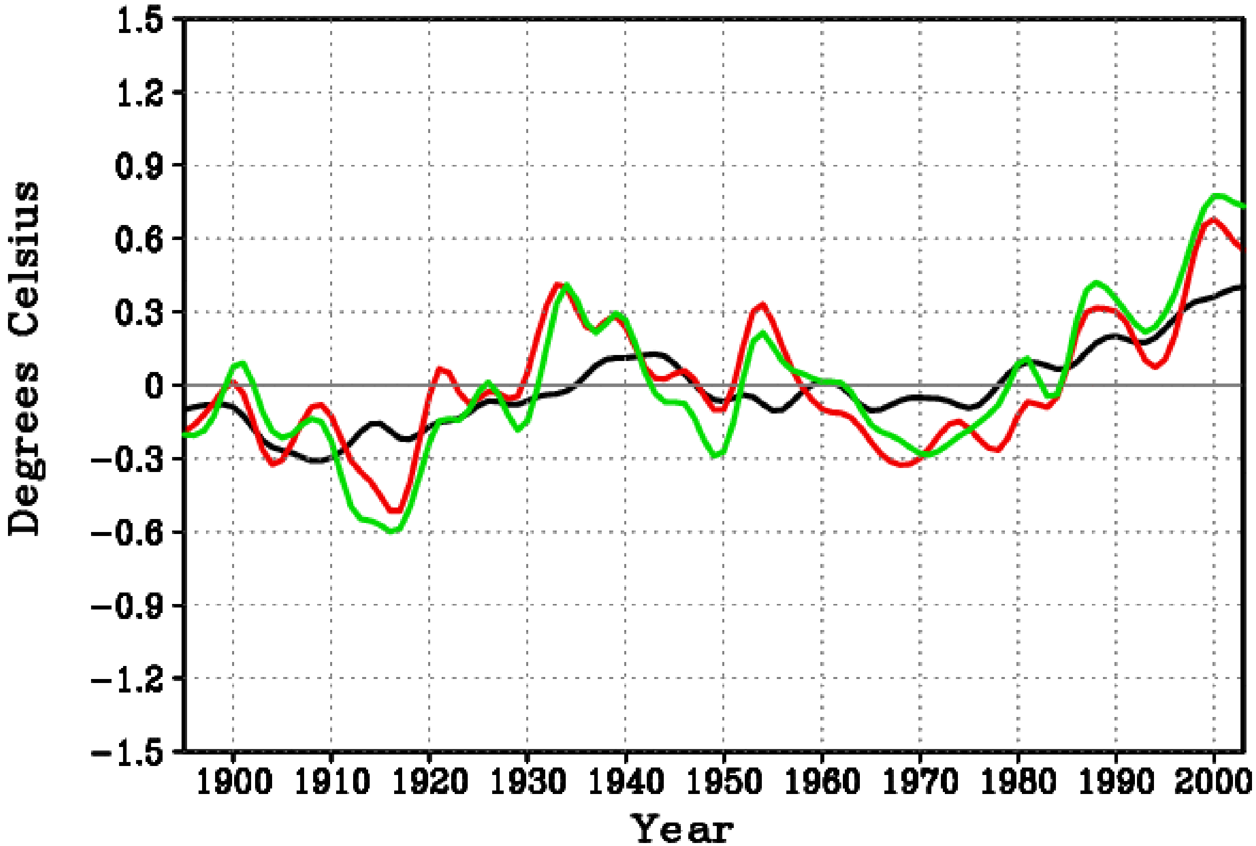
<u>Rainfall</u> (normal 8 inches)
1964: 6.00 inches
1989: 4.94 inches



1964-1989: 9°F in 26 years = 0.35°F/year

SRP Water Resource Operations: jas 04/2006

Global: 0.4°C/100yrs
United States: 0.37°C/100yrs
Western U.S.: 0.56°C/100yrs

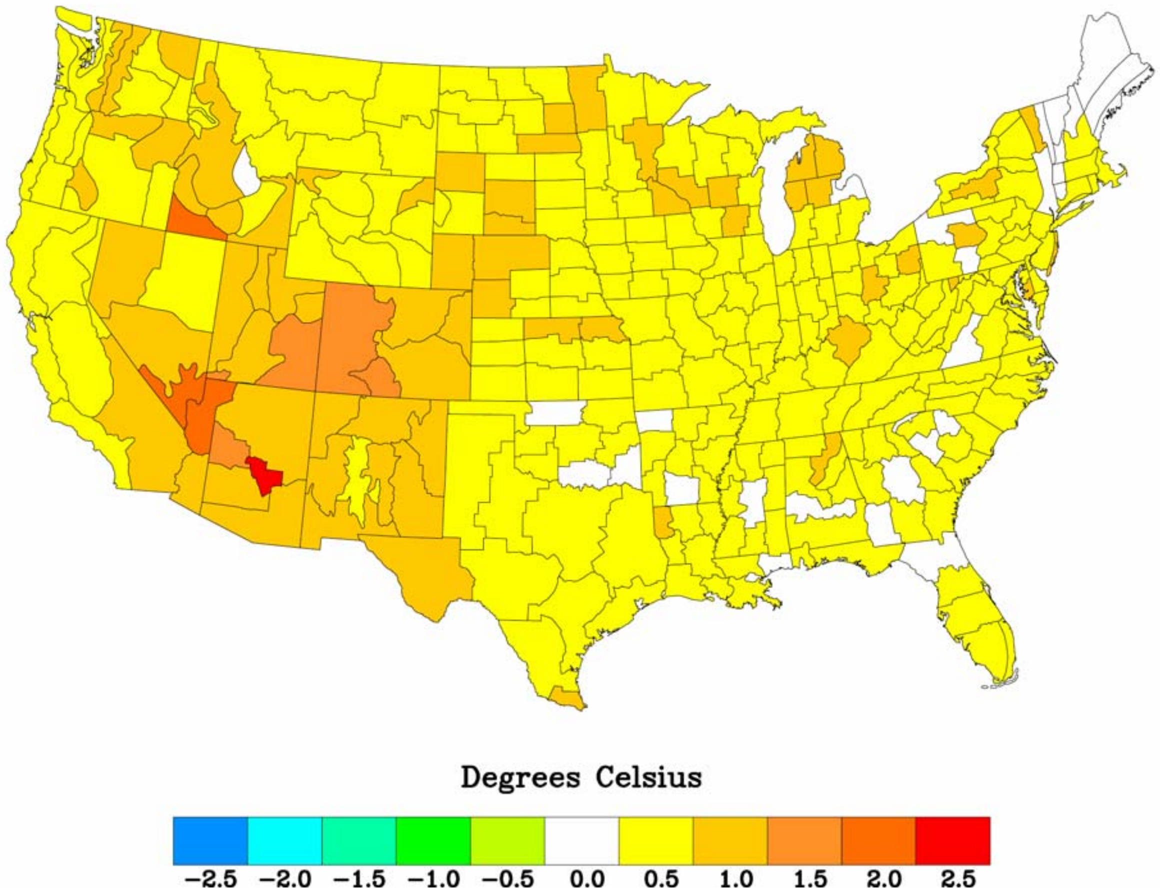


Marty Hoerling

NOAA-CIRES Climate Diagnostics Center

http://www.cdc.noaa.gov

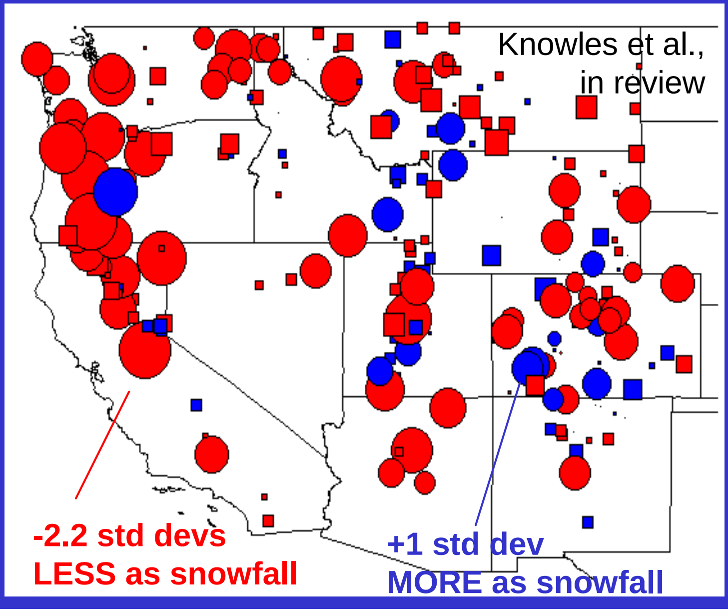
Observed U.S Annual Temperature Departure
(2000–04) minus (1961–90)



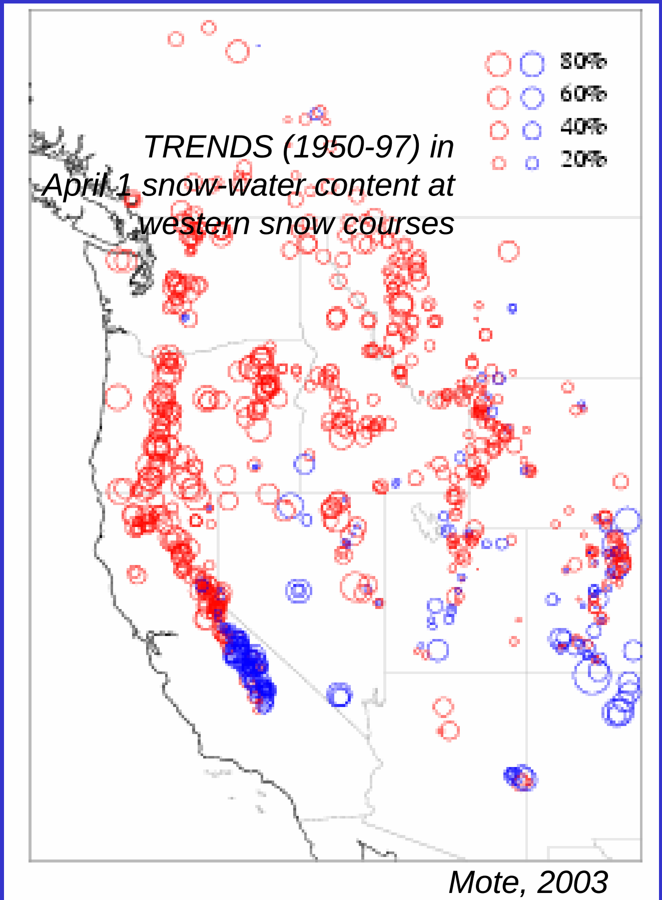
Marty Hoerling

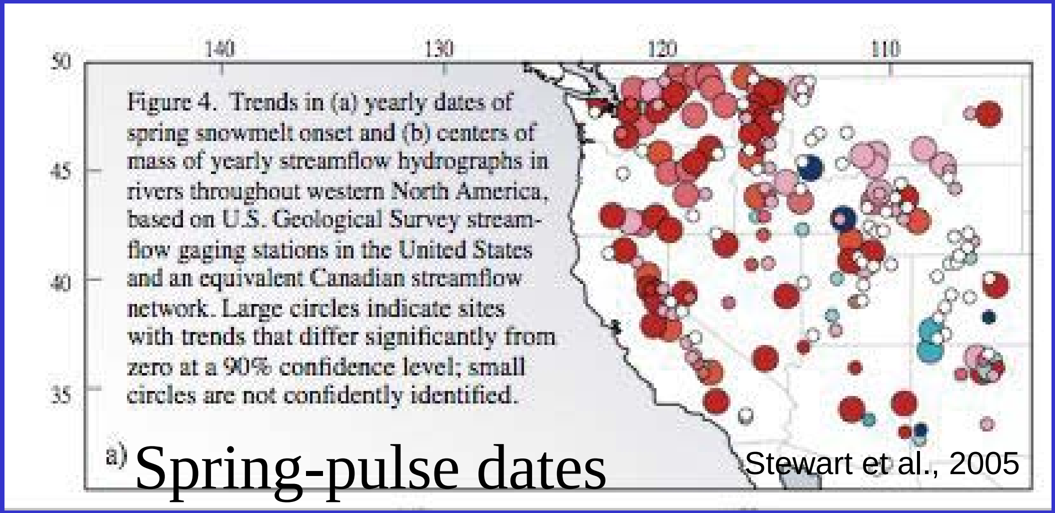
Recent warming already has driven significant hydroclimatic changes.

Less snow/more rain



Less spring snowpack

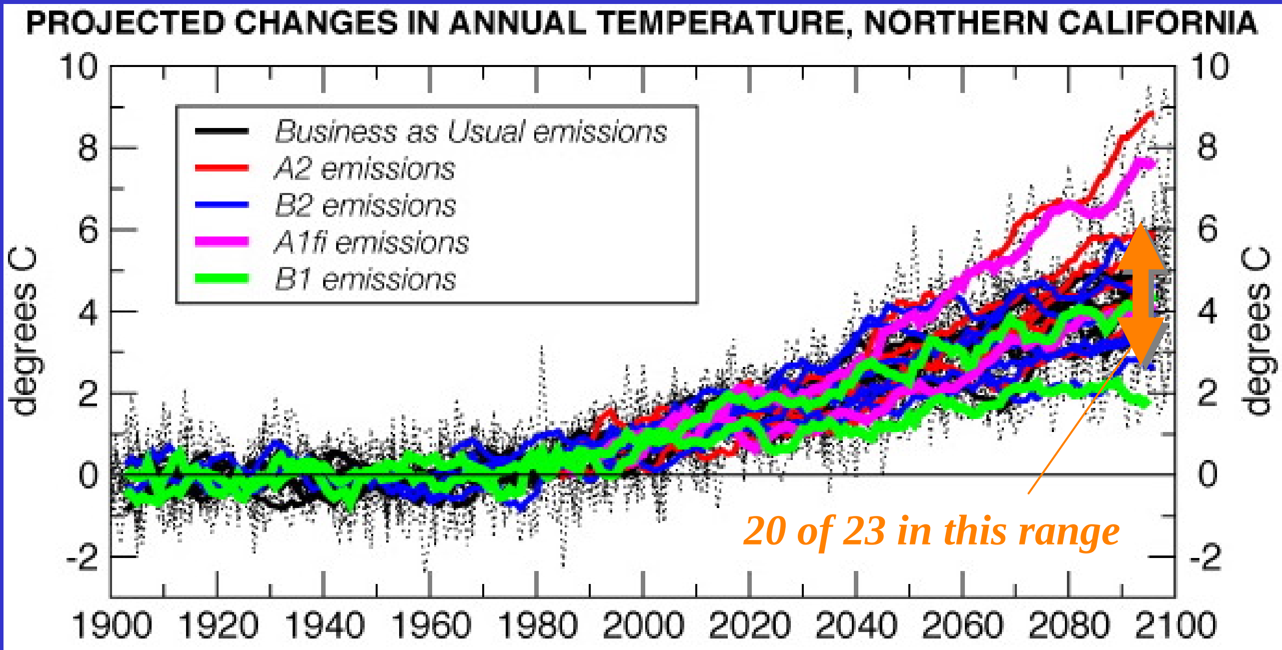


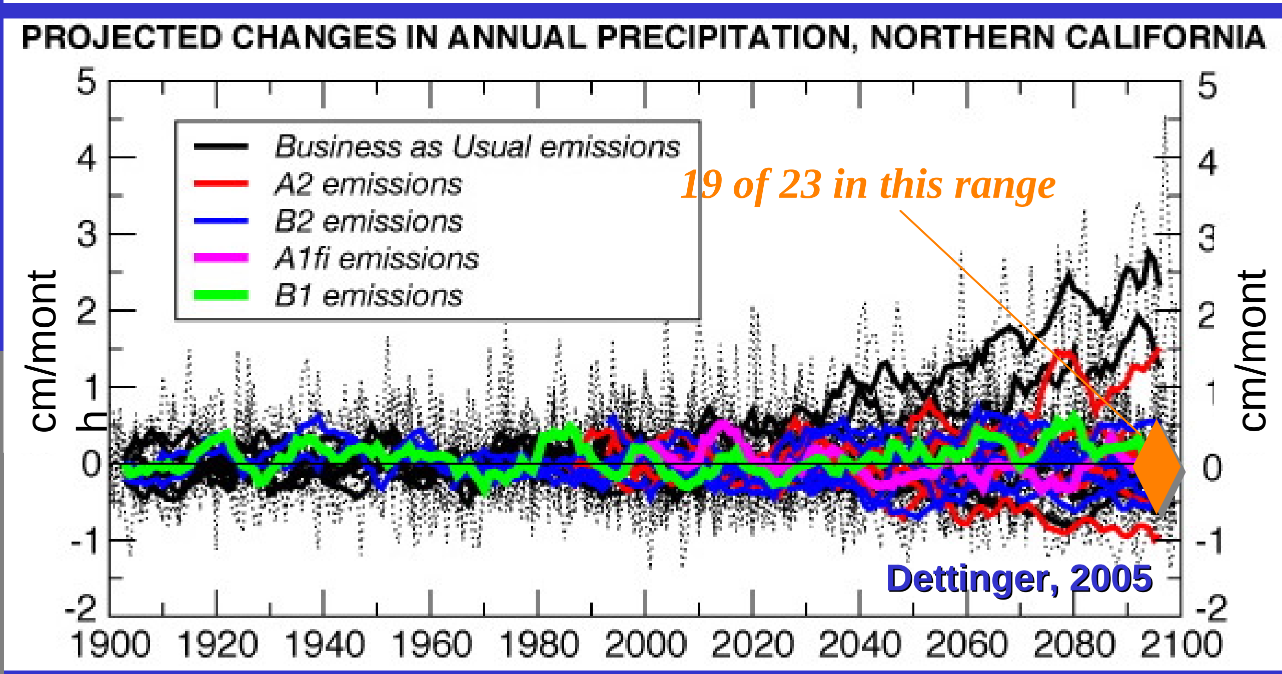


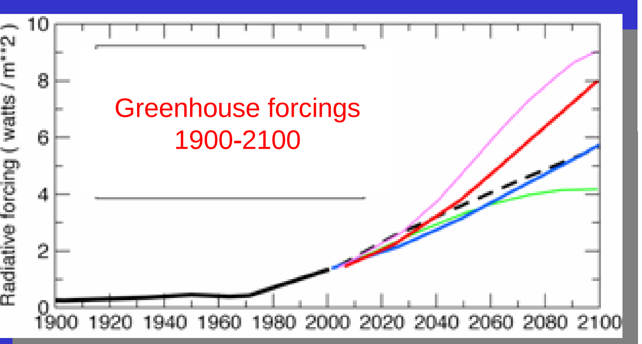
Earlier snowmelt runoff

Mike Dettinger, USGS, SIO

Under projected greenhouse forcings, climate models yield a fairly narrow range of warming scenarios and (amidst a broad overall range) a tendency for little precipitation change in California and most of the West.







Mike Dettinger, USGS, SIO

Questions?

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(602) 236-2819

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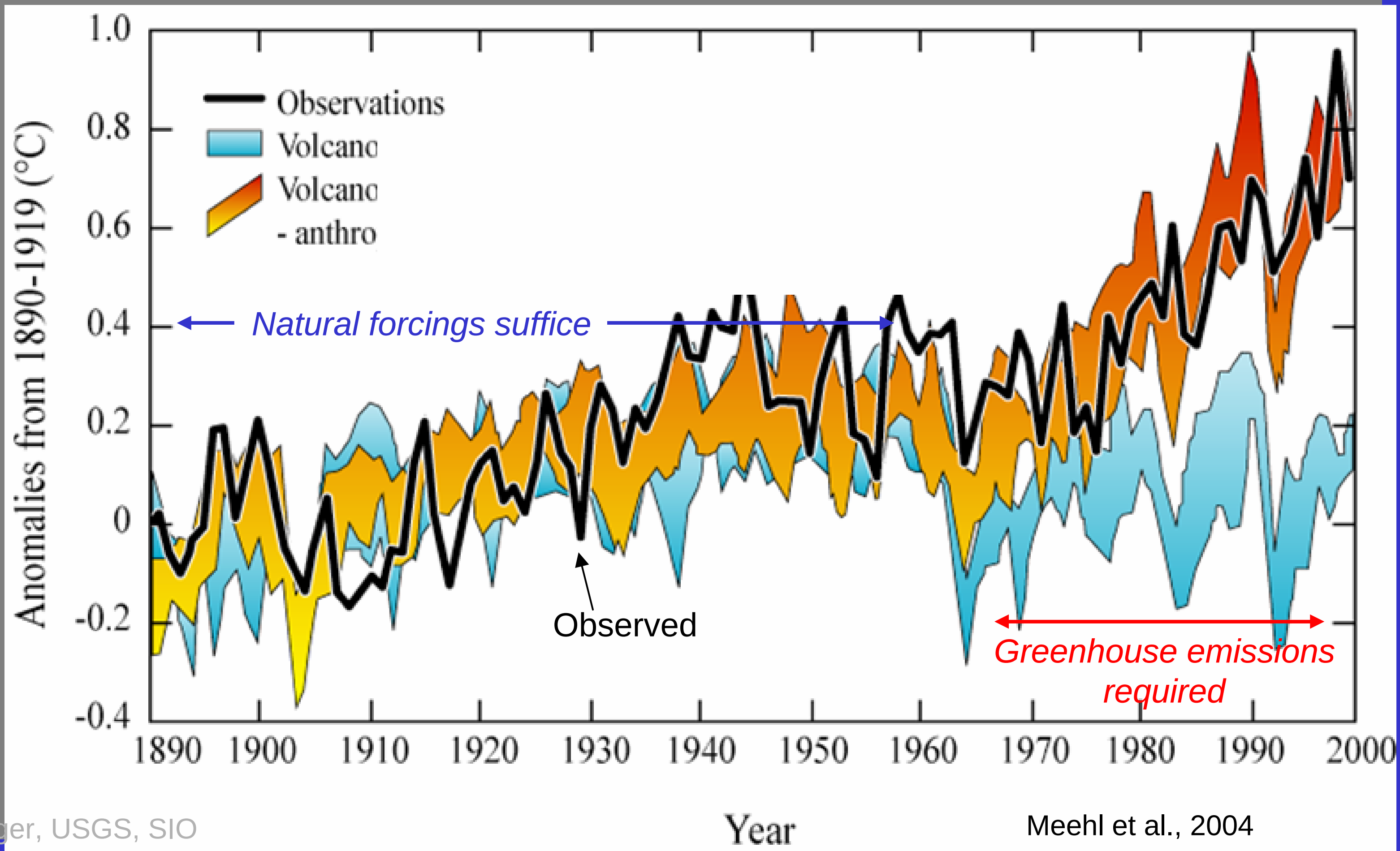
During the past 30 years--and in the near-term future--natural climate variability has been *augmented* by warming trends associated with increases in the global greenhouse effect.

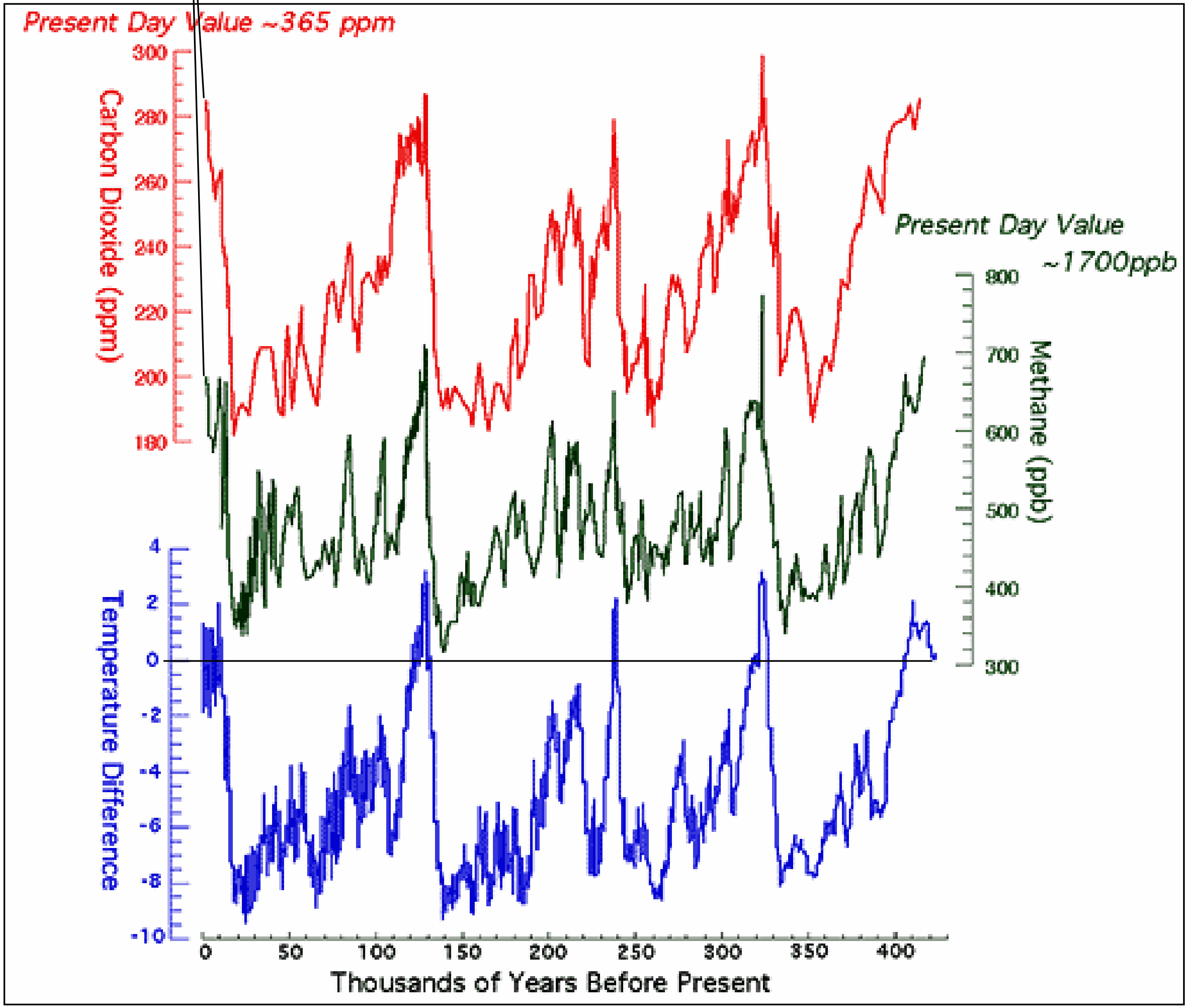
Climate-model simulations of global-average temperature



Meehl et al., 2004

Mike Dettinger, USGS, SIO

Climate Records from the Vostok Ice Core Covering the Last 420,000 Years



http://www.exploratorium.edu/climate/cryosphere/data2.html