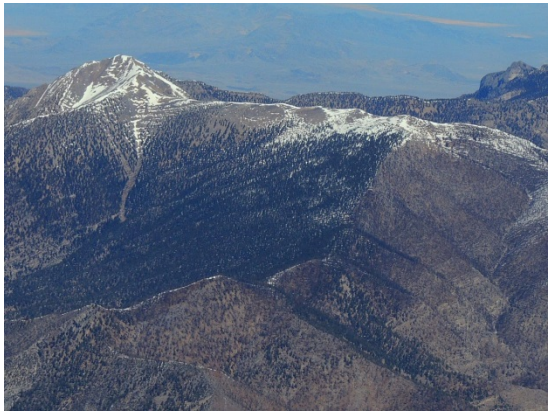
# Western United States Drought:

# Where Are We Now ?




**Kelly T. Redmond**

**Regional Climatologist**

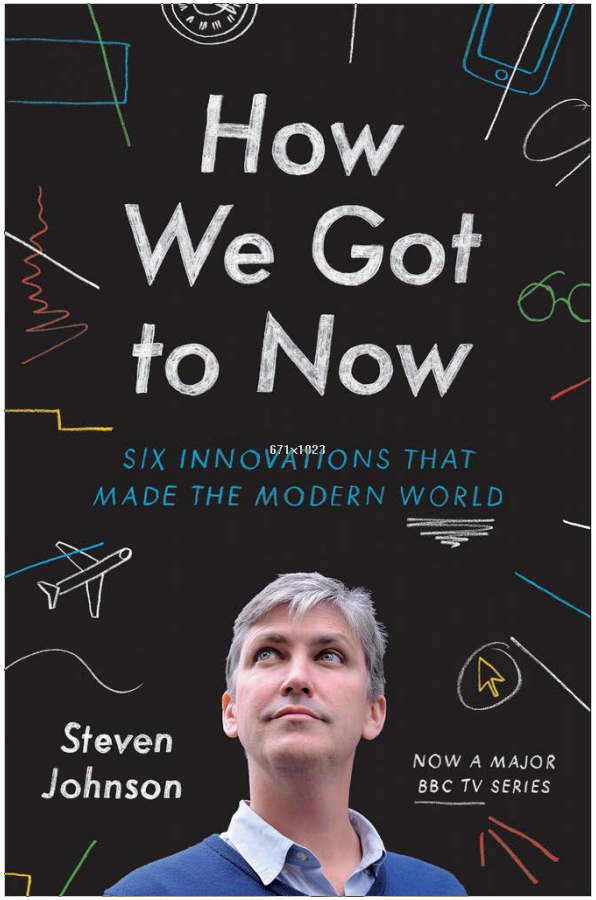
**Western Regional Climate Center**

**Desert Research Institute**

**Reno Nevada**

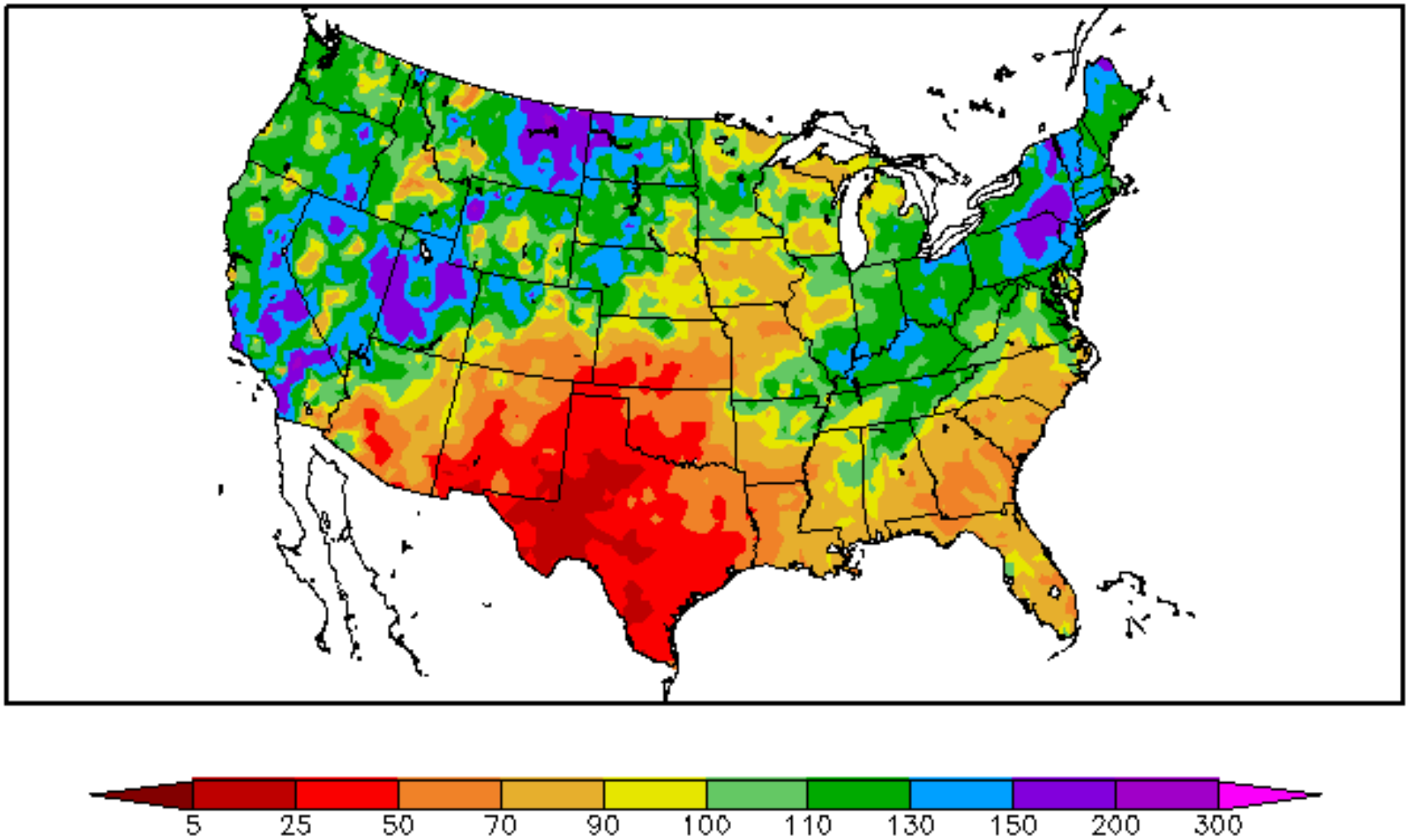

**Western States Drought Coordinators**
**and Emergency Managers Meeting**
**Seattle Washington 21-22 July 2015**

# Borrowing the phraseology of Steven Johnson ...



**Water Year**
**2010-11**
**01 Oct 2010**
**Thru**
**30 Sep 2011**

# Percent of Normal Precipitation (%)
## 10/1/2010 – 9/30/2011

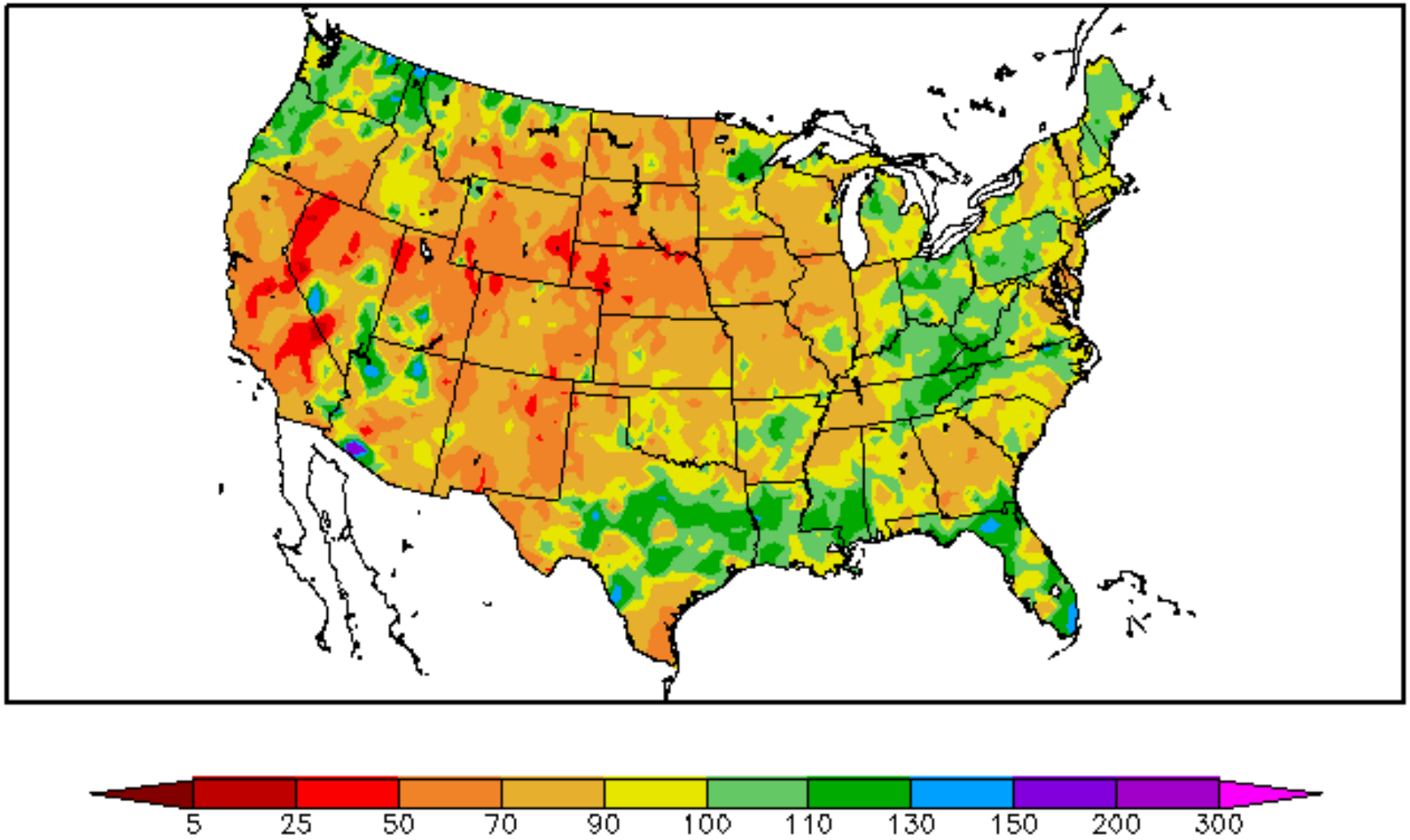



Generated 6/15/2012 at HPRCC using provisional data.

Regional Climate Centers

**Water Year**
**2011-12**
**01 Oct 2011**
**Thru**
**30 Sep 2012**

# Percent of Normal Precipitation (%)
## 10/1/2011 – 9/30/2012

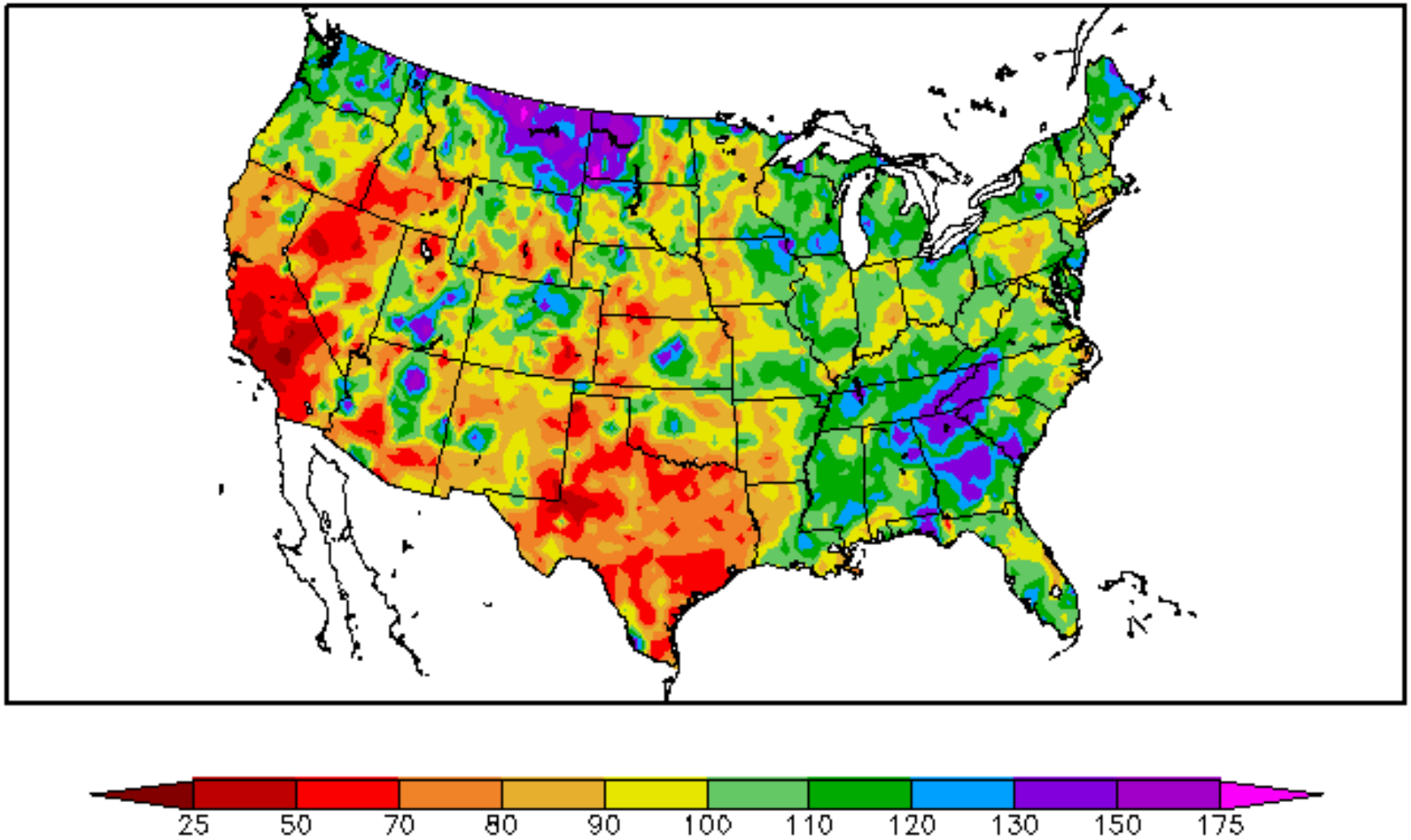



Generated 10/11/2012 at HPRCC using provisional data.

Regional Climate Centers

**Water Year**
**2012-13**
**01 Oct 2012**
**Thru**
**30 Sep 2013**

# Percent of Normal Precipitation (%)
## 10/1/2012 – 9/30/2013

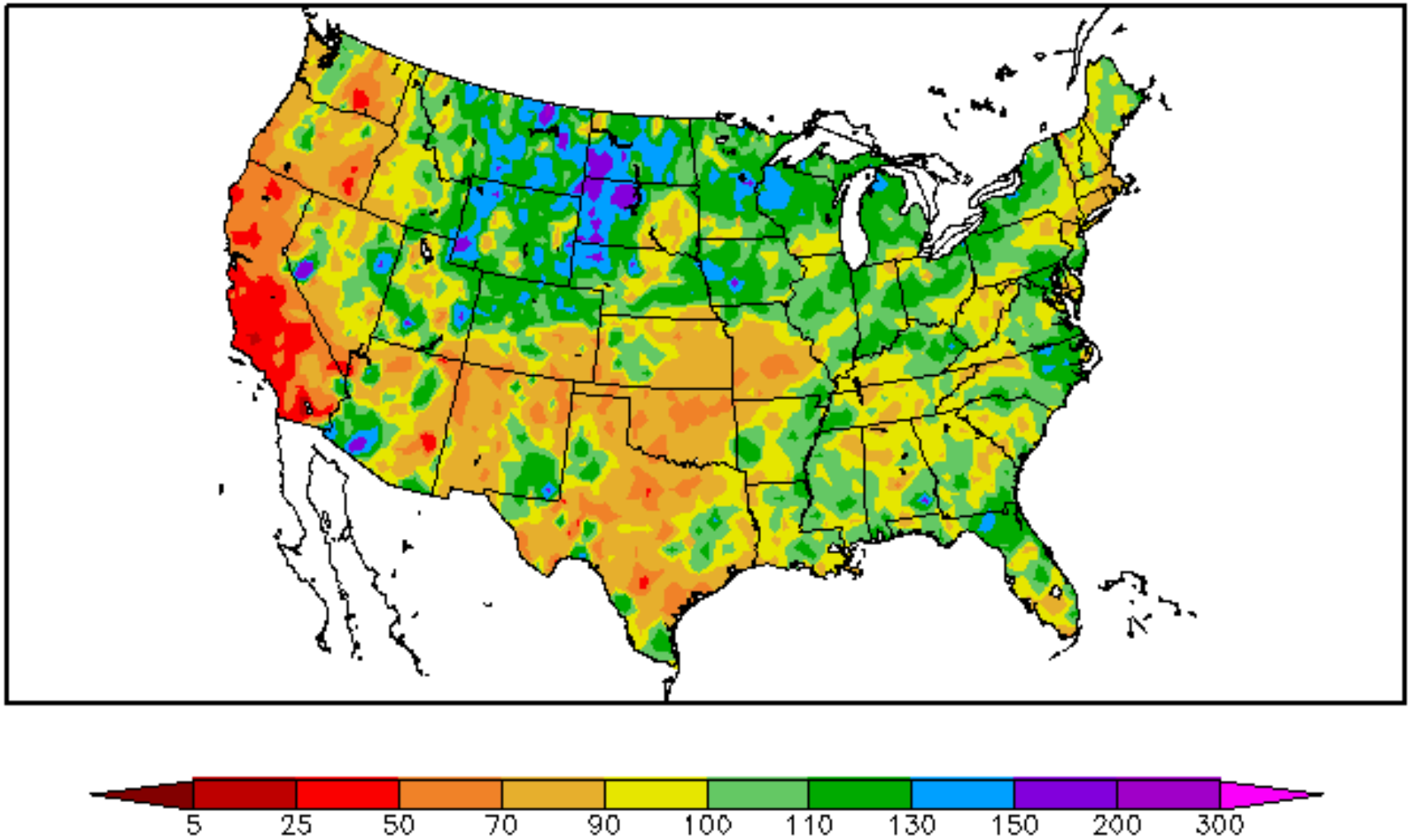



Generated 10/11/2013 at HPRCC using provisional data.

Regional Climate Centers

**Water Year**
**2013-14**
**01 Oct 2013**
**Thru**
**30 Sep 2014**

# Percent of Normal Precipitation (%)
## 10/1/2013 – 9/30/2014

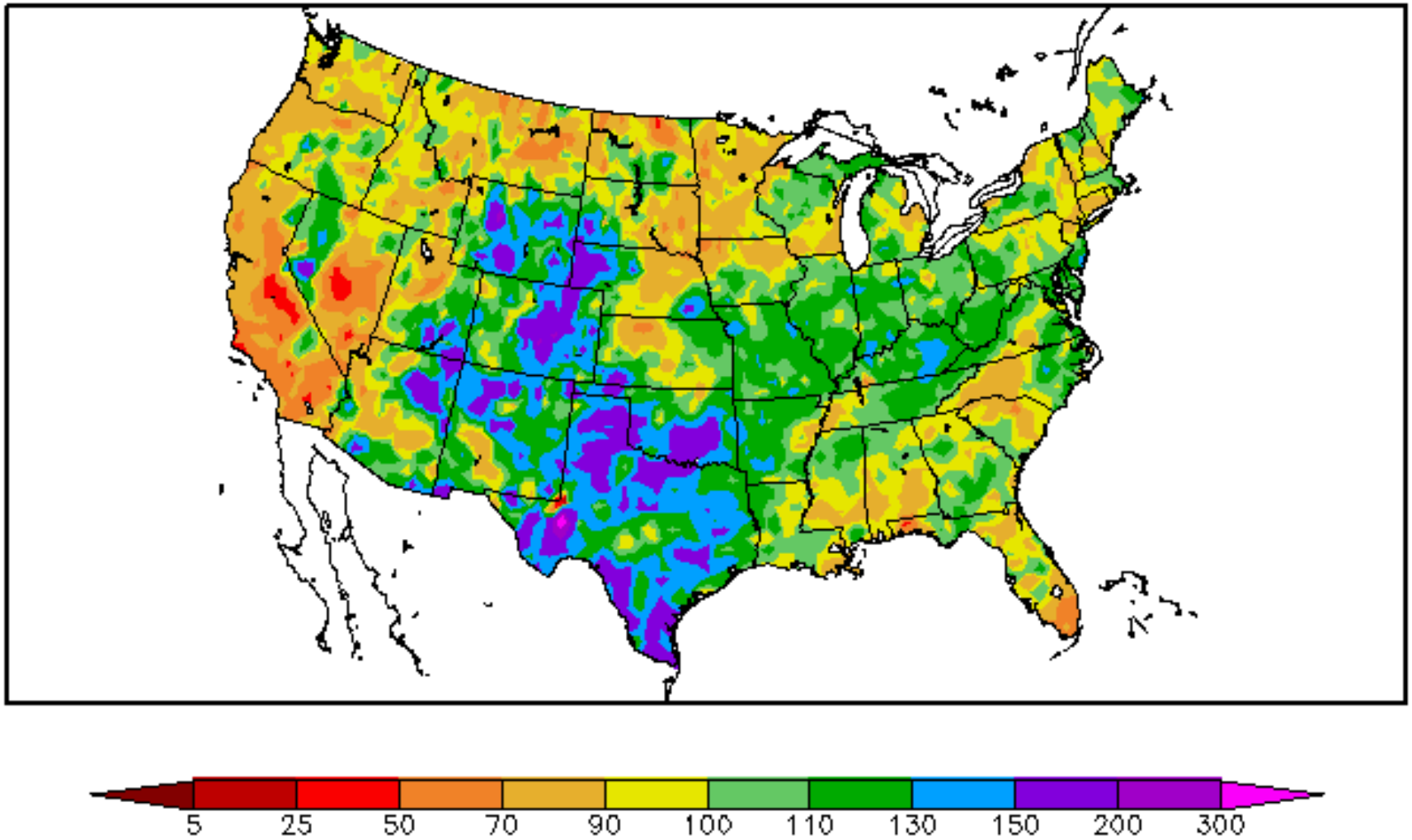



Generated 10/11/2014 at HPRCC using provisional data.

Regional Climate Centers

**Water Year to Date**
**2014-15**
**01 Oct 2014**
**Thru**
**18 Jul 2015**

# Percent of Normal Precipitation (%)
## 10/1/2014 – 7/18/2015

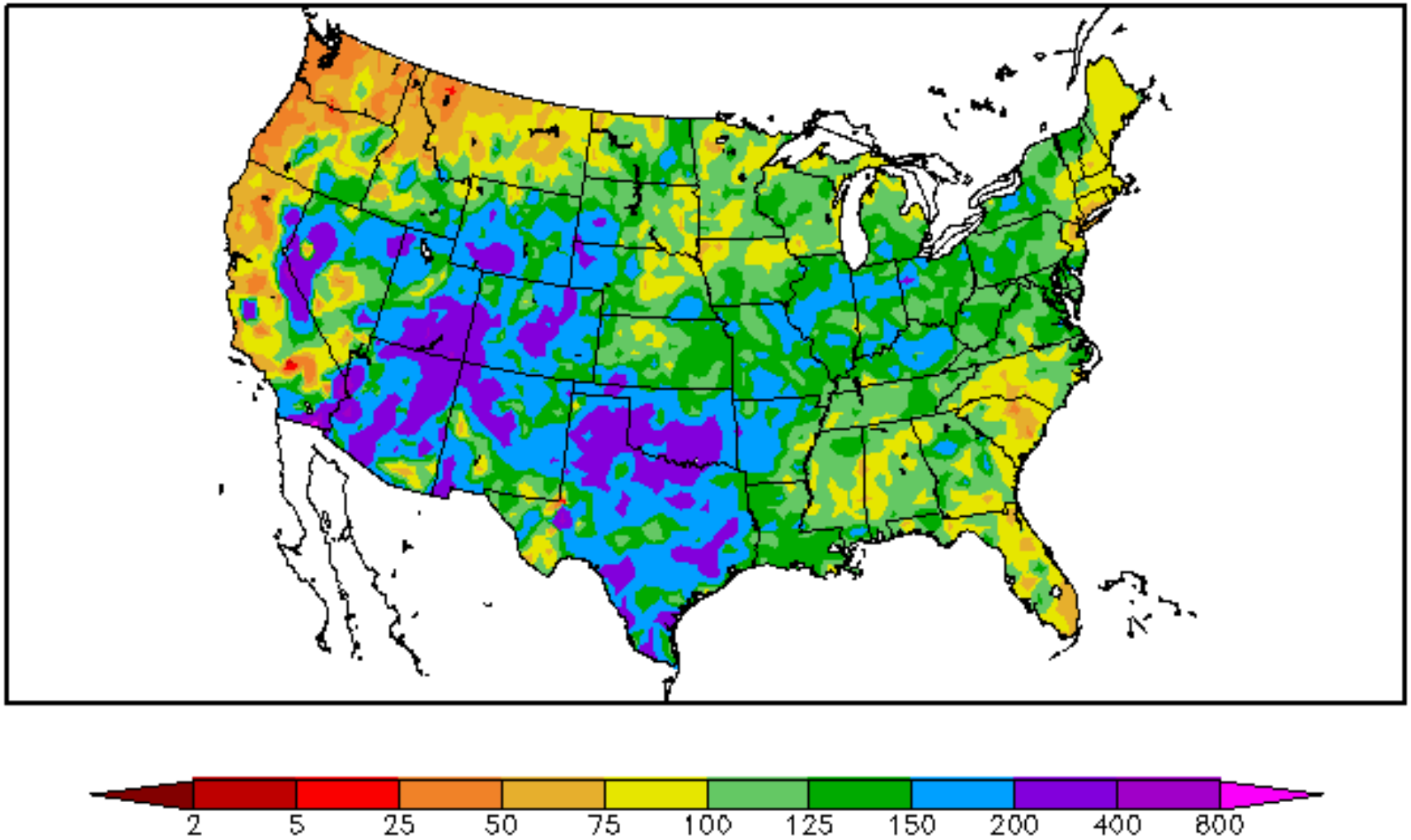



Generated 7/19/2015 at HPRCC using provisional data.

Regional Climate Centers

**Since Late Spring 2015**
**01 Apr - 18 Jul 2015**

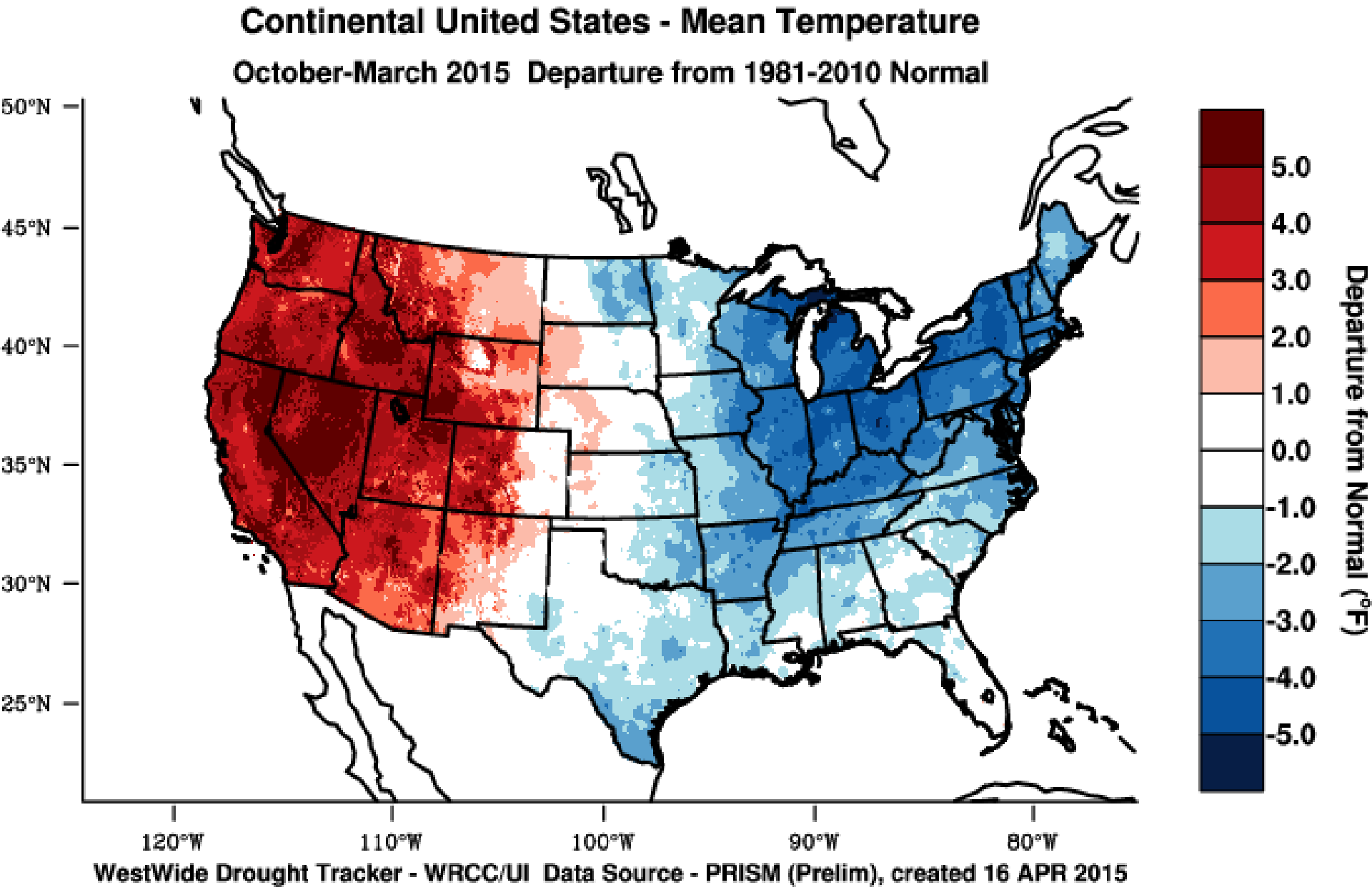
# Percent of Normal Precipitation (%)
## 4/1/2015 – 7/18/2015




Generated 7/19/2015 at HPRCC using provisional data.

Regional Climate Centers

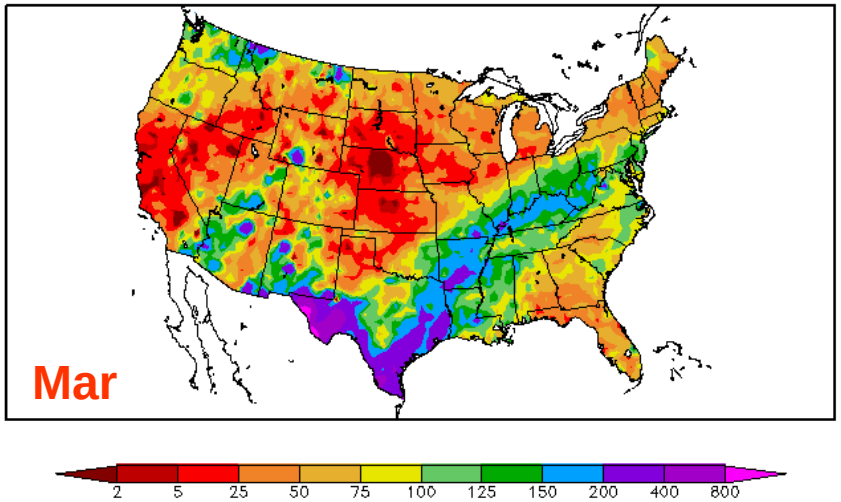
# Temperature Departure Oct - Mar 2014-15



# Precipitation Percent of Average

## Spring 2015

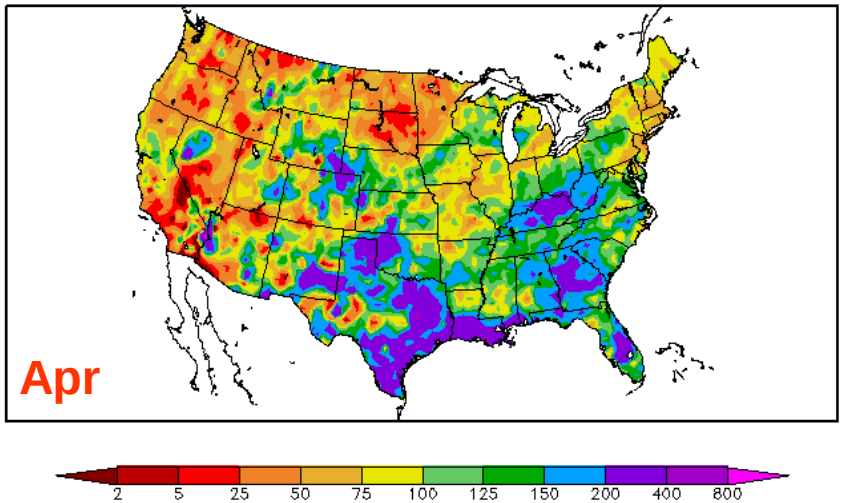
Percent of Normal Precipitation (%)
3/1/2015 – 3/31/2015



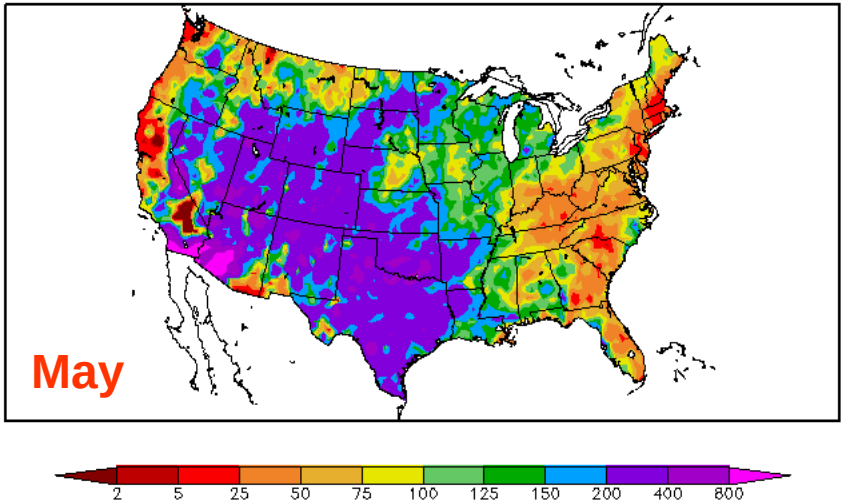

Generated 4/11/2015 at HPRCC using provisional data.

Regional Climate Centers

Percent of Normal Precipitation (%)
4/1/2015 – 4/30/2015



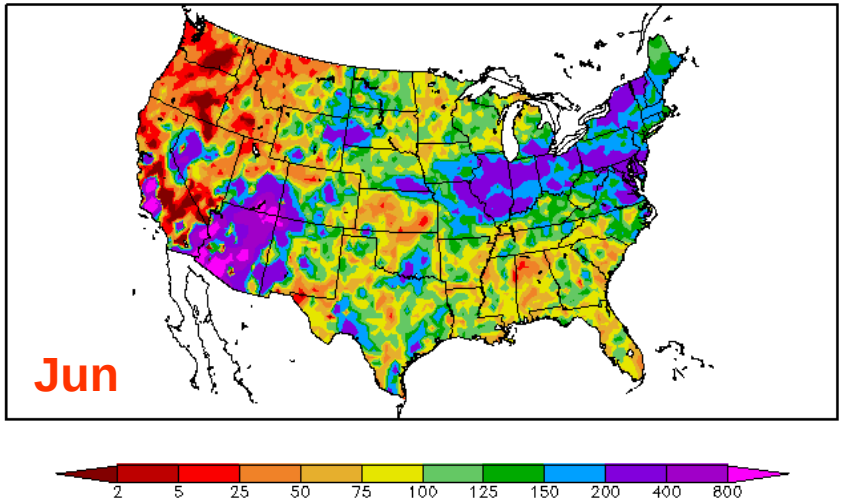

Percent of Normal Precipitation (%)
5/1/2015 – 5/31/2015




Generated 6/11/2015 at HPRCC using provisional data.

Regional Climate Centers

Percent of Normal Precipitation (%)
6/1/2015 – 6/30/2015



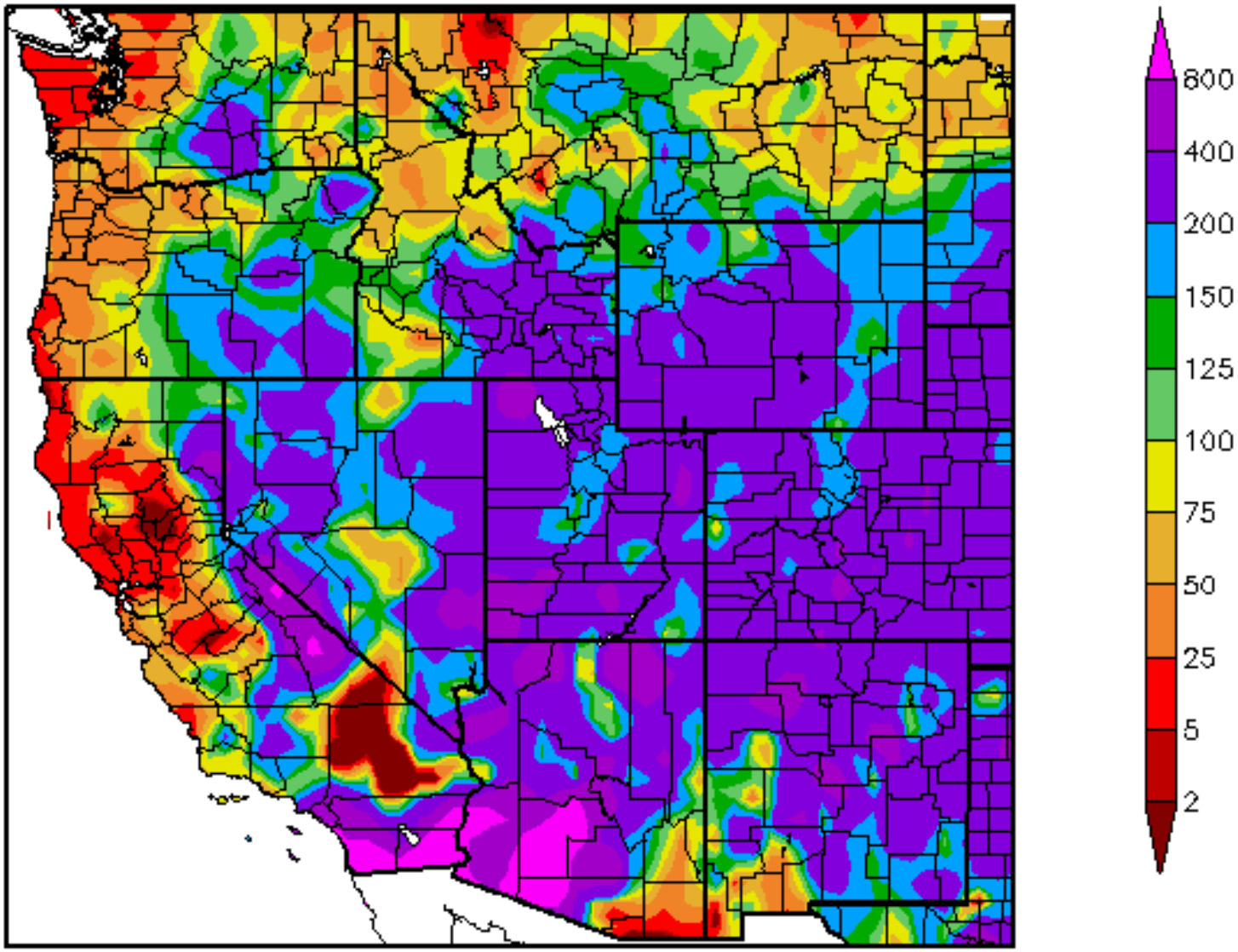

Generated 7/11/2015 at HPRCC using provisional data.

Regional Climate Centers

**May 2015 Precipitation Percent of Normal**

**01 May 2015 Thru 31 May 2015**

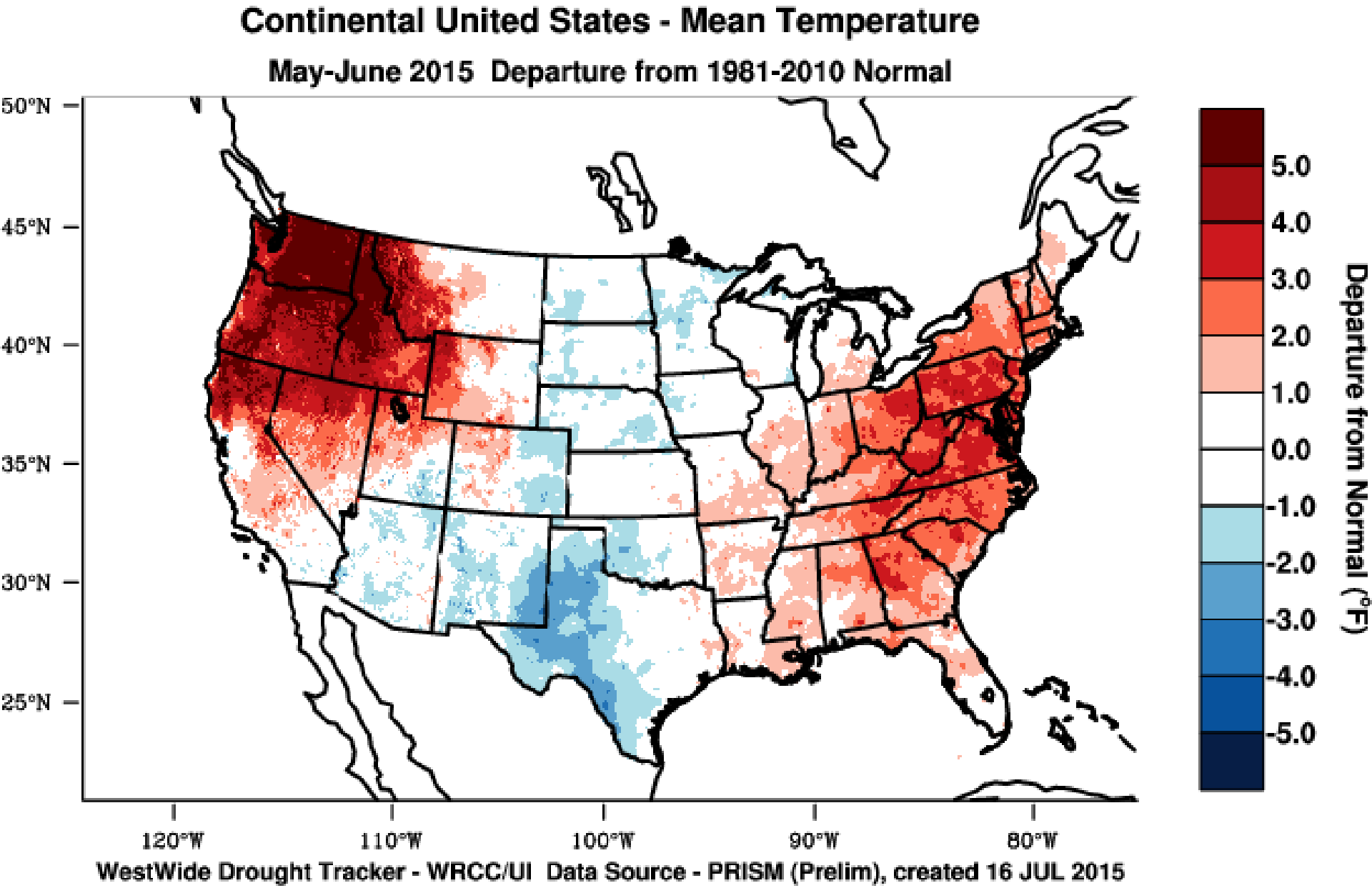
# Percent of Normal Precipitation (%)
## 5/1/2015 – 5/31/2015




Generated 6/11/2015 at HPRCC using provisional data.

Regional Climate Centers

# Temperature Departure May - Jun 2015

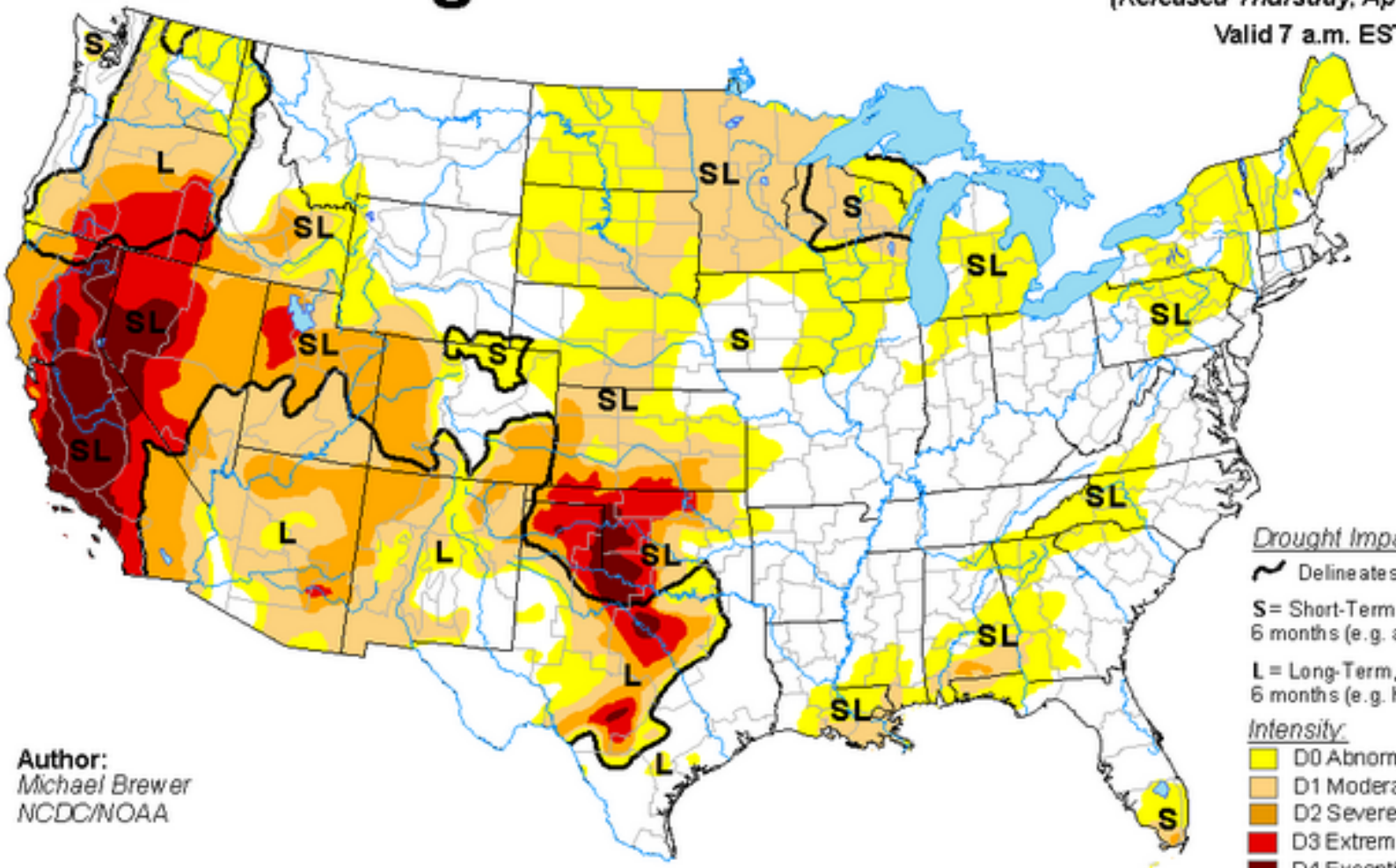


# U.S. Drought Monitor

**April 7, 2015**

*(Released Thursday, Apr. 9, 2015)*

Valid 7 a.m. EST





**Author:**
*Michael Brewer*
*NCDC/NOAA*


*Drought Impact Types:*

Delineates dominant impacts

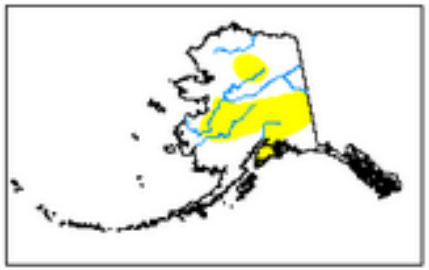
**S** = Short-Term, typically less than 6 months (e.g. agriculture, grasslands)

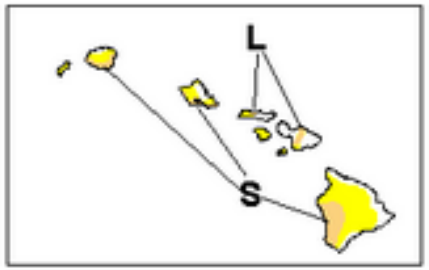
**L** = Long-Term, typically greater than 6 months (e.g. hydrology, ecology)

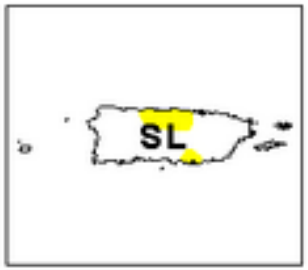
*Intensity:*

- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

*The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.*





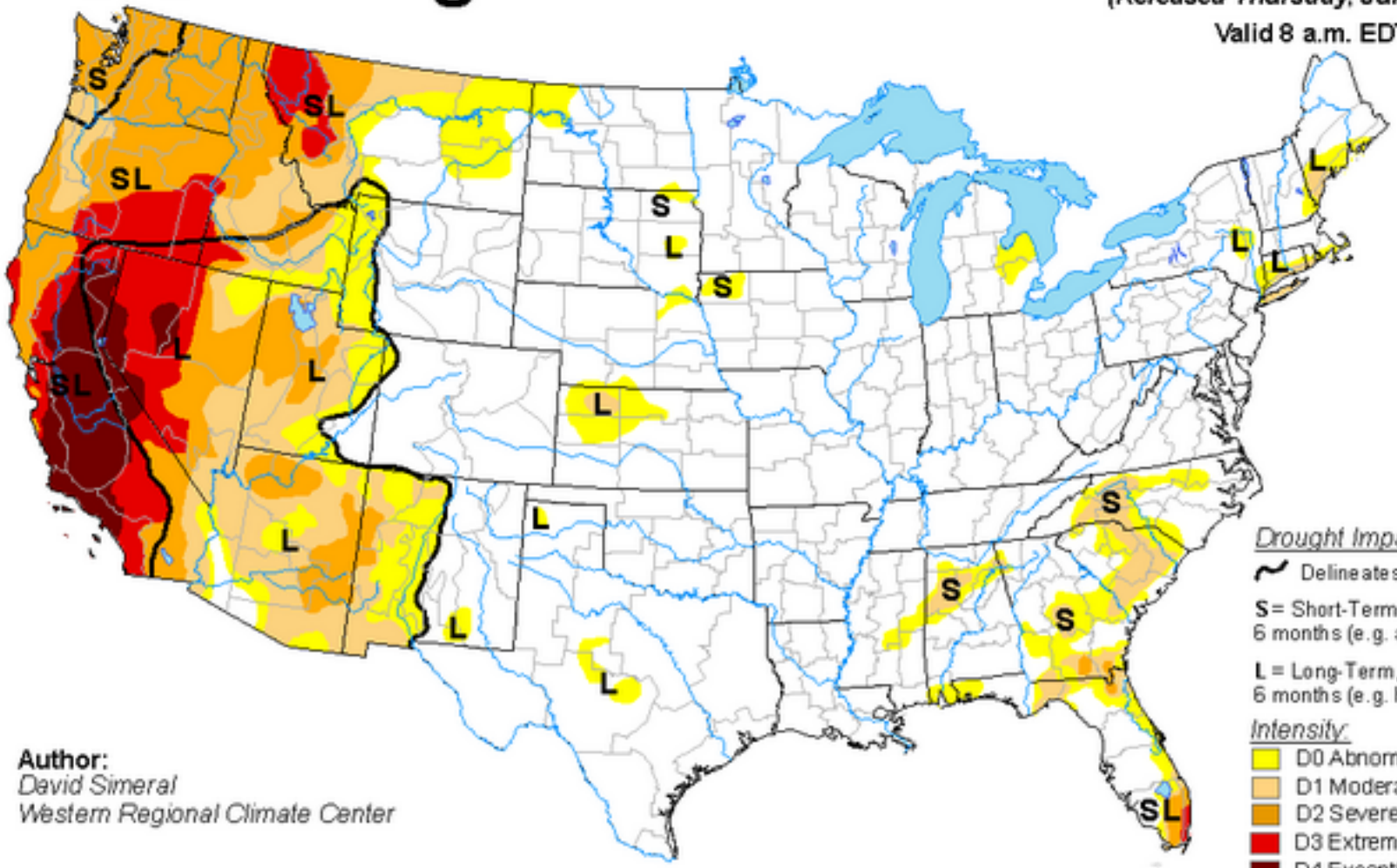

http://droughtmonitor.unl.edu/

# U.S. Drought Monitor

**July 14, 2015**

*(Released Thursday, Jul. 16, 2015)*

Valid 8 a.m. EDT





**Author:**
*David Simeral*
*Western Regional Climate Center*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Delineates dominant impacts

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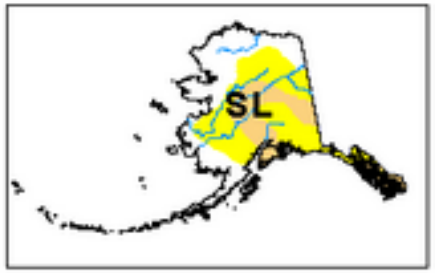
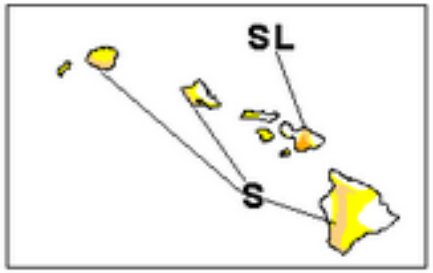
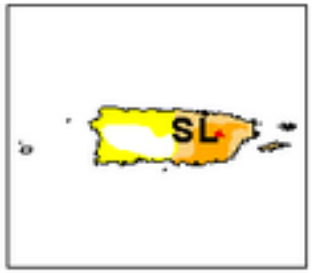
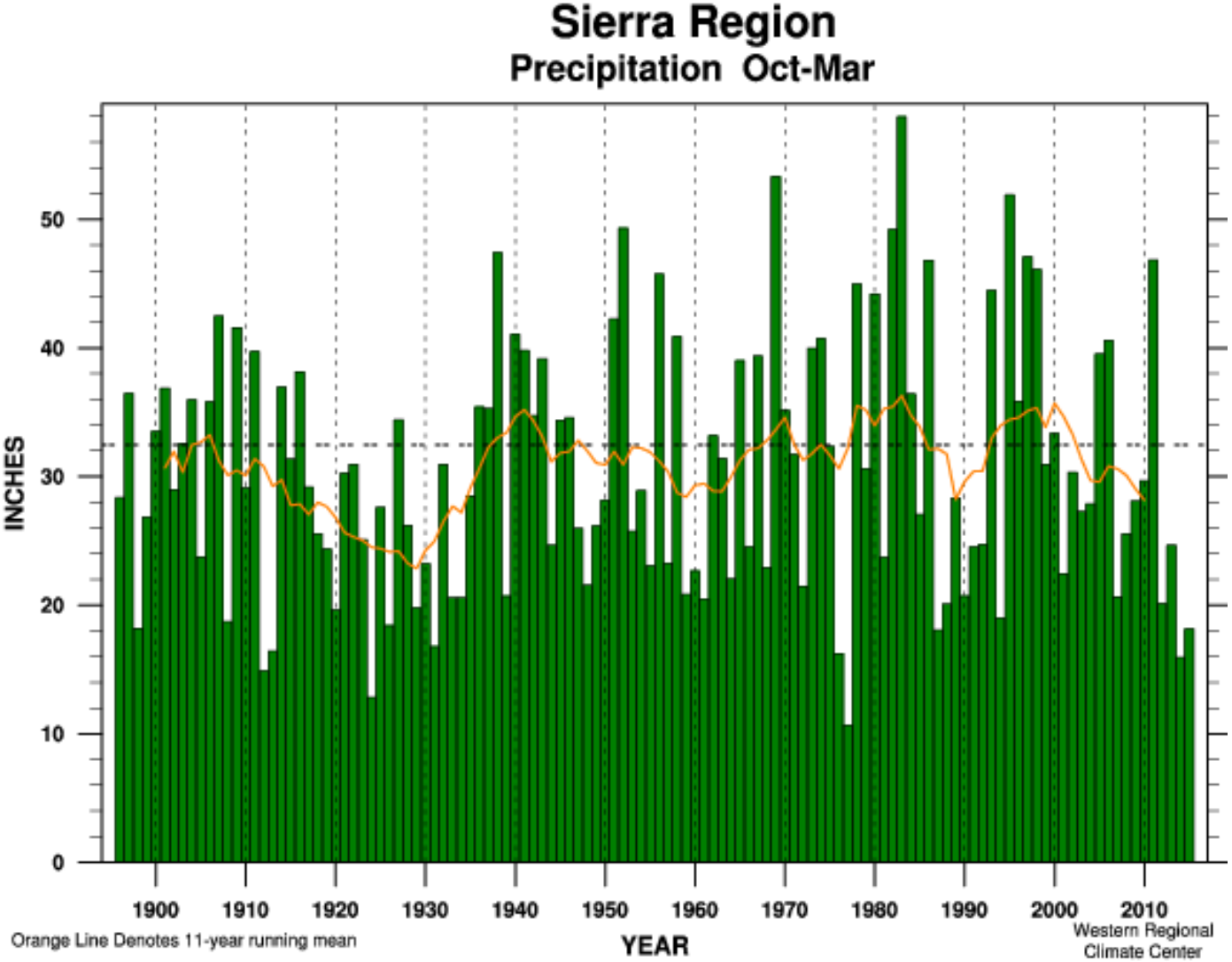



http://droughtmonitor.unl.edu/




| | | | |
|---|---|---|---|
| Linear Trend 1895-present | + 2.23 ± 5.10 in. | (+ 6 ± 15%) per 100 yr | |
| Linear Trend 1949-present | - 5.05 ± 14.08 in. | (- 15 ± 43%) per 100 yr | |
| Linear Trend 1975-present | -15.13 ± 32.55 in. | (- 46 ± 100%) per 100 yr | |
| Wettest Year | 57.99 in. ( 178%) in 1983 | MEAN | 32.48 in. |
| Driest Year | 10.69 in. ( 32%) in 1977 | STDEV | 10.87 in. |
| Oct-Mar 2015 | 18.14 in. ( 55%) | RANK | 9 of 120 |

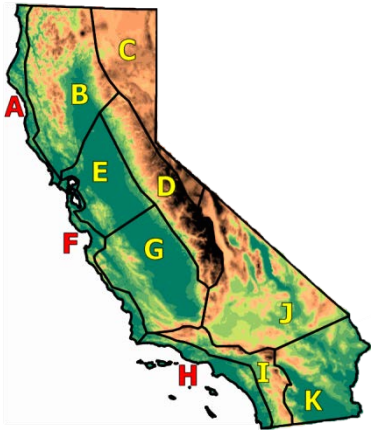
**Sierra Nevada Precipitation**

**Snow Season**

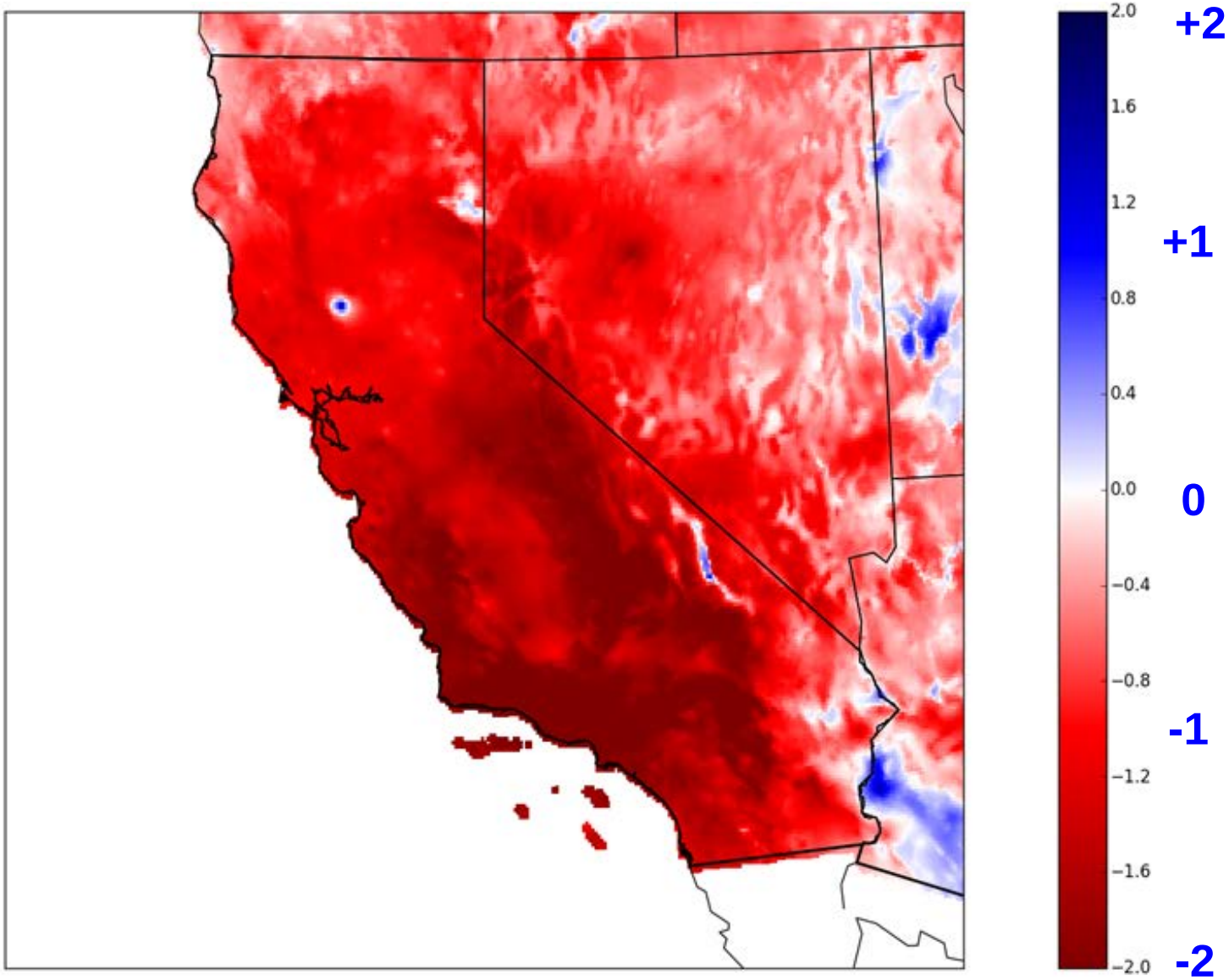
**Oct-Mar**

**1895-96 thru 2014-15**

**California Climate Tracker**



# The Missing Years:
# Precipitation Deficits Over Four Winters 2011-12/14-15
# Expressed in Units of Average Annual Precipitation.
# Based on PRISM. Courtesy Paul Iniguez, NWS Phoenix.

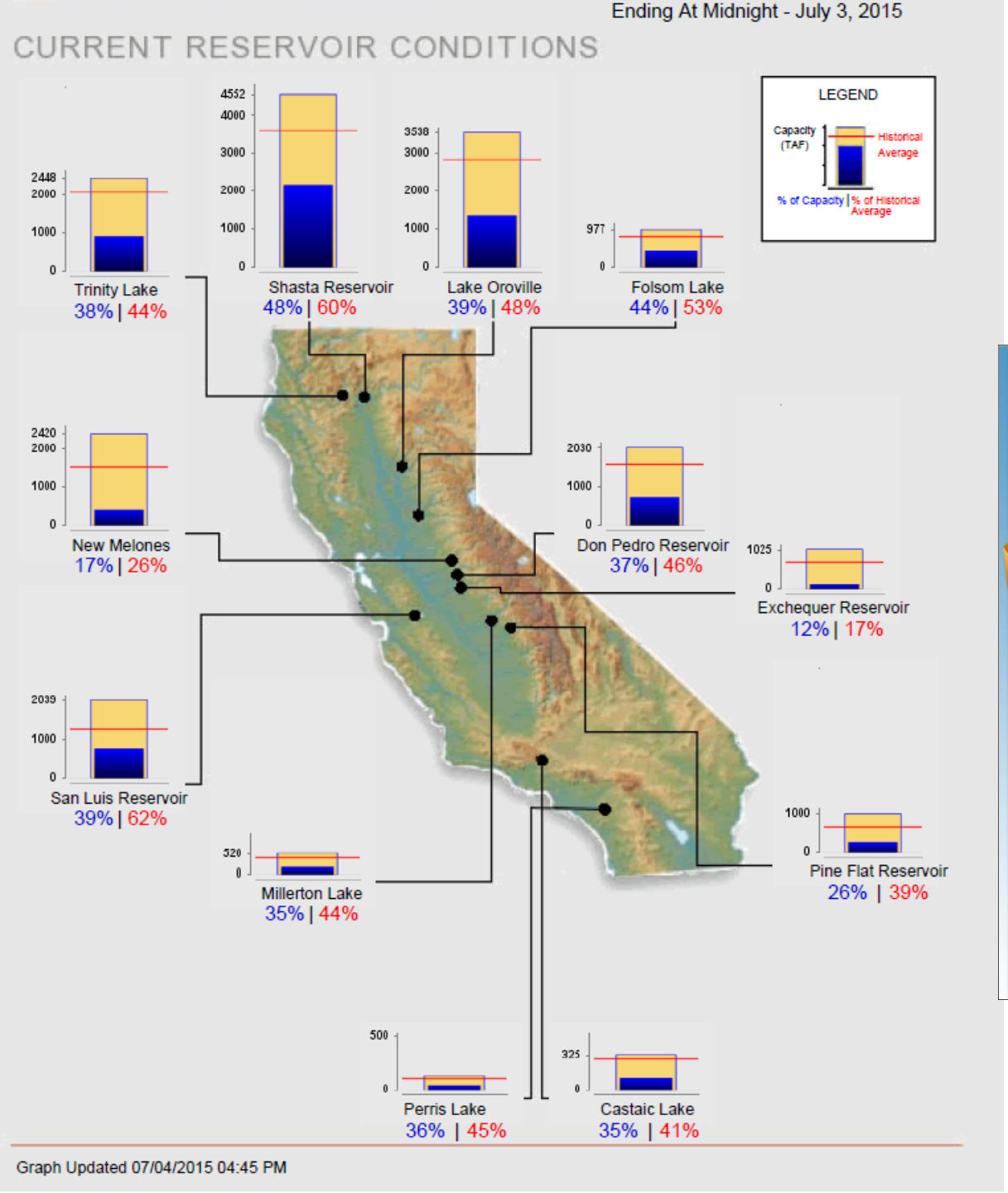


Green Bridge
Lake Oroville
Feather River

2011 July 20

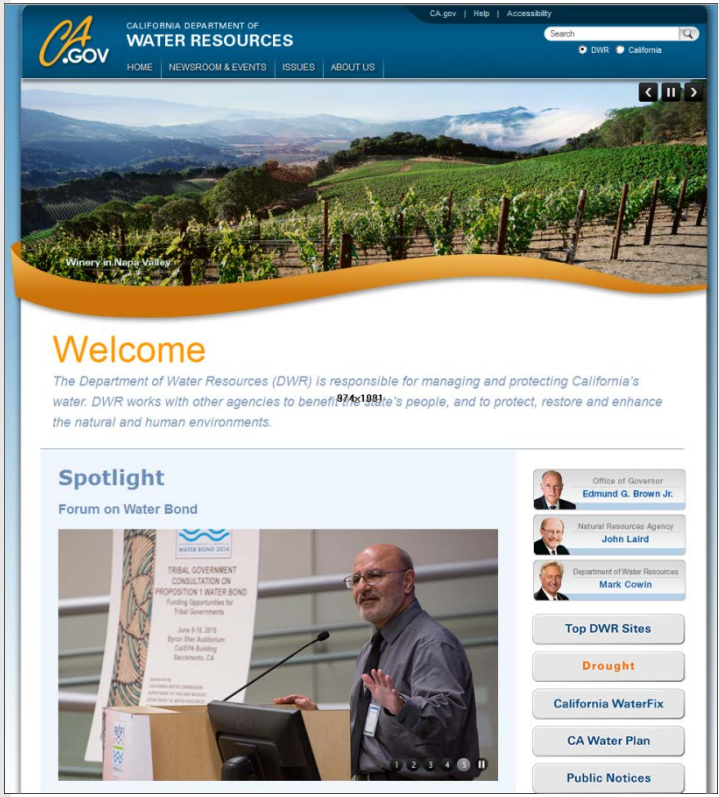
Enterprise Bridge
Lake Oroville
Feather River

2014 August 20



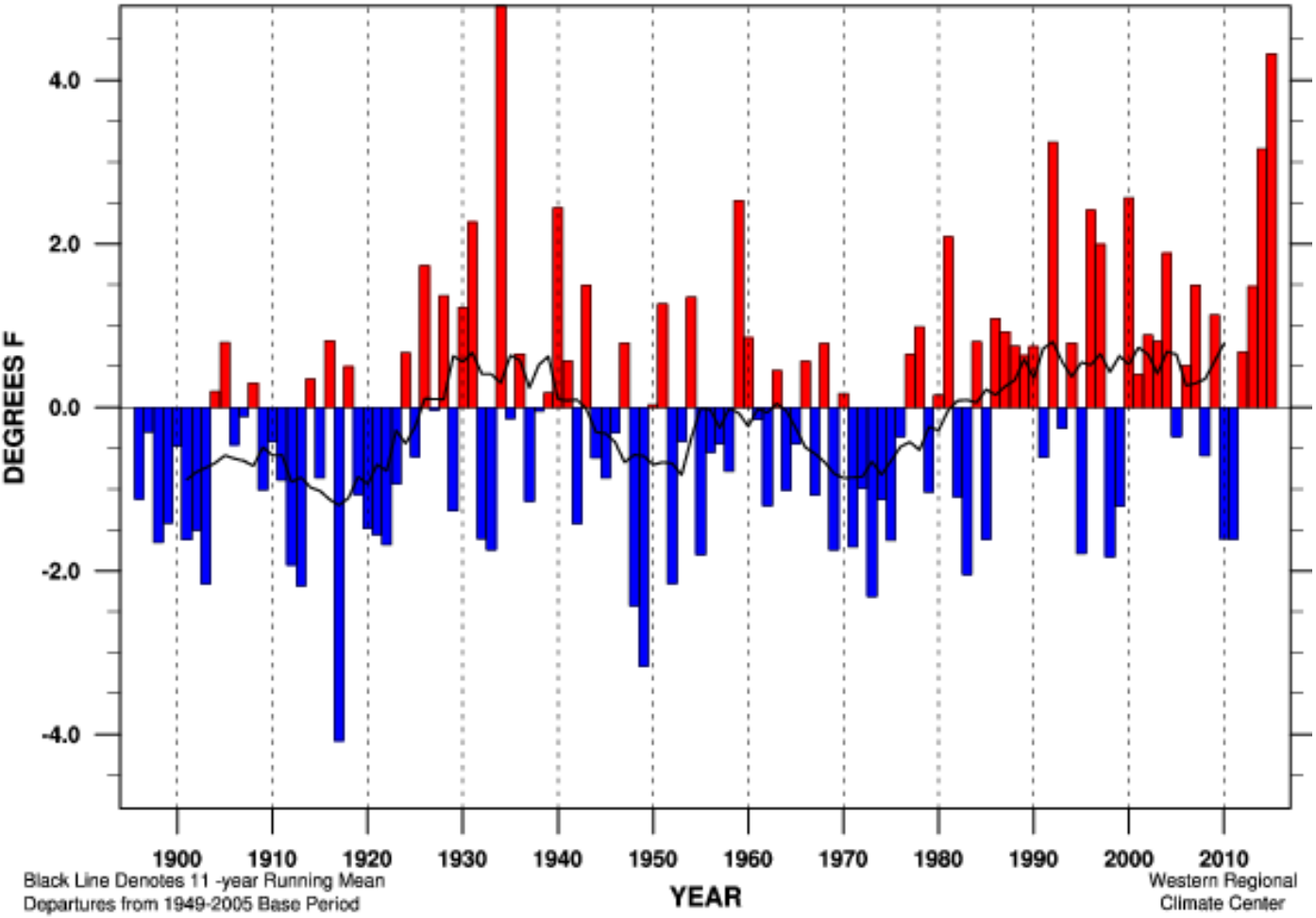

# Many Sources of Drought Information Fed-State-Local-NGO-etc.

## Here: CA DWR



# Sierra Region

## Mean Temperature Departure Oct-May



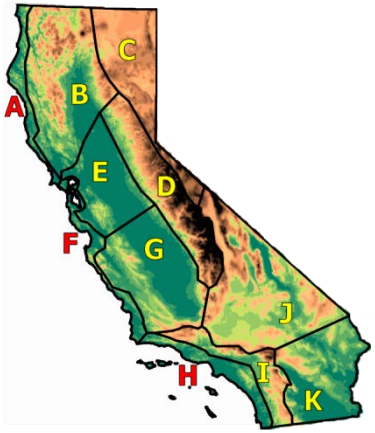

| | | | |
|---|---|---|---|
| Linear Trend 1895-present | + 1.27 ± 0.75 °F/100yr | | |
| Linear Trend 1949-present | + 2.43 ± 1.81°F/100yr | | |
| Linear Trend 1975-present | + 3.10 ± 4.14 °F/100yr | | |
| Warmest Year | 47.0 °F (+ 4.9 °F) in 1934 | MEAN | 42.1°F |
| Coldest Year | 38.0 °F (- 4.1°F) in 1917 | STDEV | 1.35 °F |
| Oct-May 2015 | 46.4 °F (+ 4.3 °F) | RANK | 119 of 120 |

**Sierra Nevada Temperature**

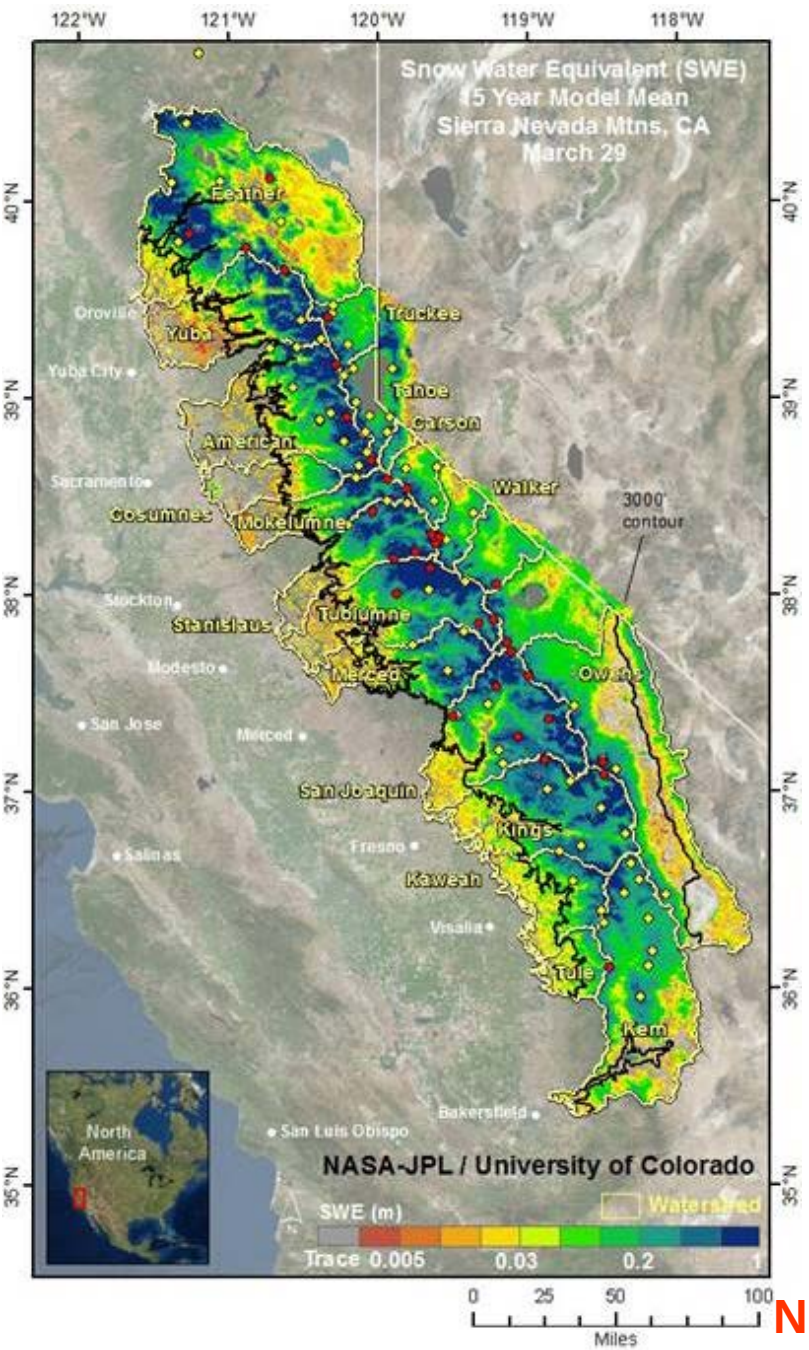
**Oct-May**

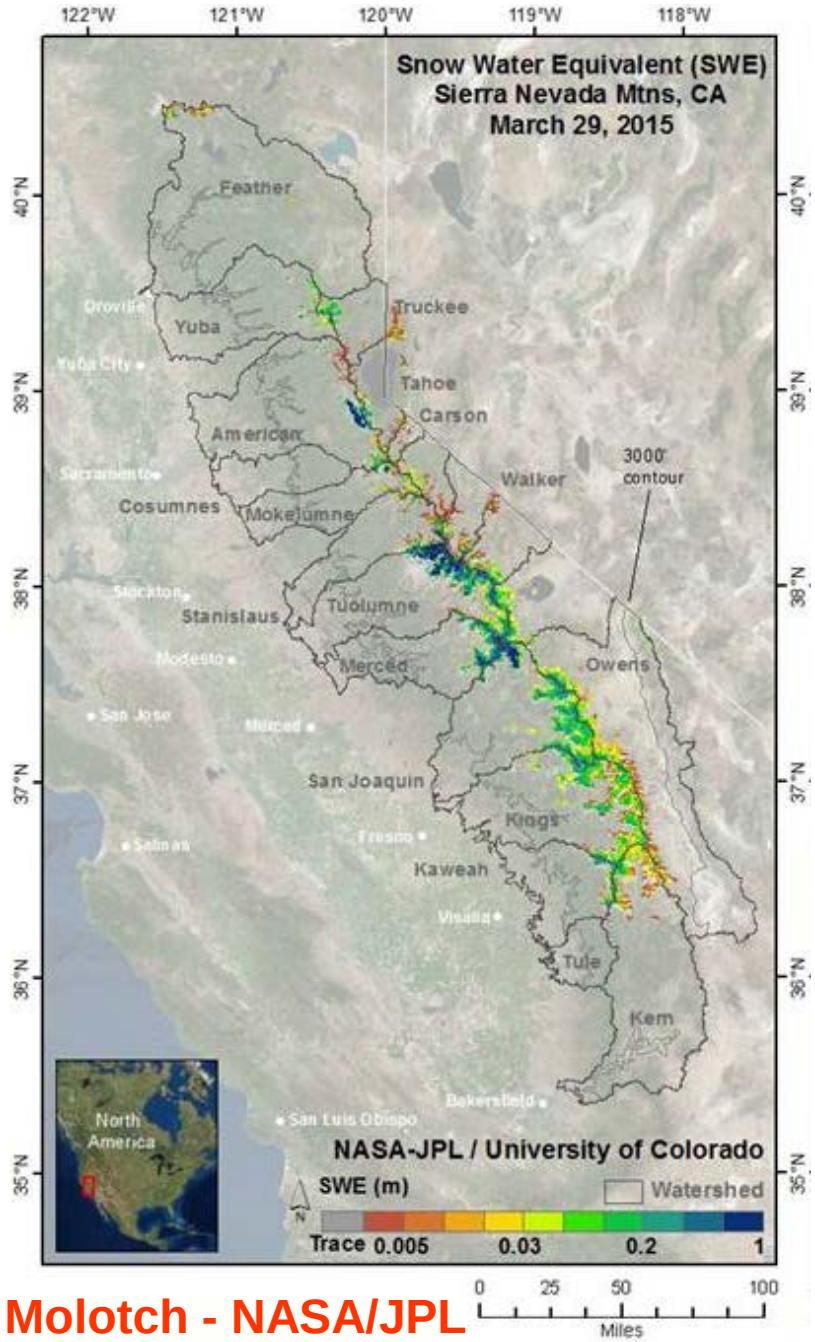
**1895-96 thru 2014-15**

**California Climate Tracker**



# 15-Year Mean Sierra Snow Water Equivalent 2015 March 29

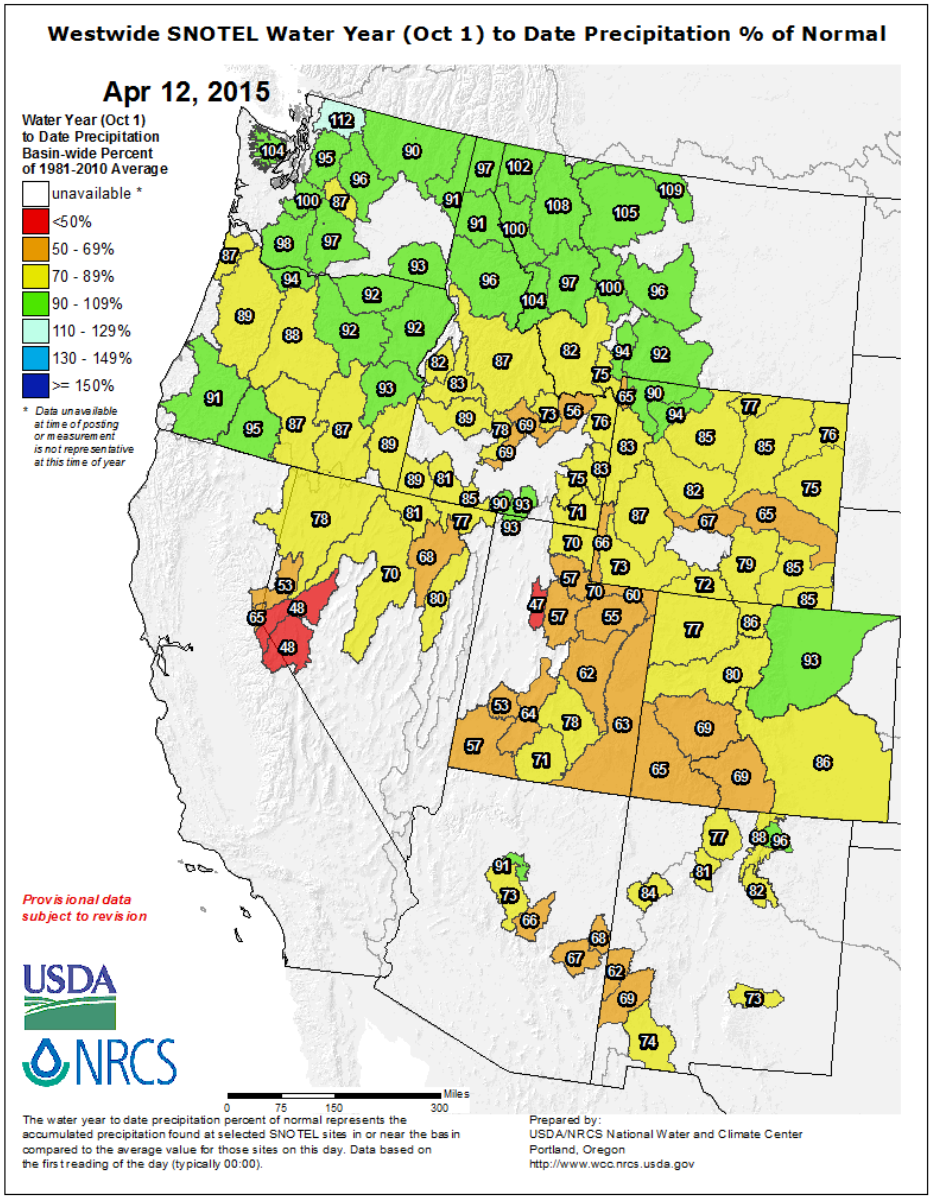


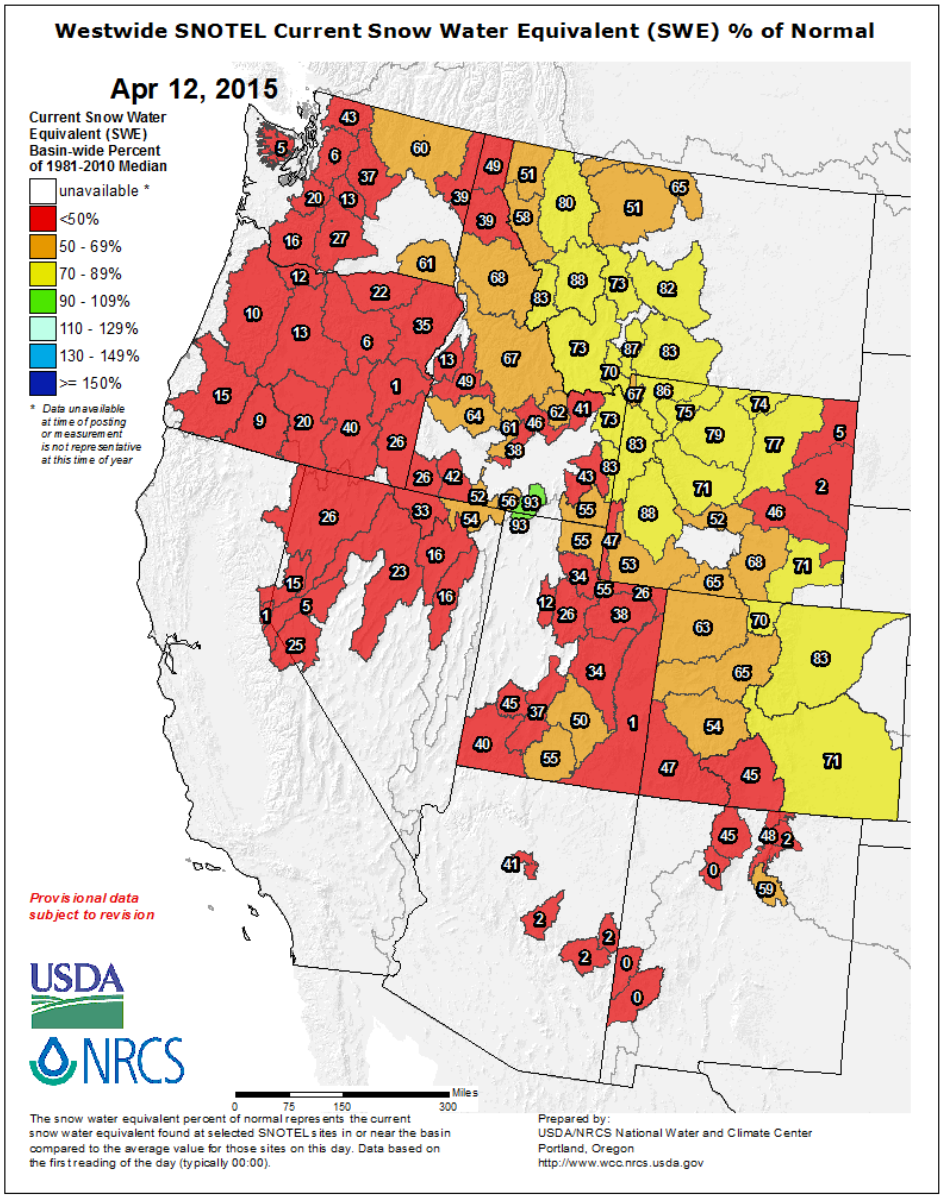

Noah Molotch - NASA/JPL

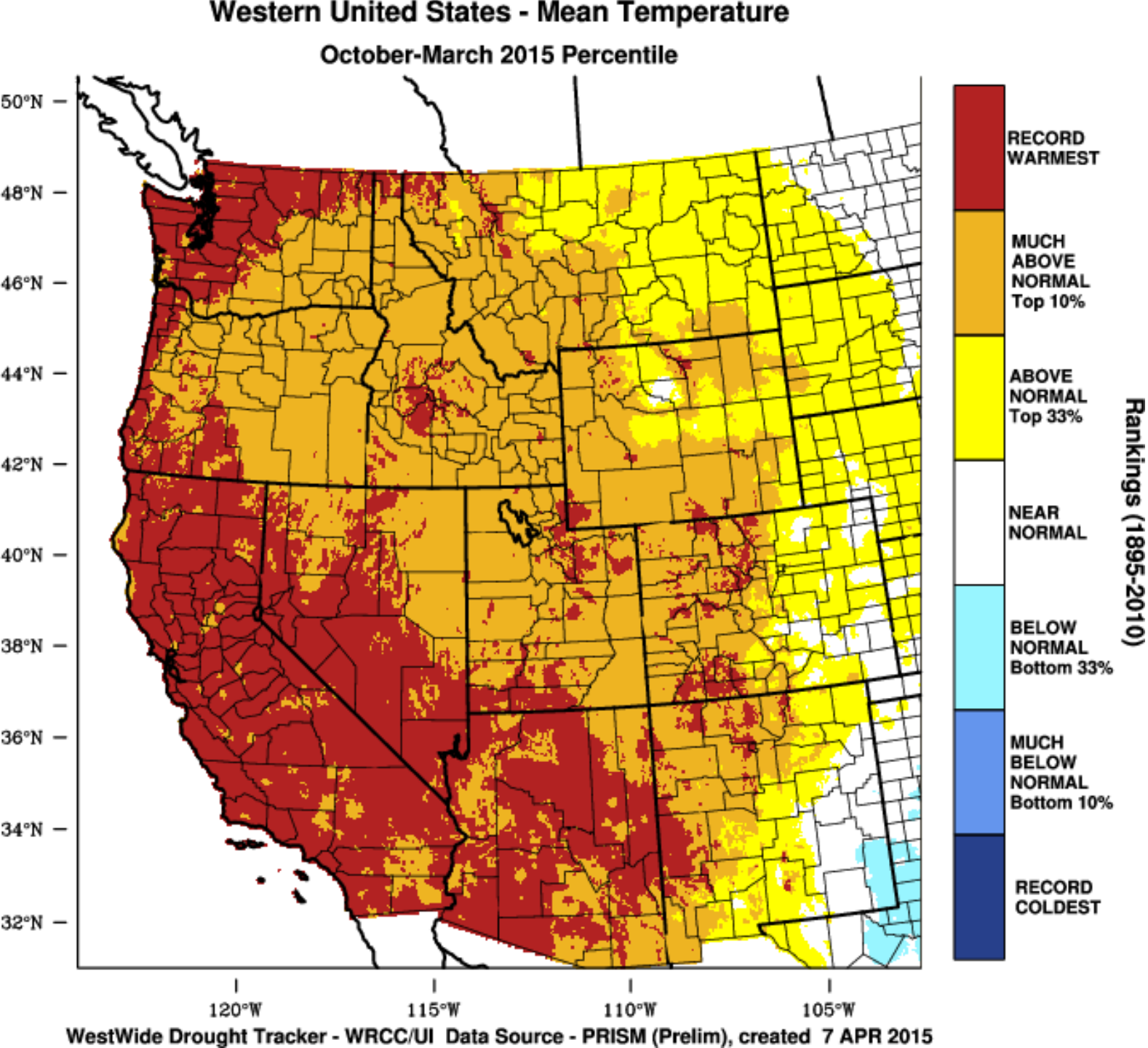
# The Great Snow Drought of 2014-15

## Precipitation




## Snowpack






**Western US Temperature Percentiles**

**Water Year To Date**

**Oct 2014 thru Mar 2015**

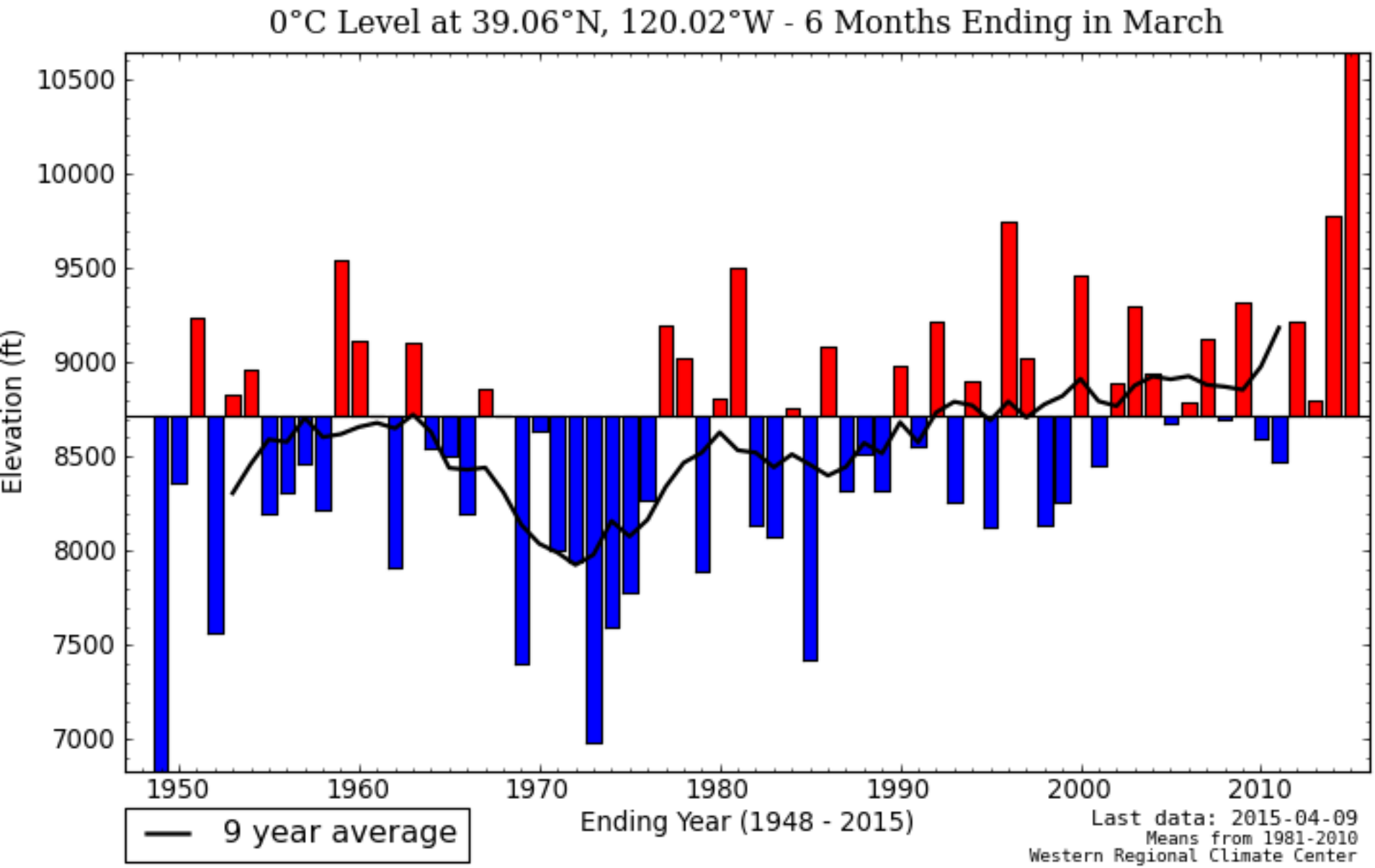
**Reference Period 120 Years 1895-2015**

**WestWide Drought Tracker**

**Updated Monthly**

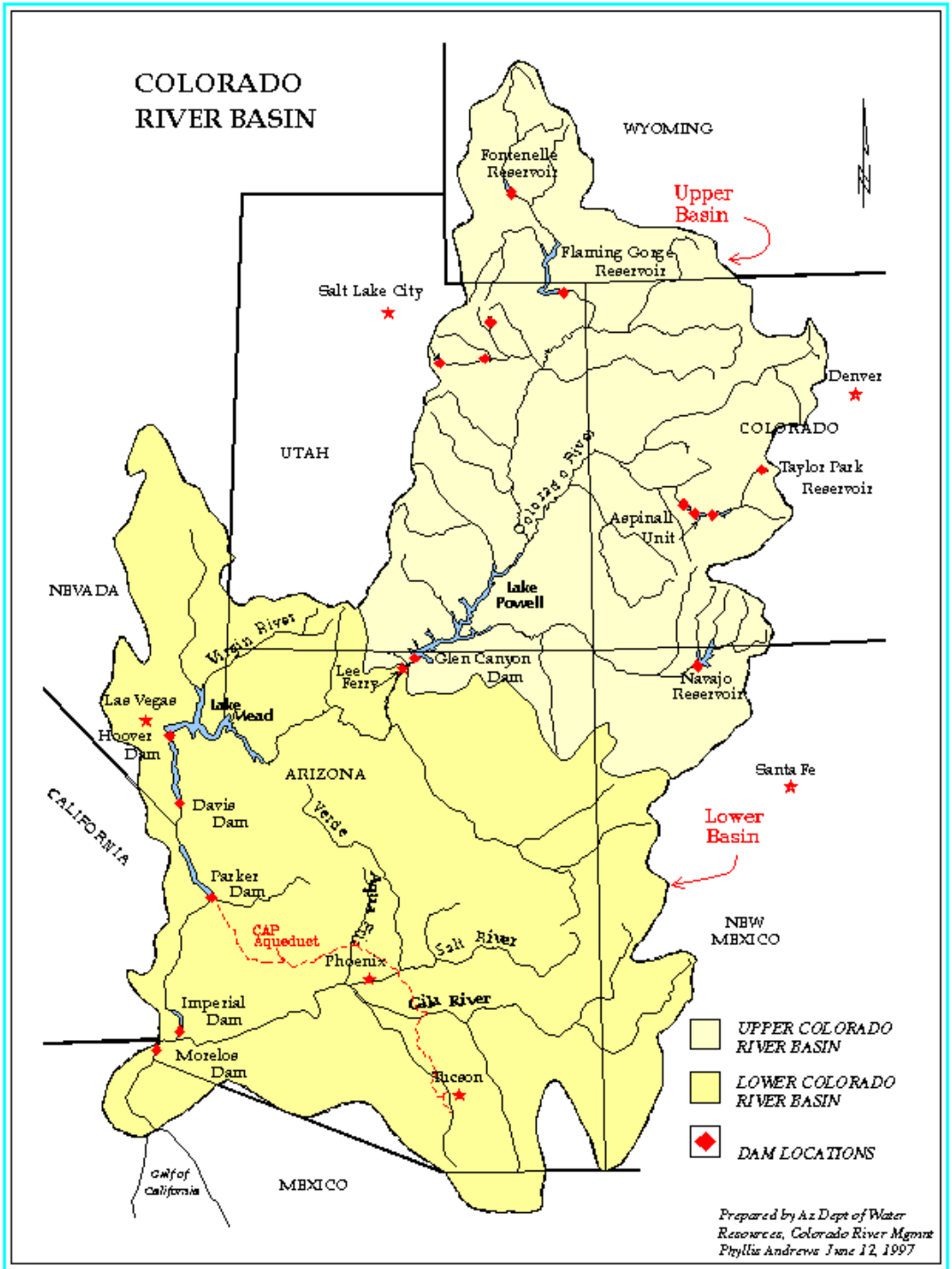
**WRCC**

# Oct-Mar Freezing Level Over Lake Tahoe.
# 1948-49 thru 2014-15

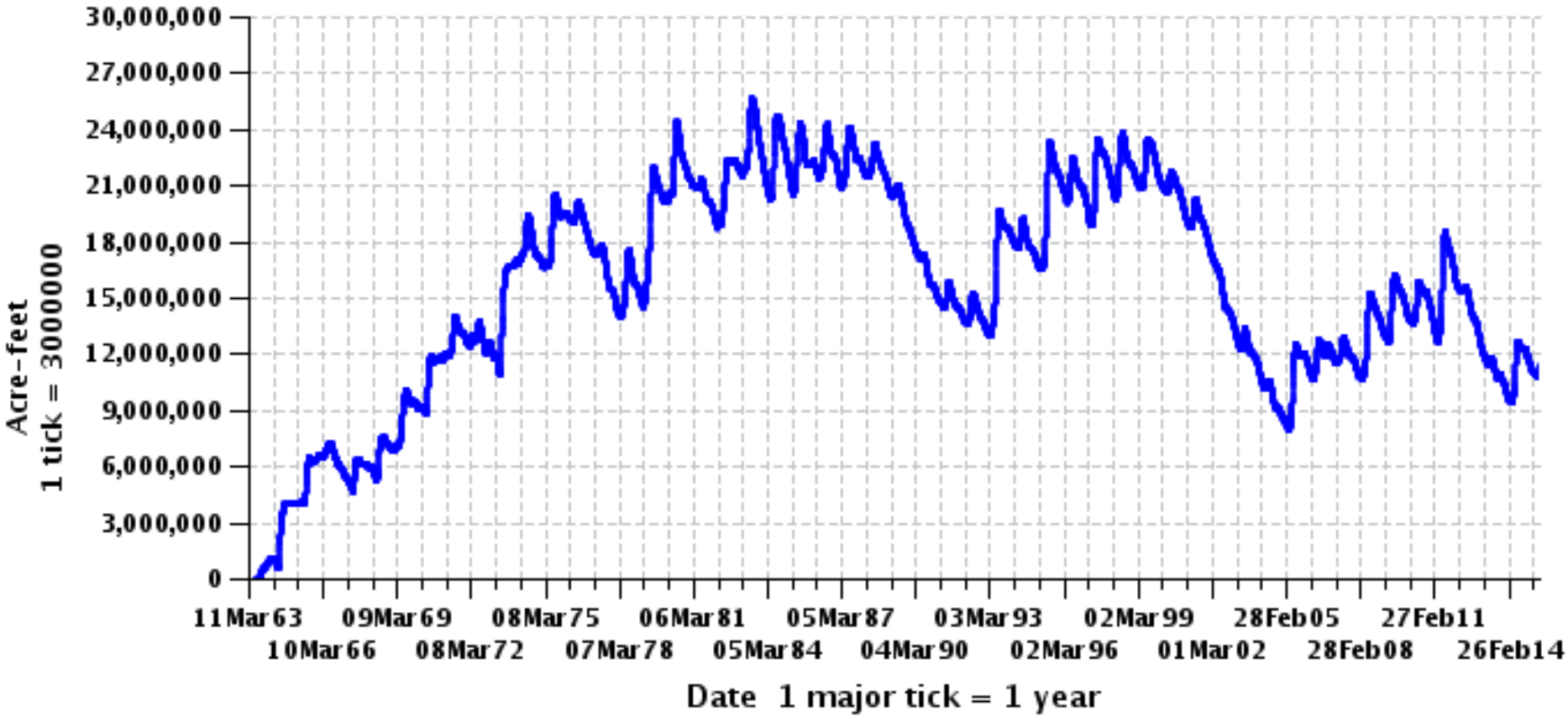


Mt Charleston.  Kelly Redmond  20150315

**What would a Drought Monitor map look like that incorporated this complexity ???**


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

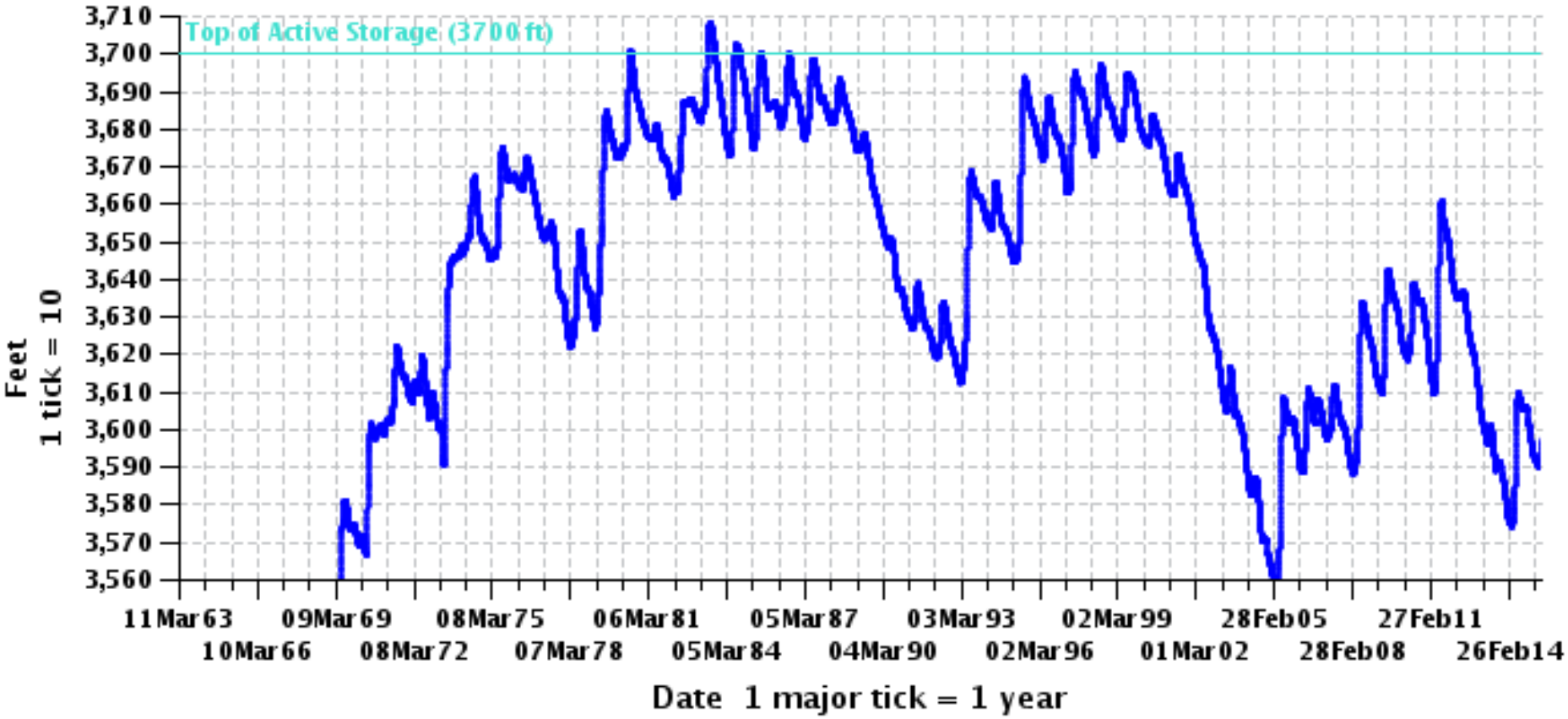
# Lake Powell Storage Through May 31, 2015




**Currently 48 % full** (capacity 24.17 MAF)

**Minimum: 33 % full on April 8, 2005**

# Lake Powell Elevation Through May 31, 2015




**Water level on April 10, 2015 was 3597.27 ft, -103 ft below full.**

**Minimum level on April 8, 2005 was 3555 ft, -145 ft below full.**

**Source: www.usbr.gov/uc/water/index.htl**

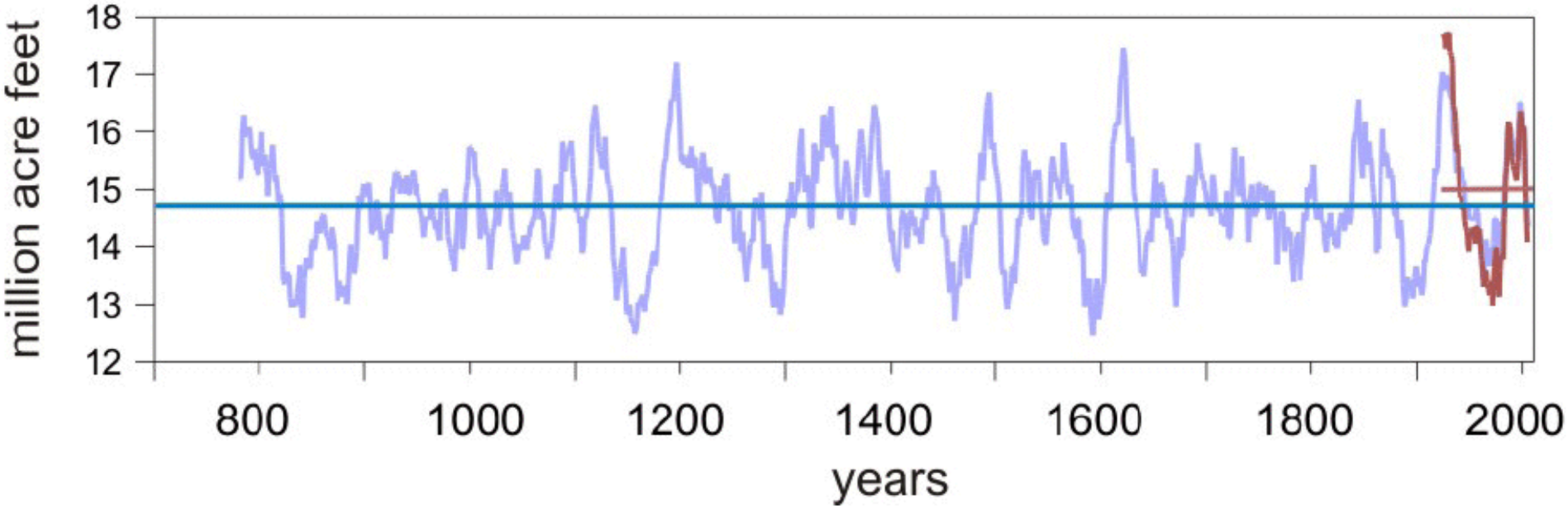
Lake Mead.  Kelly Redmond  20150220

Lake Mead.  Kelly Redmond  20150220

Kelly Redmond 20150329

# Lessons from History.

## Colorado River Flow. Lees Ferry. Reconstructed 762 thru 2005 A.D.




**Red: Gauged record.**
**Blue: Reconstructed record.**
**20-Year moving averages.**


Meko, D.M., C.A. Woodhouse, C.H. Baisan, T. Knight, J.J. Lukas, M.K. Hughes, and M.W. Salzer, 2007.
Medieval drought in the upper Colorado River basin.
Geophysical Research Letters 34m L10705, doi: 10.1029/2007GL029988

?

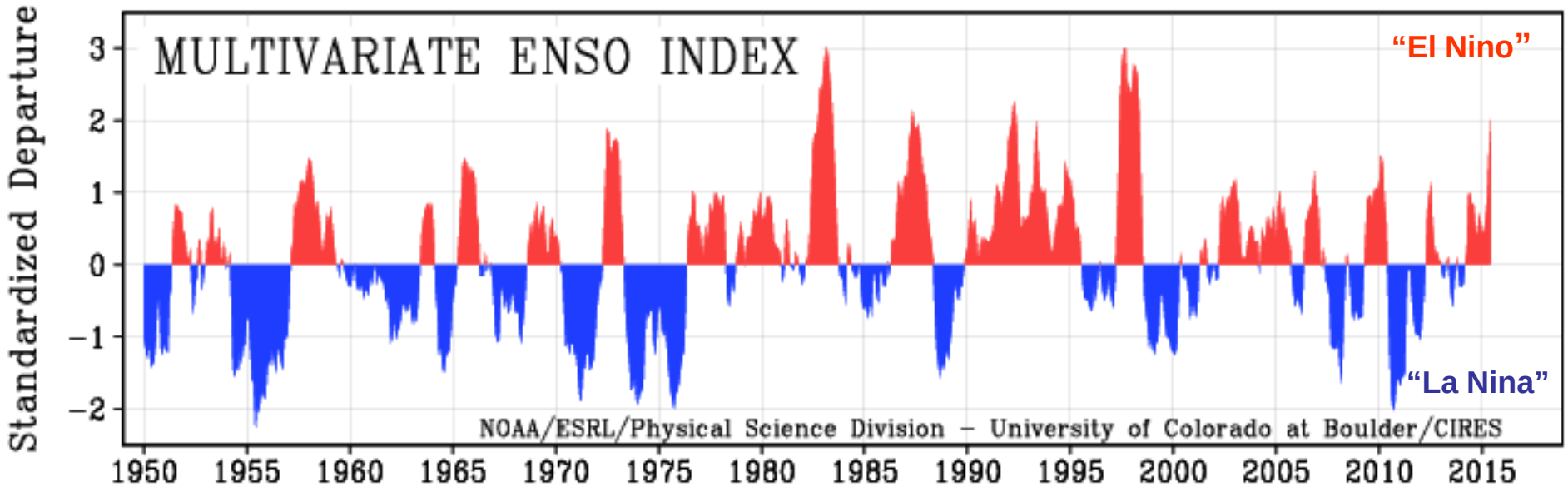
**Is the current Southwest drought a once-or-twice-a-century drought like those of the past 500 years …**

? … or … ?

**a harbinger of things to come, a different type of drought that we have not observed before ?**

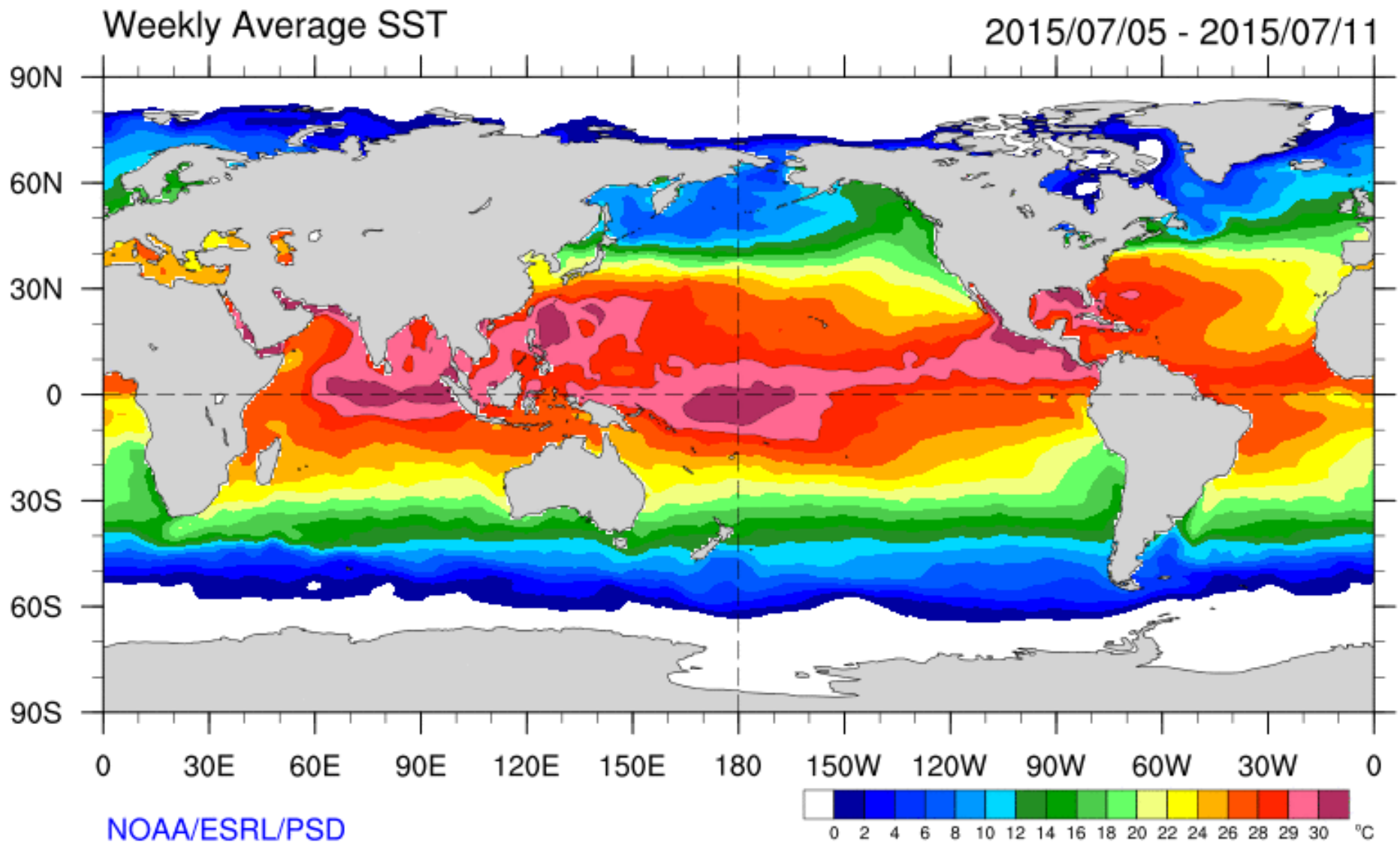
?

## Through June 2015



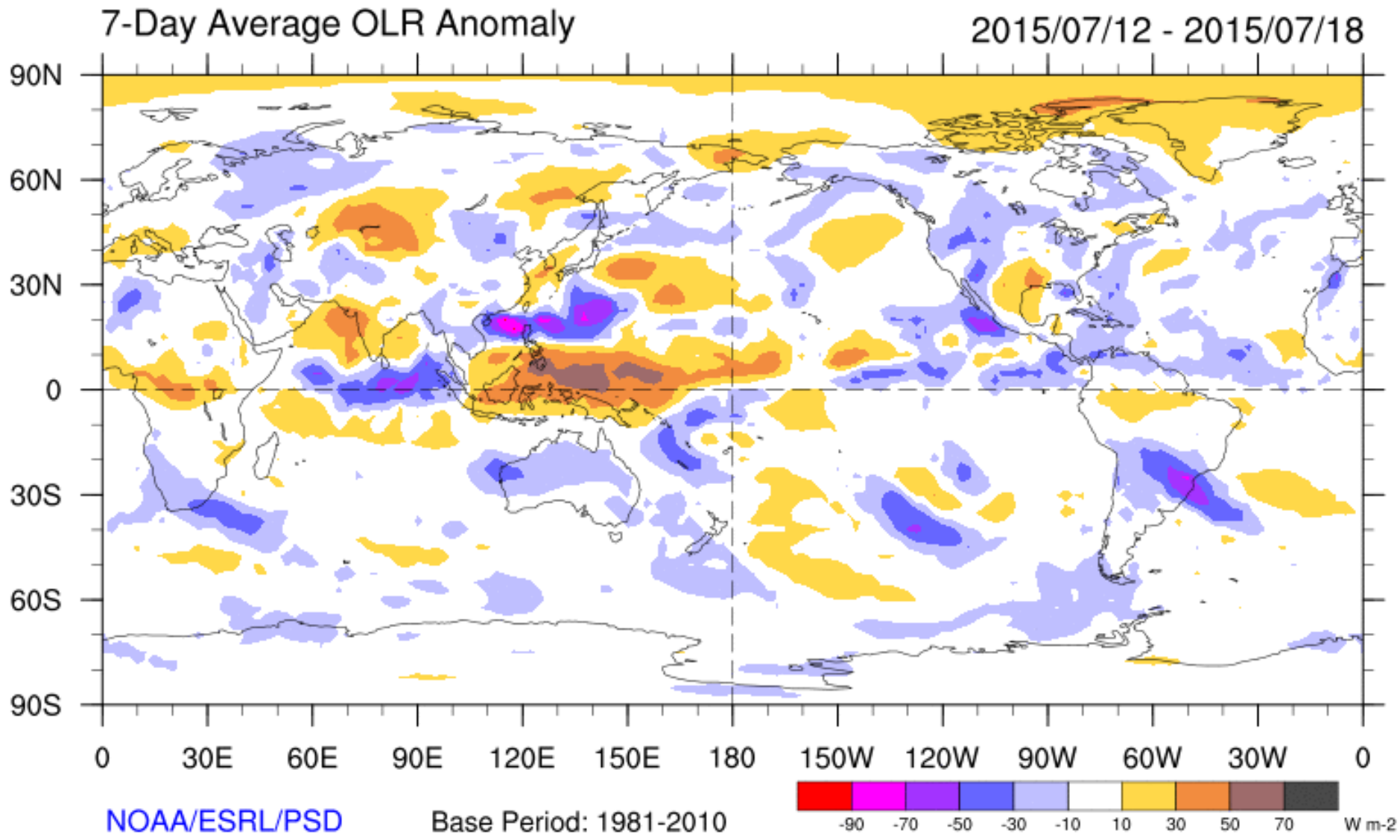

NOAA ESRL ("CDC"), Wolter and Timlin

# Ocean Temperature ( C )  5 - 11 Jul 2015

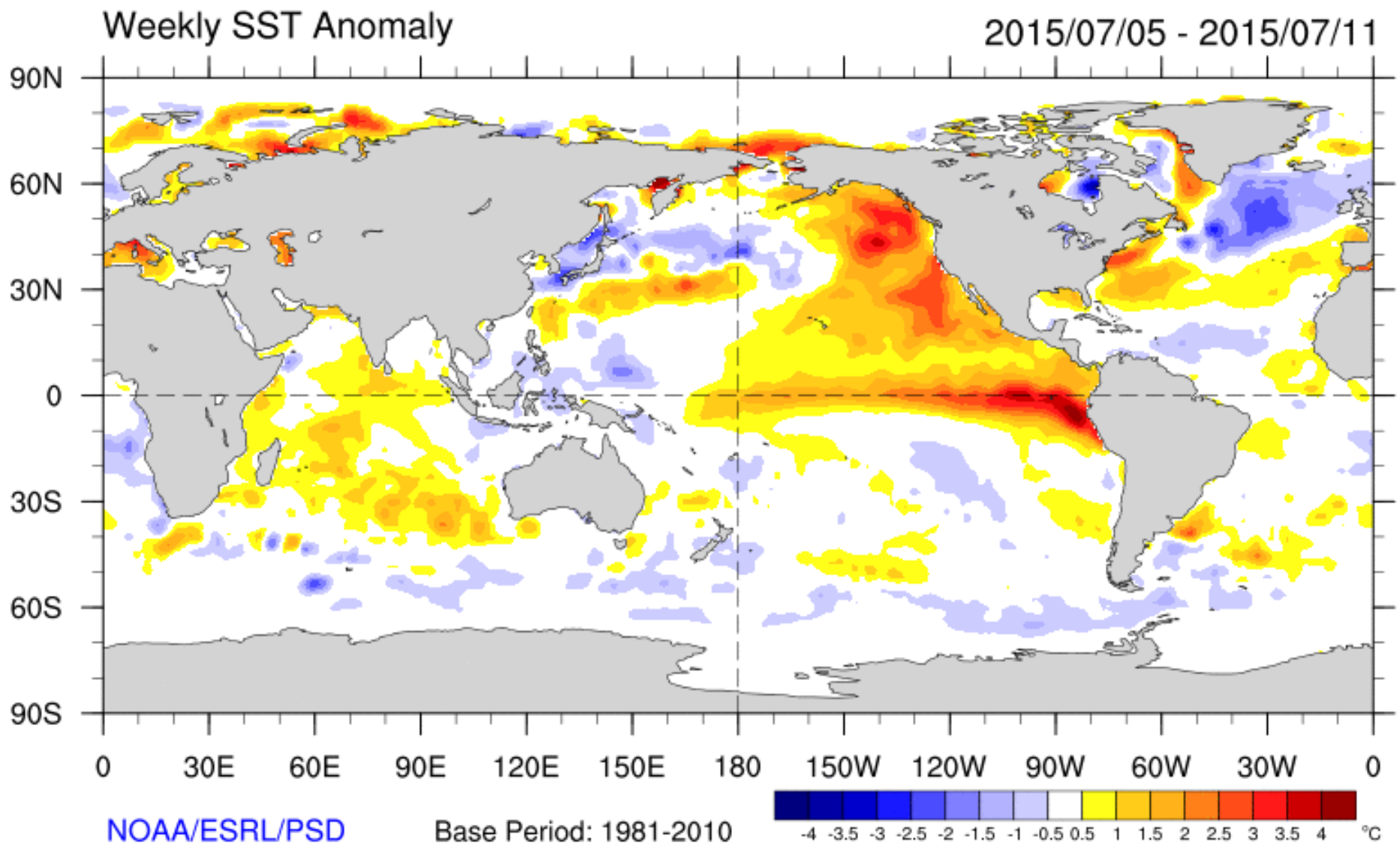


**Cloudiness Departure from Average 5 - 11 Jul 2015**

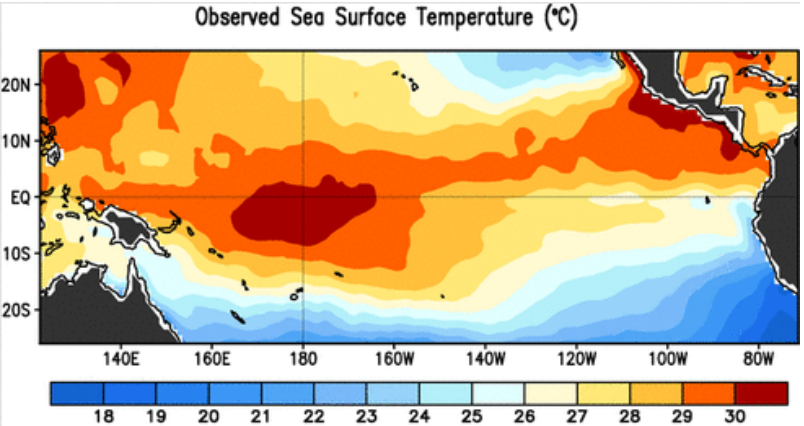
**Red / Orange = Less. Blue = More.**

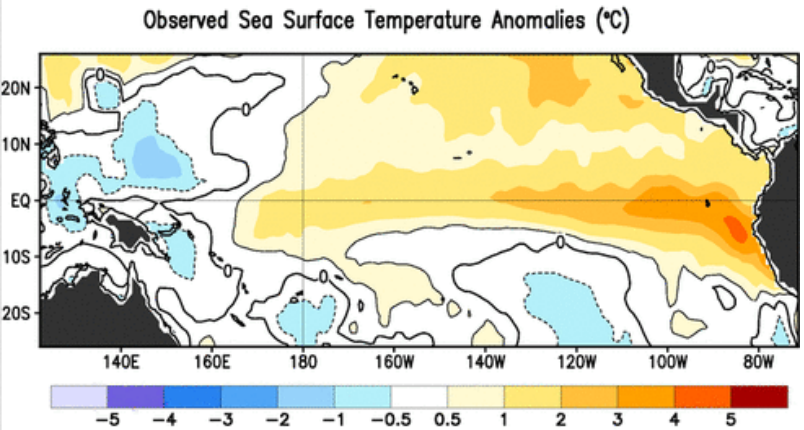


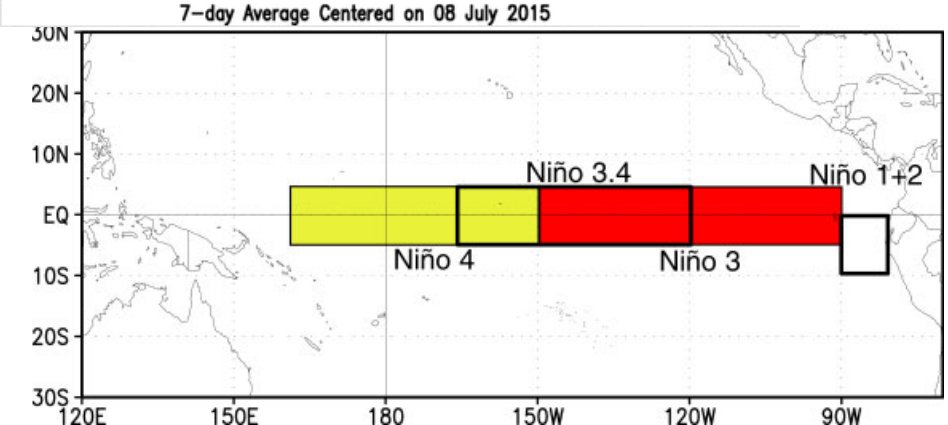
# Ocean Departures from Average Temperature ( C )  5 - 11 Jul 2015

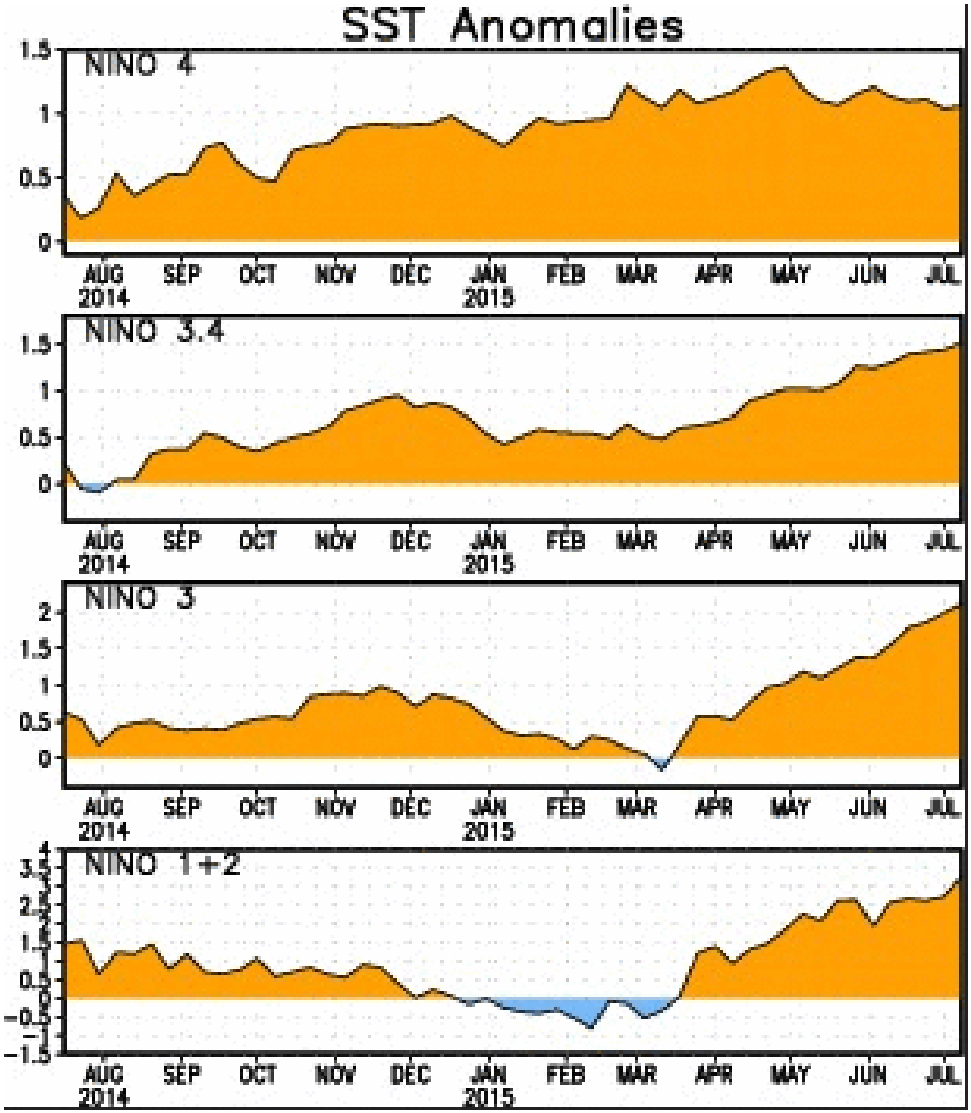


# Recent Evolution of Equatorial Pacific SST Departures



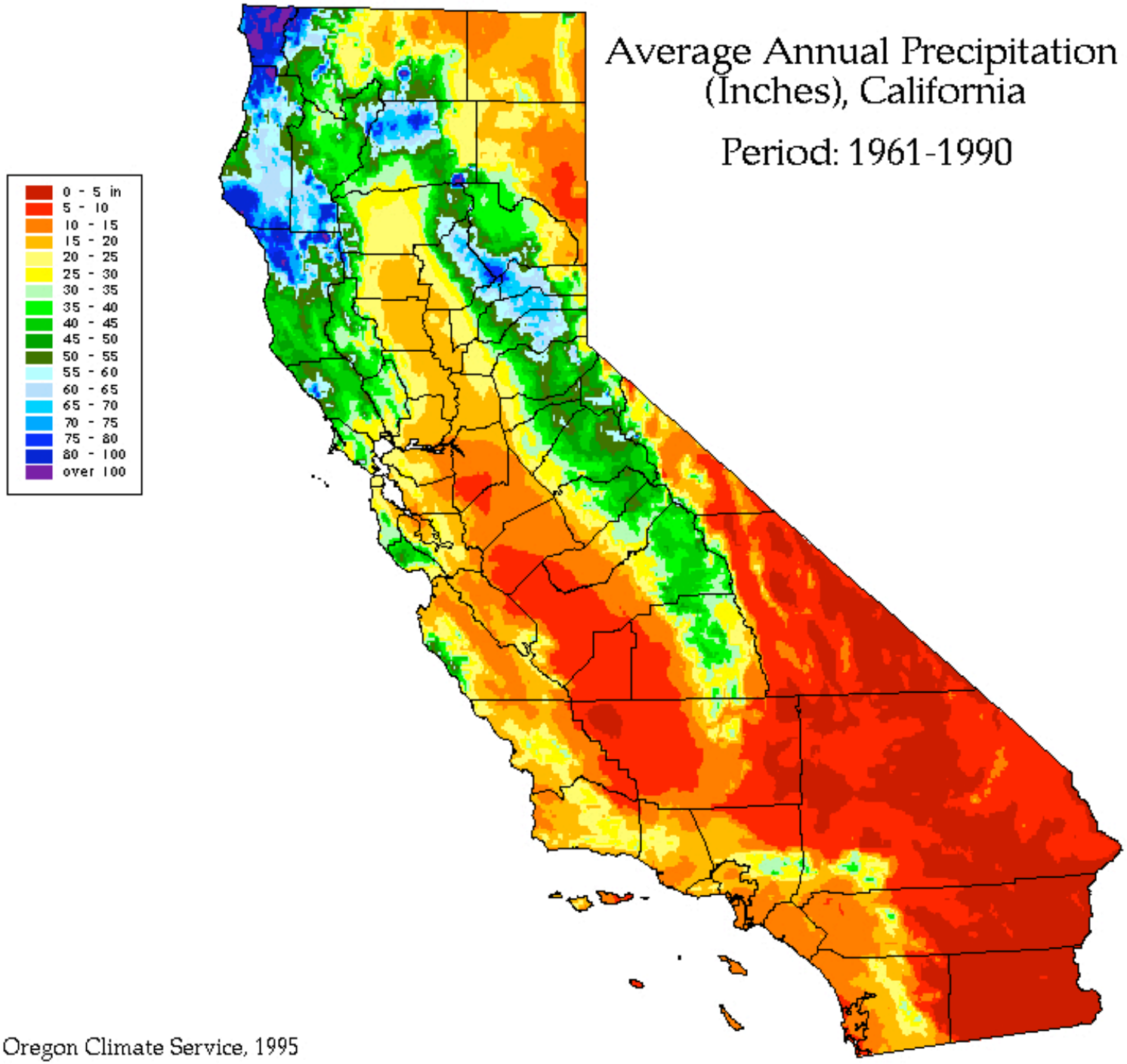




**Updated through 5 - 11 Jun 2015**

**Climate Prediction Center**

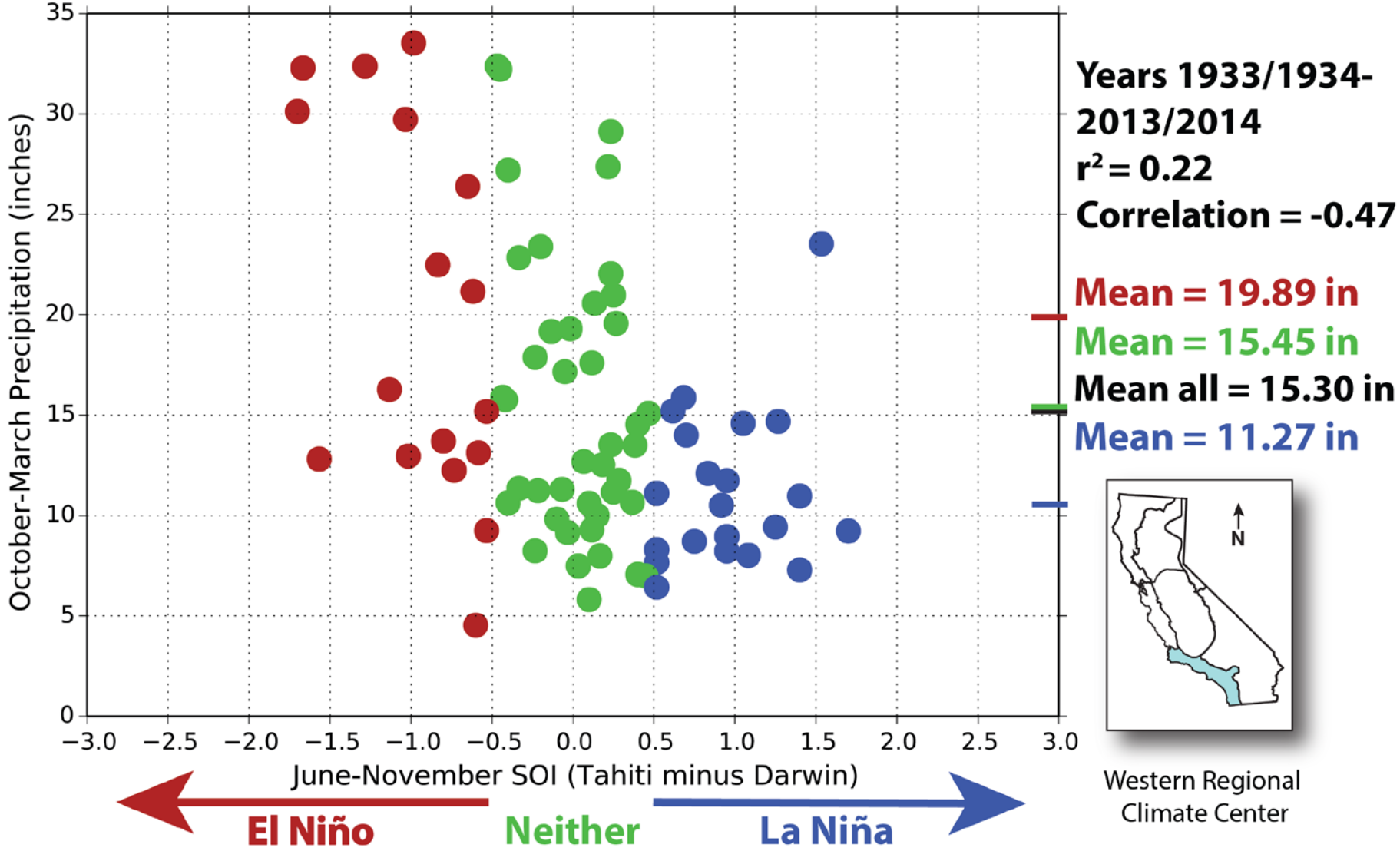



Oregon Climate Service, 1995

**What would a Drought Monitor map look like that incorporated this complexity ???**

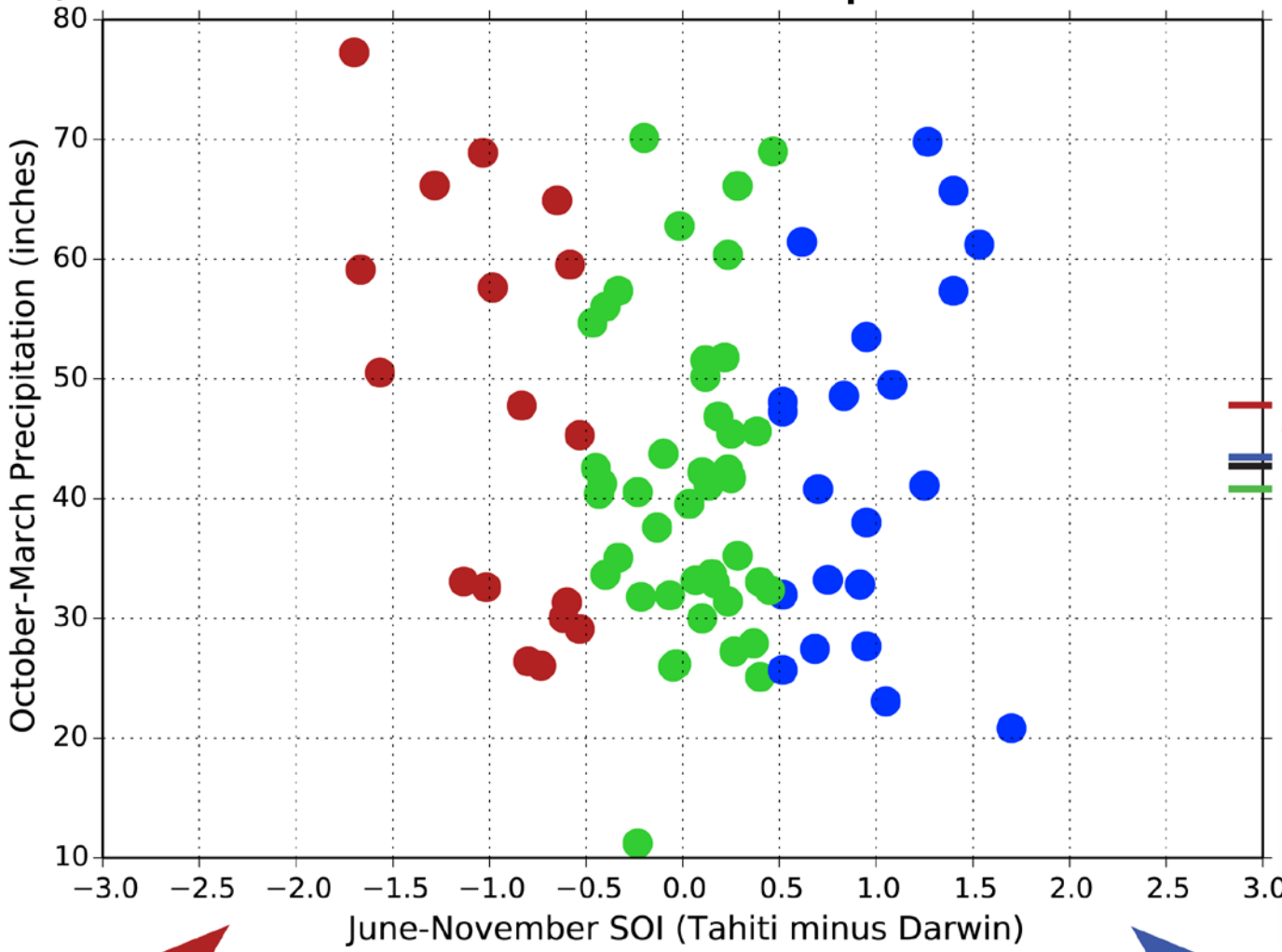
# CA Division 6 October-March Precipitation

## (versus Southern Oscillation Index for prior June-November)



# CA 8-Station Index October-March Precipitation

## (versus Southern Oscillation Index for prior June-November)




**Years 1933/1934-2013/2014**

**$r^2 = 0.02$**

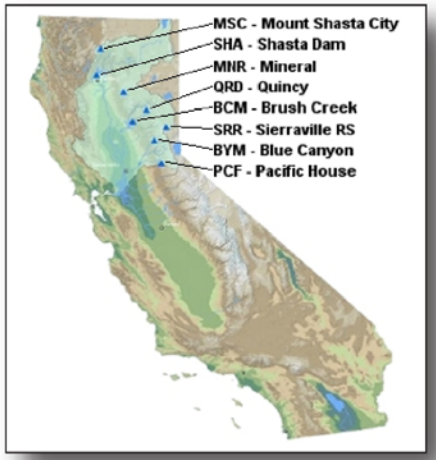
**Correlation = -0.13**

**Mean = 47.4 in**

**Mean = 43.11 in**

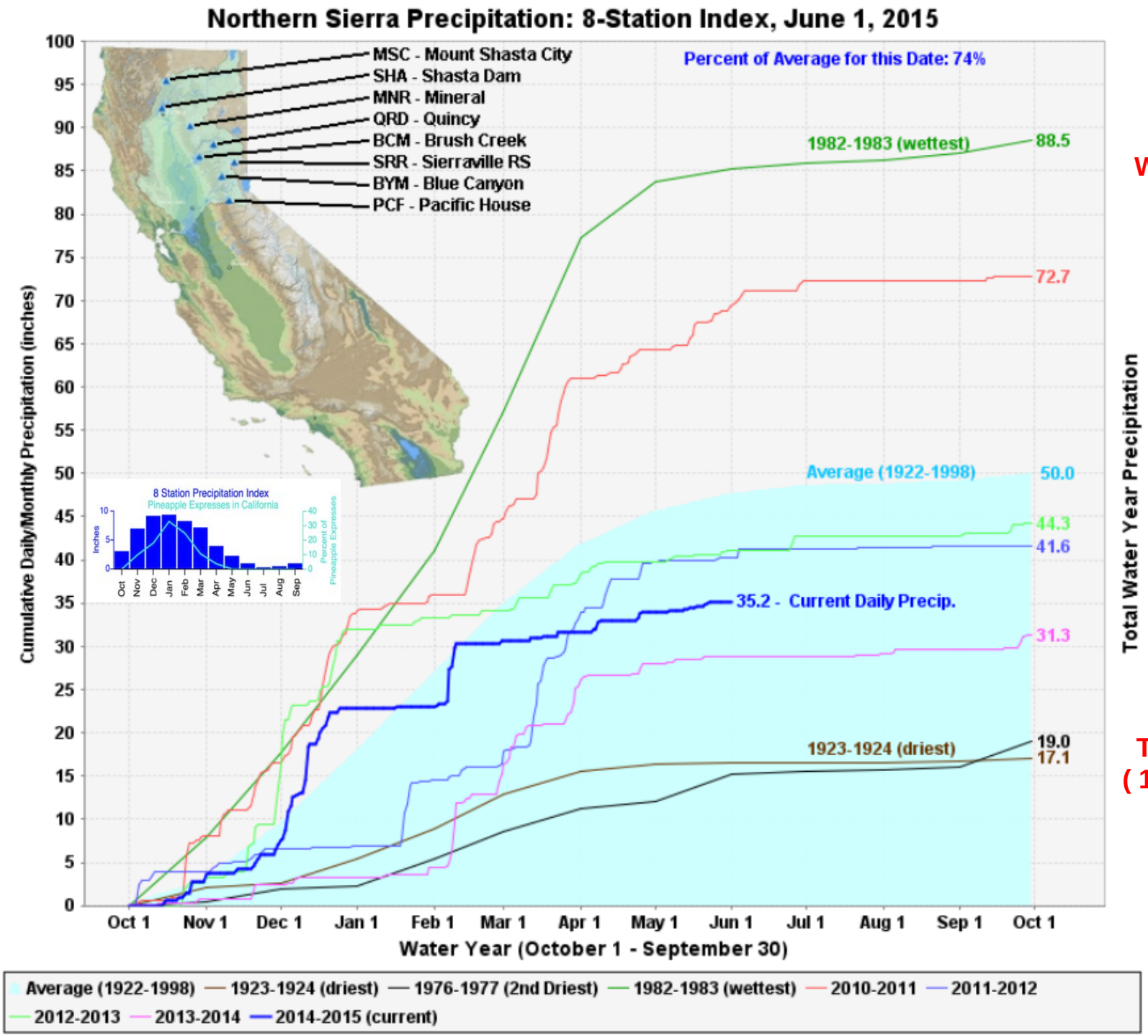
**Mean all = 43.09 in**

**Mean = 41.38 in**




**El Niño** **Neither** **La Niña**

Data Source: CA DWR
Western Regional Climate Center




**8-Station Index Precipitation**

**Wettest (1982-83)**

**2010-11**

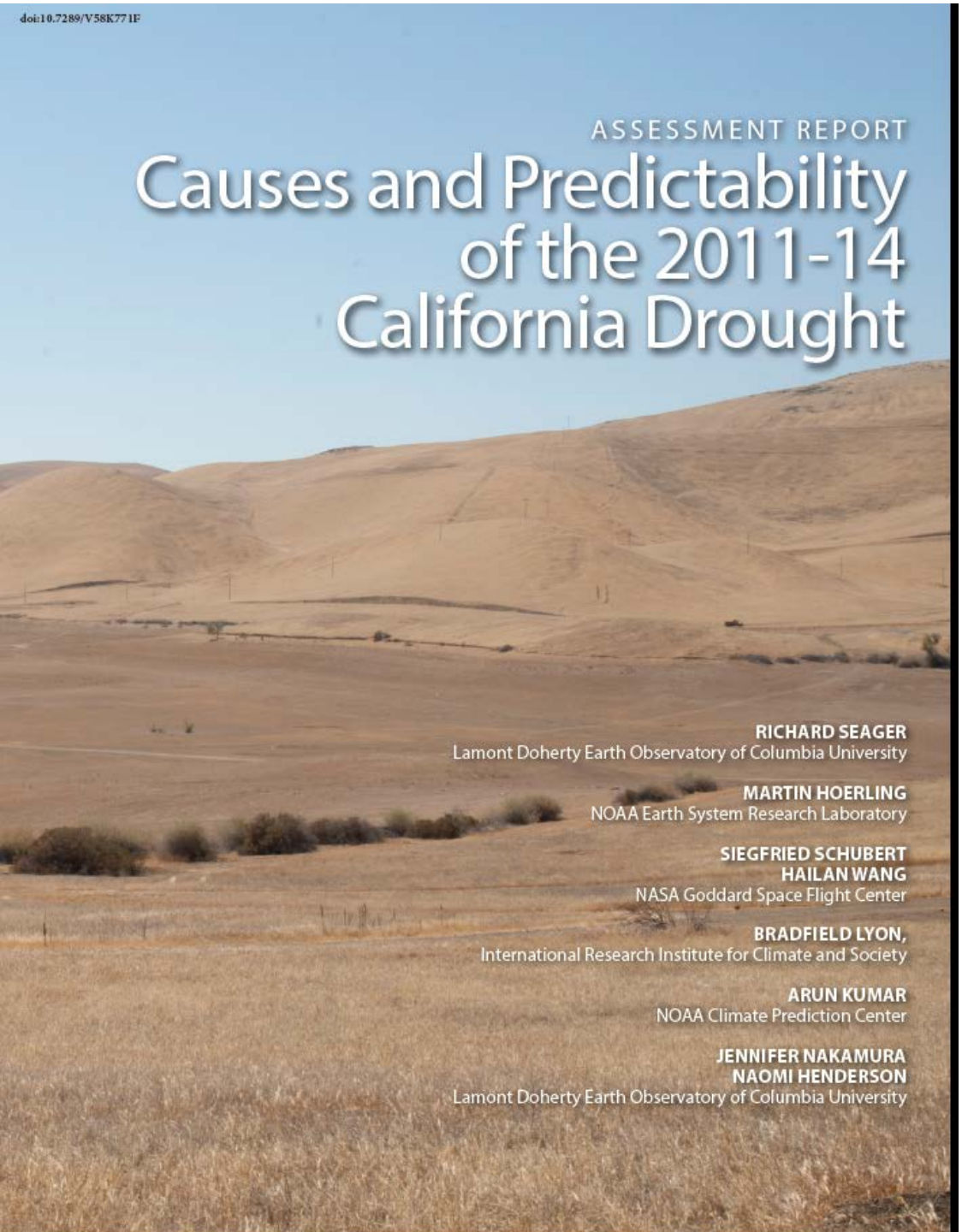
**2012-13**
**2011-12**

**2014-15**
**2013-14**

**Two driest years, ( 1976-77, 1923-24 )**

**CA - DWR**

Total Water Year Precipitation




## The First Three Winters of Drought

## ( 2014-2015 Update in the Works )

**Each winter played out differently**

**Background and thus causes somewhat different each winter**

**2014-15 cause also likely not identical to previous three winters**

**Explanations reach to western Pacific and eastern Indian Oceans**

**Not much sign of climate change as a contributor**

**But, possible harbinger of future droughts:**

**Not just <u>dry</u>, but extremely <u>warm</u>**

# Western Drought . 2015-16. Commentary and Suggestions.

NIDIS as a Drought Early Warning System

Managers and decision-makers worst fear: Being taken by surprise

A Tale of Two Droughts: Ongoing Colorado River, Recent West Coast. Connected ??

How to portray current status more optimally and completely - drought in managed systems

Concerted push on prediction communities

Biggest question: What is next winter going to bring ??? HUGE interest !!

What has stayed the same (in the climate system) over the past 4 years ??

Not great prospects for rapid seasonal / interannual forecast improvement

Thus, also need a focus on <u>coping mechanisms</u>

Is this drought "natural" or "climate change enhanced" or some combination?

Enlarging the climate knowledge sand pile

The Colorado River drought (12 of last 15 years) ... is this a megadrought??

Snow drought (snow deficiencies worse than precipitation deficiencies)

A harbinger for the future?

Why, in particular, was 2014-15 winter <u>so</u> warm ? What about <u>next</u> winter ?

Exploring and understanding the effects of temperature, other demand variables

EL Nino : Unreliably wet winters in southern California. Can / may help, but not guaranteed.

Near-term focus: Why some El Nino winters wet, others dry, in California?

Connection between climate-scale and weather-scale seems crucial

Extreme events (large storms) often make or break a winter

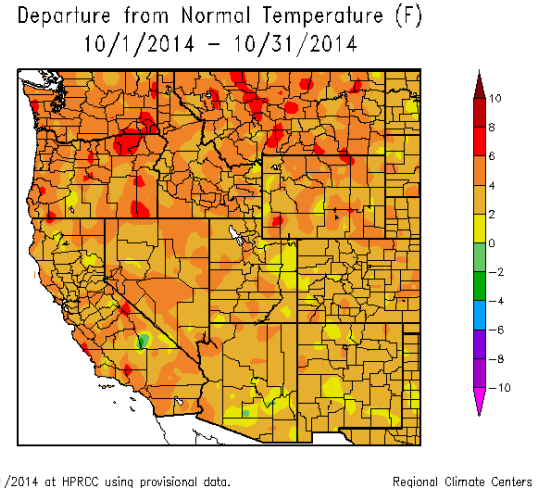
Other biological phenomena: fish, marine mammals, harmful algal bloom, "the Blob"

Never waste a crisis

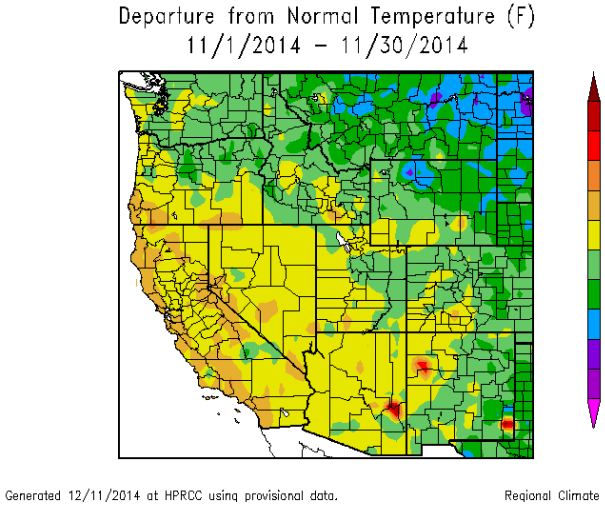
Thank You !
Mather RAWS Station
Great Basin Nat Park

# DISCARDS
# and
# EXTRAS
# and
# ELABORATIONS

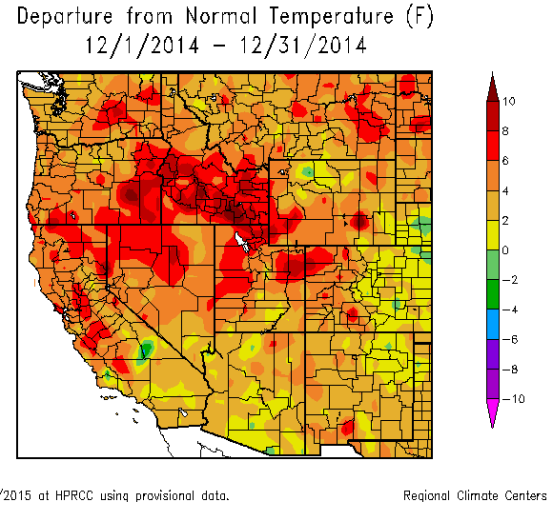
# Mean Temperature Departure from Normal



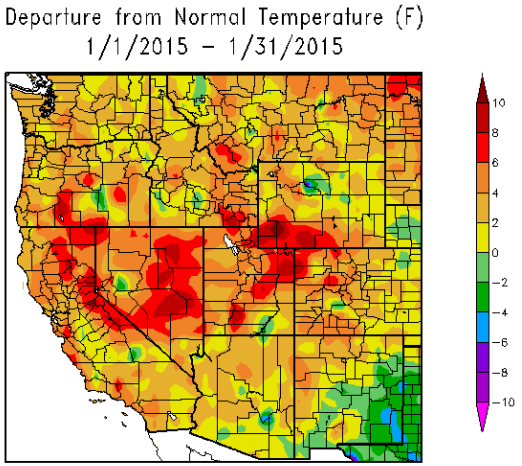

## Oct 2014



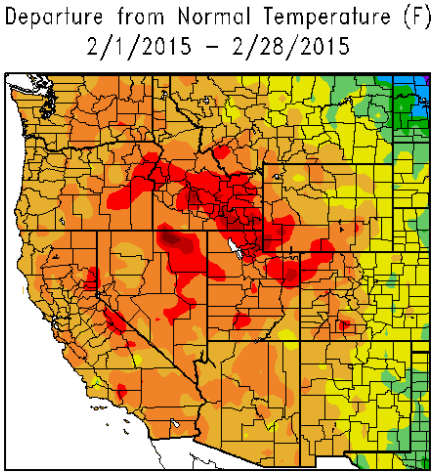

## Nov 2014



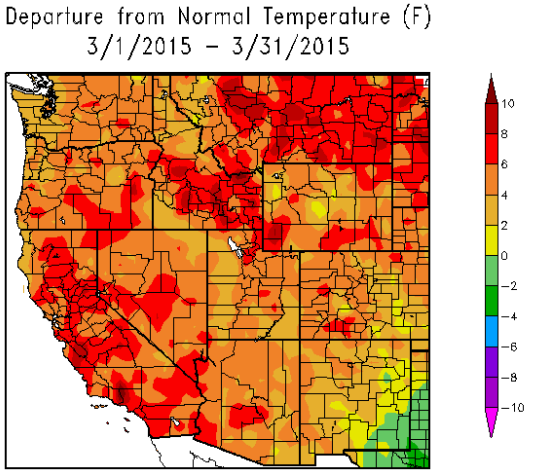

## Dec 2014




## Jan 2015

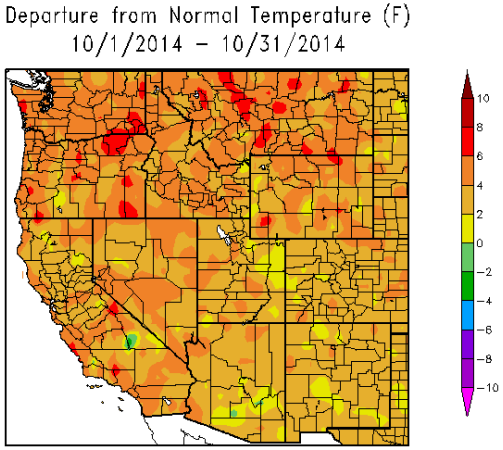



## Feb 2015



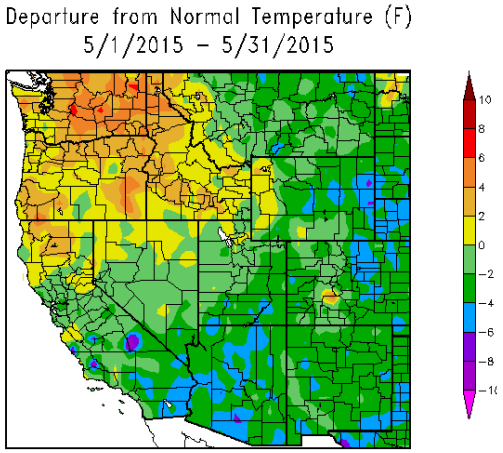

## Mar 2015

# Mean Temperature Departure from Normal



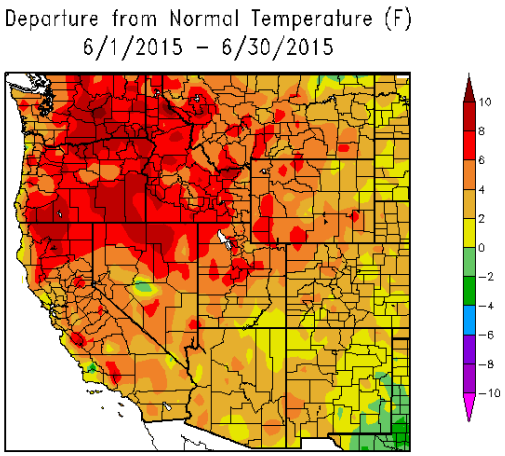

Generated 11/11/2014 at HPRCC using provisional data.

Regional Climate Centers




Generated 6/11/2015 at HPRCC using provisional data.

Regional Climate Cer



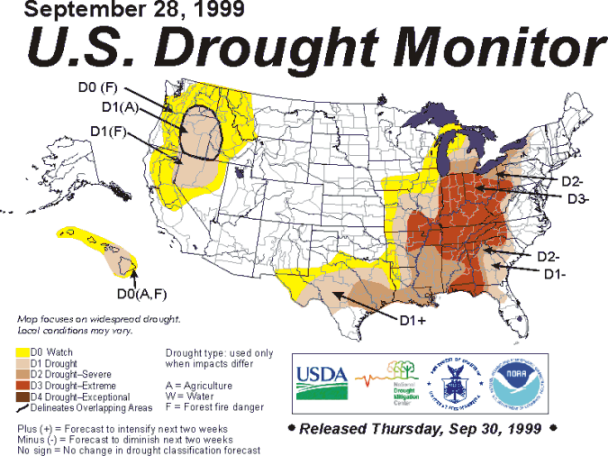

Generated 7/2/2015 at HPRCC using provisional data.

Regional Climate Centers

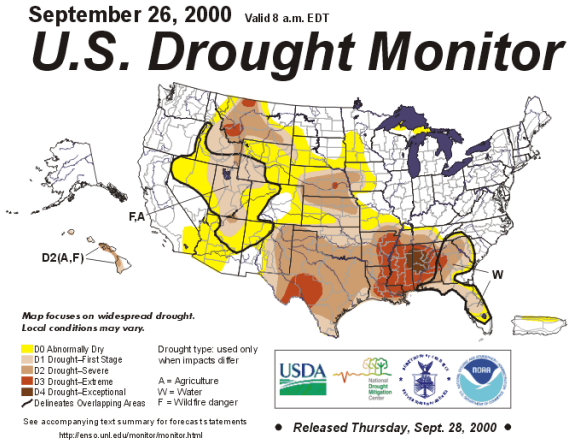
**April 2015**

**May 2015**

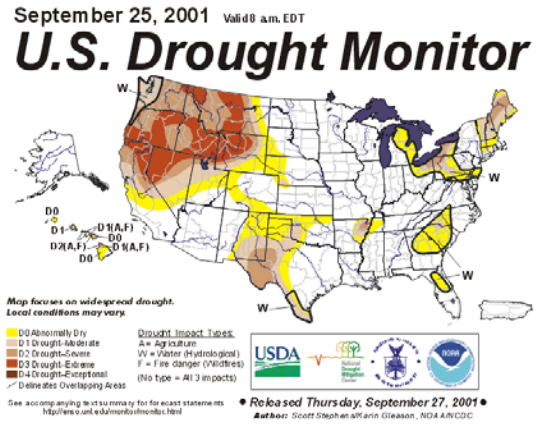
**June 2015**



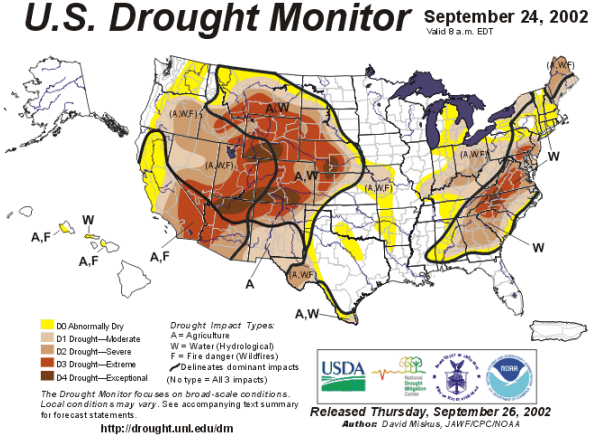

Sep 28, 1999



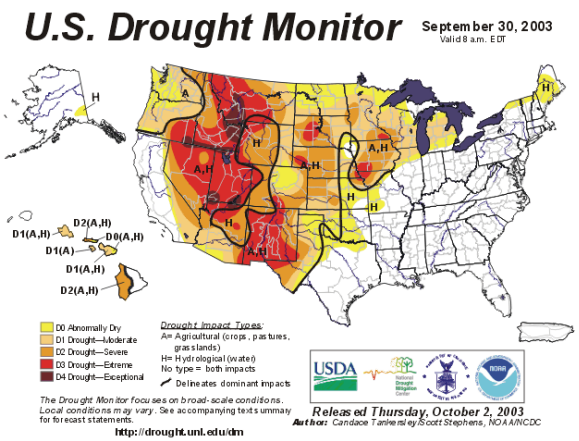

Sep 26, 2000



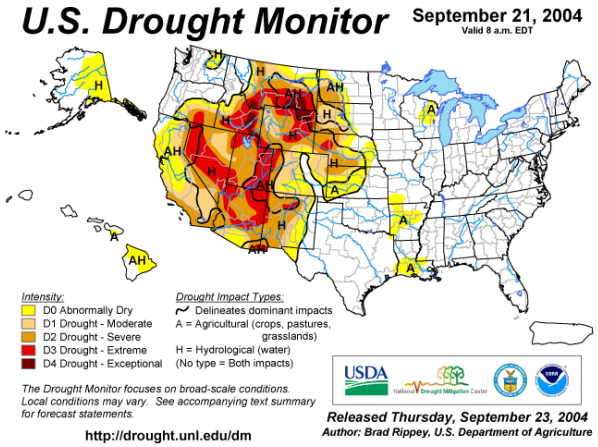

Sep 25, 2001



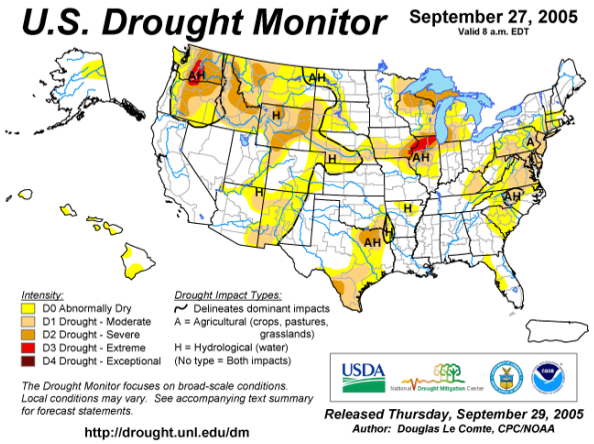

Sep 24, 2002



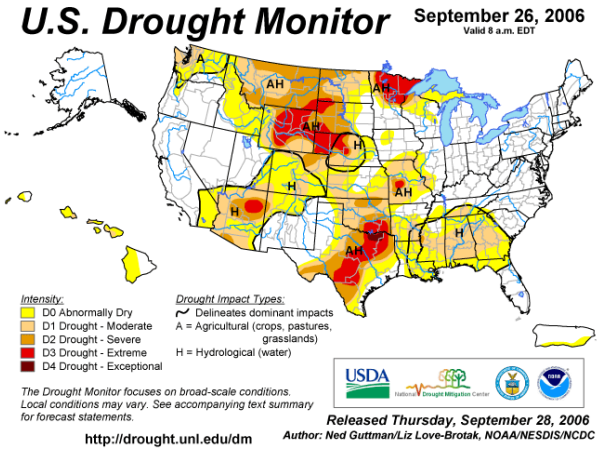

Sep 30, 2003



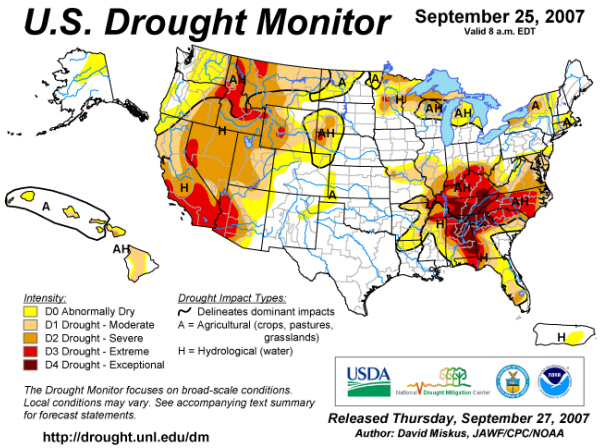

Sep 21, 2004




Sep 27, 2005




Sep 26, 2006

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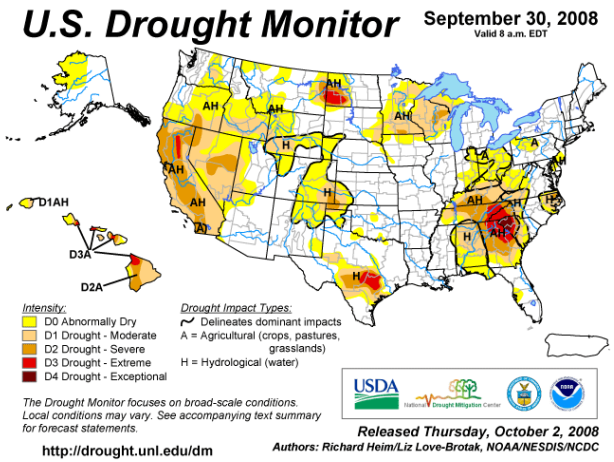
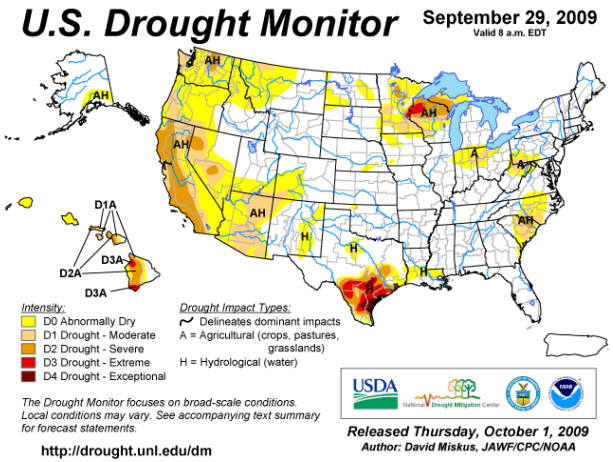
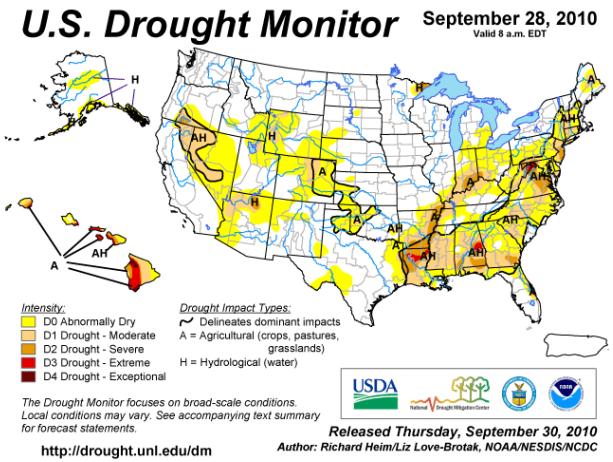


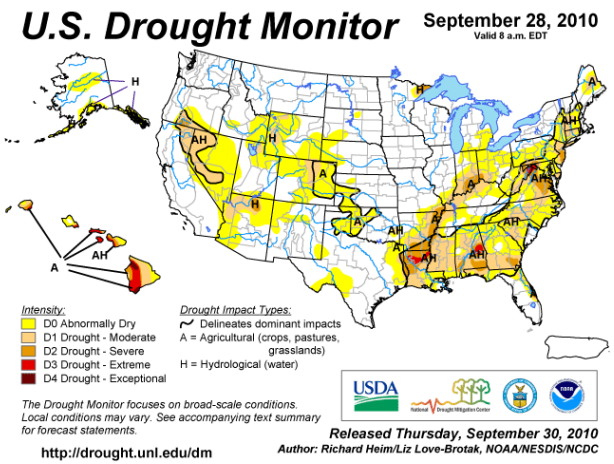

Sep 30, 2008



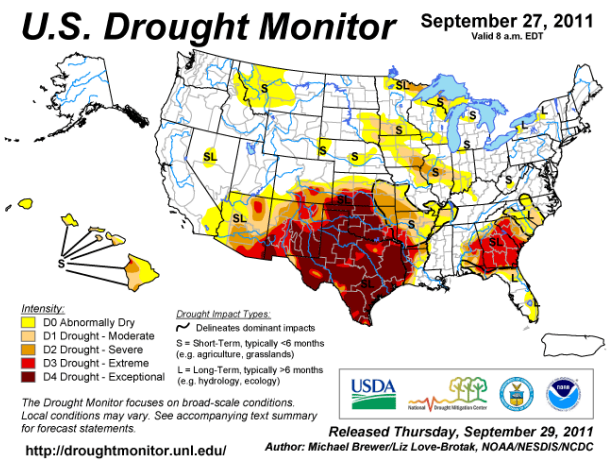

Sep 29, 2009



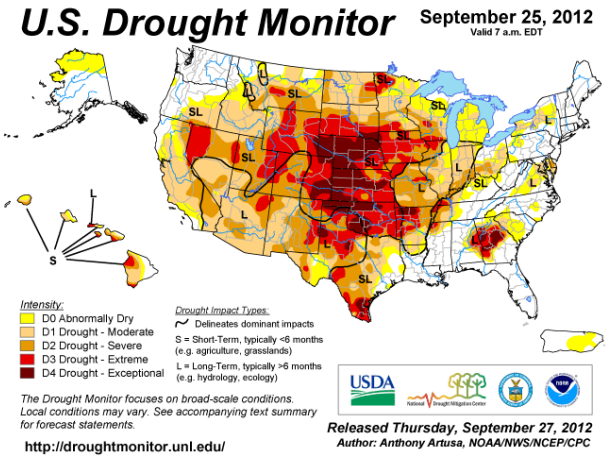

Sep 28, 2010



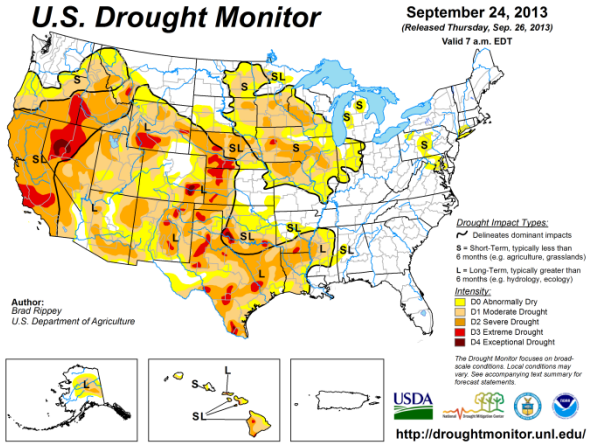

Sep 28, 2010



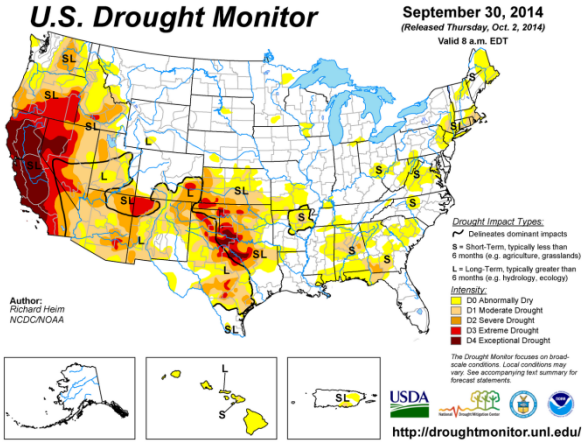

Sep 27, 2011



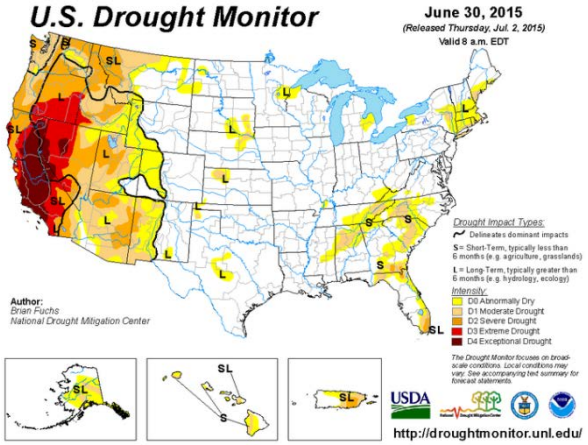

Sep 26, 2012




Sep 24, 2013

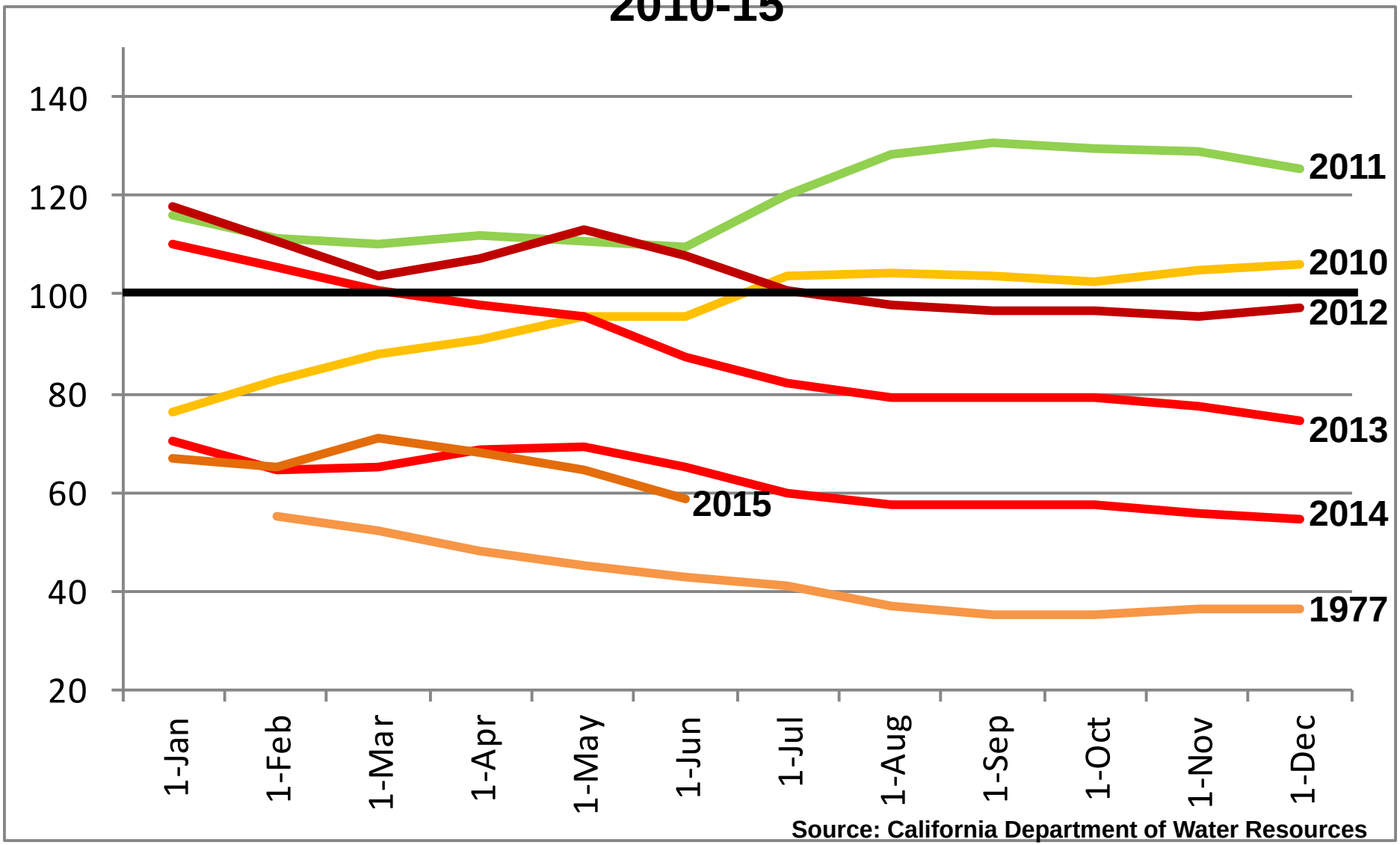



Sep 30, 2014

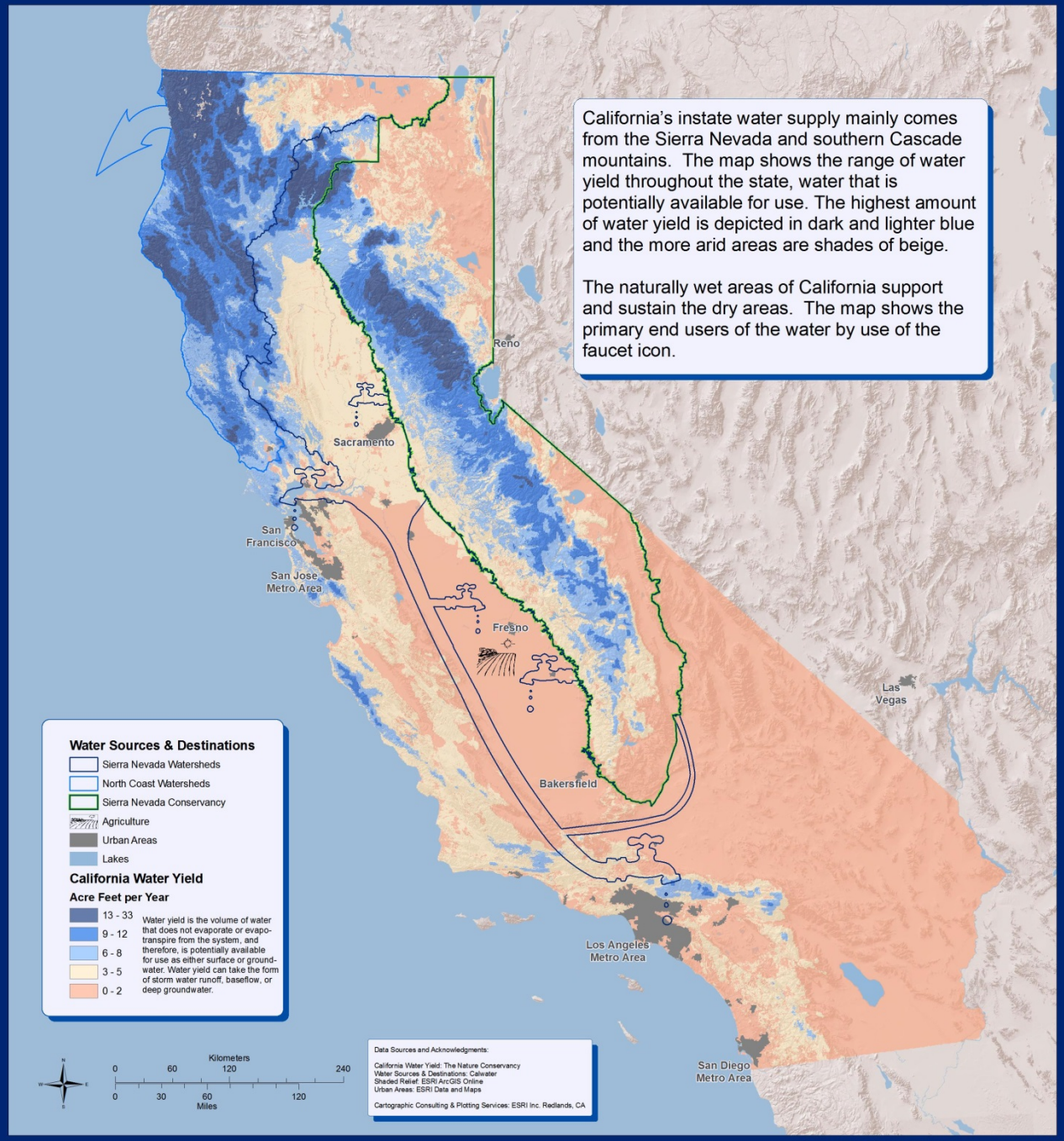



Jun 30, 2015

# California Reservoir Storage, Percent of Normal, 1977 and 2010-15



# California's Sierra Nevada - Your Source of Water

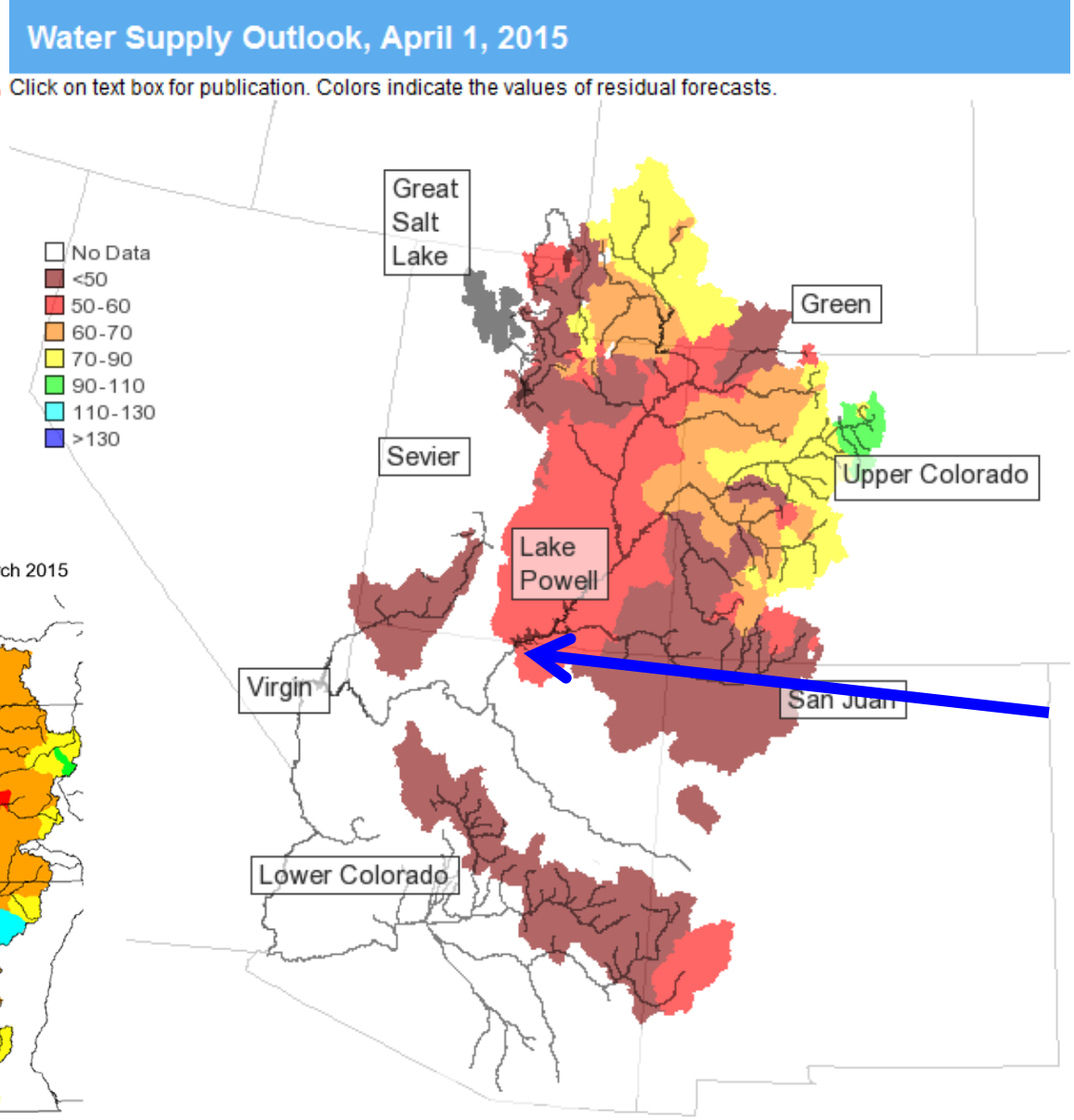


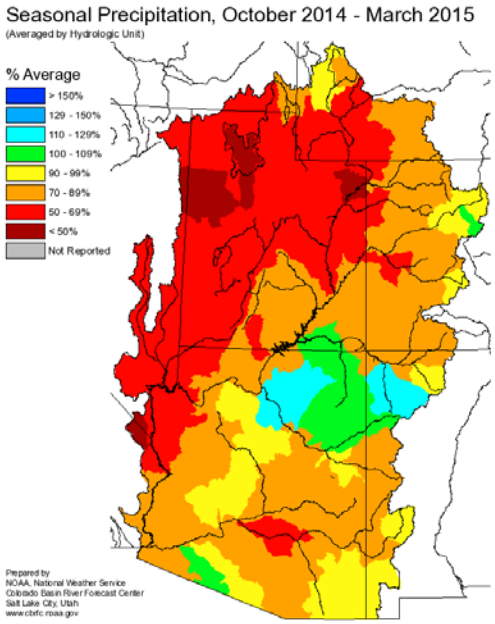

California's instate water supply mainly comes from the Sierra Nevada and southern Cascade mountains. The map shows the range of water yield throughout the state, water that is potentially available for use. The highest amount of water yield is depicted in dark and lighter blue and the more arid areas are shades of beige.

The naturally wet areas of California support and sustain the dry areas. The map shows the primary end users of the water by use of the faucet icon.

*Prepared by: The Sierra Nevada Conservancy - 2009*

# 2015 April 1




Prepared by
NOAA, National Weather Service
Colorado Basin River Forecast Center
Salt Lake City, Utah
www.cbrfc.noaa.gov

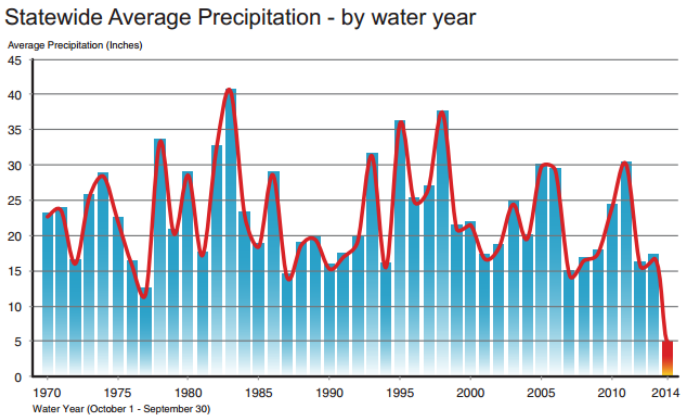
**From: Colorado Basin River Forecast Center**

**Apr-Jul Flow Forecast:**
**March 1:**
**71 % of median**
**April 1:**
**52 % of median**

**Higher flows Jan-Mar on many streams, with early meltout.**

**3 of 15 past years above average inflow.**

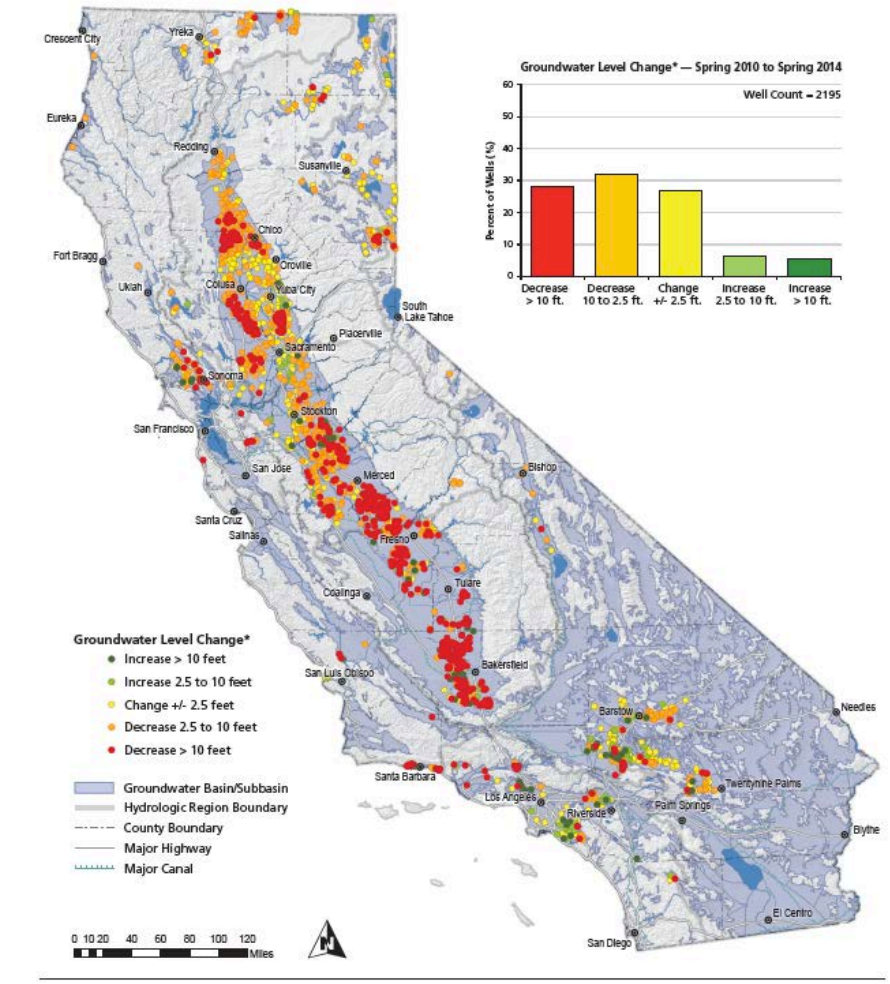
# 2014 California Drought




- 2013 driest calendar year on record
- 2014 was 4th driest Water Year on record
- In 2014, many growers had surface water allocations <10% of full allocation
- 2014 fallow up 40% (500,000 acres) compared to 2011
- 2015 not much better
  - Precip is 86% of avg for CY, but only 46% of avg for WY
  - Snowpack just 21% of normal
  - Reservoirs at 67% of avg statewide

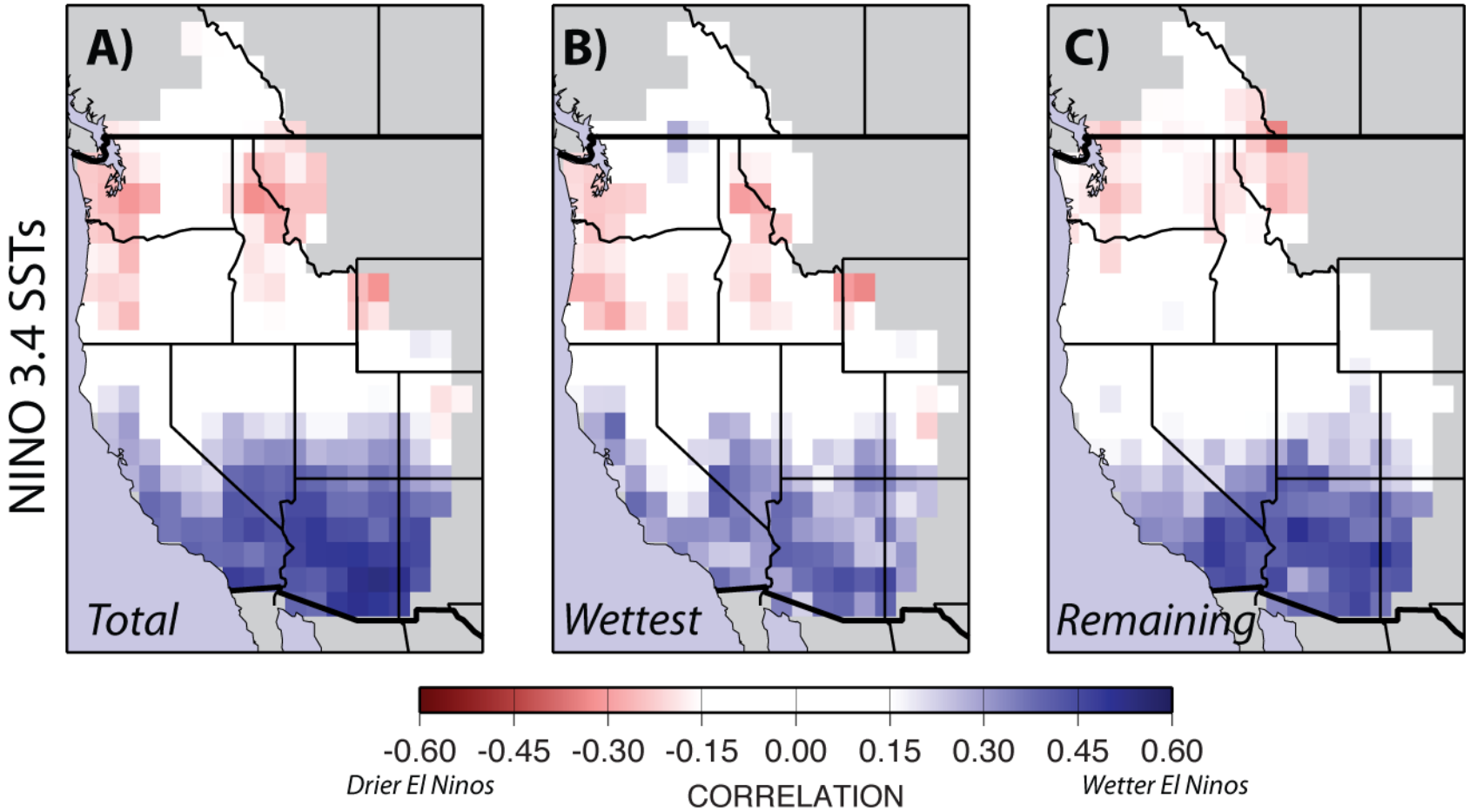
## Groundwater change Spring 2010 to Spring 2014

Figure 6: Change in Groundwater Levels in Wells - Spring 2010 to Spring 2014



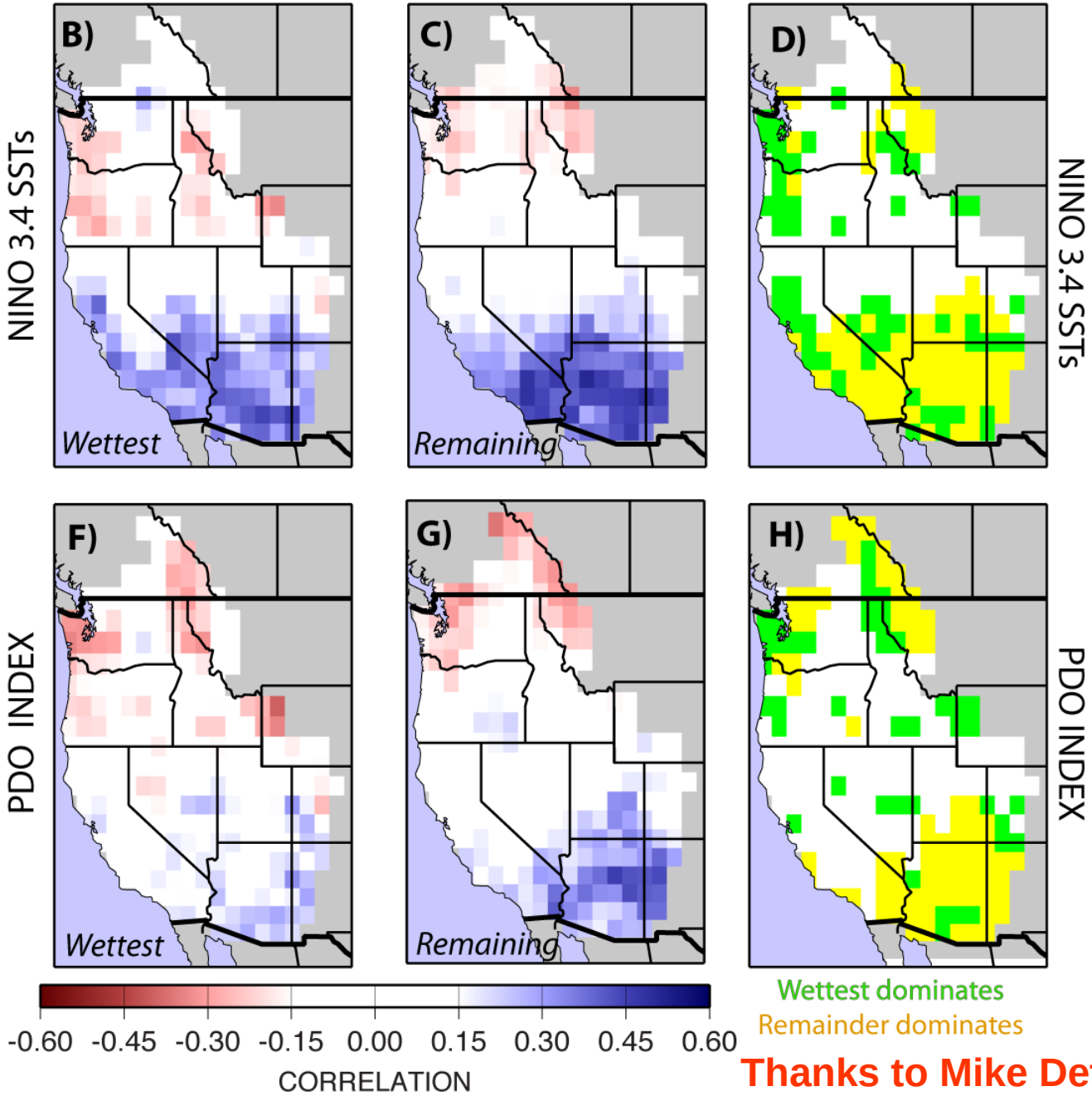

*Groundwater level change determined from water level measurements in wells. Map and chart based on available data from the DWR Water Data Library as of 11/08/2014. Data subject to change without notice.

# RELATIONS BETWEEN NINO3.4 SSTs & TOTAL PRECIP, CONTRIBUTIONS FROM WETTEST 5% OF WET DAYS, AND REMAINING DAYS, 1916-2011



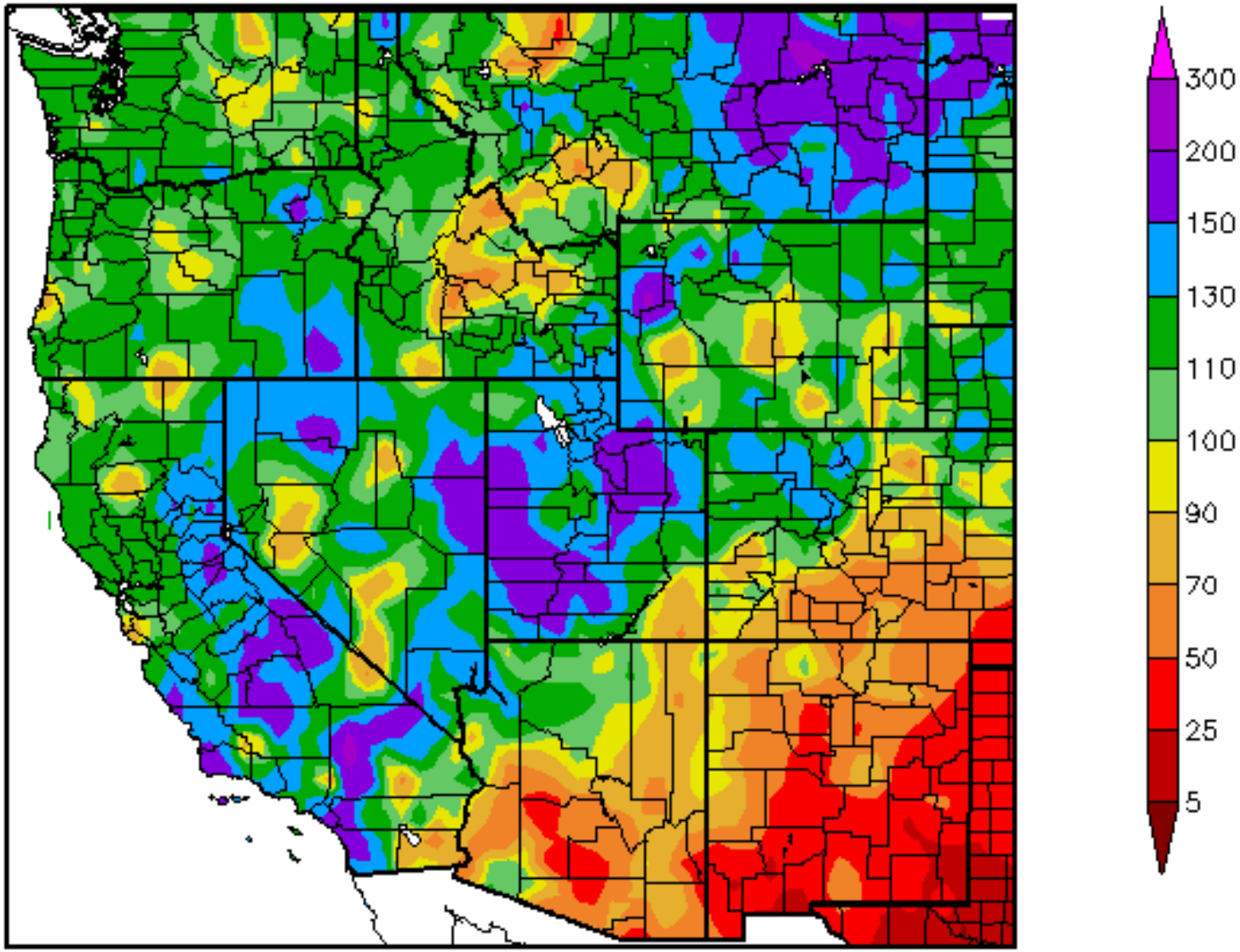

Thanks to Mike Dettinger

# RELATIONS BETWEEN NINO3.4/PDO & CONTRIBUTIONS FROM WETTEST 5% OF WET DAYS AND REMAINING DAYS, 1916-2011




**Thanks to Mike Dettinger**

# Percent of Normal Precipitation (%)
## 10/1/2010 – 9/30/2011

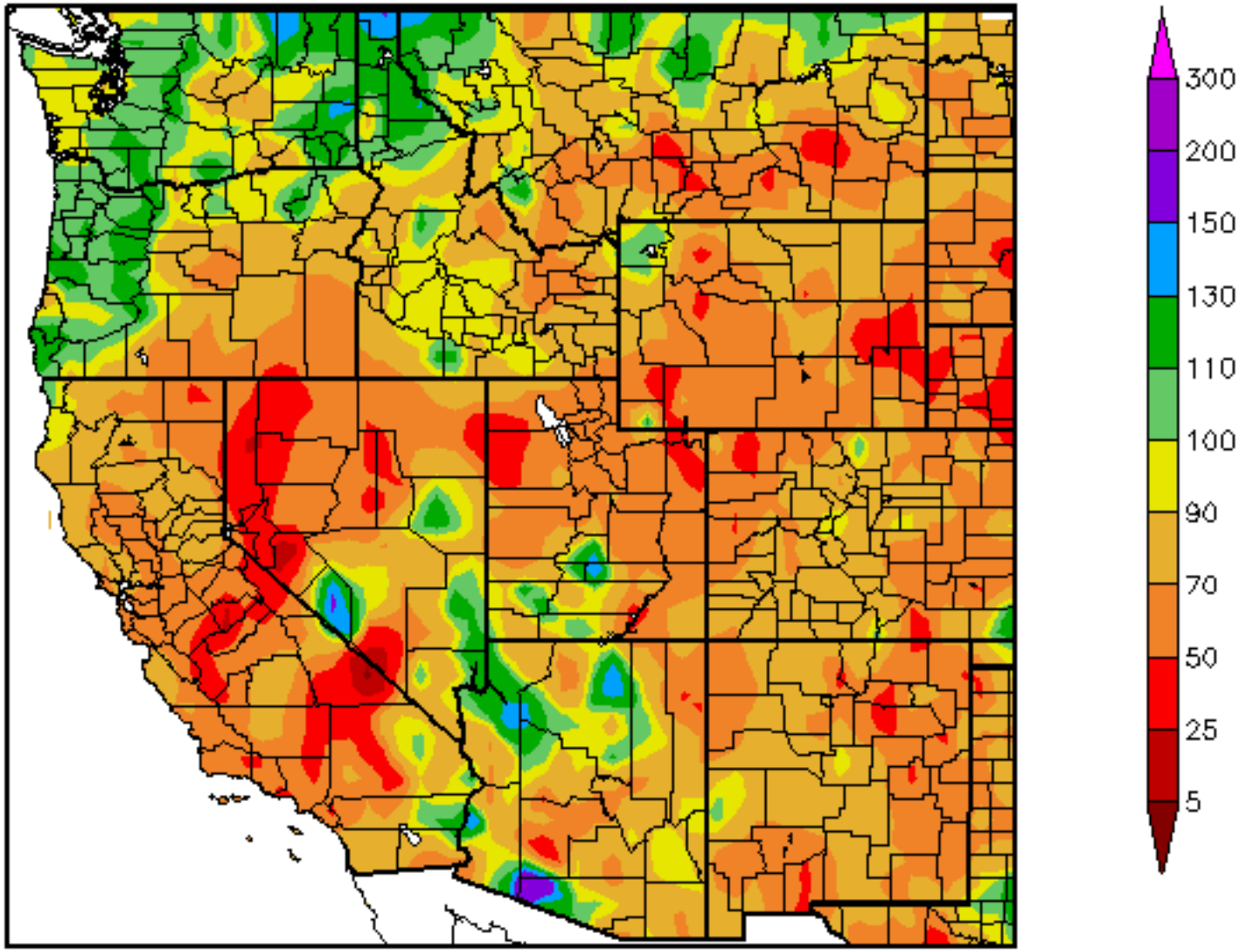



Generated 6/15/2012 at HPRCC using provisional data.

Regional Climate Centers

**Water Year**
**2011-12**
**01 Oct 2011**
**Thru**
**30 Sep 2012**

# Percent of Normal Precipitation (%)
## 10/1/2011 – 9/30/2012

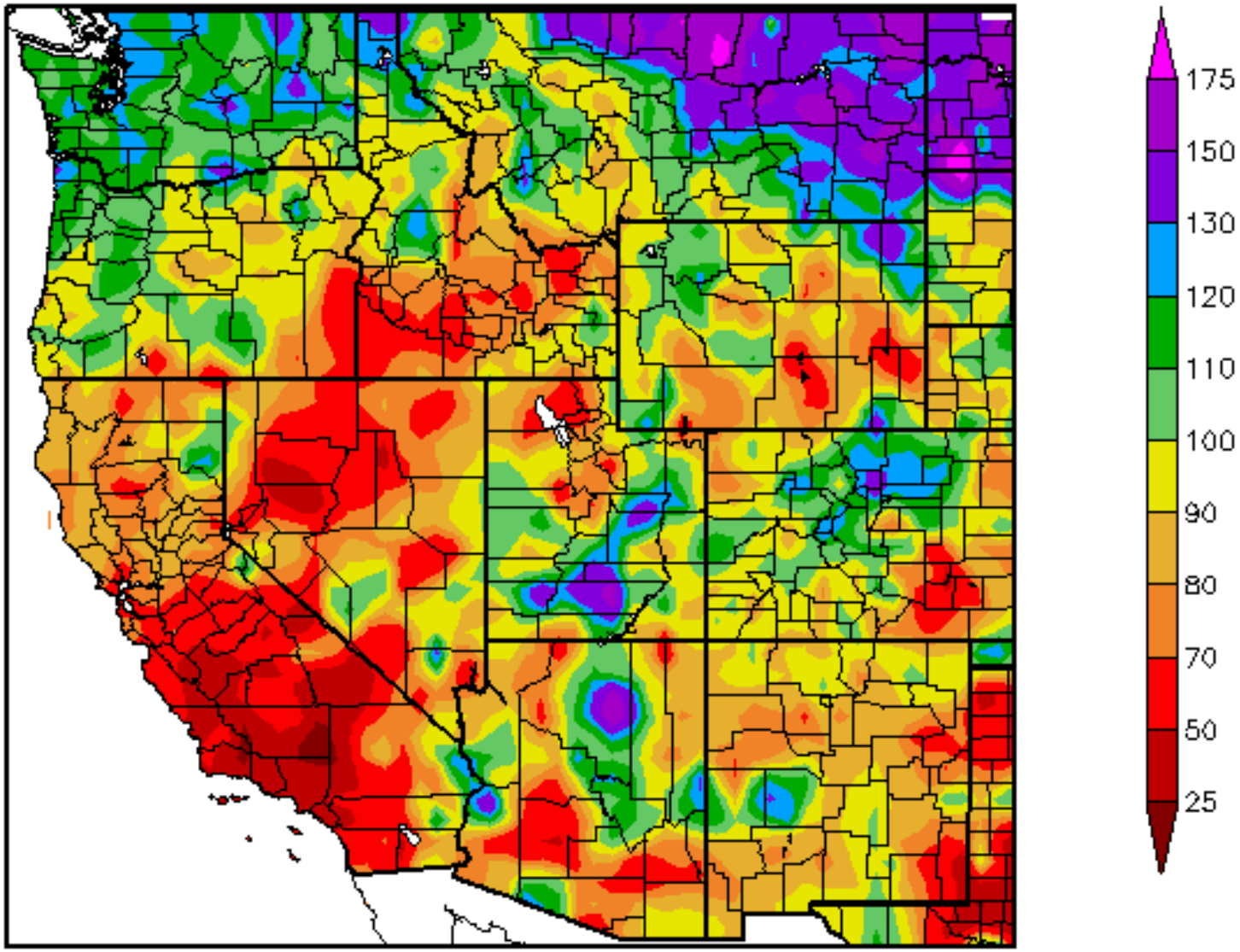



Generated 10/11/2012 at HPRCC using provisional data.

Regional Climate Centers

**Water Year**
**2012-13**
**01 Oct 2012**
**Thru**
**30 Sep 2013**

# Percent of Normal Precipitation (%)
## 10/1/2012 – 9/30/2013

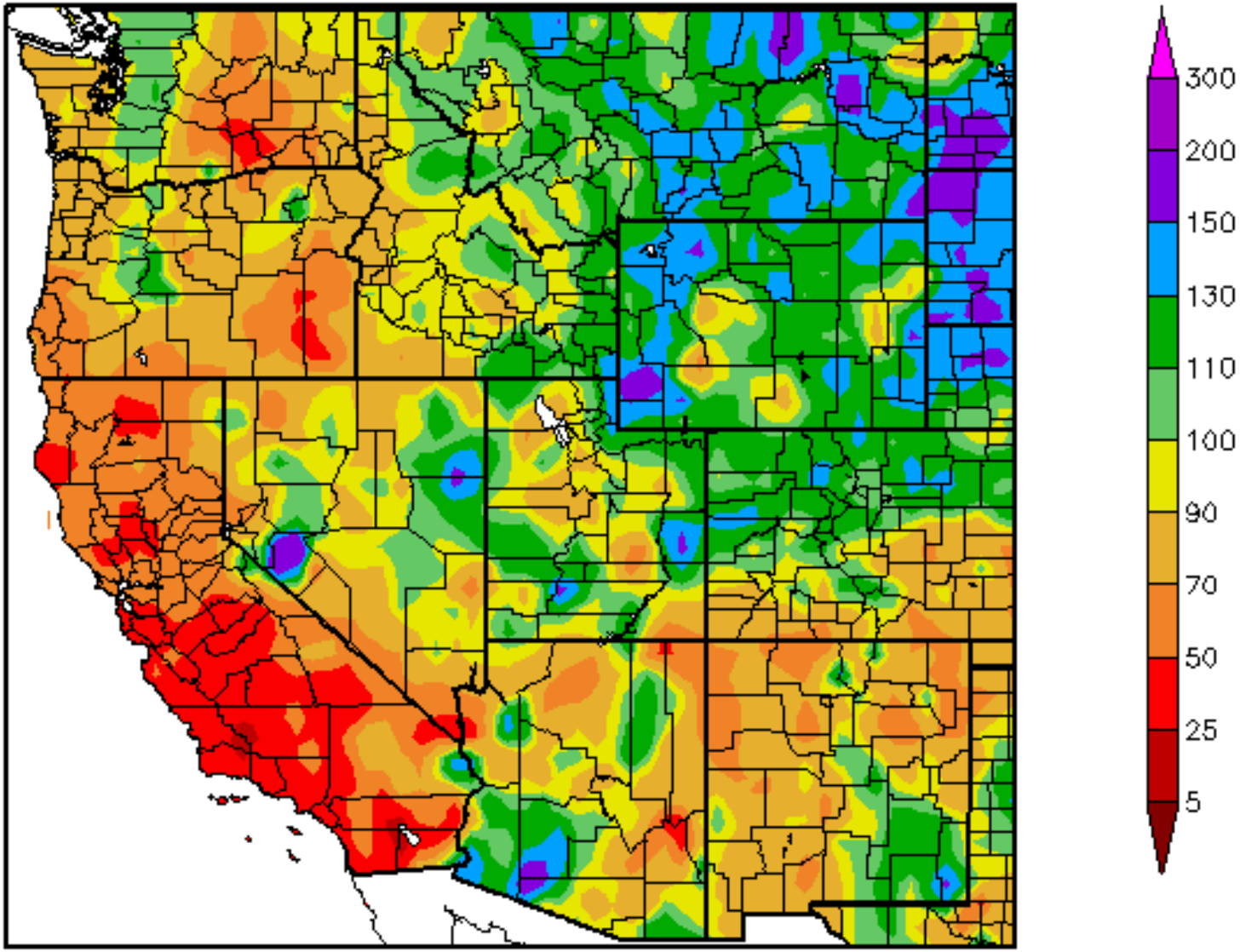



Generated 10/11/2013 at HPRCC using provisional data.

Regional Climate Centers

**Water Year**
**2013-14**
**01 Oct 2013**
**Thru**
**30 Sep 2014**

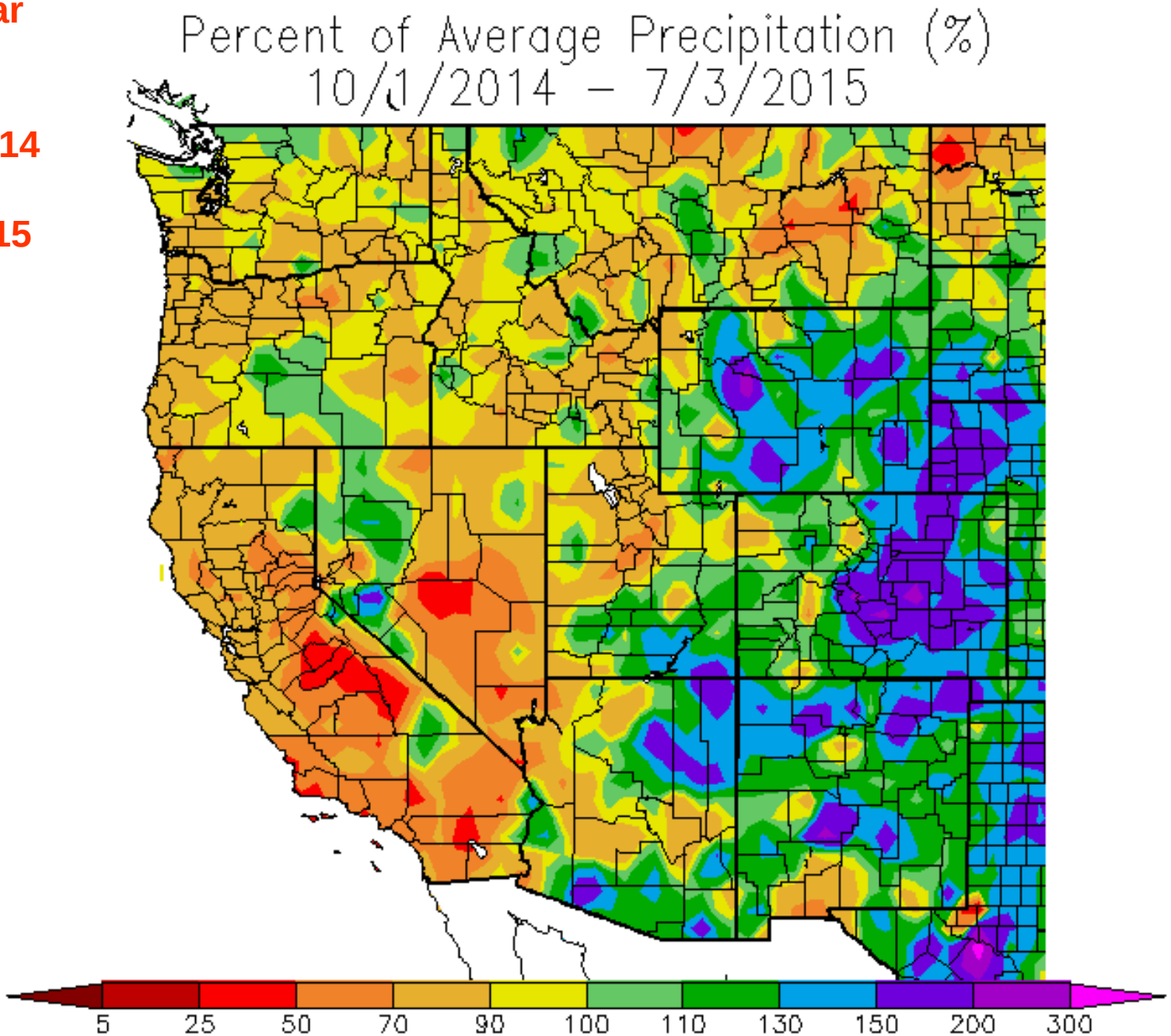
# Percent of Normal Precipitation (%)
## 10/1/2013 – 9/30/2014



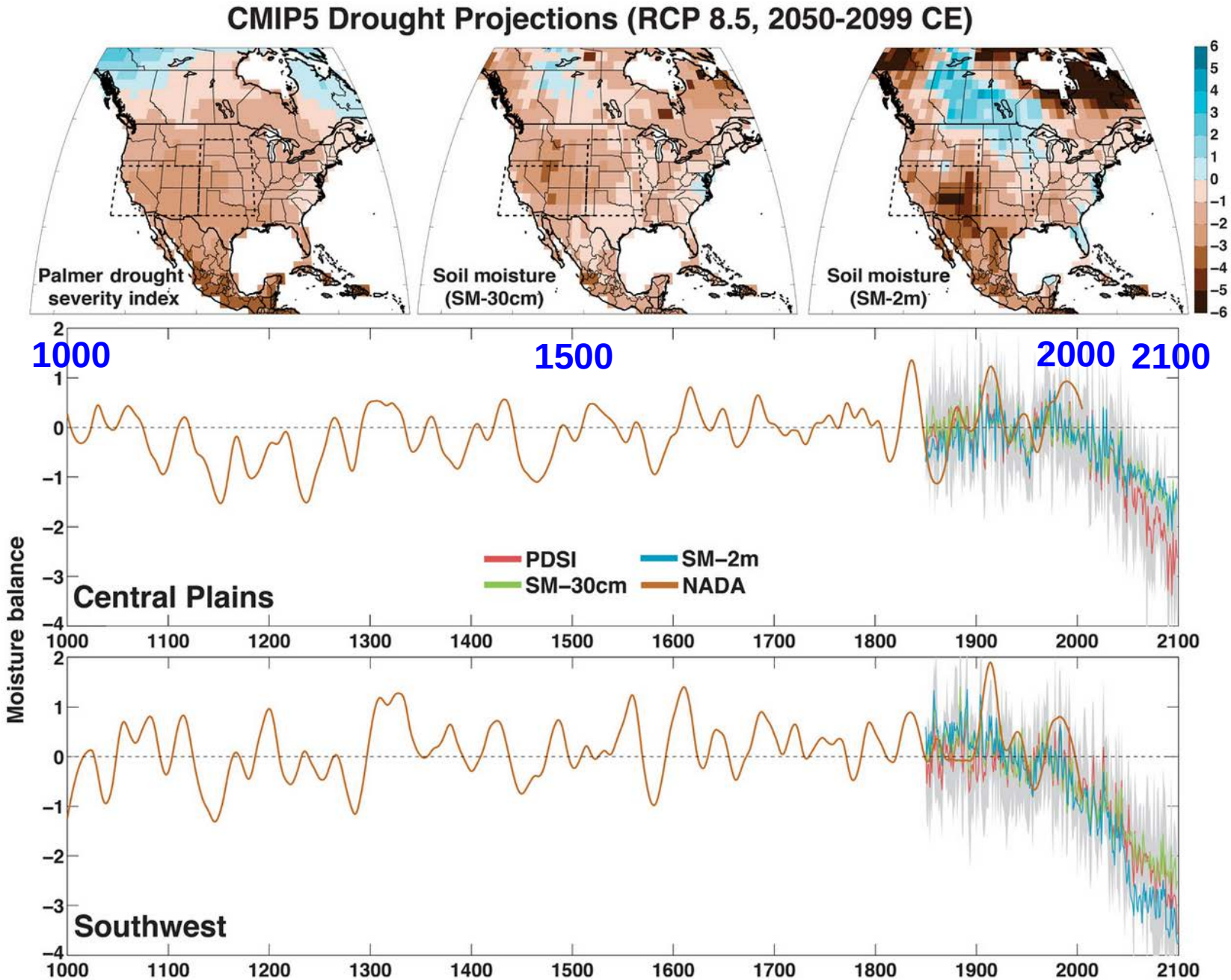

Generated 10/11/2014 at HPRCC using provisional data.

Regional Climate Centers

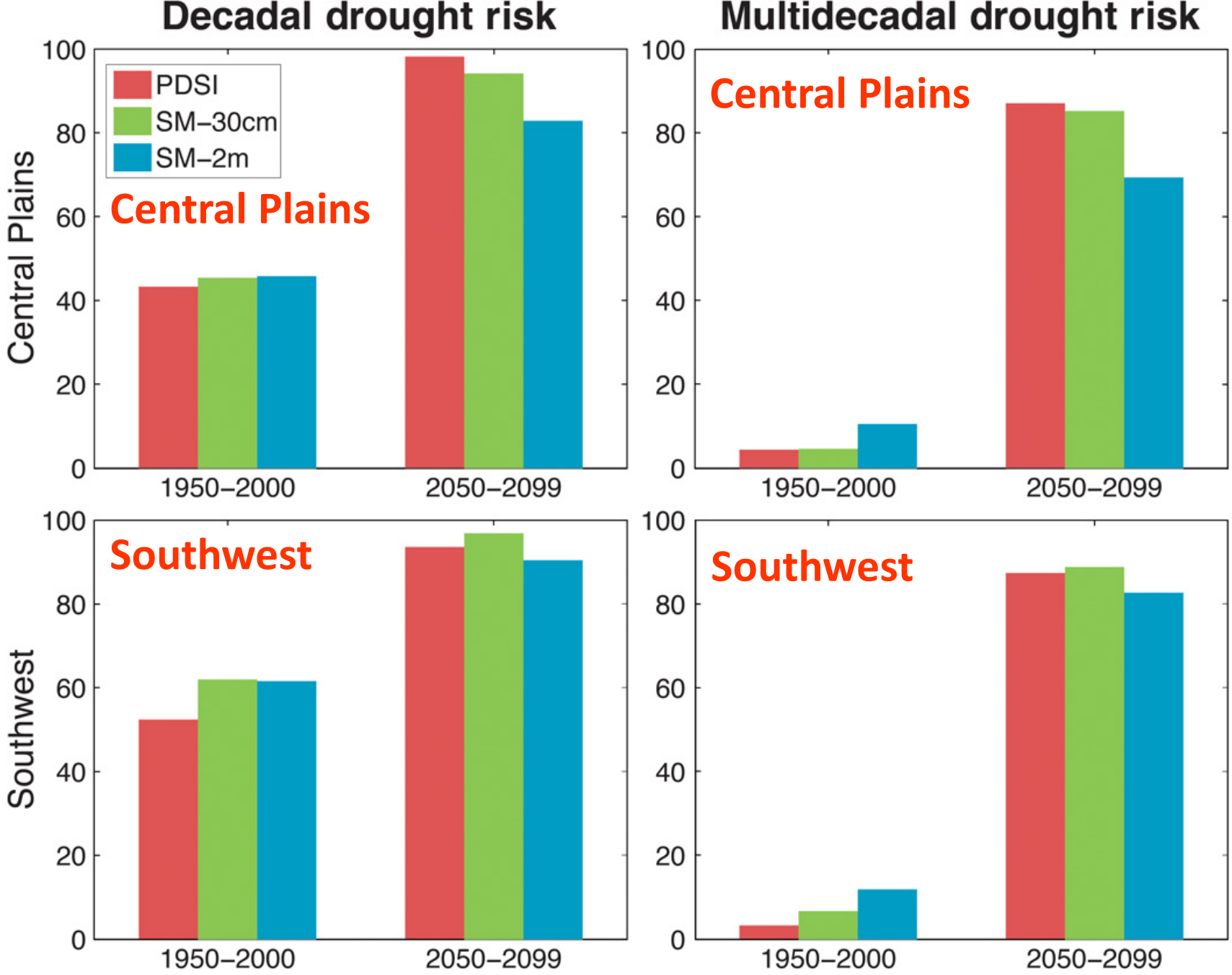
**Water Year To Date 2014-15 01 Oct 2014 Thru 3 July 2015**



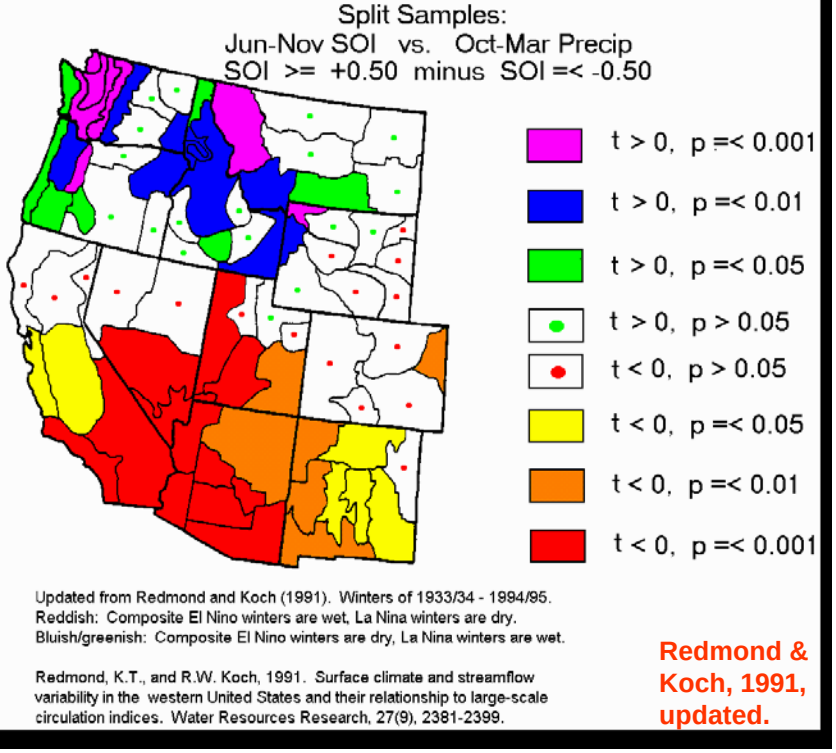

Generated 7/04/2015 at WRCC using provisional data.
NOAA Regional Climate Centers



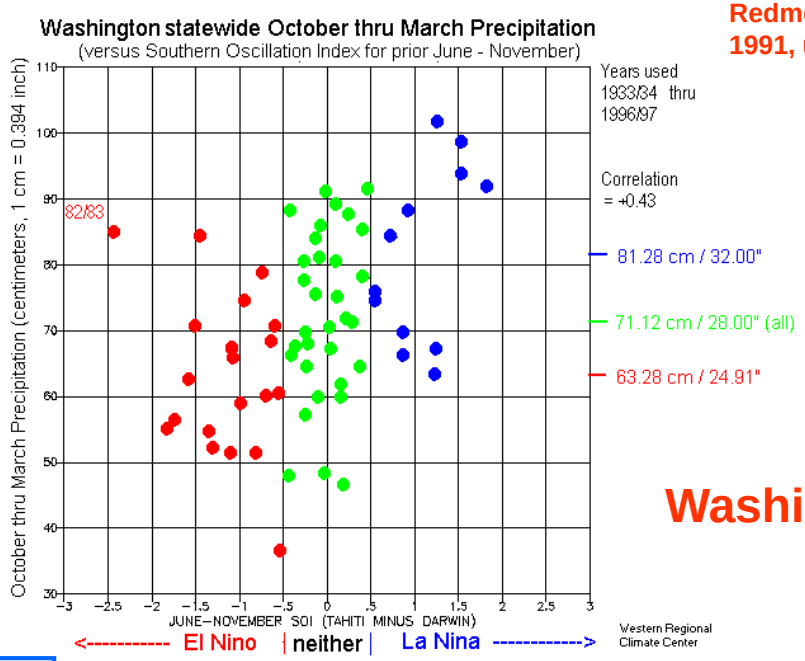

Benjamin Cook, Toby Ault, Jason Smerdon, 2015. Unprecedented 21st century drought risk in the American Southwest and Central Plains. Science Advances, 12 Feb 2015. 10.1126/sciadv.1400082




Benjamin Cook, Toby Ault, Jason Smerdon, 2015. Unprecedented 21st century drought risk in the American Southwest and Central Plains. Science Advances, 12 Feb 2015. 10.1126/sciadv.1400082



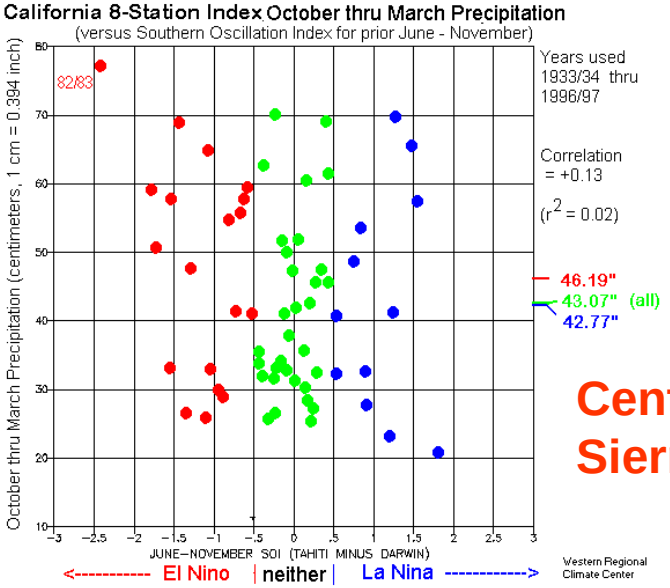

Redmond & Koch, 1991, updated.



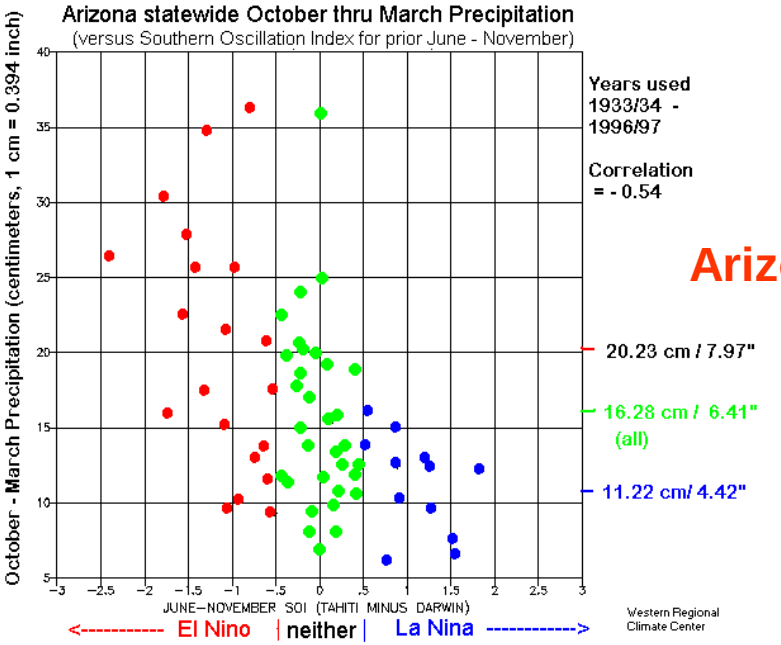

Redmond & Koch, 1991, updated.

Washington

ENSO



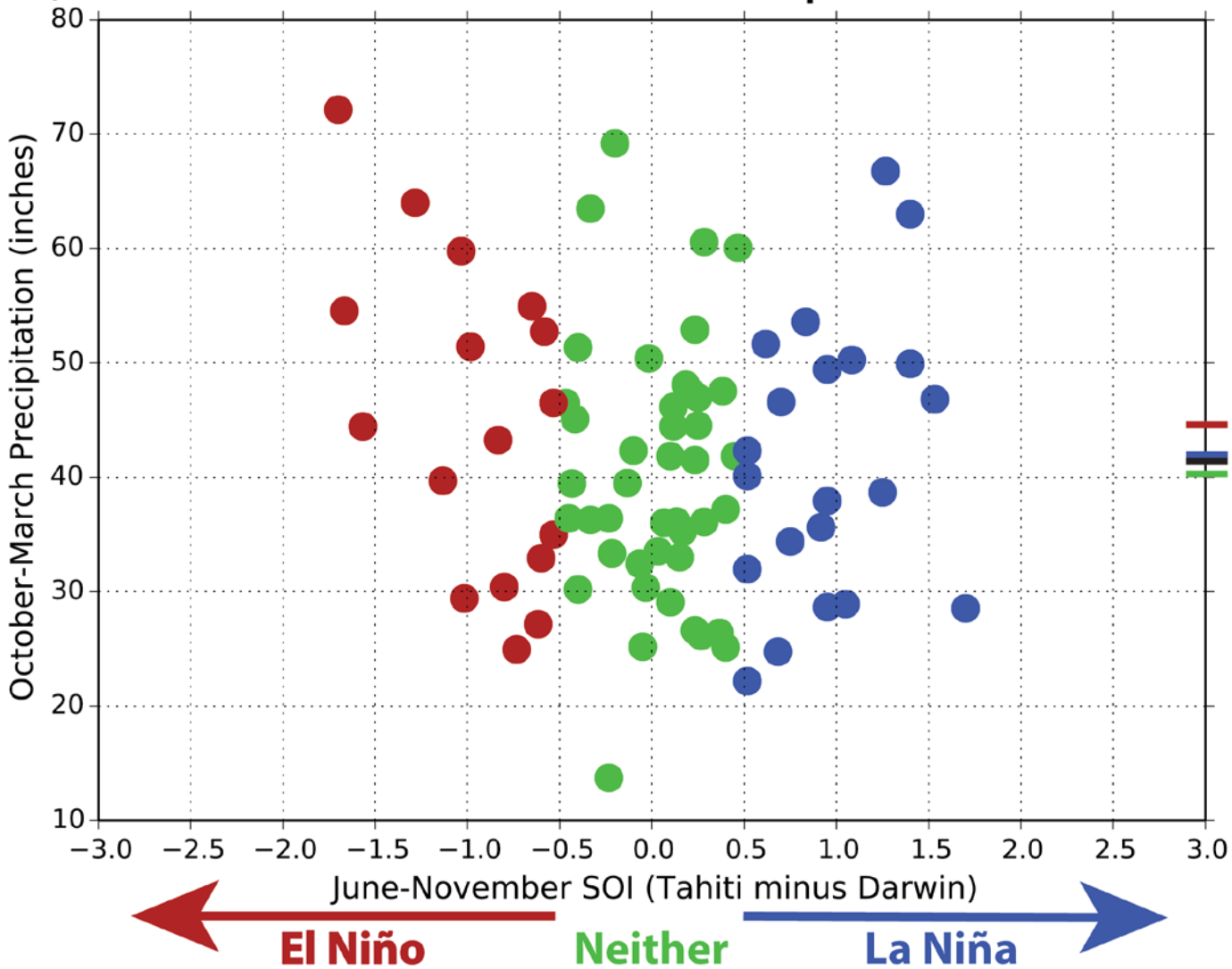

Central Sierra




Arizona

# CA Division 1 October-March Precipitation

## (versus Southern Oscillation Index for prior June-November)




**Years 1933/1934-2013/2014**

**$r^2 = 0.01$**

**Correlation = -0.11**

**Mean = 44.9 in**

**Mean = 41.53 in**

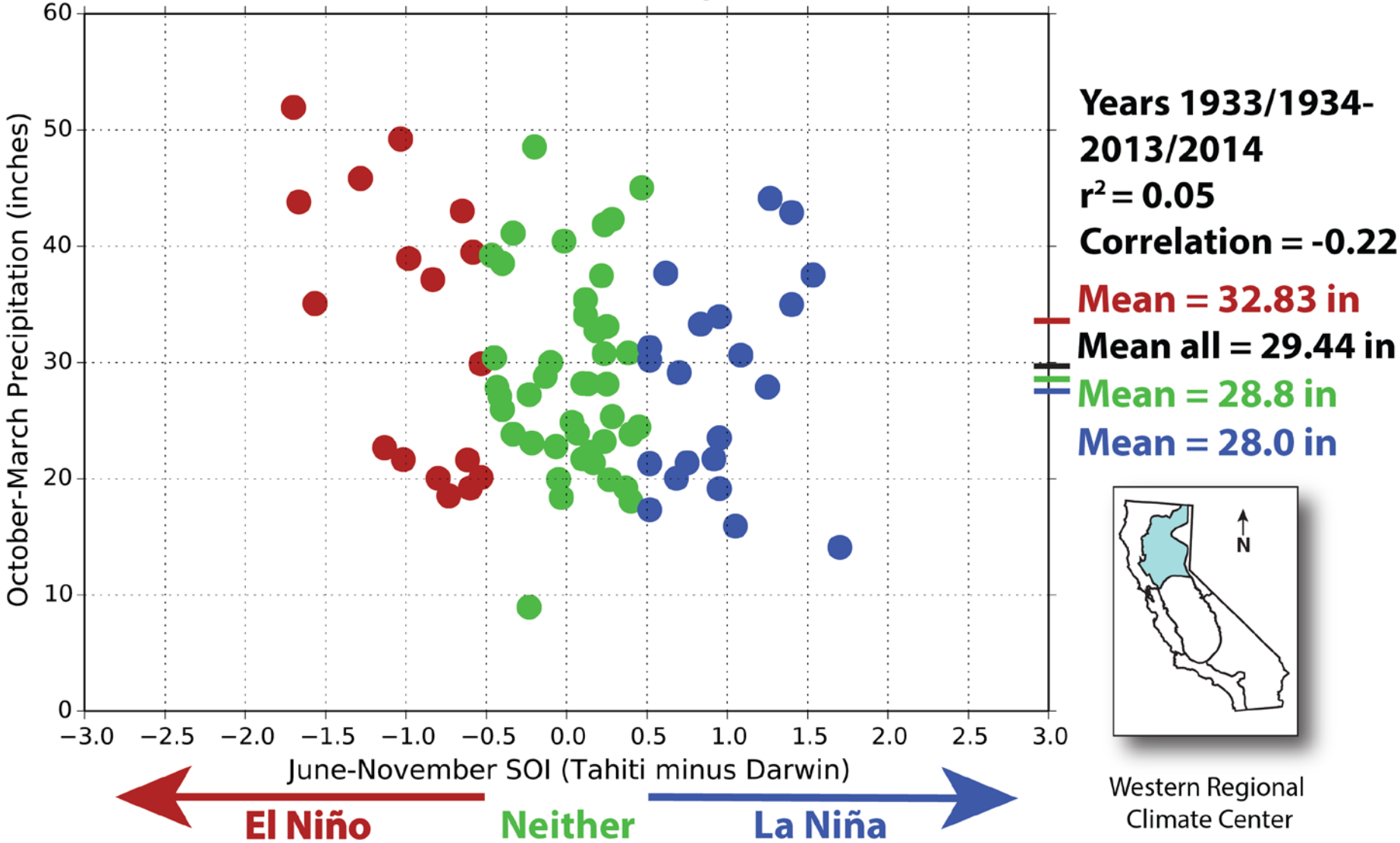
**Mean all = 41.51 in**

**Mean = 40.15 in**

Western Regional Climate Center

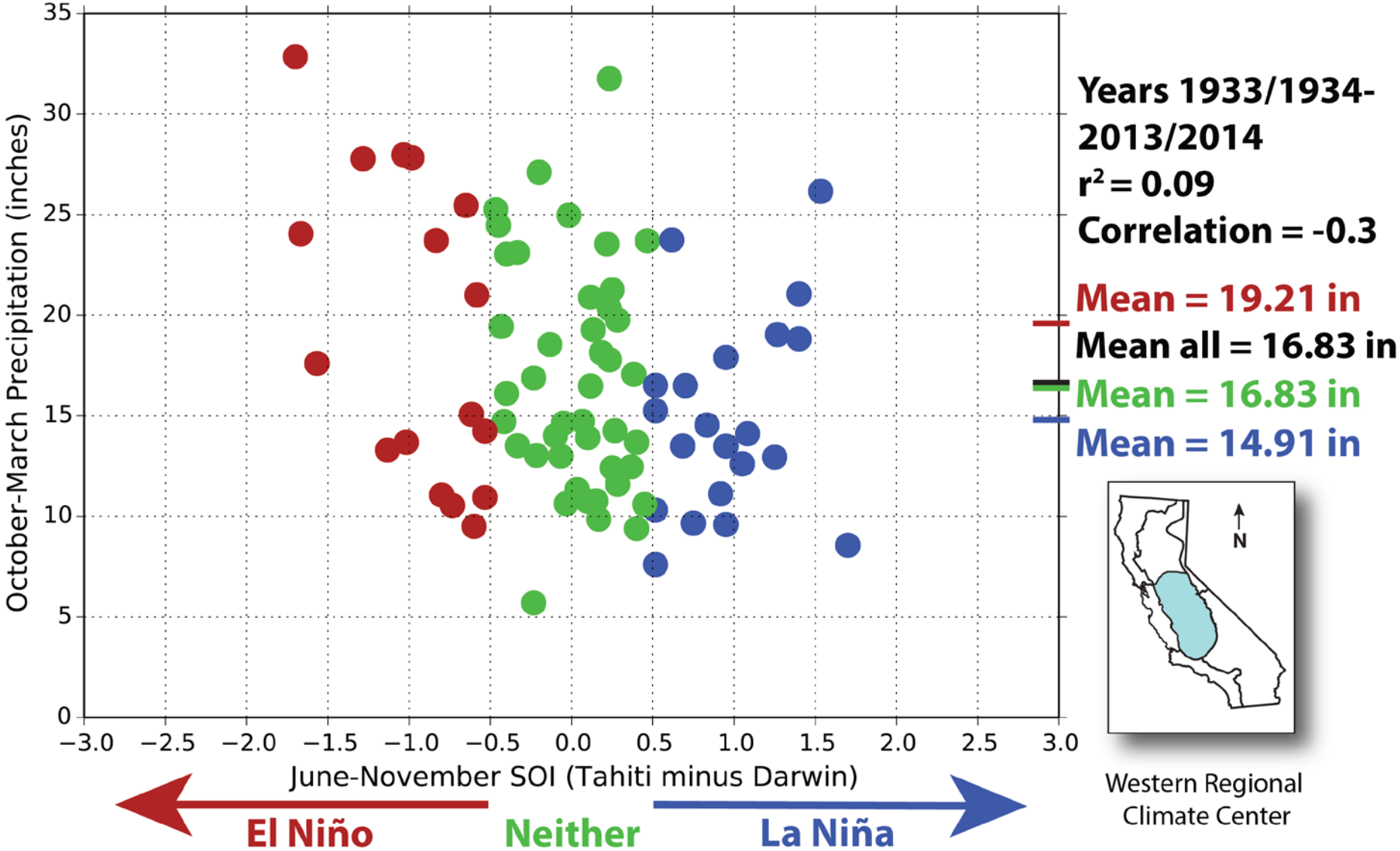
# CA Division 2 October-March Precipitation

## (versus Southern Oscillation Index for prior June-November)



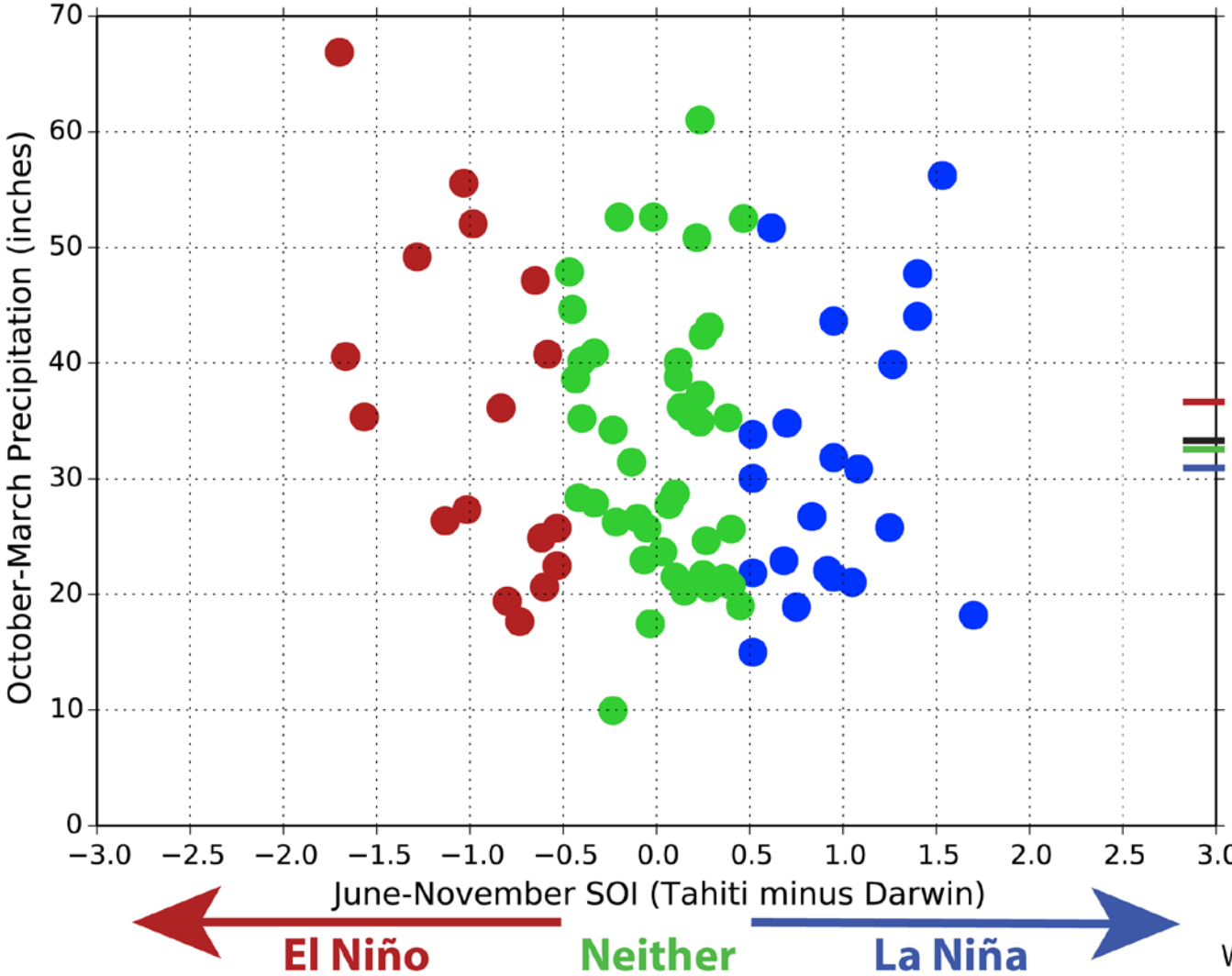
# CA Division 5 October-March Precipitation

## (versus Southern Oscillation Index for prior June-November)



# CA 5-Station Index October-March Precipitation

## (versus Southern Oscillation Index for prior June-November)




**Years 1933/1934-2013/2014**

**$r^2 = 0.03$**

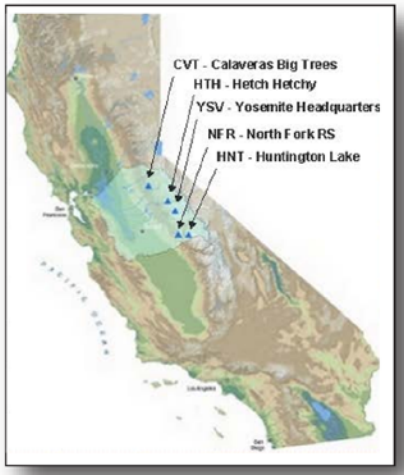
**Correlation = -0.17**

**Mean = 35.77 in**

**Mean all = 33.02 in**

**Mean = 32.74 in**

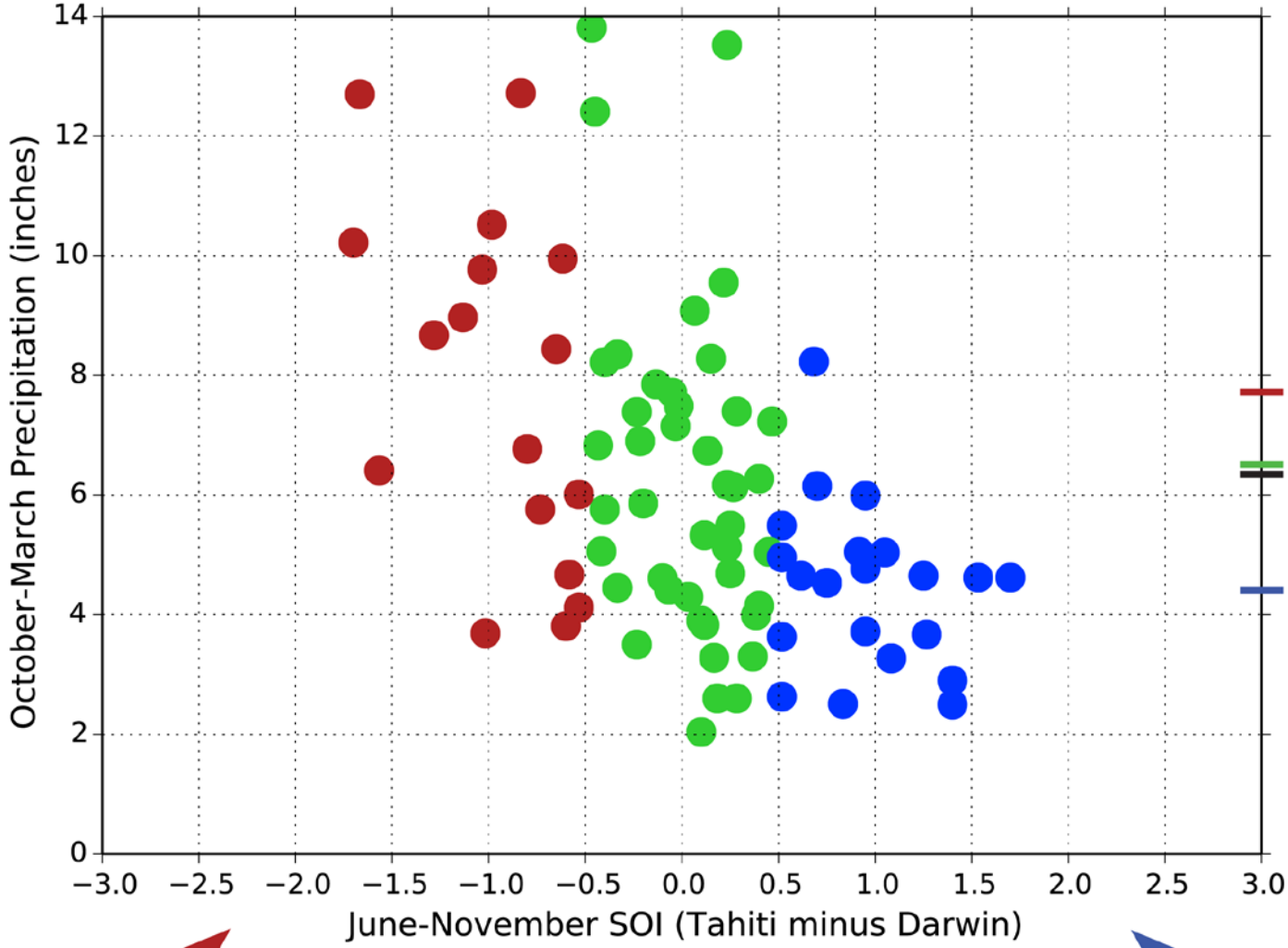
**Mean = 31.36 in**




Data Source: CA DWR
Western Regional Climate Center

# Arizona Statewide October-March Precipitation

## (versus Southern Oscillation Index for prior June-November)




**Years 1933/1934-2013/2014**

**$r^2 = 0.27$**

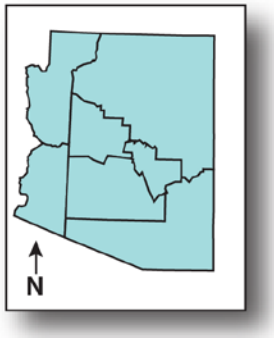
**Correlation = -0.52**

**Mean = 7.84 in**

**Mean = 6.23 in**

**Mean all = 6.11 in**

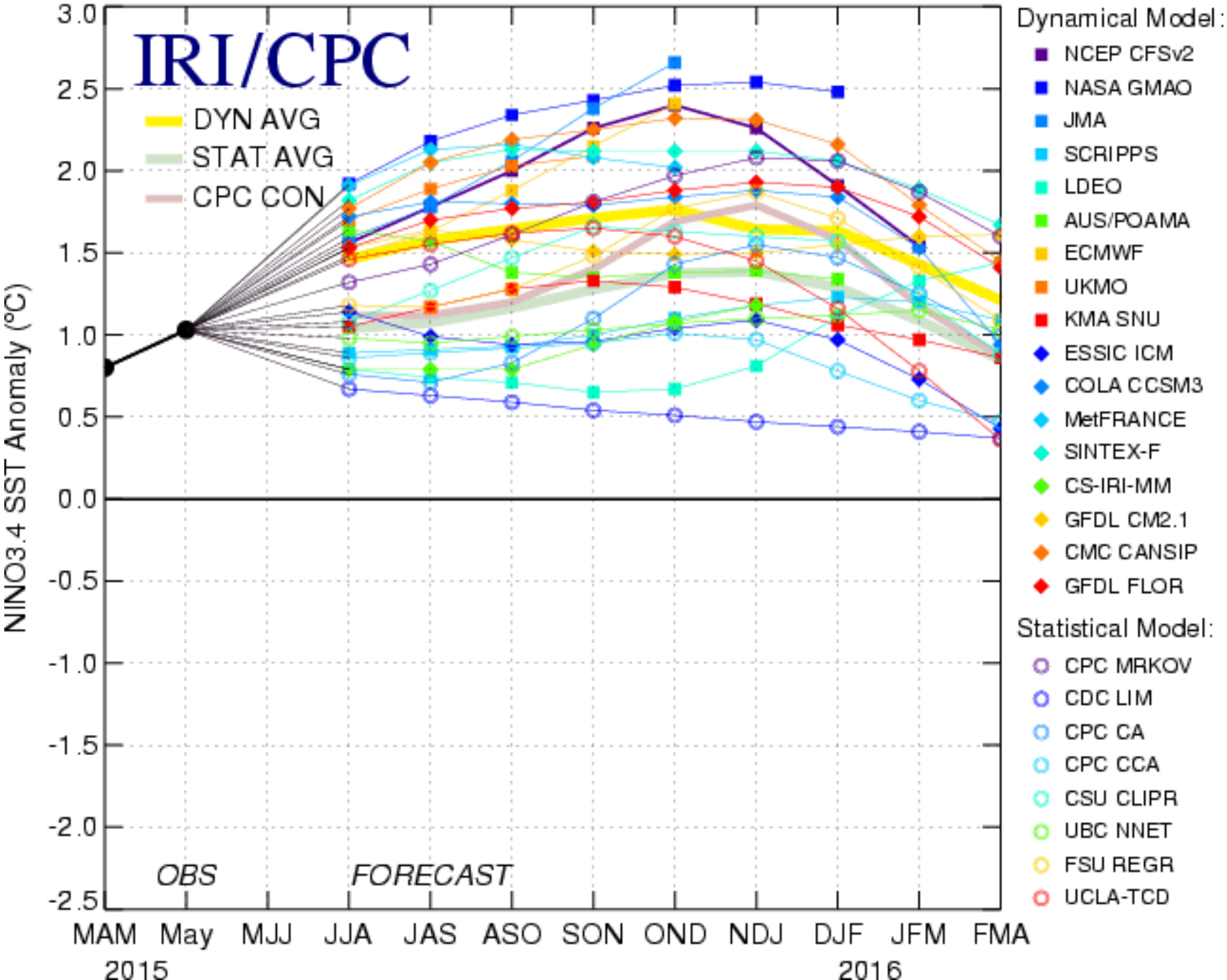
**Mean = 4.46 in**

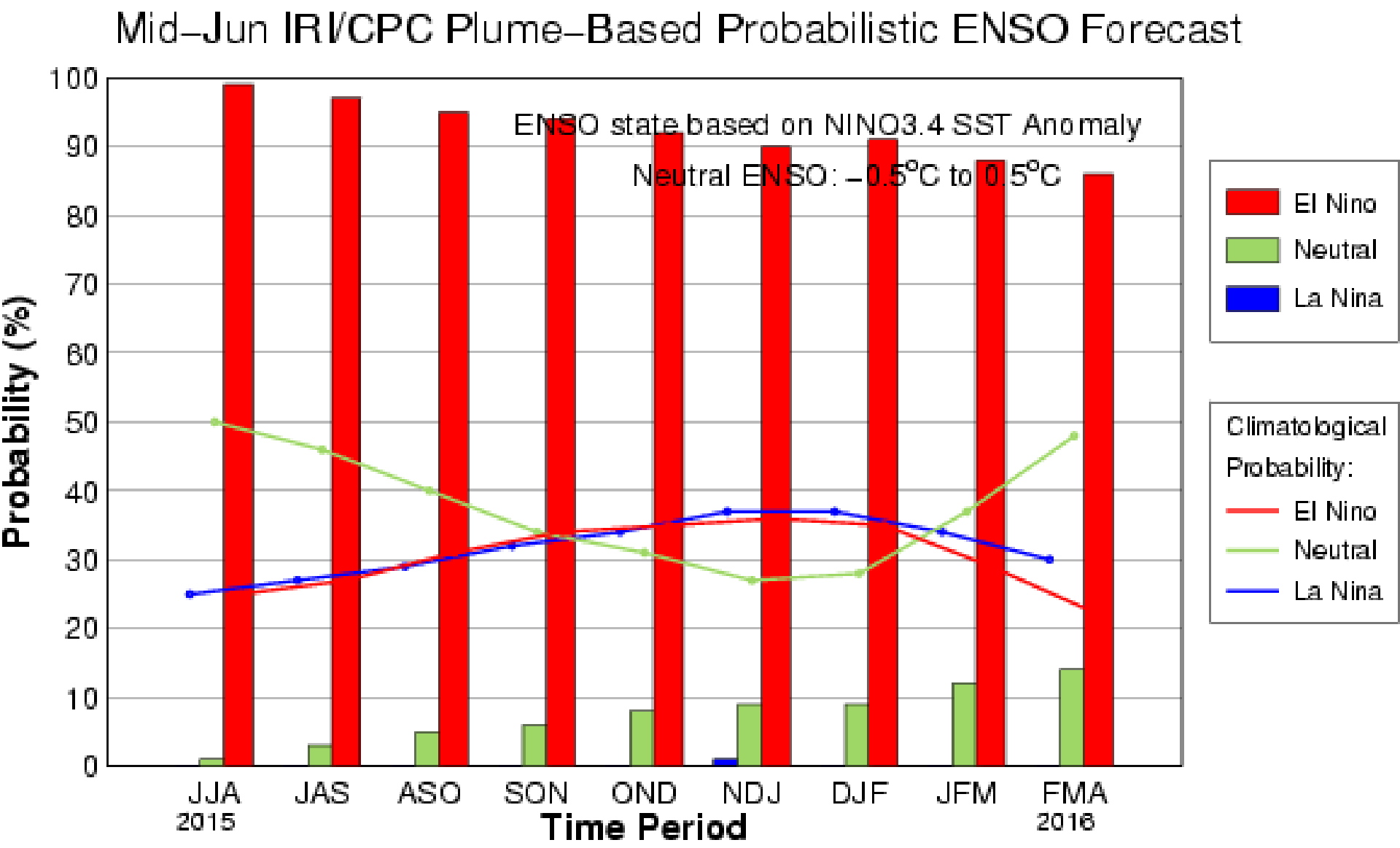



**El Niño** **Neither** **La Niña**

Western Regional Climate Center

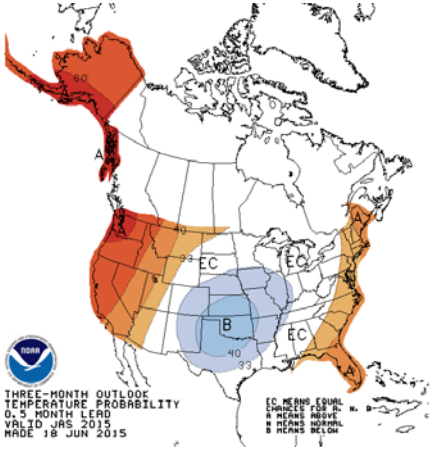
# Mid-Jun 2015 Plume of Model ENSO Predictions

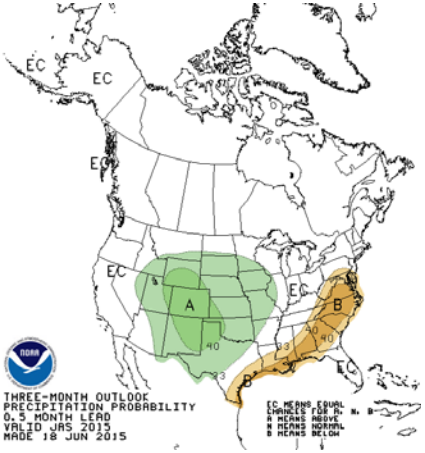


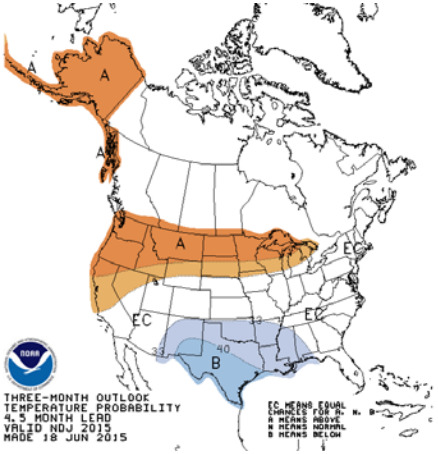

Mid–Jun IRI/CPC Plume–Based Probabilistic ENSO Forecast
ENSO state based on NINO3.4 SST Anomaly
Neutral ENSO: –0.5°C to 0.5°C
Probability (%)
100
90
80
70
60
50
40
30
20
10
0
JJA
2015
JAS
ASO
SON
OND
NDJ
DJF
JFM
FMA
2016
Time Period
El Nino
Neutral
La Nina
Climatological Probability:
El Nino
Neutral
La Nina

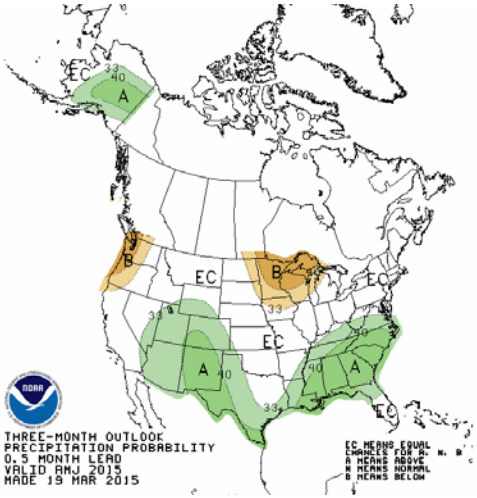
# Temperature & Precipitation
# Official Outlooks
## Three Month Summer 2015 Three Month Winter

**Jul-Aug-Sep T** **Jul-Aug-Sep P** **Nov-Dec-Jan T** **Nov-Dec-Jan P**



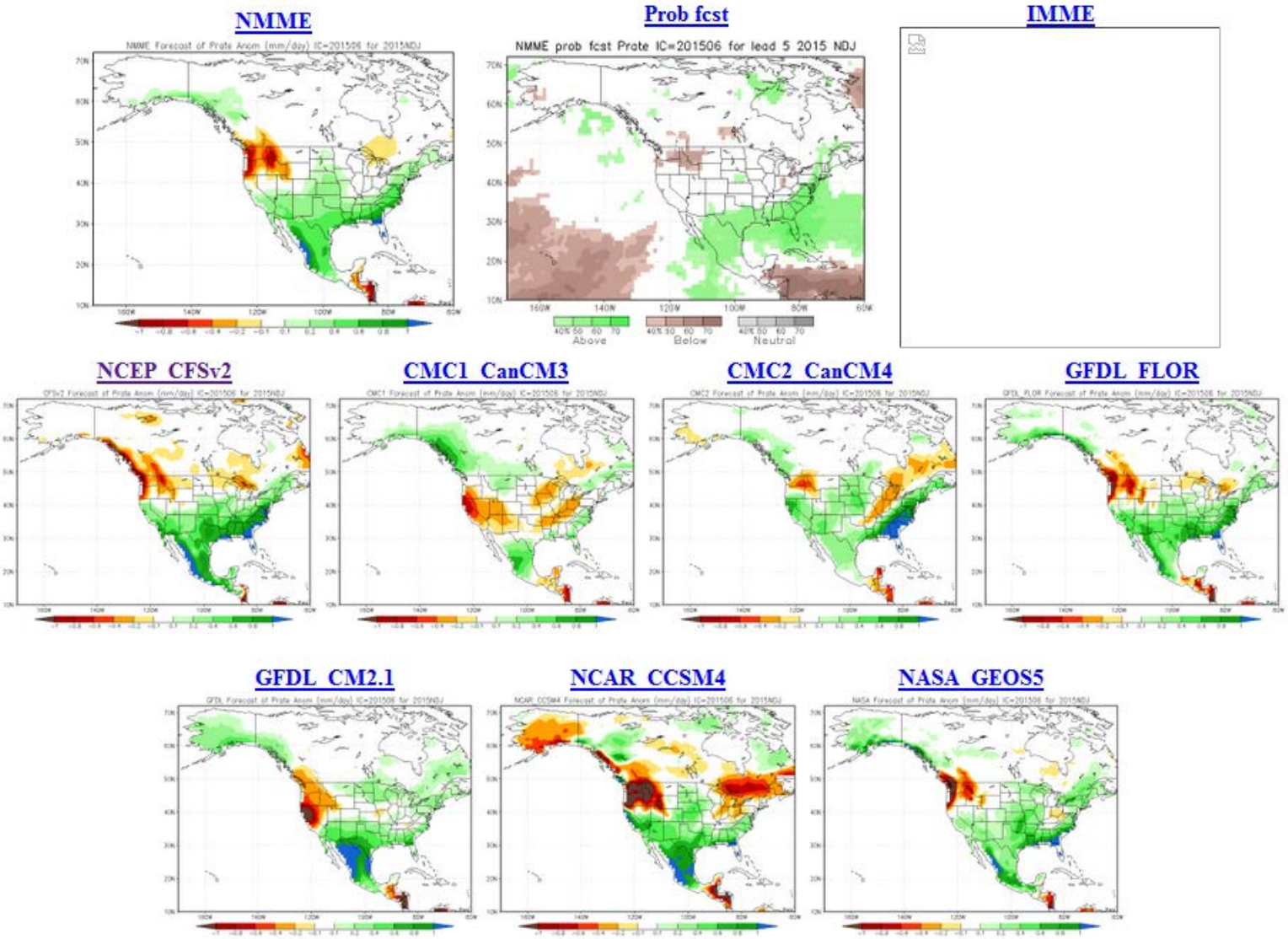

**Orange / Red** - Higher likelihood of drier than usual
**Green** - Higher likelihood of wetter than usual

NOAA Climate Prediction Center

# Seven experiments in near-term climate forecasting Nov-Jan 2015-6. Precipitation.

## NMME (National Multi-Model Ensemble).

## IMME (International Multi-Model Ensemble).




## Dynamical Models

**CFSv2:** US Climate Forecasting System version 2
**CMC1:** Canadian Meteorological Center version 1
**CMC2:** Canadian Meteorological Center version 2
**GFDL:** US Geophysical Fluid Dynamics Laboratory
**NCAR:** US National Center for Atmospheric Research
**NASA:** US National Aeronautics and Space Administration
**NMME:** National Multi-Model Ensemble
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2015 Jul 3

# Seven experiments in near-term climate forecasting Jul-Sep 2015. Temperature.

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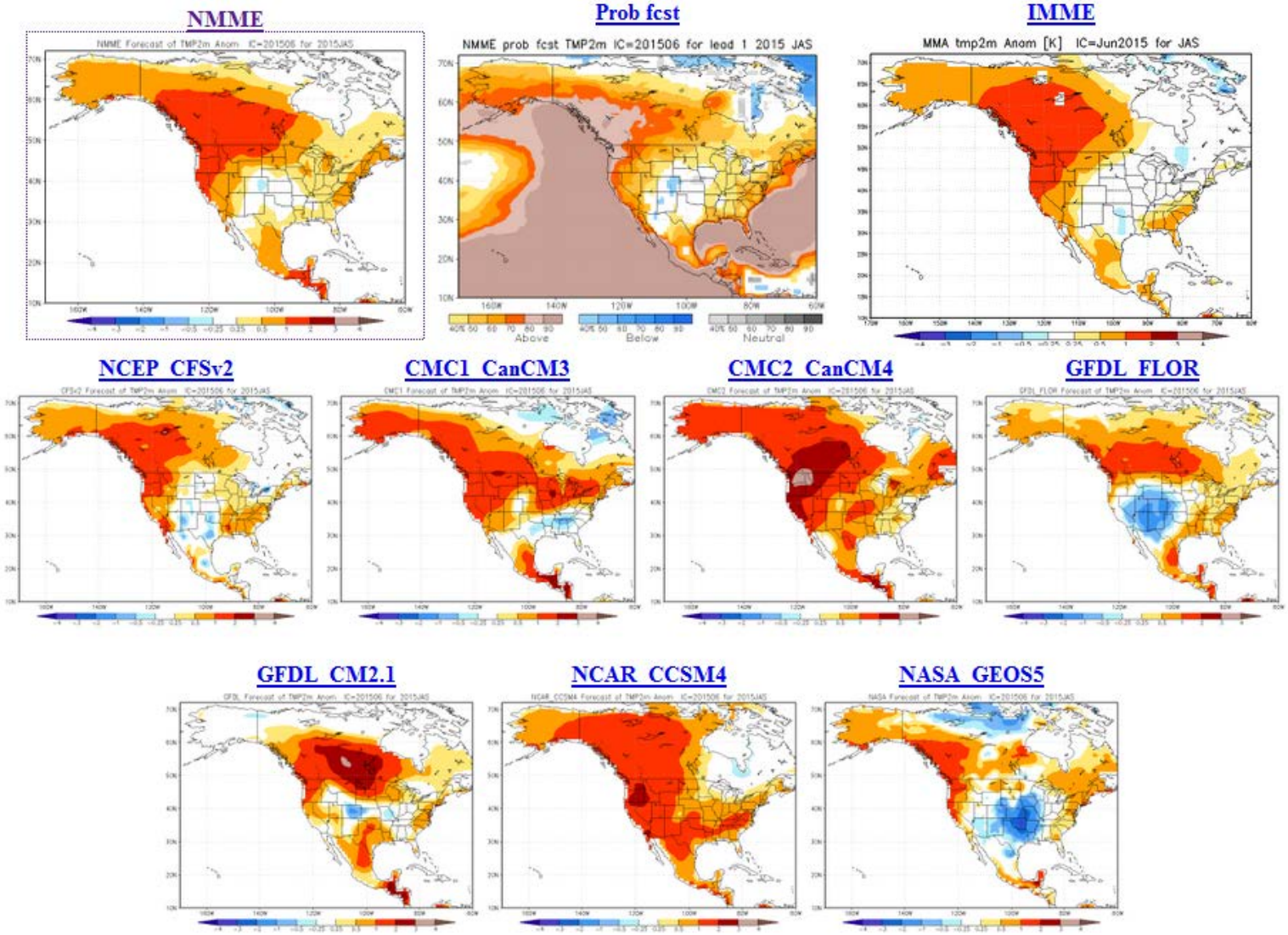
## IMME (International Multi-Model Ensemble).




## Dynamical Models

**CFSv2:** US Climate Forecasting System version 2
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2015 Jul 3

# Seven experiments in near-term climate forecasting Nov-Jan 2015-6. Temperature.

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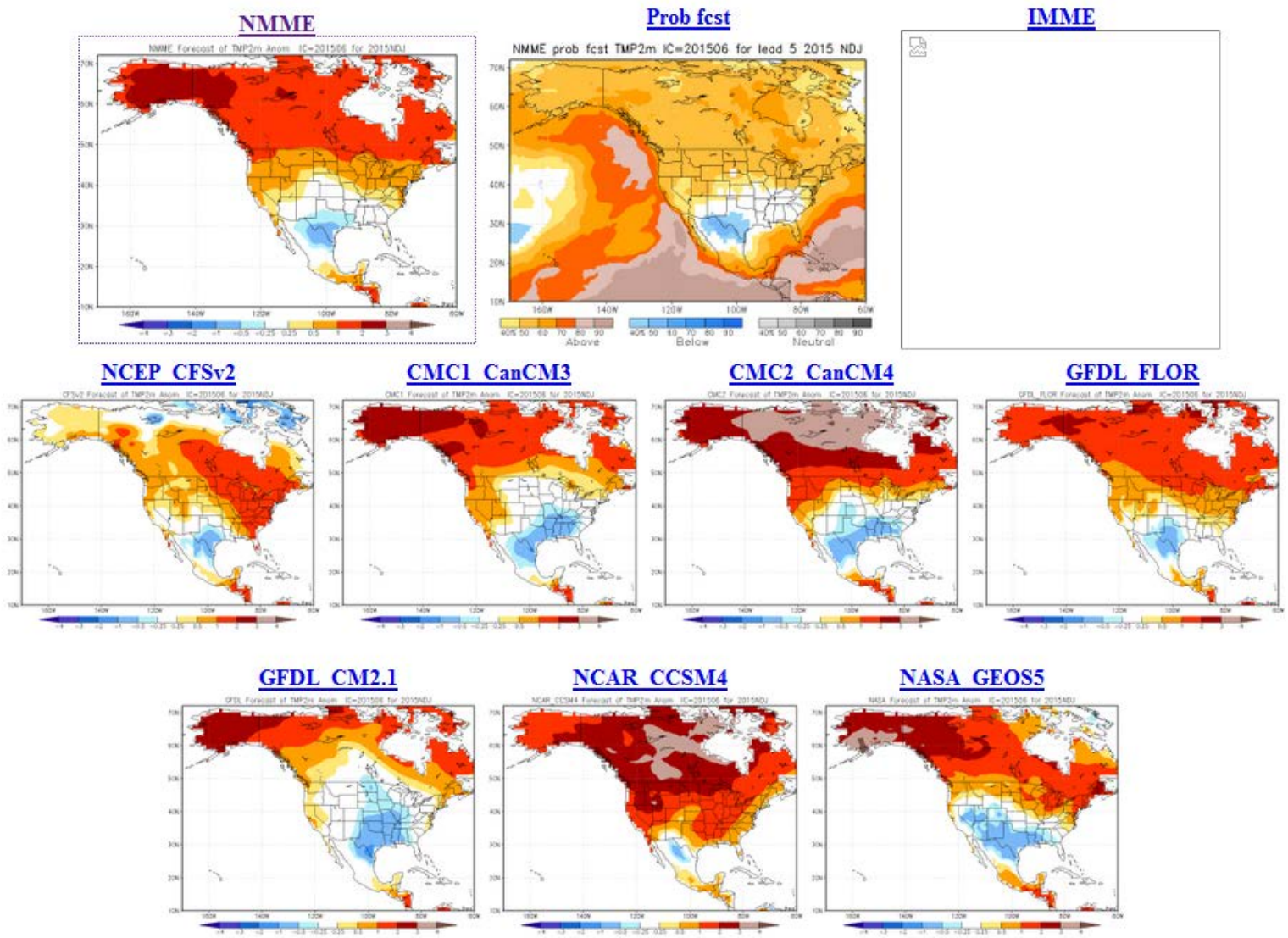


## Dynamical Models

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**NMME:** National Multi-Model Ensemble
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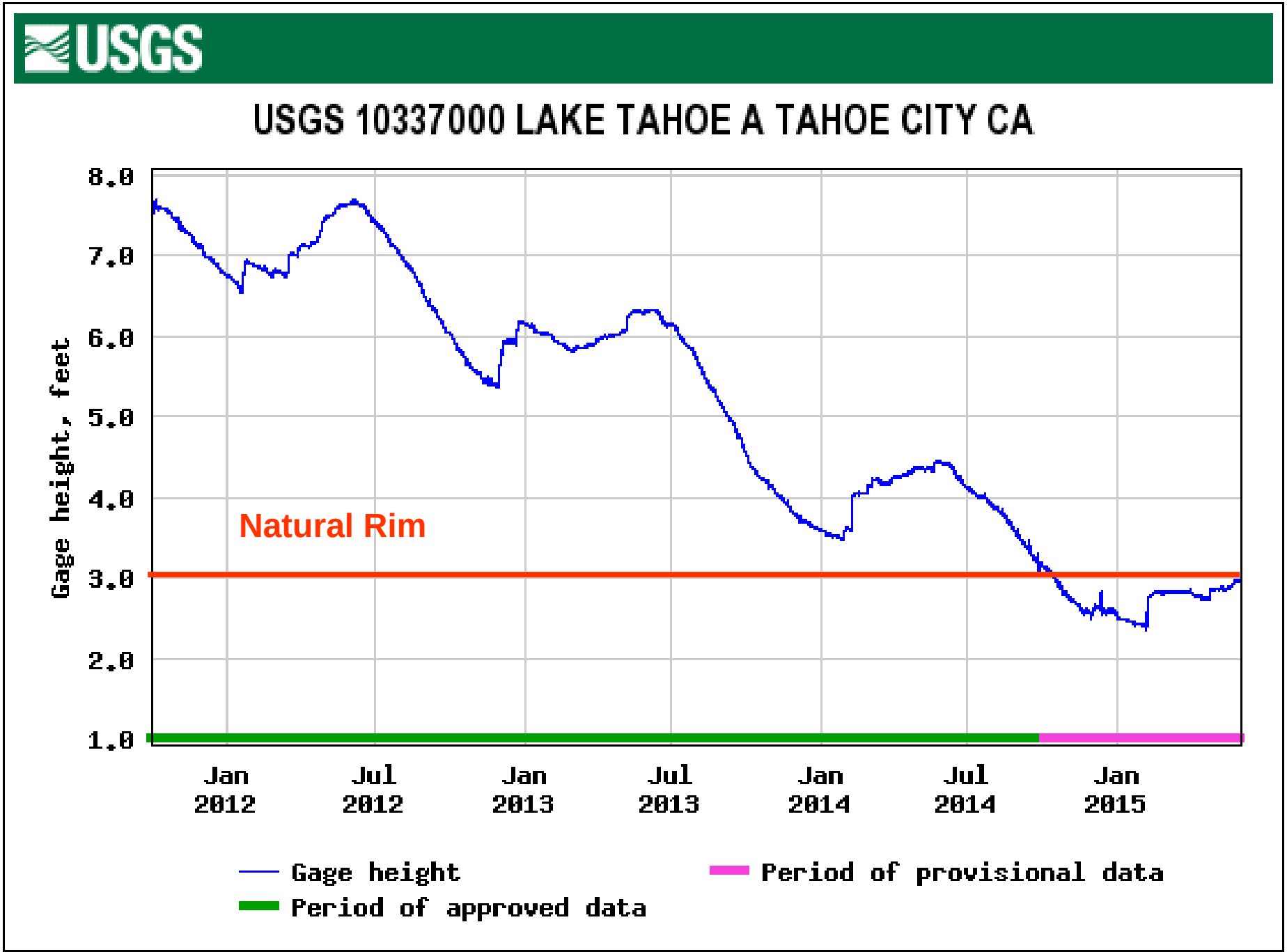
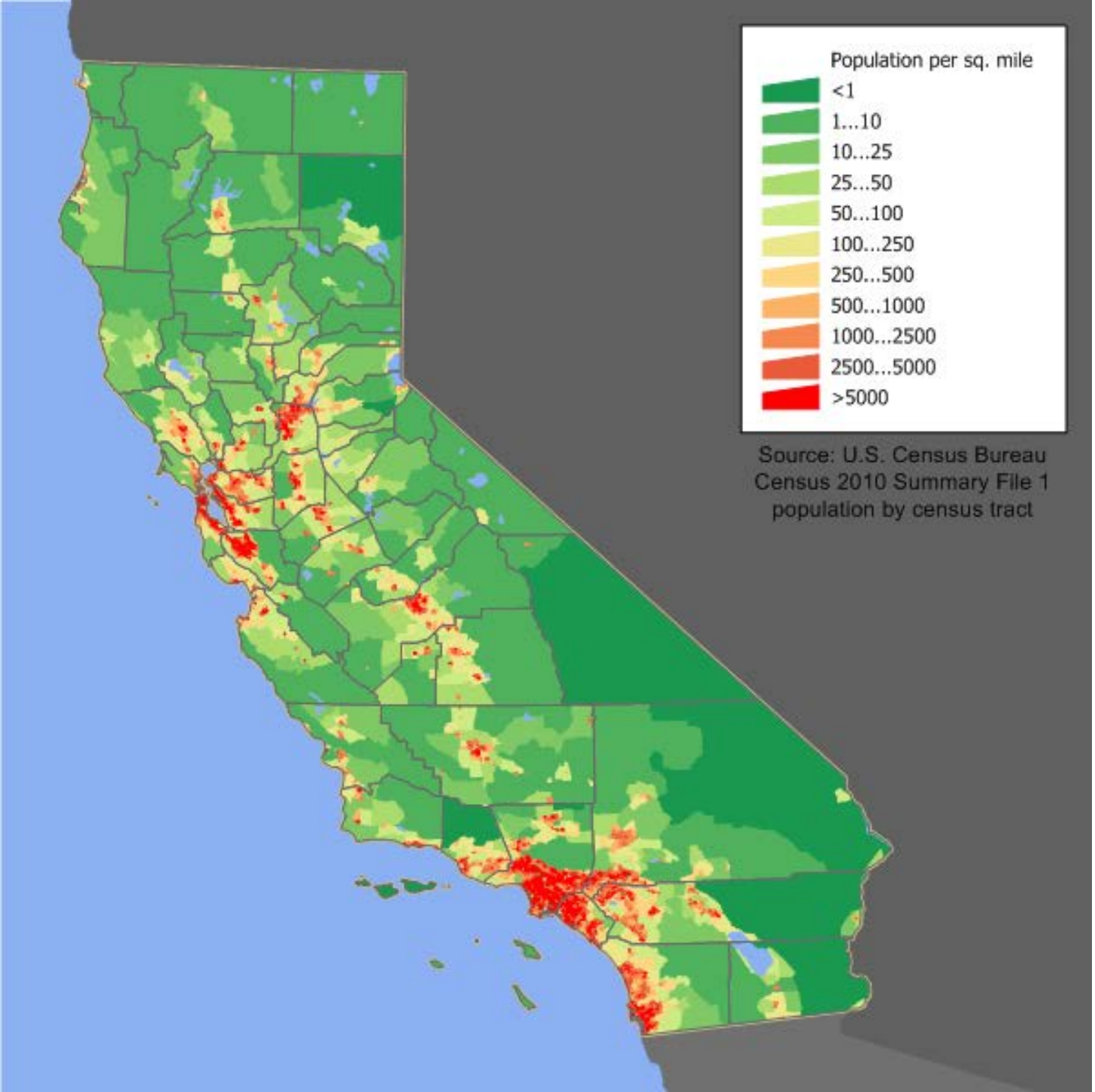
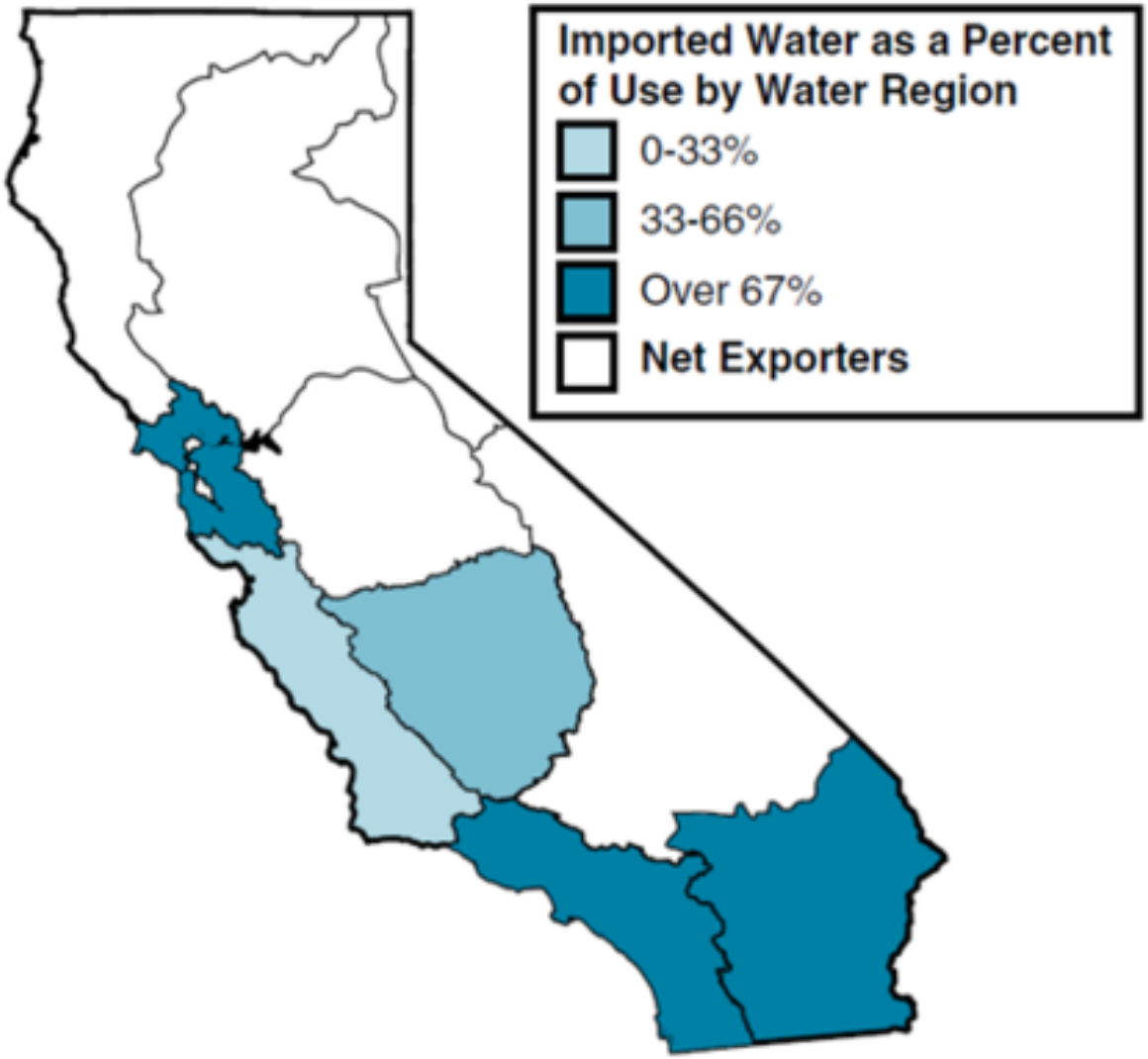
2015 Jul 3

# Elevation of Lake Tahoe at Tahoe City 2011 Oct 01 - 1 Jun 2015



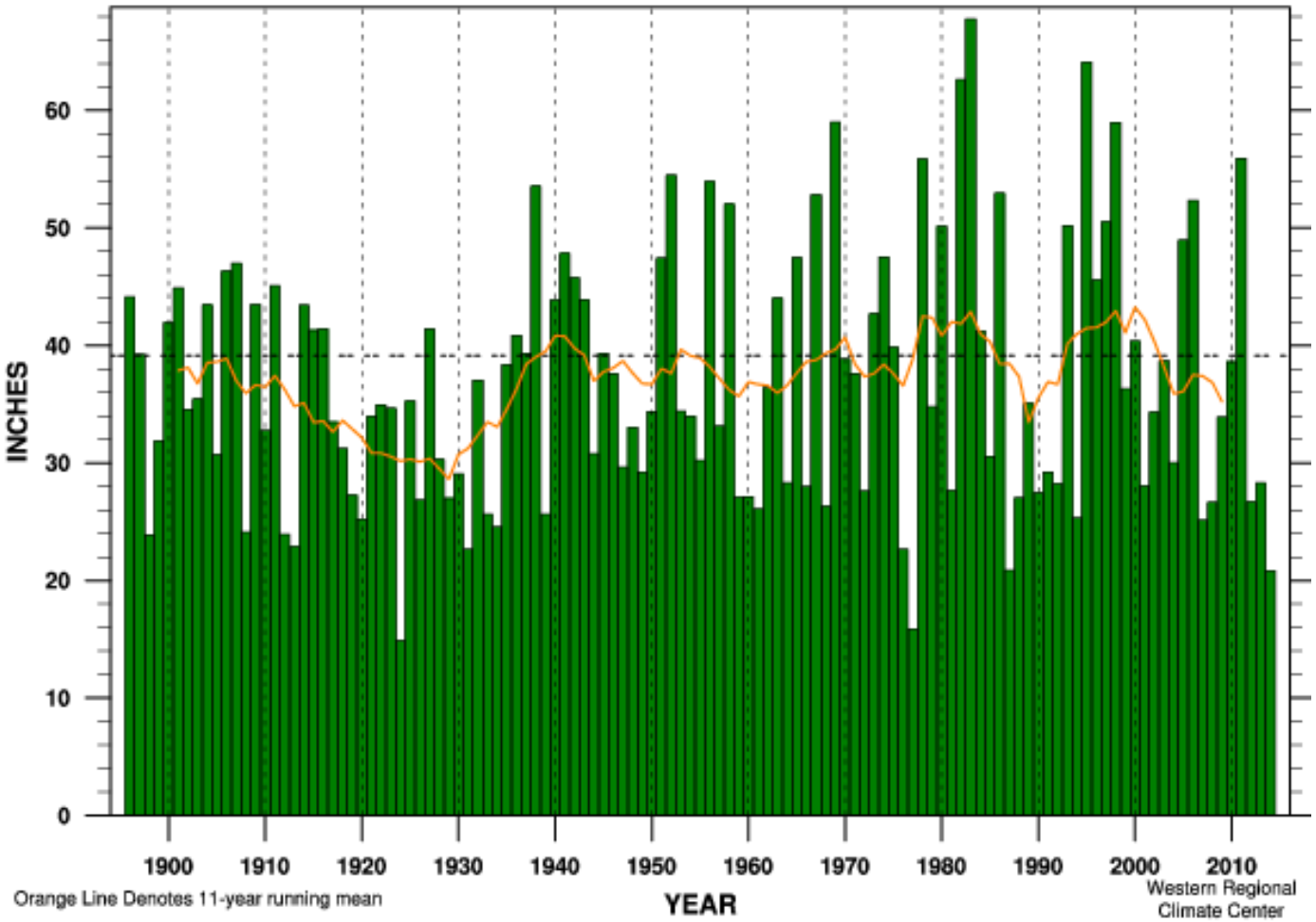

Population per sq. mile
<1
1...10
10...25
25...50
50...100
100...250
250...500
500...1000
1000...2500
2500...5000
>5000
Source: U.S. Census Bureau
Census 2010 Summary File 1
population by census tract

# Population Centers Rely Heavily on Imported Water




California Legislative Analyst's Office 2013

# Sierra Region
## Precipitation Oct-Sep




| | | | |
|---|---|---|---|
| Linear Trend 1895-present | + 3.32 ± 5.69 in. | (+ 8 ± 14%) per 100 yr | |
| Linear Trend 1949-present | - 3.85 ± 16.39 in. | (- 9 ± 41%) per 100 yr | |
| Linear Trend 1975-present | -11.68 ± 39.68 in. | (- 29 ± 101%) 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 2014 | 20.81 in. ( 53%) | RANK | 3 of 119 |

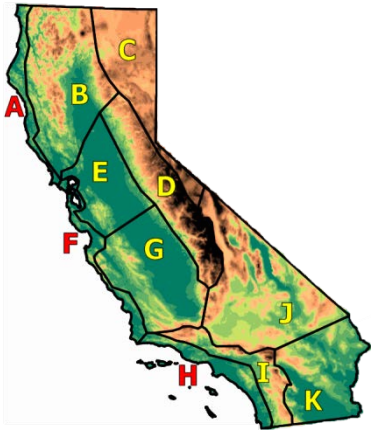
**Sierra Nevada Precipitation**

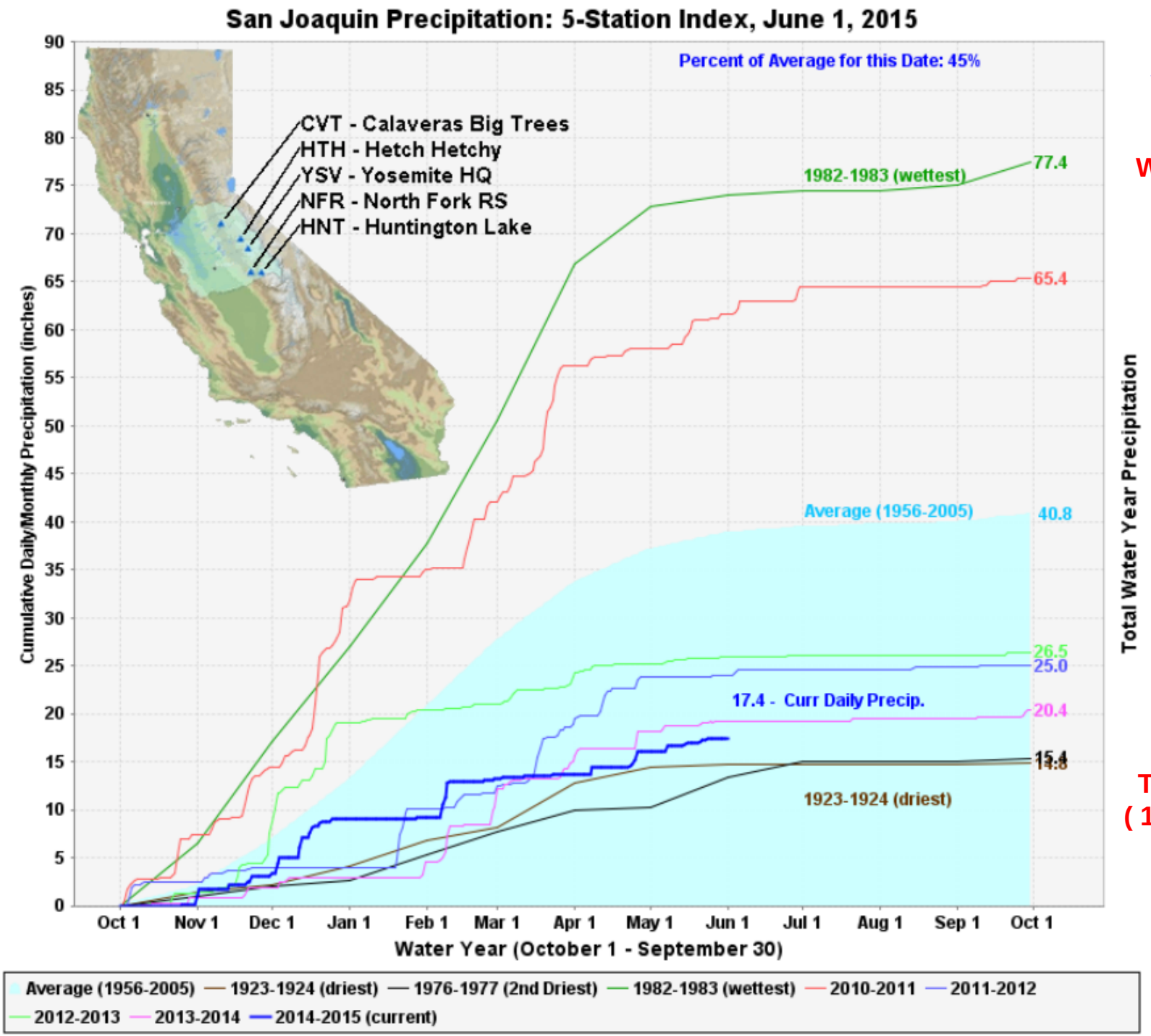
**Water Year**

**Oct-Sep**

**1895-96 thru 2013-14**

**California Climate Tracker**






**5-Station Index Precipitation**

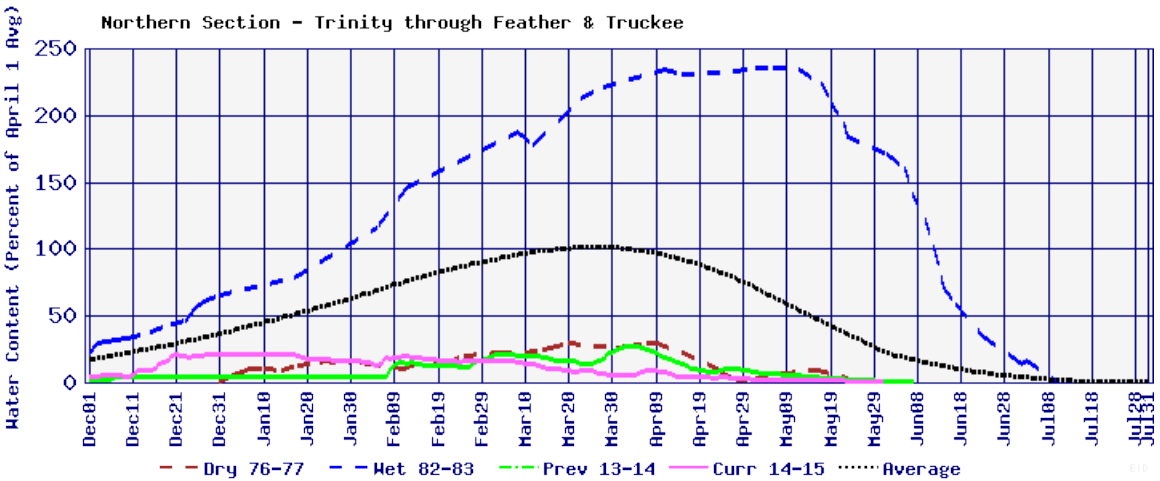
**Wettest (1982-83)**

**2010-11**

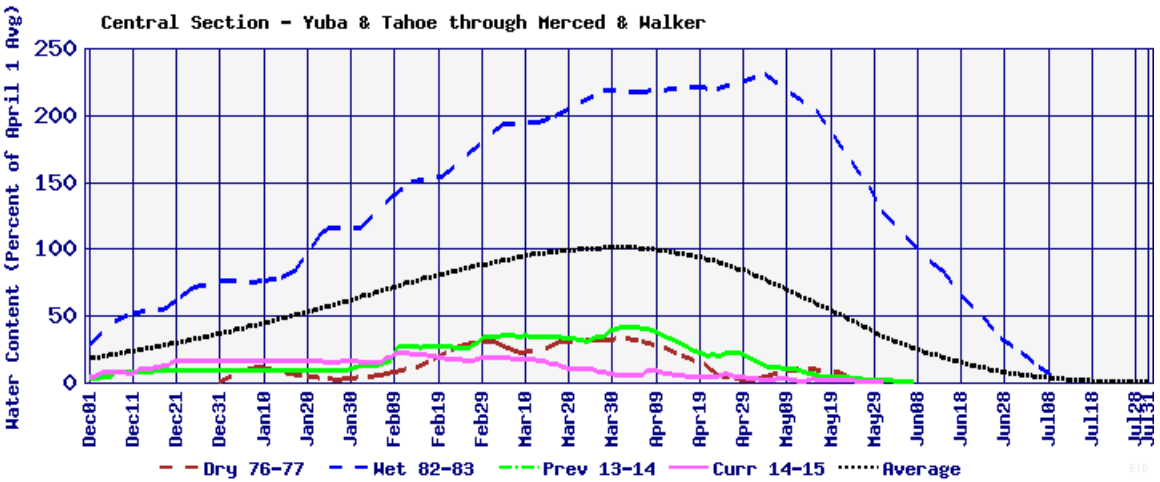
**2012-13**
**2011-12**
**2013-14**
**2014-15**
**Two driest years,**
**( 1976-77, 1923-24 )**

**CA - DWR**

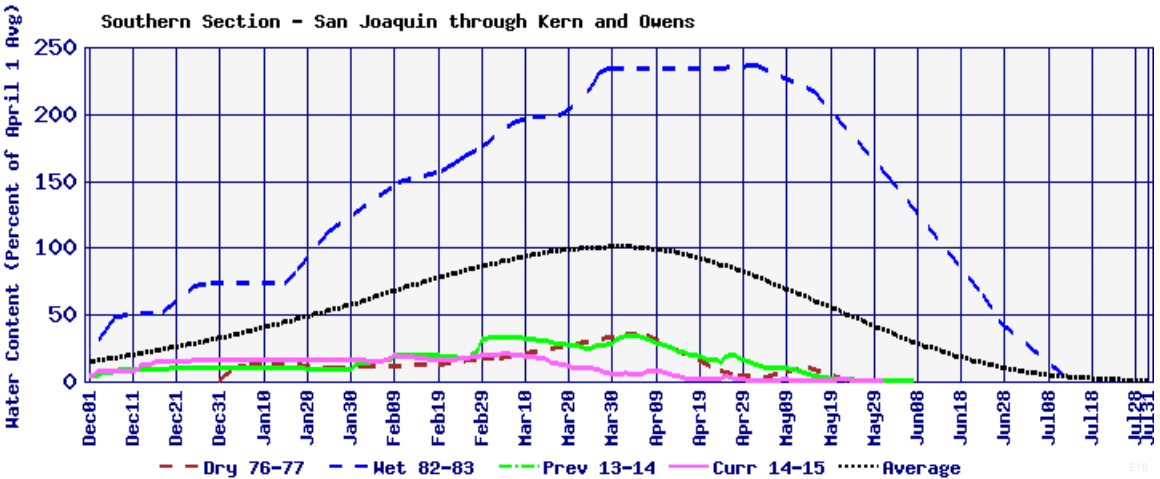
# Winter Season Snow Water Content




## Northern Sierra




## Central Sierra




## Southern Sierra

**1982-83 wettest**

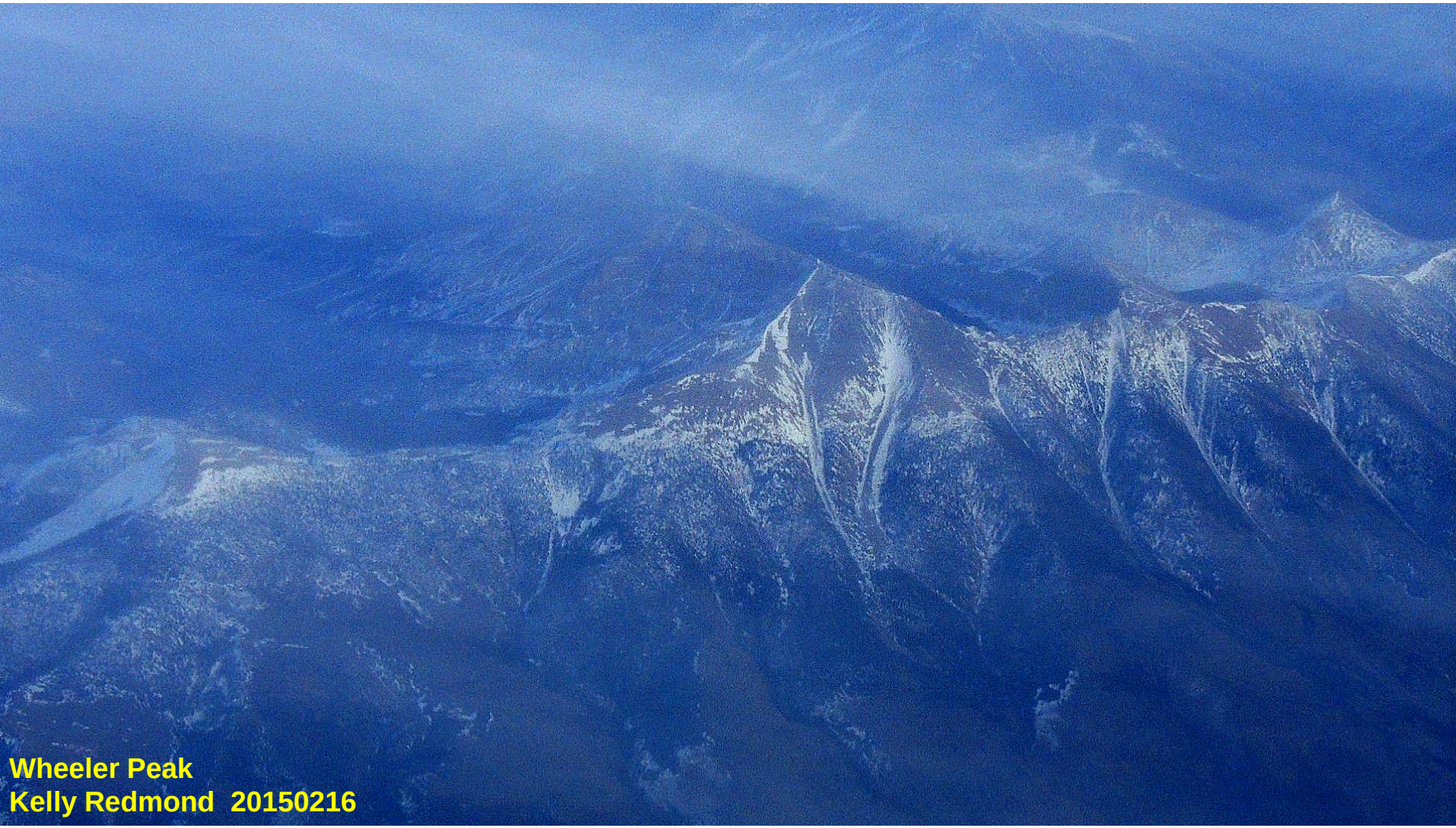
**Average**

**2013-14**

**2014-15**

**1976-77 driest**

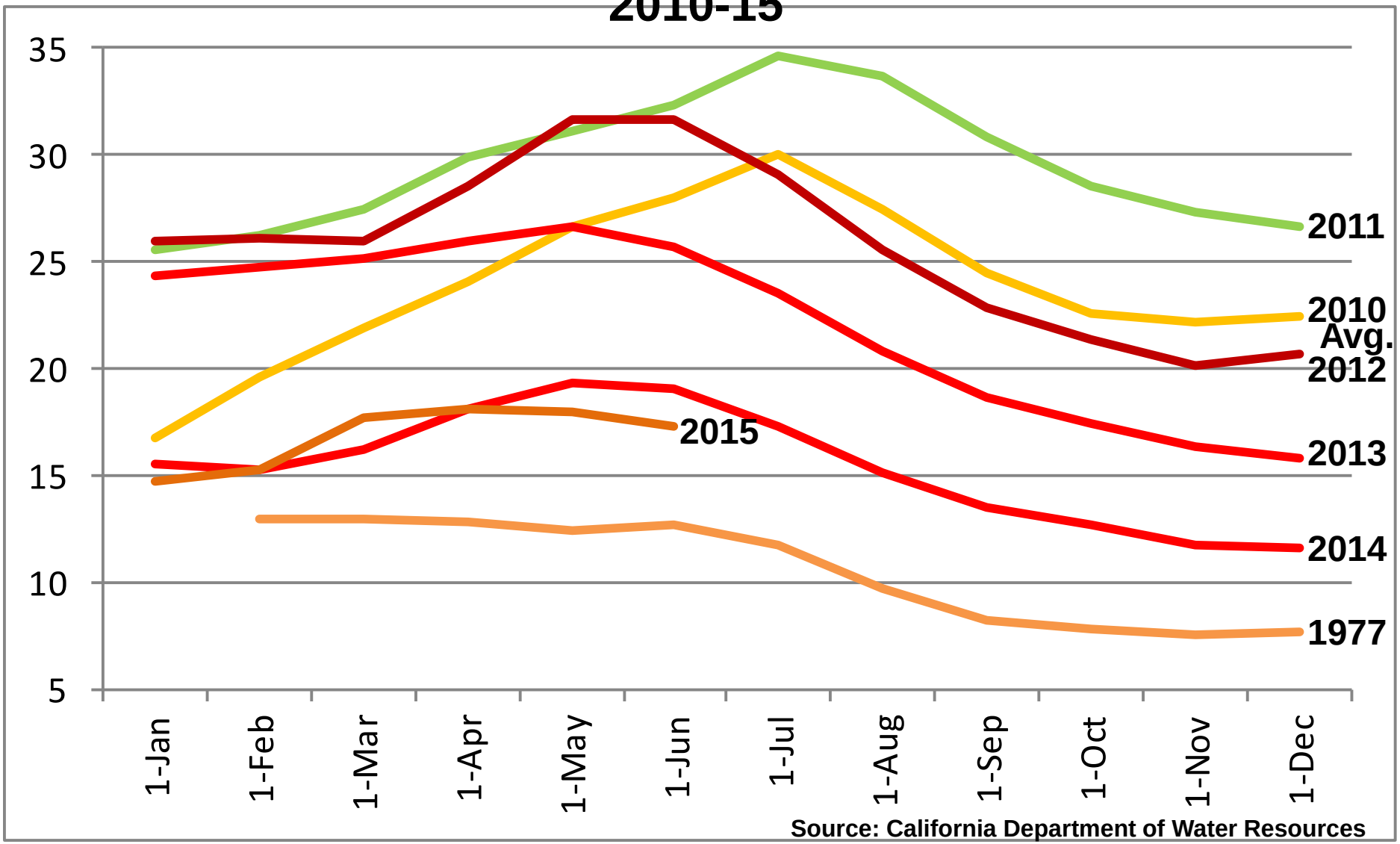
**Thru 01 Jun 2015**
**Cal DWR**


Wheeler Peak
Kelly Redmond 20150216

Marina, Overton, Lake Mead.
Kelly Redmond 20150220

Lake Mead. Kelly Redmond 20150220

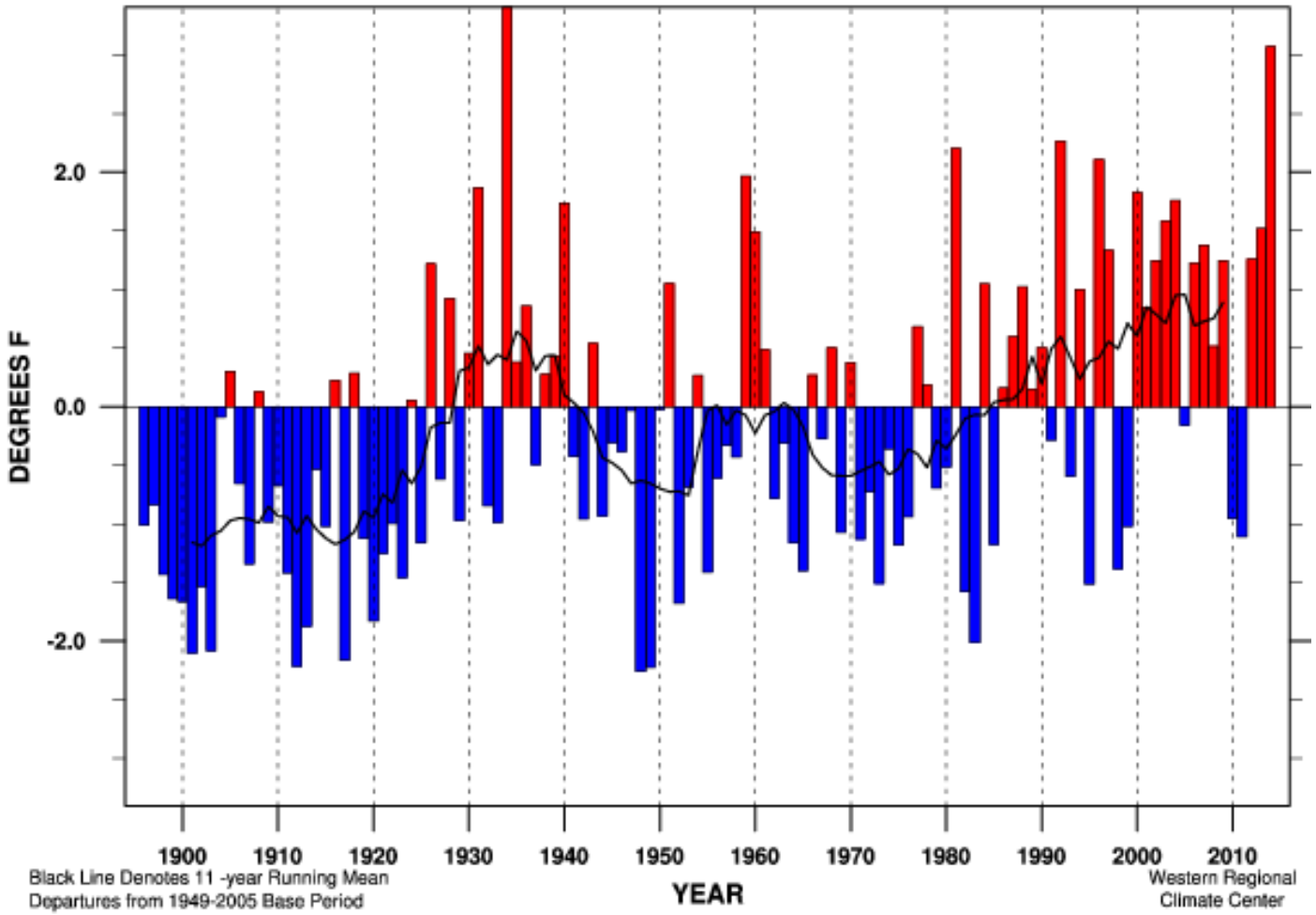
# California Reservoir Storage, Million Acre-Feet, 1977 and 2010-15




Note: One acre-foot is equal to 325,851 gallons, or the amount of water it takes to cover one acre to a depth of one foot.

# Sierra Region

## Mean Temperature Departure Oct-Sep




| | | | |
|---|---|---|---|
| Linear Trend 1895-present | + 1.50 ± 0.58 °F/100yr | | |
| Linear Trend 1949-present | + 2.33 ± 1.47 °F/100yr | | |
| Linear Trend 1975-present | + 3.82 ± 3.45 °F/100yr | | |
| Warmest Year | 52.4 °F (+ 3.4 °F) in 1934 | MEAN | 49.0 °F |
| Coldest Year | 46.8 °F (- 2.3 °F) in 1948 | STDEV | 1.15 °F |
| Oct-Sep 2014 | 52.1°F (+ 3.1°F) | RANK | 118 of 119 |

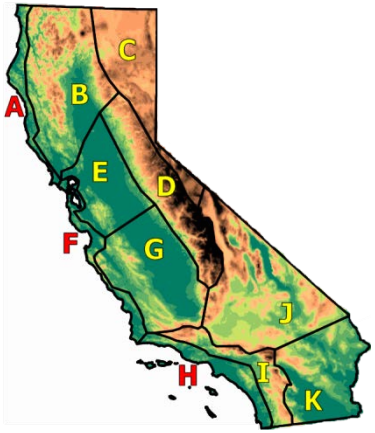
**Sierra Nevada Temperature**

**Water Year**

**Oct-Sep**

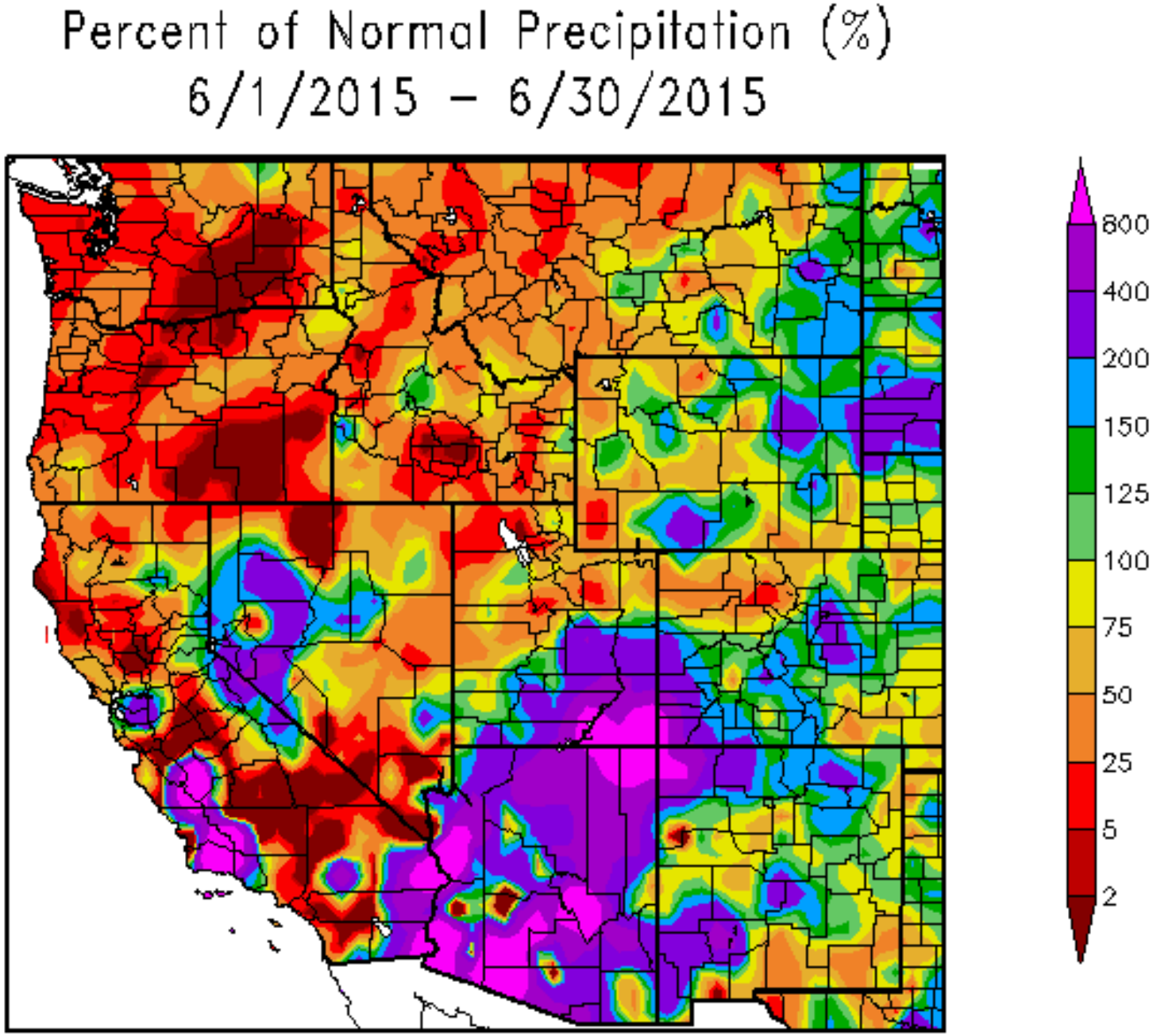
**1895-96 thru 2013-14**

**California Climate Tracker**



**June 2015 Precipitation Percent of Normal**

**01 June 2015 Thru 30 June 2015**




Generated 7/2/2015 at HPRCC using provisional data.

Regional Climate Centers