California's Drought of the Future (2042-2047)

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Image credit Justin Sullivan/Getty

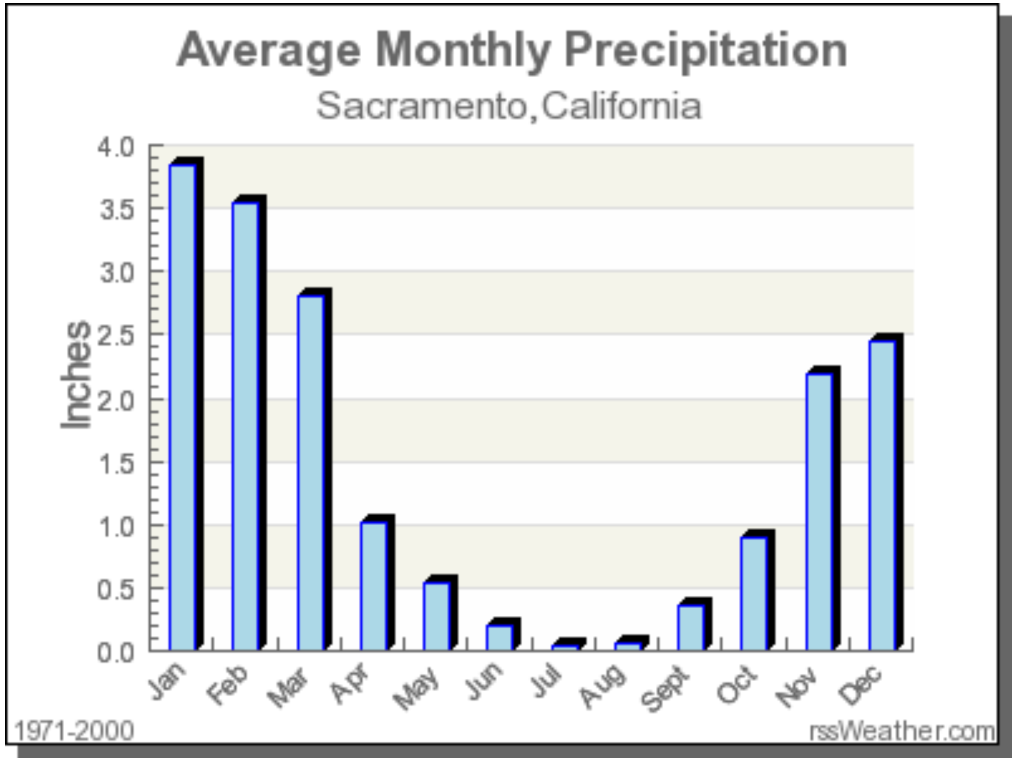
California Climate

California's Climate is largely Mediterranean.

Translation:
Wet winters, dry summers.

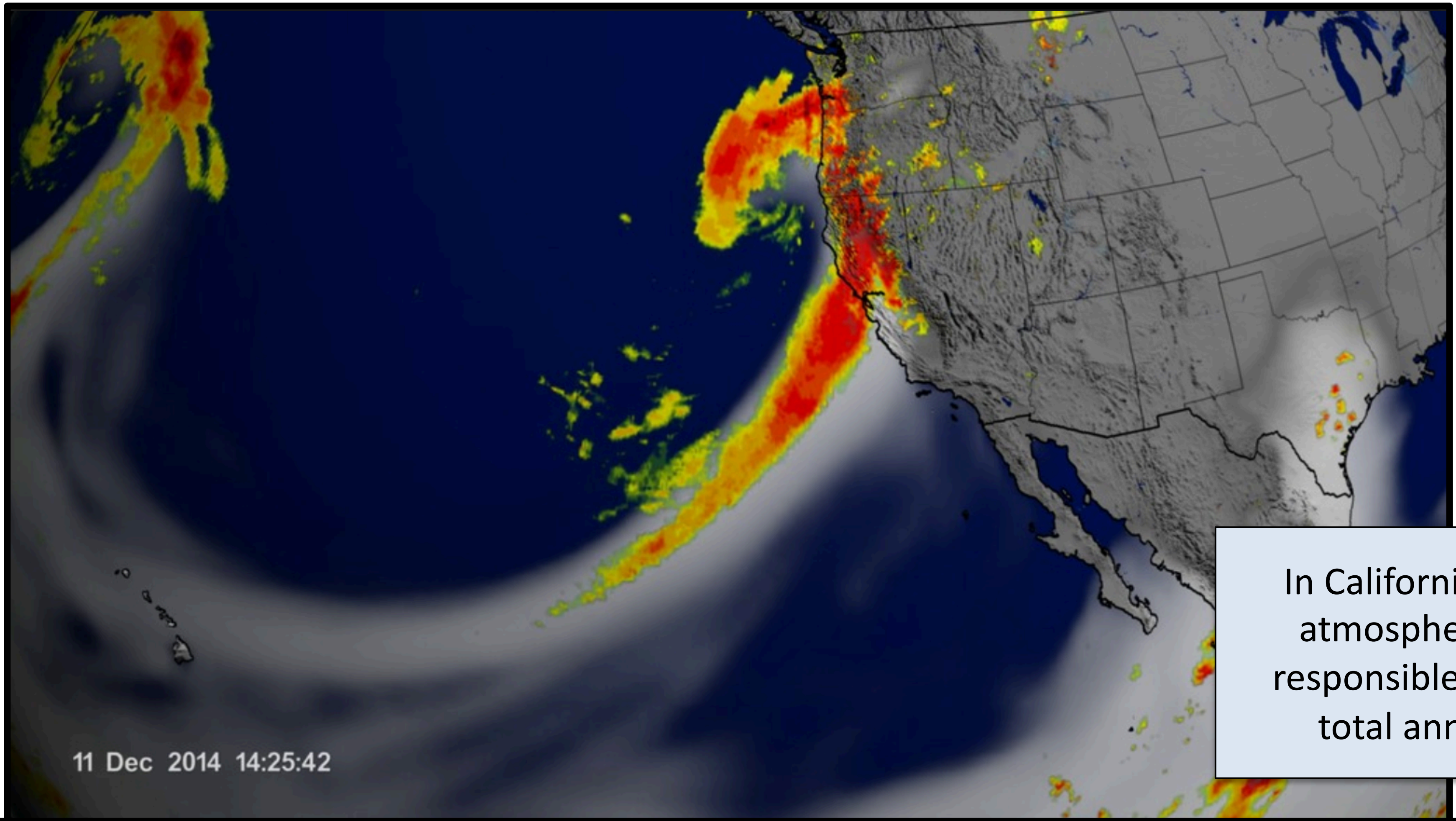
Almost all precipitation comes in the winter months, particularly December, January, and February.

Most precipitation falls in the Sierra Nevada mountains, and is driven by orographic uplift.



California Climate

Most big precipitation events come in the form of **Atmospheric Rivers**.



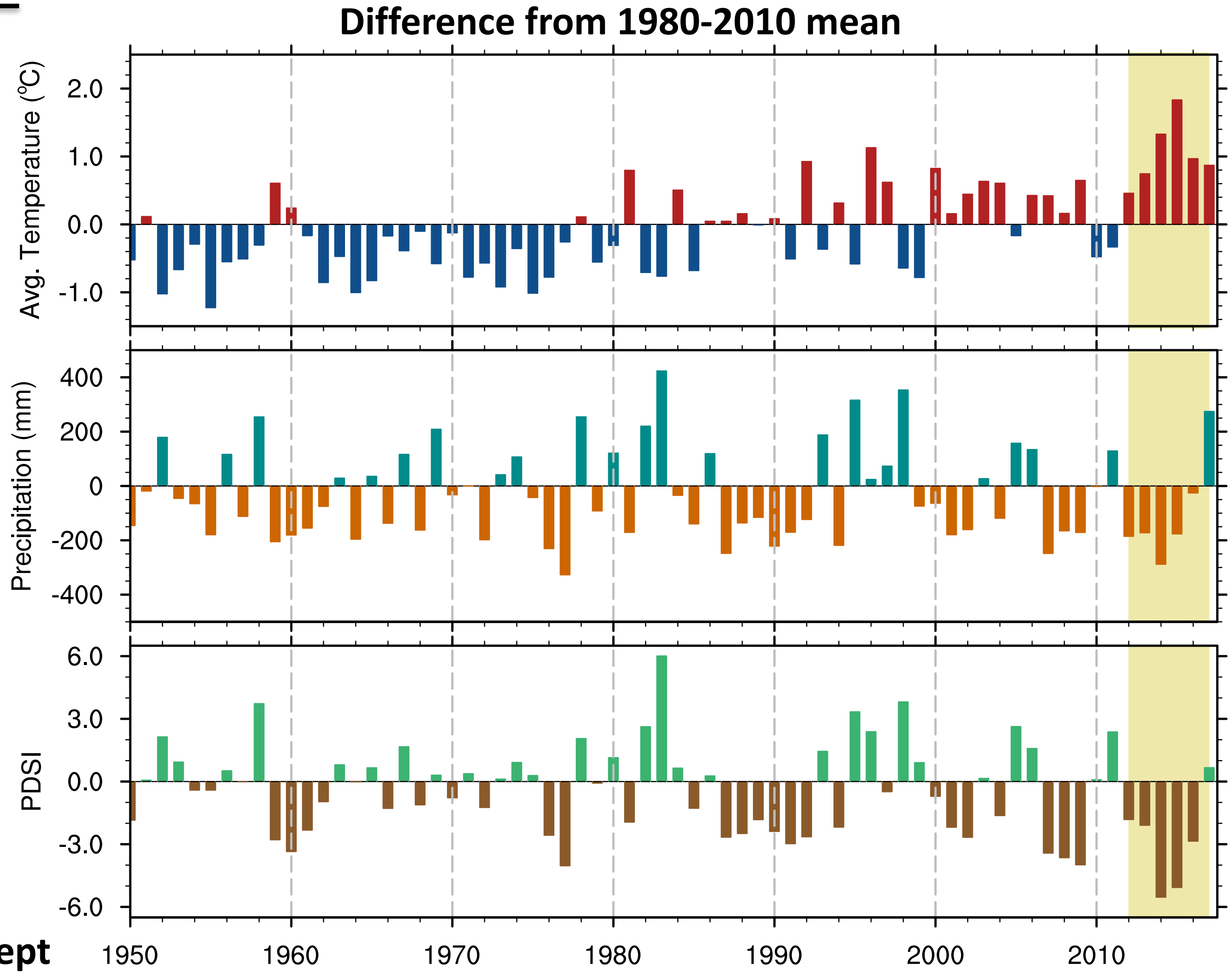
In California, wintertime atmospheric rivers are responsible for 30-40% of total annual rainfall.

2012-2016 California Drought

Persistently dry conditions were experienced by California over this period, finally broken up by the anomalously wet winter of 2016-2017.

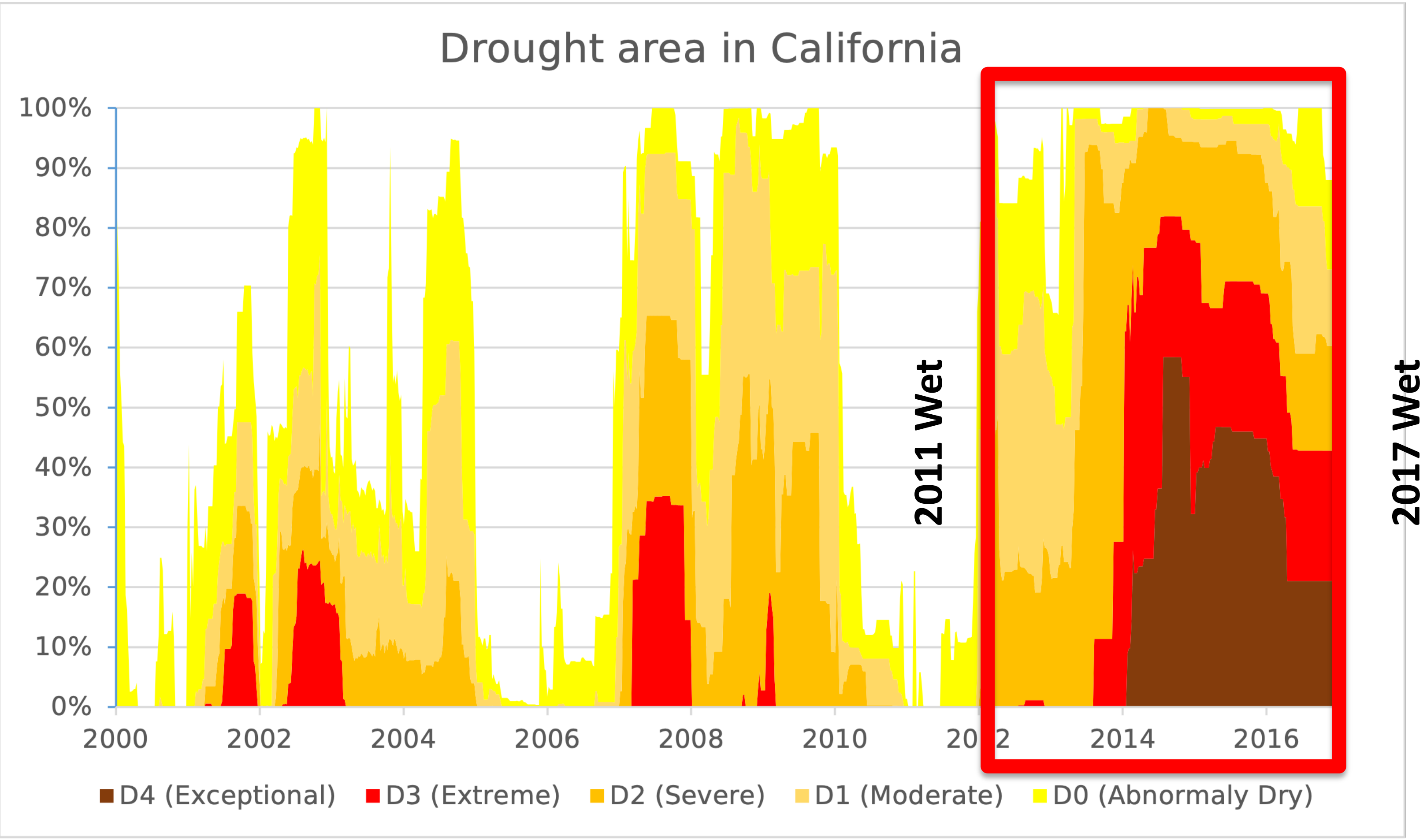
As of October 2016, California had an accumulated **“rain debt”** equal to **one year of average precipitation**.

California's Climate History



Water Year Oct-Sept

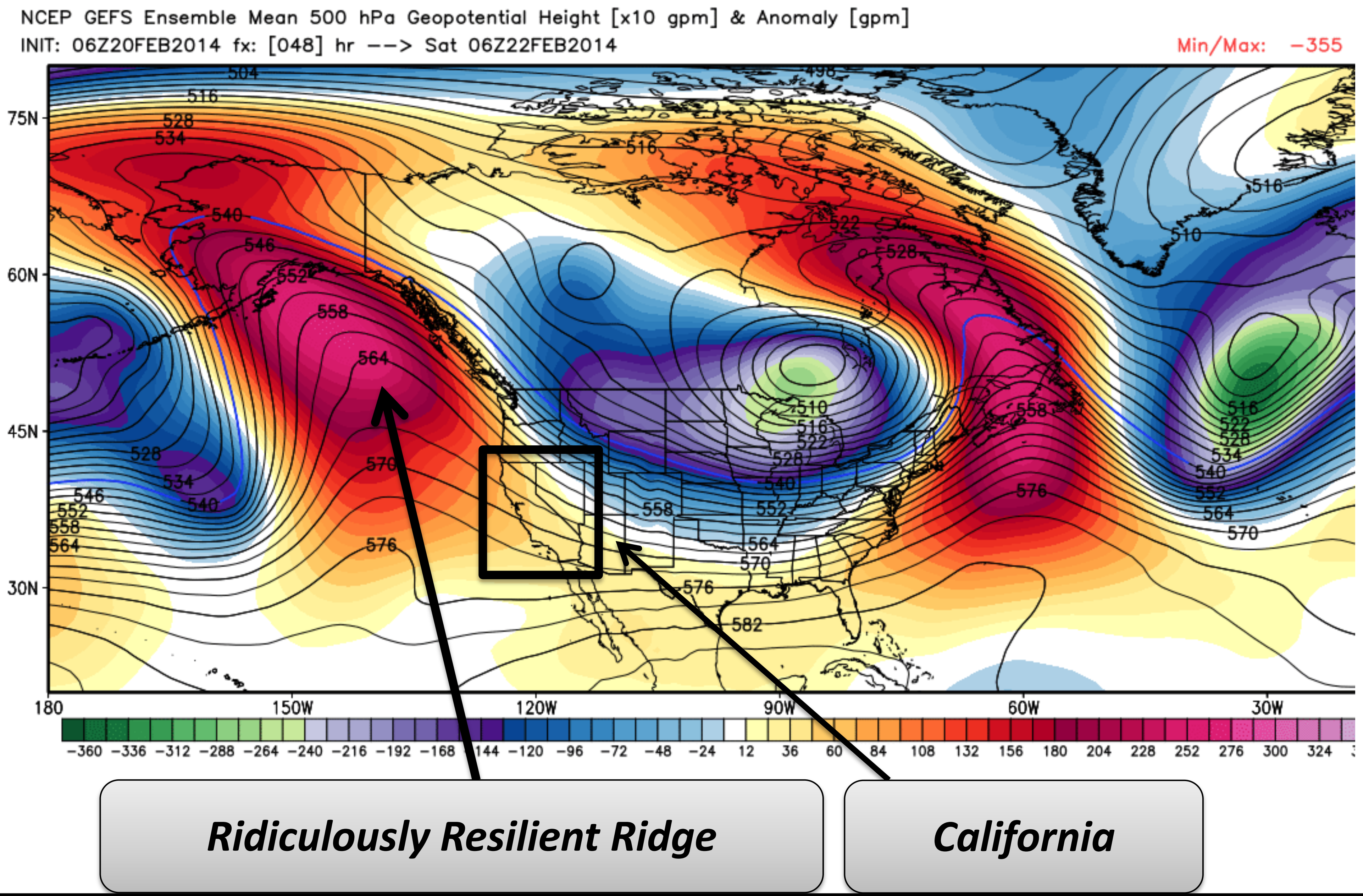
California's Climate History

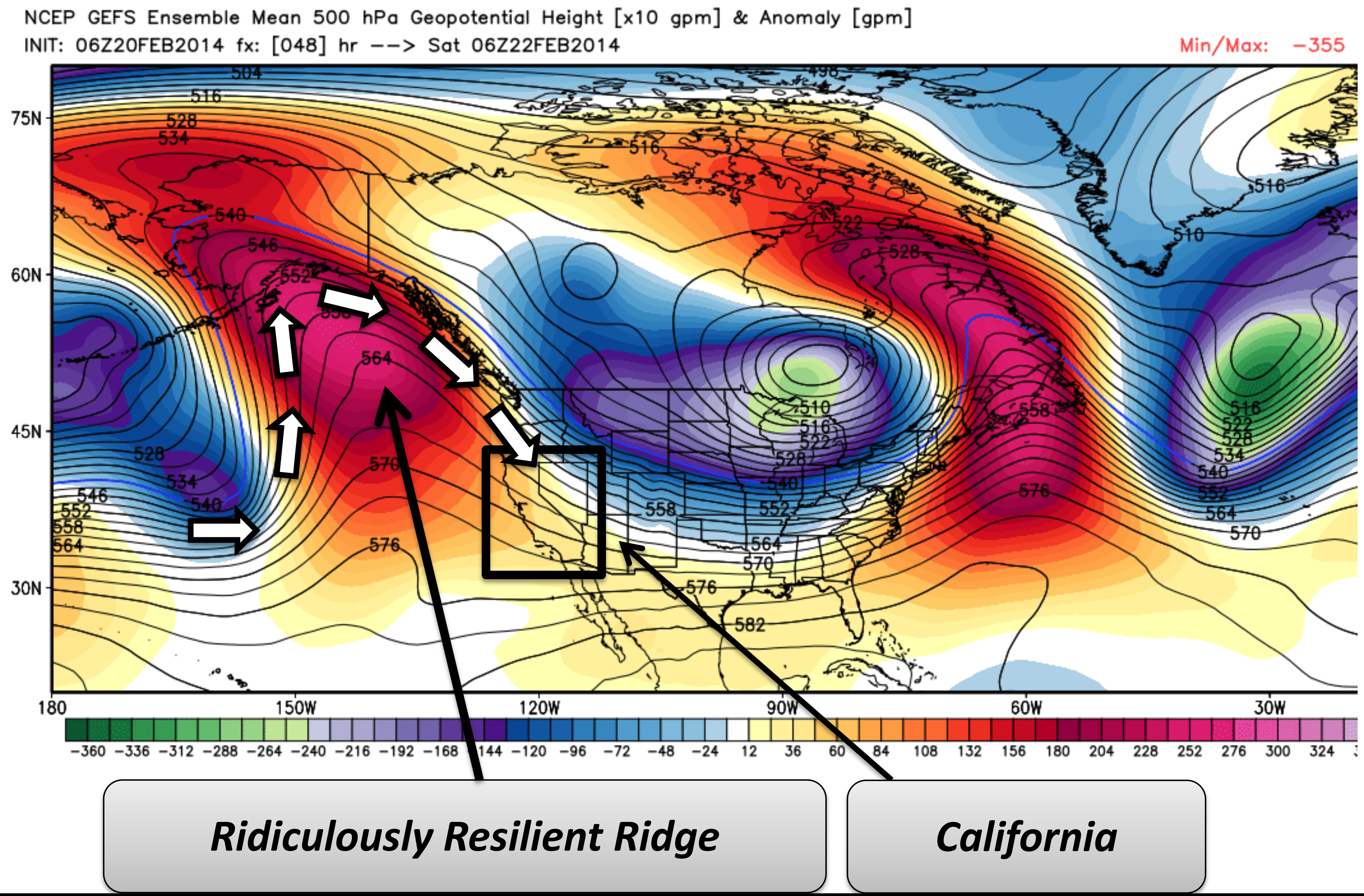


Three Key Drought Years

Key point: All drought years have a unique "character"

- **2013-2014:** Rain drought due to atmospheric ridging.
- **2014-2015:** Snow drought due to high temperatures.
- **2015-2016:** Drought due to shift in storm track.
- **2016-2017:** The drought-buster.


NCEP GEFS Ensemble Mean 500 hPa Geopotential Height [x10 gpm] & Anomaly [gpm]
INIT: 06Z20FEB2014 fx: [048] hr --> Sat 06Z22FEB2014
Min/Max: −355
75N
60N
45N
30N
180
150W
120W
90W
60W
30W
−360 −336 −312 −288 −264 −240 −216 −192 −168 −144 −120 −96 −72 −48 −24 12 36 60 84 108 132 156 180 204 228 252 276 300 324
Ridiculously Resilient Ridge
California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Ridiculously Resilient Ridge
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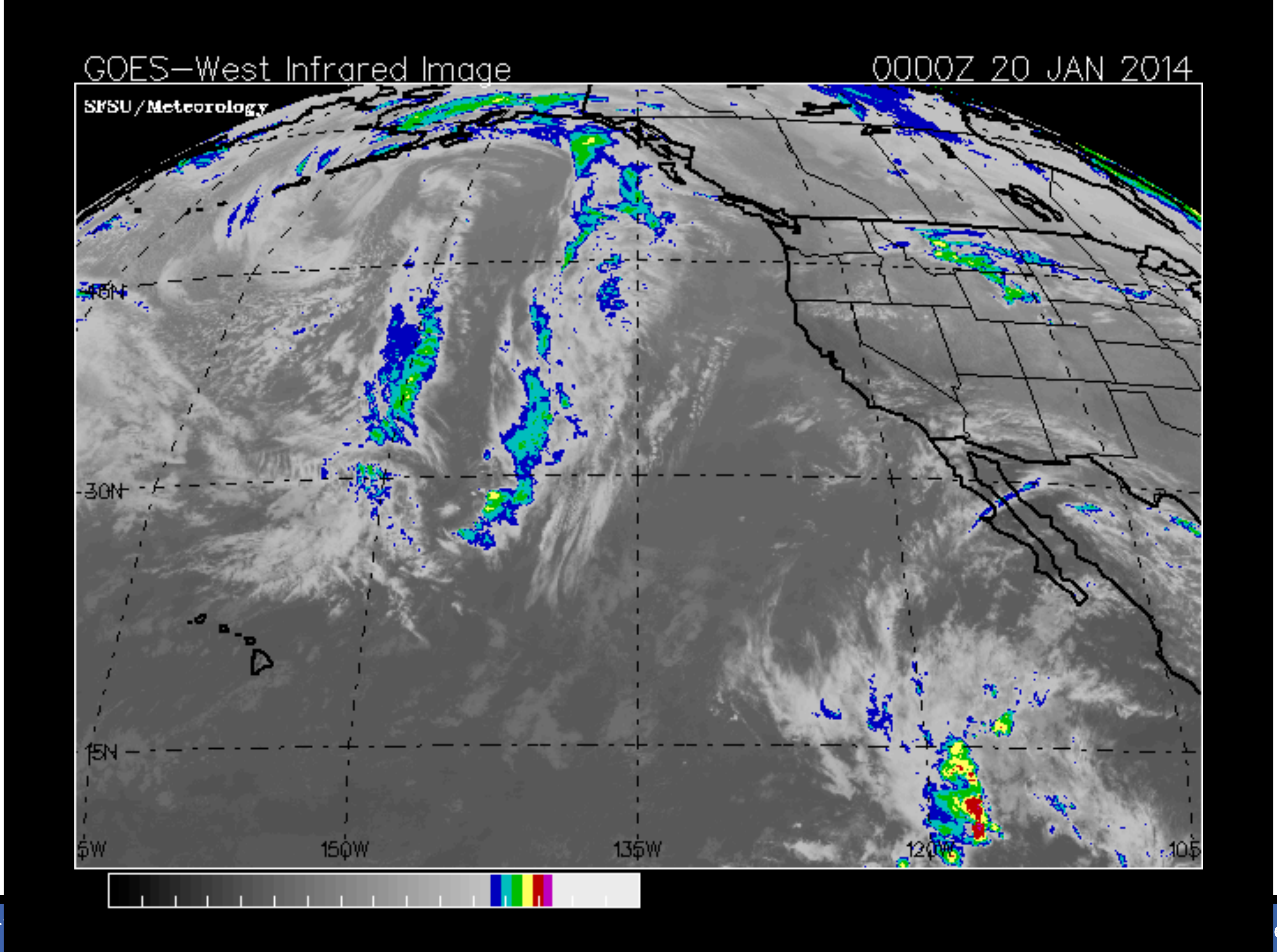
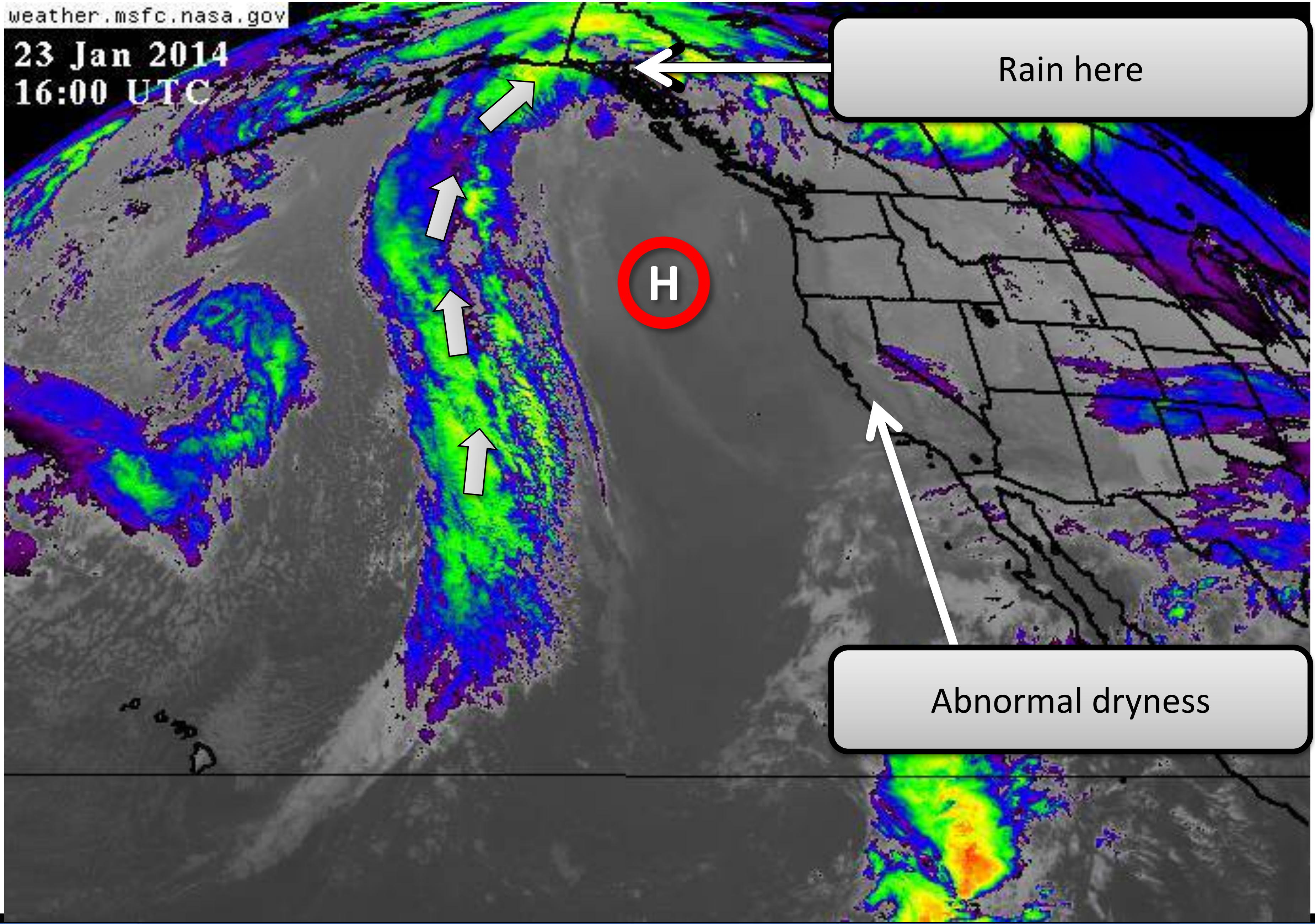
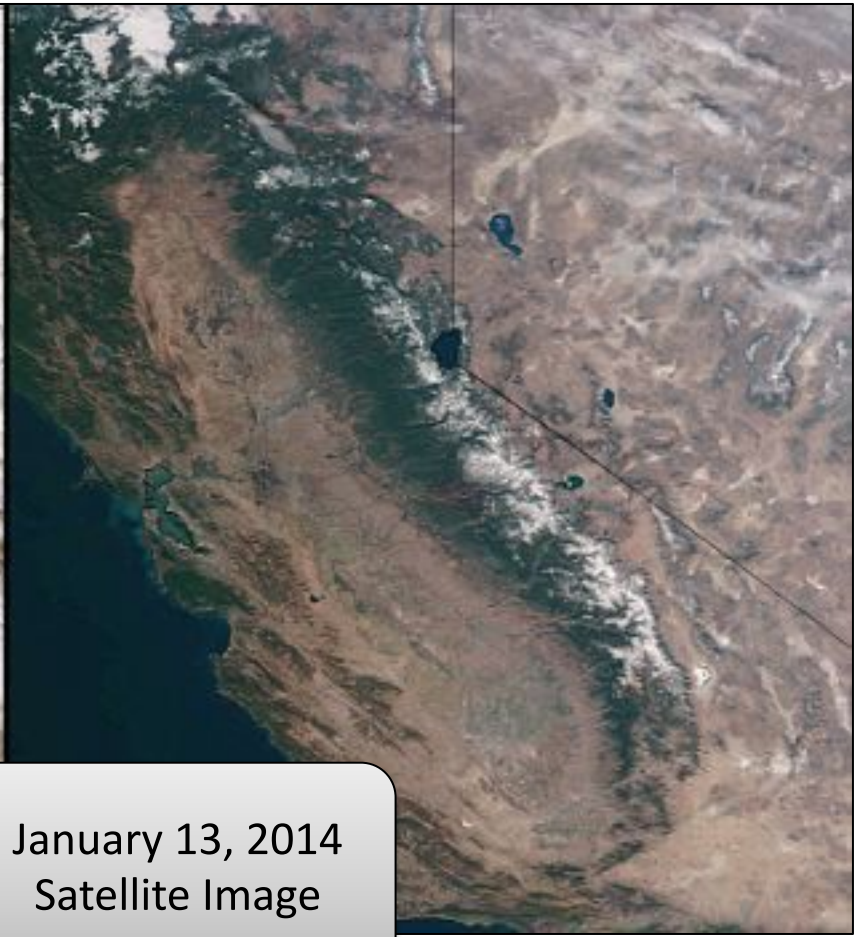

GOES–West Infrared Image
0000Z 20 JAN 2014
SFSU/Meteorology
45N
30N
15N
150W
135W
120W


weather.msfc.nasa.gov
23 Jan 2014
16:00 UTC
Rain here
H
Abnormal dryness

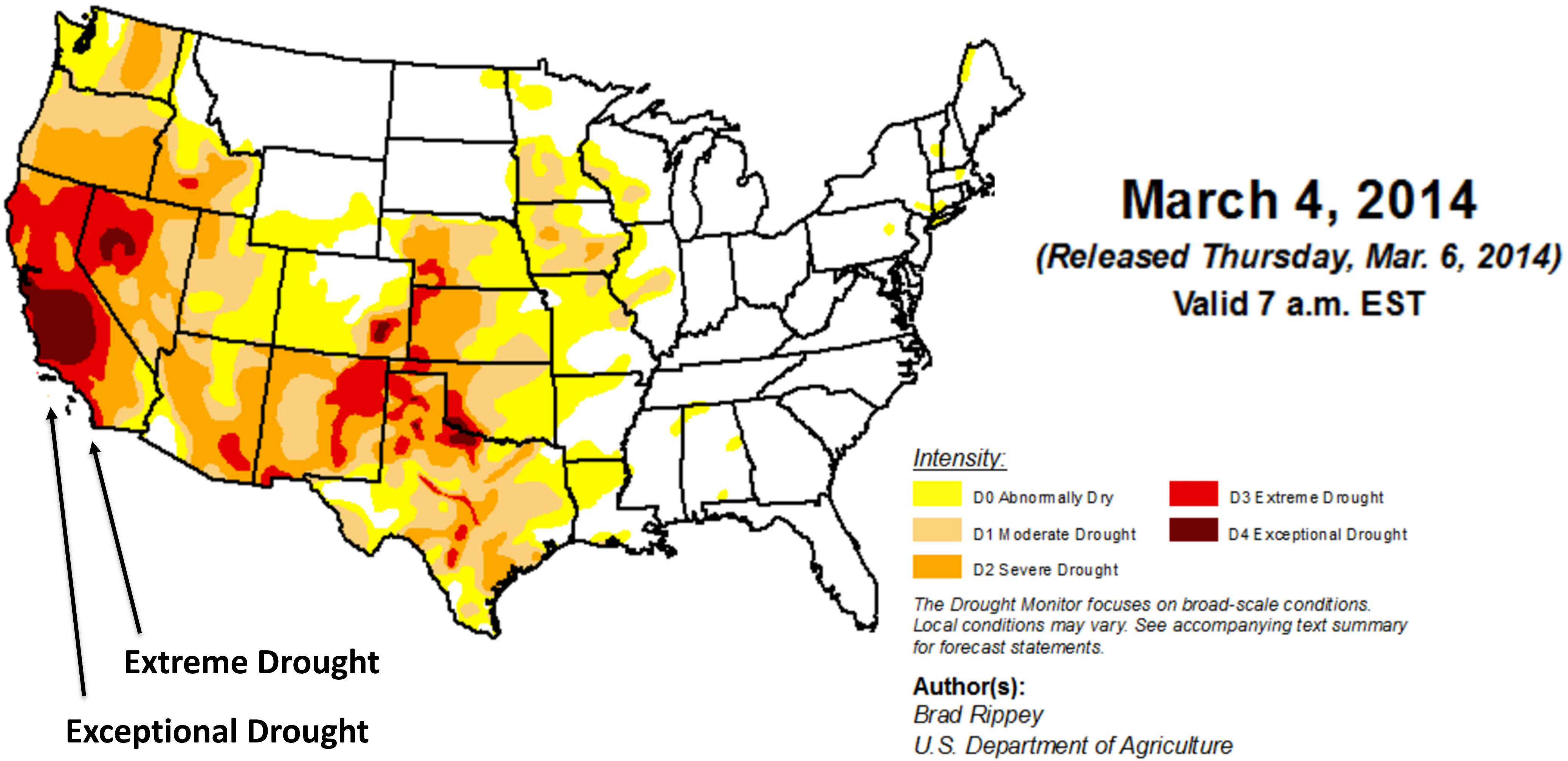
Mountain Snowpack

January 13, 2013
Satellite Image

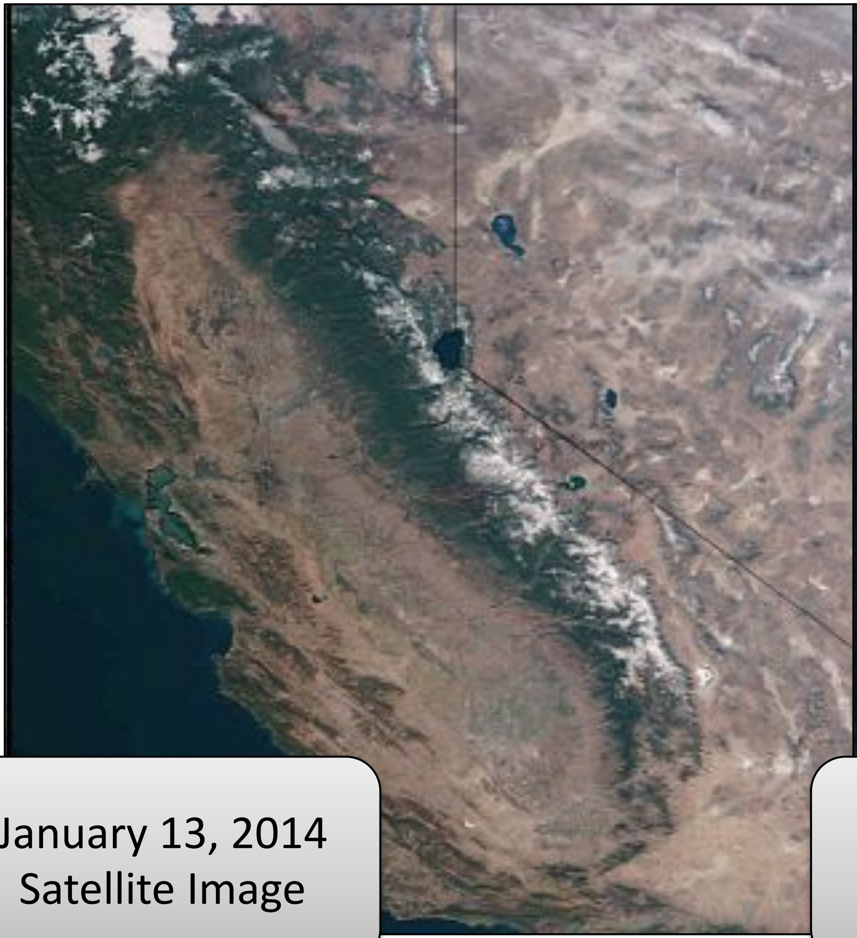


January 13, 2014
Satellite Image

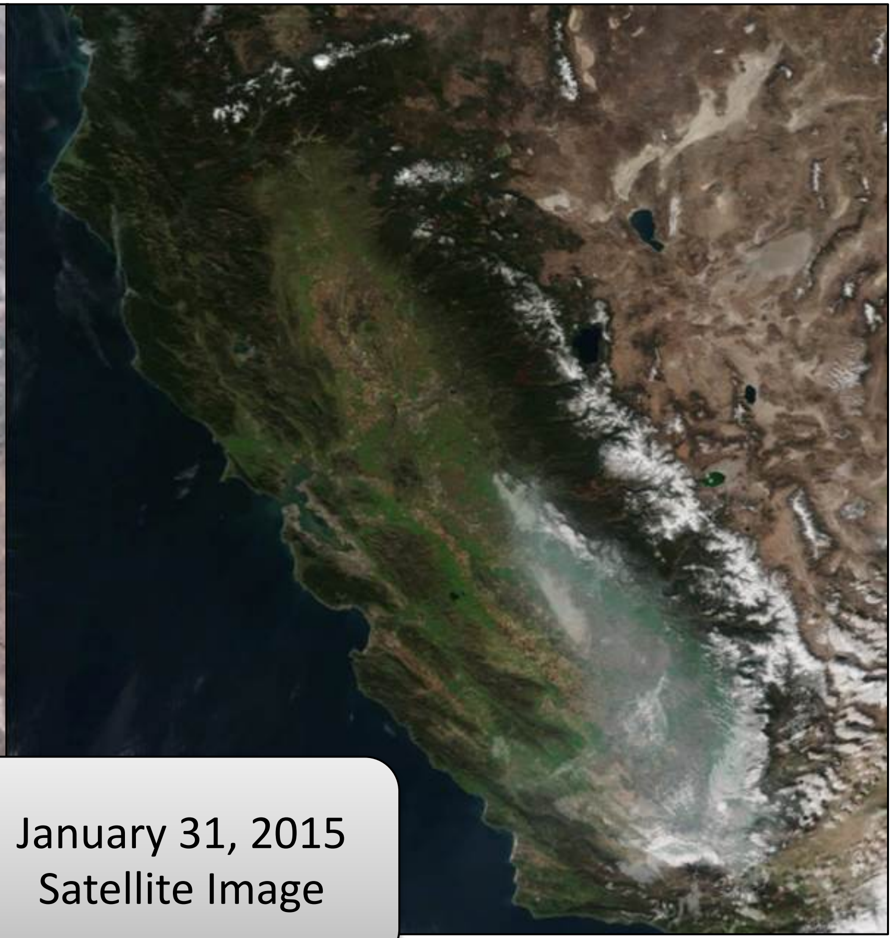
U.S. Drought Monitor



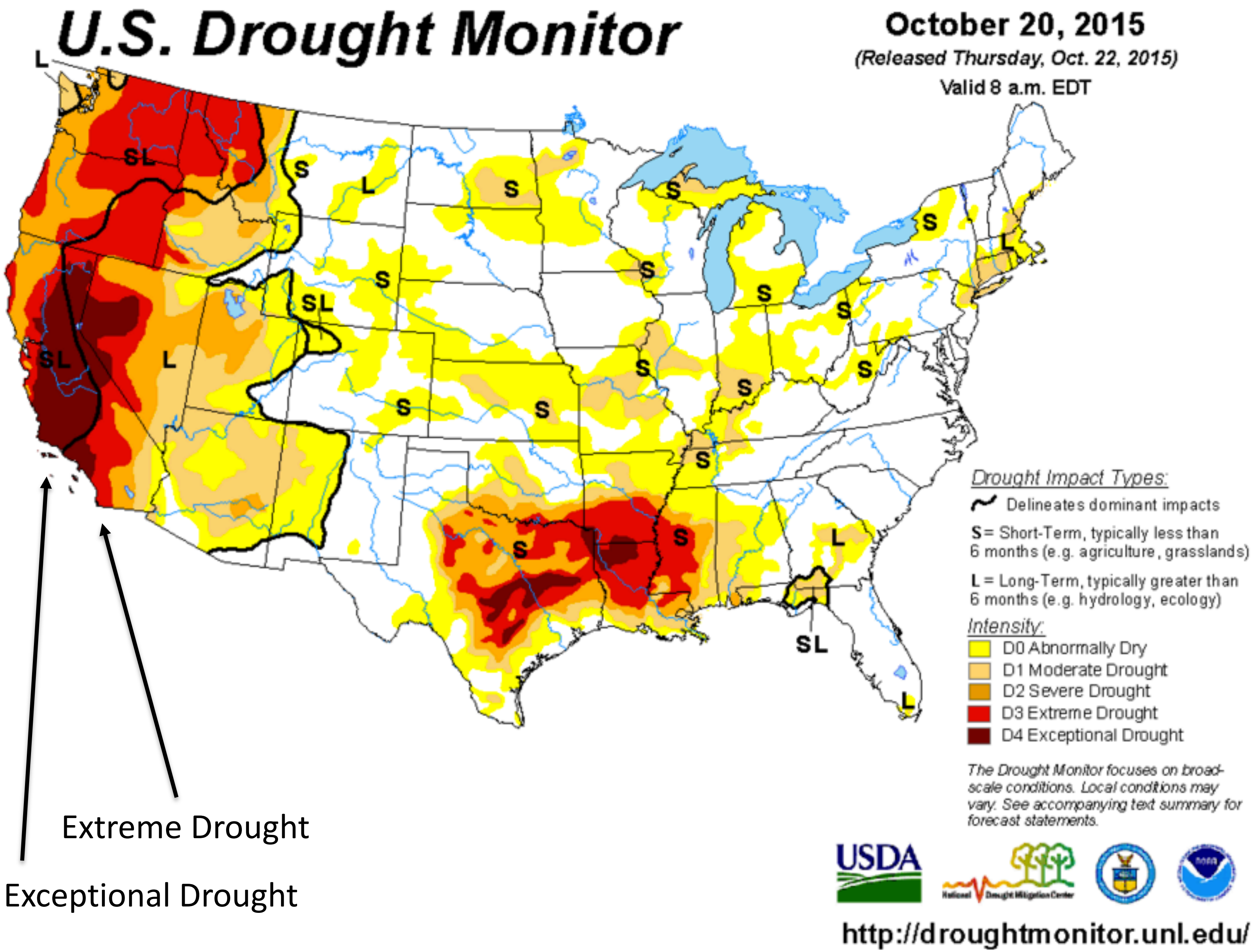
2015 Mountain Snowpack



January 13, 2014
Satellite Image



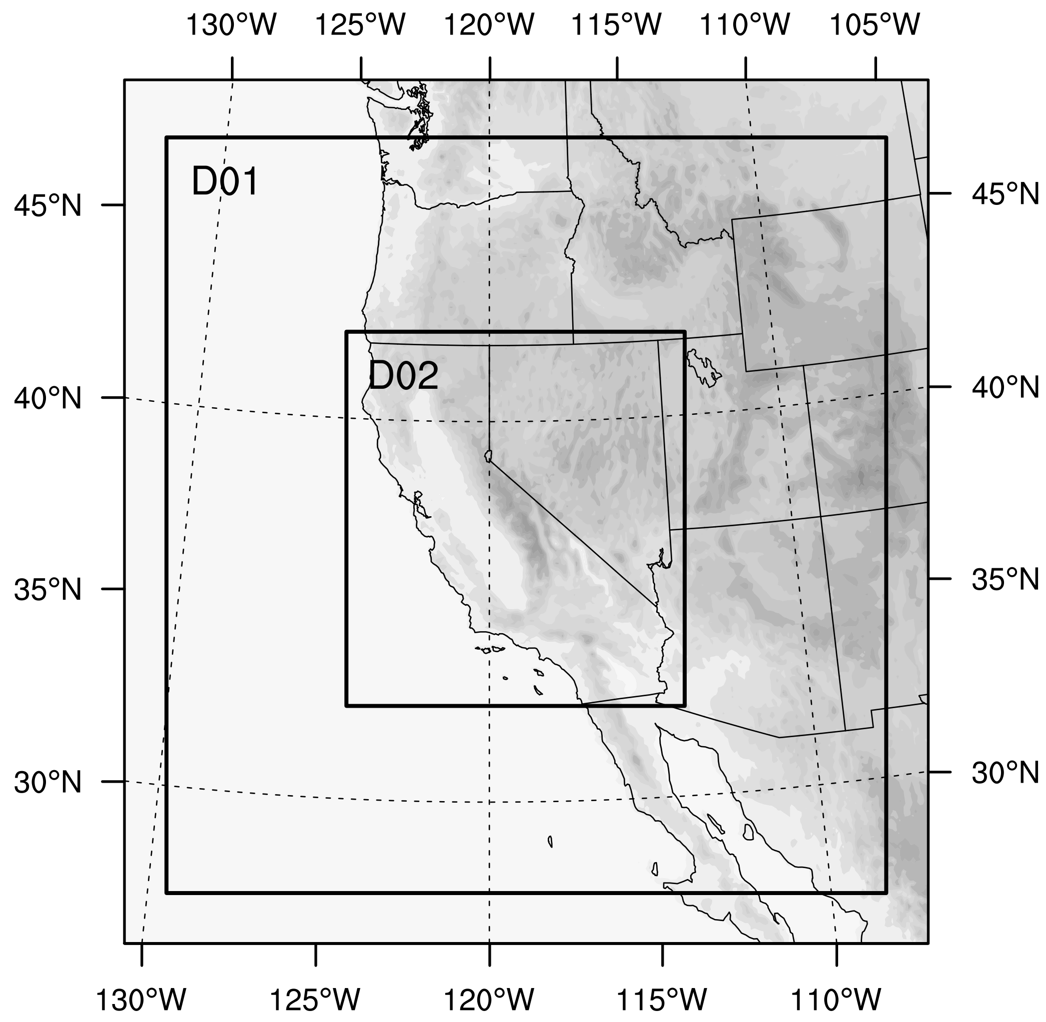
January 31, 2015
Satellite Image



Extreme Drought

Exceptional Drought

Building a Drought of the Future



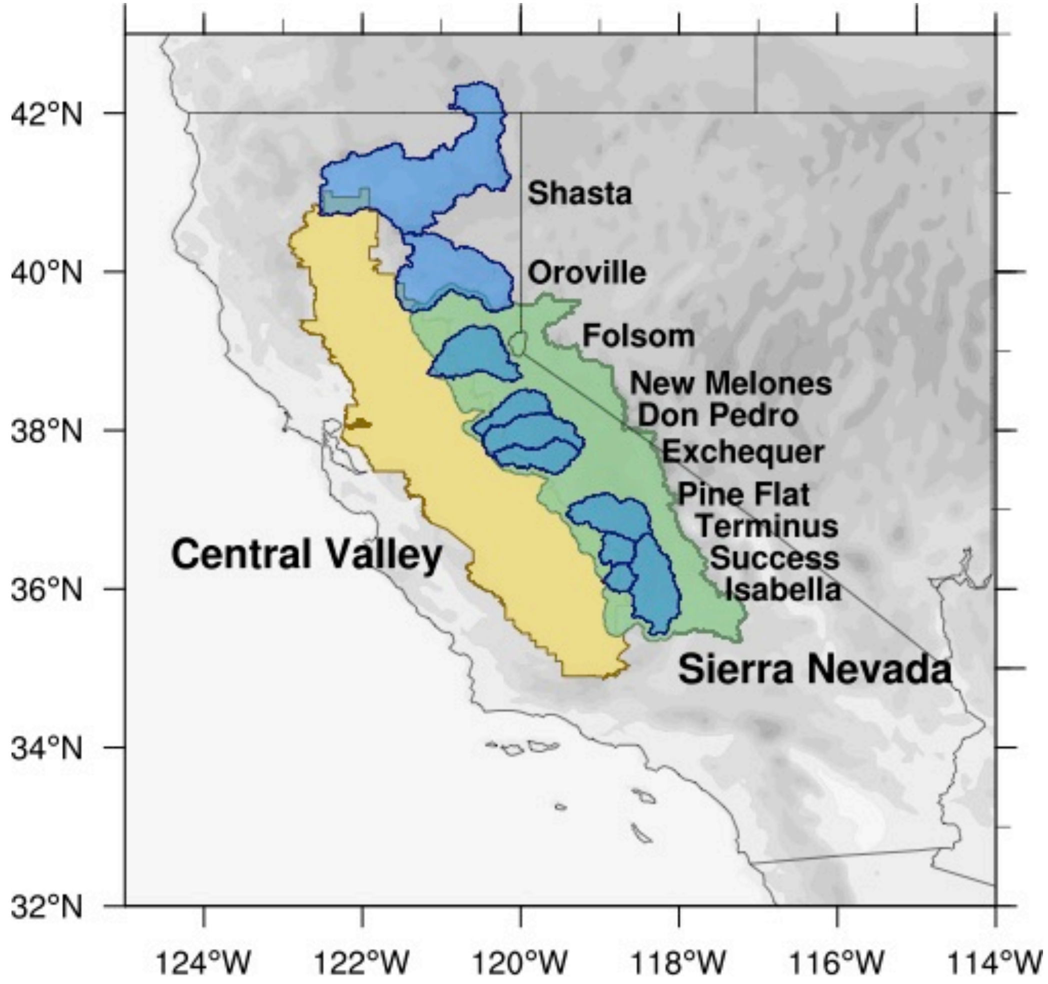
Model: Weather Research and Forecasting (WRF) model with Community Land Model (CLM) land surface.

Domain (Figure): High-resolution (9km) WRF simulation domain in.

Simulation Period:
Historical: 06/01/2012 – 08/31/2017
Projected: 06/01/2042 – 08/31/2047

Historical Conditions: Lateral and sea-surface forcing from historical reanalysis (FNL).

Building a Drought of the Future



Simulation Period:
Historical: 06/01/2012 – 08/31/2017
Future: 06/01/2042 – 08/31/2047

Future Conditions: Boundary temperatures modified with a constant **delta** to match temperature projections from RCP8.5 CMIP5 future simulations. **Sea-surface temperatures** also modified using **delta** approach. **Relative humidity kept constant**. Atmospheric carbon dioxide concentration modified to match future projections.

Building a Drought of the Future

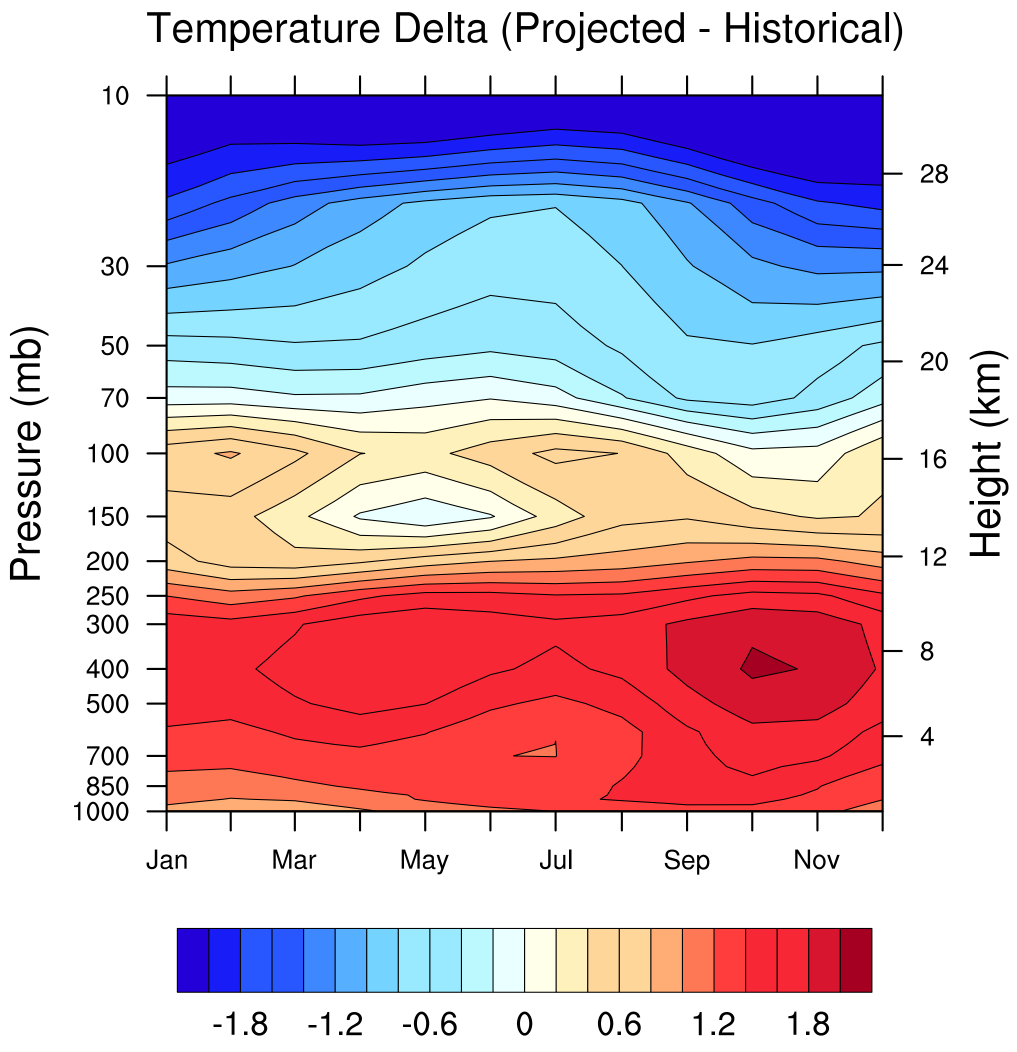
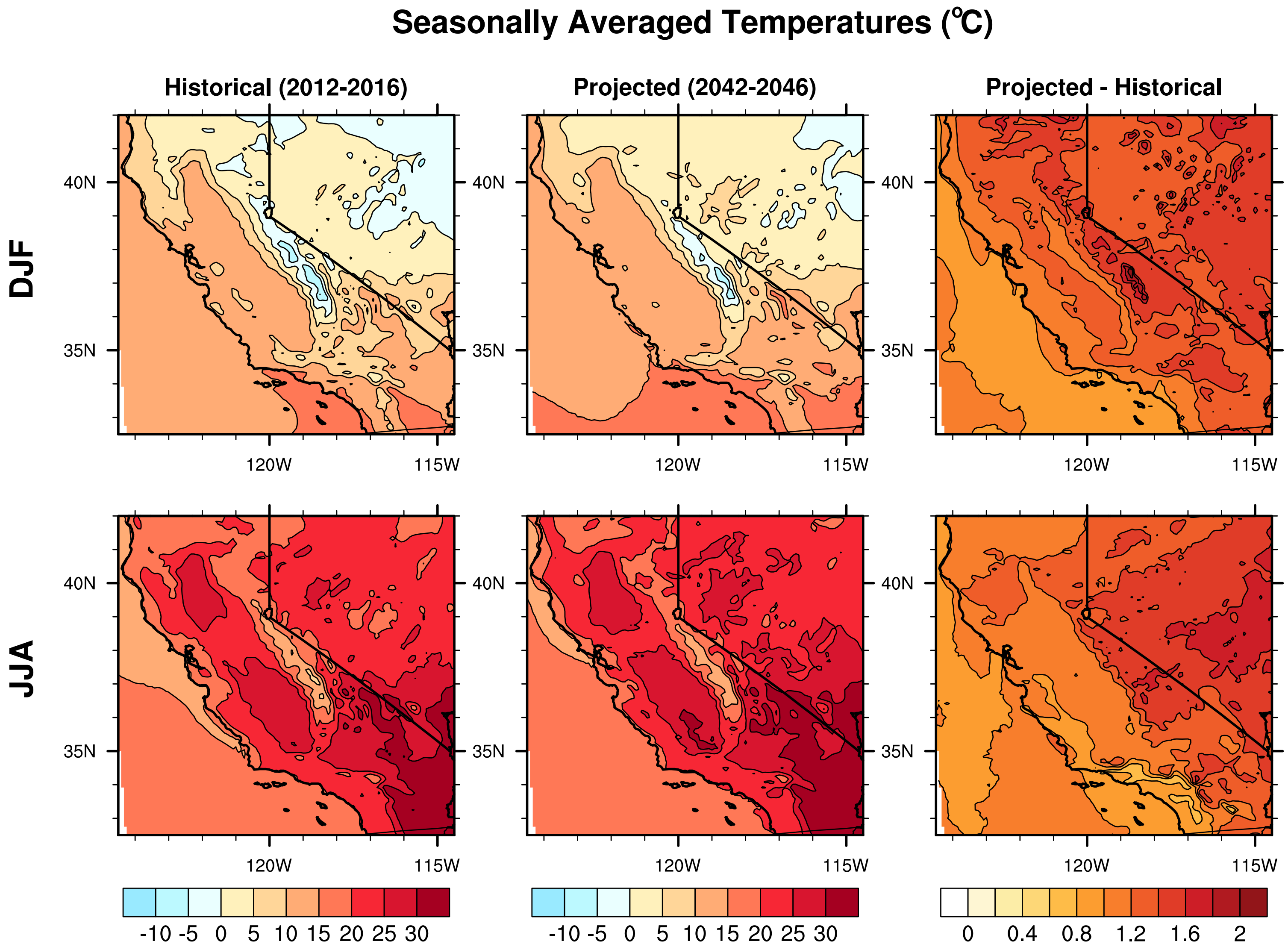


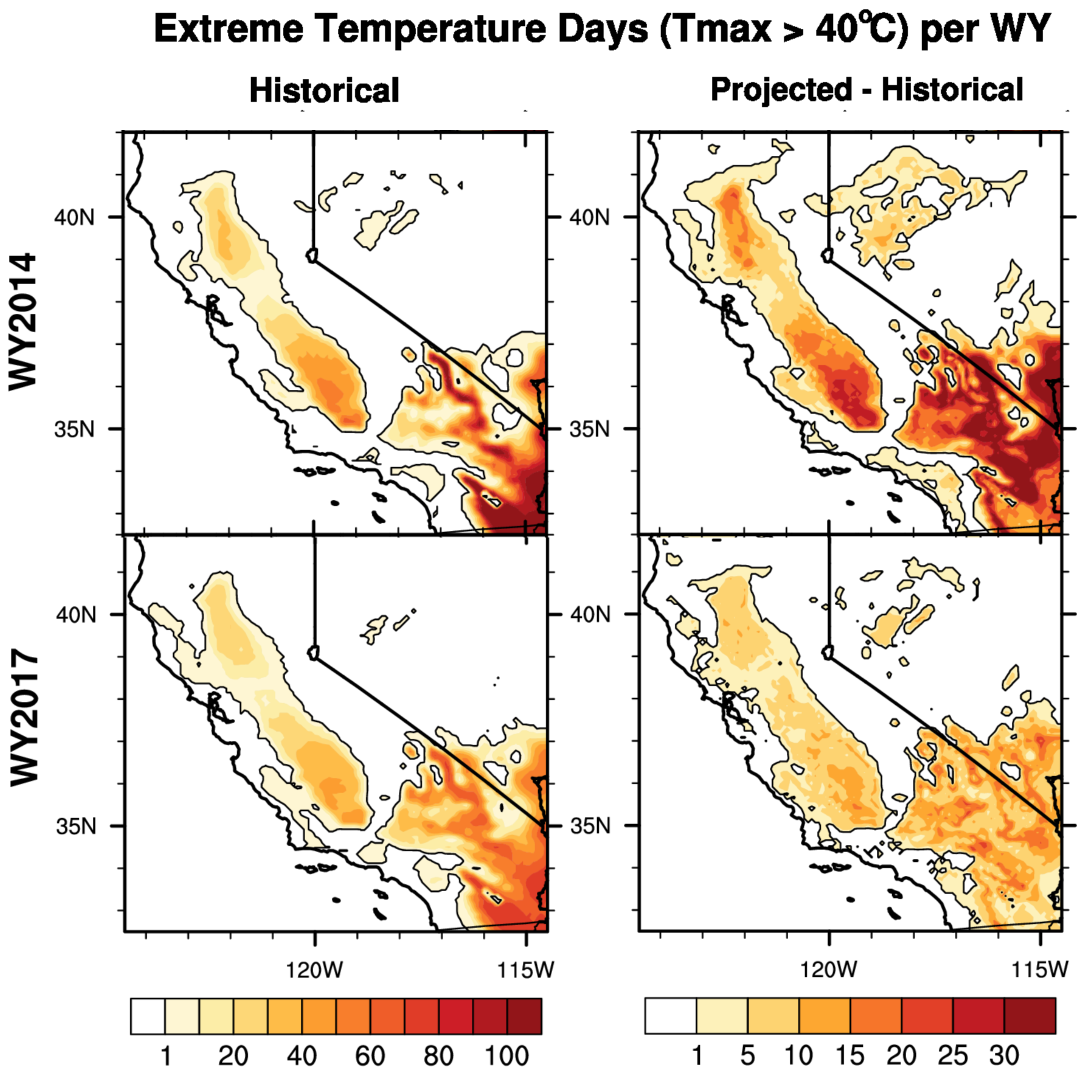
Figure: Temperature difference between 2040s and 2010s from CMIP5 data.

Relative humidity kept fixed in accordance with observations from CMIP5 (overall more water vapor in atmosphere)

Temperature Projections



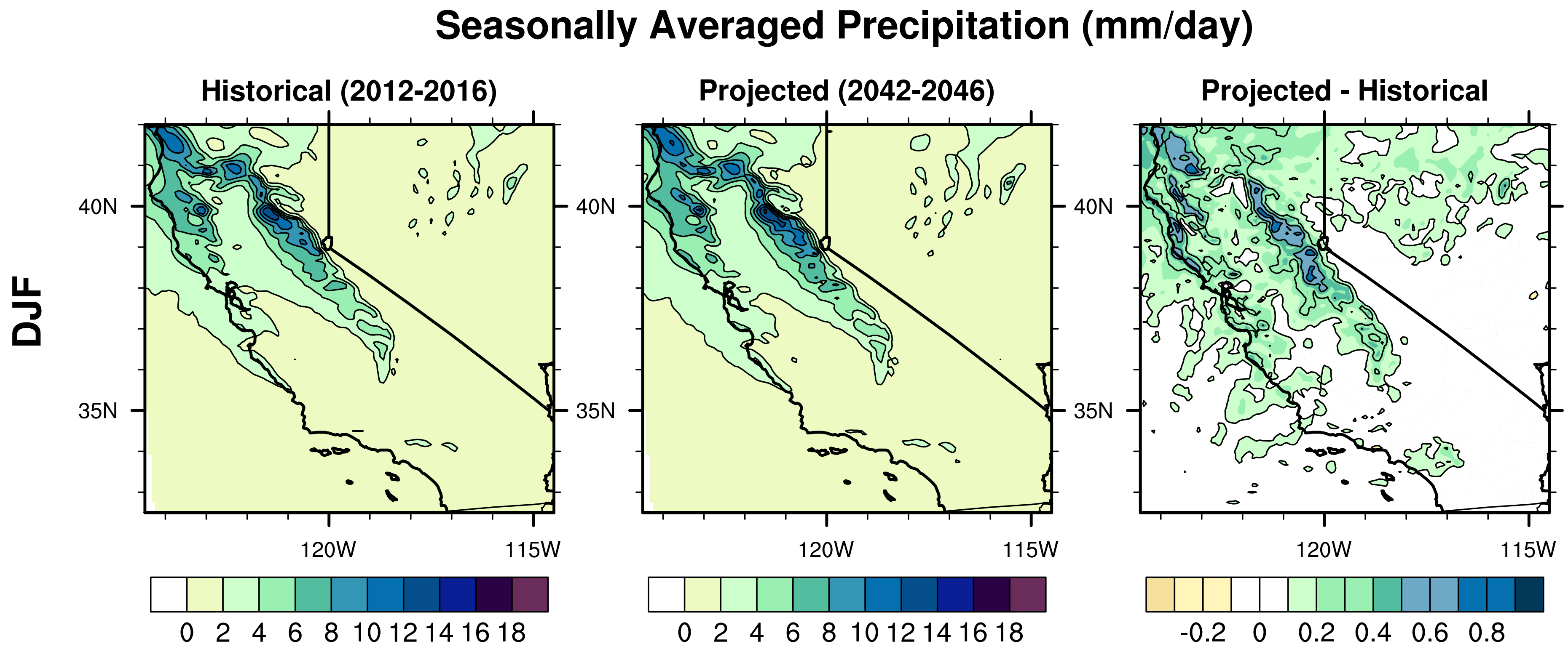
Extreme Temperature Days



Exceptionally Dry Year

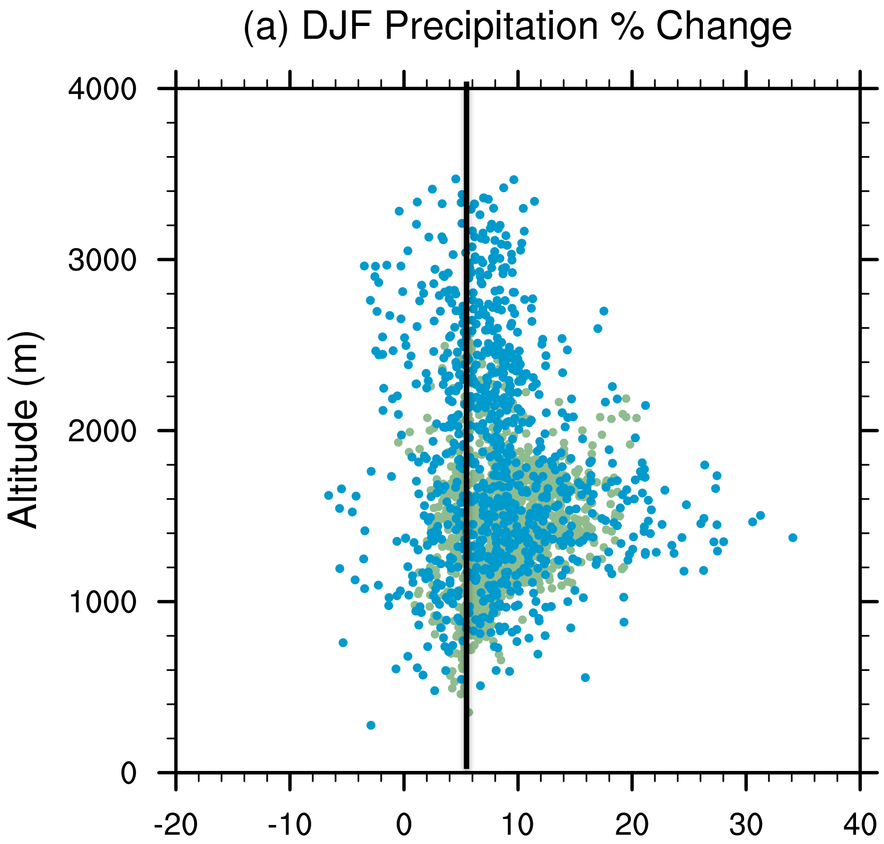
Exceptionally Wet Year

Precipitation Projections



Increase in precipitation in accordance with sub-Clausius-Clapeyron scaling (~5%)

Precipitation Projections



Increase in precipitation in accordance with sub-Clausius-Clapeyron scaling (~5%)

Very little change with altitude.

Precipitation Projections

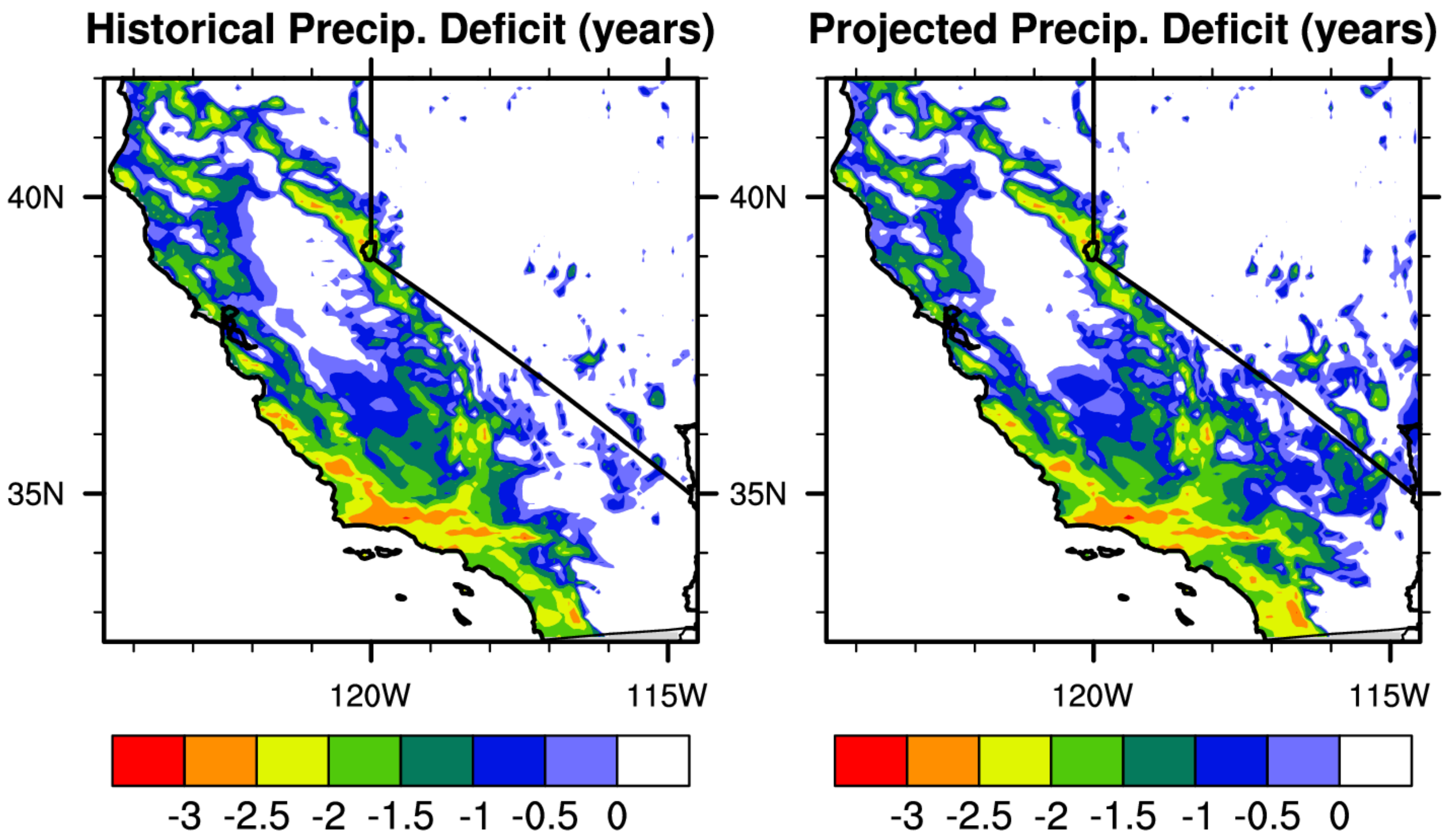
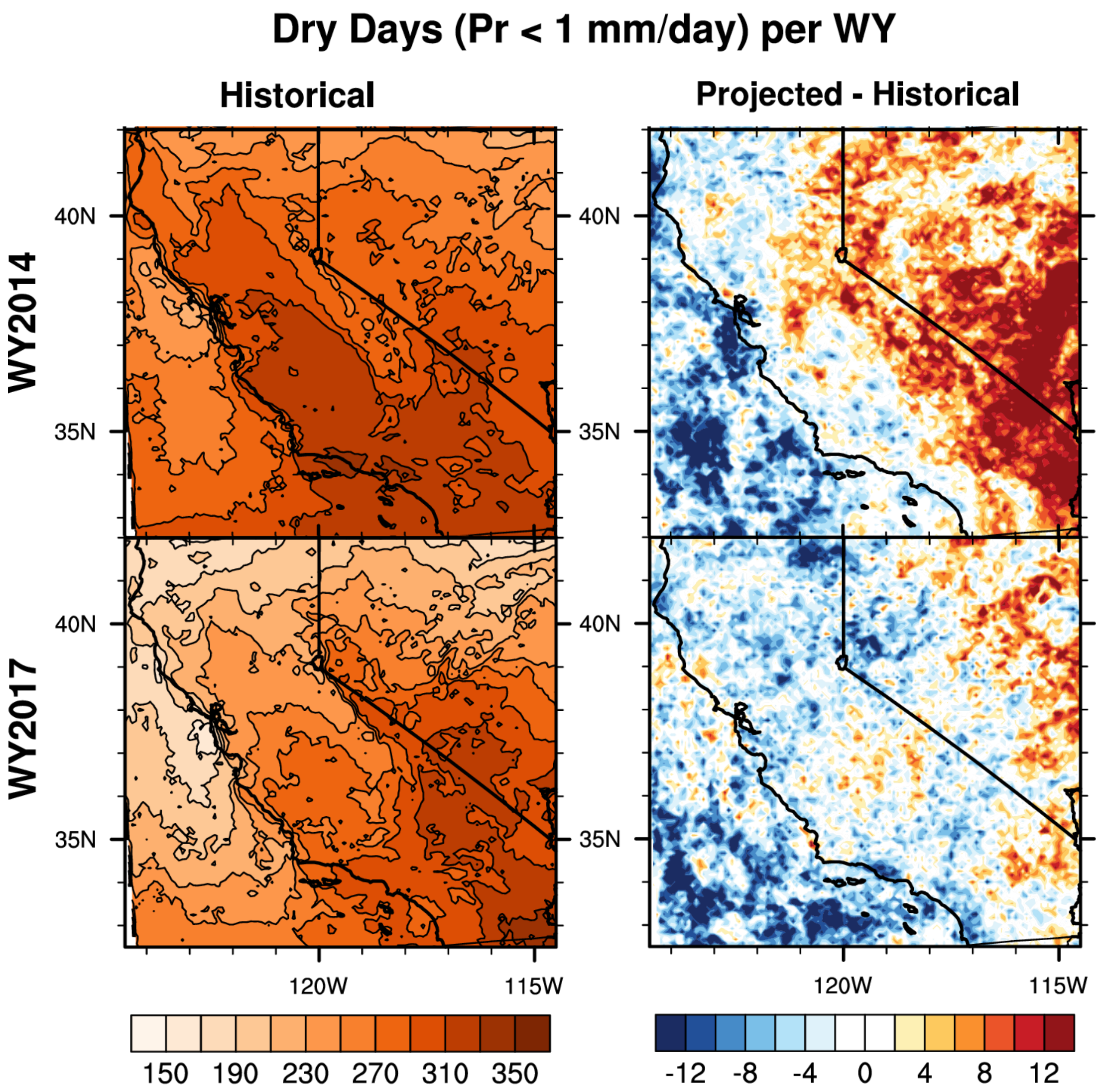


Figure: Overall change in precipitation deficit is small.

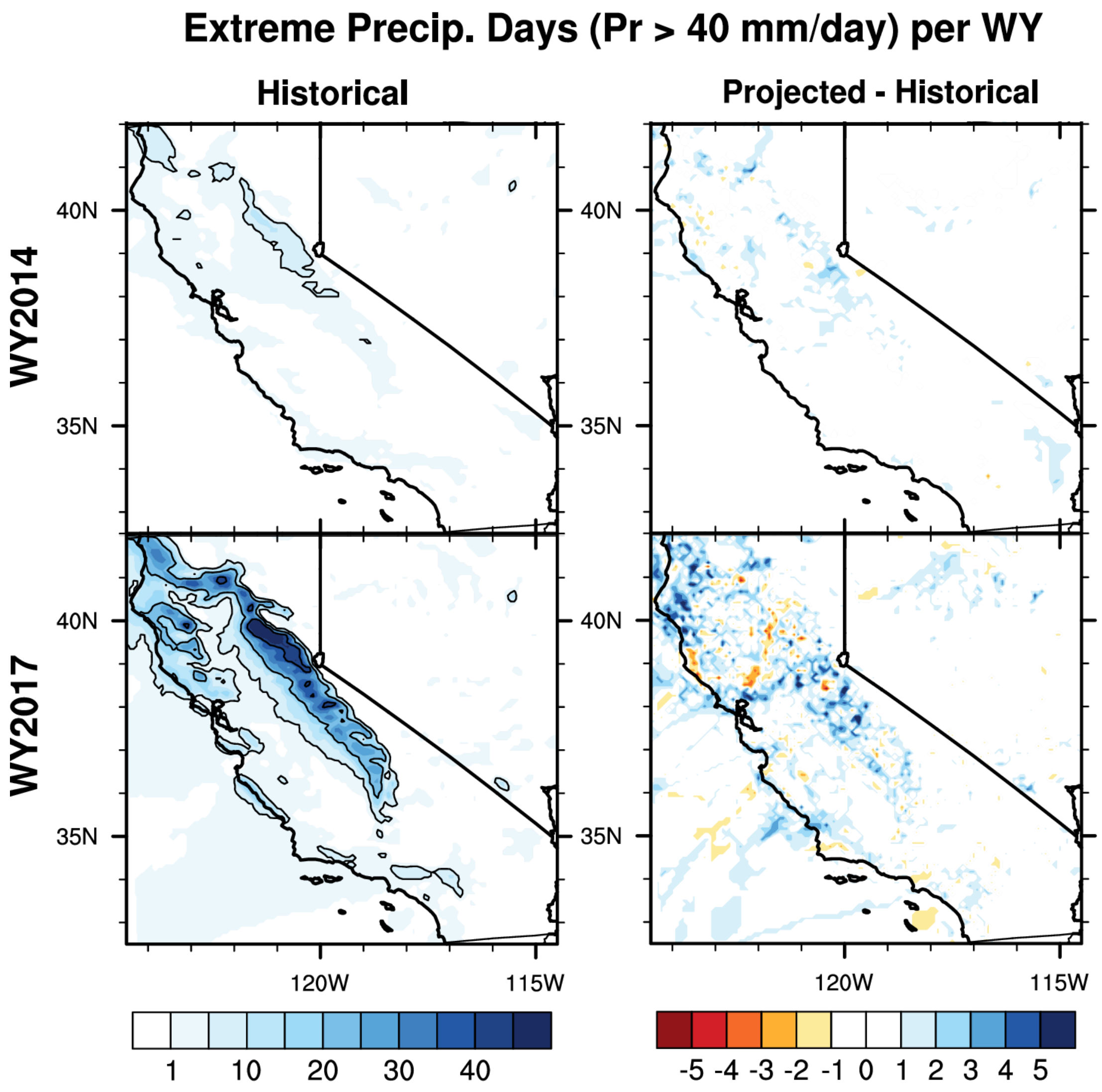
Dry Days



Exceptionally Dry Year

Exceptionally Wet Year

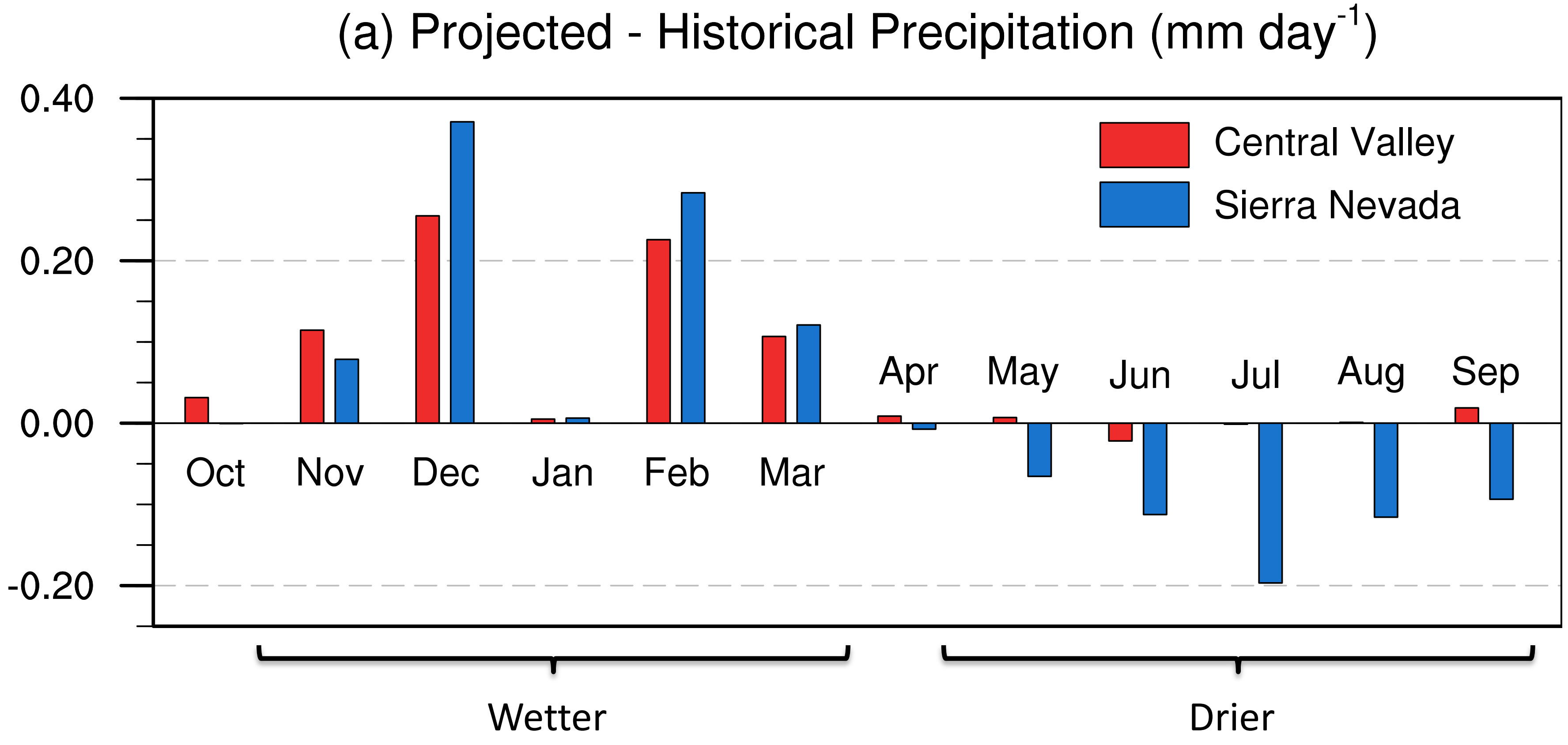
Extreme Precipitation Days



Exceptionally Dry Year

Exceptionally Wet Year

Changing Seasonality

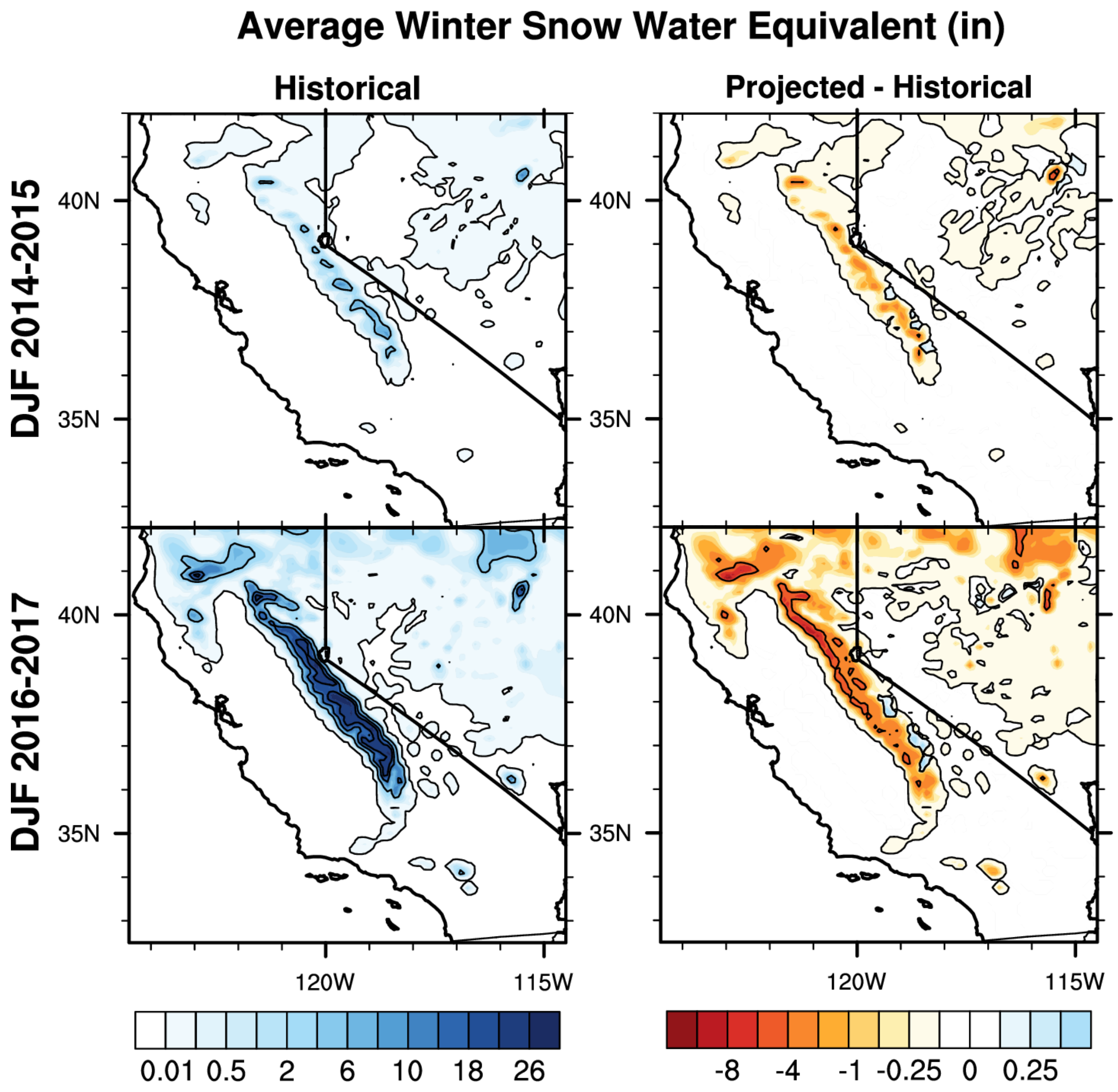


Increased seasonality of precipitation:
Wet winters become wetter, dry summers become drier.

Snowpack

Because of increased temperatures, increased precip. does not translate to increased snowpack.

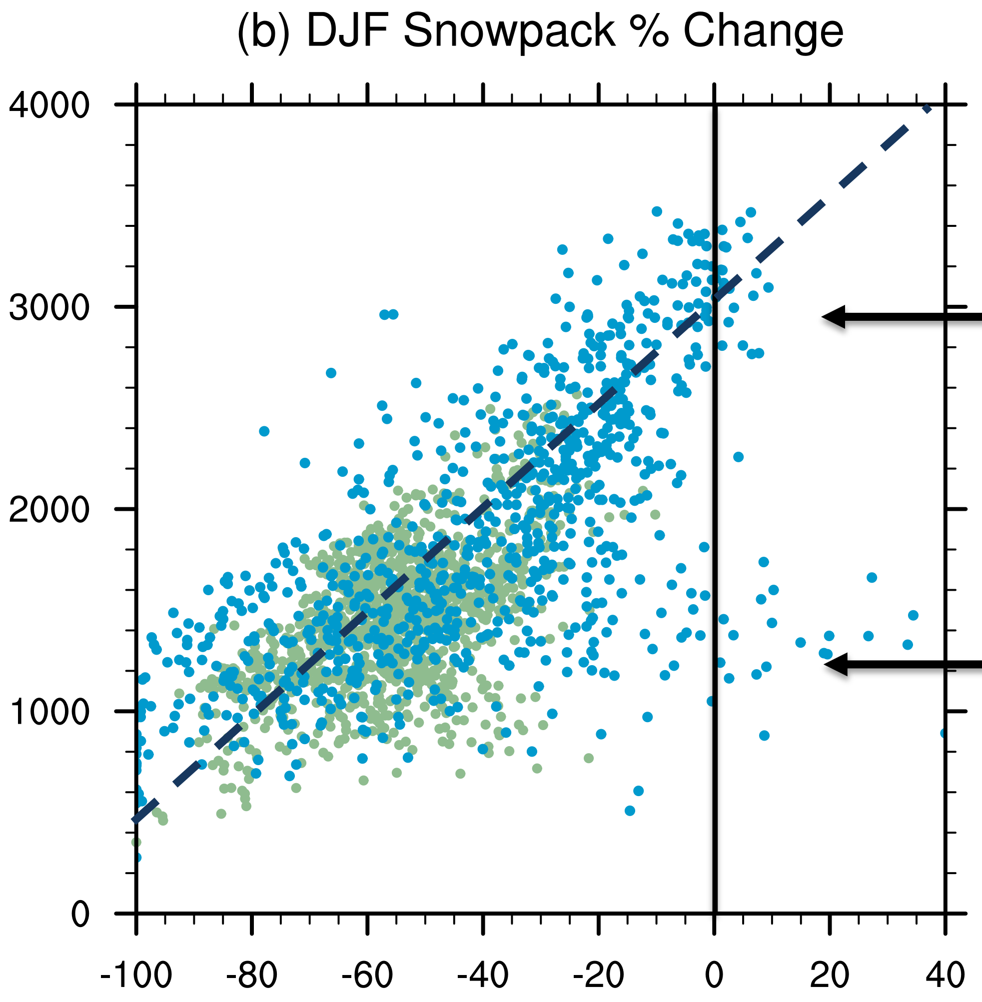
Simulated peak total **snow water equivalent (SWE)** diminished between 16% to 30% across the five water years from 32.6 MAF to 25.5 MAF, a net loss of 7.1 MAF or 22%.



Dry Year

Snowy Year

Peak SWE / Snow Season Length

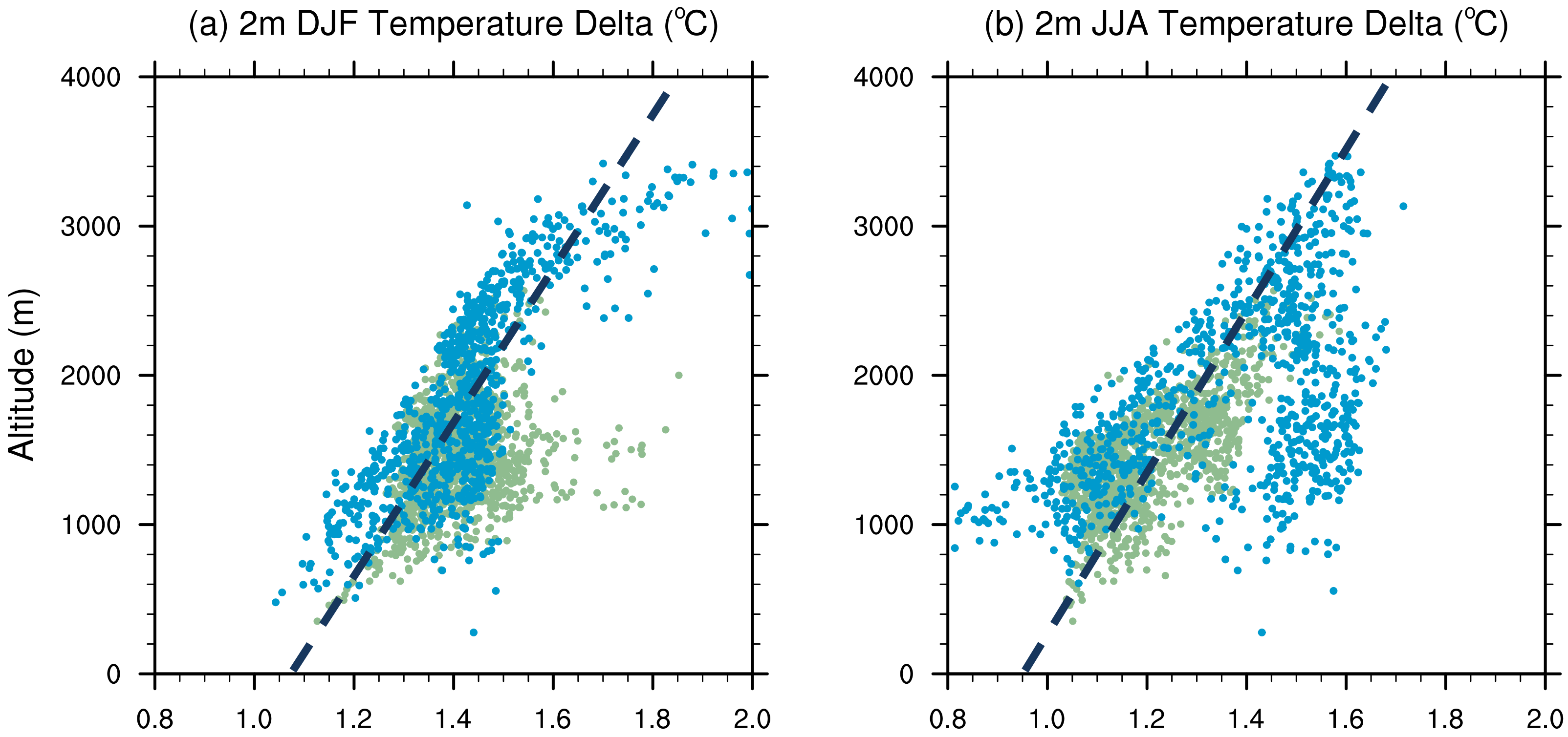


Most snowpack retained at higher altitudes.

Most snowpack lost at lower altitudes.

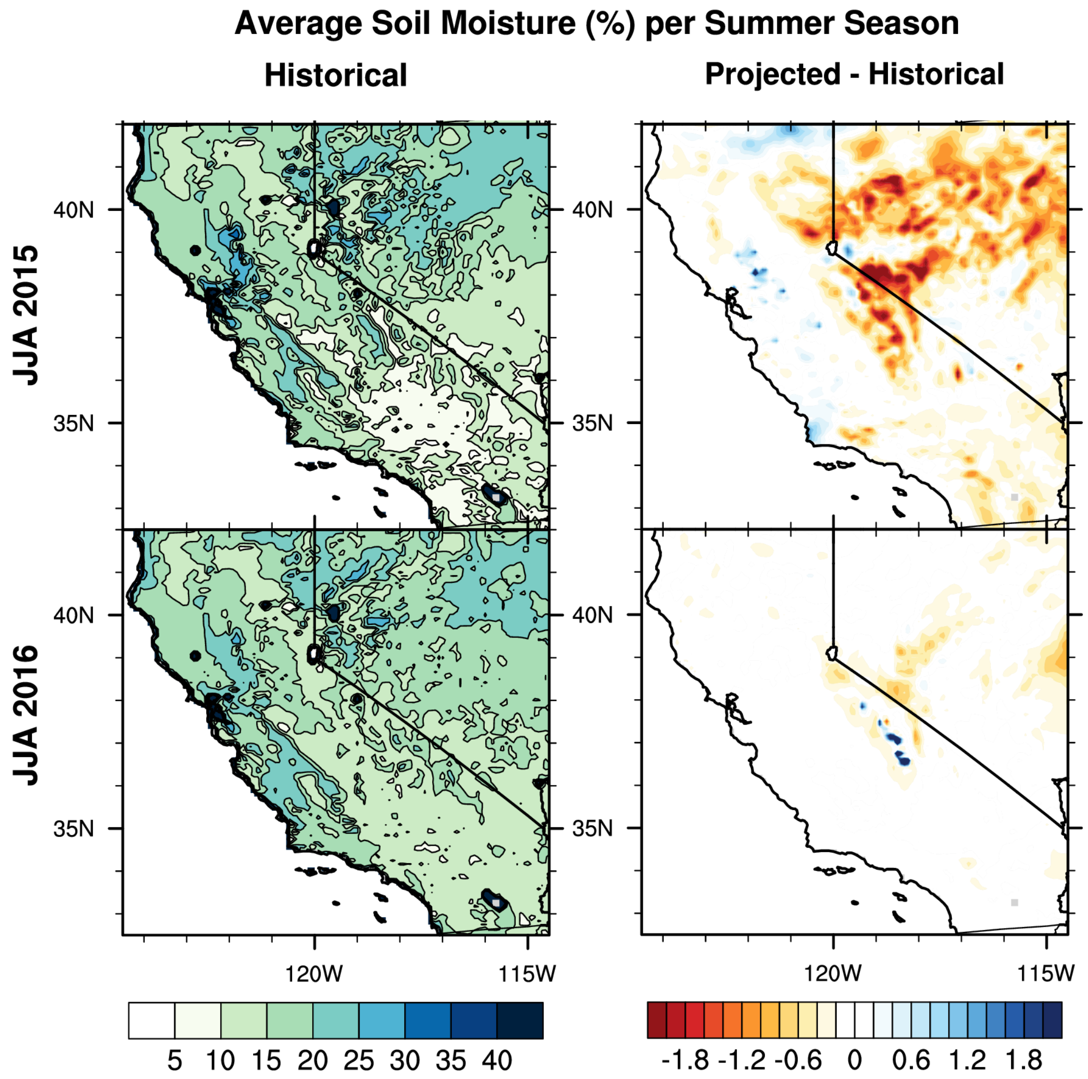
Result: Rising temperatures more strongly impacts lower-altitude snowpack.

Elevation-Dependent Warming



Result: Loss of snowpack leads to elevation-dependent enhancement of temperature signal in DJF and JJA.

Soil Moisture

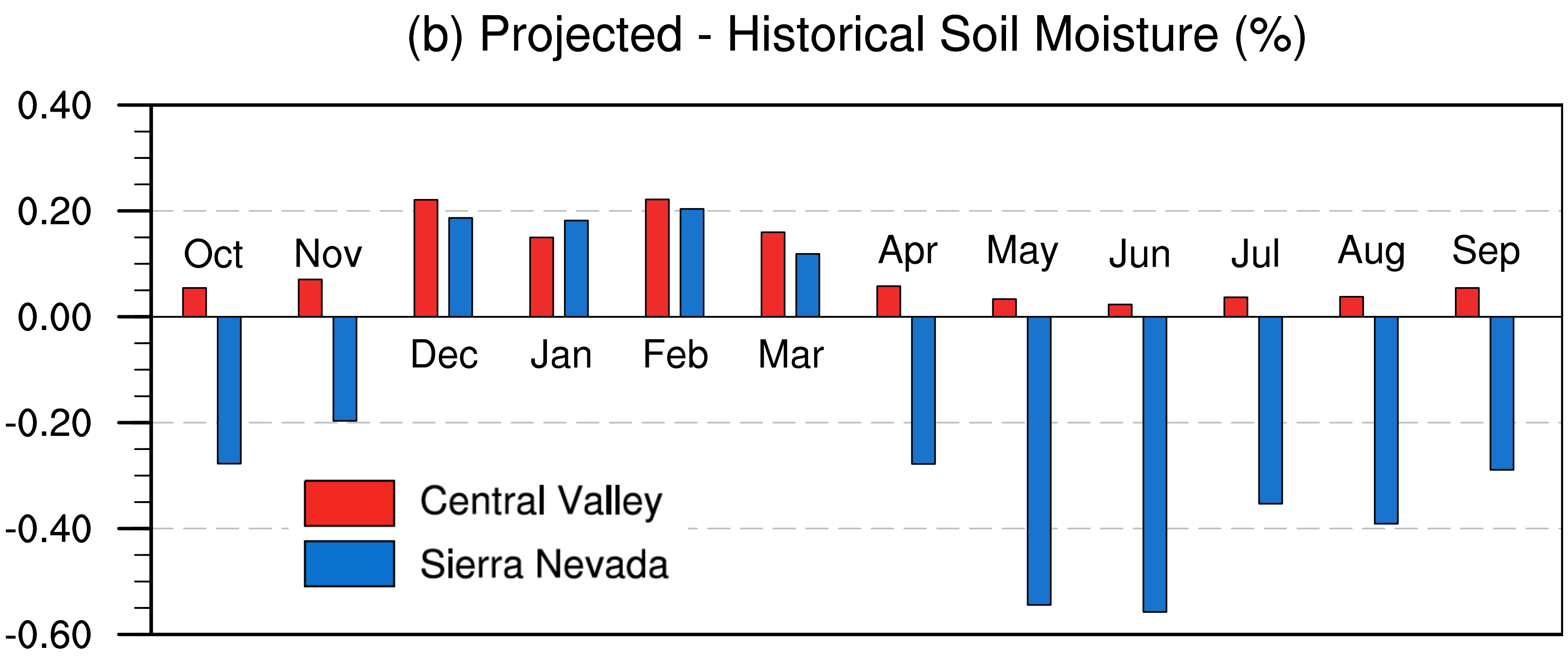


Drying of soil moisture primarily concentrated in the mountain region and Sierra Nevada leeward.

Change in soil moisture primarily modulated by snow water.

Result: Loss of snowpack leads to extreme summertime drying in the mountain region.

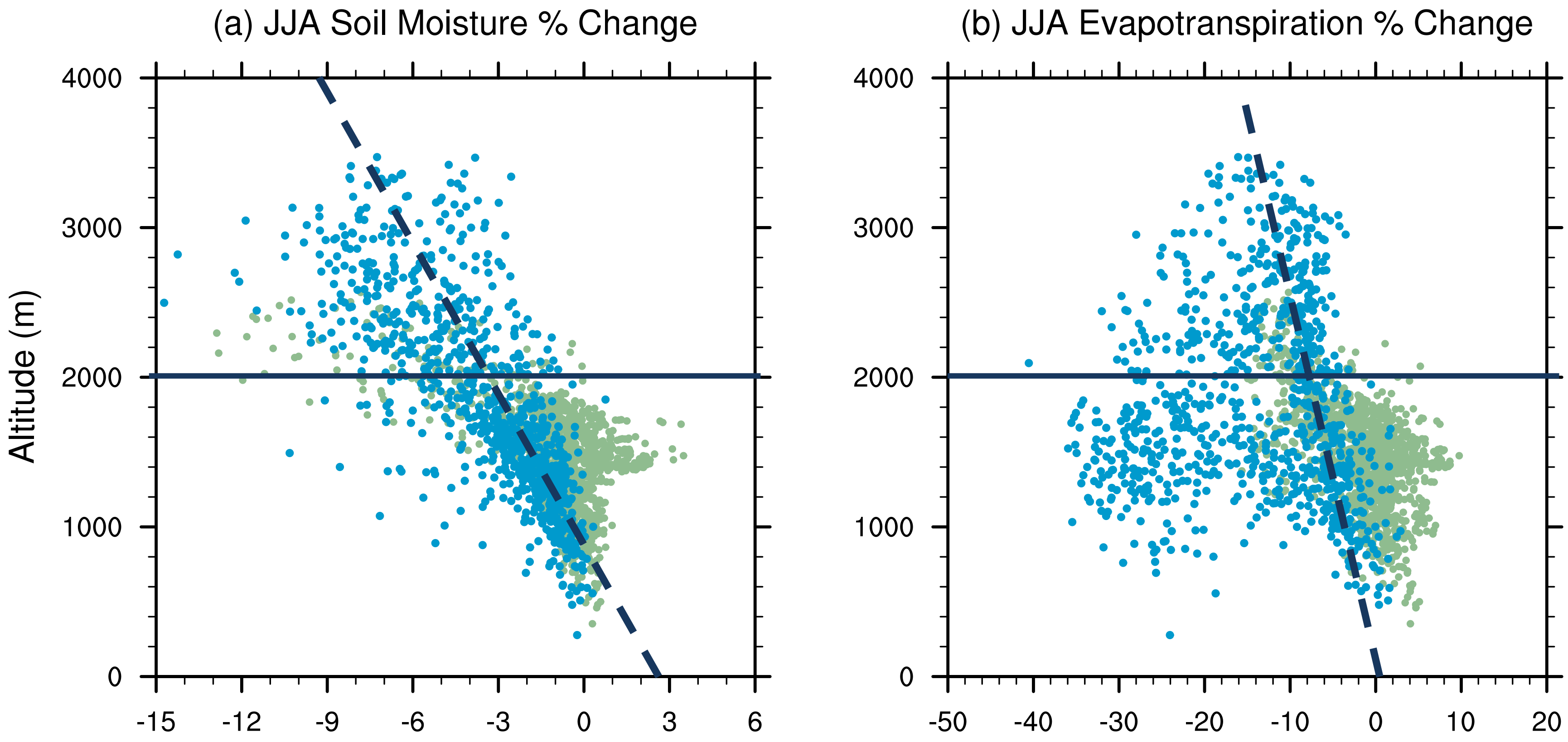
Soil Moisture



Result: Higher precipitation in wintertime leads to higher soil moisture, but not enough to counteract extreme drying in summertime.

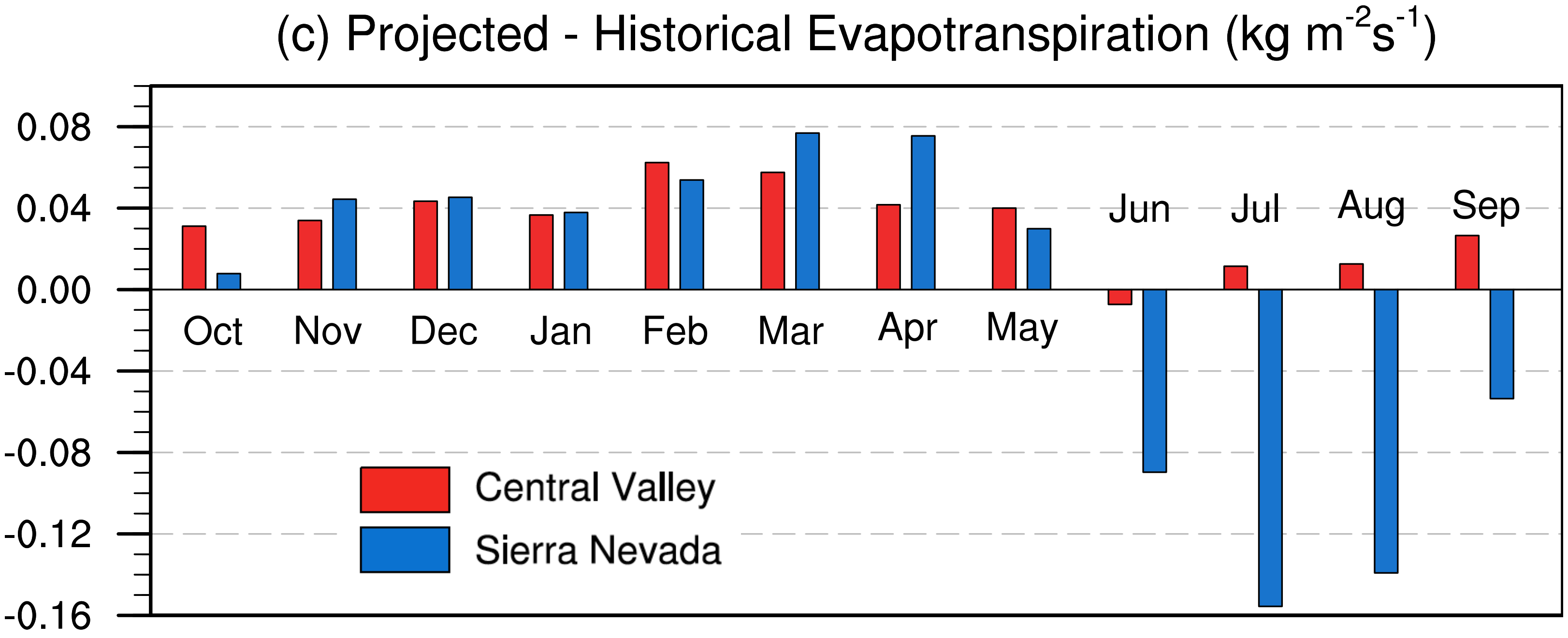
Change in soil moisture primarily found in Sierra Nevada region.

Soil Moisture



Result: Greatest change in summertime soil moisture occurs at elevations above 2000m.

Evapotranspiration



Result: Higher evapotranspiration outside of summer season, but much lower in summer due to water availability.

Conclusions

The **pseudo-global warming methodology** is effective for modeling the impacts of modified thermodynamics on the climatology of particular periods over relatively small regions.

Here we analyzed **California's 2012-2016 drought period** in light of climate change driven forcing.

This allowed us to understand what a drought over the **midcentury 2042-2046 period** would look like.

The results of this project are then useful for **future drought planning**.

Conclusions

Temperatures during the drought period are expected to be 0.8-1.4°C higher in the Central Valley, and 1.2-2.0°C higher in the mountainous regions and interior.

Extreme temperature days (>40°C) expected to increase by 50% in CV

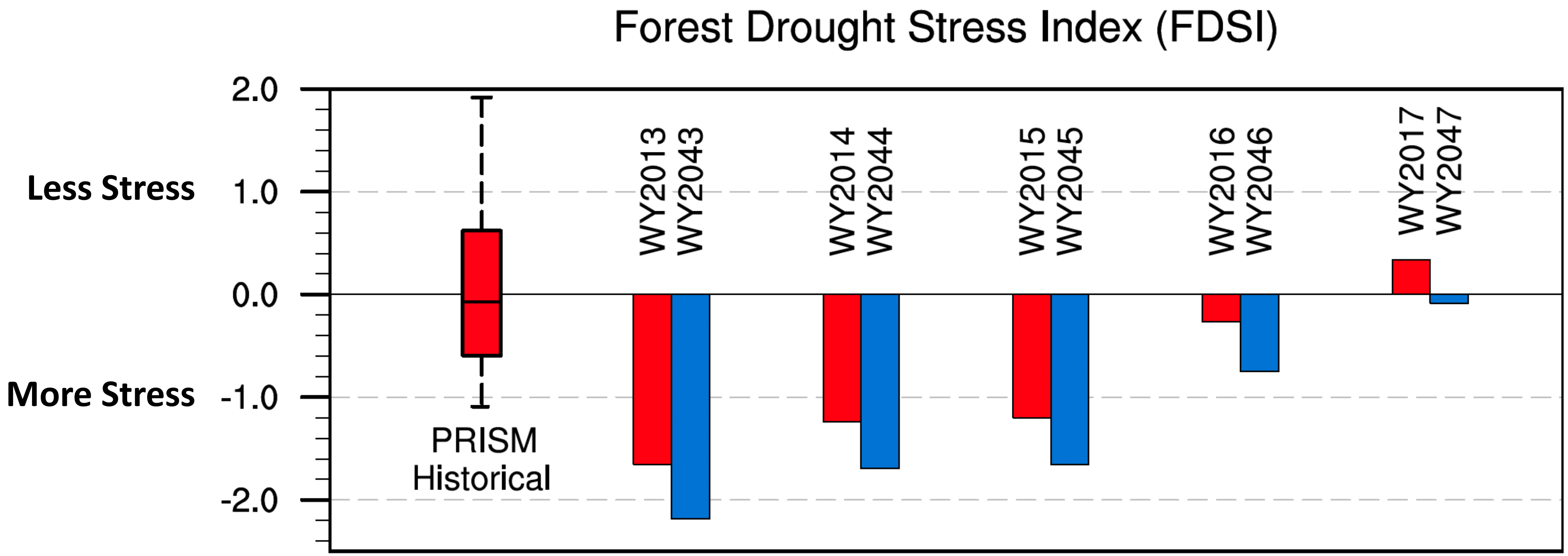
Average water year precipitation through the mountains increased by approximately 5% across all years. No significant change in precipitation elsewhere.

More **extreme precipitation days** (0.5 days in dry years, 1 day in wet years).

Peak total snow water equivalent (SWE) water volume diminished between 16% to 30% across the five water years from 32.6 MAF to 25.5 MAF, a net loss of 7.1 MAF or 22%. Note 2012-2016 drought already depleted vs. 20th century.

Average JJA soil moisture in dry years is reduced by 1-2% at higher elevations.

Forest Drought Stress Index (FDSI)

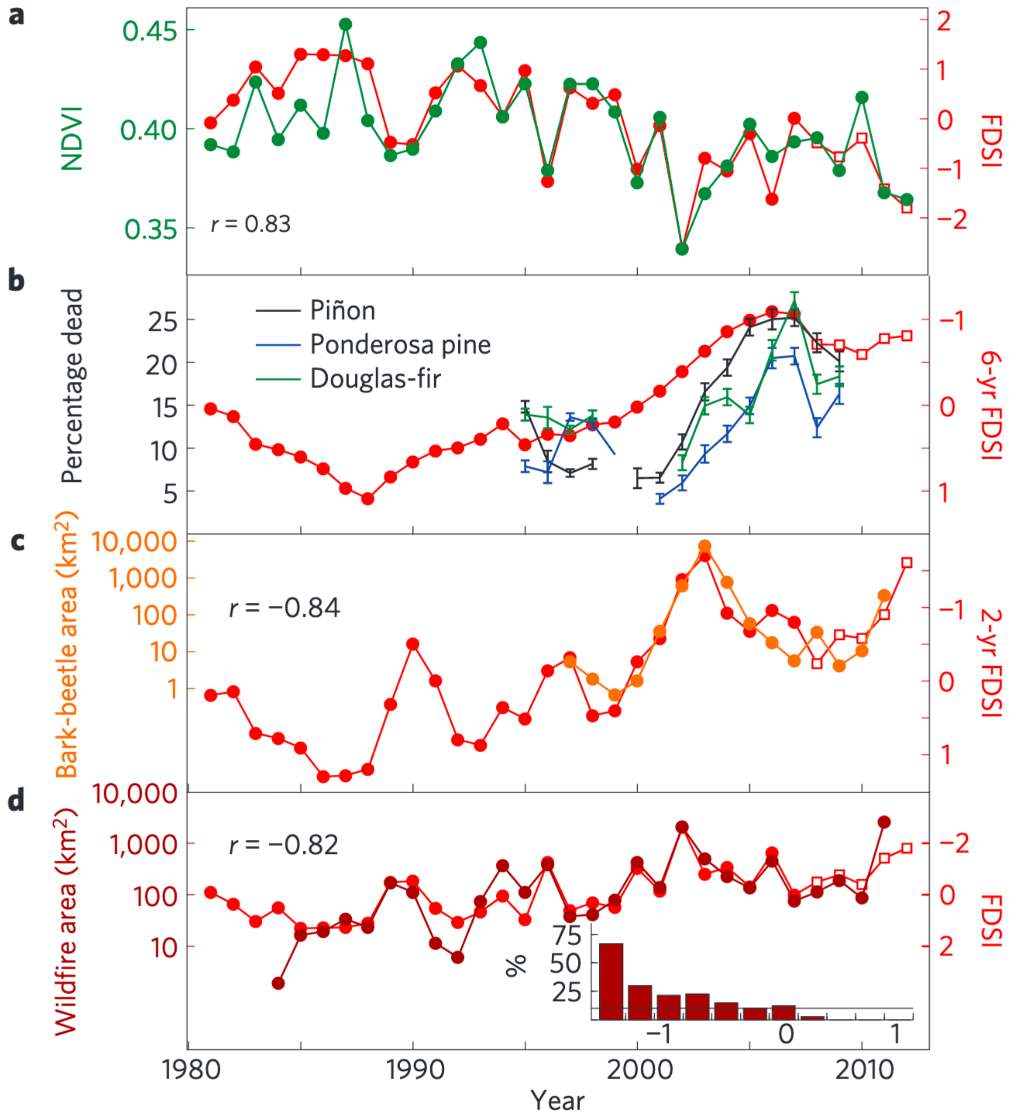


Forest Drought Stress Index is defined in Williams et al. (2012, Nature Climate Change).

Forest Drought Stress Index (FDSI)

Figure: Measurements of forest productivity and mortality overlaid on the FDSI, reproduced from Williams et al. (2012) Figure 2. NDVI denotes the normalized difference vegetation index, a satellite-derived regional measure of vegetation growth.

FDSI Values of -1 or lower correspond to **widespread bark-beetle area** (thousands of square kilometers), **wildfires** over hundreds of square kilometers, and over 25% of **dead forests**. Values below -2 are unprecedented.



Drought, Climate Change and Forests

PPIC Managing Drought in a Changing Climate: Four Essential Reforms

Long-standing management practices—including logging methods and decades of wildfire suppression—have led to dense, dry forests that are susceptible to insects, disease, and increasingly intense wildfires. Hotter temperatures and more variable precipitation have made conditions worse. During the 2012–16 drought alone, 15 million trees died annually, surpassing anything in recorded history.

Extreme wildfires are likely to increase, potentially leading to the conversion of thousands of acres of conifer forest to shrublands, and harming air quality, water quality, habitat, recreation, and rural economies.

Adapting to climate trends and reducing the risk of severe wildfires will require major changes in forest management by federal and state governments, in cooperation with local agencies and landowners.

https://www.ppic.org/wp-content/uploads/managing-drought-in-a-changing-climate-four-essential-reforms-september-2018.pdf

Drought, Climate Change and Forests

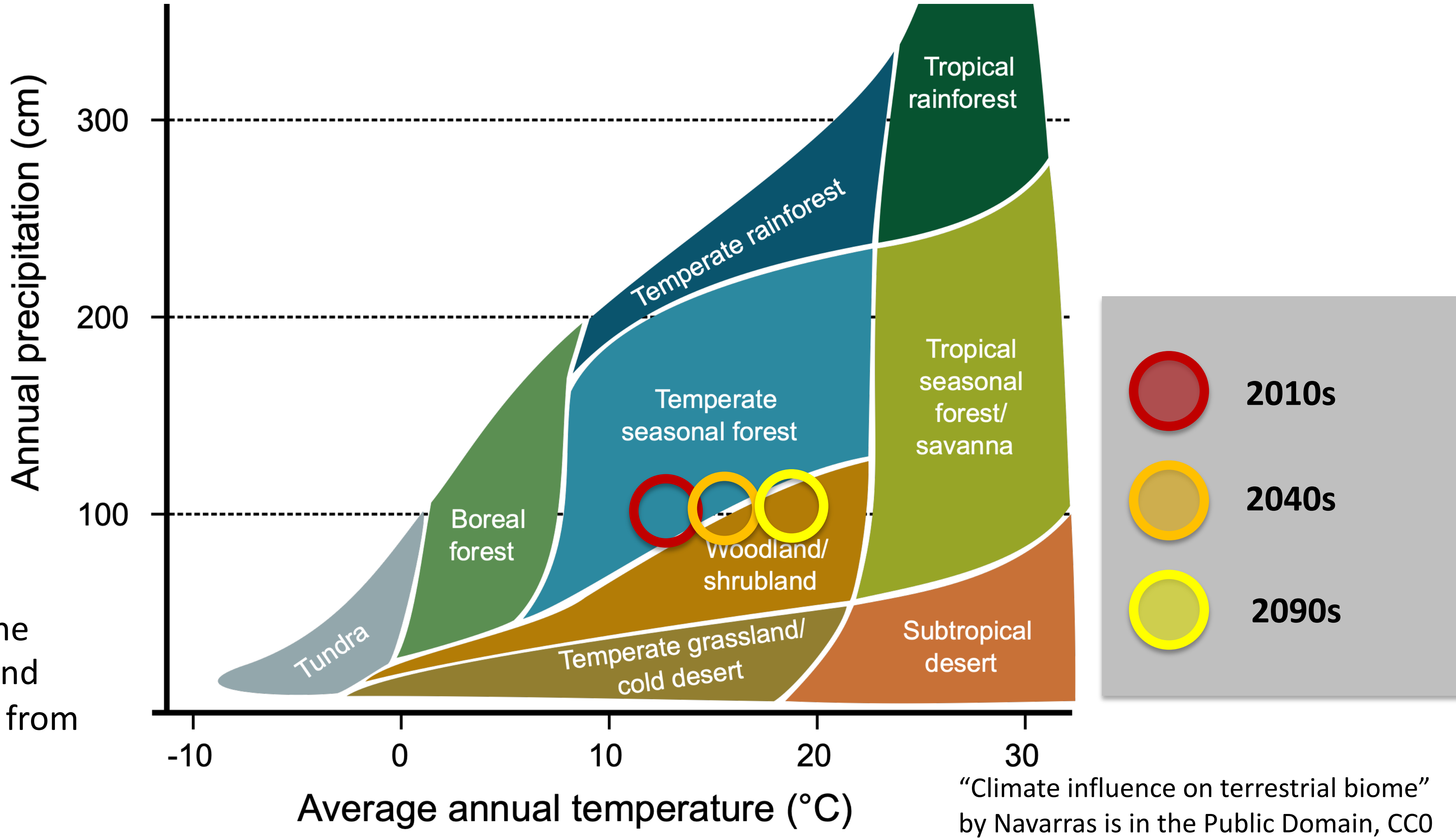
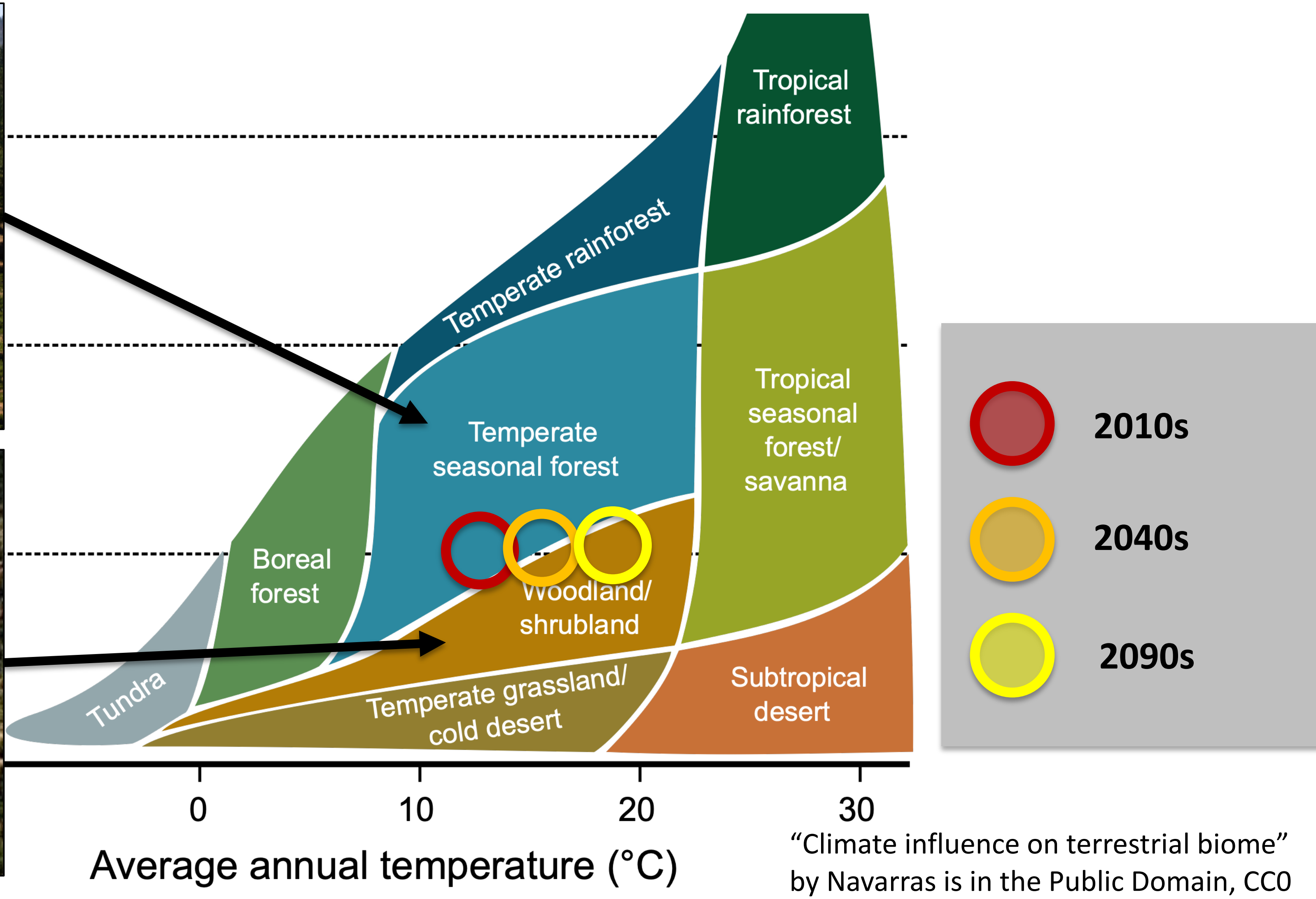


Figure: Climate biomes of Pine Grove, California at present and into the future. Climate data from cal-adapt.org.

"Climate influence on terrestrial biome" by Navarras is in the Public Domain, CC0

Drought, Climate Change and Forests



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Thank You!

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