

# California's Future – Warmer, Drier and Wetter

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**thanks David Pierce, SIO    Mike Dettinger USGS**

## *Sponsors:*

California Energy Commission (CEC)  
NOAA via CNAP RISA  
USGS/DOI via SW Climate Science Center  
U.S. Department of Energy

## Summary: Projected Future of California Hydroclimate

Warmer climate produces greater moisture deficits and diminished spring snow pack

Climate models project higher variability of precipitation in California,  
within seasons and across years

Increased wetness, when it occurs, owes to more frequent, more intense precipitation events.

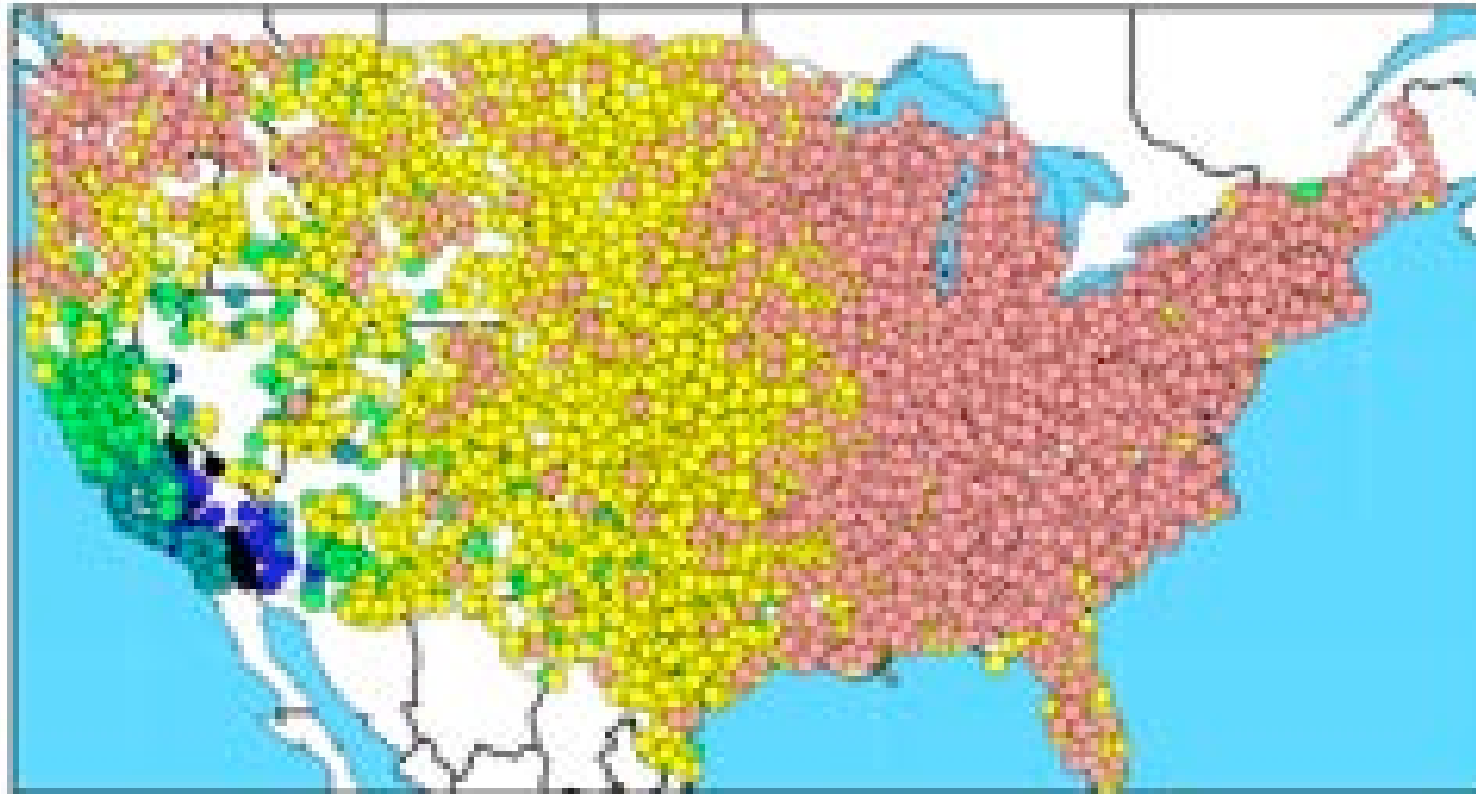
Heavier precipitation events and higher mountain snow altitudes produce larger floods

Increased dry days in spring and fall leads to shorter wet season.

Increased dry days leads to more dry years; More dry years leads to more dry decades.

More dry years in presence of warming leads to severely diminished snow pack

Coefficient of Variation of Total Precipitation  
from COOP records, WY 1951-2008



Western U.S. has high  
year-to-year variability  
especially in the Southwest

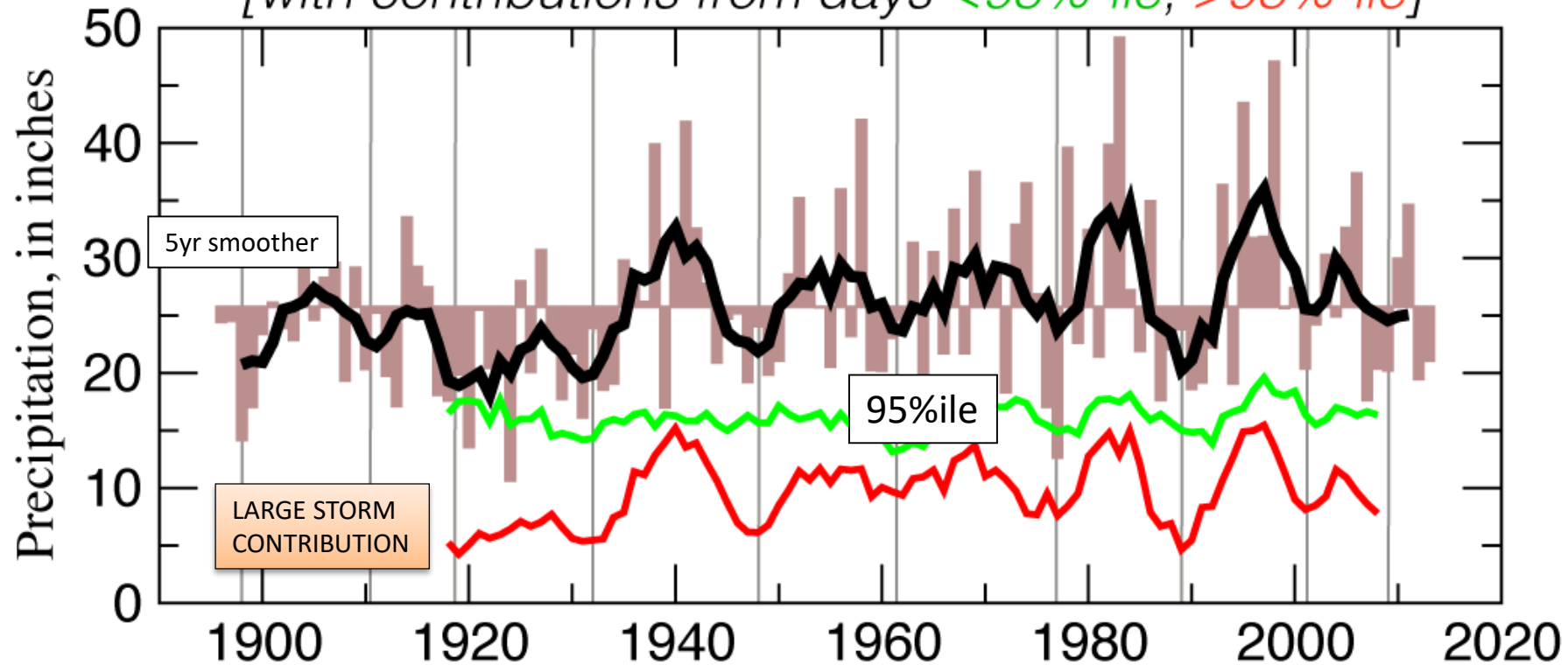


# a few large storms (or their absence)

account for a disproportionate amount of California's precipitation variability

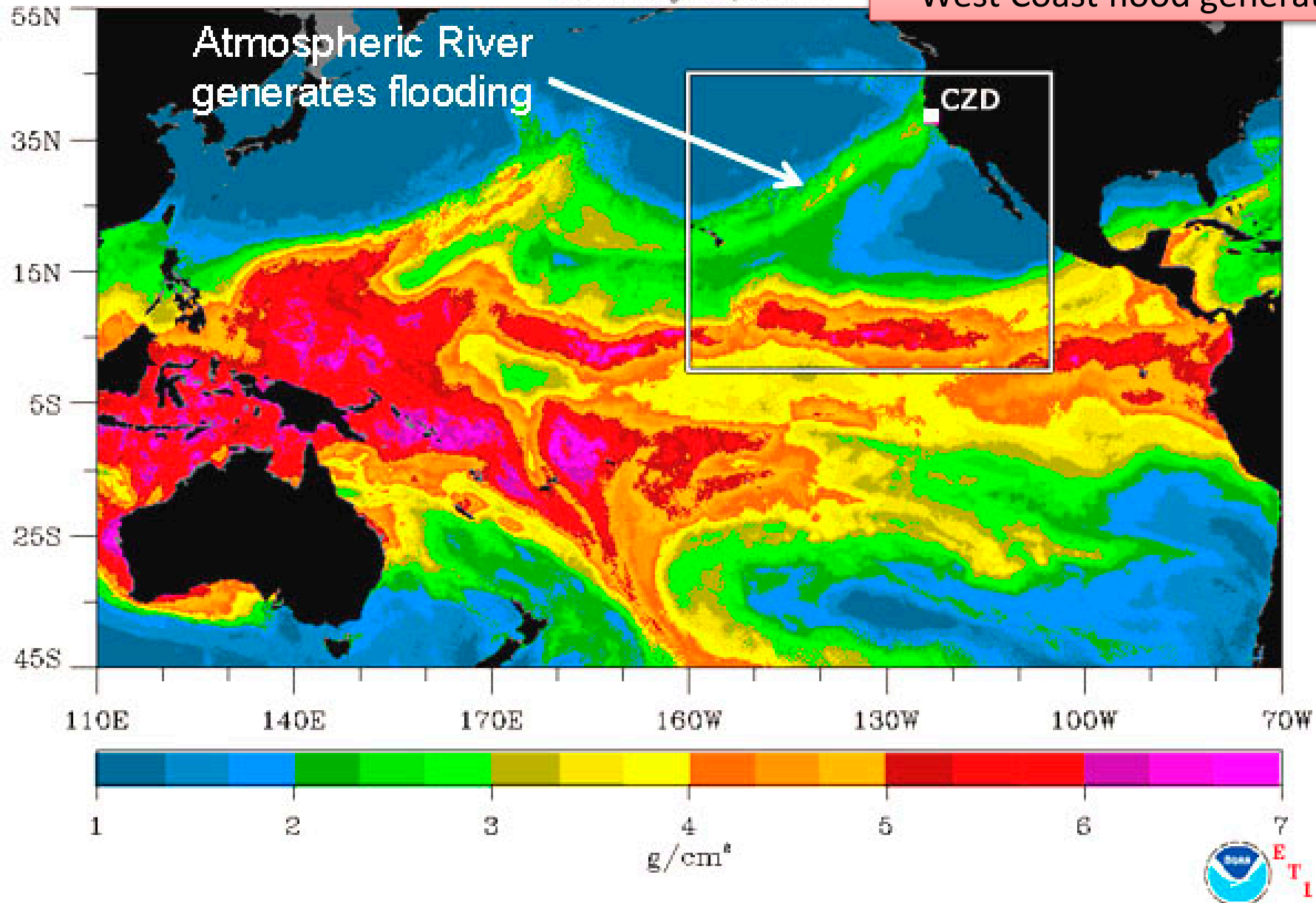
## a) Water-Year Precipitation, Delta Catchment

[with contributions from days <95%-ile, >95%-ile]

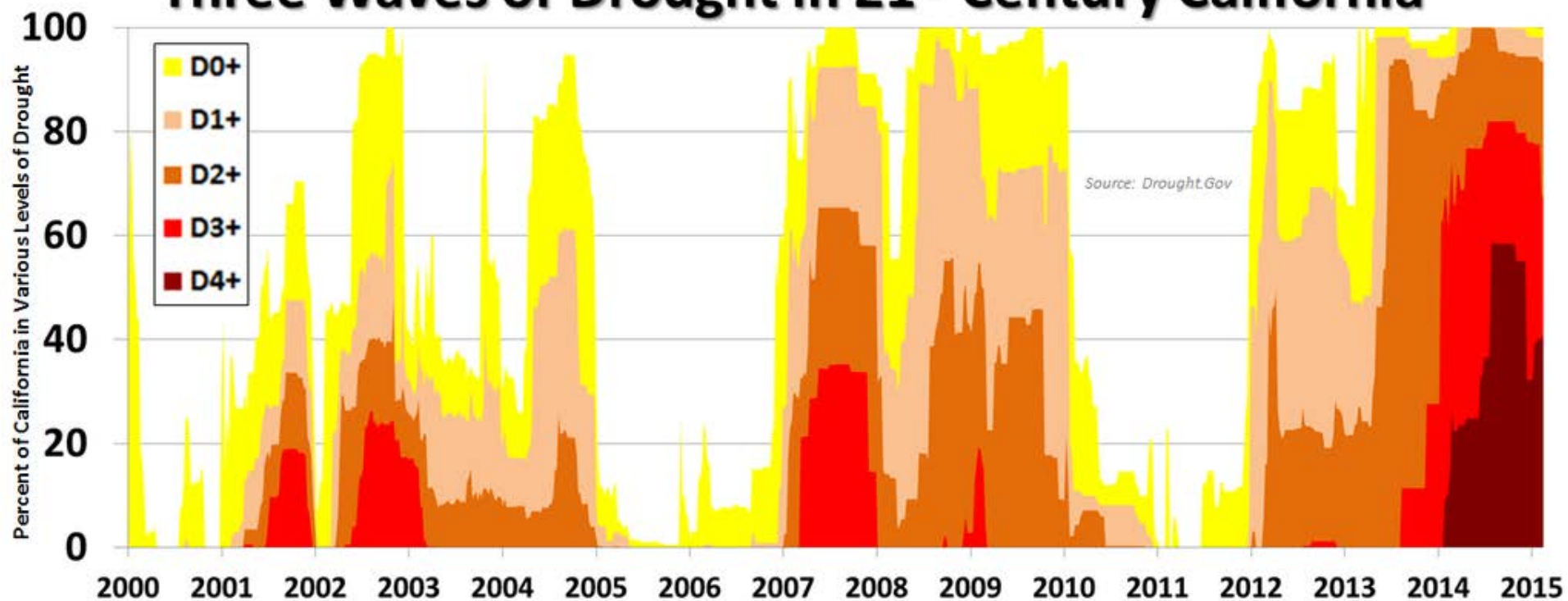


SSM/I Water Vapor (Schluesse)  
February 18, 2004

Atmospheric Rivers  
West Coast flood generators



## Three Waves of Drought in 21<sup>st</sup> Century California



Source: Drought.Gov

Interact With Us



[Weather.Gov/Hanford](http://Weather.Gov/Hanford)



[NWSHanford](https://www.facebook.com/NWSHanford)

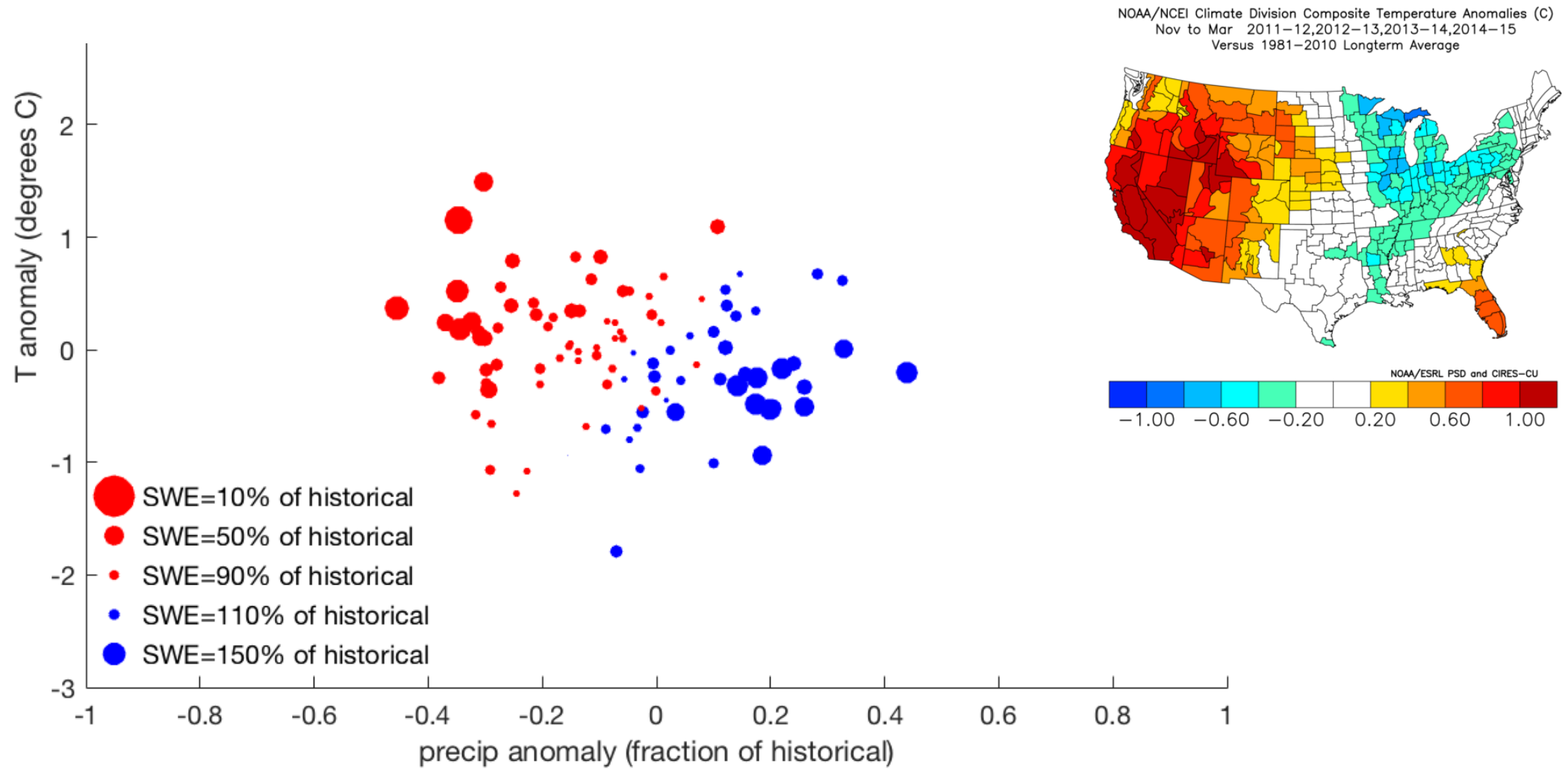


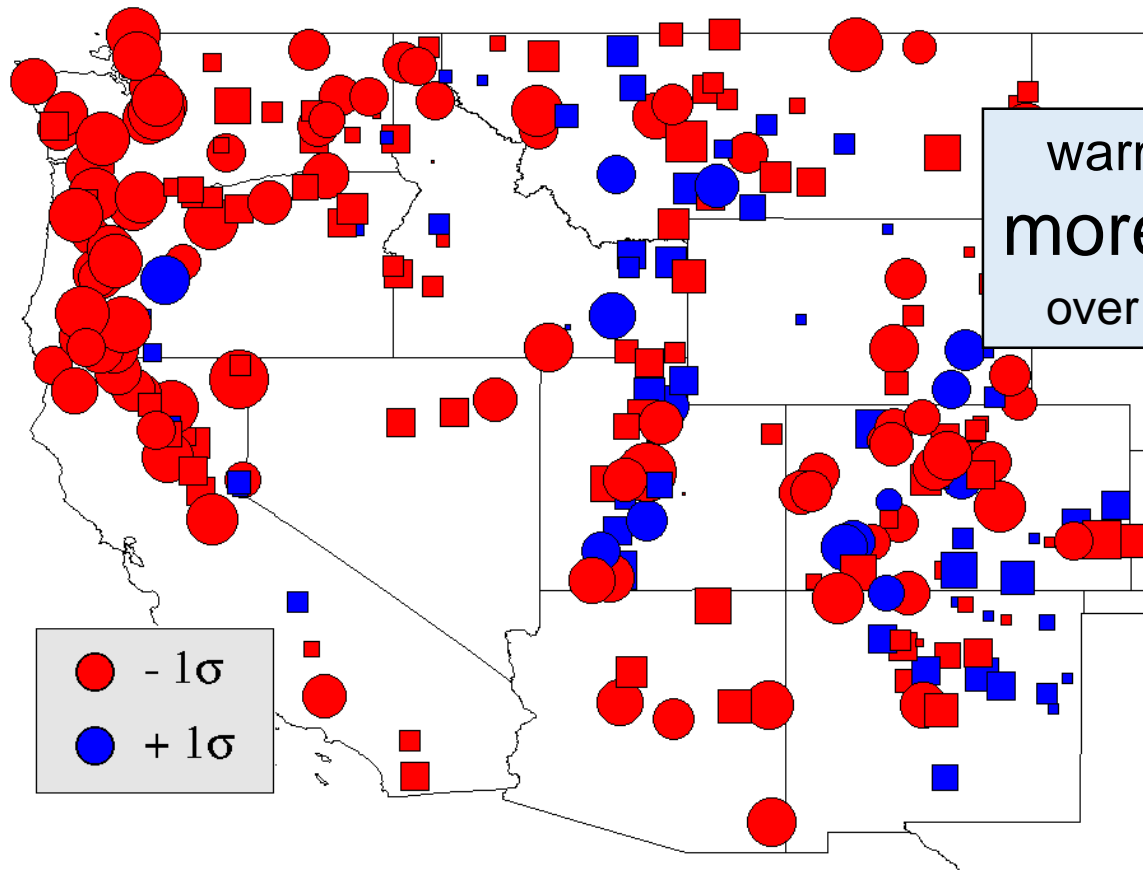
[@NWSHanford](https://twitter.com/NWSHanford)



[NWSHanford](https://www.youtube.com/NWSHanford)

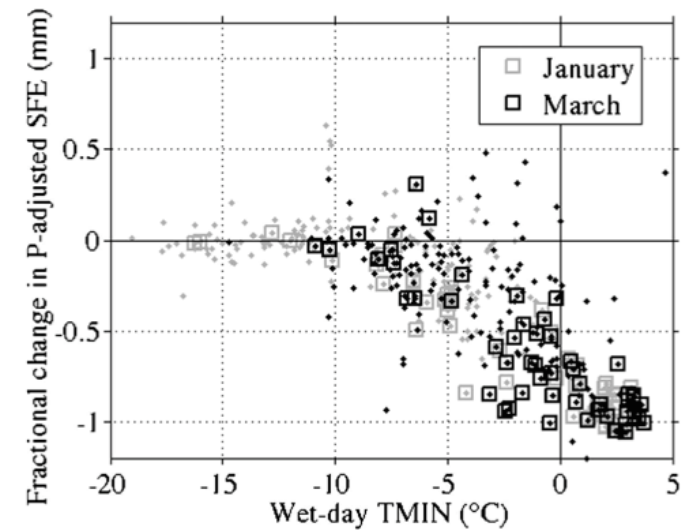
# Unusual warmth 2011-2015





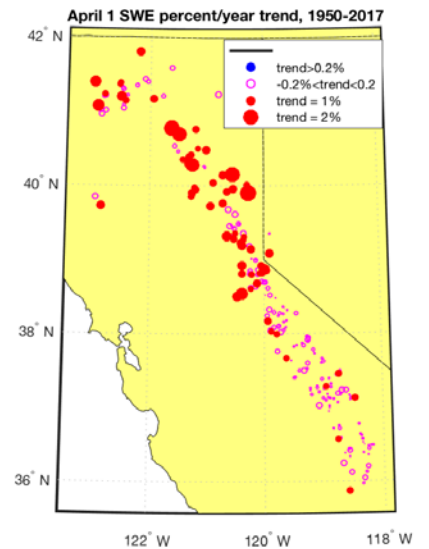
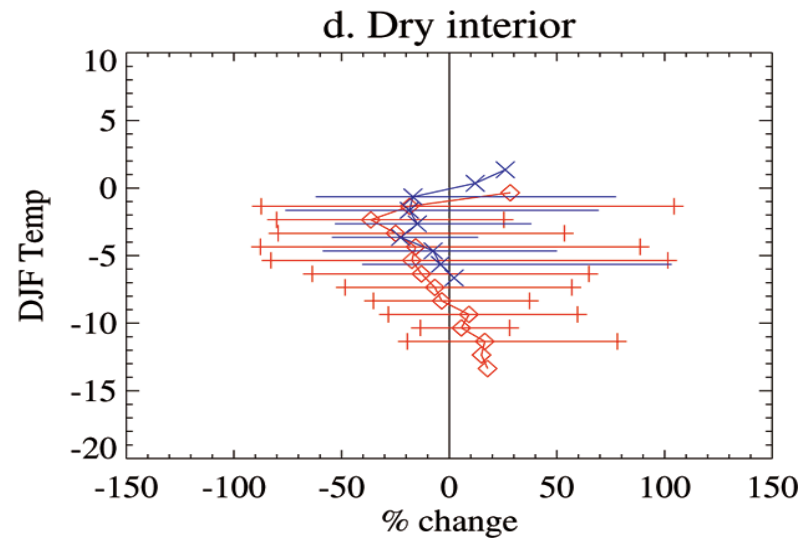
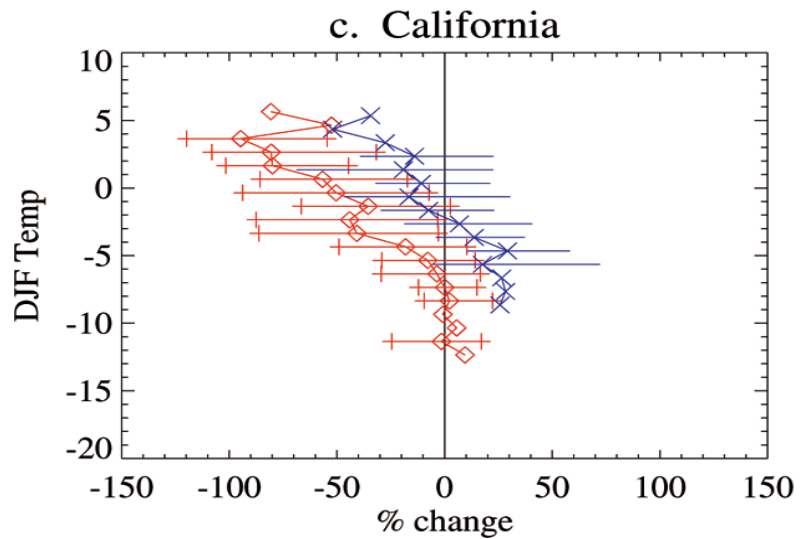
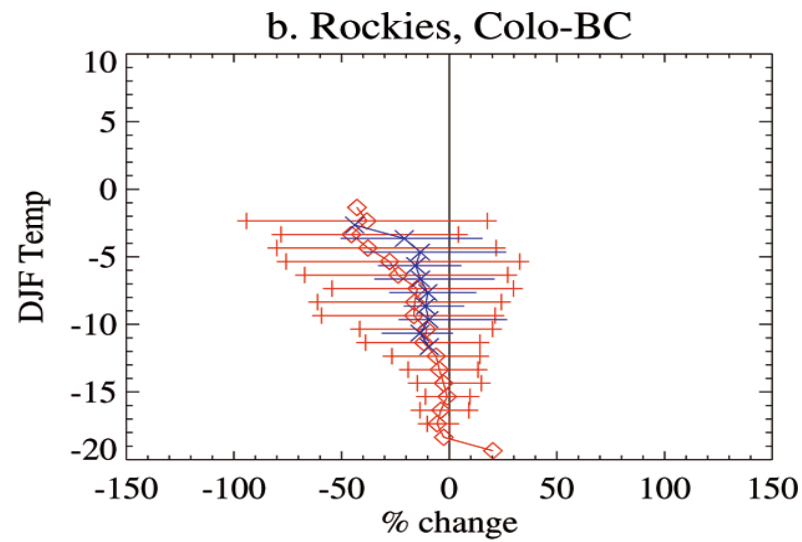
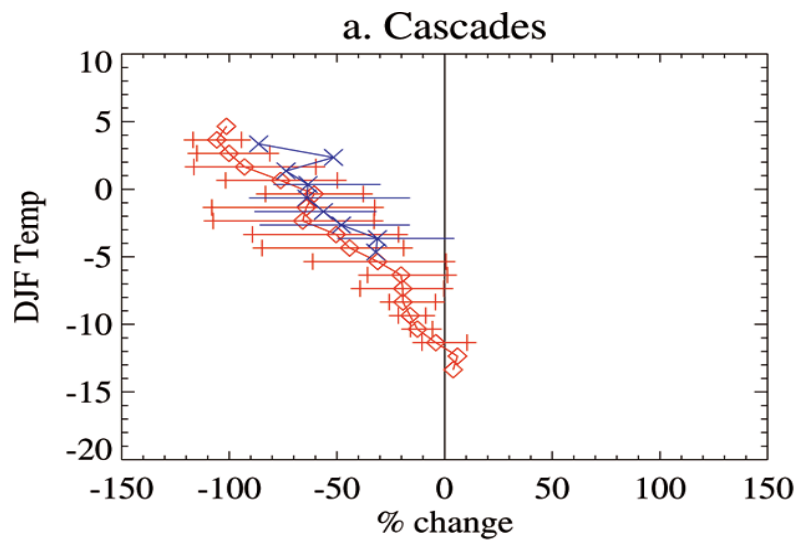
warming-driven changes  
**more rain, less snow**  
 over period of 1949-2004

Winter (Nov-Mar) SFE/P trends at western US weather stations: symbol area is proportional to study-period changes, measured in standard deviations as indicated; circles indicate high trend significance ( $p < 0.05$ ), squares indicate lower trend significance ( $p > 0.05$ ).



Snow-to-Rain Changes have occurred  
 in lower elevation warmer sites





Across the western U.S., Apr 1 snow losses have occurred in lower (warmer) elevations as shown directly from snow course observations (blue) and VIC hydrological model reanalysis (red) by Mote and colleagues (2005)

Regional Climate Change is being evaluated in the Fourth National Climate Assessment (NCA4) and the Fourth California Climate Change Assessment

Numerous Other Variable and Measures are being investigated :

amongst those:

- winds
- wildfire occurrence
- waves
- coastal effects

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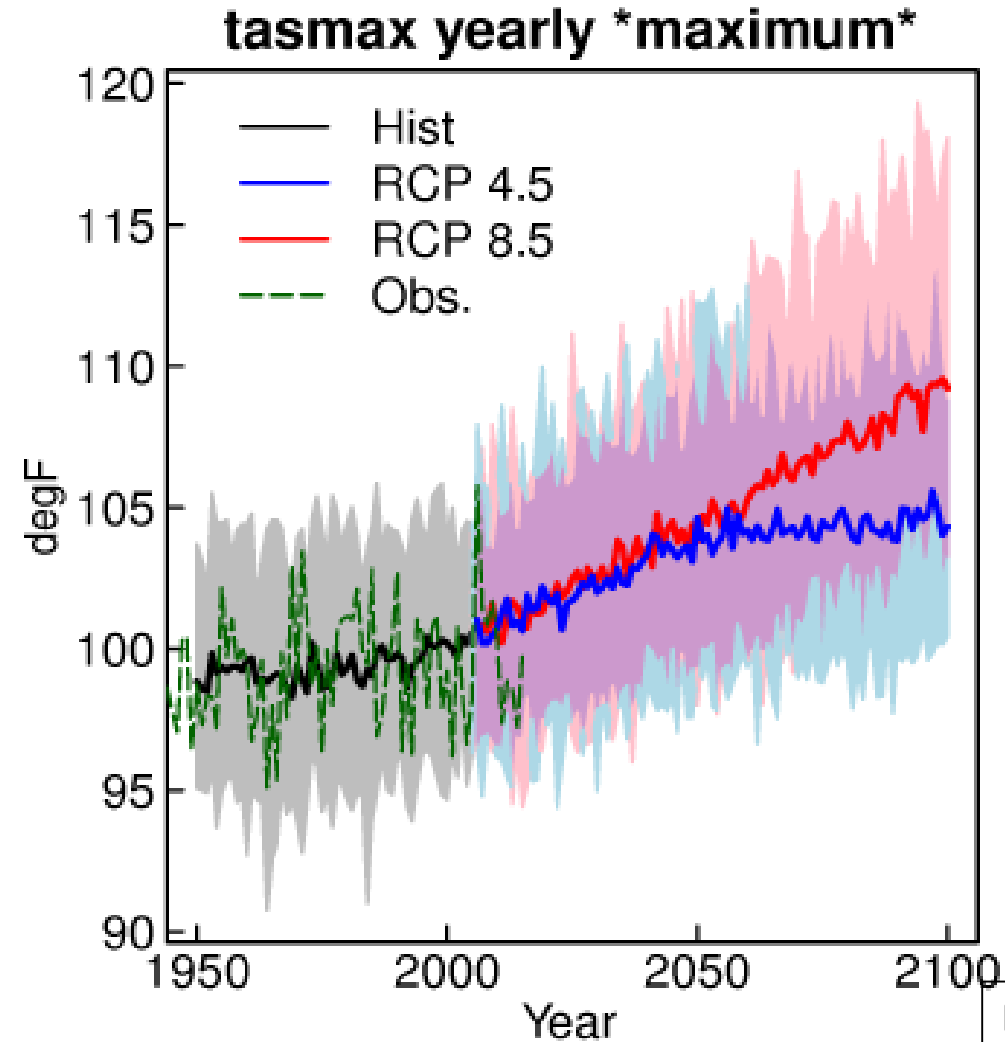
..

RCP 8.5 greenhouse loading excesses over RCP 4.5 become increasingly large, especially after 2050.

Dark lines are averages over 32 models,  
Clouds show range of model results for each year

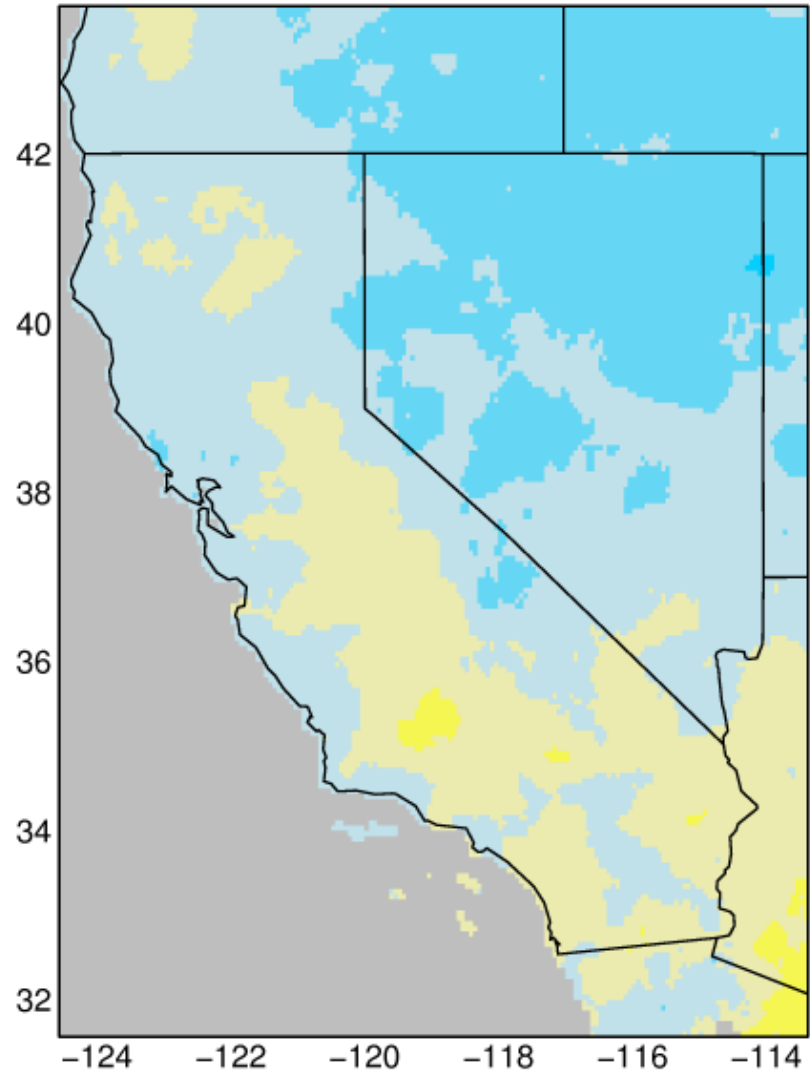
# Hottest Day of the Year will likely get hotter!

from 32 downscaled CMIP5 GCMs averaged over San Diego County moderate (RCP 4.5) and high (RCP 8.5) greenhouse gas emissions scenarios

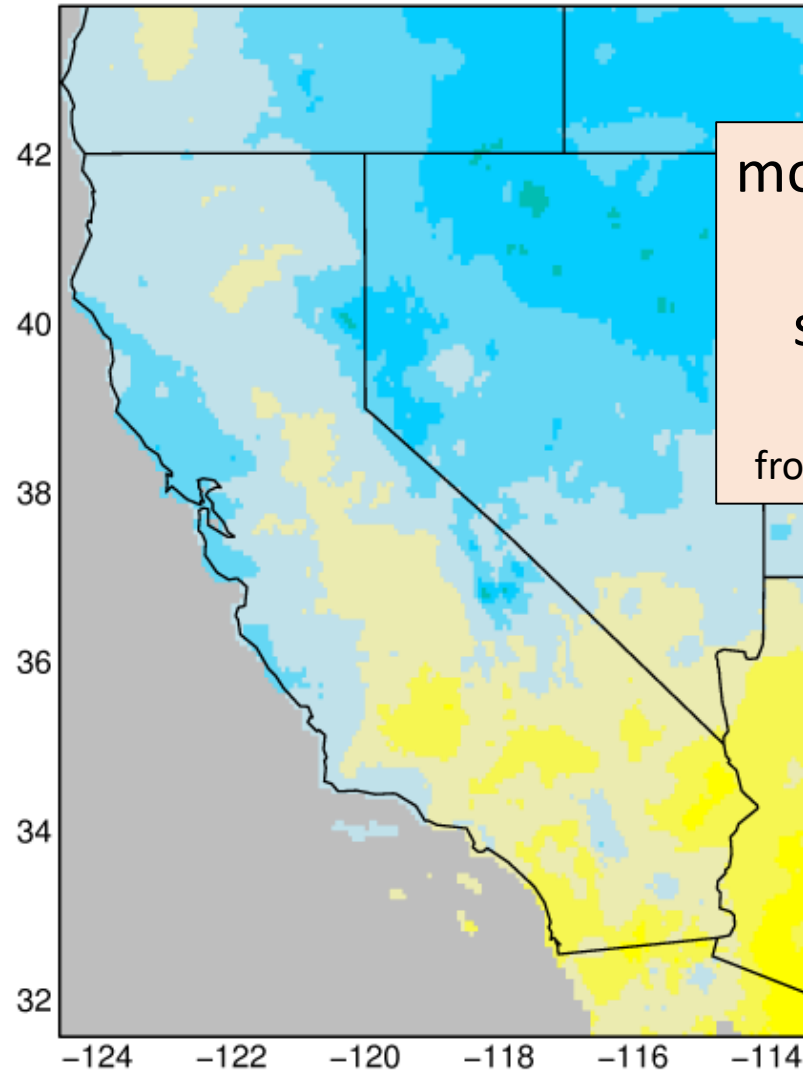


# Change in annual precip [%], 2070–2100 w.r.t. 1950–2005

## RCP 4.5

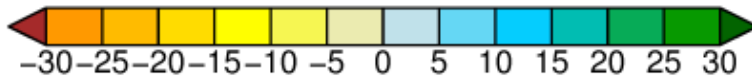
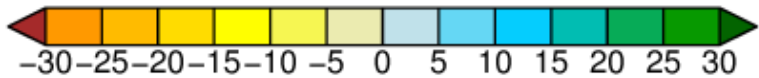


## RCP 8.5



models suggest:  
somewhat wetter NoCal  
somewhat *drier* SoCal

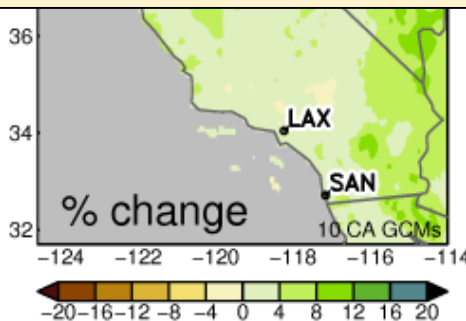
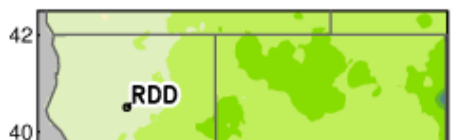
from 32 CMIP5 GCMs downscaled w LOCA



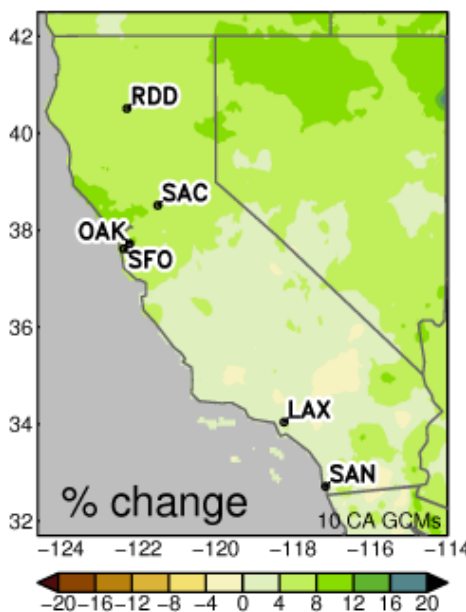
# 10 models

Projected Precipitation Change DJF  
10 GCMs early mid late 21<sup>st</sup> Century

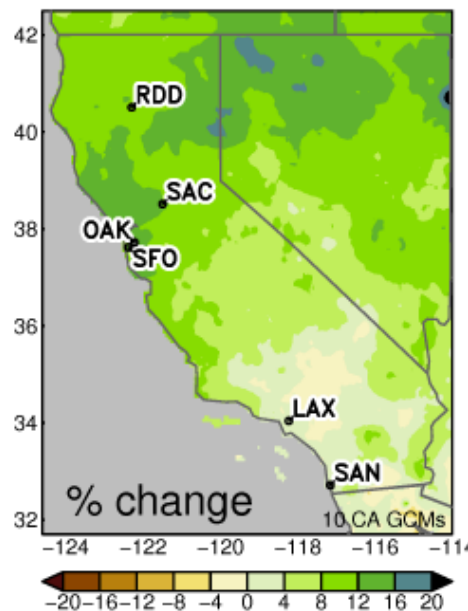
DJF avg precip change by 2006–2039 rcp45



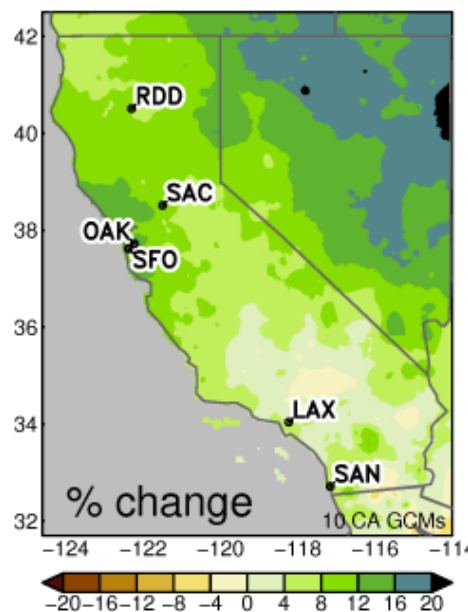
DJF avg precip change by 2006–2039 rcp85



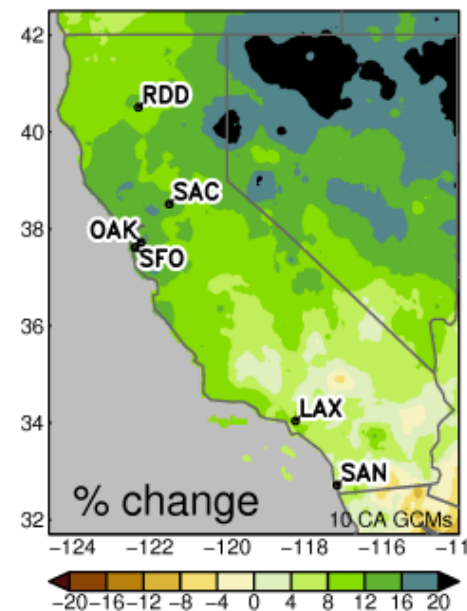
DJF avg precip change by 2040–2069 rcp45



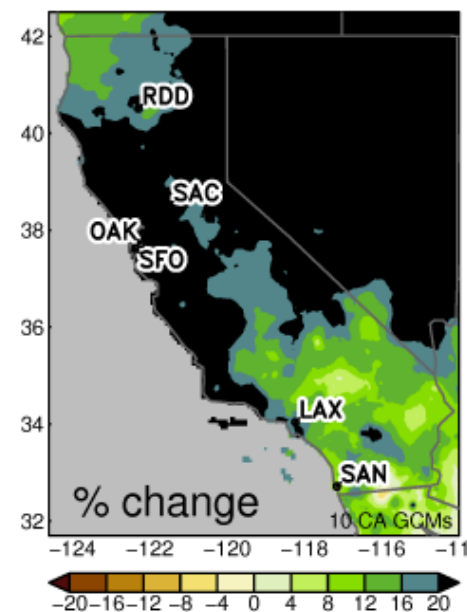
DJF avg precip change by 2040–2069 rcp85



DJF avg precip change by 2070–2100 rcp45



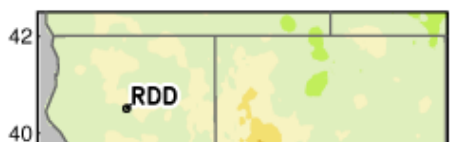
DJF avg precip change by 2070–2100 rcp85



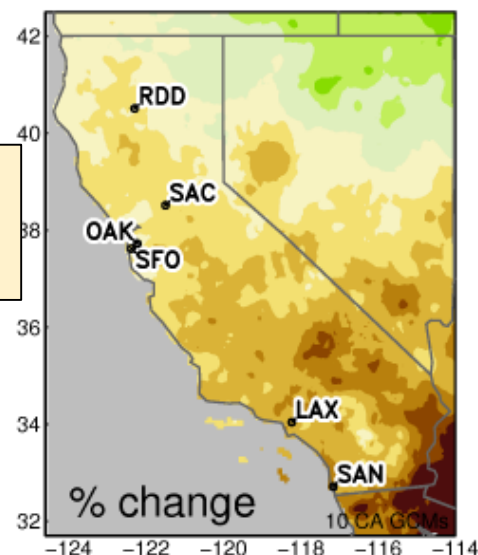
# 10 models

Projected Precipitation Change MAM  
10 GCMs early mid late 21<sup>st</sup> Century

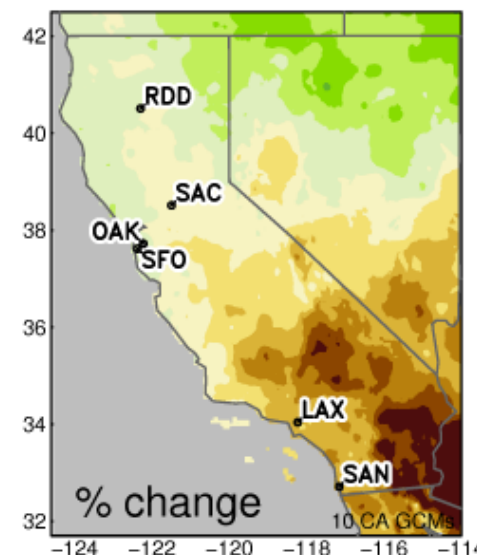
MAM avg precip change by 2006–2039 rcp45



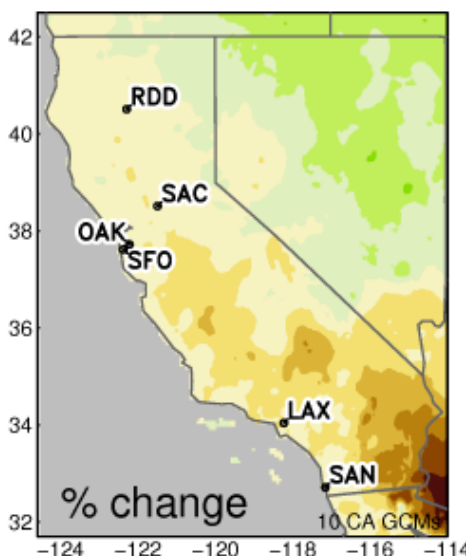
MAM avg precip change by 2040–2069 rcp45



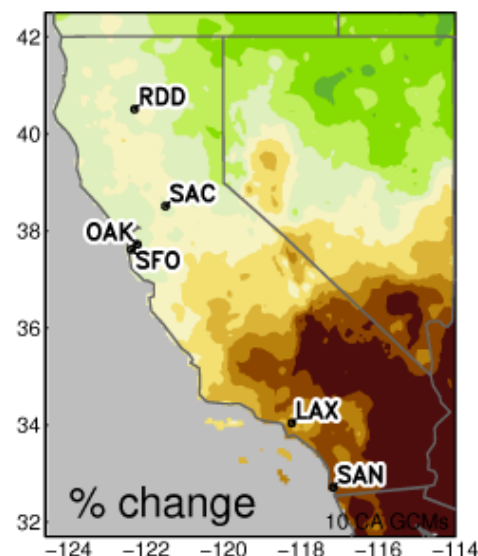
MAM avg precip change by 2070–2100 rcp45



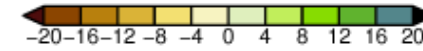
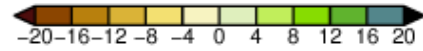
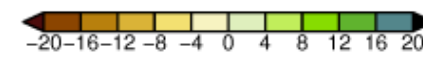
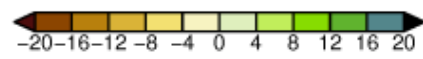
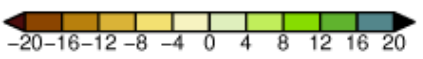
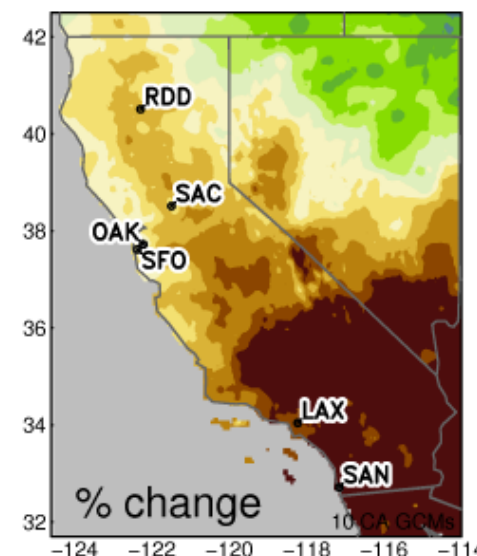
MAM avg precip change by 2006–2039 rcp85



MAM avg precip change by 2040–2069 rcp85



MAM avg precip change by 2070–2100 rcp85



# Increasing Frequency of Dry Years and Decades

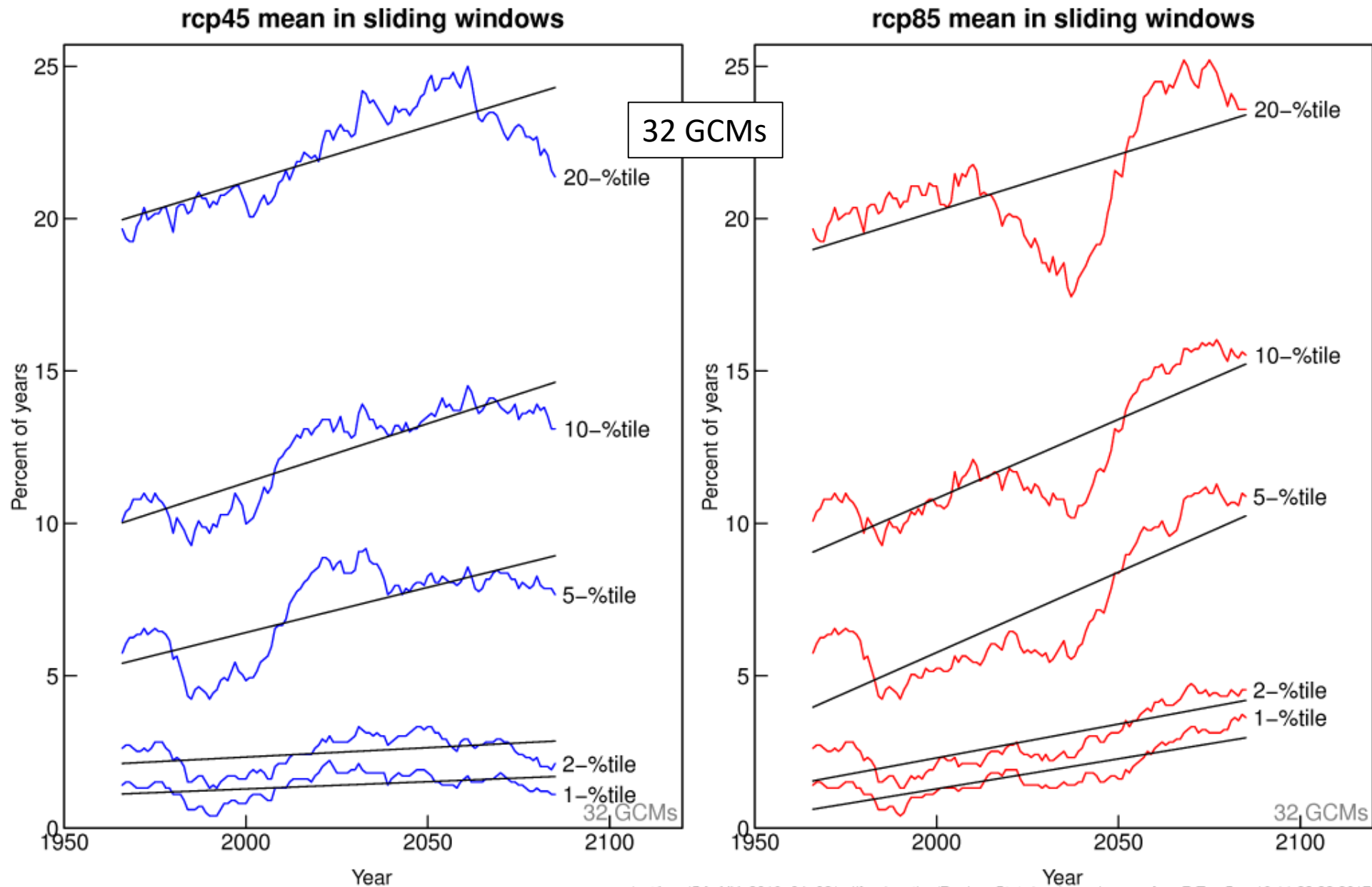
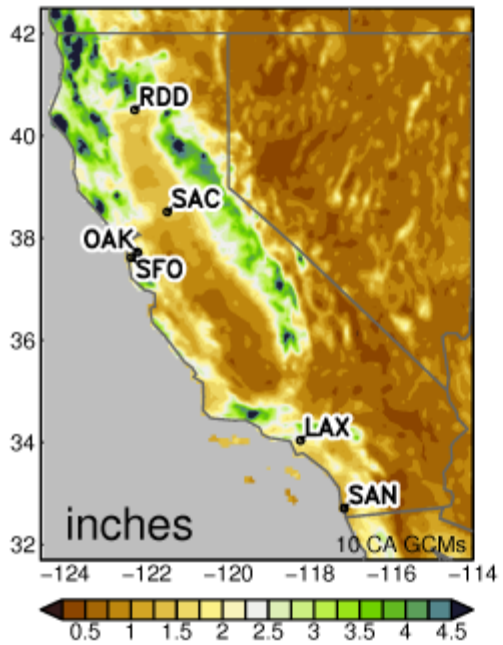
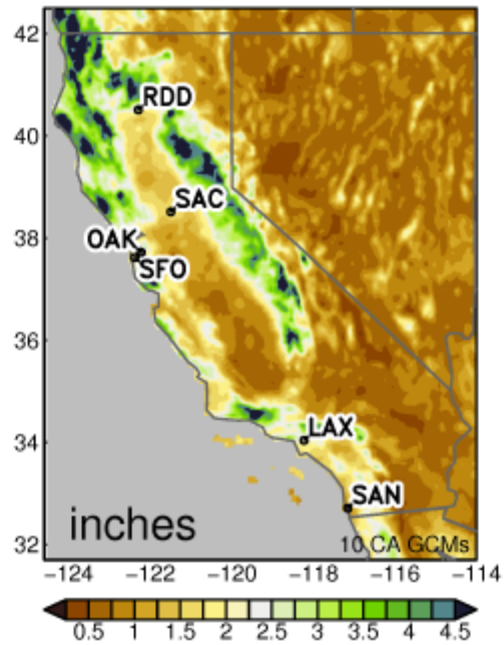


Figure 12a

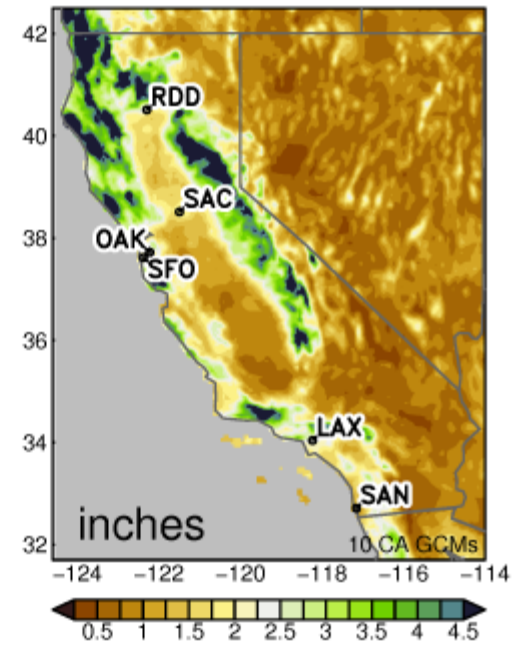
Avg wettest day/year, 1976–2005 (inch)



Avg wettest day/yr (inch), 2070–2100 rcp45

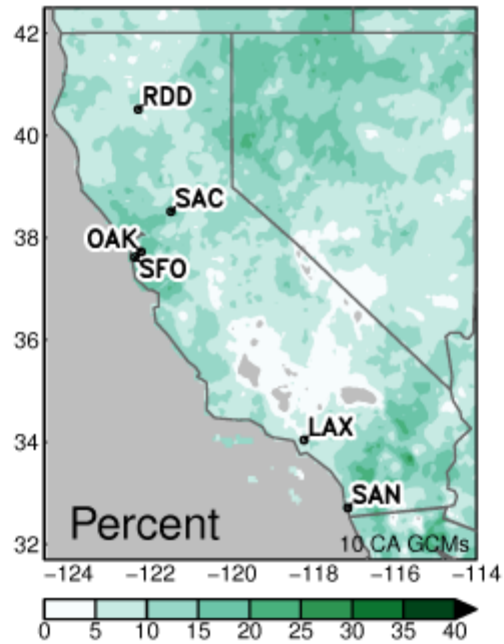


Avg wettest day/yr (inch), 2070–2100 rcp85



Wet Days  
get Wetter

Change in avg wettest day/yr (%) rcp45



Change in avg wettest day/yr (%) rcp85

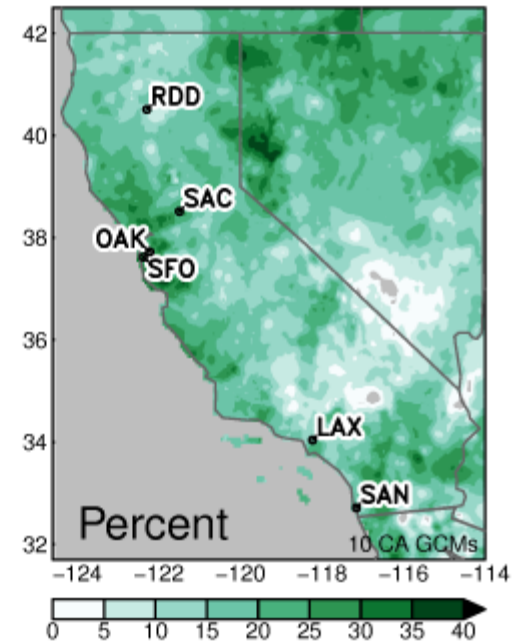
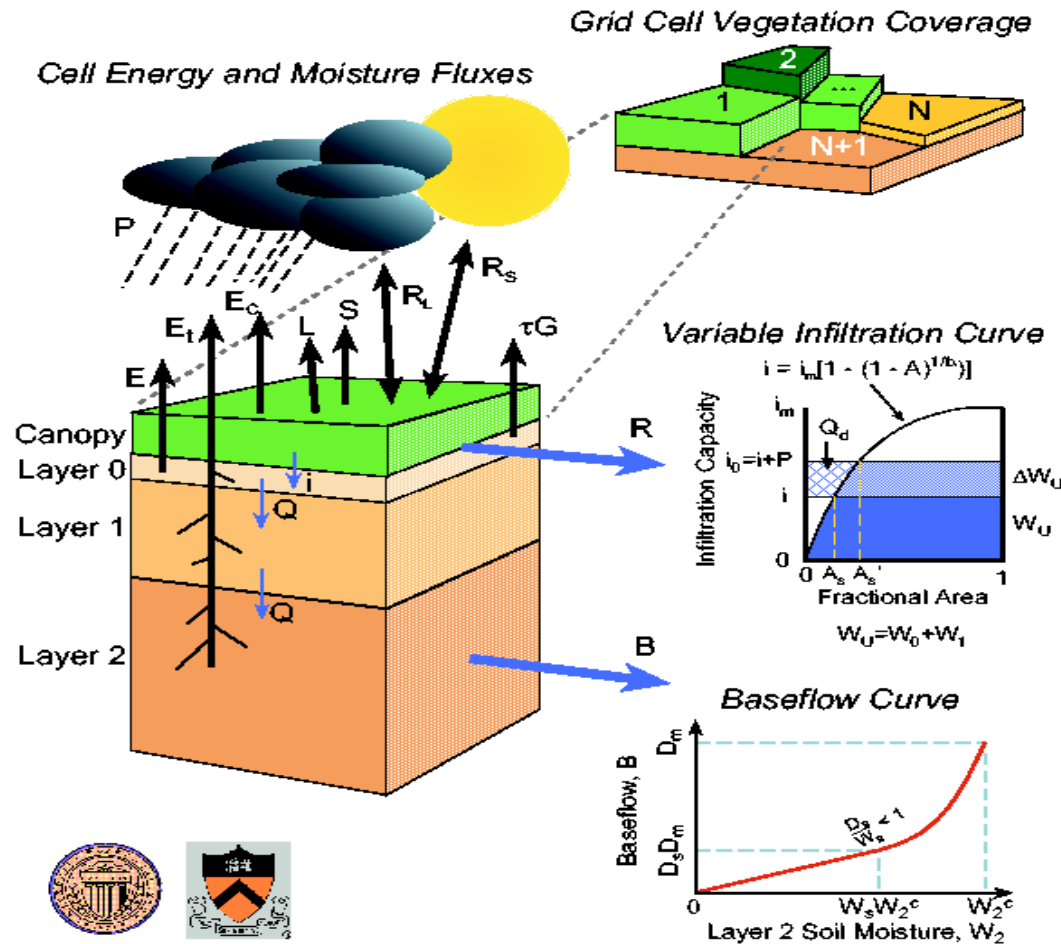


Figure 11

## Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model



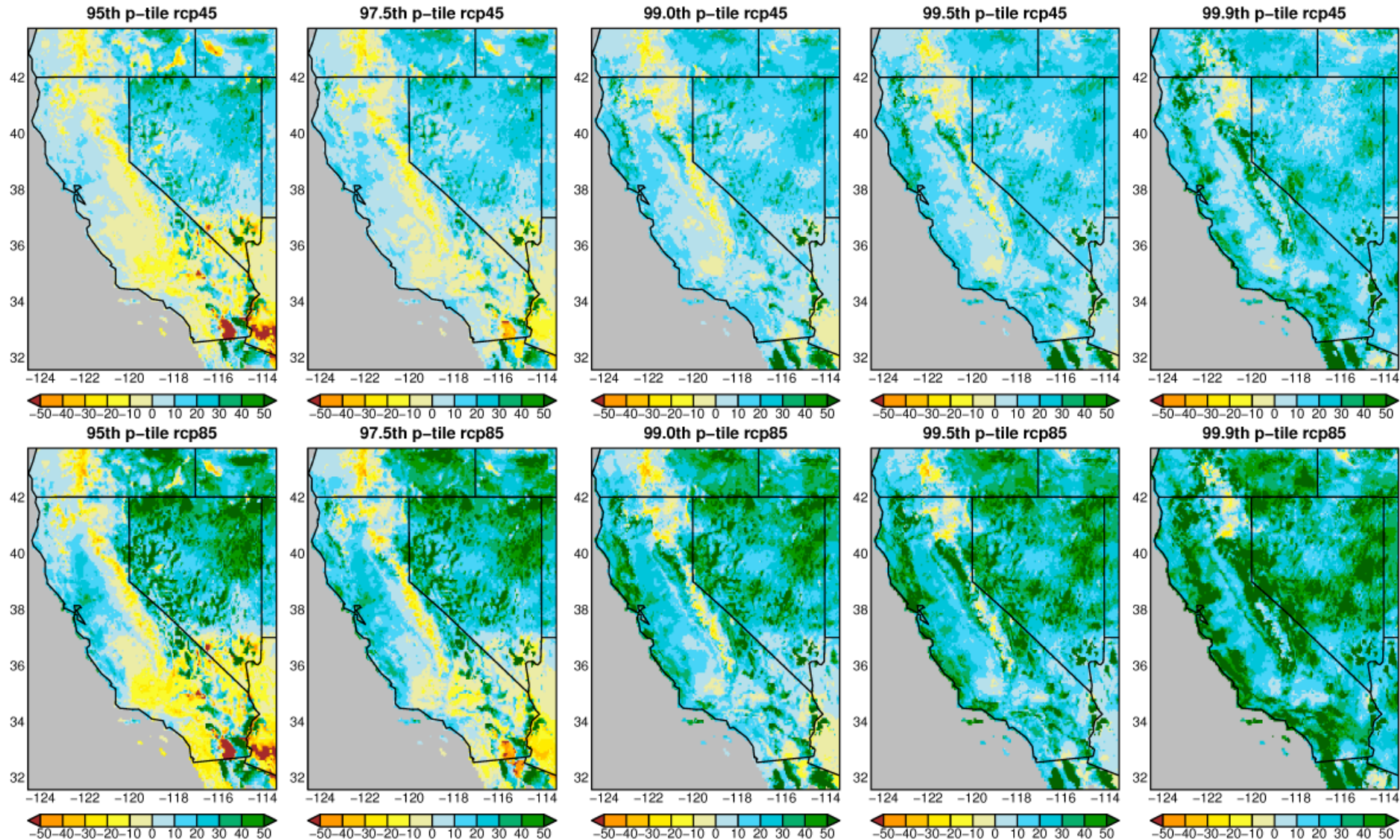
to estimate water balance,  
Including snow water equivalent  
(SWE)  
we use VIC, a land surface  
water and energy accounting  
model

VIC developed by U Washington  
and colleagues

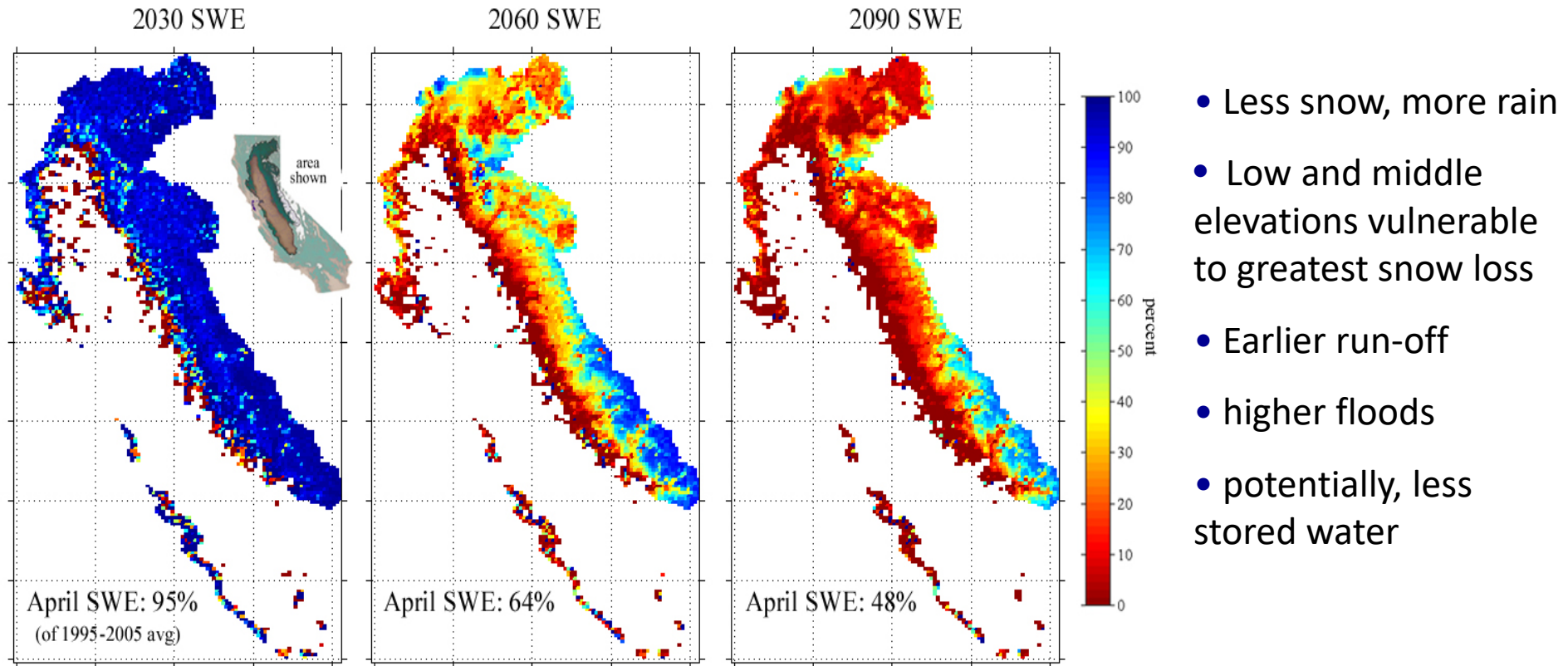
we drive VIC with LOCA downscaled  
precipitation, temperature and winds  
over the California region United



# Projected Increases (%) in higher runoff percentiles

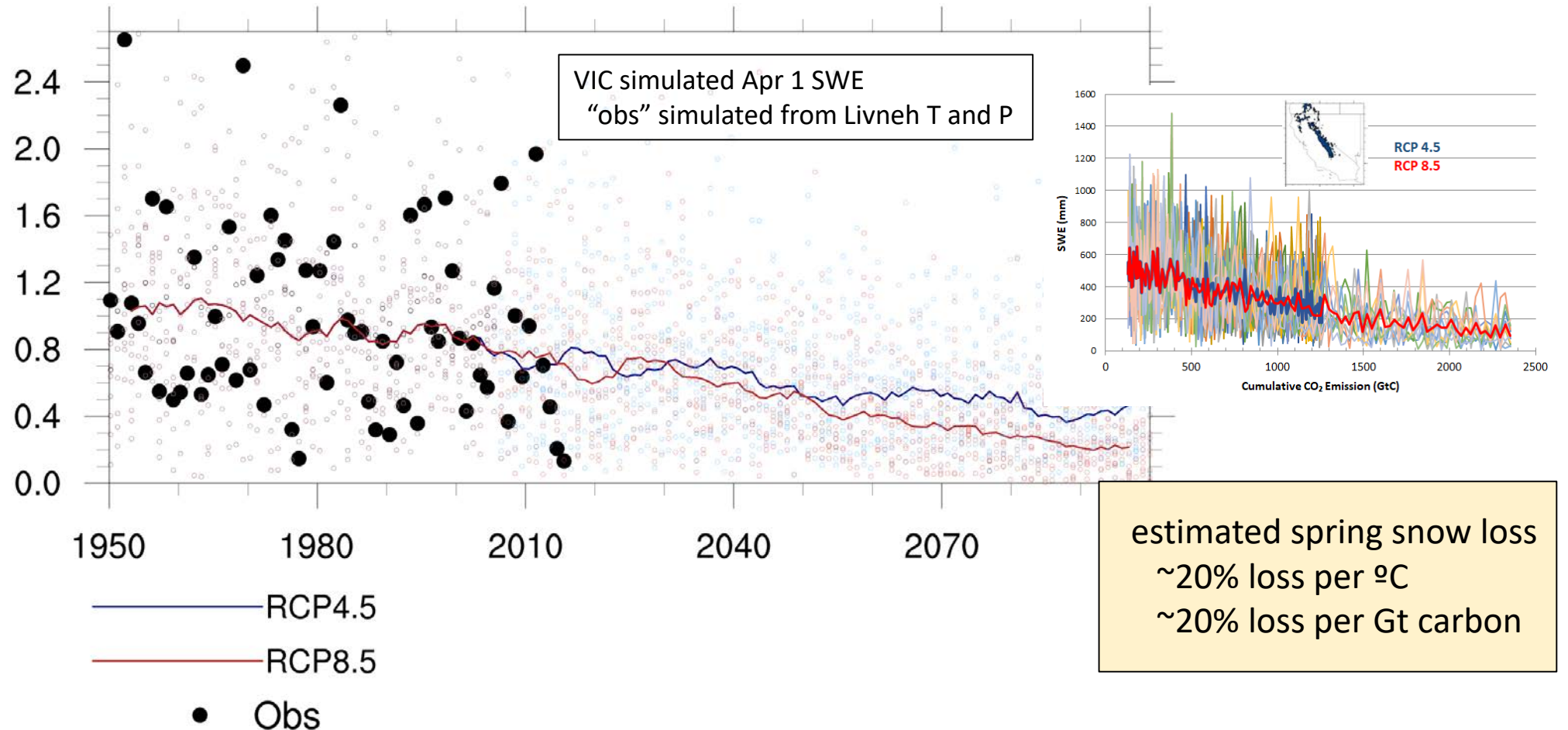


# One model: California is confronted with substantial loss of spring snowpack



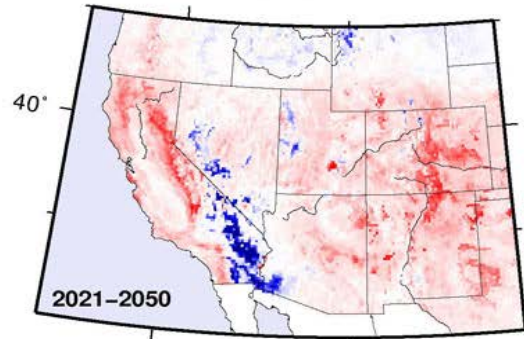
*By the end of the century California could lose more than half of its spring snow pack due to climate warming. This simulation by Noah Knowles and Dan Cayan is guided by relatively moderate warming scenario, approximately  $+2.1^{\circ}\text{C}$  by 2090 from PCM's Business-as-usual climate simulation. (a middle of the road greenhouse gas emissions scenario)*

# Spring Snow Storage Decline under projected warming



median june 1 soil moisture  
percent of historical (1971–2000) BCS D

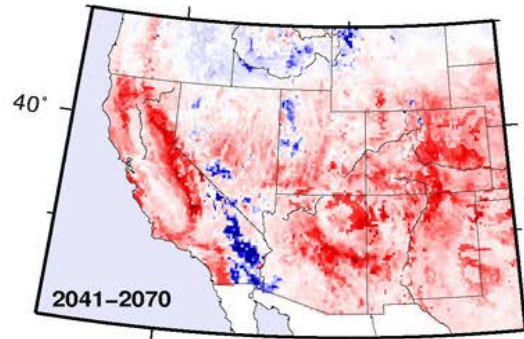
16 SRESA2



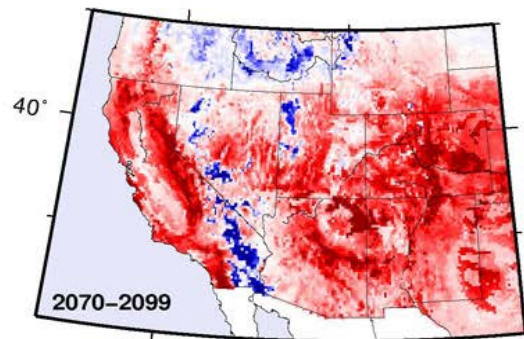
early 21st

**Drier Summer Landscapes**  
increased warming and diminished snow  
causes successively greater soil drying  
throughout 21<sup>st</sup> Century

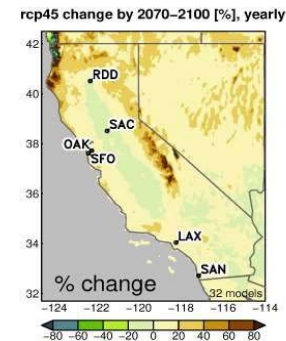
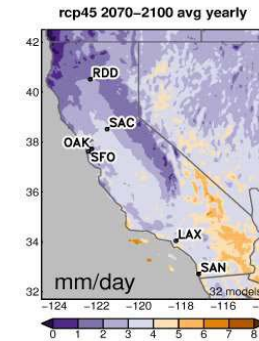
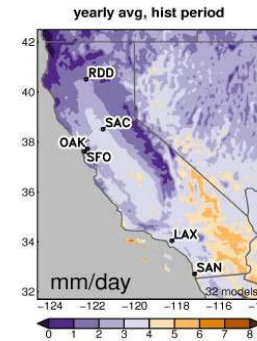
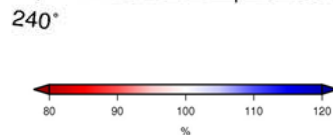
*(these projections derived from CMIP3 GCMs)*



middle 21st



late 21st



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