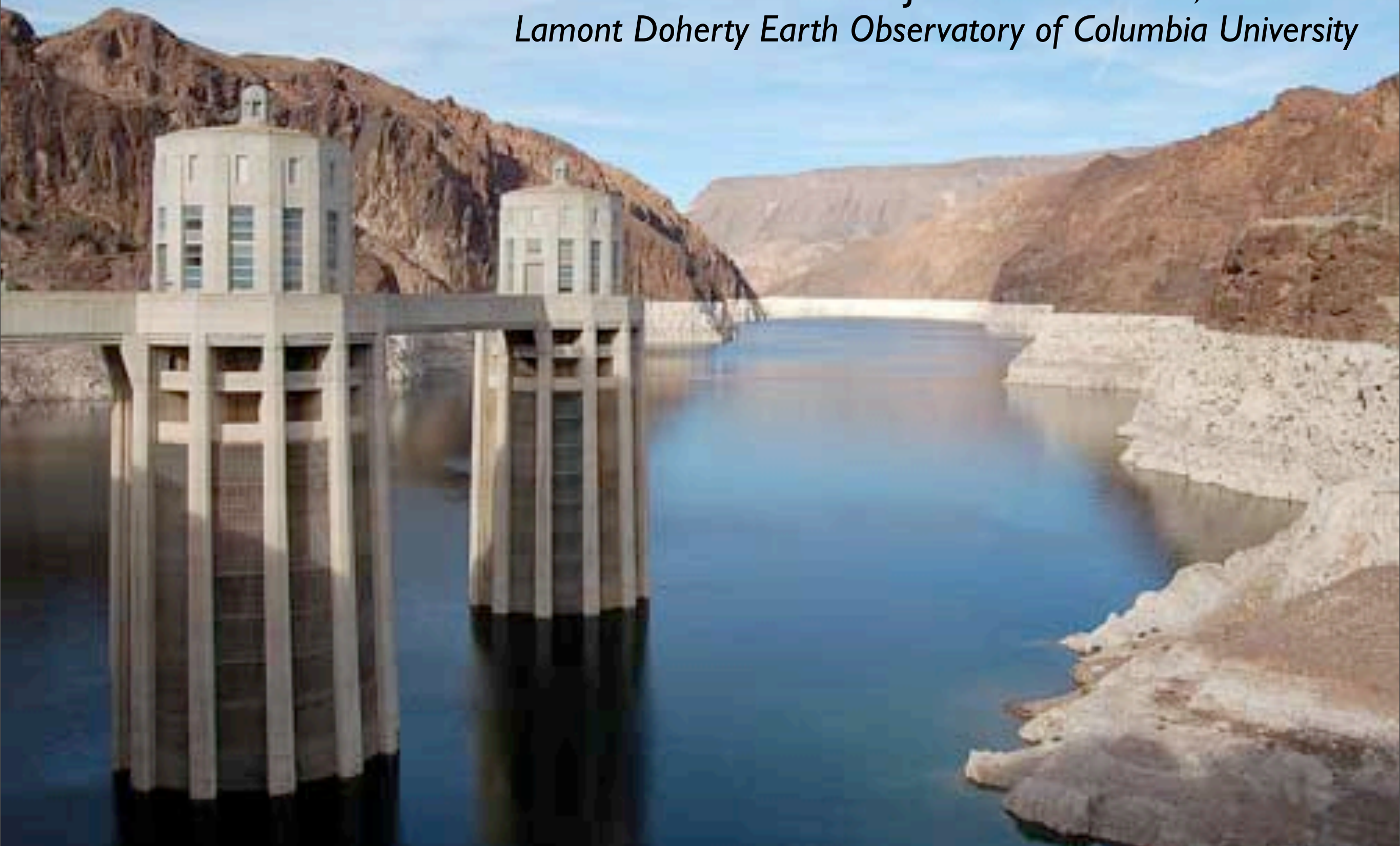


# Anthropogenic Southwest Drying CMIP5 Style

Richard Seager, Mingfang Ting, Cuihua Li, Ben Cook, Naomi Naik,  
Jennifer Nakamura, Haibo Liu  
*Lamont Doherty Earth Observatory of Columbia University*

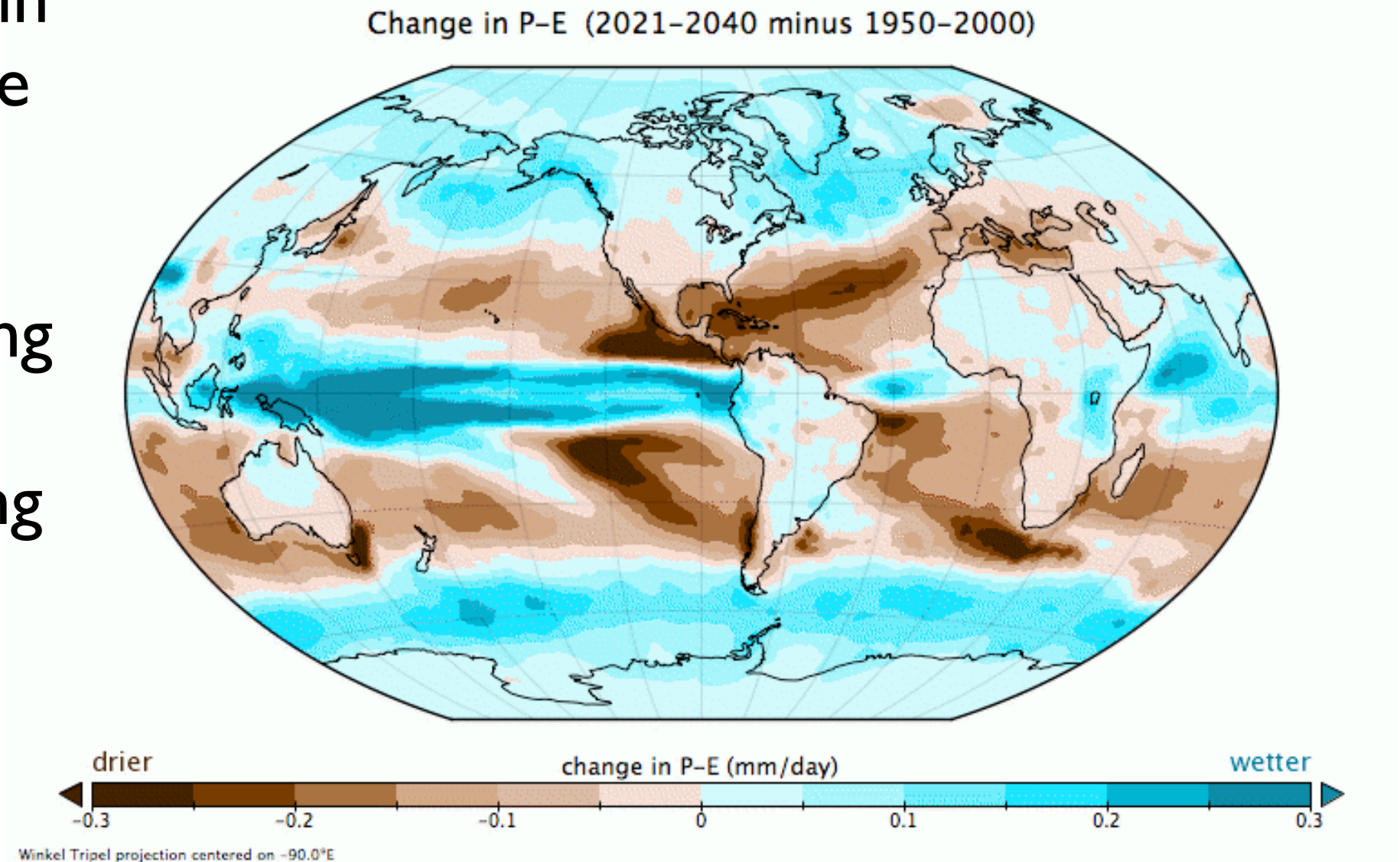




# *To recap .... greenhouse warming will impact patterns of precipitation across the planet*

Projected change in mean hydroclimate has

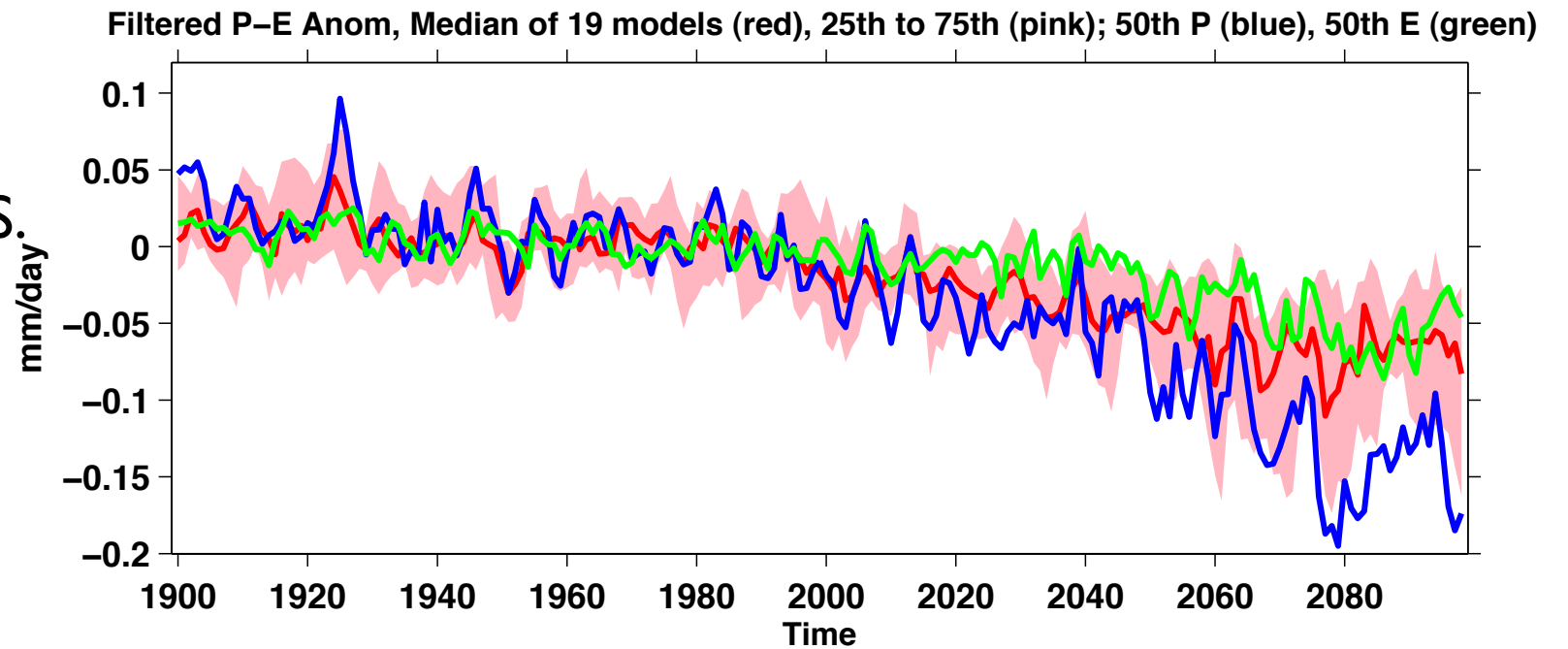
- 1) wet areas getting wetter
- 2) dry areas getting drier
- 3) subtropical dry zones expanding poleward



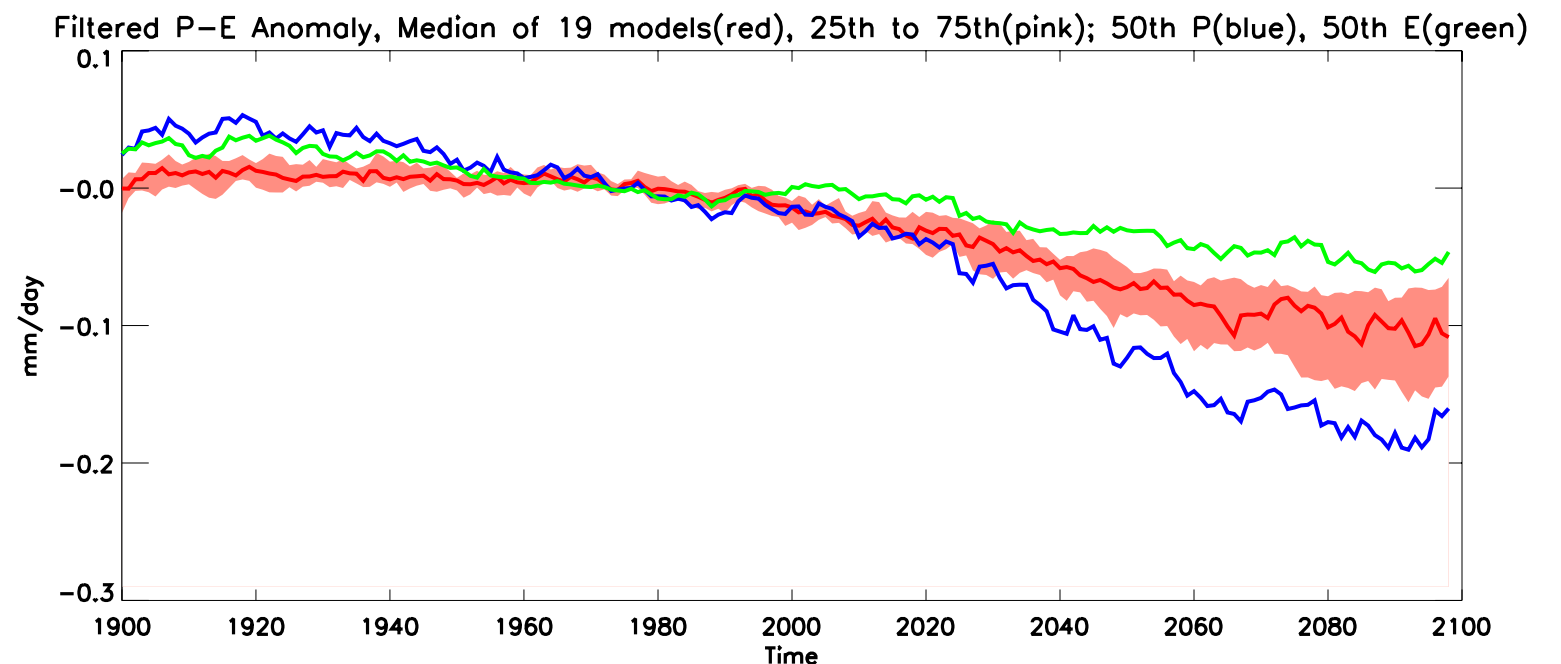
Held and Soden 2006, IPCC 2007,  
Previdi and Liepert 2007, Seager et al. 2007, 2010

In semi-arid regions IPCC AR4 models predicted a robust, imminent, and serious drying, forced by rising GHGs

Southwest U.S.  
and Mexico



land areas  
around  
Mediterranean





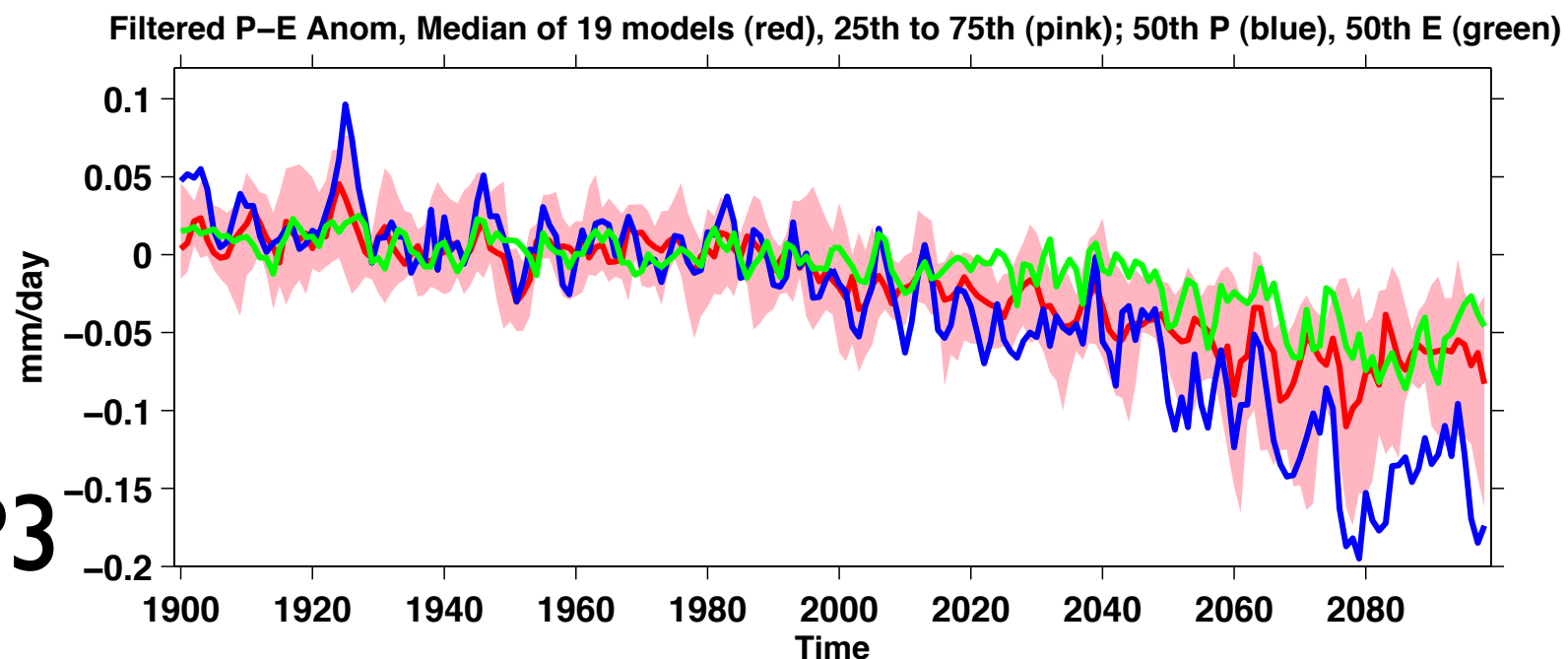
An aerial photograph of a large concrete dam with multiple spillways, situated in a mountainous region. A large reservoir is visible behind the dam, and a river flows through a forested valley in the foreground. The background features rolling hills and a prominent snow-capped mountain peak under a clear blue sky.

What about CMIP5?  
Hydrological change by water resource region?  
*P, E, P-E*, runoff, soil moisture?

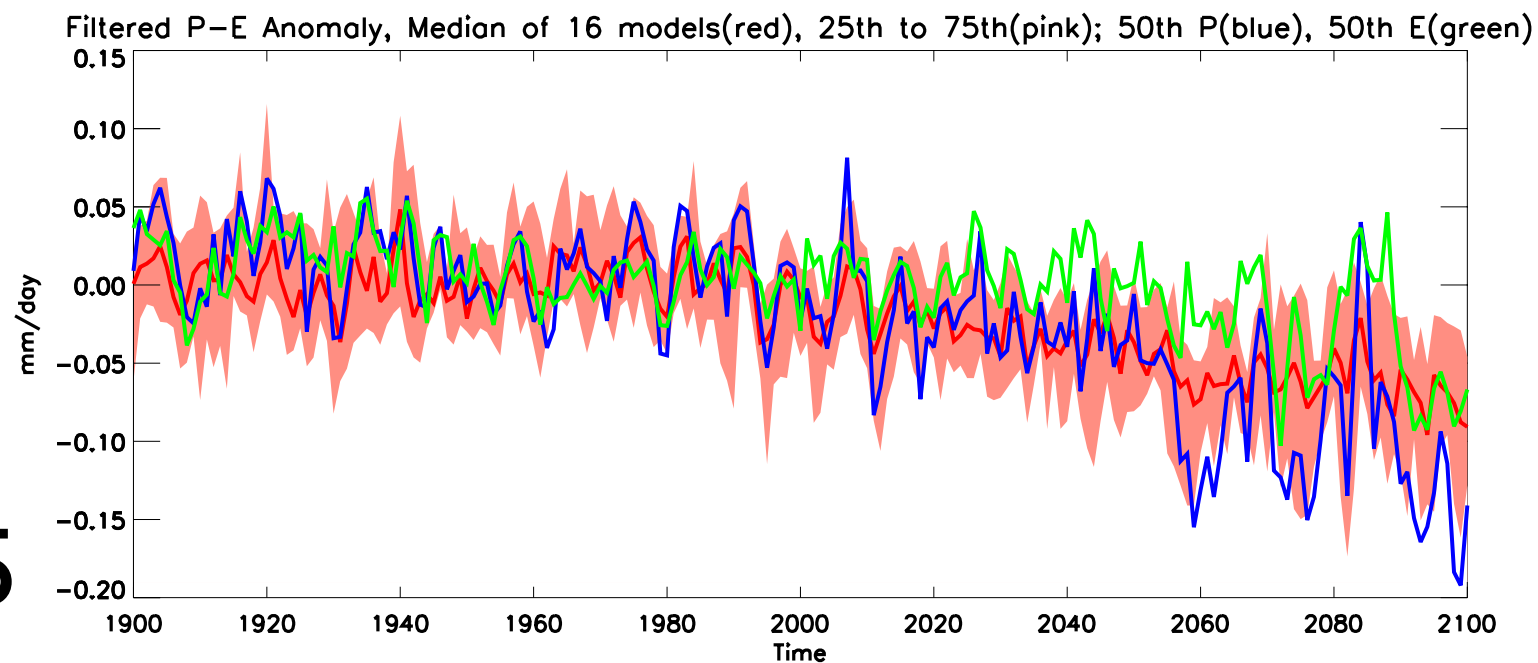


*P-E, P and E*  
averaged  
over  
southwest  
N.America  
(25-40N,  
125-95W)

CMIP3



CMIP5



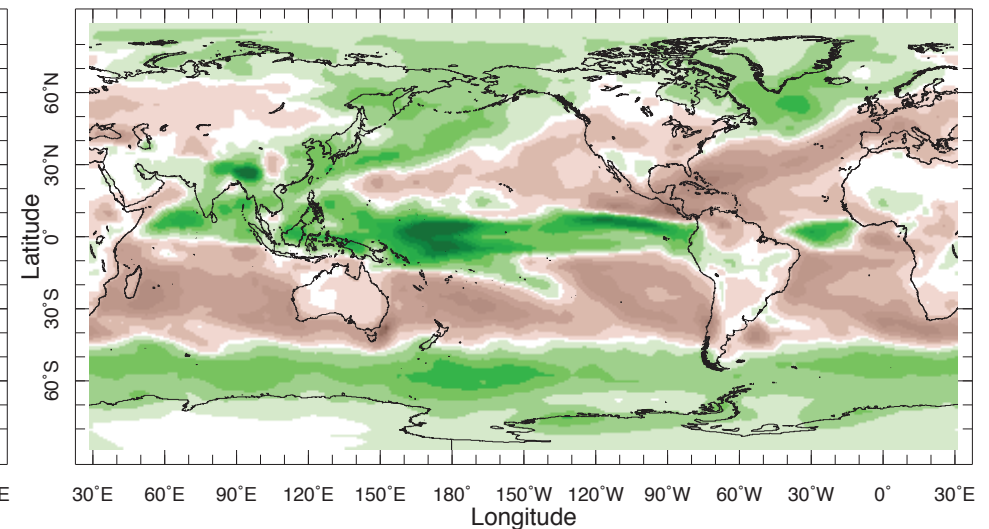
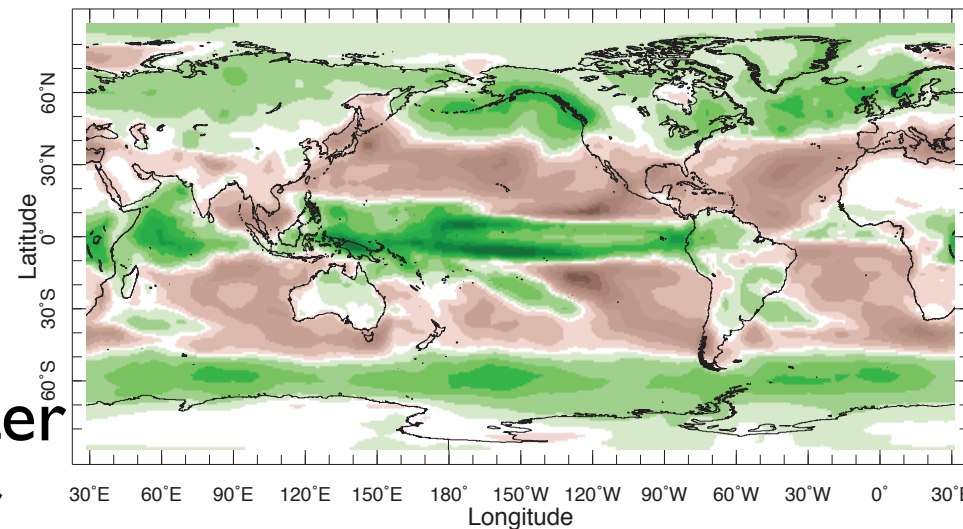
# Large scale patterns of CMIP3 and CMIP5 are very similar (except Sahel)

P-E (2021-2040) - (1951-1999)

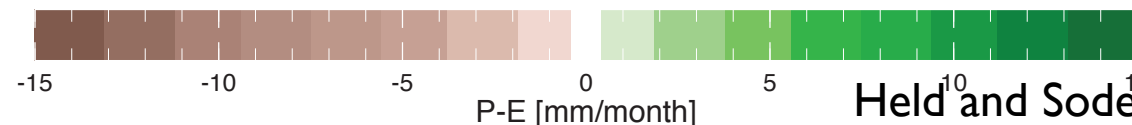
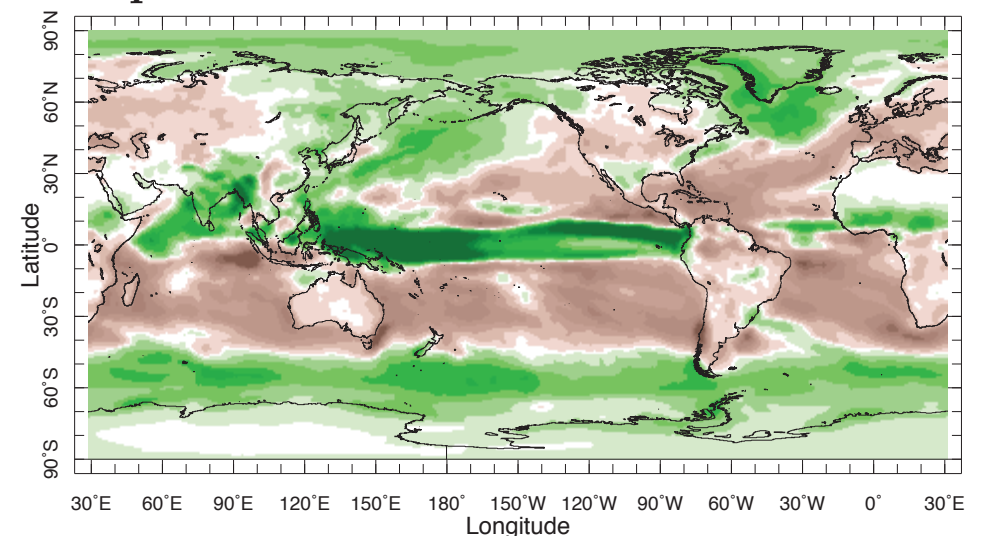
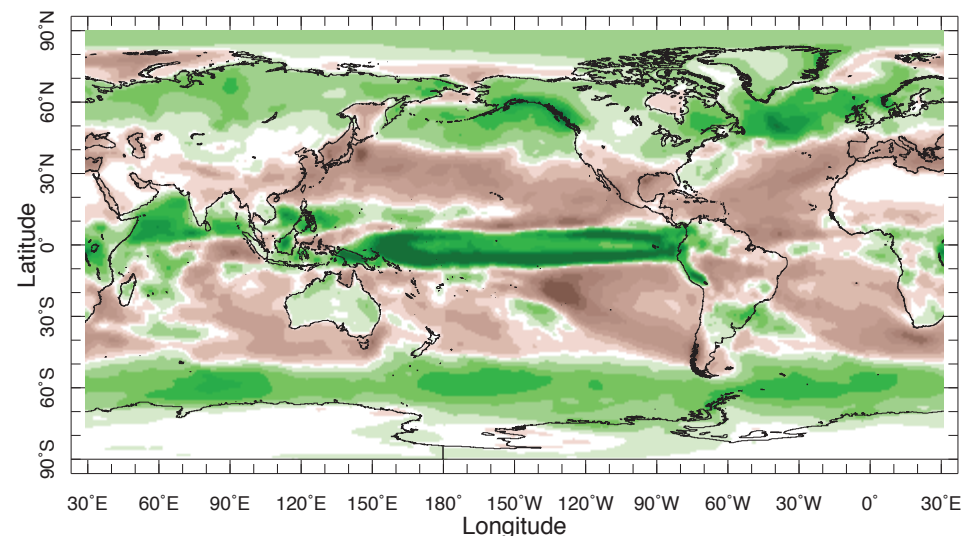
Oct-Mar

Apr-Sep

CMIP3 sresa1b



CMIP5 rcp85



Held and Soden 2006, IPCC 2007,  
Previdi and Liepert 2007, Seager et al. 2007, 2010

Still the case that:

- 1) wet areas get wetter
- 2) dry areas get drier
- 3) subtropical dry zones expand poleward

P-E (2021-2040) - (1951-1999)

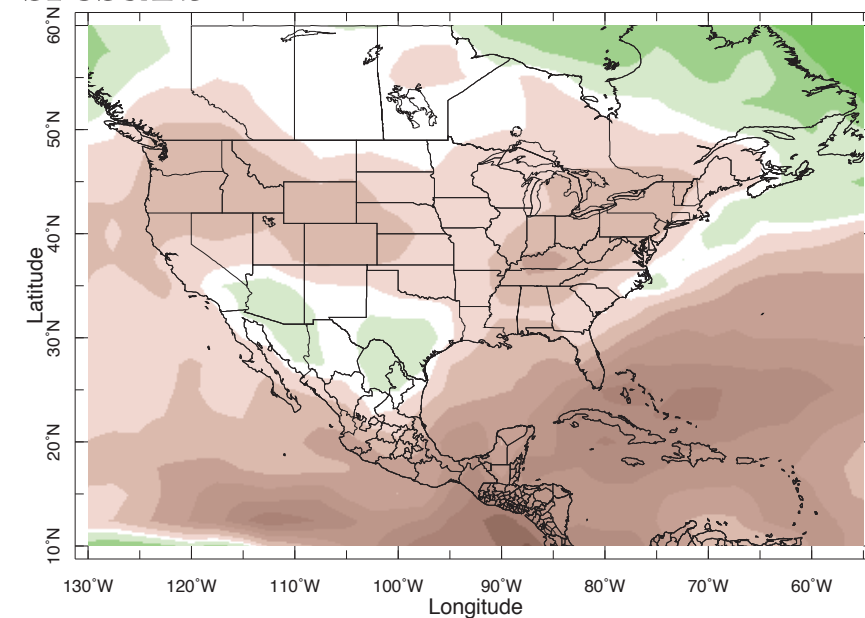
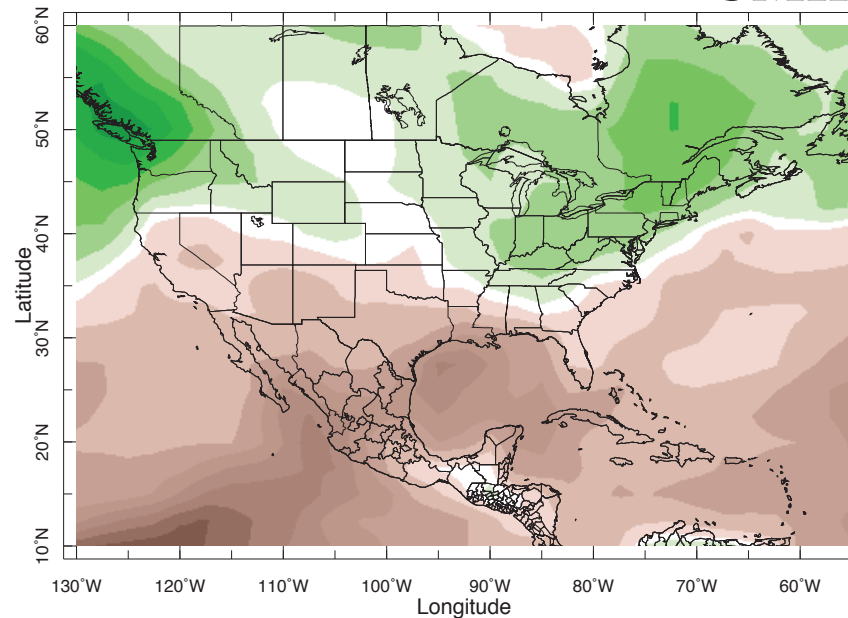
Oct-Mar

Apr-Sep

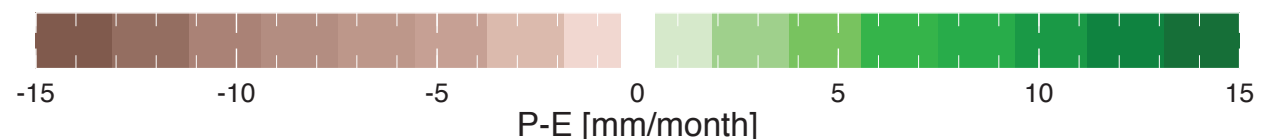
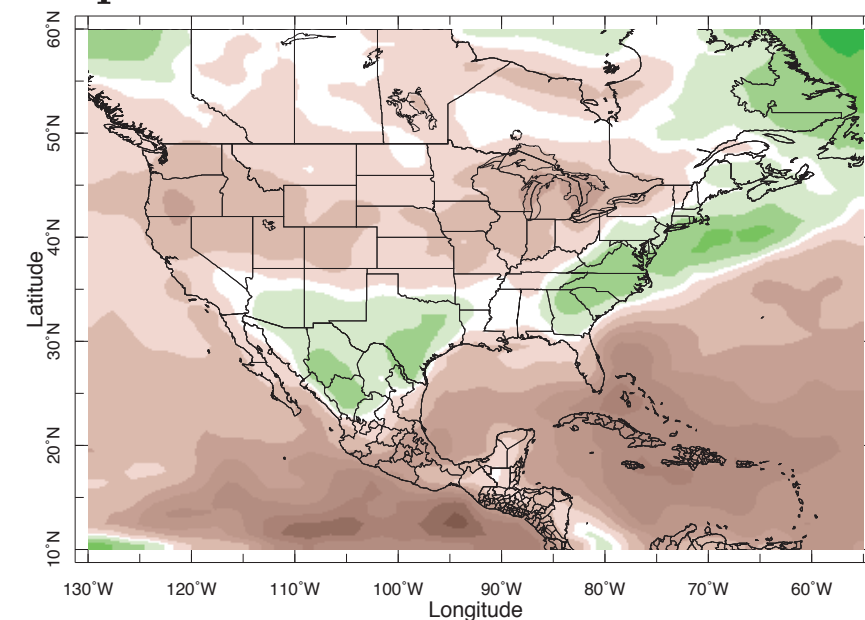
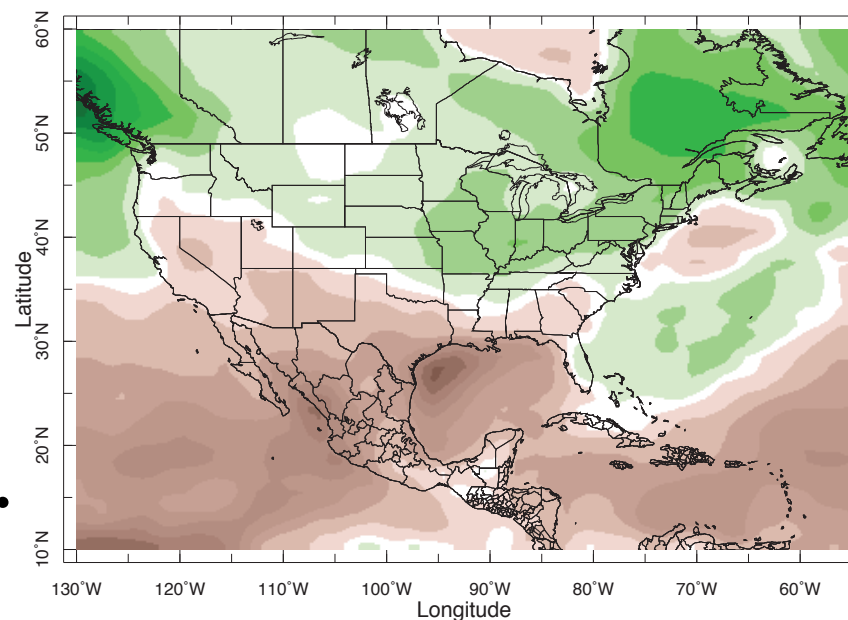
CMIP3 and CMIP5  
similarity holds up for  
Southwest N.America.

Dries in winter.  
Northern monsoon  
region and TX have  
increased P-E in  
summer.  
Impacts on agricultural  
production (irrigated,  
rain-fed), water  
resources, ecosystems ..

CMIP3 sresa1b



CMIP5 rcp85



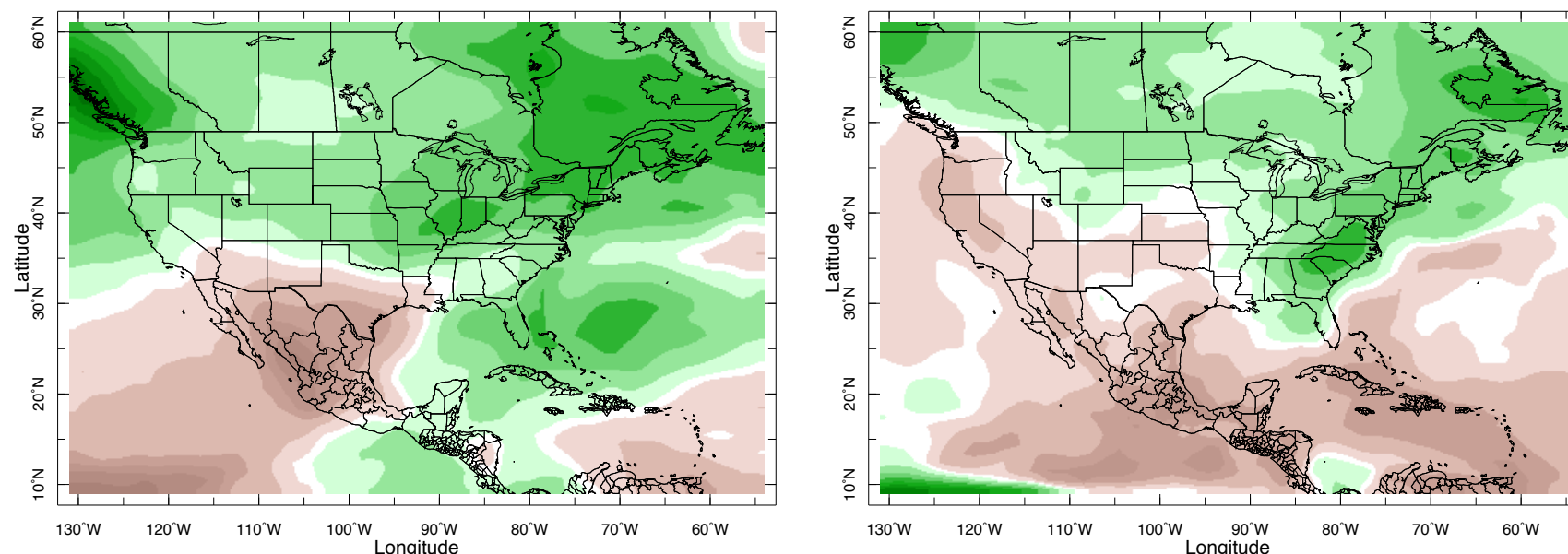
# CMIP5 rcp85 (2021-2040) - (1951-1999)

Oct-Mar

Apr-Sep

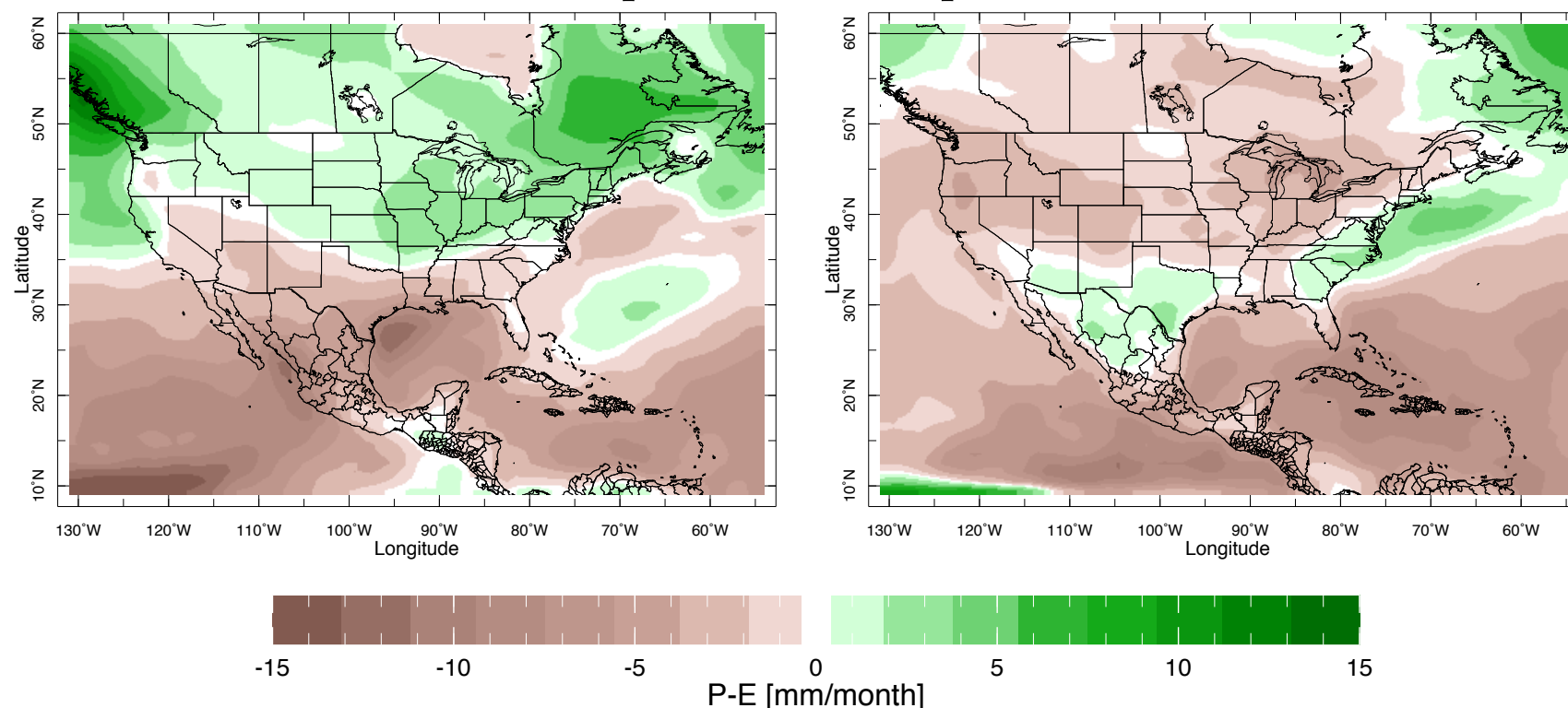
Evaporation increase  
- due to atmospheric warming - causes negative  $P-E$  region to extend poleward of negative  $P$  region

Precipitation



- most of CA, increased winter  $P$ , decreased  $P-E$   
- Texas and N. Mexico decreased summer  $P$ , increased  $P-E$

Precipitation - Evaporation





California  
imports water  
to southern  
California  
from Colorado  
River and  
moves water  
from wet north  
to dry south

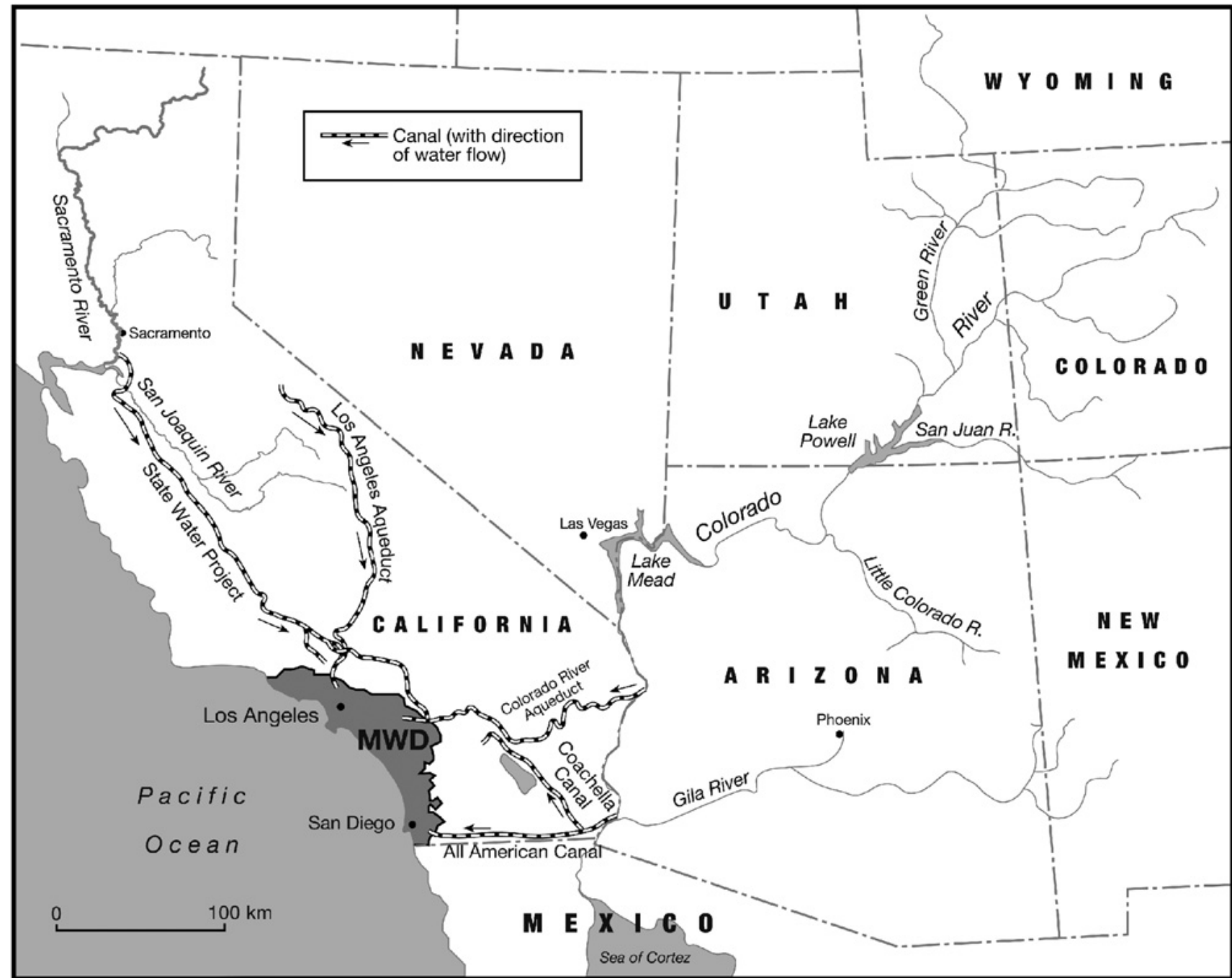


Fig. 1. Sacramento and Colorado river systems and major aqueducts supplying southern California and the Metropolitan Water District (MWD).

# State Water Project

Apparently in LA  
you can flush  
Mount Shasta  
water down your  
toilet. On its way it  
comes across the  
S.F. Bay delta -  
major ecological  
problems - and  
then up over the  
San Bernadino  
mountains.

## The Sierra

The snow pack in the Sierra Nevada range is critical to the State Water Project, which supplies much of California. Snow melt runs down rivers to replenish reservoirs along the California Aqueduct. This year's snow water content is at **98-126 percent** of normal.

The State Water Project is a system of reservoirs, aqueducts, pumps and power plants for collecting and storing water, and delivering it to water agencies throughout the state. Much of the project's water comes from the snowpack in the Sierra Nevada Mountains. Orange County also gets water from the Colorado River, the Santa Ana River and the deep aquifer beneath north and central county, managed by the Orange County Water District.

## Bay delta region

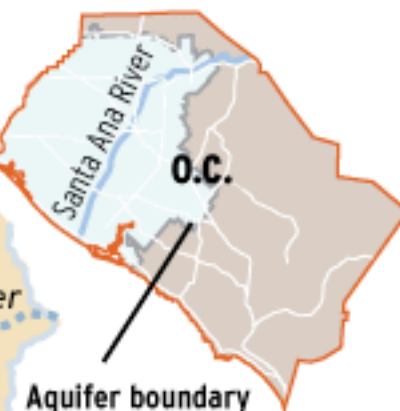
Efforts to protect native species, such as the Delta smelt, have led to restrictions on water flow out of the delta.

## Santa Ana watershed

Water from more than 2,200 square miles of land drains into the Santa Ana River, eventually to fill a huge basin behind Prado Dam. While the dam's main function is flood control, a portion of this water - up to 26,000 acre feet - is held in reserve for the Orange County Water District.

## Central valley

The California Aqueduct running down the state's midsection supplies a large portion of the imported water for Los Angeles, Orange and San Diego counties.

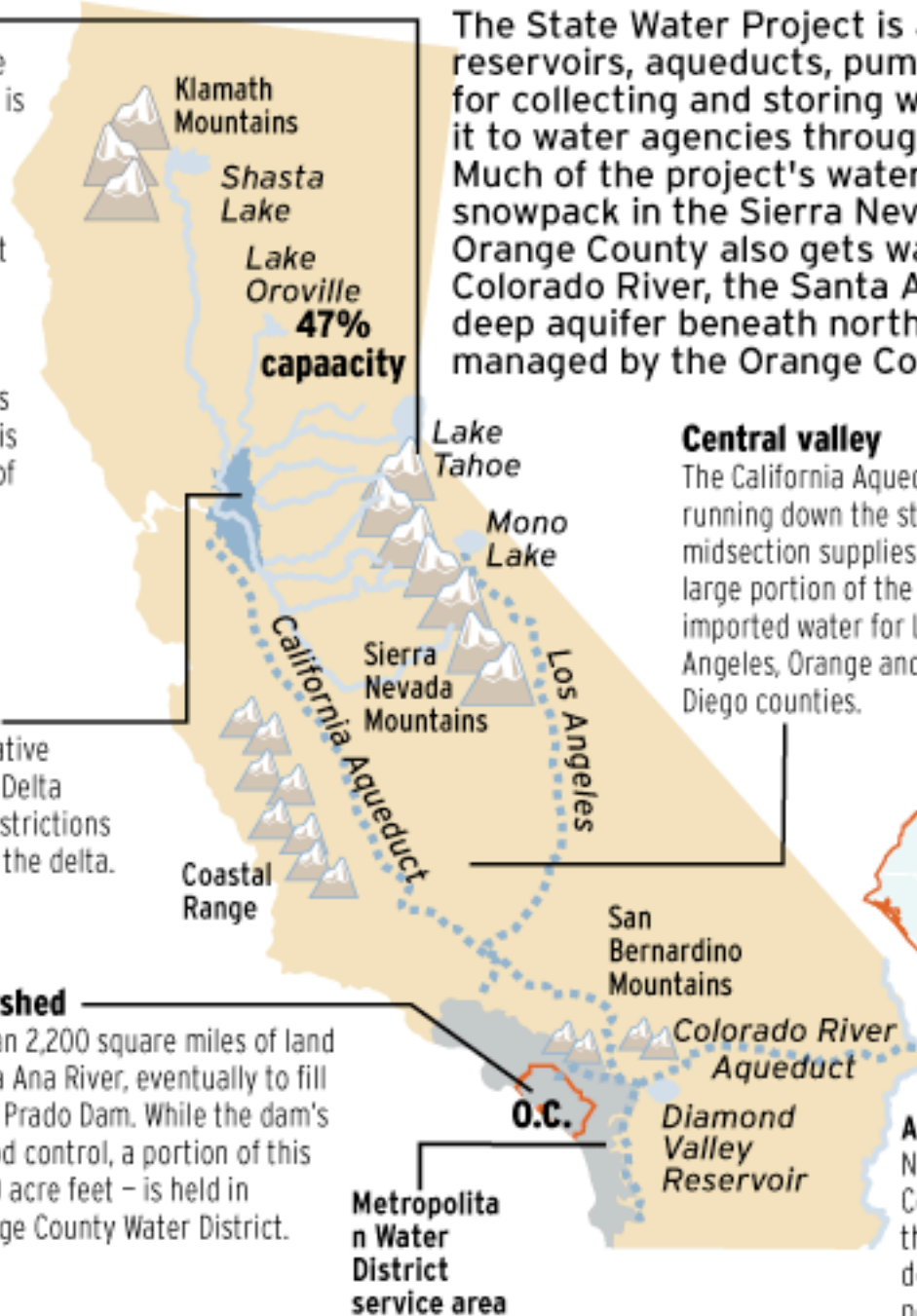


## Aquifer boundary

North and central Orange County typically gets more than half its water from the deep aquifer - at present 64 percent. Almost all of south county's supply is imported.

Sources: Orange County Water District;  
California Department of Water Resources

The Register





The Colorado River - mean annual flow about 15 maf - provides water to 7 states and Mexico (1.5 maf).

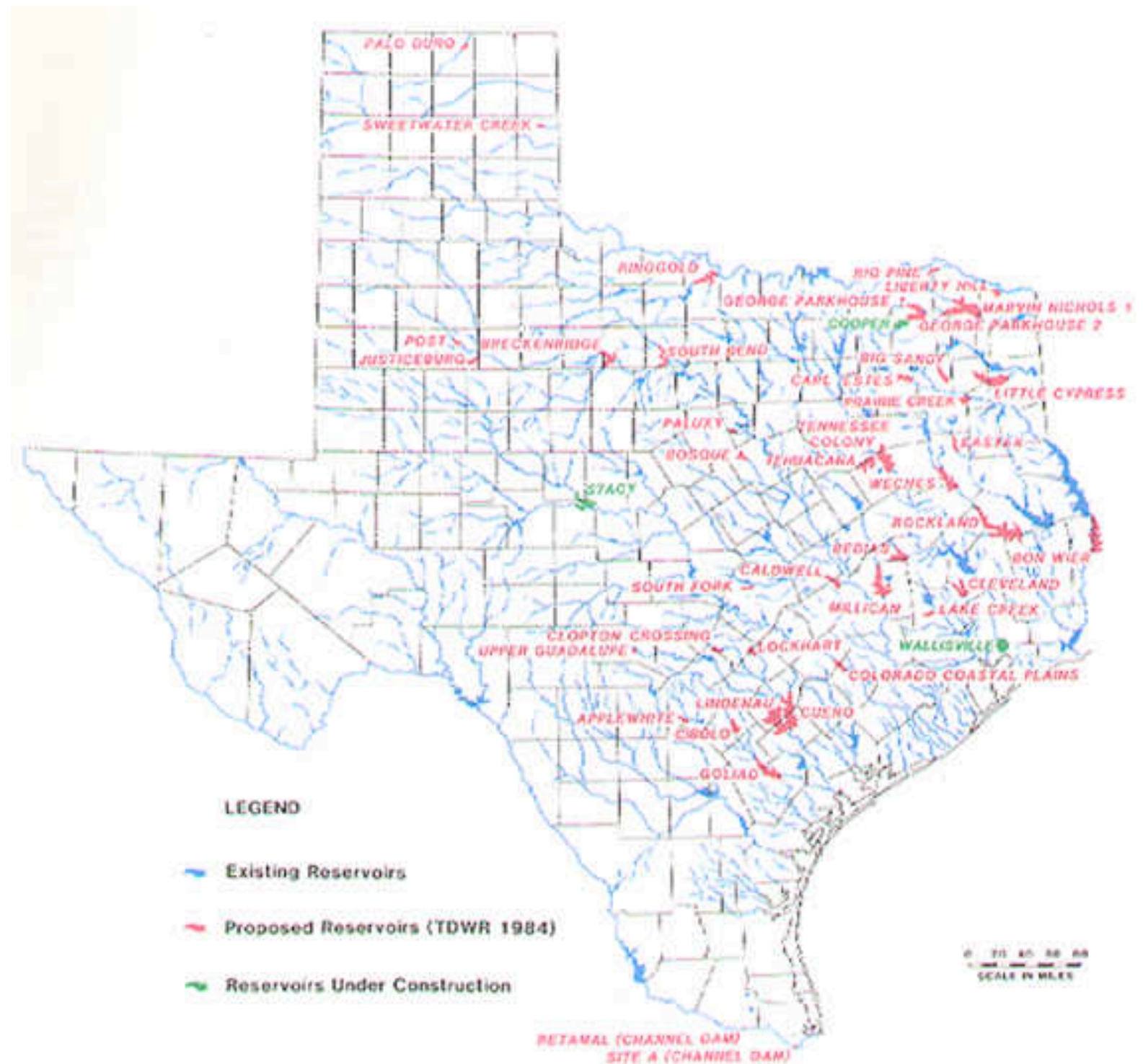
About 4.4 maf goes to CA via Colorado River aqueduct and the All American Canal.

Central Arizona Project diverts 1.5 maf to central and southern AZ (including Phoenix and Tucson).

85-90% of flow comes from snows in Colorado and Wyoming. Less than 15% of flow comes from Lower Basin tributaries but 60% of use is in the Lower Basin. Sort of like The Nile.



Texas relies for its water on a network of in-state reservoirs, a few on rivers flowing across borders, and extensive (unsustainable) groundwater extraction from aquifers





# Focus on 3 regions

## **CA/NV**

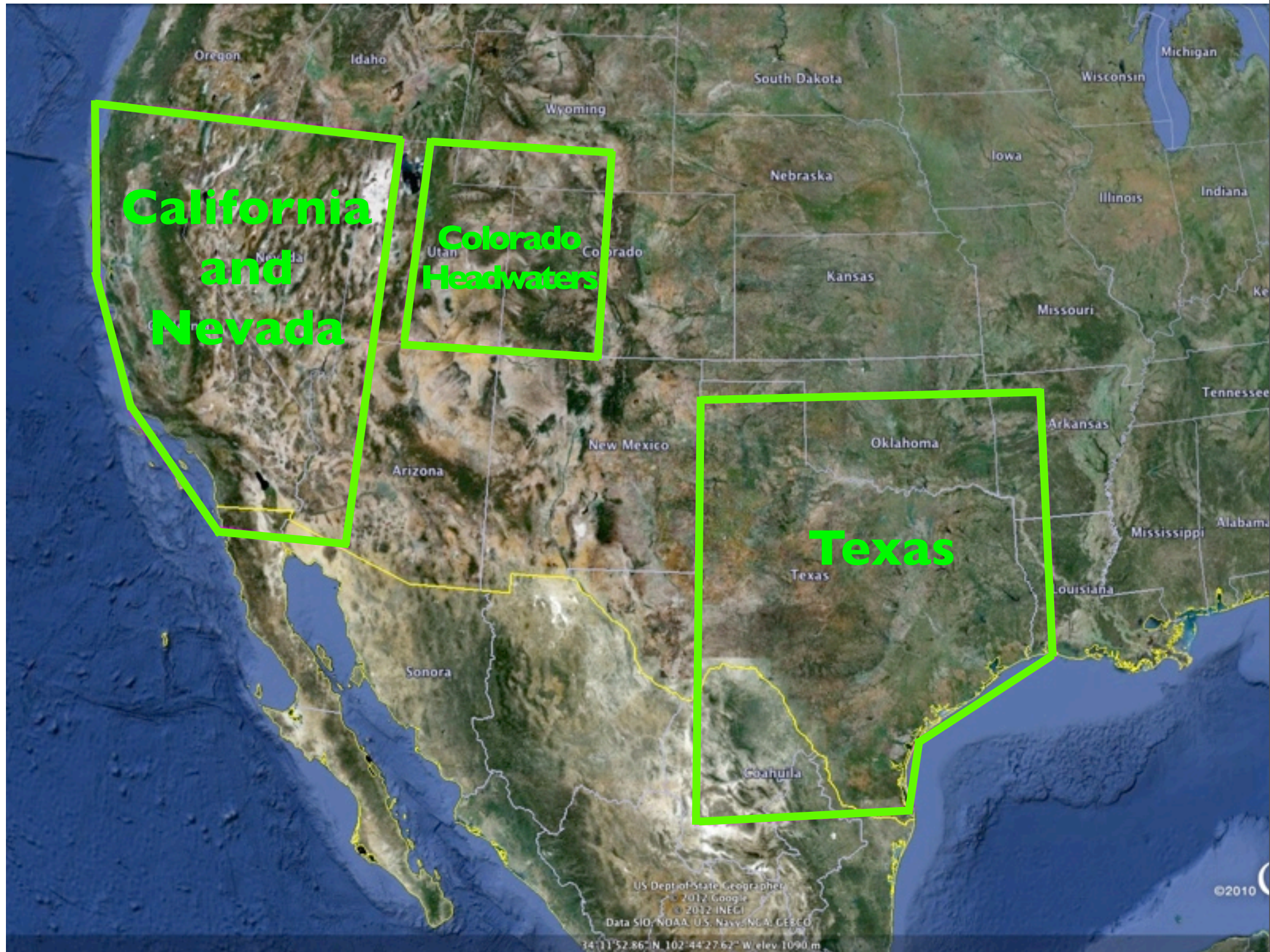
Winter *P*, dry  
summers

## **Colorado headwaters**

Winter *P* but  
summer storms. CR  
provides water for 7  
states plus Mexico

## **Texas**

winter storms  
and summer  
'monsoonal' *P*.  
Self sufficient  
in water.



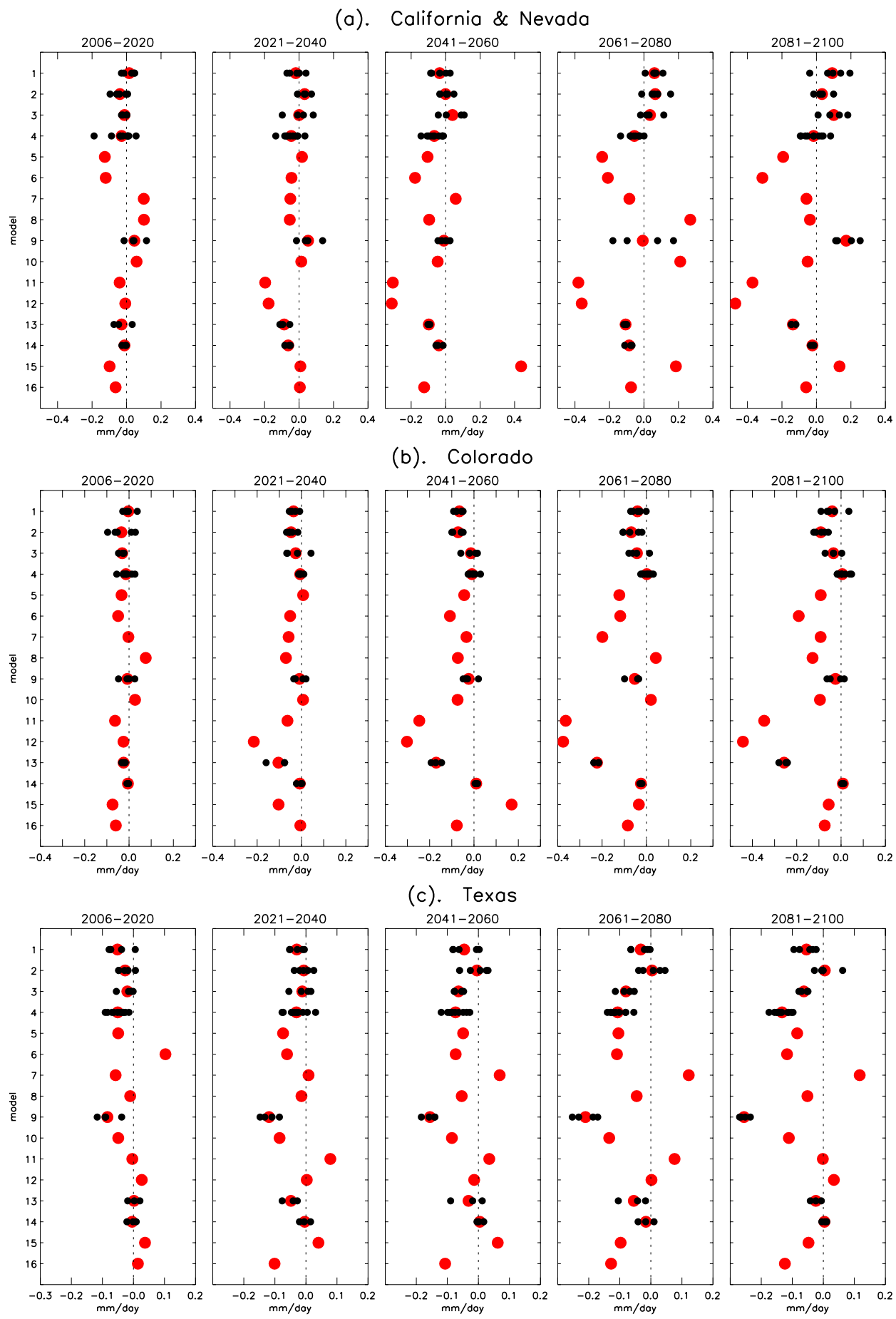


# Change in $P-E$ for all simulations of all models by two-decade 21st C periods

California + Nevada

Colorado headwaters

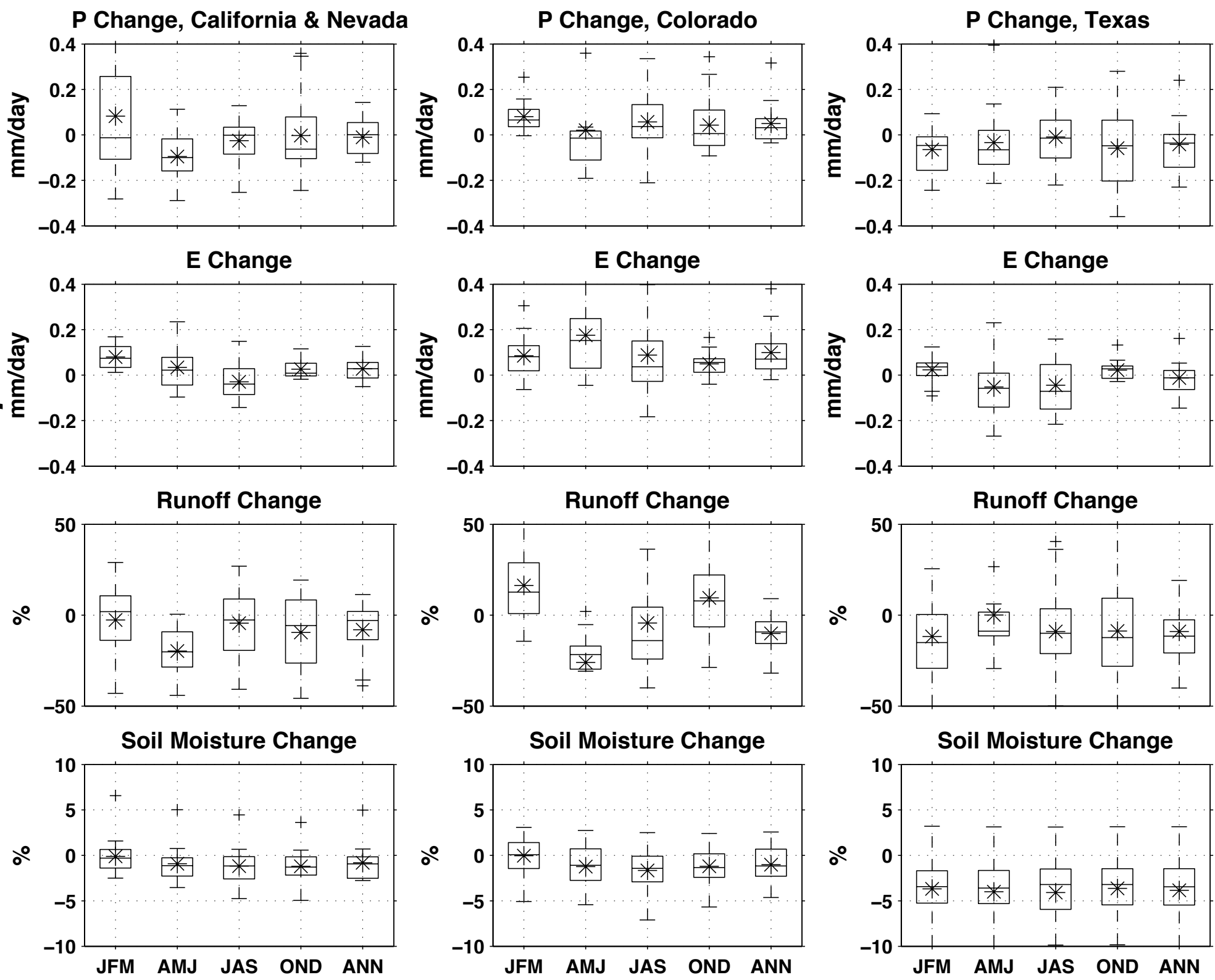
Texas





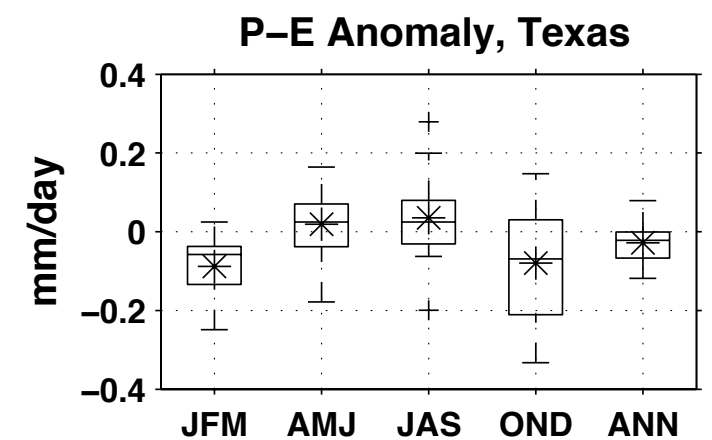
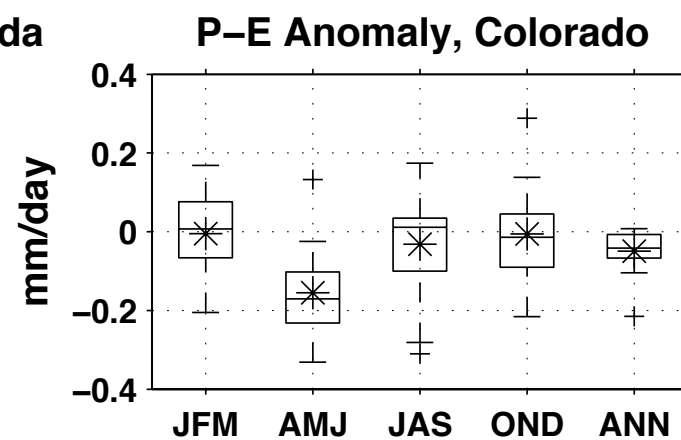
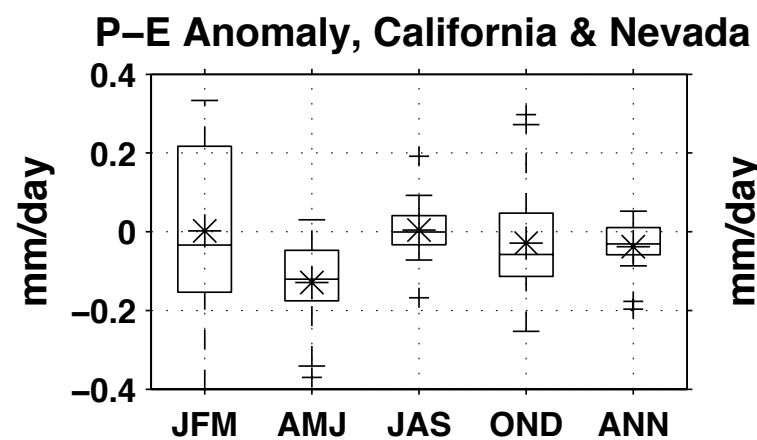
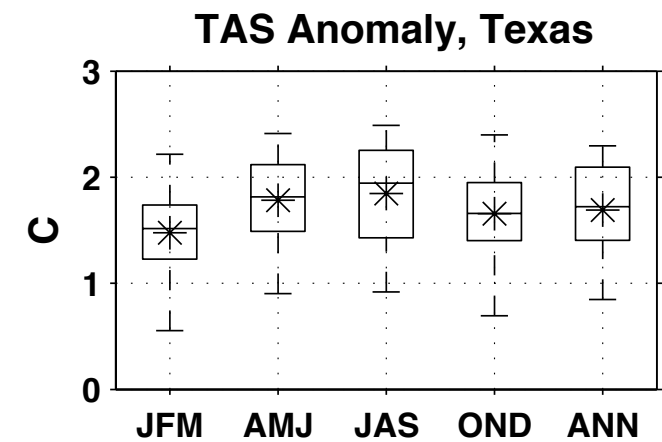
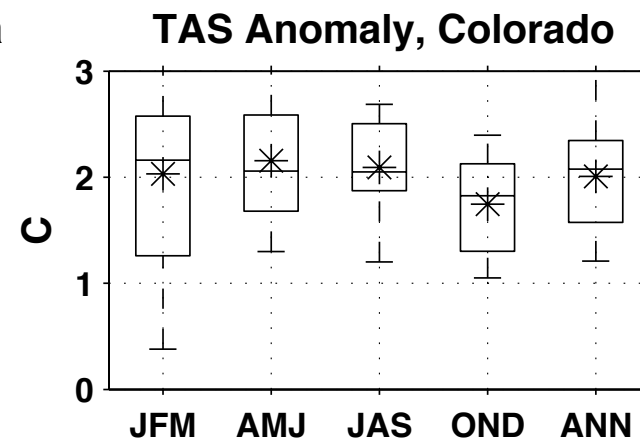
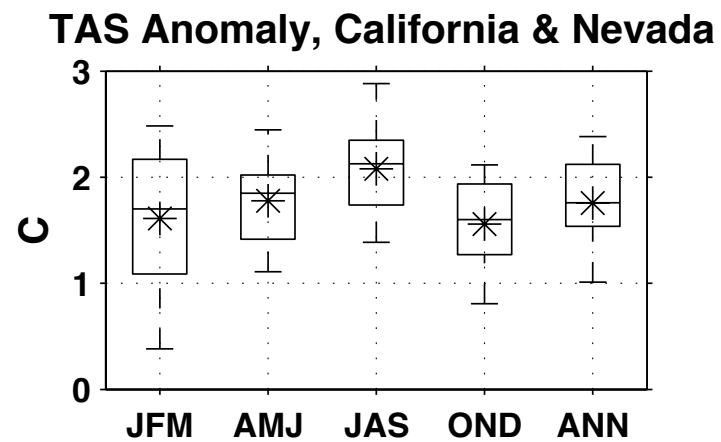
Seasonal changes for 2021-2040

Drops in runoff throughout year in CA/NV and TX and in spring for CR. Modest drops in soil moisture for all regions.



Every simulation warms in every season in every region, contributing to drop in  $P-E$

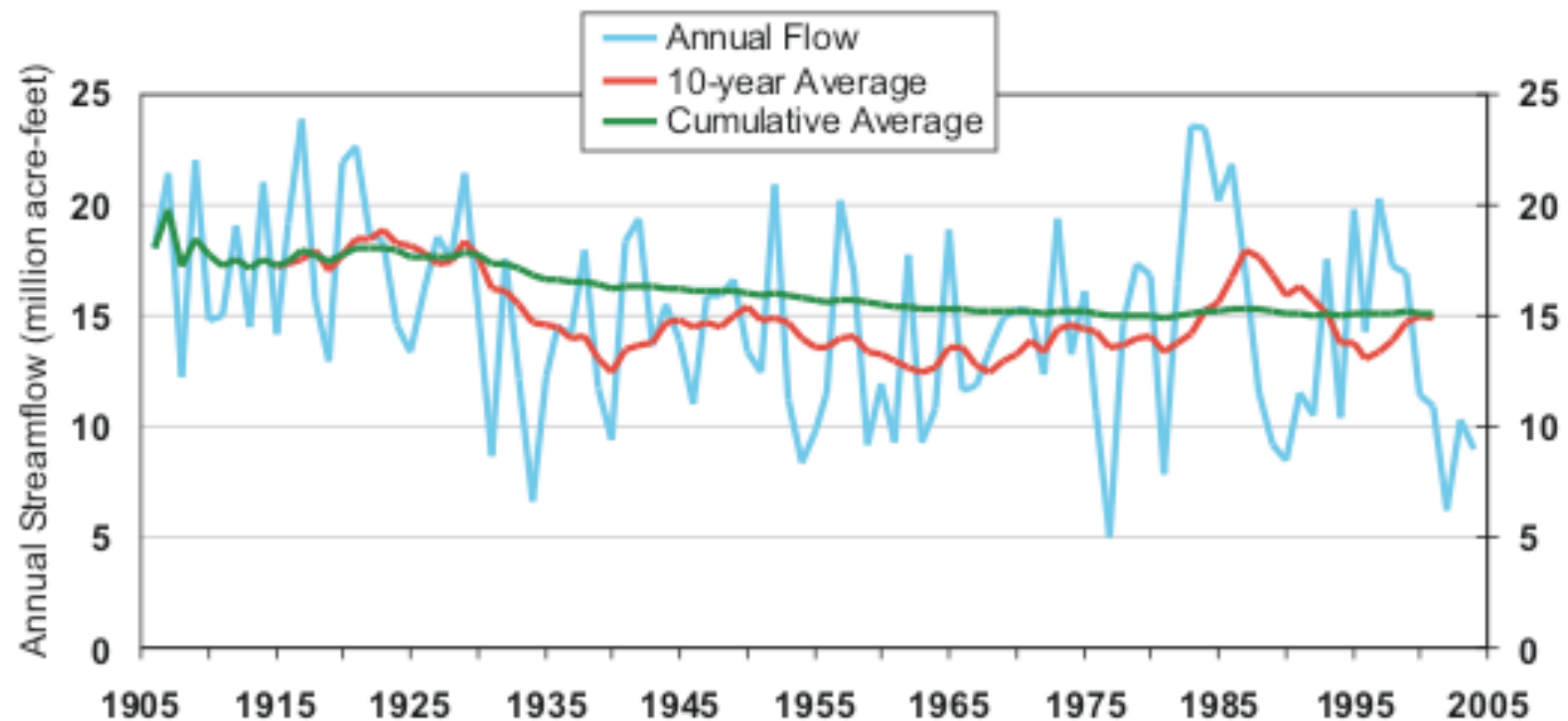
However TX has increased JAS  $P-E$  but reduced  $P$





*As point of comparison ...*

## Natural Colorado River Flow at Lee's Ferry



1906-2004 average = 15 maf

10 year average varies 12.4 to 18 maf (i.e. 17-20%)

Projected 2021-2040 annual mean decline about 10%



# Conclusions

CMIP5 results confirm CMIP3 results of Southwest drying in coming decades - both pattern and amplitude

For CA/NV and CR winter increases in P cannot overwhelm increased E and spring and annual mean runoff declines

For TX P drops year-round and can cause E to drop such that P-E increases in summer but annual mean runoff declines

As multidecadal means, changes in runoff comparable in amplitude to past multidecadal variability

