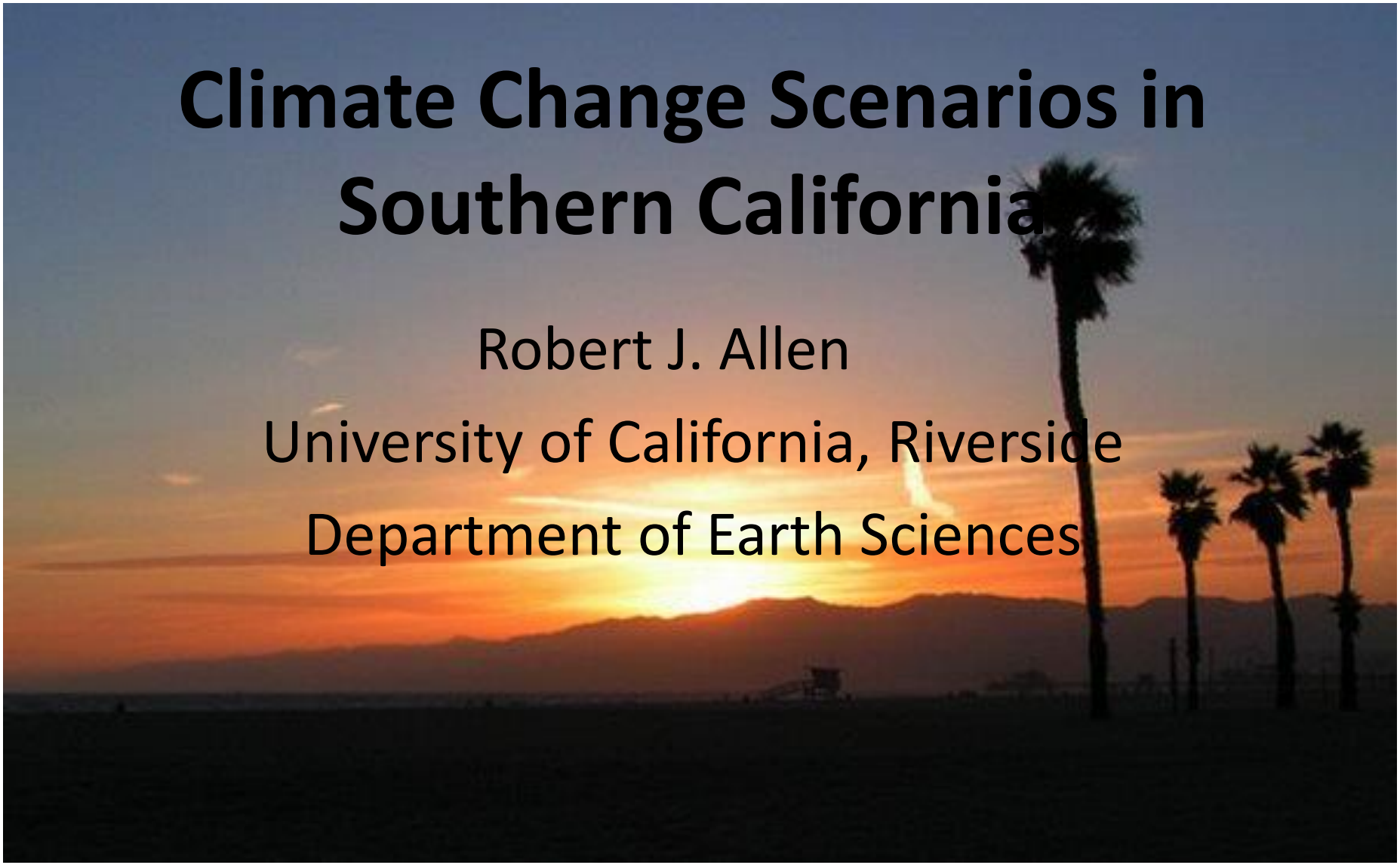


Climate Change Scenarios in Southern California

Robert J. Allen

University of California, Riverside

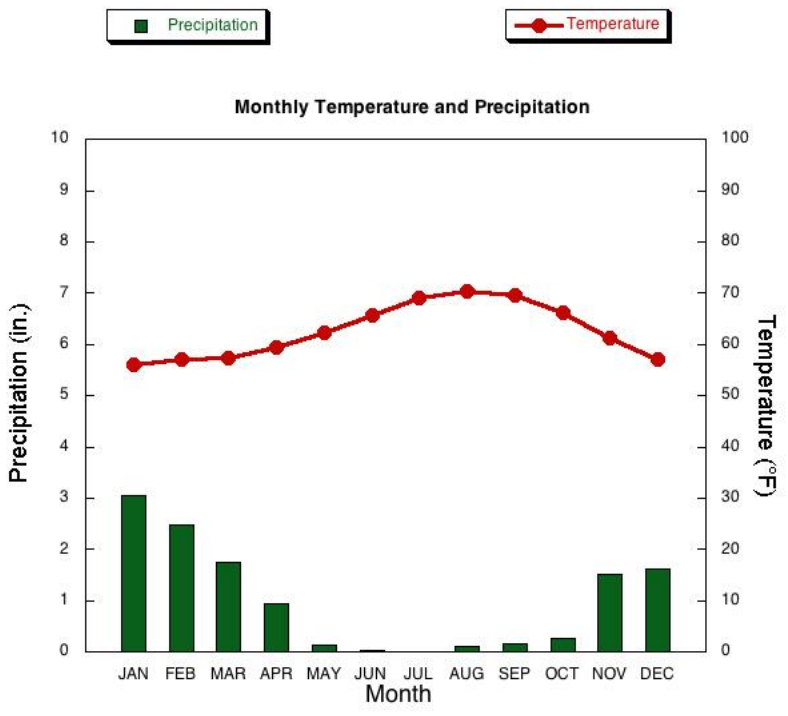
Department of Earth Sciences

Overview

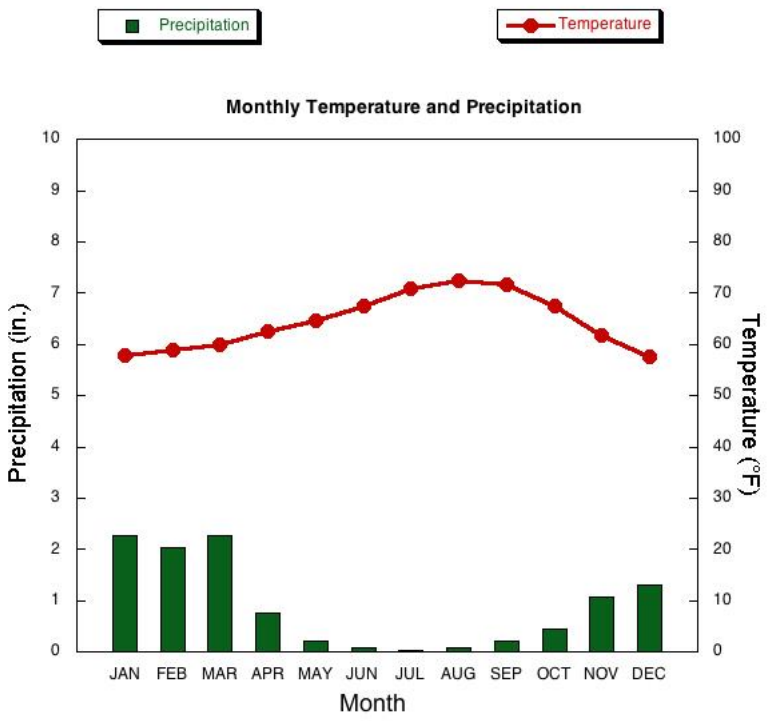
- Climatology of Southern California
  - Temperature and precipitation
  - Importance of mid-latitude cyclones and ENSO
- Climate Models & GHG Emission Scenarios
  - Coupled Model Intercomparison Project phase 3 (**CMIP3**)
  - Bias Corrected Spatially Downscaled CMIP3 (**BCSD-CMIP3**)
  - North American Regional Climate Change Assessment Program (**NARCCAP**)
  - **CMIP5**
- SoCal Climate Change by 2100:
  - Highly significant, robust projection → **2-4°C warming**
  - Less certain projection → **decreased precipitation, runoff, streamflow, soil moisture**
  - For medium and medium-high emissions scenarios, **precipitation reduction becomes *significant at 5-10%***.
  - Why models may underestimate this decrease

Climatology of Southern California

Los Angeles



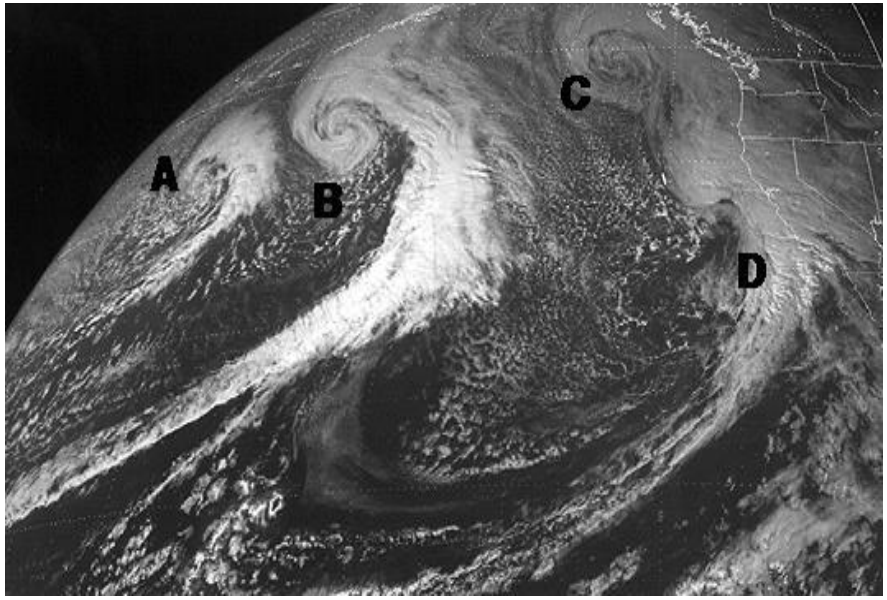
San Diego



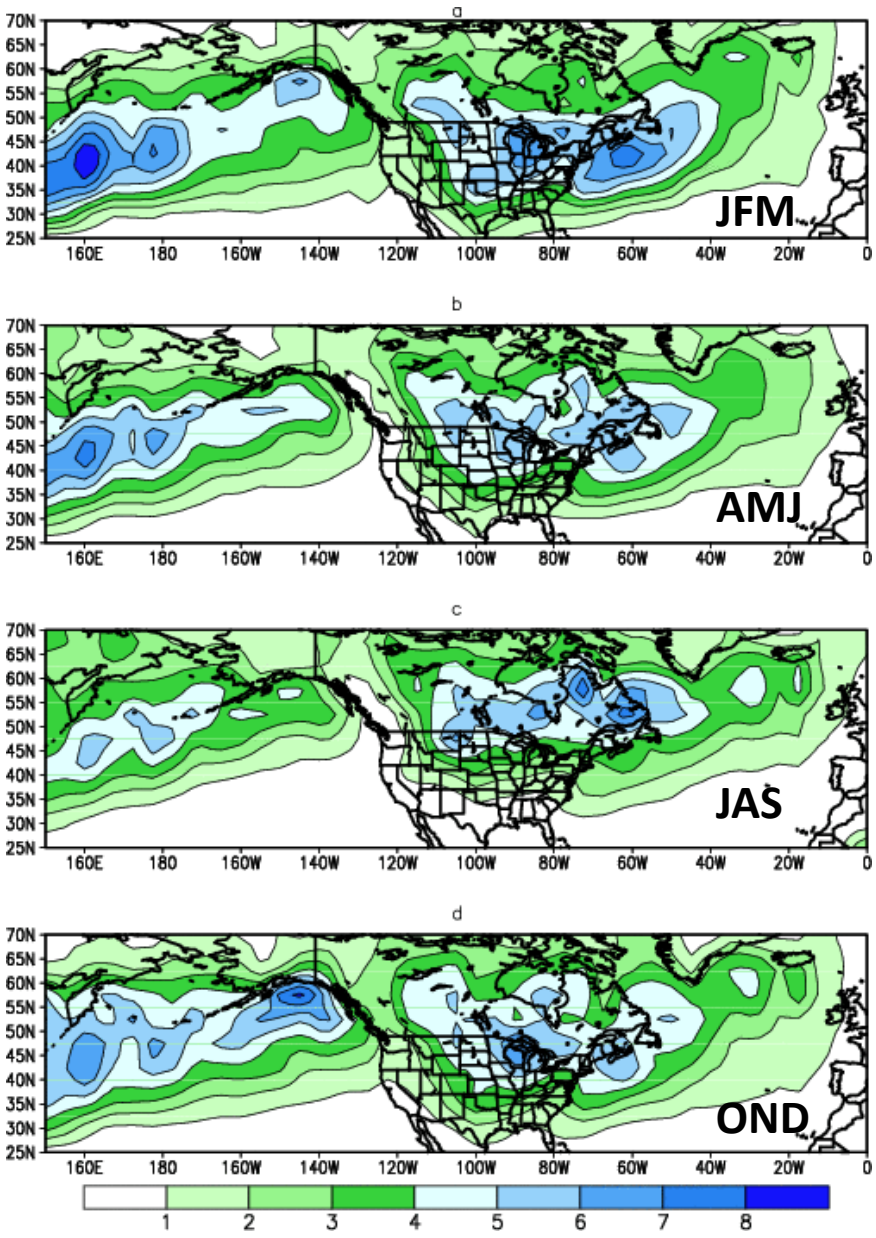
- **Mediterranean climate** → hot, dry summers and mild, relatively wet winters
- Most precipitation occurs during winter/early spring due to large-scale mid-latitude cyclones propagating westward from the Pacific Ocean

http://drought.unl.edu/archive/climographs

Importance of Midlatitude Cyclones/Storm Tracks

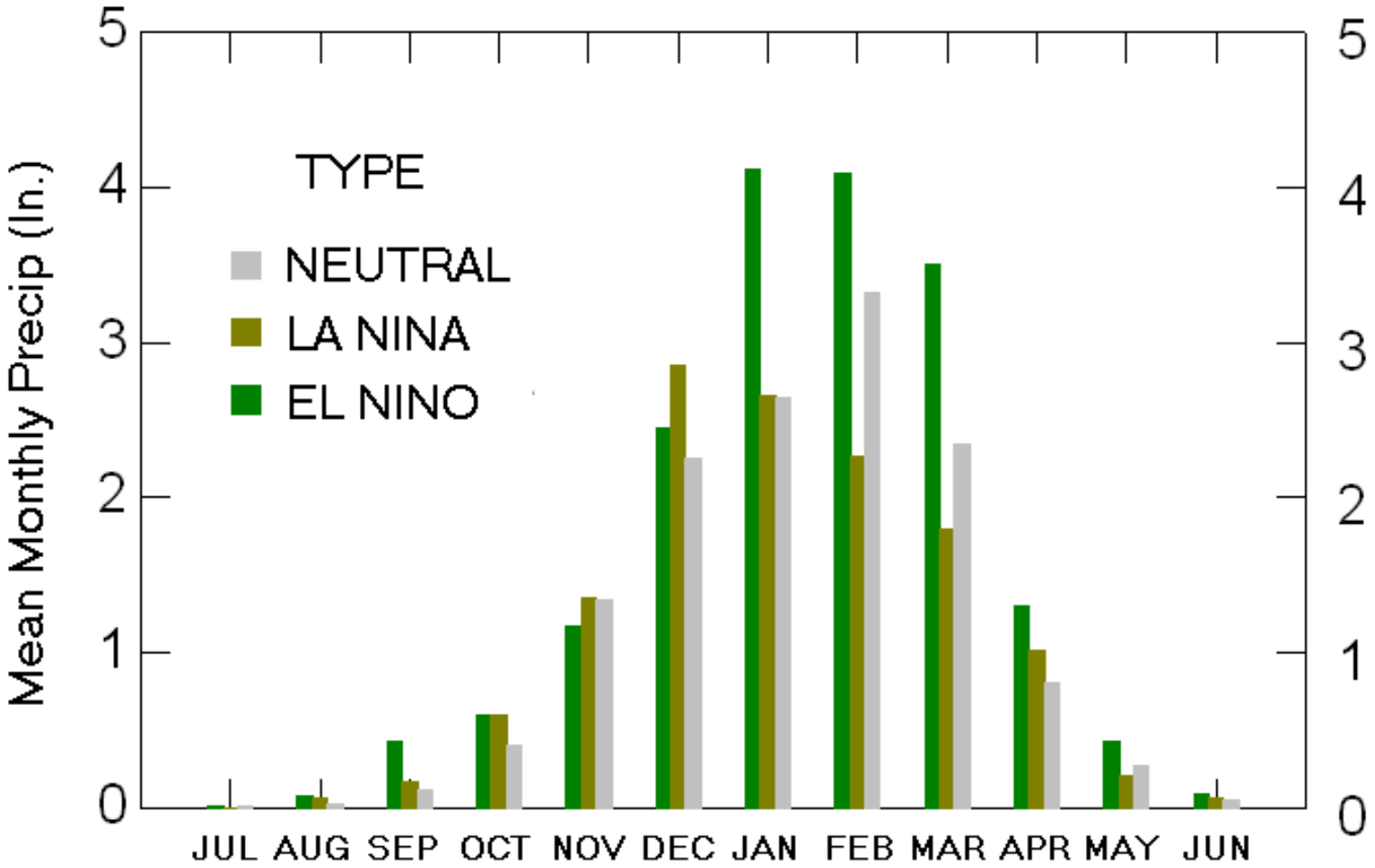


Most precipitation in SoCal comes from **mid-latitude cyclones**, especially during winter/late spring



Climate Prediction Center

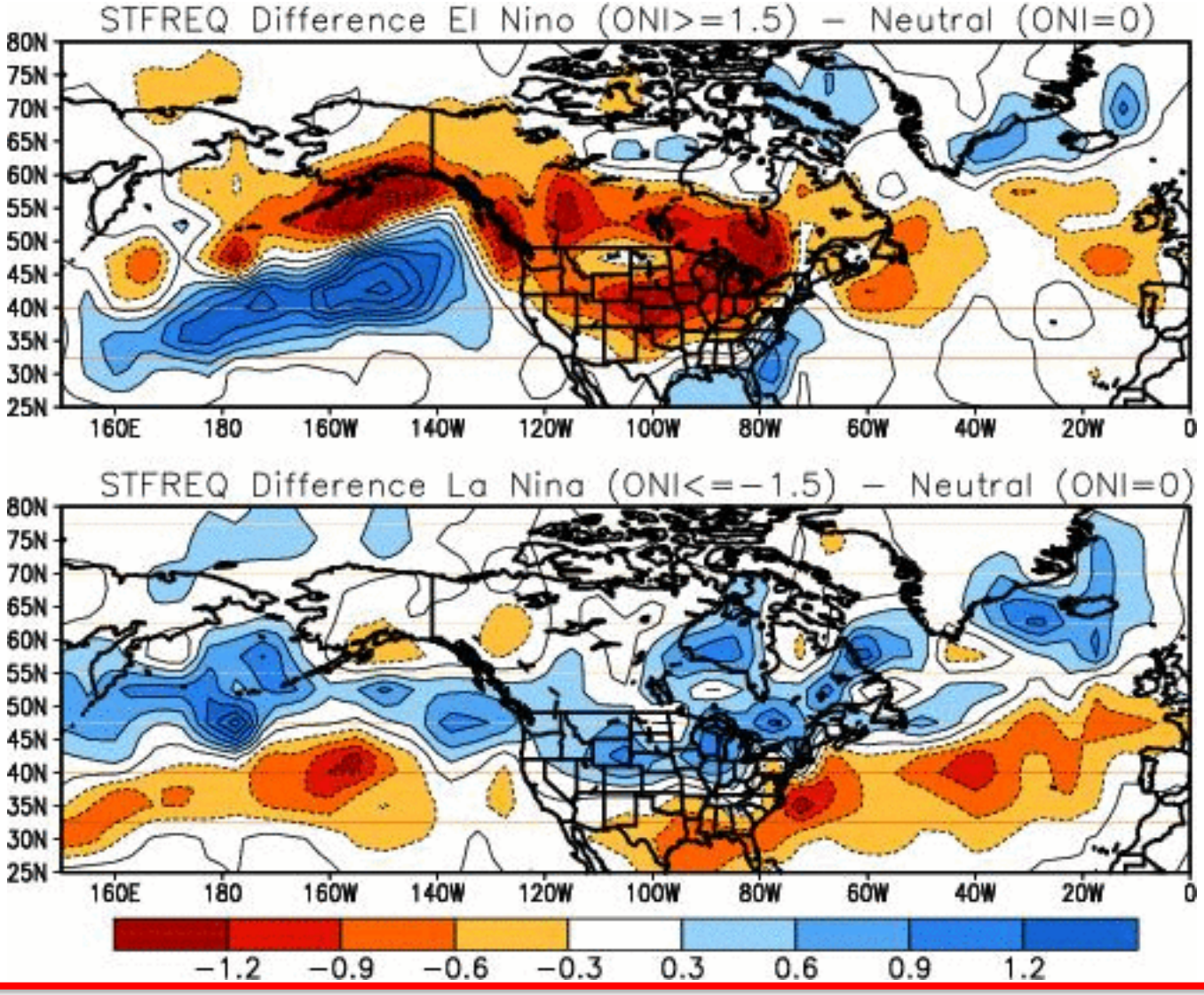
MEAN MONTHLY PRECIPITATION FOR NEUTRAL,
LA NINA, & EL NINO EPISODES - DOWNTOWN LOS ANGELES
- 1877-78 THRU 2008-09 SEASONS -



Source of El Nino, La Nina, & Neutral Seasonal Breakdowns:
http://www.wrh.noaa.gov/10x/climate/Los%20Angeles%20Yearly%20Rainfall%20-%20jo_8822-image001.gif

~40% more rain during an **El Nino** year relative to a neutral year and **~50% more rain** relative to a La Nina year.

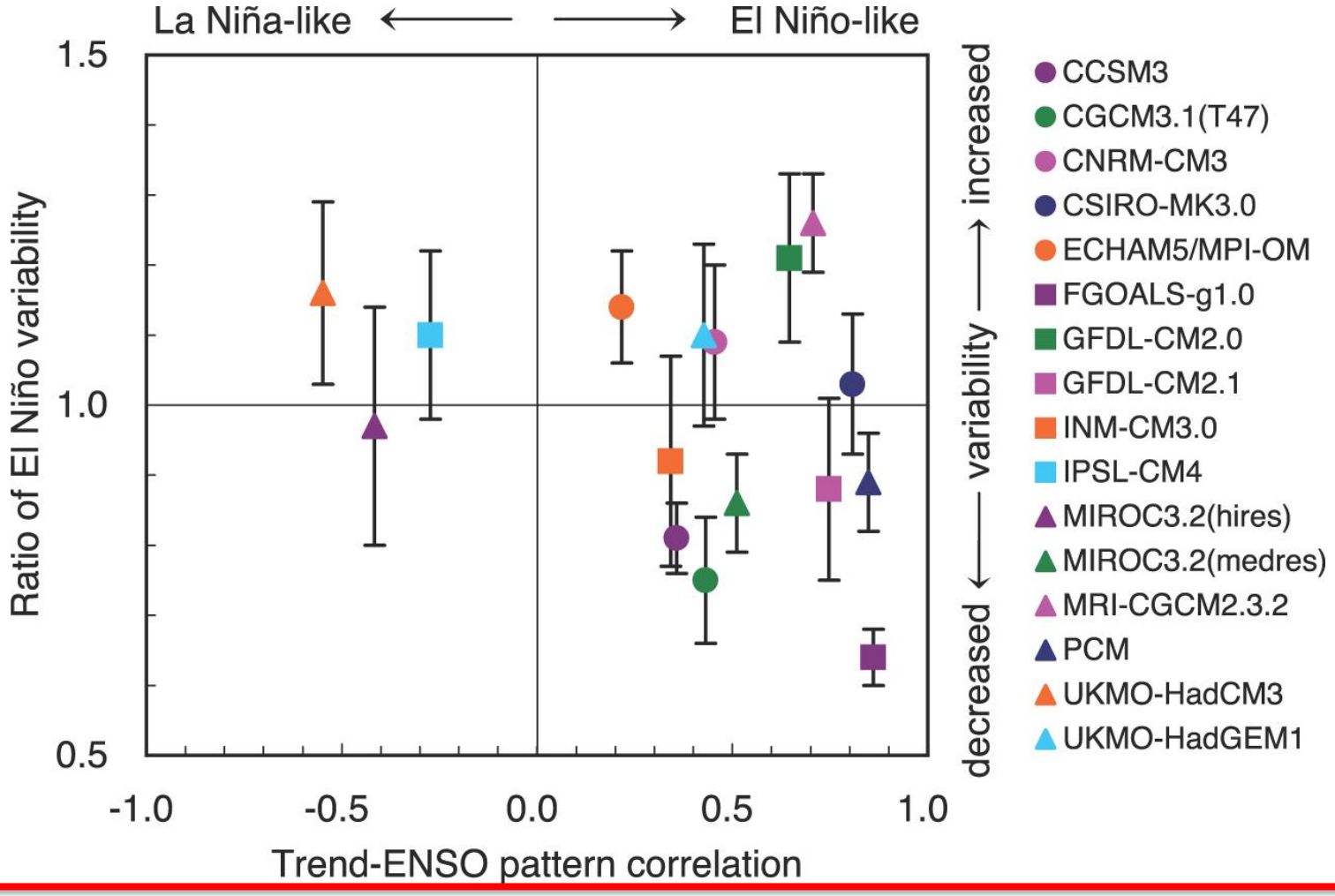
ENSO and Storm Tracks



El Nino → ***Southward*** **shift** of storm track from northern to southern part of US (including Southern California) → **more** **precipitation**

Climate Prediction Center

How Does ENSO Change With Warming?



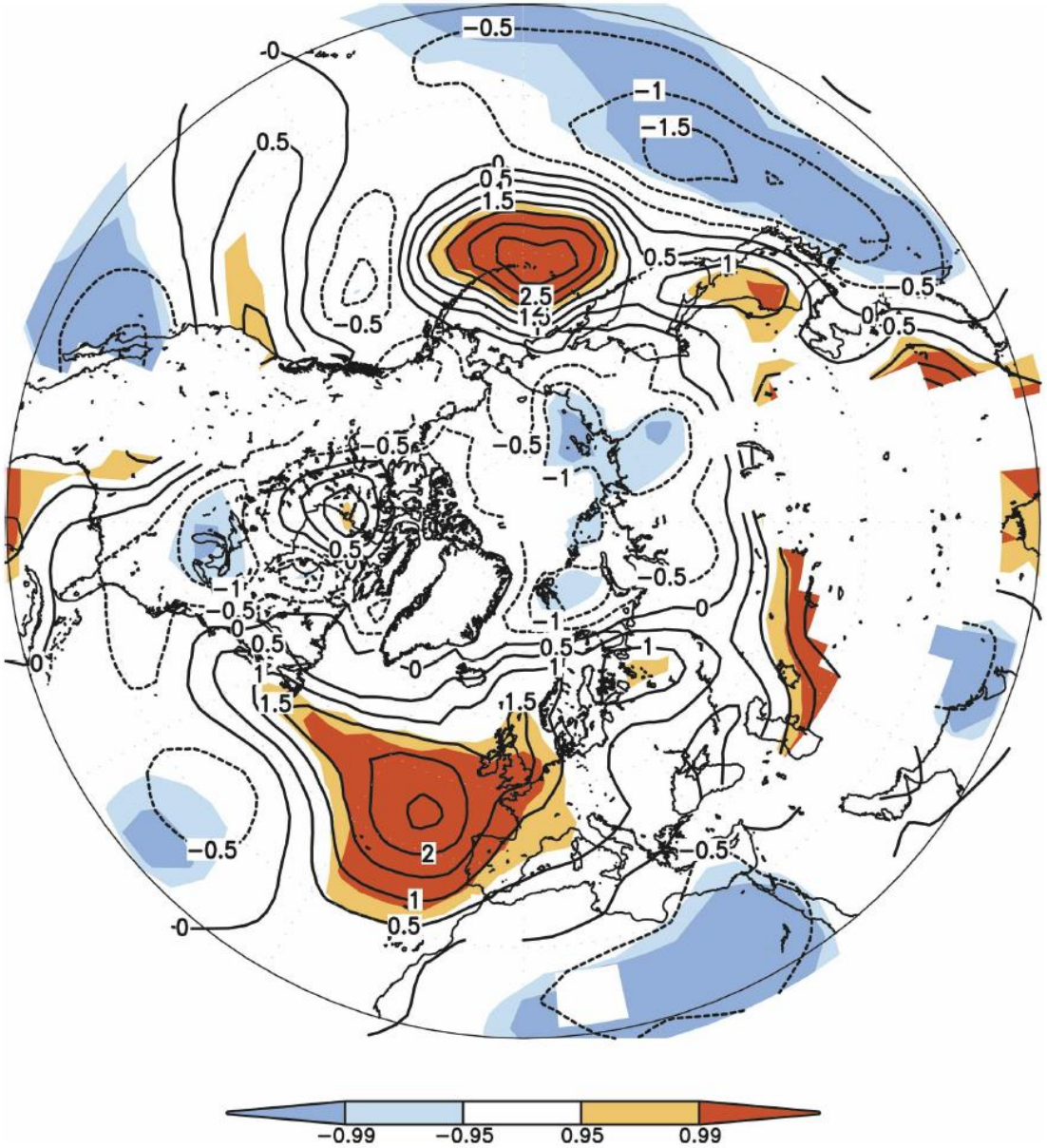
→ Most models project a ***weak shift*** towards an "**El Nino-like**" background state, but **large differences in amplitude of ENSO variability** in the future.

→ **How ENSO will change in the future is *not* well-known**.

IPCC, 2007

How do Storm Tracks Change?

→ *Storm tracks* ***move poleward*** in response to greenhouse gases (NOTE: poleward shift in NH has already been observed ~0.4° per decade)



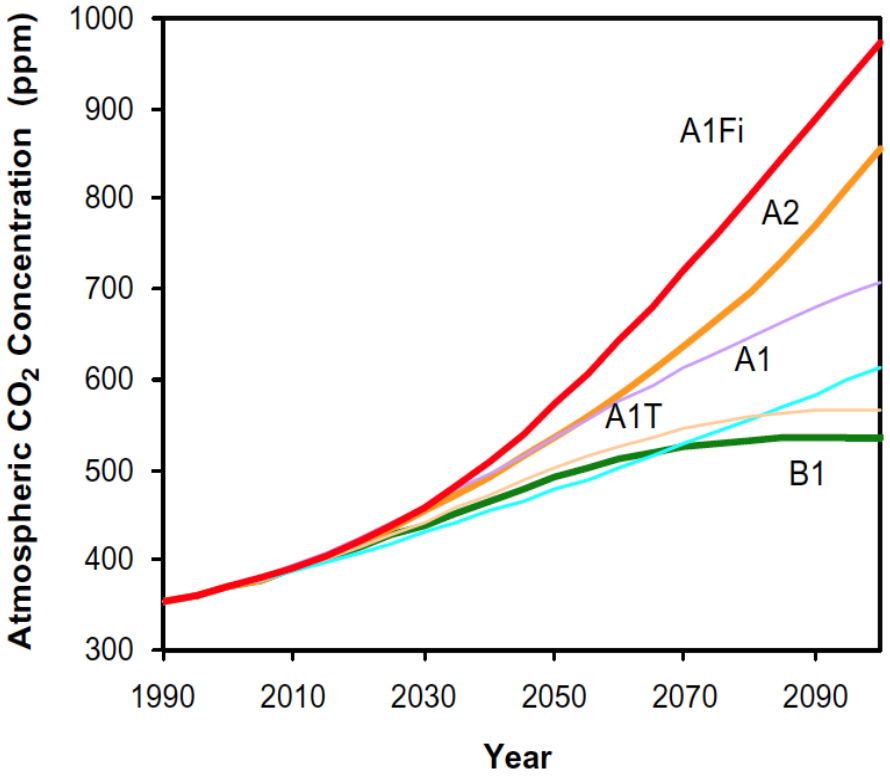
Ulbrich et al., 2008

Climate Models

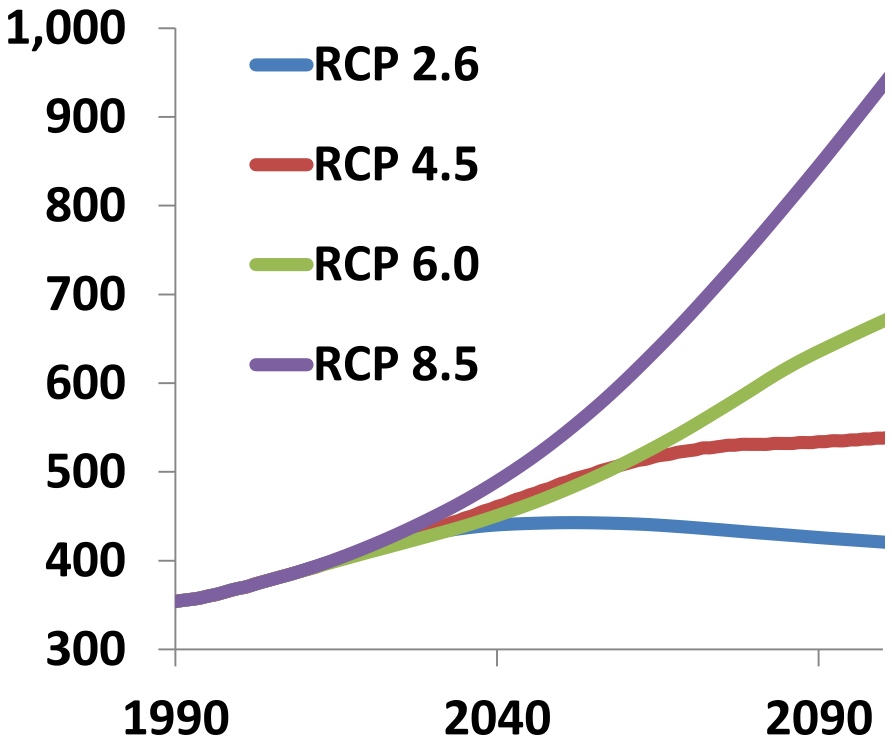
- **CMIP3** archive → 25 atmosphere-ocean global climate models (AOGCM) w/ spatial resolution ~200 km.
- **BCSD-CMIP3** → CMIP3 models are spatially "downscaled" using observations to ~12 km resolution. ~38 climate projections each w/ SRESB1, A1B and A2 from 1950-2099.
- **NARCCAP** → 6 regional climate models (50 km resolution) nested within several different CMIP3 GCMs. 10 total projections based on SRESA2 from 1971-2070.
- **CMIP5** archive → ~45 projections from 28 AOGCMs/Earth System Models at ~100 km spatial resolution using RCP8.5 from 1850-2099

Future Greenhouse Gas Emission Scenarios

CMIP3 Scenarios



CMIP5 Scenarios



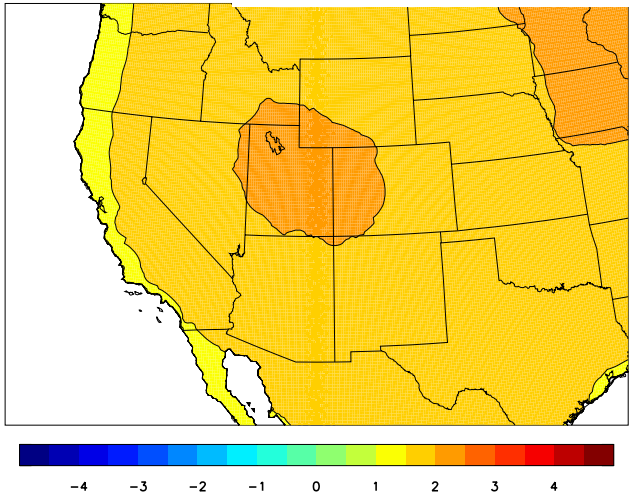
1. **SRESB1** → ***low emission*** scenario (500 ppm CO_2 by 2100)
2. **SRESA1B** → ***medium*** emissions (720 ppm by 2100)
3. **SRESA2** → ***medium-high*** emissions (850 ppm by 2100).
4. **RCP8.5** → ***high*** emissions scenario for **CMIP5** (950 ppm by 2100)

Nakicenovic and Swart, 2000; Moss et al. Nature 2010

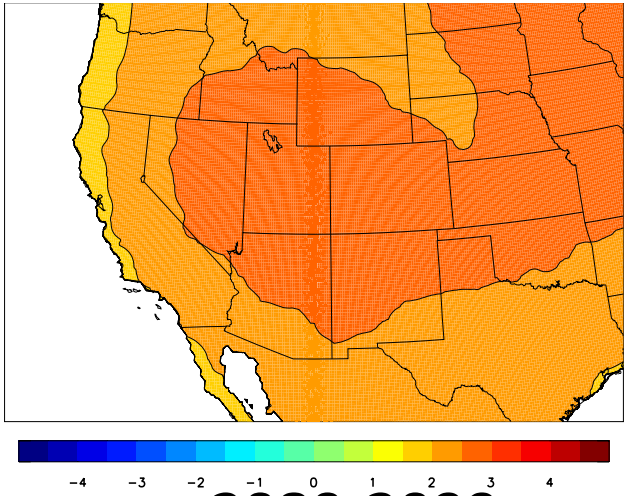
BCSD-CMIP3 Western US Temperature Change

2041-2070

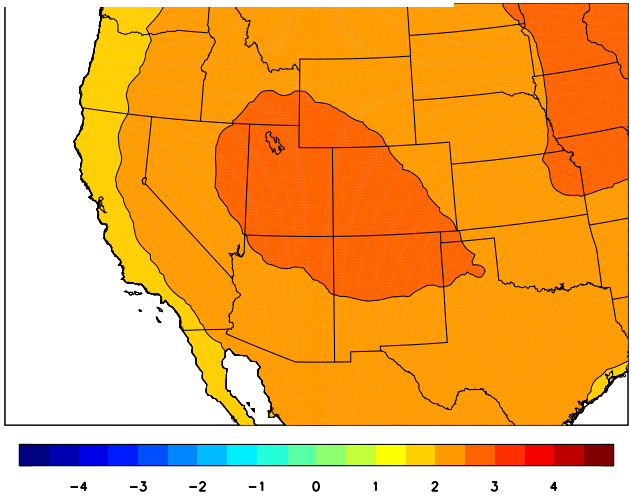
SRESB1



SRESA1B

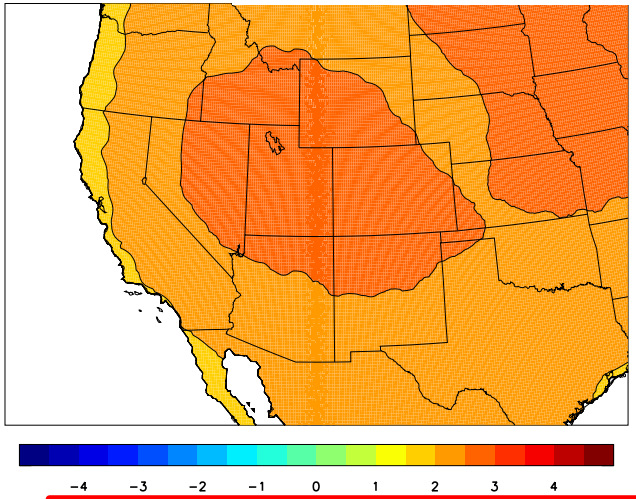


SRESA2

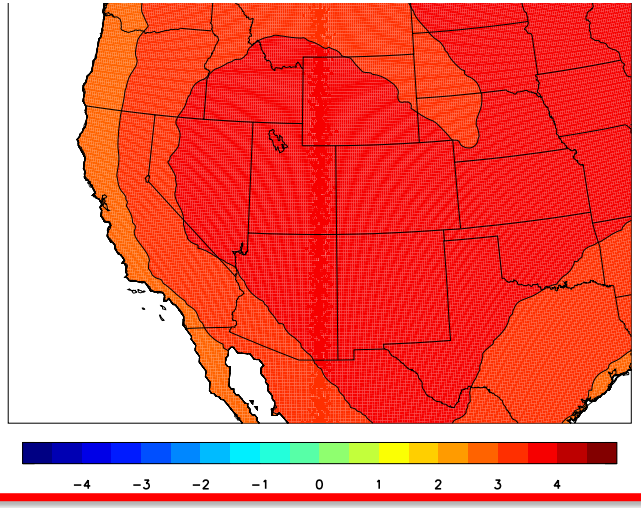


2080-2099

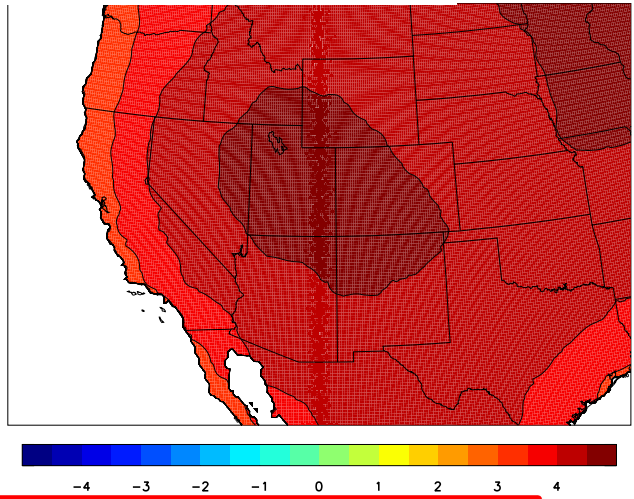
SRESB1



SRESA1B



SRESA2

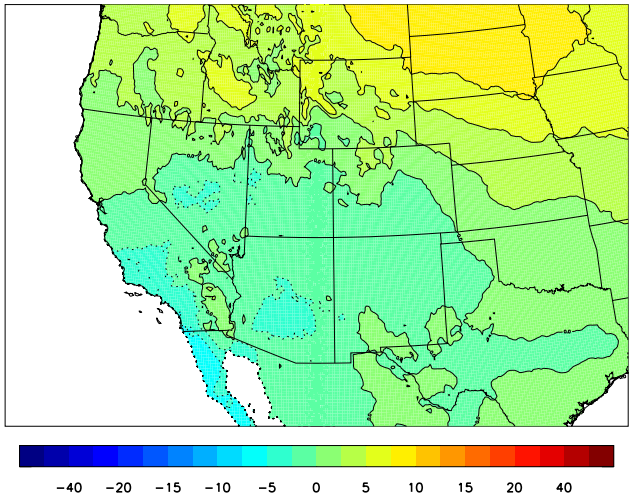


→General warming of western US, with minimum warming along west coast

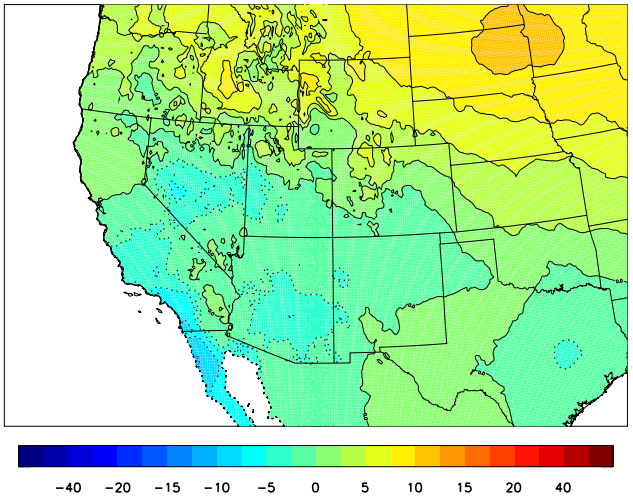
BCSD-CMIP3 Western US Precipitation Change

2041-2070

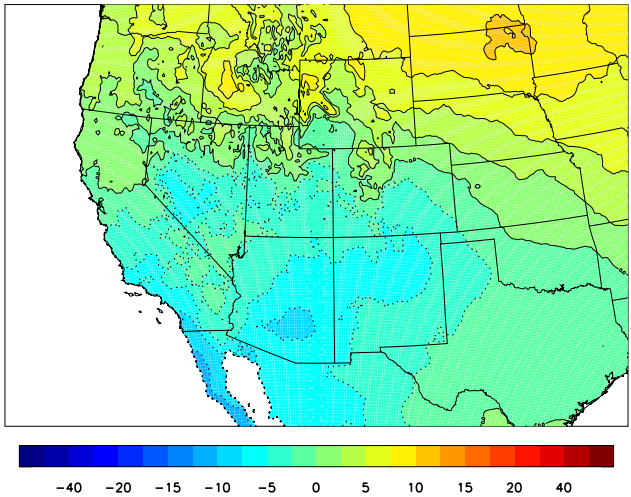
SRESB1



SRESA1B

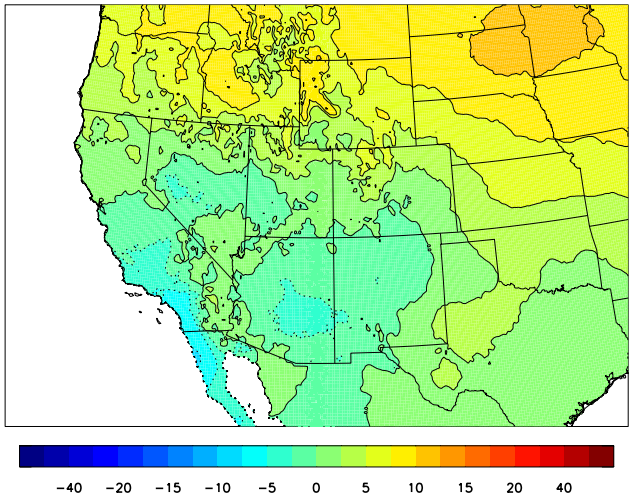


SRESA2

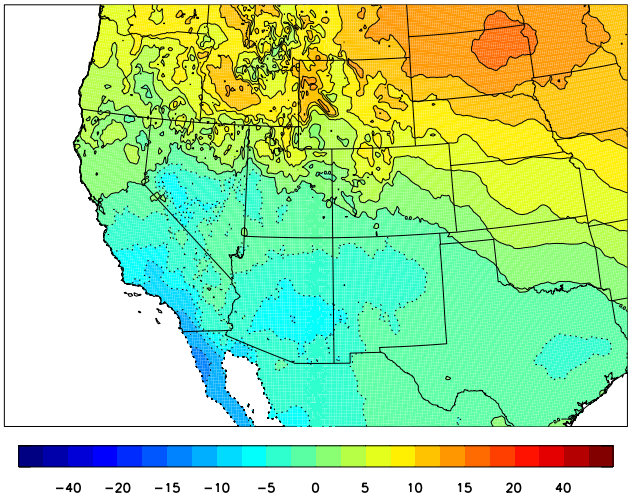


2080-2099

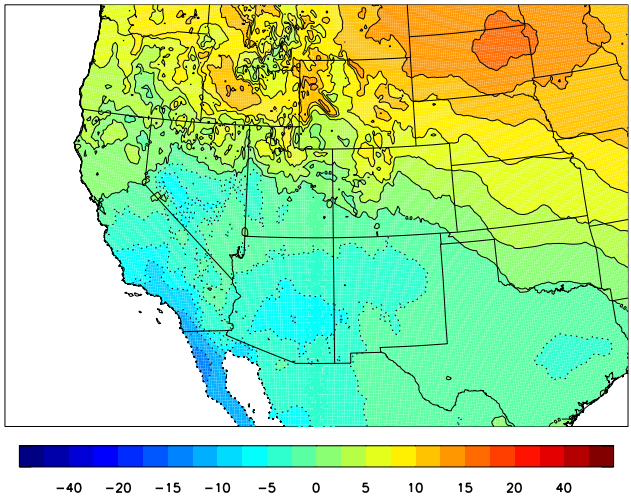
SRESB1



SRESA1B



SRESA2

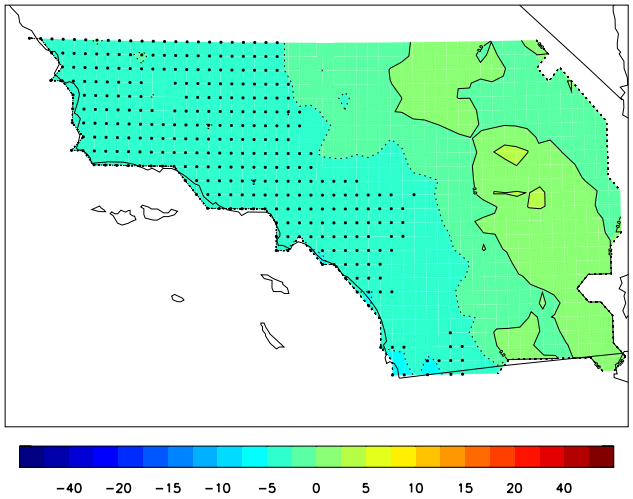


→General **increases** in precipitation to the north and (weaker) **decreases** to the south.

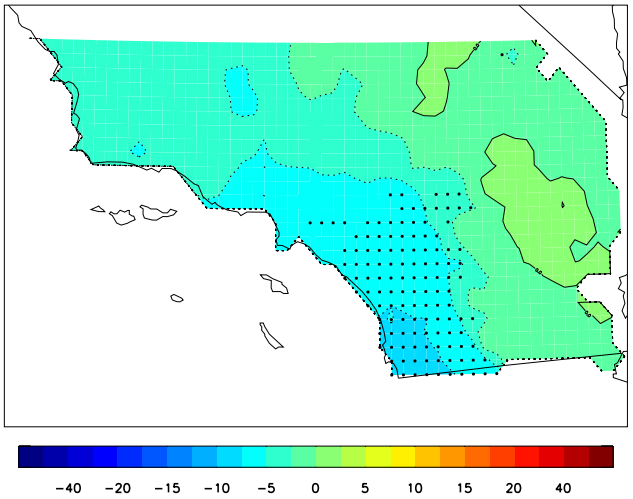
BCSD-CMIP3 SoCal Precipitation Change

2041-2070

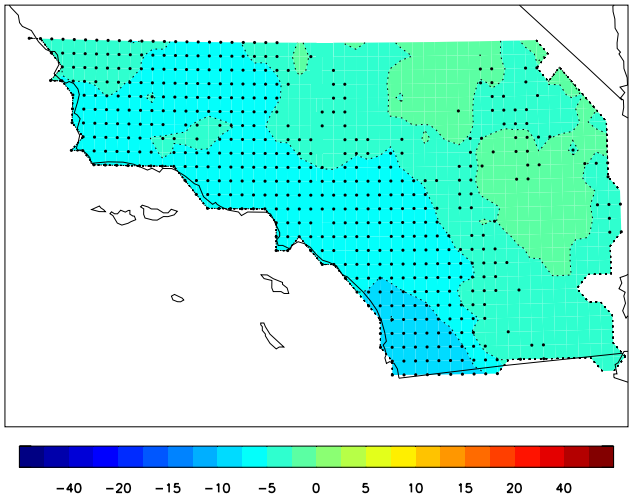
SRESB1



SRESA1B

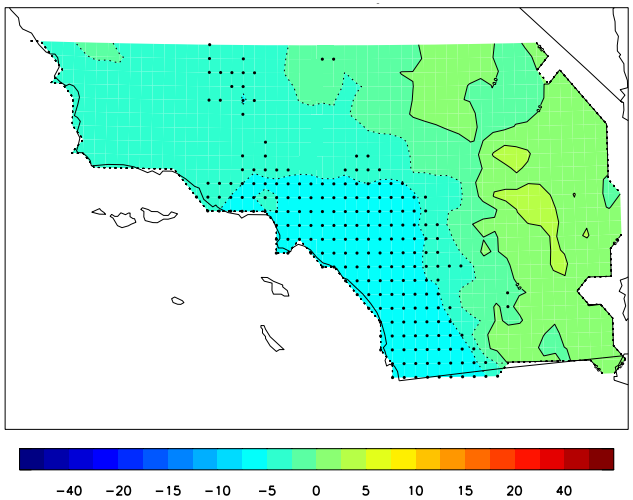


SRESA2

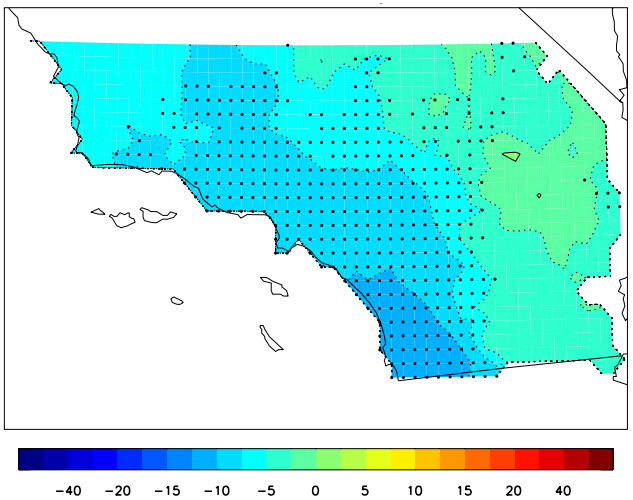


2080-2099

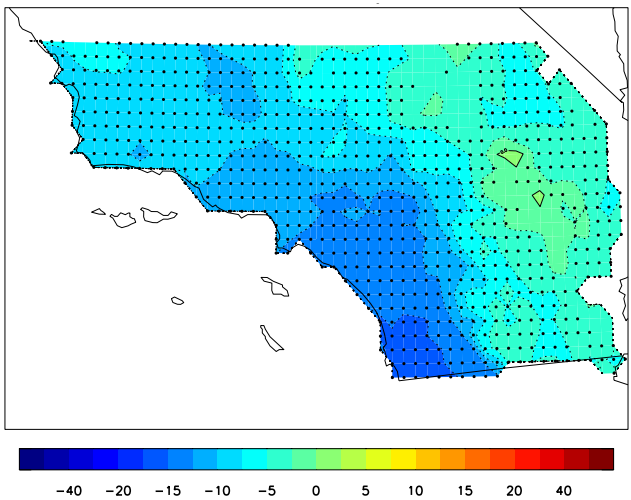
SRESB1



SRESA1B

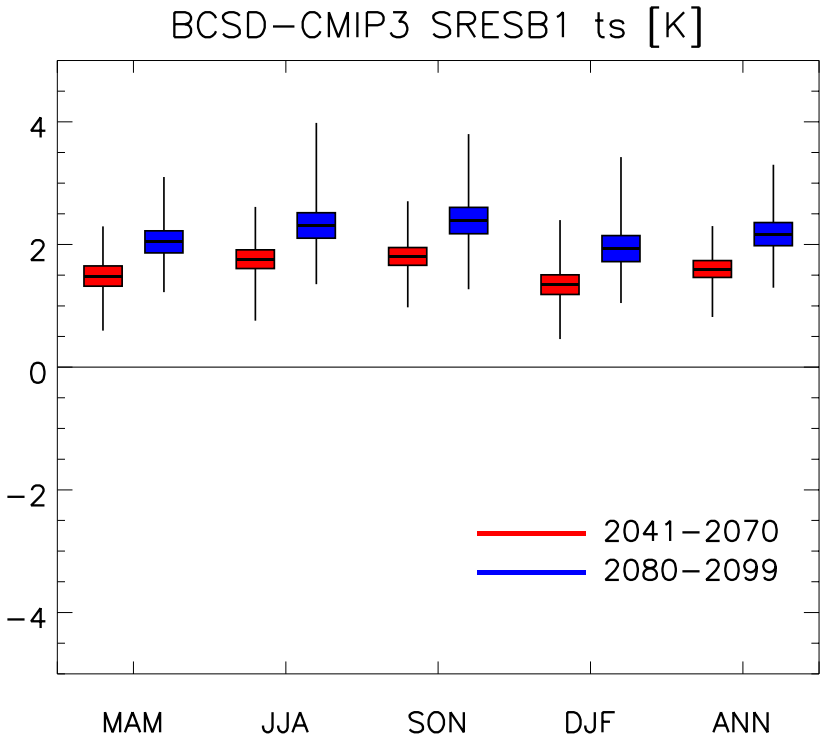


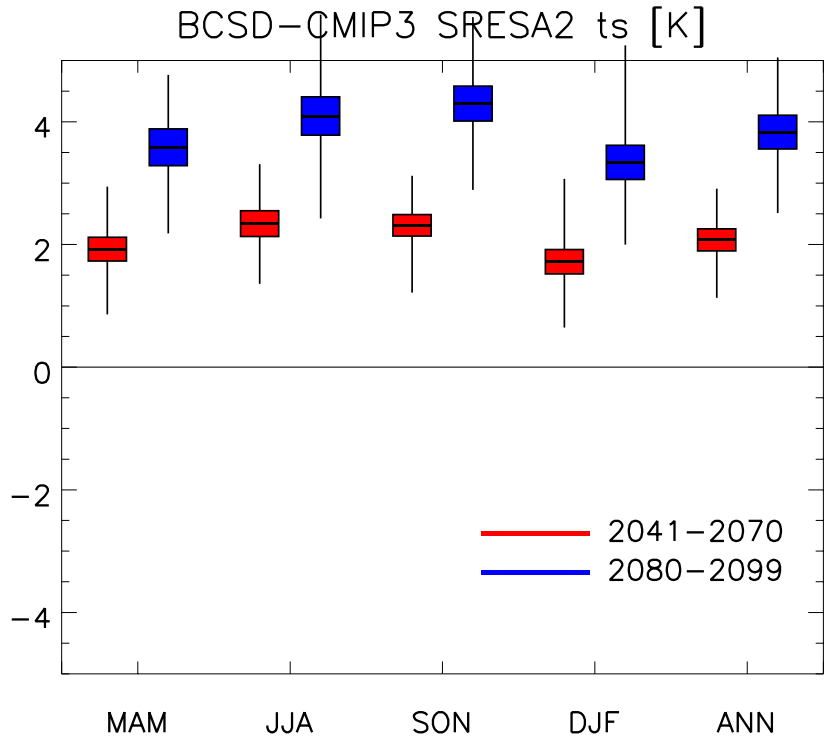
SRESA2



→ Largest precipitation reductions occur 1. along the coast; 2. in the southwest corner

BCSD-CMIP3 SoCal ΔT Seasonal "Box-Plots"

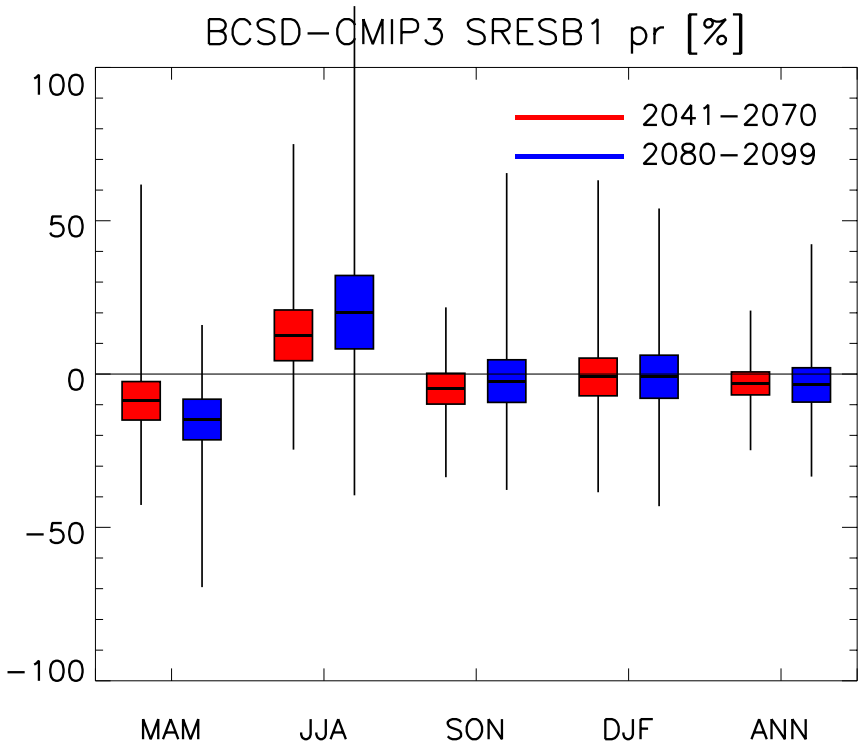


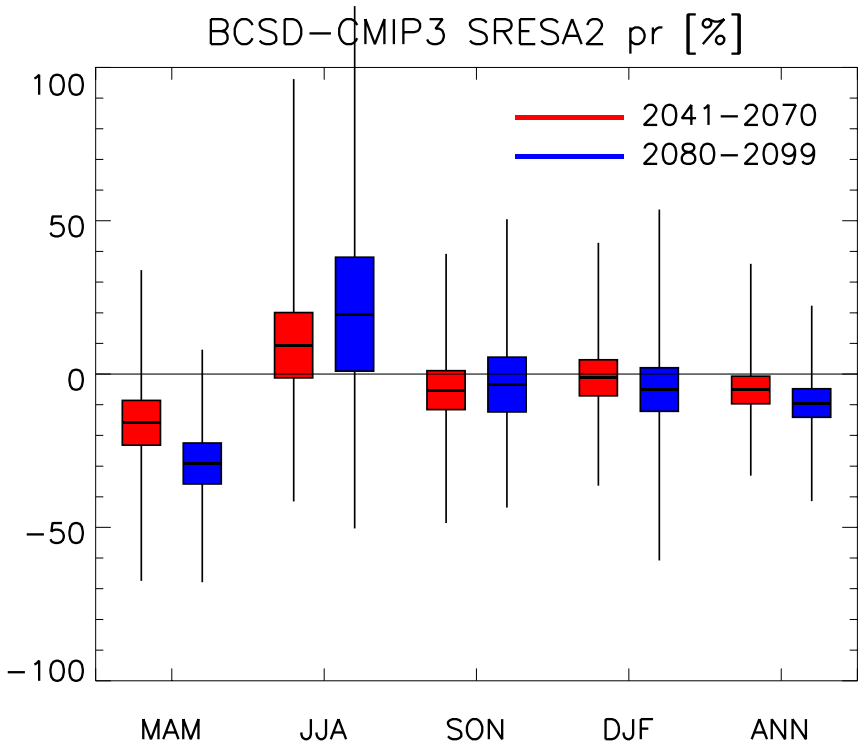


→ Highly ***significant warming*** of **1.6-2.1°C** by 2041-2070 and **2.2-3.8°C** by 2080-2099.

→ Maximum warming in JJA/SON.

BCSD-CMIP3 SoCal ΔP



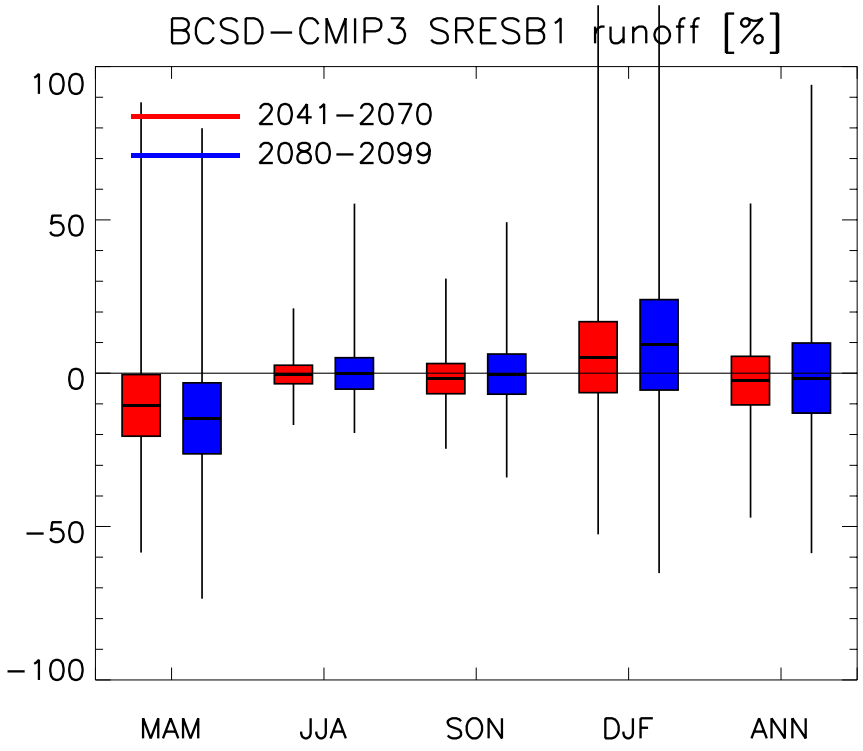


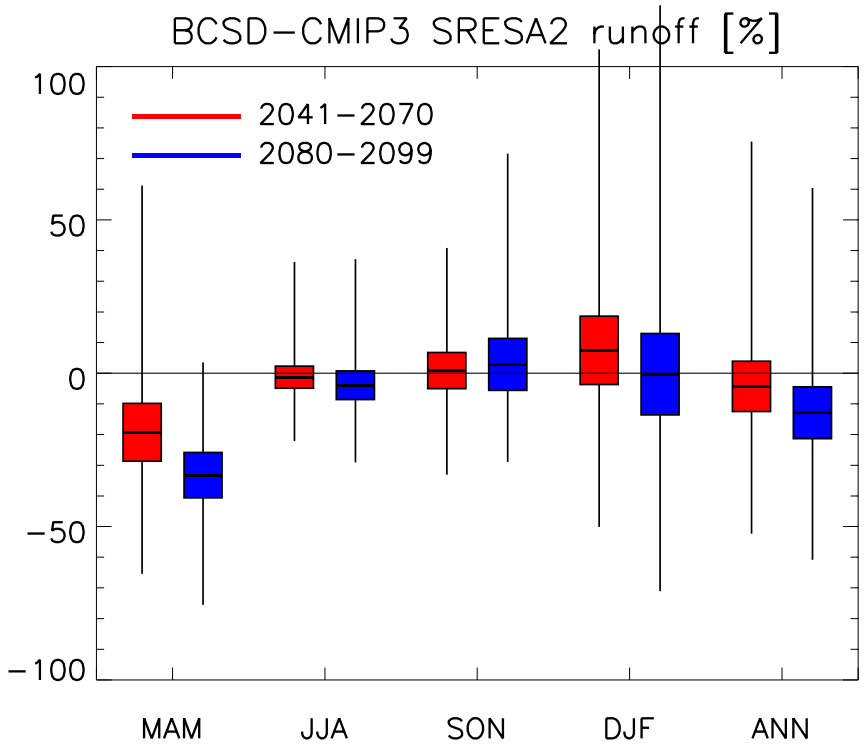
→ The high emission scenario (and A1B) shows ***significant reductions*** **of 5-10%** in SoCal precipitation for both time periods.

→ Maximum decrease in MAM of **-29%** for A2 by 2080-2099.

→ Increase in JJA precipitation (strengthening of NA monsoon?)

BCSD-CMIP3 SoCal ΔRunoff

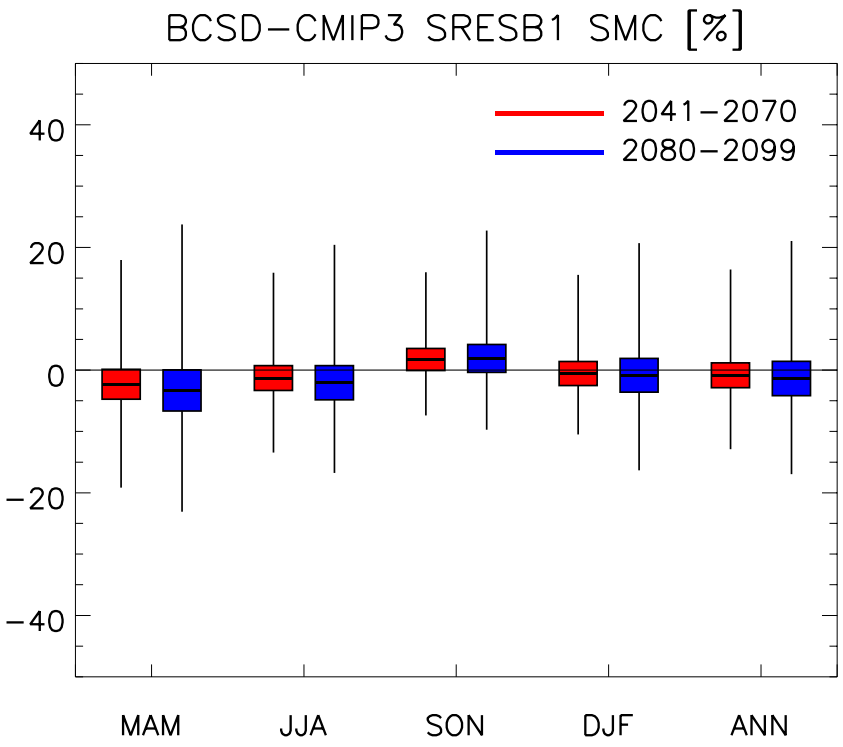


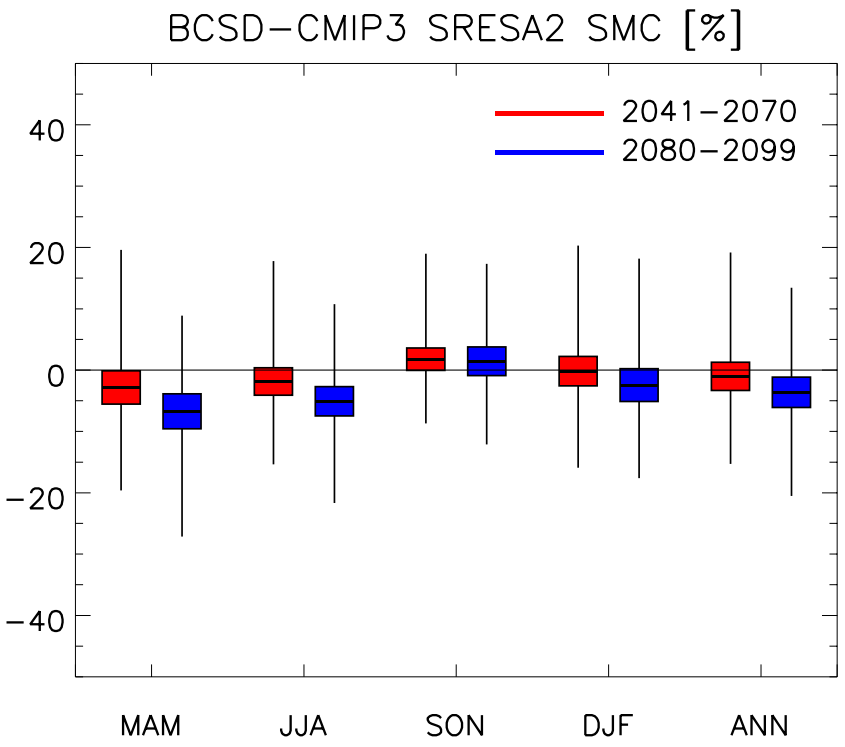


→ The high emission scenario (and A1B) shows ***significant reductions*** in SoCal runoff of **-13%** by 2080-2099.

→ Maximum decrease in MAM of **-33%** (SRESA2).

BCSD-CMIP3 SoCal ΔSoil Moisture

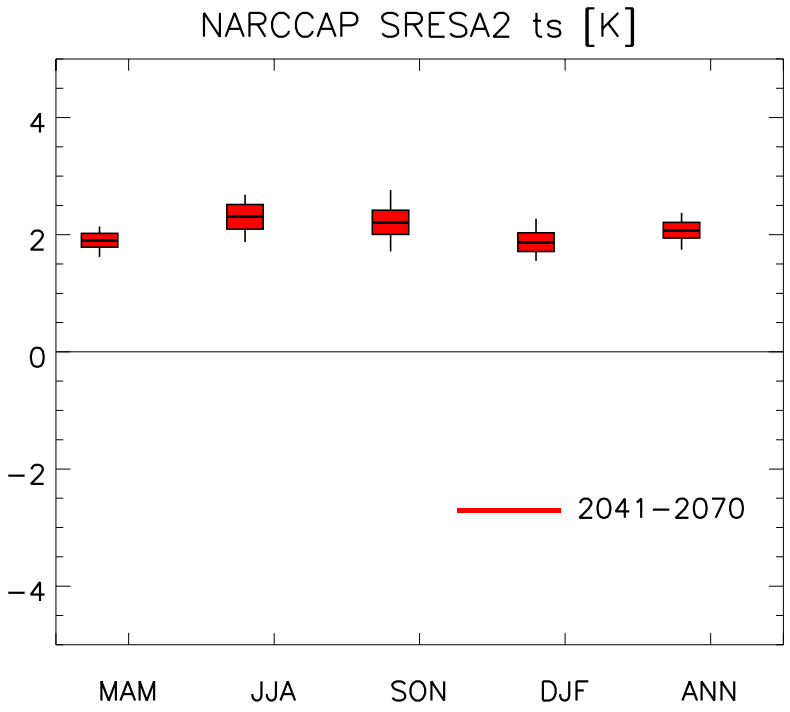


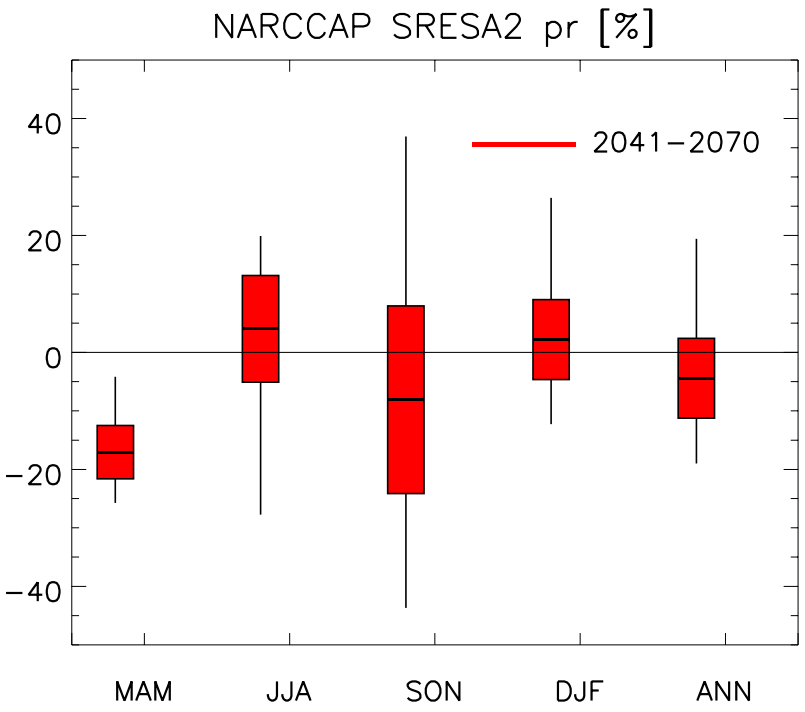


→ The high emission scenarios (and A1B) shows ***significant reductions*** in SoCal soil moisture of **-3.6%** by 2080-2099.

→ Maximum decrease in MAM.

NARCCAP SoCal Climate Change

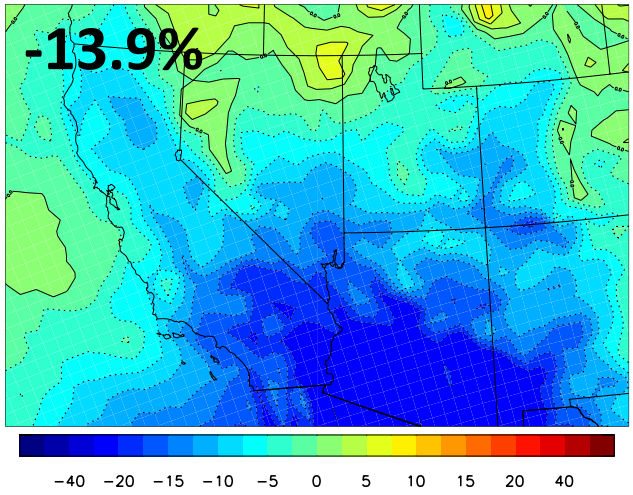




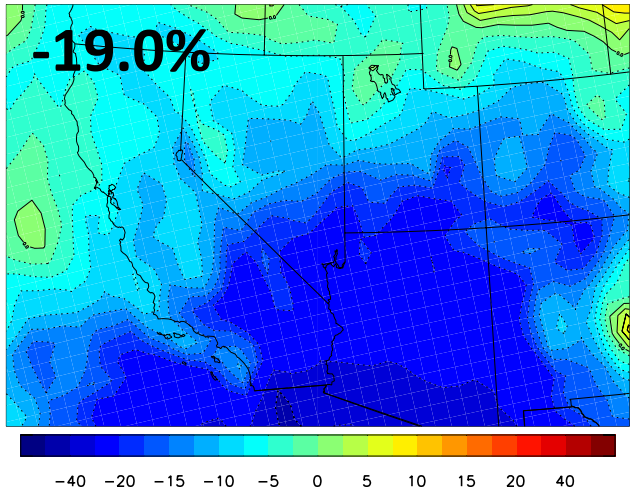
Highly significant → Annual mean ***warming*** of **2.1°C** 2041-2070 (JJA/SON maximum).
Not Significant → ***Decreases*** in annual mean precipitation of **-5%** (**-18%** MAM).
→ ΔPrecipitation is similar to BCSD-CMIP3, but with more uncertainty.

NARCCAP: CCSM vs. GFDL ΔPrecipitation

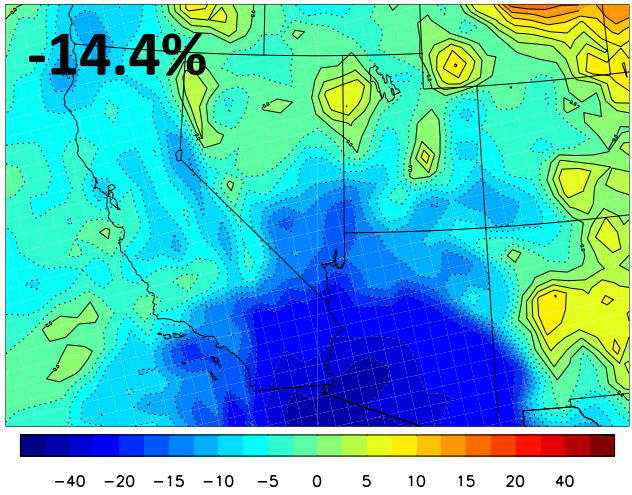
CRCM-ccsm



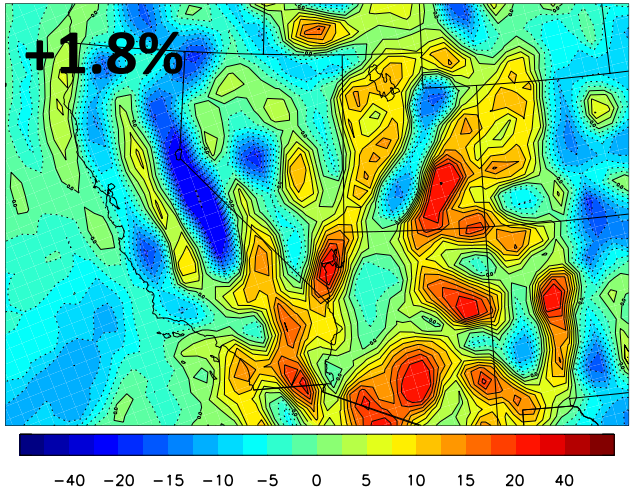
MM5I-ccsm



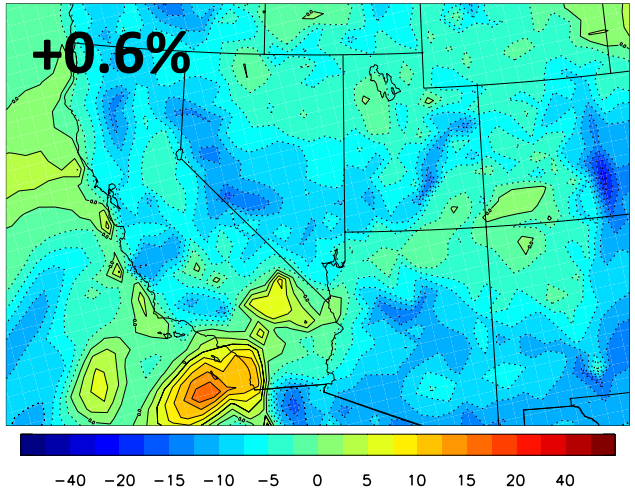
WRFG-ccsm



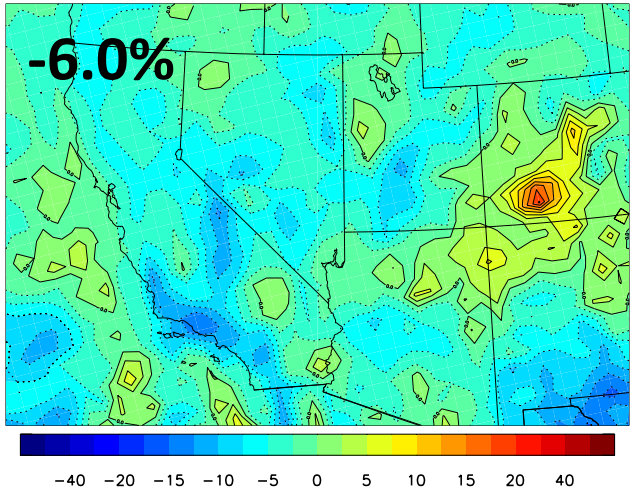
ECP2-gfdl



HRM3-gfdl



RCM3-gfdl



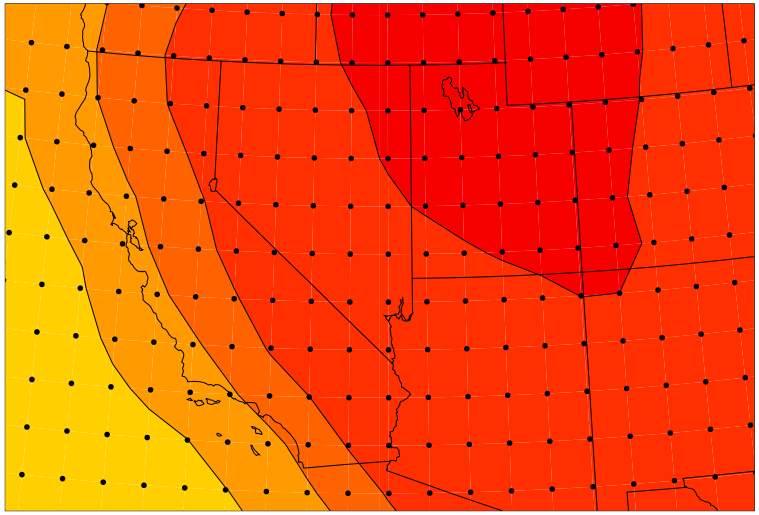
→ Large differences between RCMs using CCSM boundary conditions versus GFDL.

→ Reinforces the notion large-scale atmospheric circulation changes are likely most important.

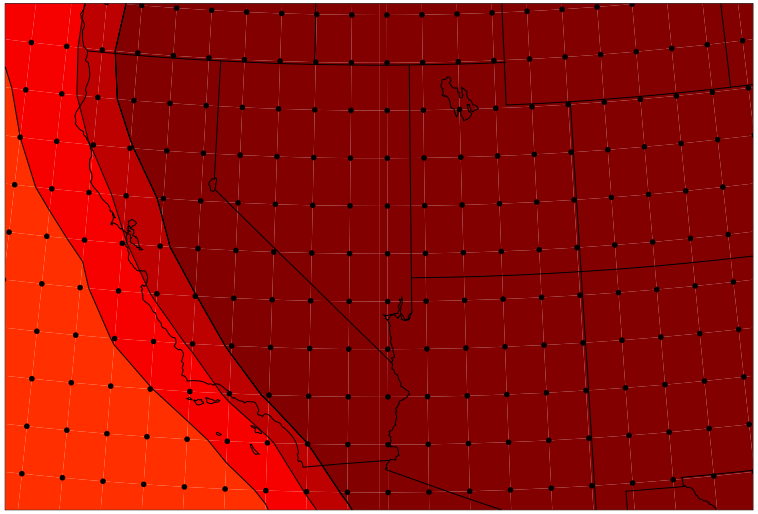
CMIP5 RCP85 Ensemble Mean Changes

2041-2070 | **2080-2099**

ΔTemperature

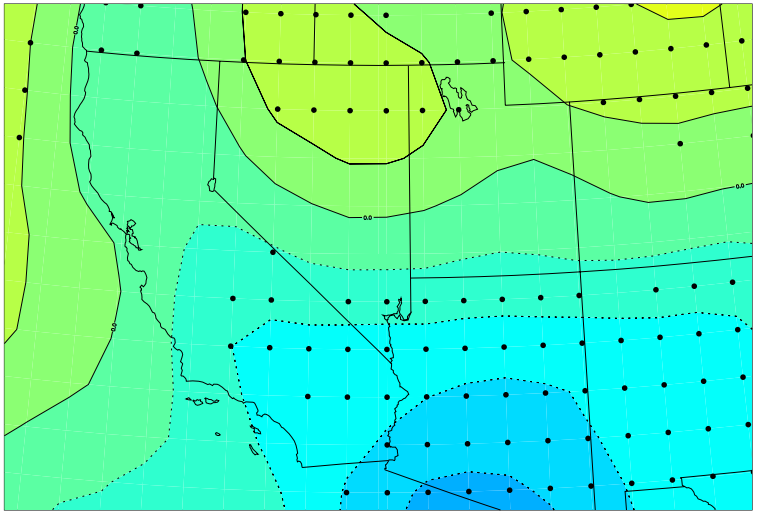


−4 −3 −2 −1 0 1 2 3 4

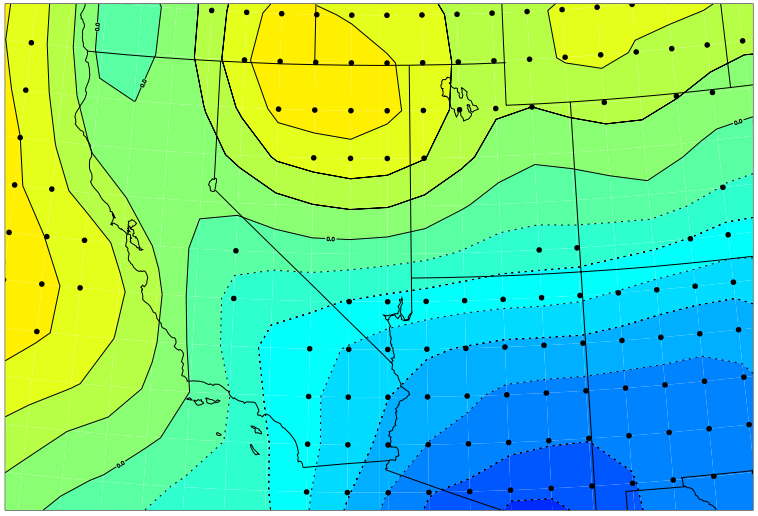


−4 −3 −2 −1 0 1 2 3 4

ΔPrecipitation



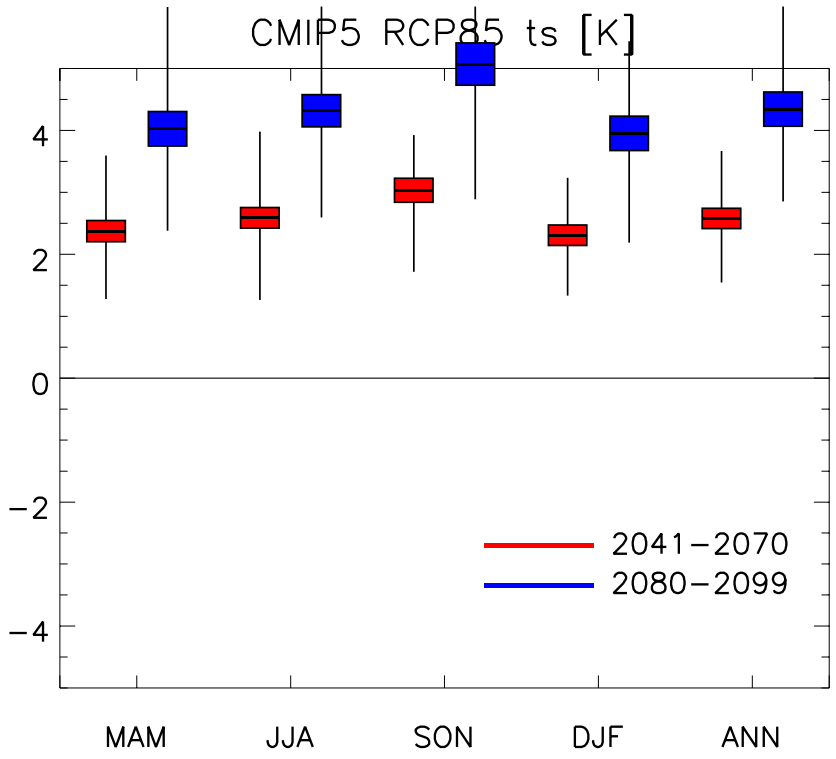
−40 −20 −15 −10 −5 0 5 10 15 20 40

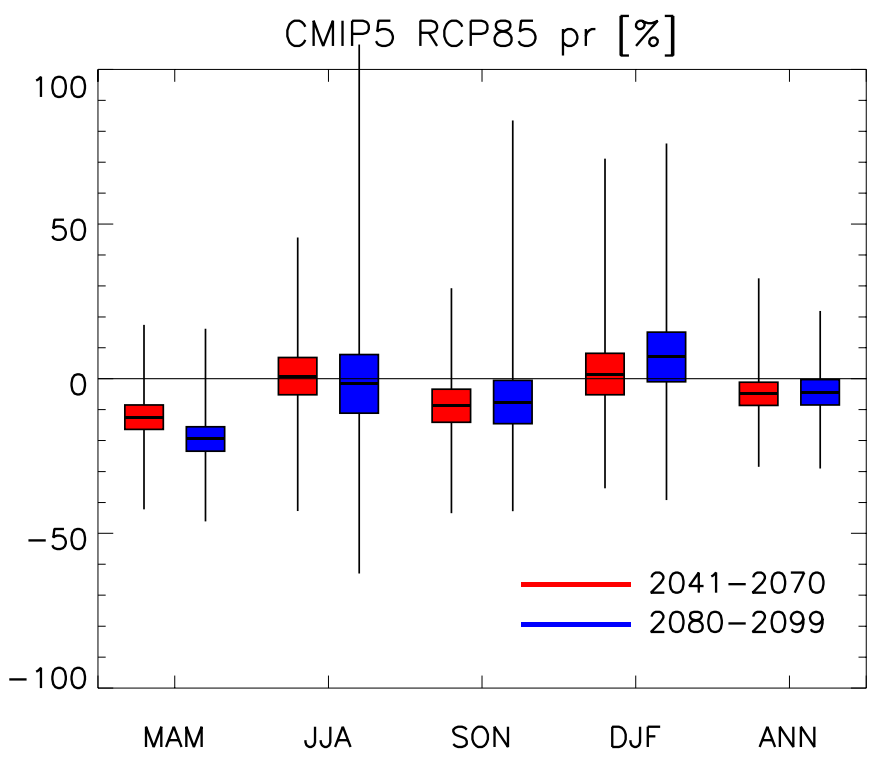


−40 −20 −15 −10 −5 0 5 10 15 20 40

→ Similar spatial pattern (for both T and Precip) to BCSD-CMIP3 ensemble mean.

CMIP5 RCP85 Seasonal SoCal Changes



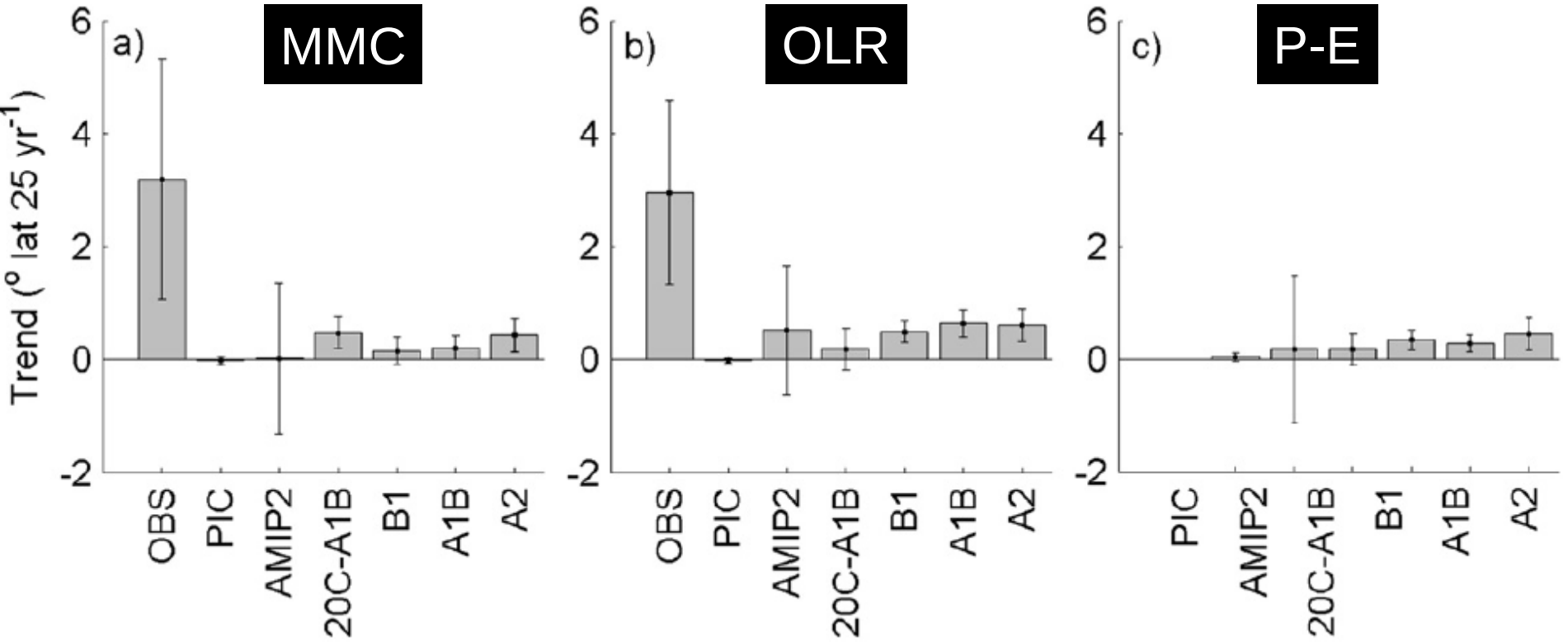


→ ***Highly significant*** annual mean ***warming*** of **2.4°C** (**4.3°C**) by 2041-2070 (2080-2099).

→ ***Significant decreases*** in annual mean precipitation of **-5%** for both time periods.

→ΔPrecipitation is similar, but **weaker than** BCSD-CMIP3 (JJA increase also lacking).

CMIP3 Models Underestimate Poleward Displacement of Circulation



→ Suggests models may *underestimate* future *decreases* in SoCal precipitation?

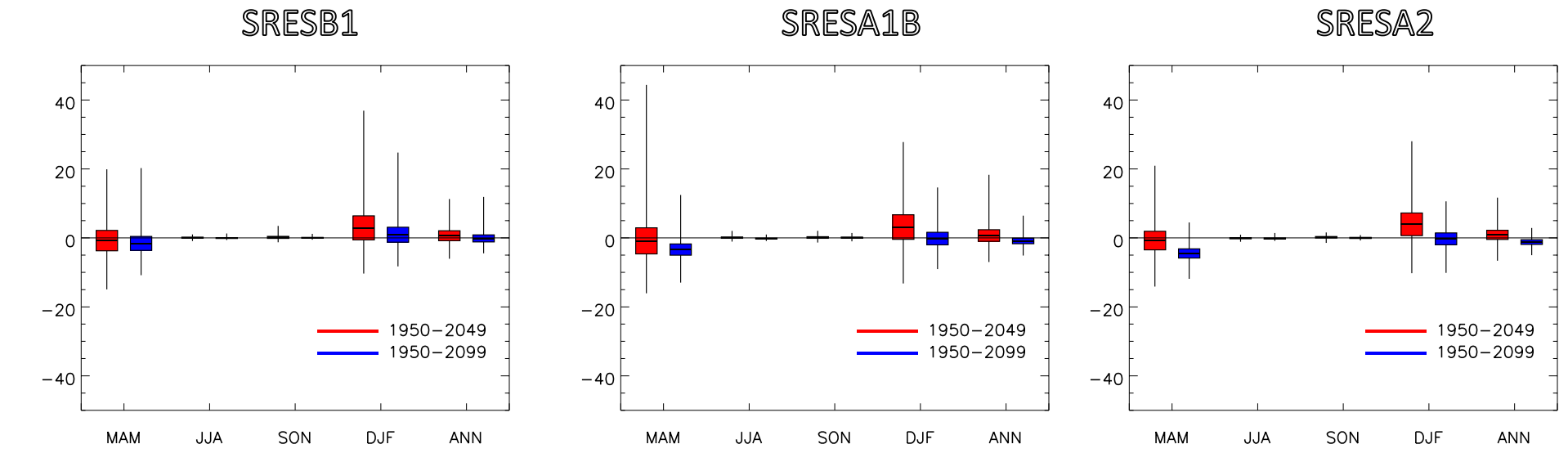
Johanson+Fu, 2009

Conclusions

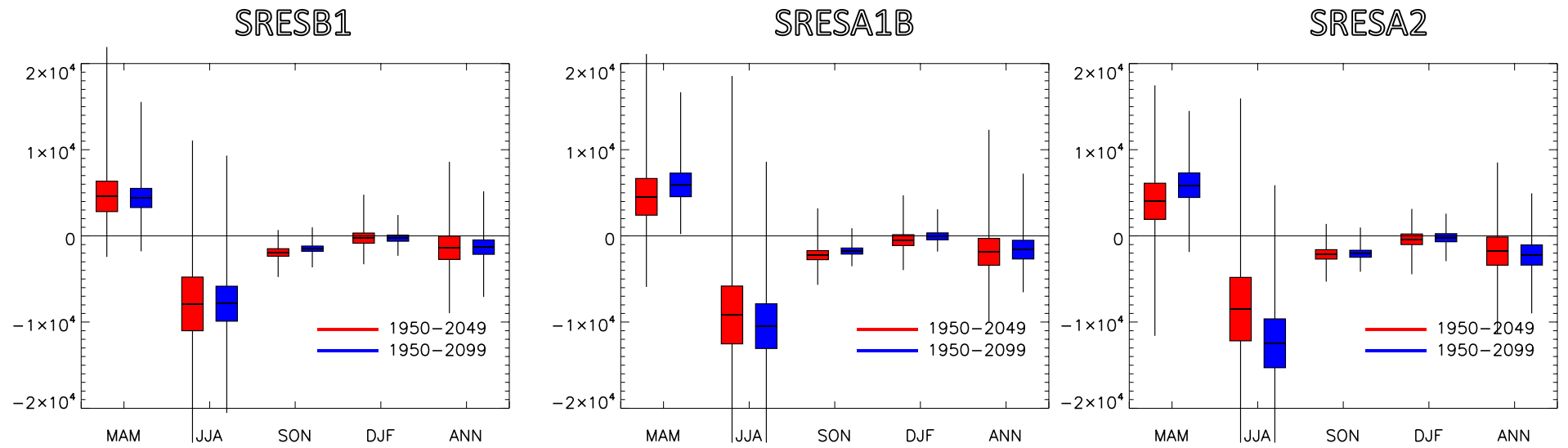
- A wide range of climate model data was evaluated to assess future SoCal climate change.
- Robust projection:
  - ***Warming*** of **1.6-2.4°C** by **mid-century**.
  - ***Warming*** of **2.2-4.3°C** by **end of century**.
- ***Precipitation changes are less certain***, but the multi-model mean shows ***decreased*** precipitation.
  - **5-10% reductions** by **end of century**.
  - Similar ***reductions*** in other hydrological variables (e.g., streamflow)
- Generally, ***larger magnitude change*** for ***higher GHG emission scenarios*** (e.g., SRESA2 and RCP85).
- ***Models may underestimate the precip decrease*** in SoCal, but uncertainties (e.g., ENSO) and large natural climate variability remain.

The End…Thanks!!

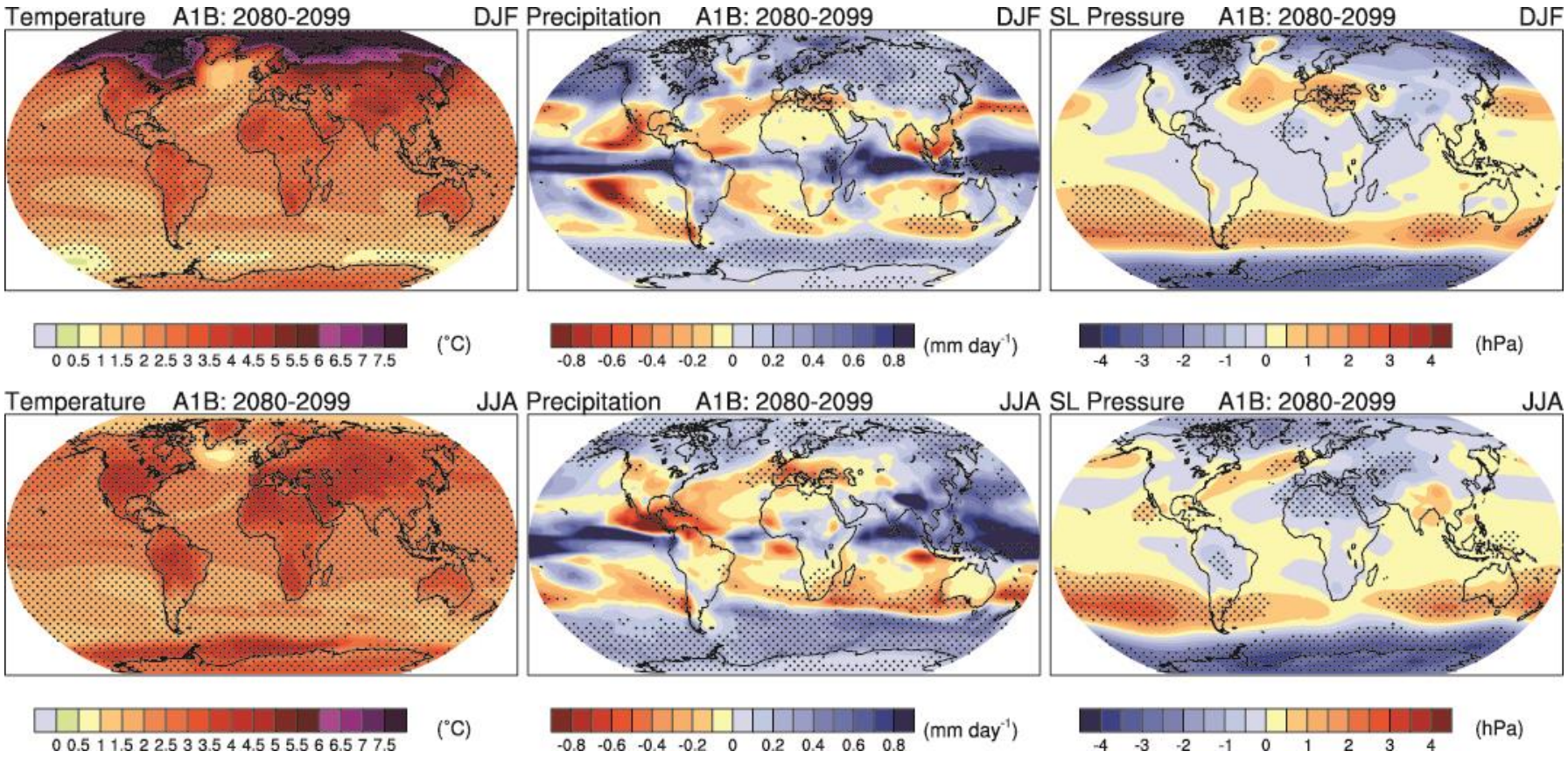
Palm Springs



Colorado River above Imperial Dam

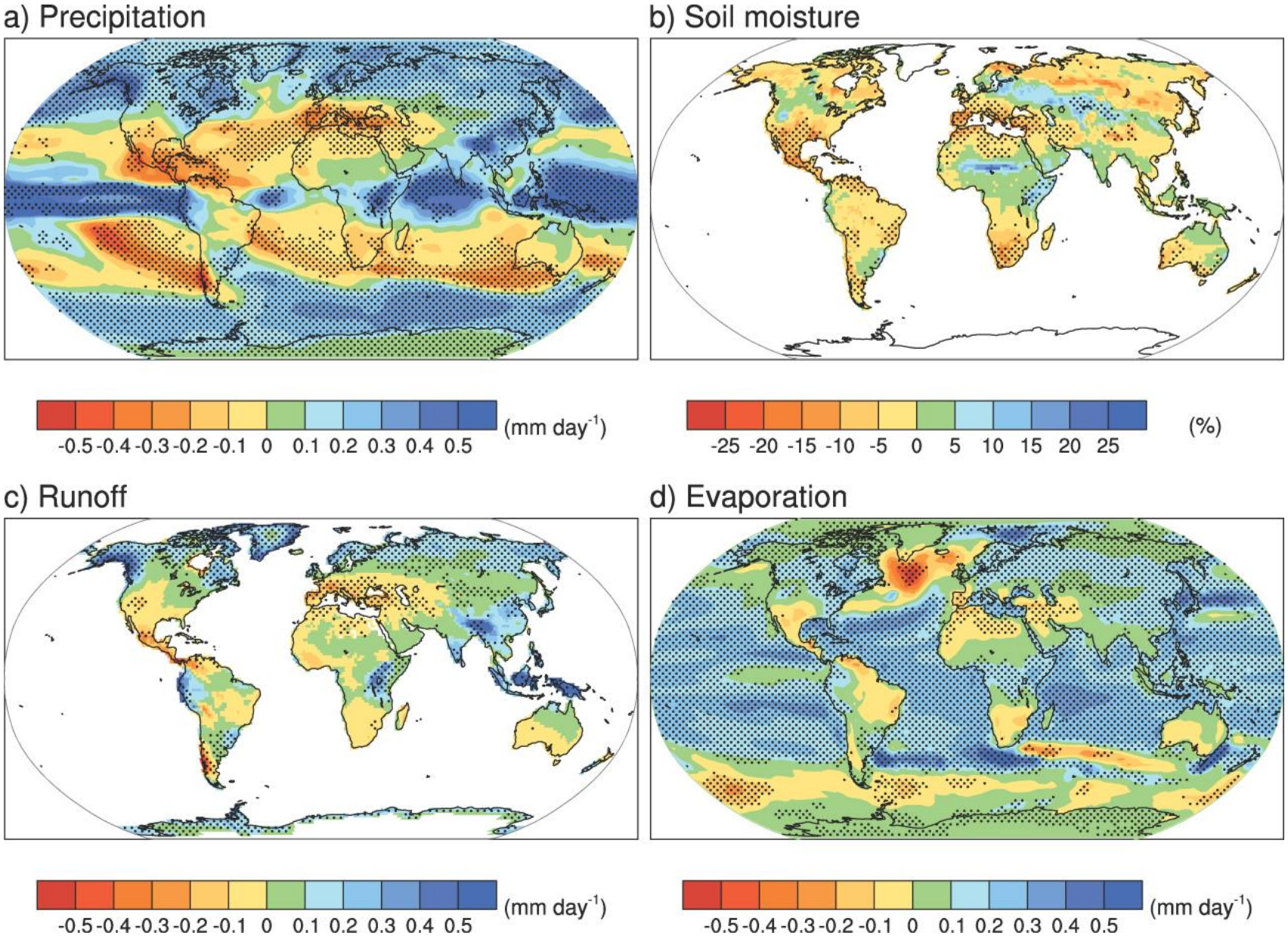


Large-Scale ΔT and ΔP: CMIP3



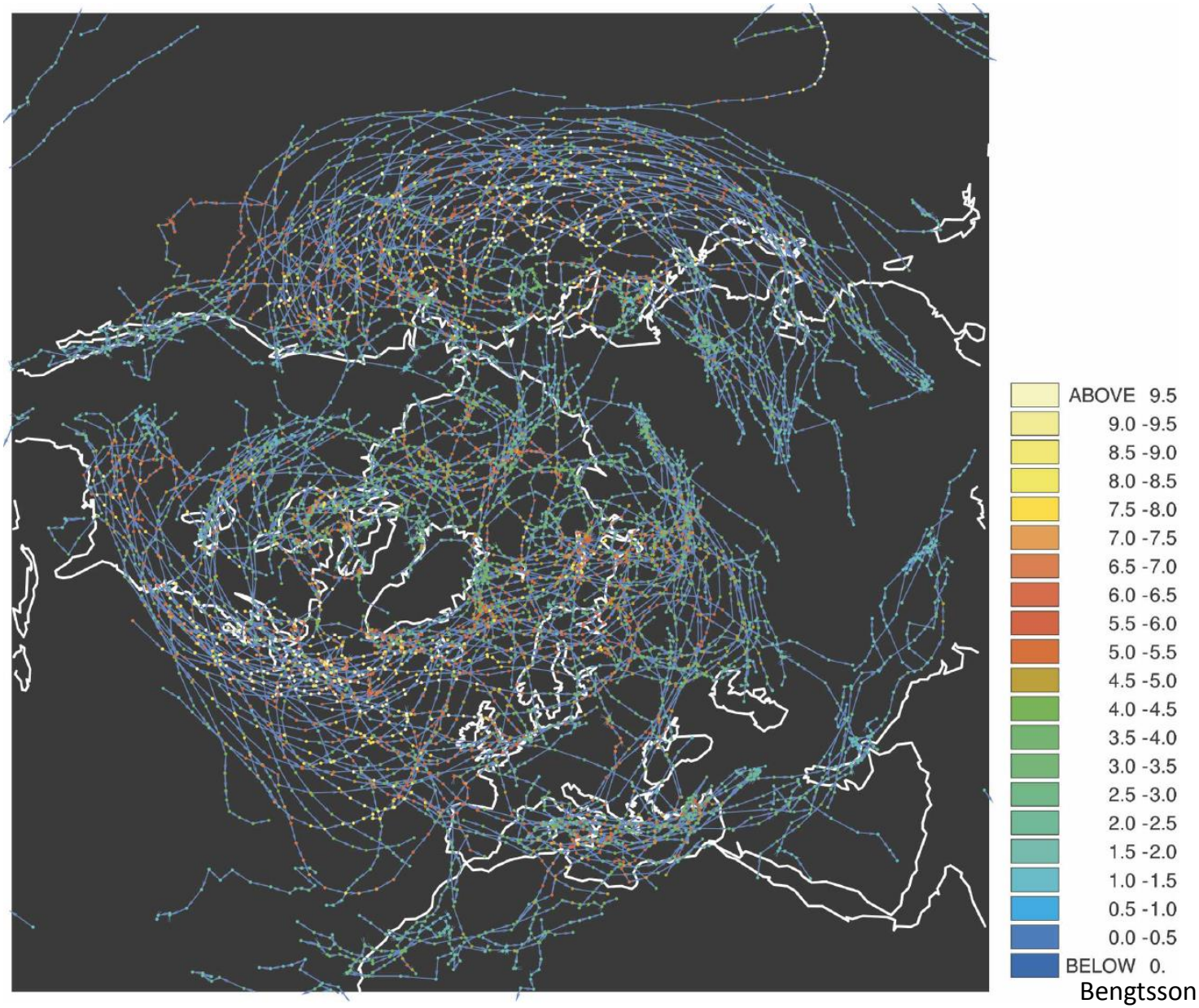
IPCC, 2007

Additional Hydrological Changes



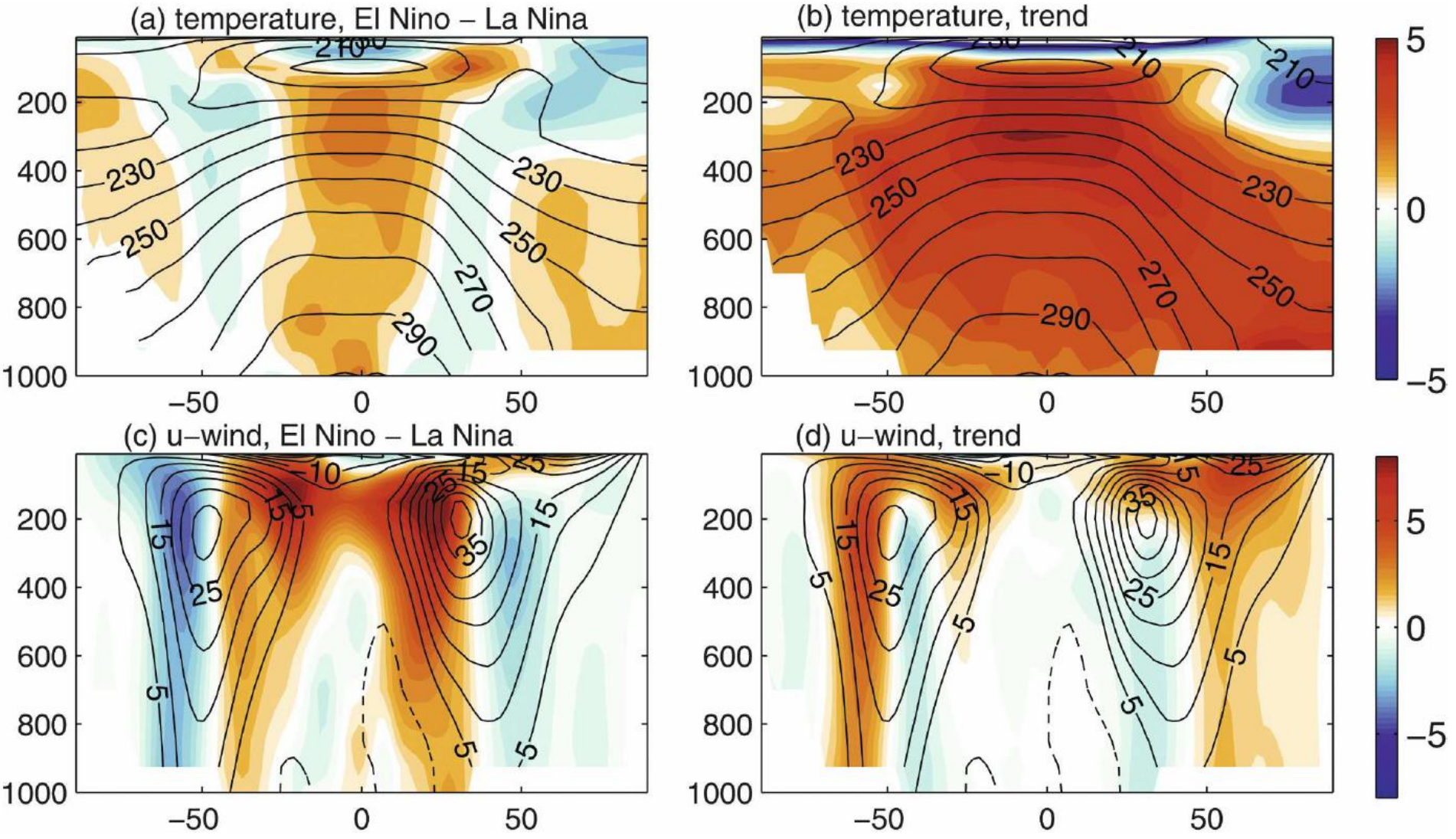
IPCC, 2007

DJF Cyclone Tracks 2002/2003



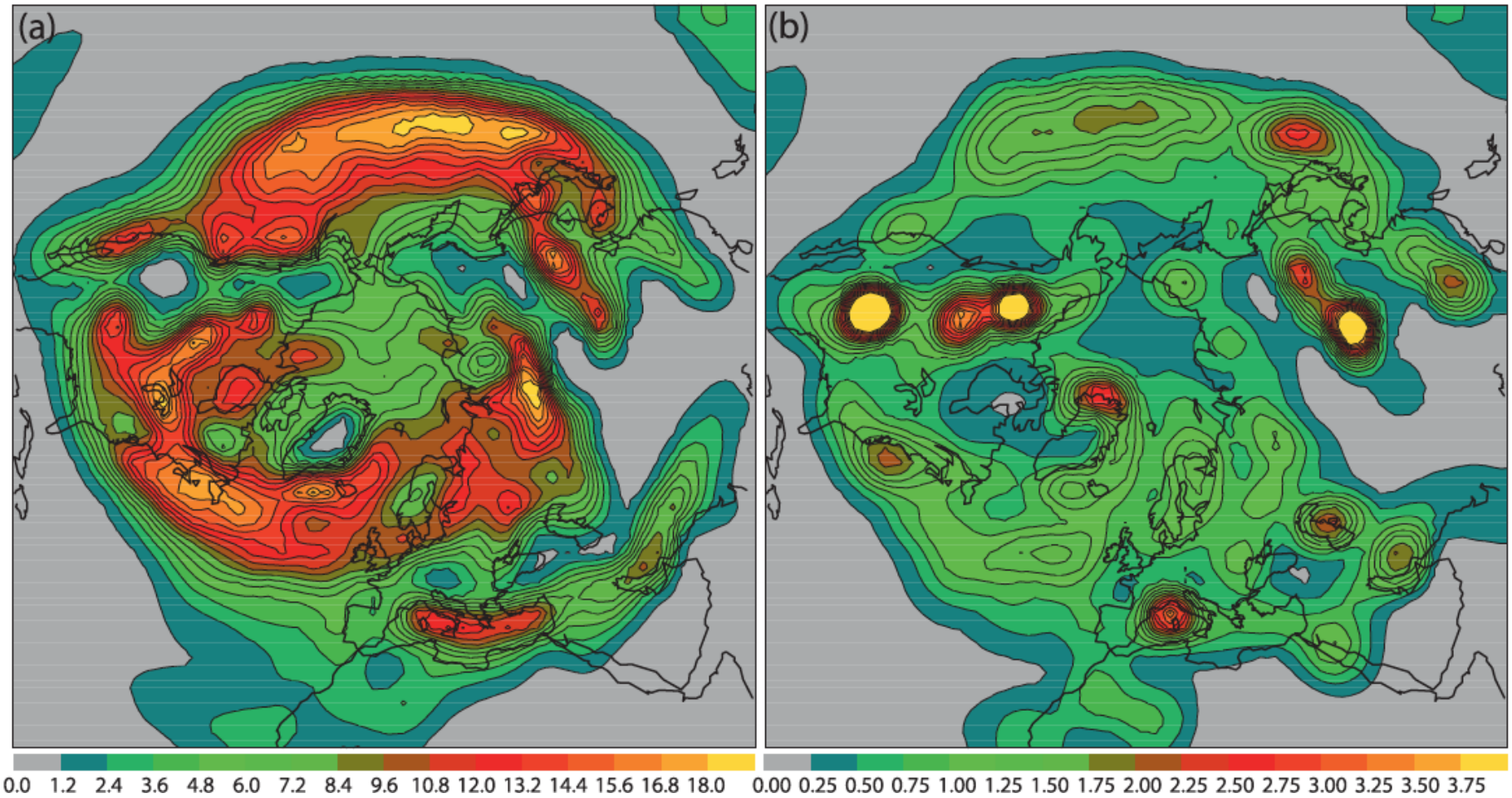
Bengtsson et al., 2006

ENSO Versus Global Warming



Lu et al, 2008

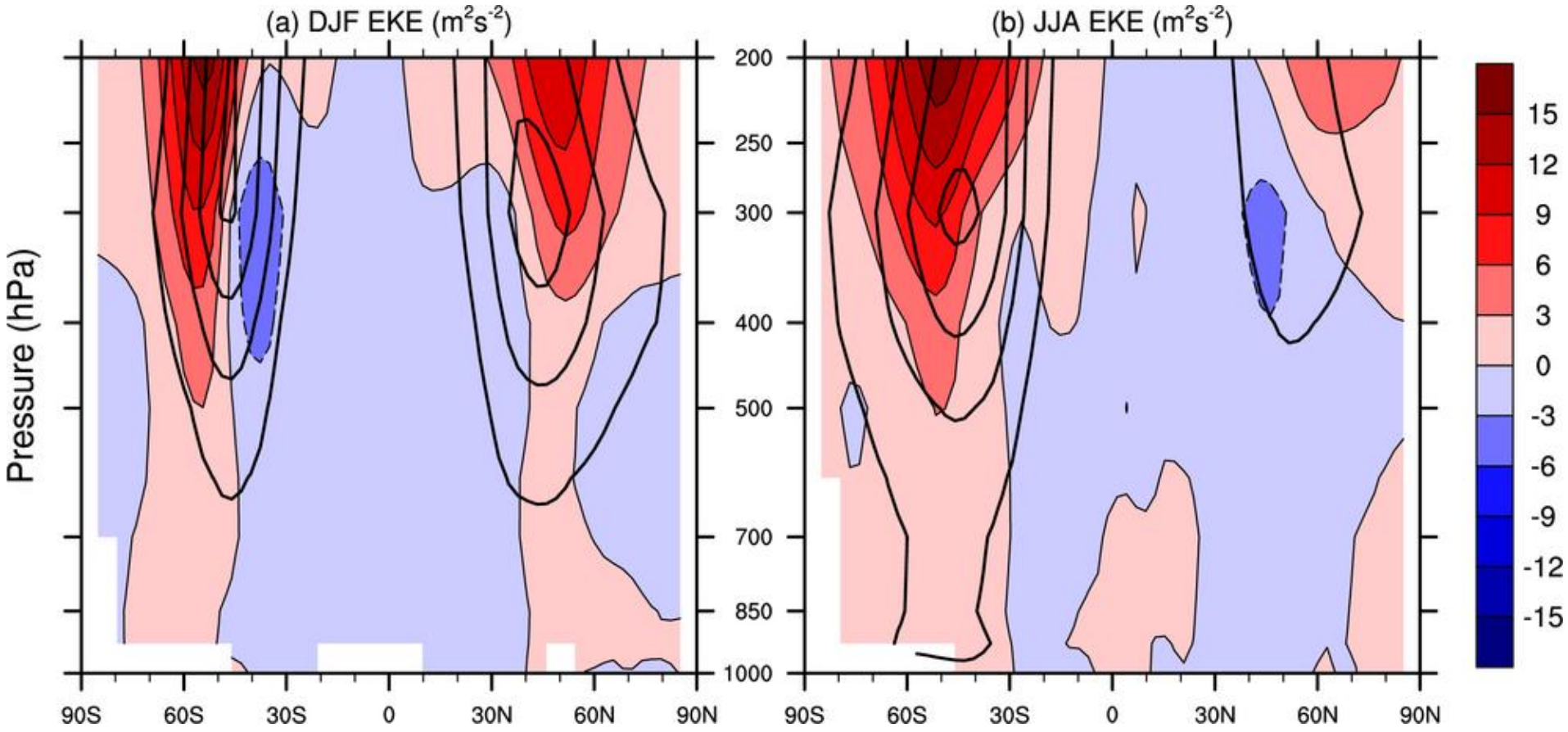
Importance of Midlatitude Cyclones/Storm Tracks



Most precipitation in SoCal comes from **mid-latitude cyclones**, especially during winter/late spring

Hodges et al., 2011

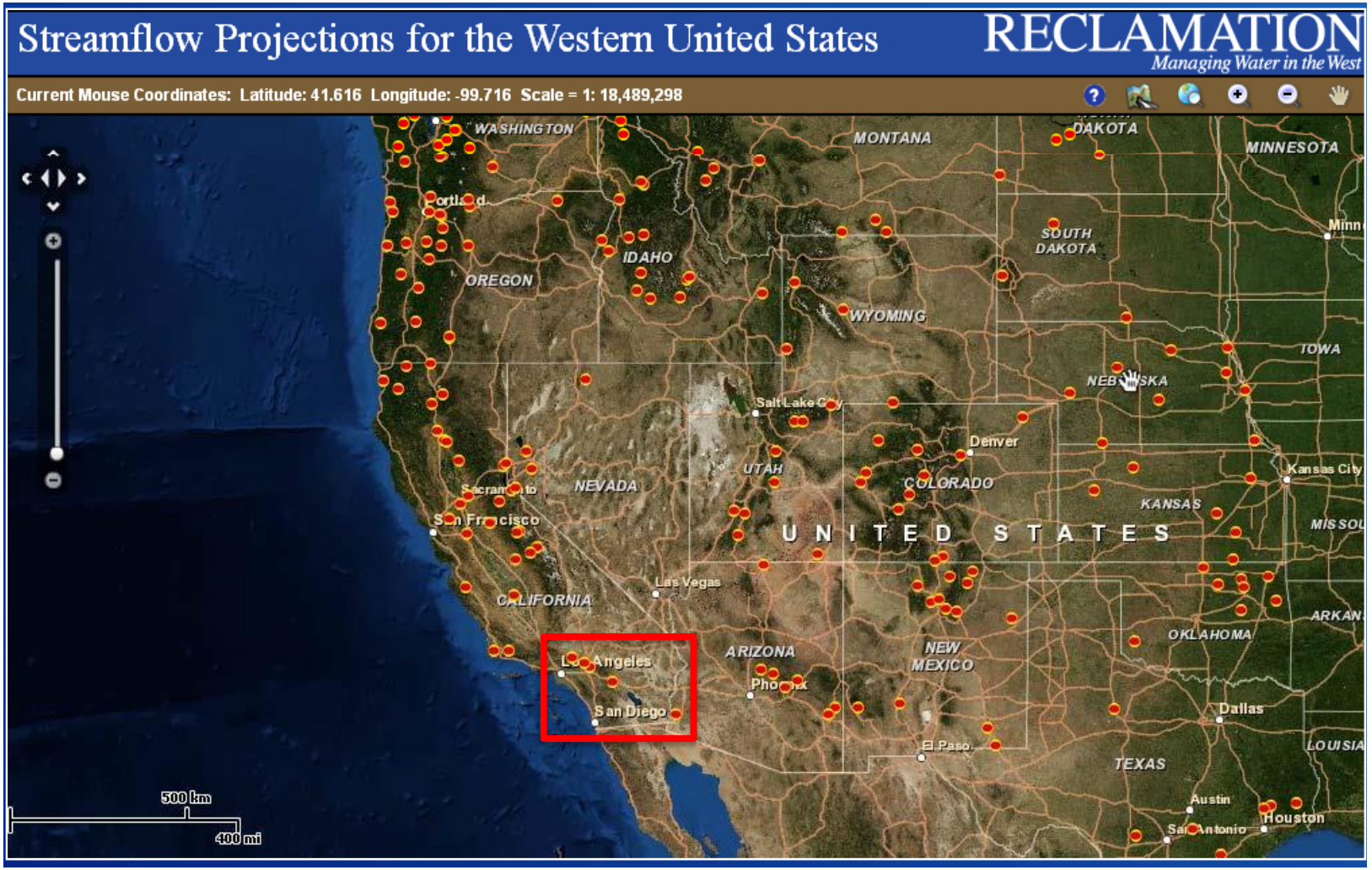
How do Storm Tracks Change?



→ *Storm tracks* ***move poleward*** in response to greenhouse gases
(NOTE: poleward shift has already been observed (~0.4° per decade)

Yin GRL, 2005

BCSD-CMIP3-Based SoCal Streamflow



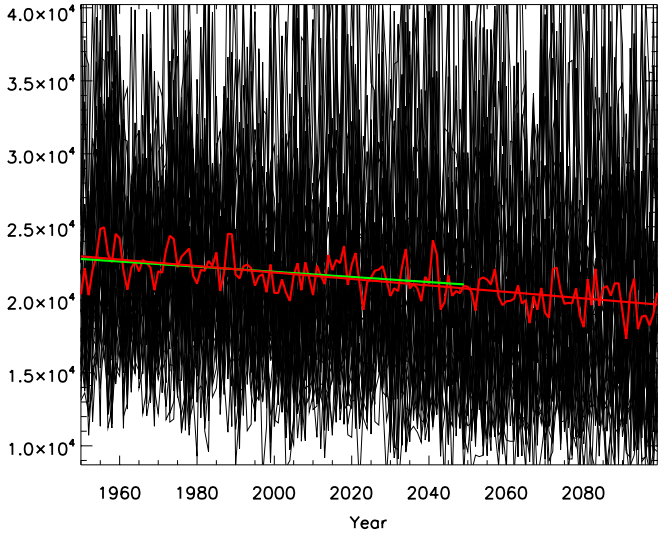
→ Five locations in Southern California: 1. Velyermo; 2. Keenbrook; 3. Arrow Head Springs; 4. Palm Springs; and 5. Colorado River above Imperial Dam.

→ Streamflow based on Variable Infiltration Capacity hydrological model.

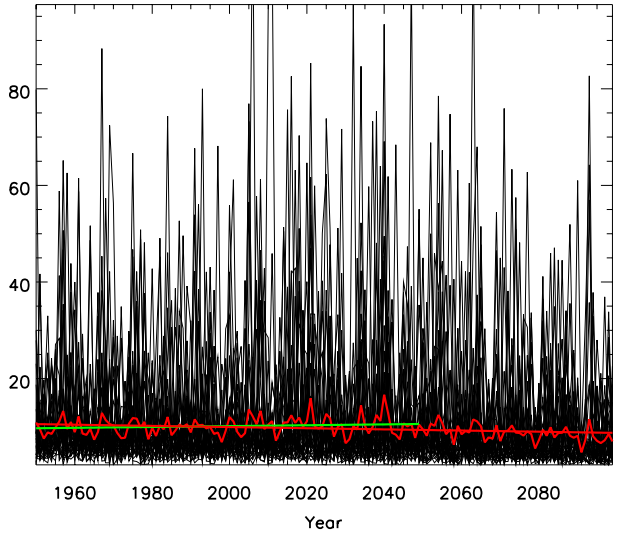
http://gis.usbr.gov/streamflow_projections/

SoCal ΔStreamflow (A2 Scenario)

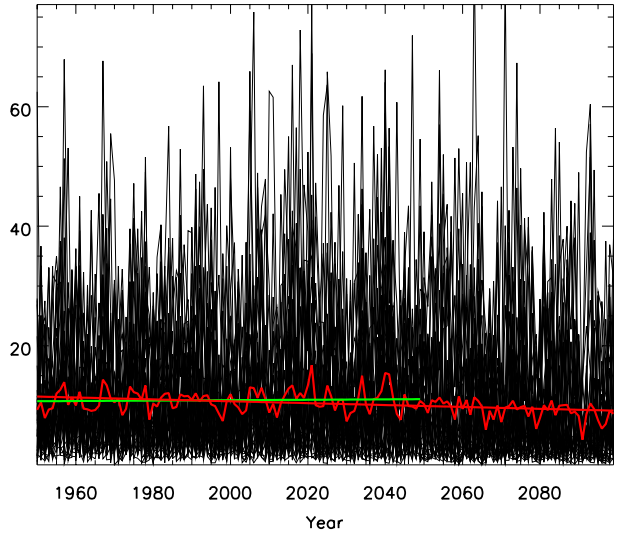
Colorado River



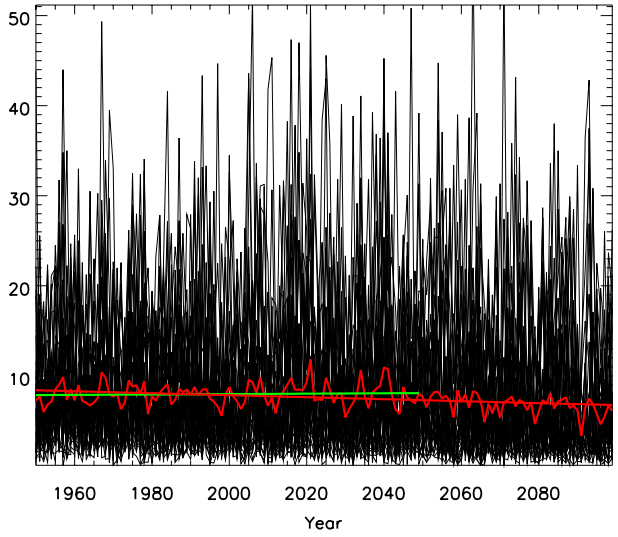
Palm Springs



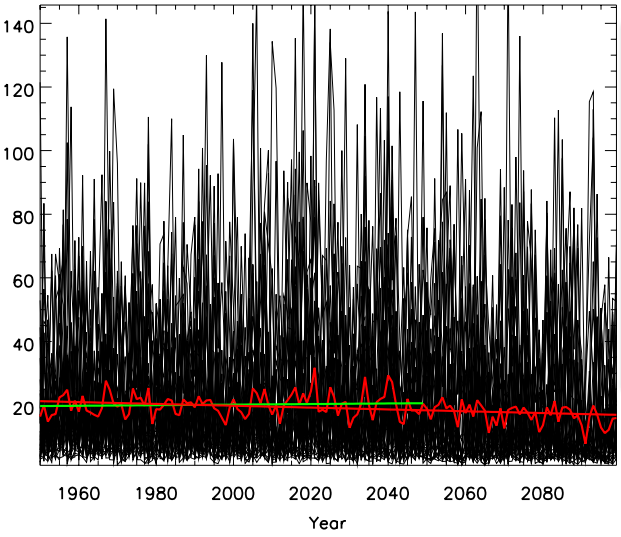
Valyermo



Arrowhead Springs

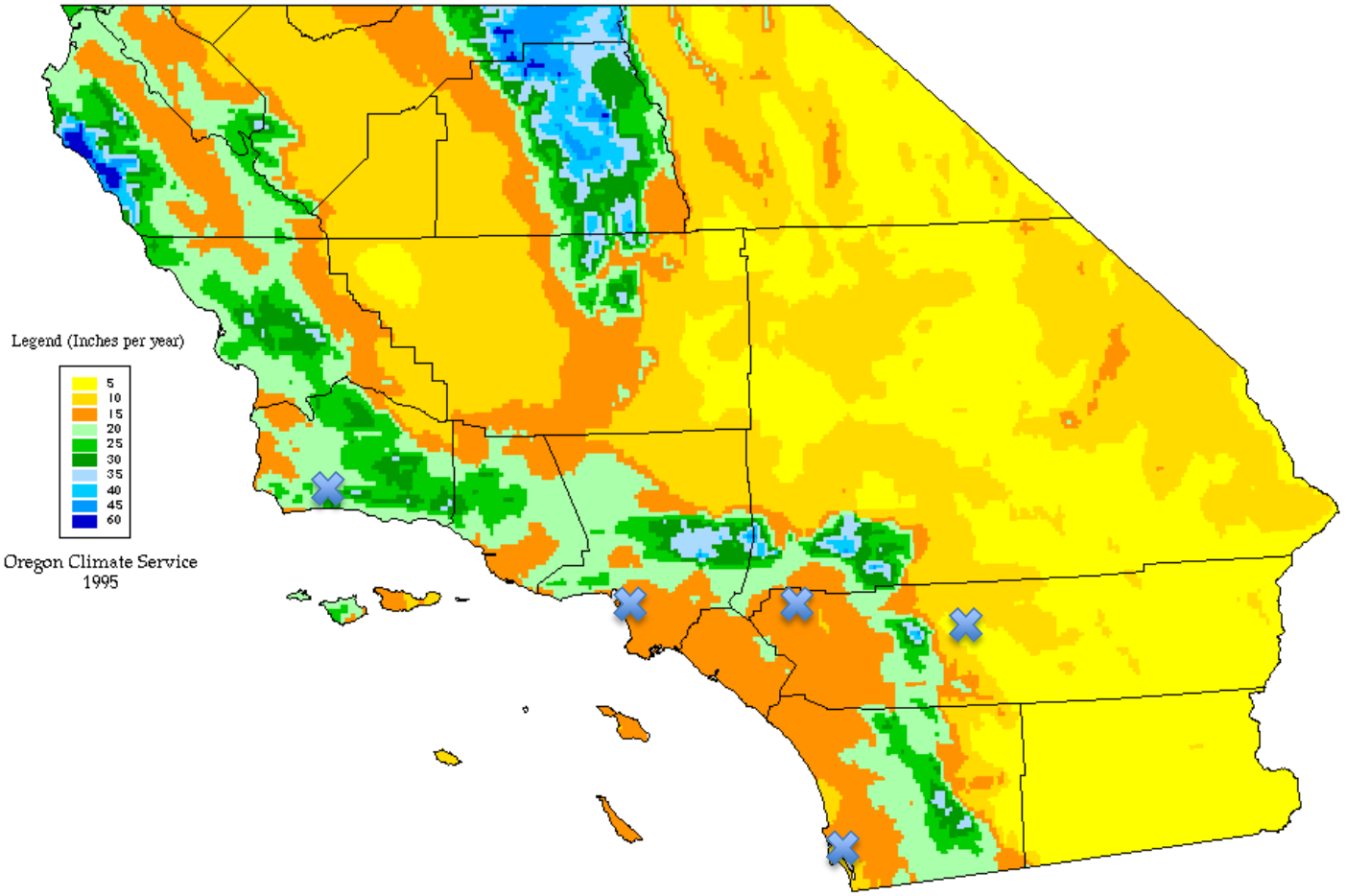


Keenbrook



→ Considerable year-to-year variability, but ***significant decreases*** at all locations by end of century.

Map of Annual Mean SoCal Precip

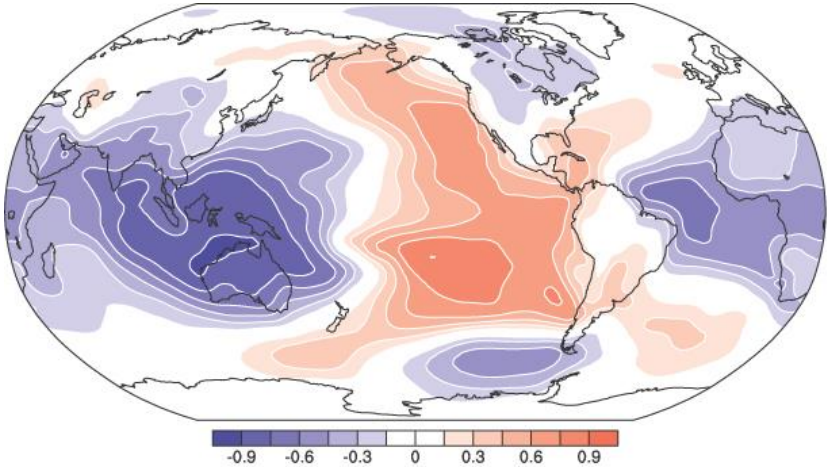


Annual Average Precipitation (Inches),
Southern California

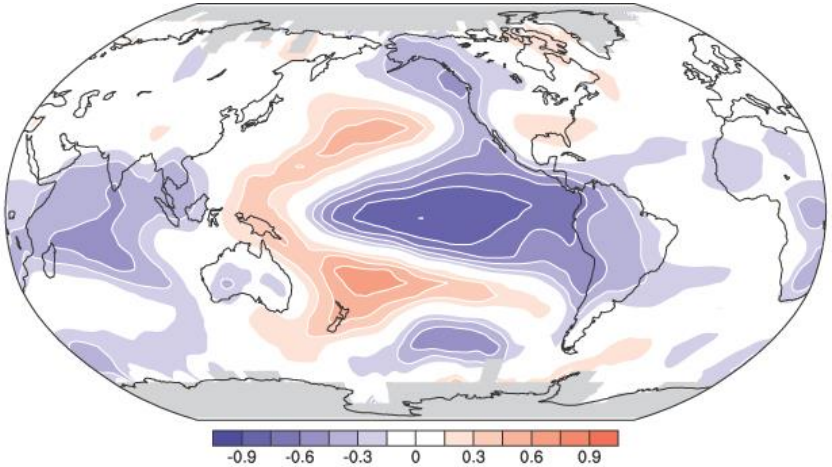
Period: 1961-1990

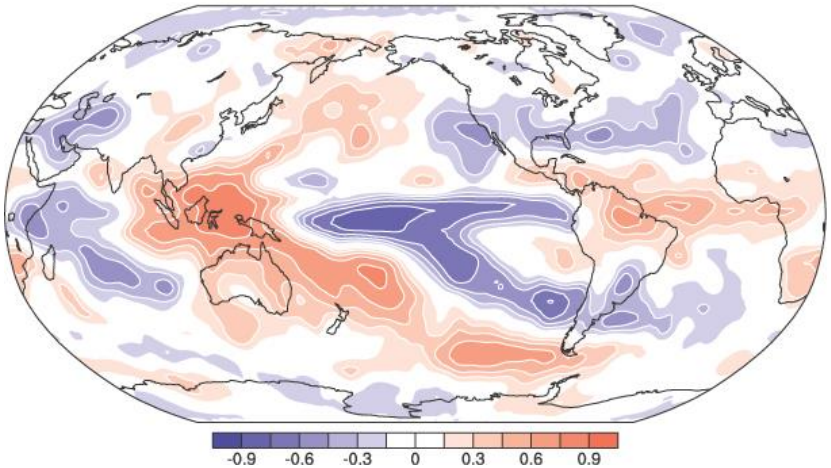
Role of El Nino-Southern Oscillation

1958-2004 Sea Level Pressure

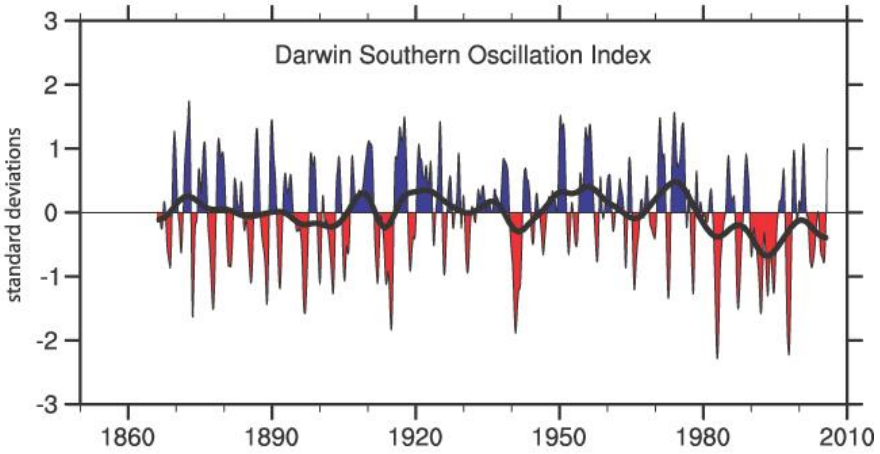


1950-2004 Surface Temperature





1979-2003 Precipitation

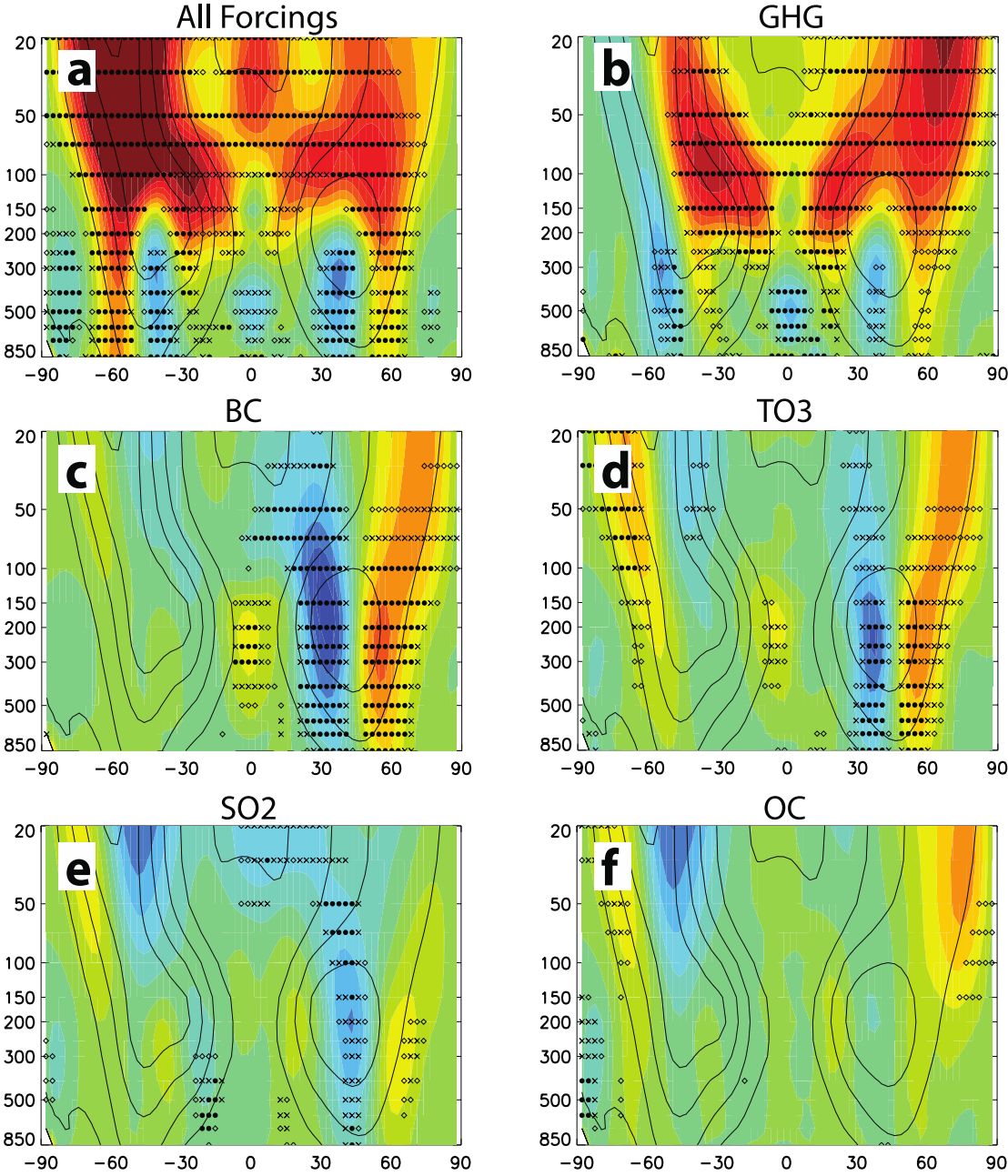


El Nino is associated with **anomalous *wet*** conditions in SoCal

IPCC, 2007

Importance of non-GHGs in Driving Poleward Displacement of Circulation

- → Other climate forcing agents besides GHGs exist.
- → Only ~50% of CMIP3 models included time-varying **black carbon** and **ozone**.
- → SRES did not specify future concentrations.
- → Further supports model underestimation



Allen et al., Nature 2012