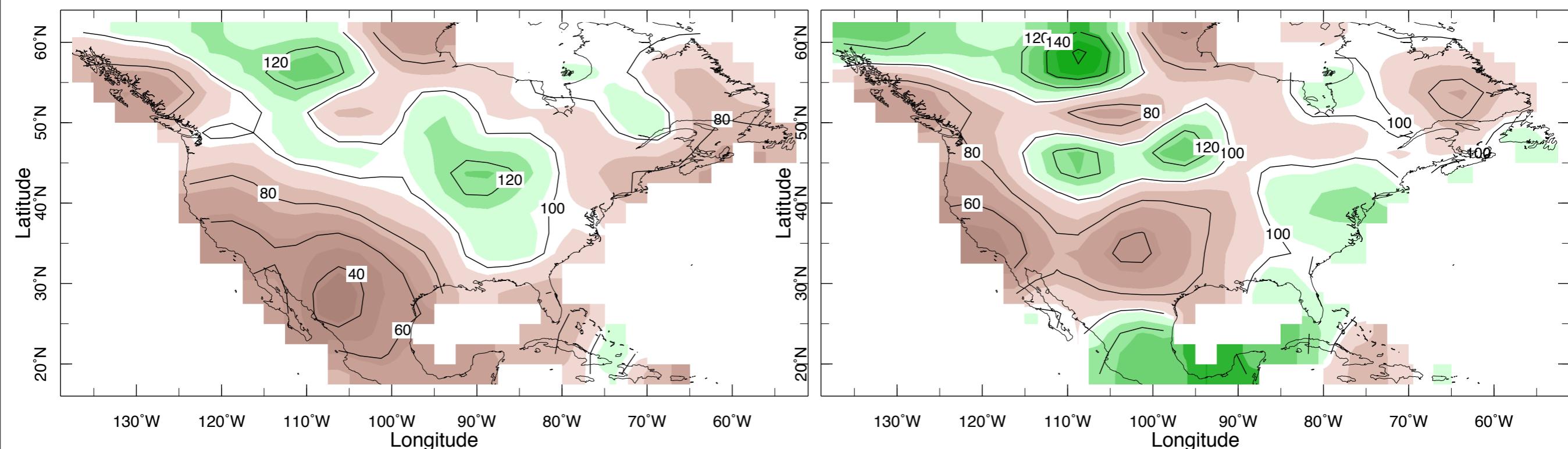


# Causes of the 2011-14 California Drought:

## An unfortunate series of weather, ocean-forced variability and/or climate change?

October 2012 to April 2013  
% of normal precipitation

October 2013 to April 2014  
% of normal precipitation



**Richard Seager<sup>1</sup>, Marty Hoerling<sup>2</sup>, Siegfried Schubert<sup>3</sup>,**  
**Hailan Wang<sup>3</sup>, Brad Lyon<sup>4</sup>, Arun Kumar<sup>5</sup>,**  
**Jennifer Nakamura<sup>1</sup>, Naomi Henderson<sup>1</sup>**

<sup>1</sup>Lamont Doherty Earth Observatory, <sup>2</sup>NOAA Earth System Research Lab, <sup>3</sup>NASA GSFC,  
<sup>4</sup>International Research Institute for Climate and Society, <sup>5</sup>NOAA Climate Prediction Center,  
NOAA Drought Task Force

Thanks also to David Neelin (UCLA) and Isla Simpson (NCAR), Naomi Henderson, Haibo Liu, Mingfang Ting, Yochanan Kushnir all (LDEO), Tiffany Shaw (U.Chicago) for contributions to CMIP5 hydroclimate change analysis.

Park Williams (LDEO) for Palmer Drought Severity Index analysis.

Sloan Coats, Jason Smerdon, Ben Cook (LDEO) and Daniel Griffin (WHOI) for paleo-NAM analysis.

# The California drought is climatically extreme but socially ghastly

Caltech, Pasadena



Porterville



***With Dry Taps and Toilets, California Drought Turns Desperate***

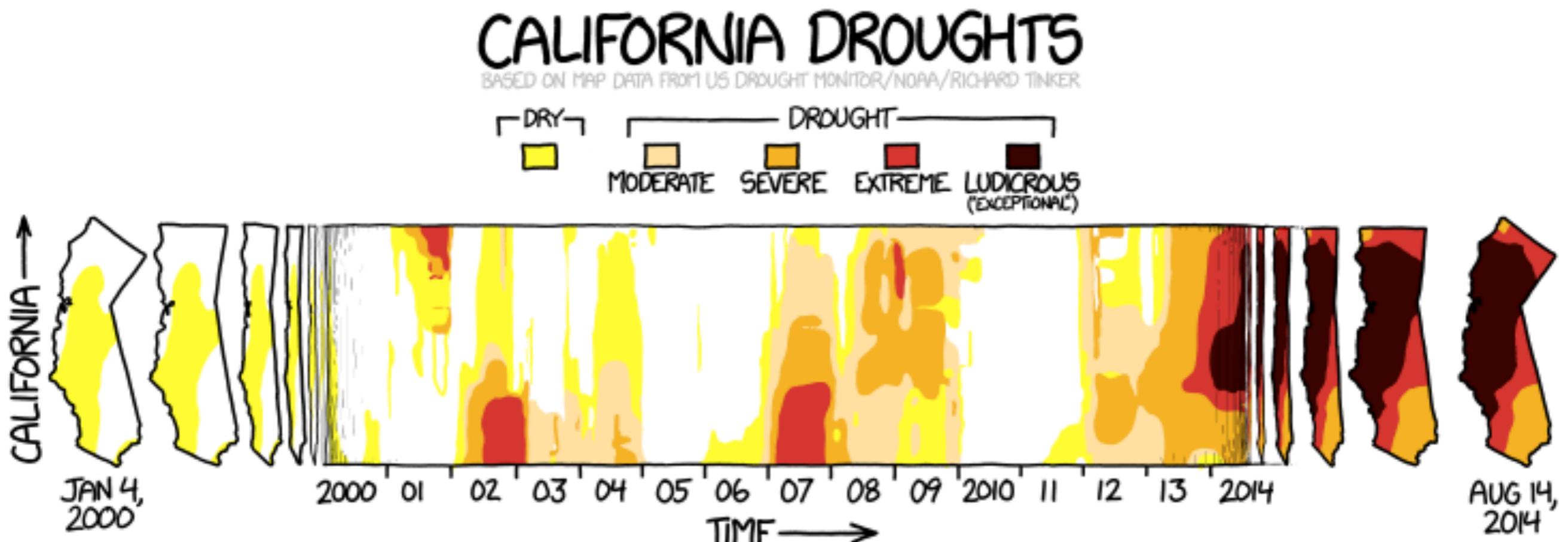
By JENNIFER MEDINA OCT. 2, 2014

# **Observational data:**

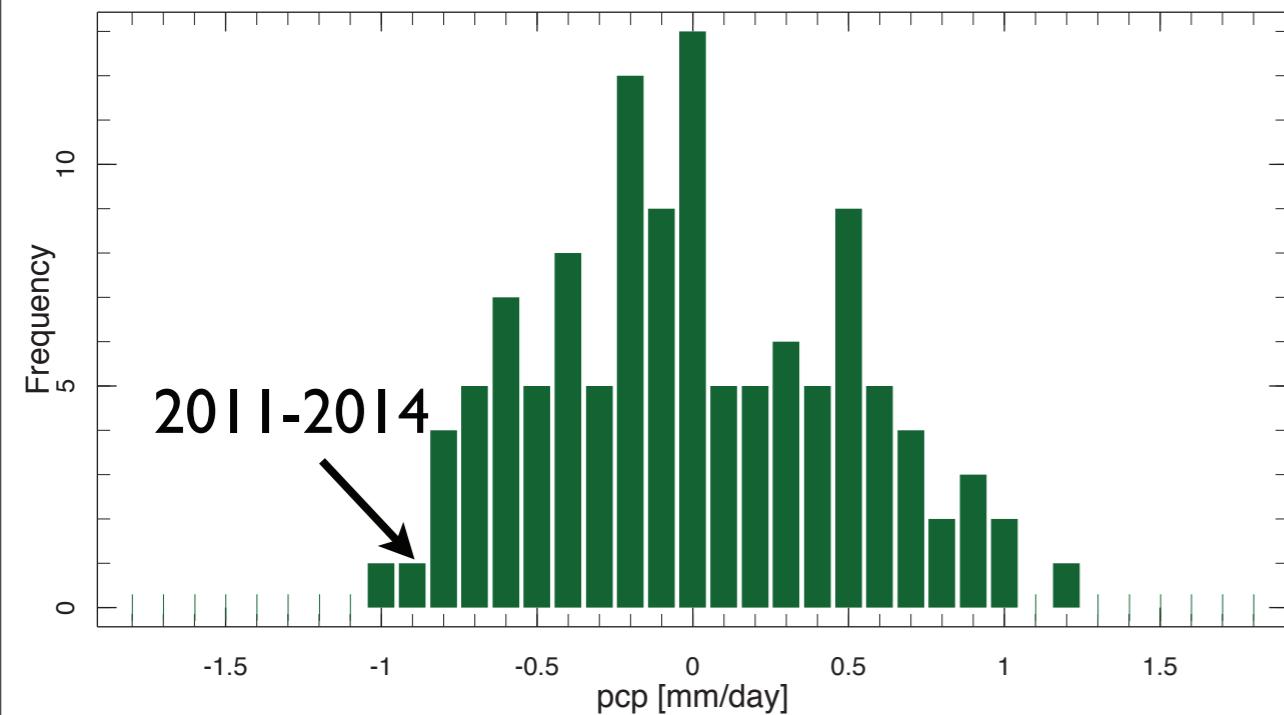
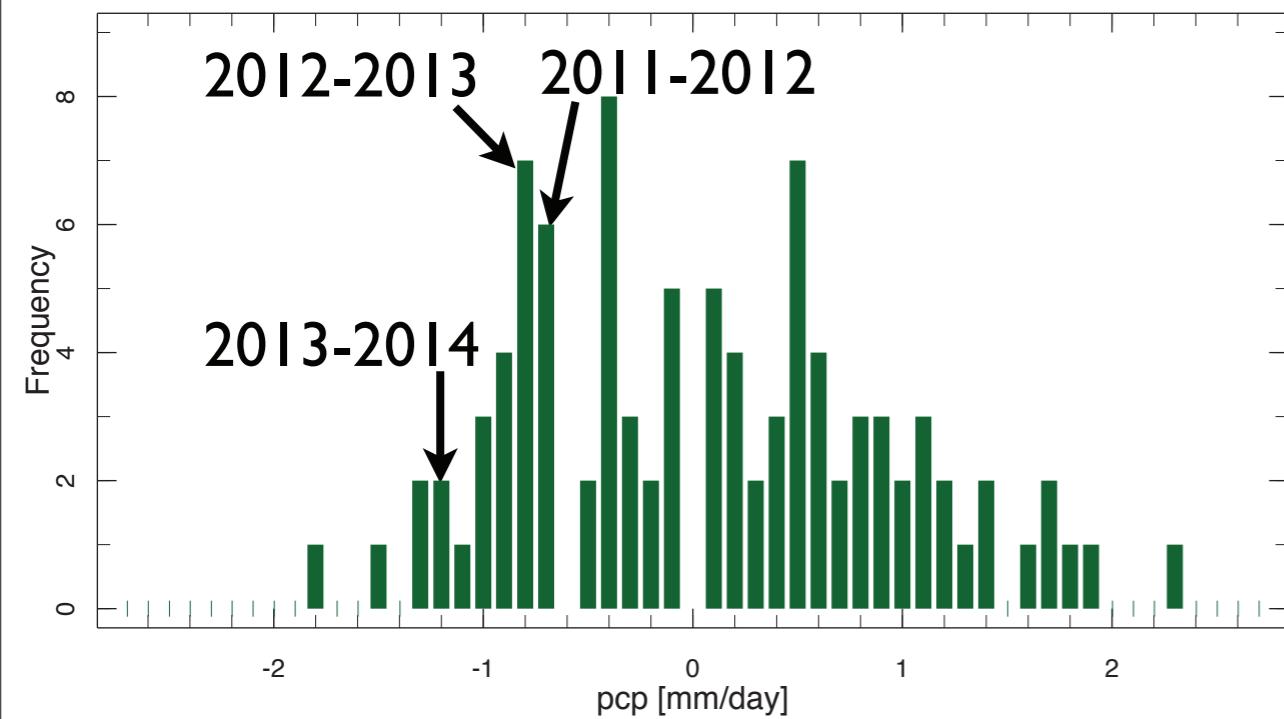
NOAA Climate Division precipitation, Jan 1895 to Apr 2014  
Hurrell, NOAA ERSST and Hadley SST products  
NCEP-NCAR Reanalysis 1949 to Apr 2014

# **Models:**

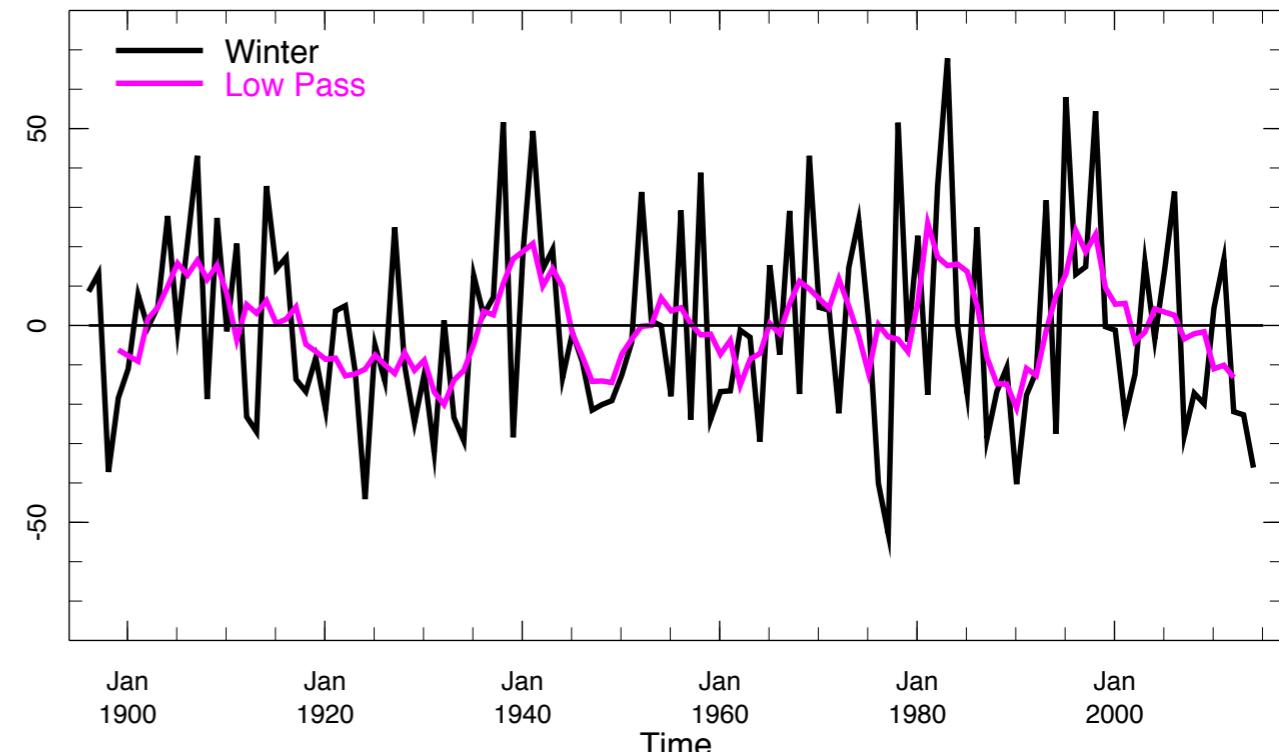
Seven SST-forced GCMs  
from Lamont, IRI, NASA, NOAA CPC and NOAA ESRL(3)



## CA Winter Climate Division Precipitation



Climate Division CA Precipitation Anomaly  
Winter (black) and Lowpass (magenta)



California has a rich history of droughts. Current drought appears as one of many such events both in terms of amplitude and duration, but it is the worst.

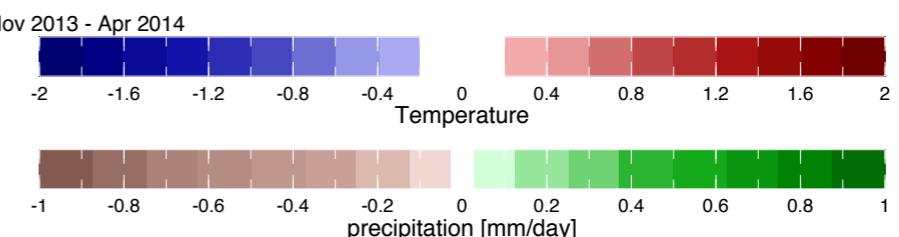
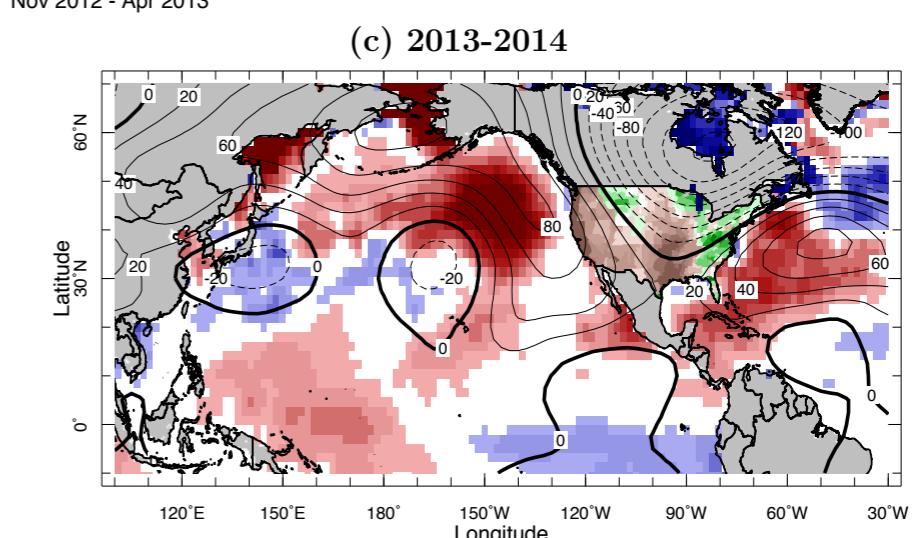
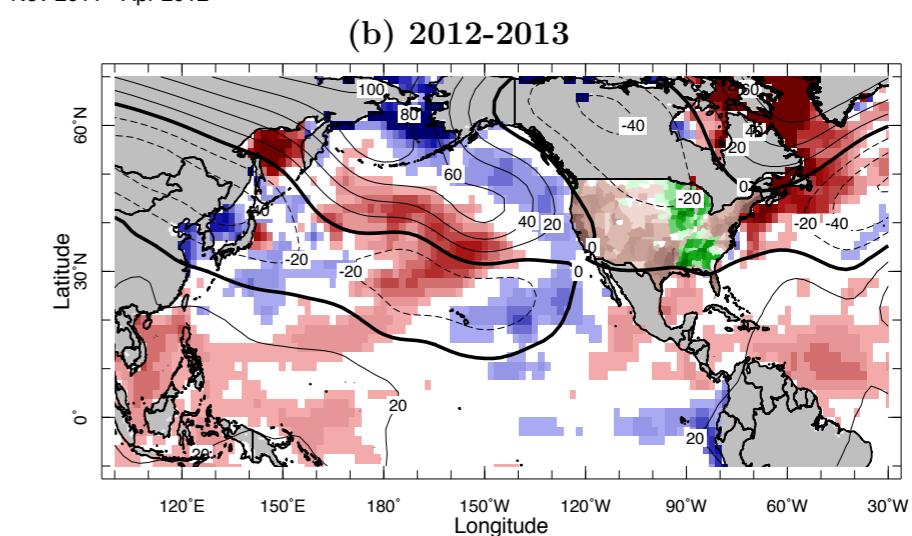
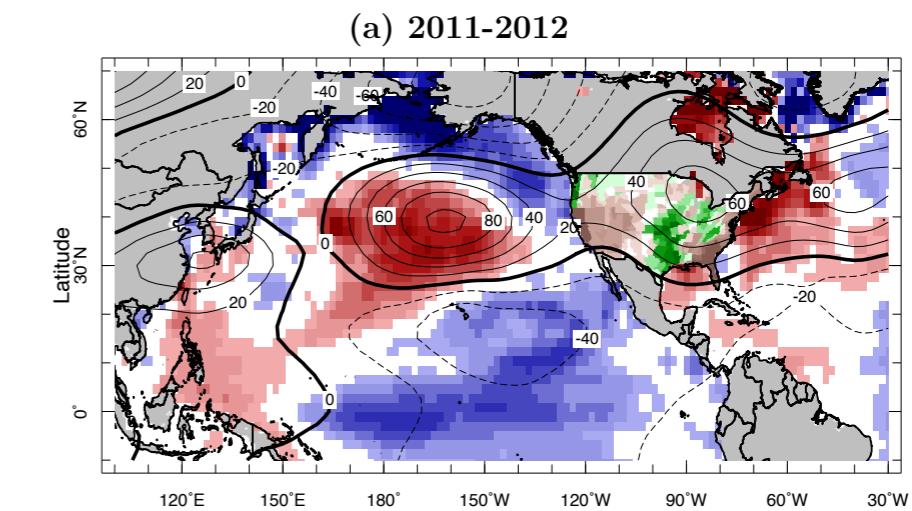
# Last 3 winters 200mb heights, SST, U.S. precipitation

2011/12 looks like a La Niña

2012/13 ENSO neutral, North Pacific ridge

2013/14 warm west tropical Pacific,  
North Pacific-west coast ridge

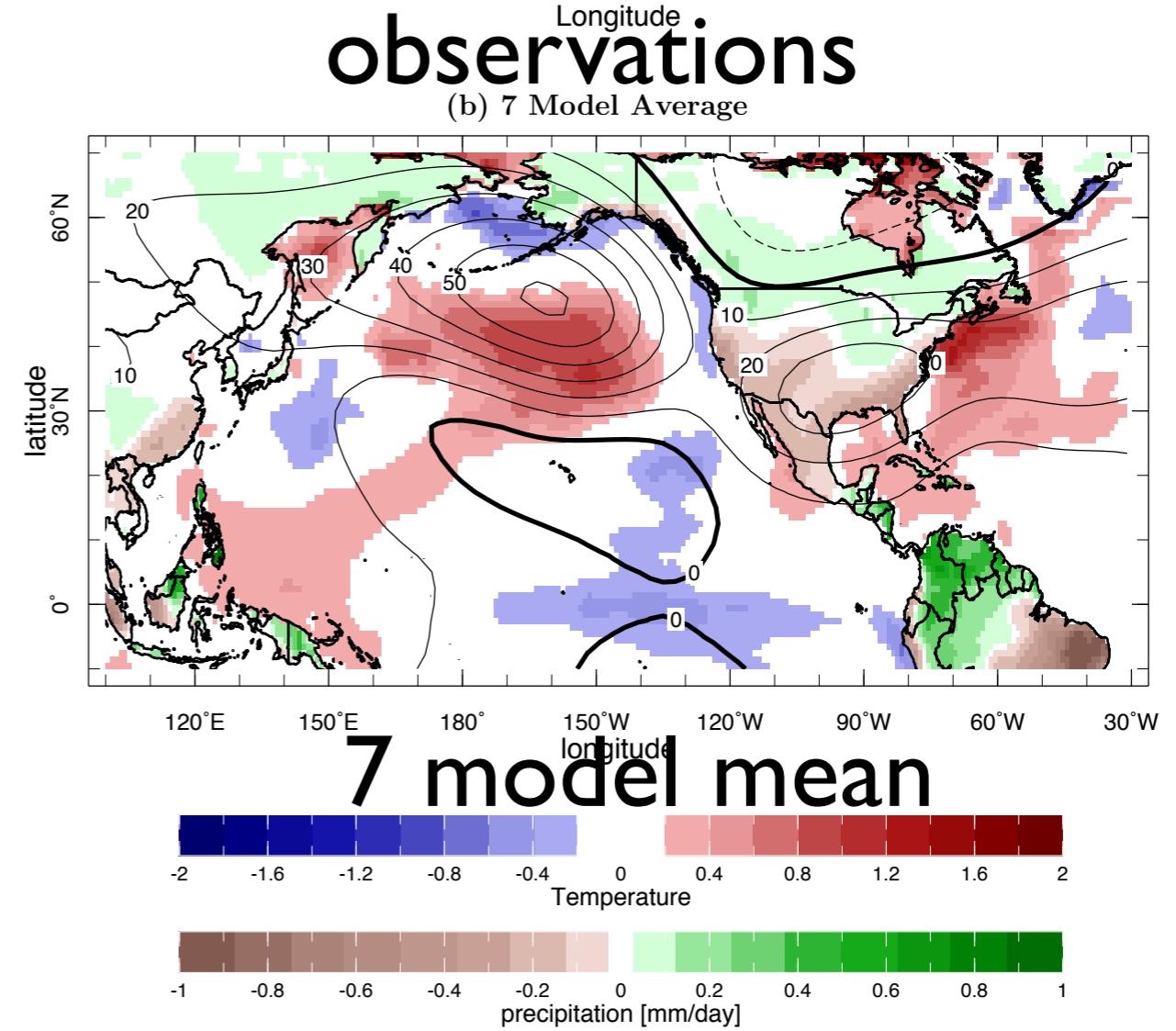
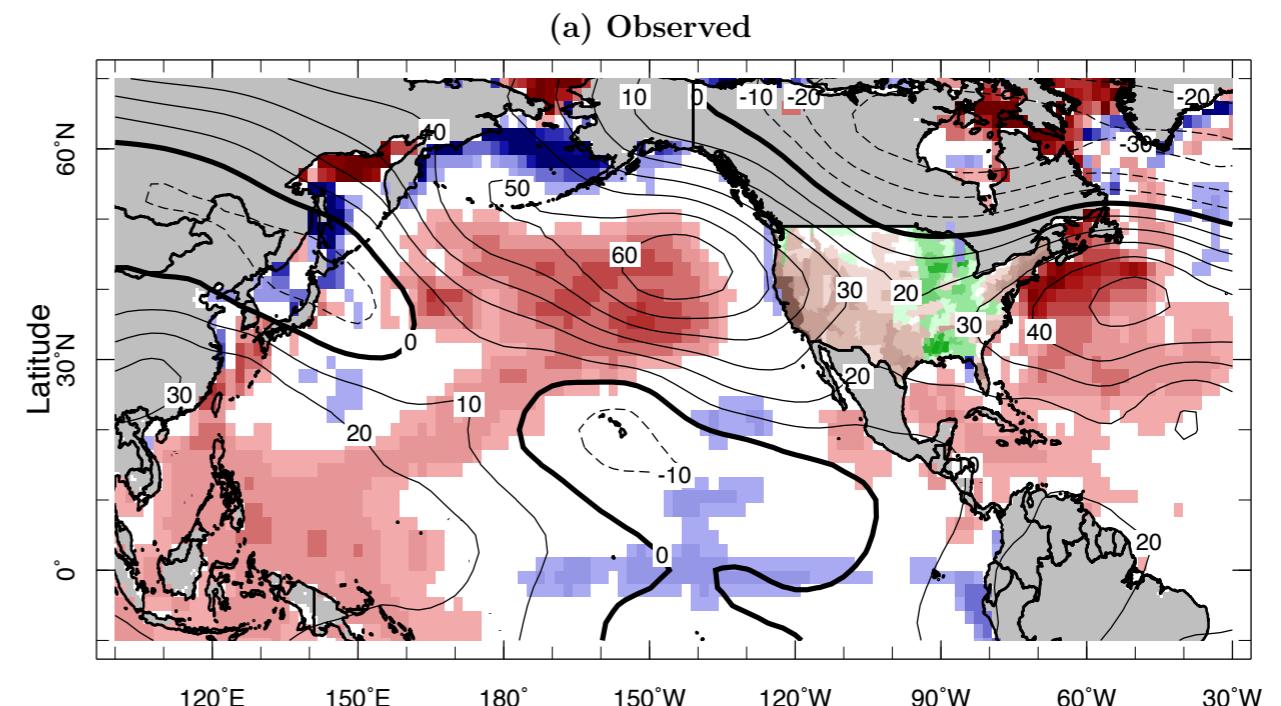
In all three CA/west coast was dry



sea surface  
temperature, 200mb  
height and  
precipitation  
anomalies averaged  
over Nov-Apr of  
2011-14

models reproduce  
northeast Pacific ridge and  
dry west coast as a  
response to SST anomalies  
alone and of likely natural  
origin

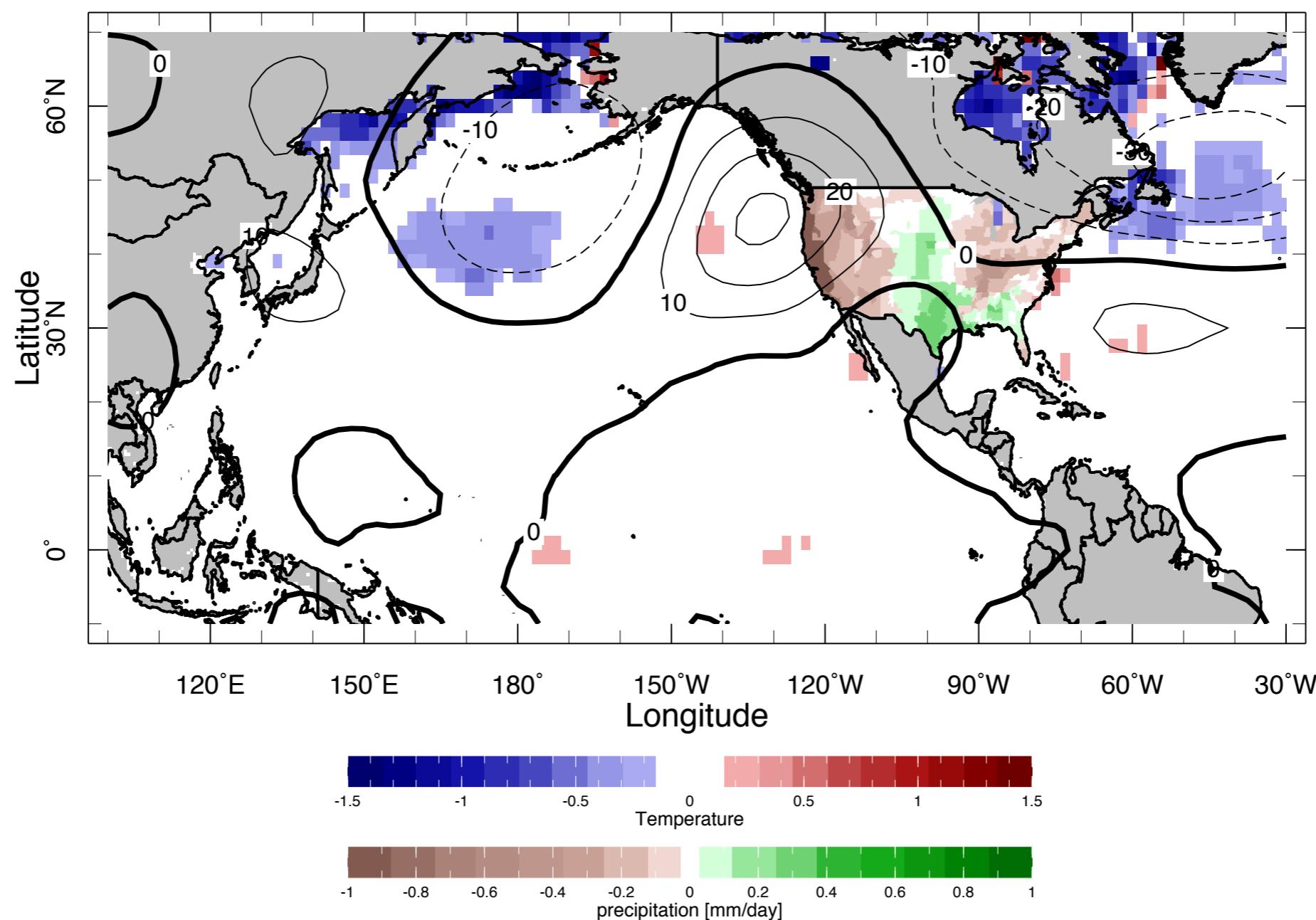
2011-2014 Winter SSTA (ocean), Precip (land), 200 mb Height (contour)



# No surprise SST-forced models do not fully capture CA P variability

Winter CA Precip(land), SSTA(ocean), 500mb Height(contour)

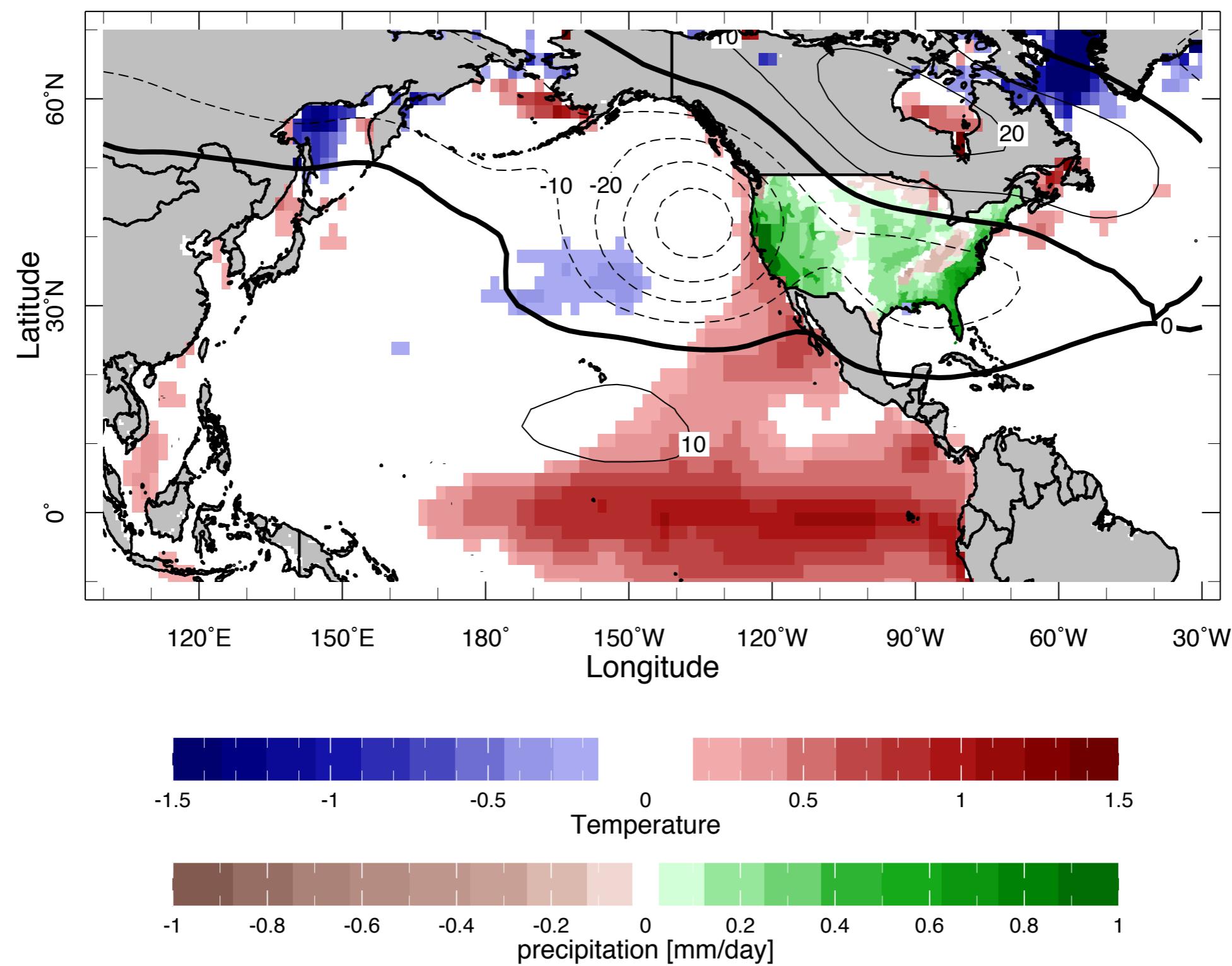
(A) Dry Years



A composite of observed CA dry winters shows the off-coast ridge but no impressive sea surface temperature anomalies

In contrast, observed wet California winters tend to be caused by El Nino events

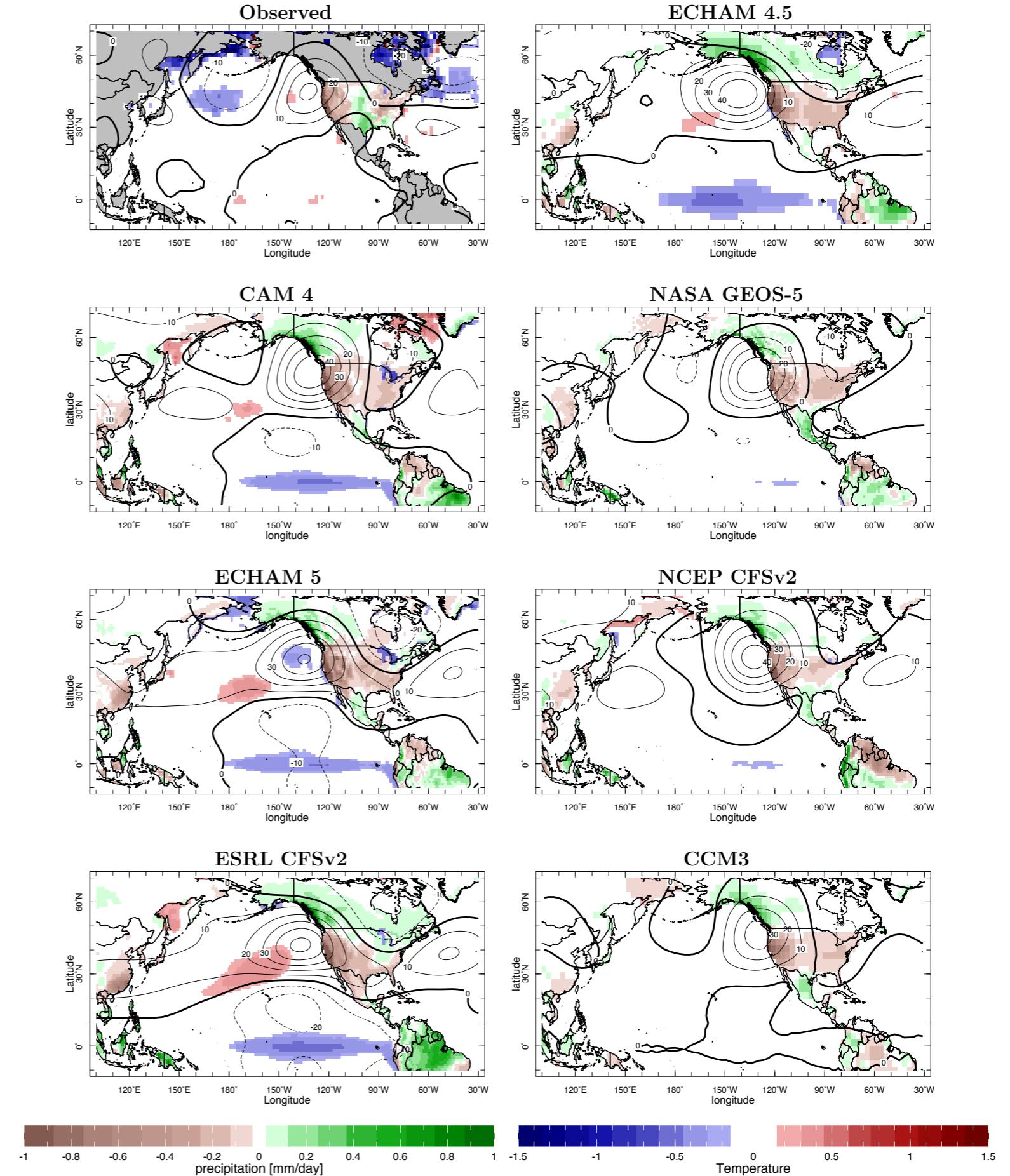
(B) Wet Years



CA Dry Winter Composite Precip(land), SSTA(ocean), 200mb Height(contour)

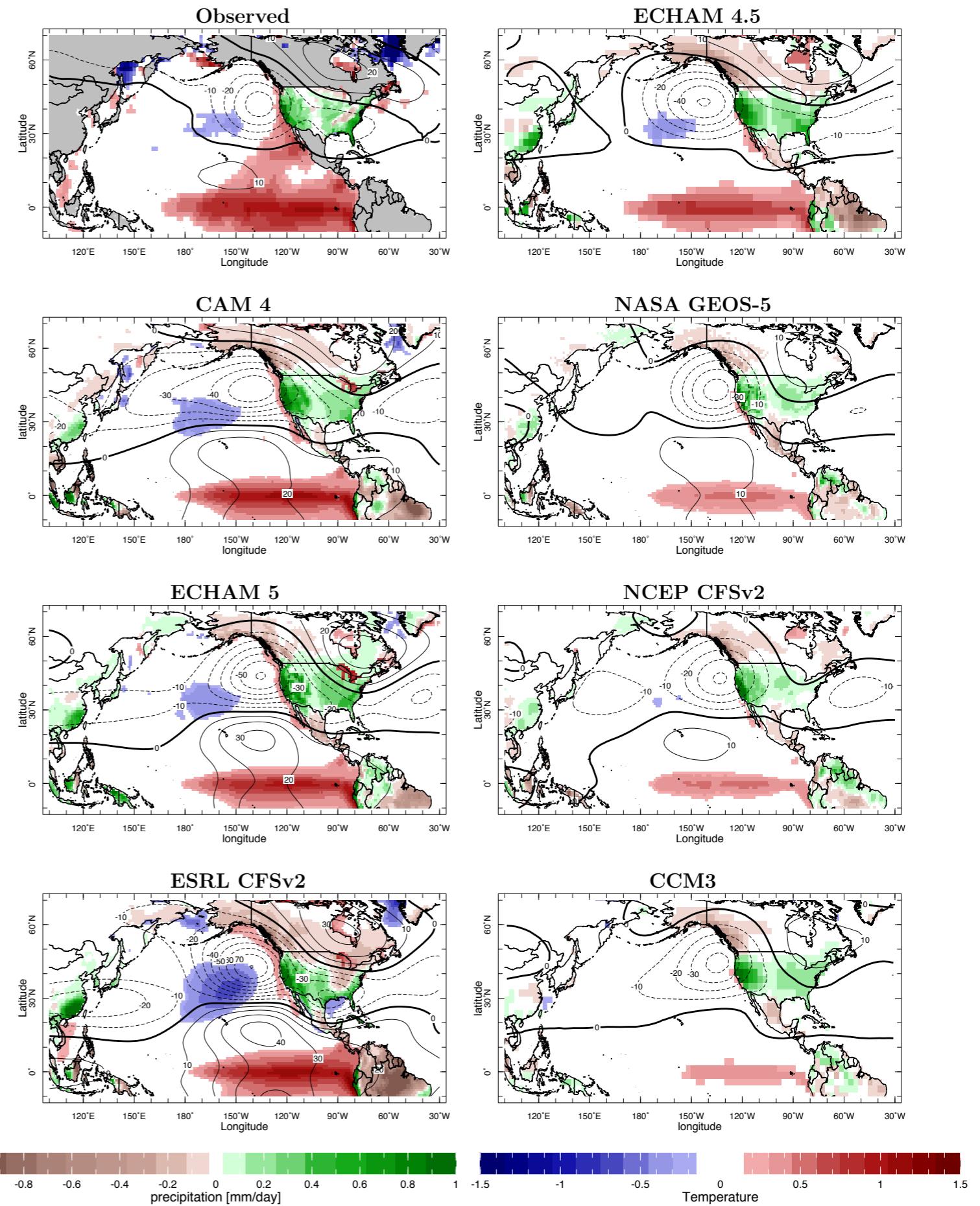
Some models  
(ECHAM4.5, ESRL  
CFSv2) appear to  
have too strong of  
a La Nina-CA dry  
relation.

Other models  
(GEOS-5, CCM3)  
seem to correctly  
link CA-dry  
winters to internal  
atmosphere  
variability.



CA Wet Winter Composite Precip(land), SSTA(ocean), 200mb Height(contour)

All models correctly link wet CA winters to El Nino, though with varying strengths of relation.  
I.e. models capture the nonlinearity of CA-SST relations.



What is the SST-forced component the models picked up for ENSO-neutral 2012/13 and 2013/14?

To check:

EOF decomposition of Nov-Apr 200mb height for 0-90N,  
1979 to 2014 (common model period)

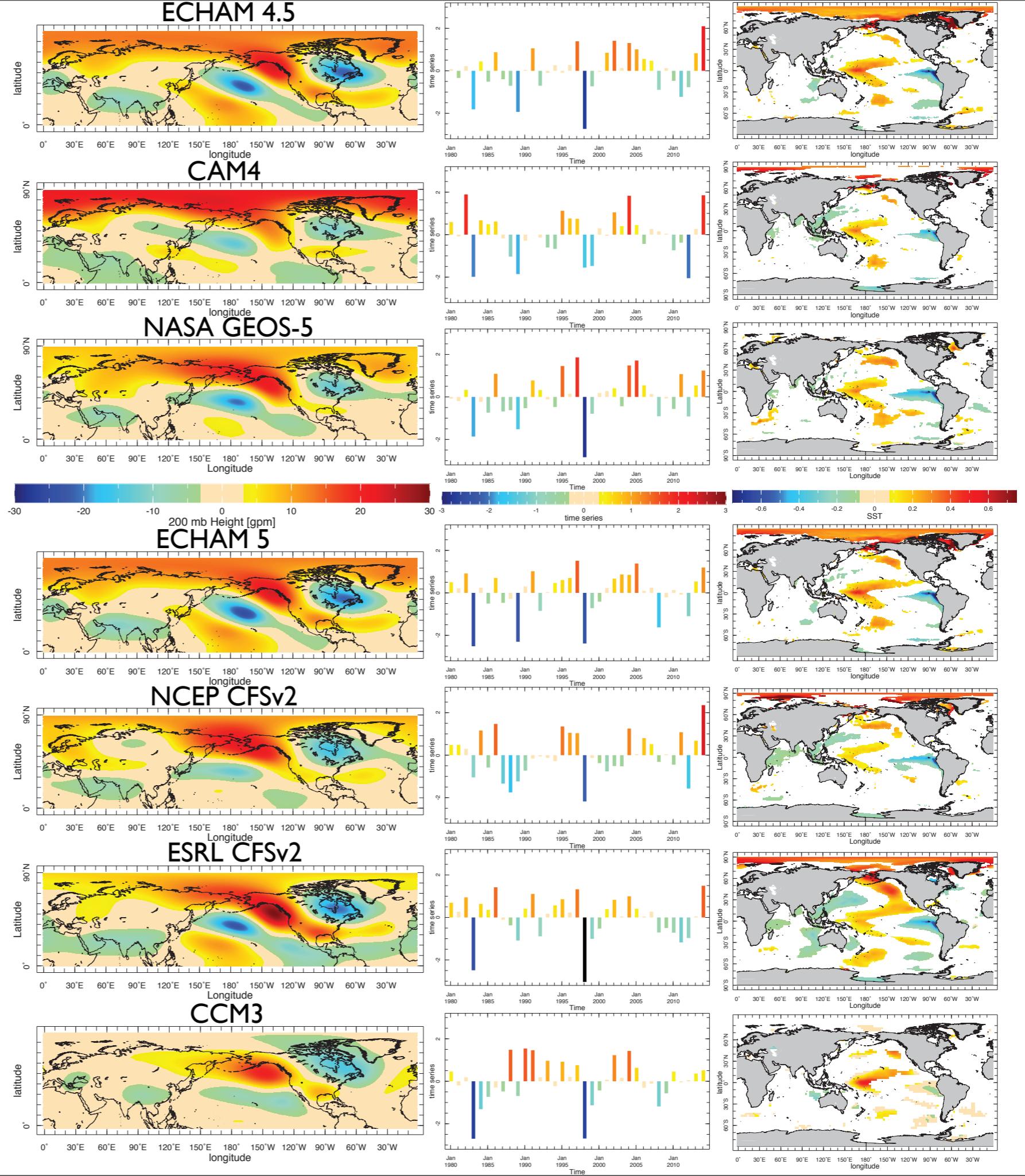
EOF/PC 1 --- ENSO

EOF/PC 2 --- decadal ENSO/PDV/trend

**EOF/PC 3:**

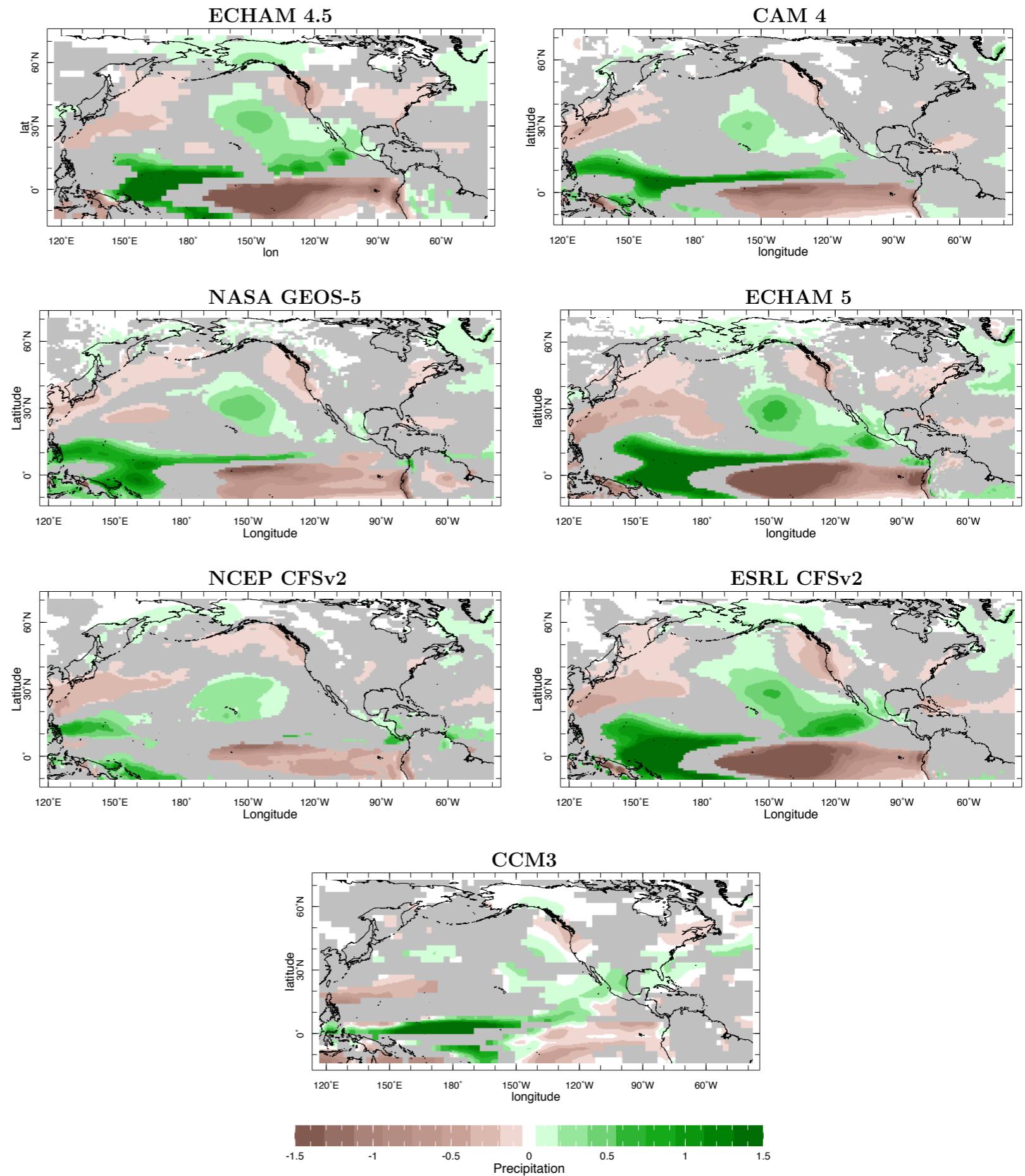
northeast Pacific-west coast ridge  
warm (cool to neutral) west (east) tropical Pacific

The SST-gradient/west coast ridge SST-forced mode in 7 models.  
 200mb height pattern, time series, SST regression  
 (shown where significant)



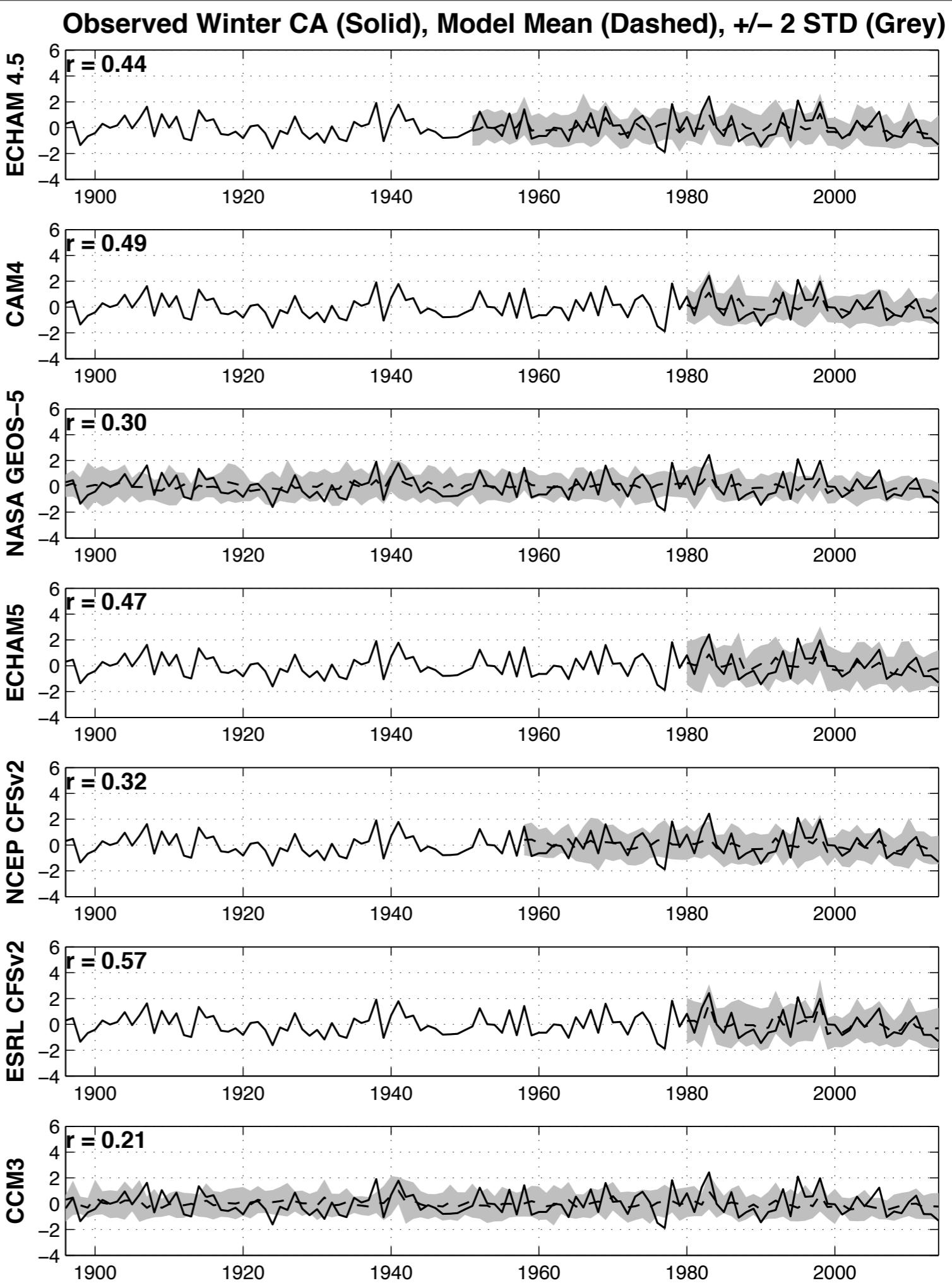
## Winter Precipitation Regression on PC 200 mb Heights

Ensemble mean  
 $P$  regressed  
onto PC3,  
shown where  
90% significant.  
Wet west  
tropical Pacific,  
dry US west  
coast.



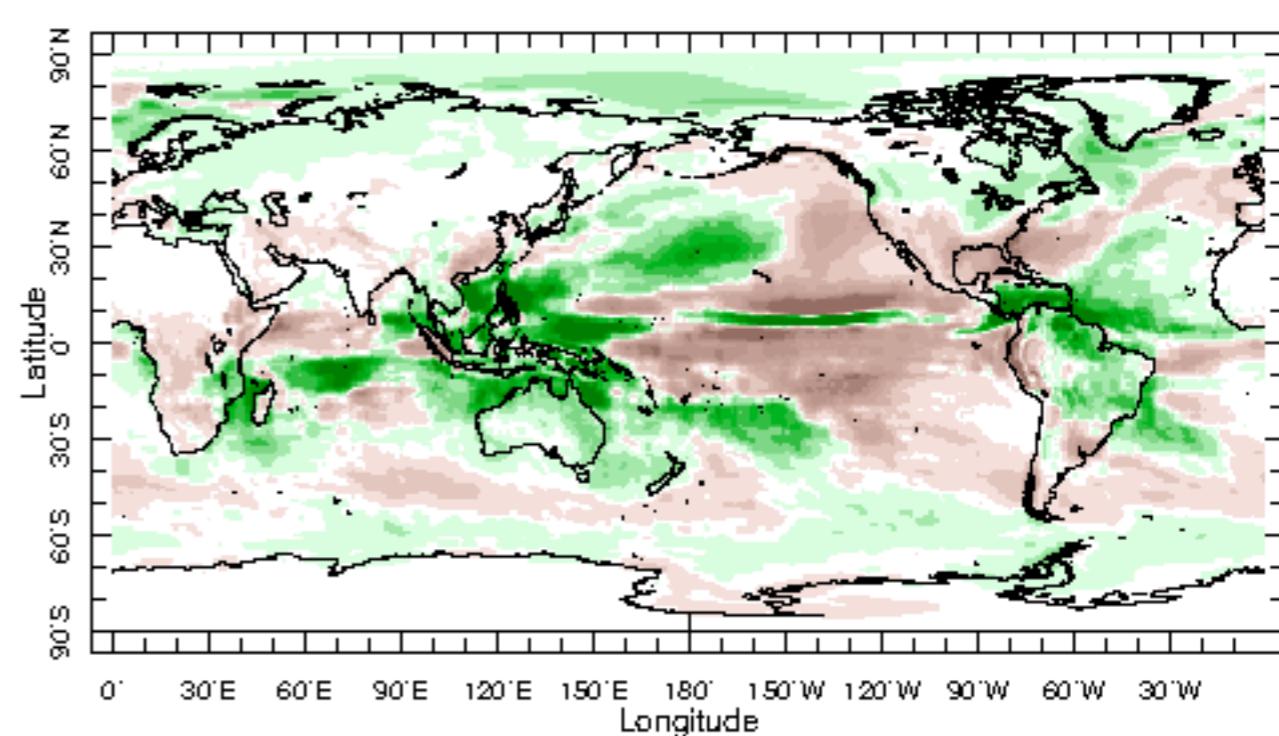
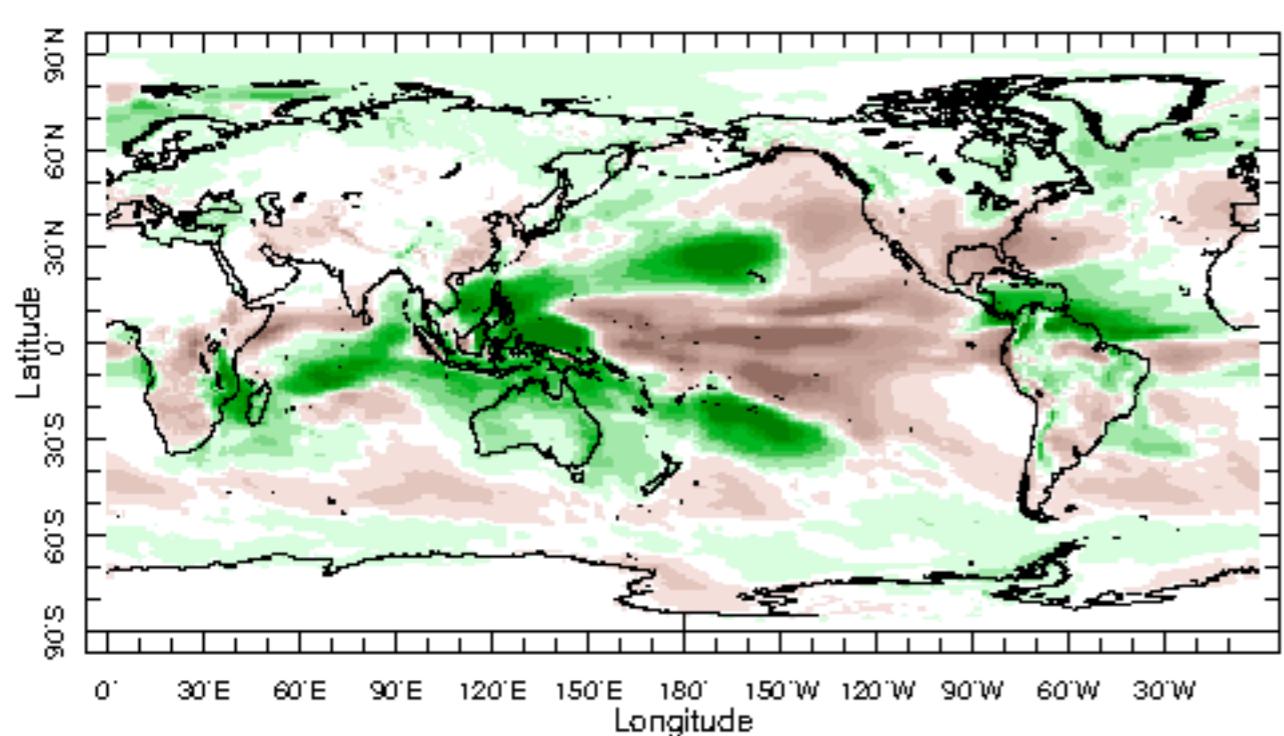
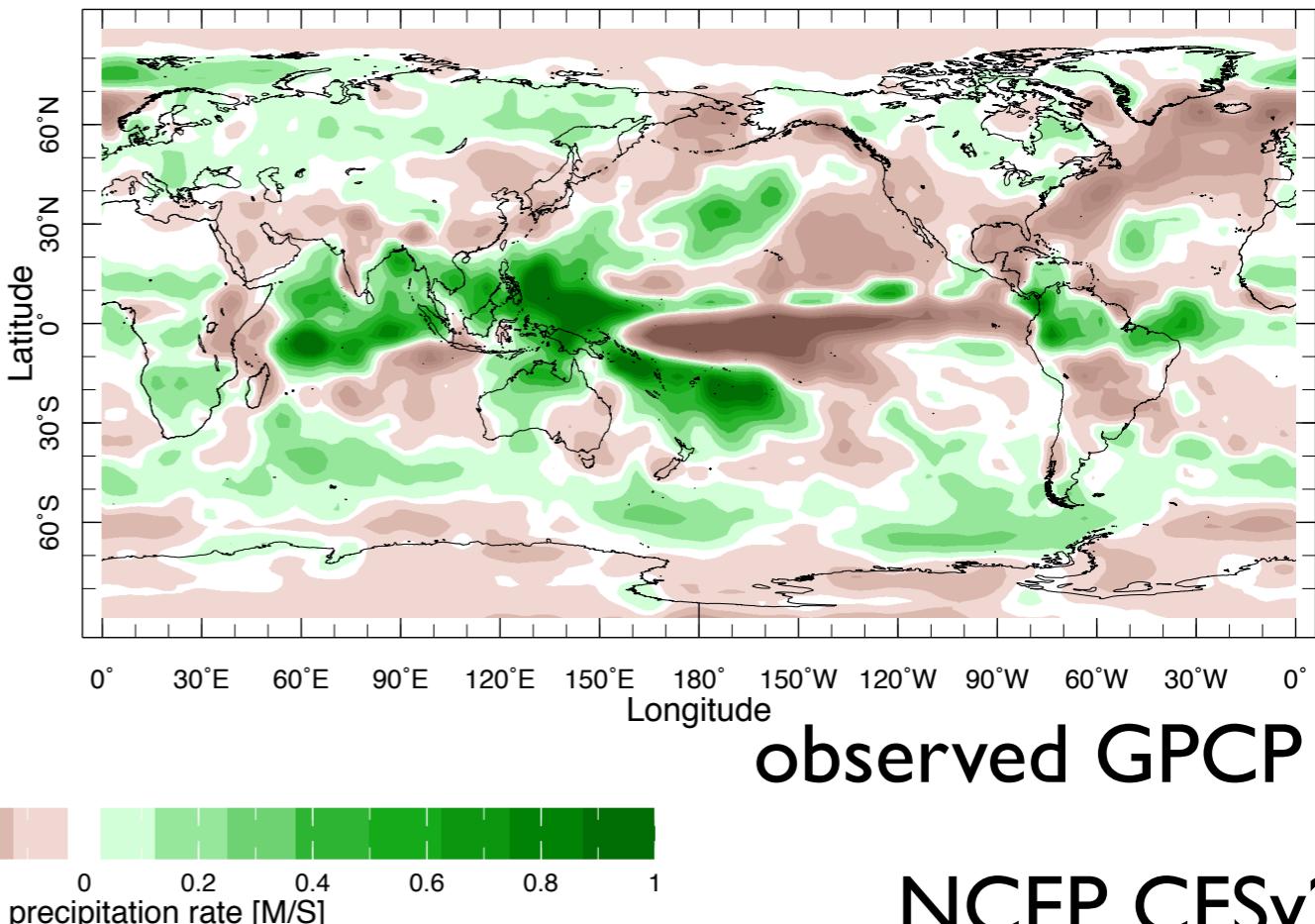
# Observed and modeled histories of California precipitation

Model skill is variable.  
Some models, e.g. ESRL CFSv2, suggest notable skill.



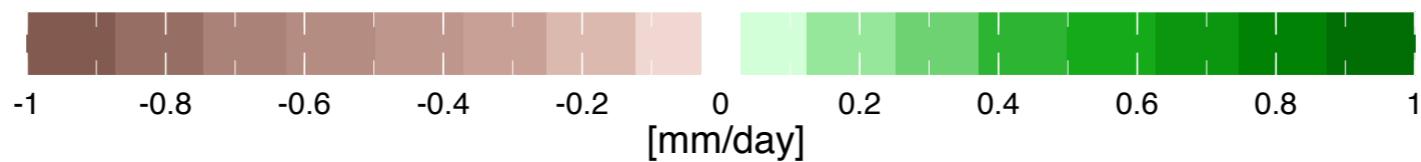
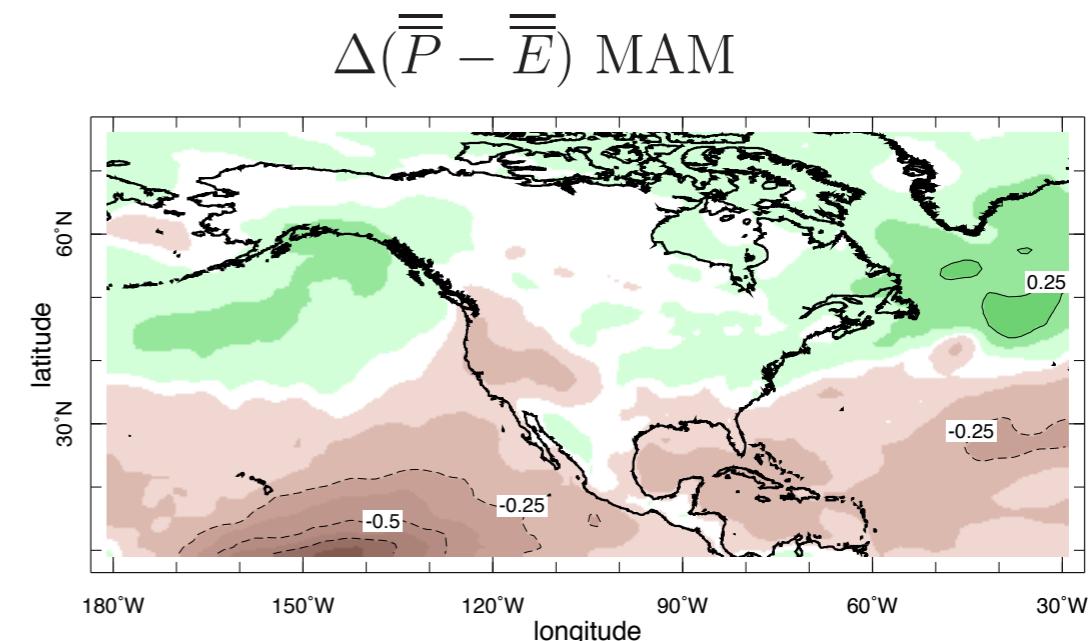
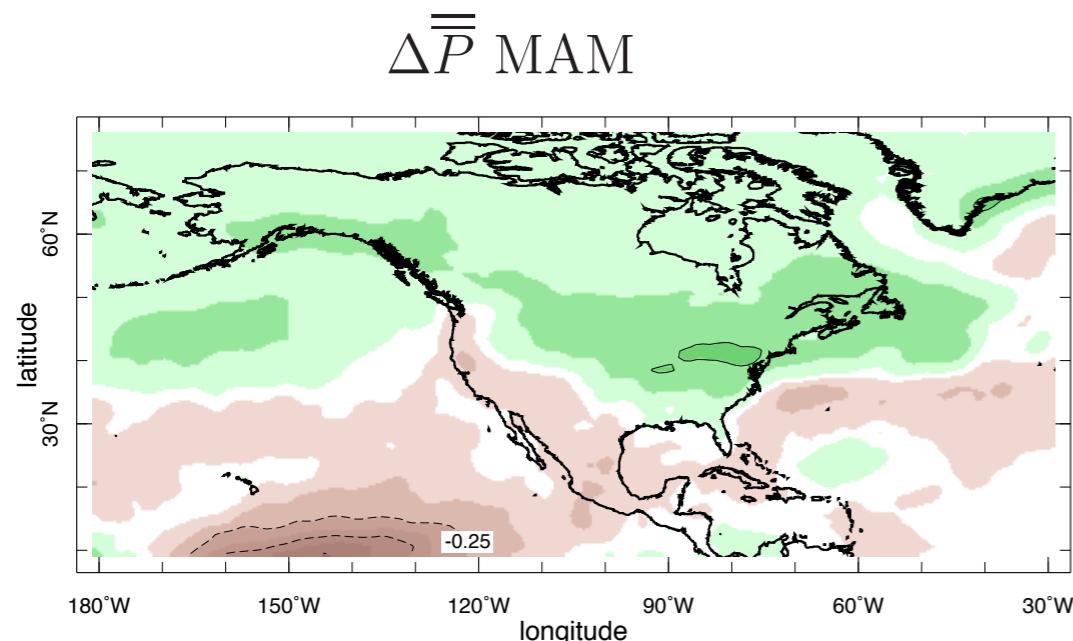
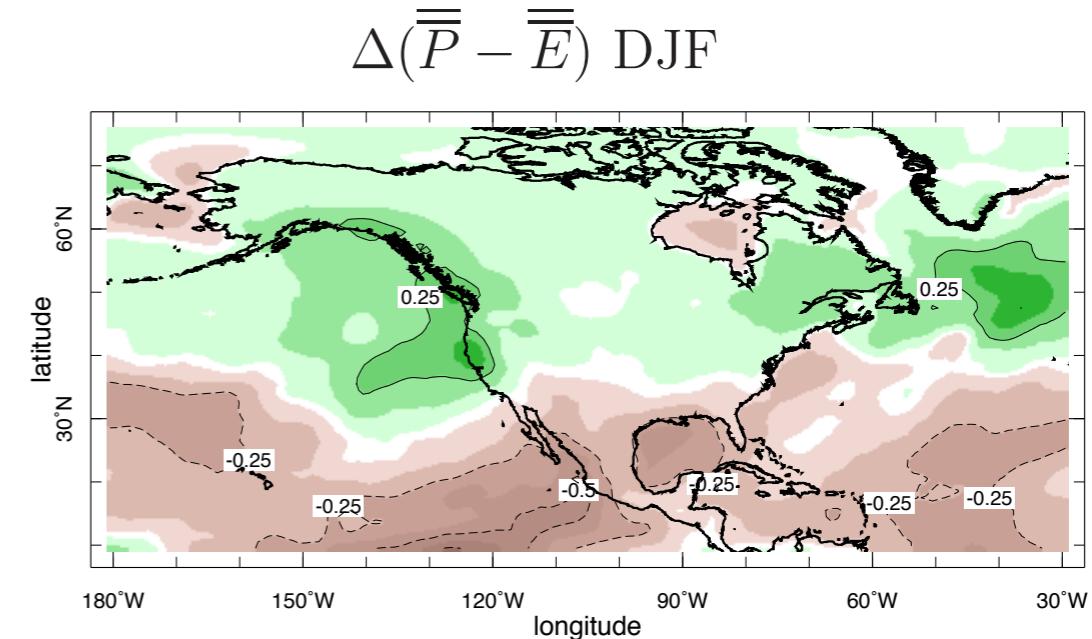
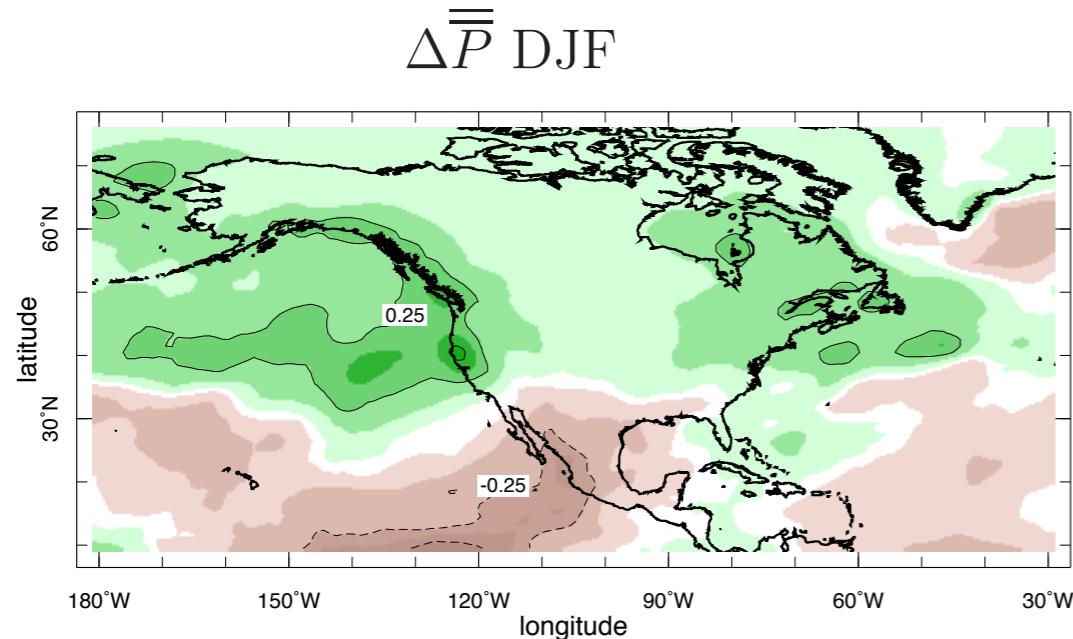
# In addition ..... 1999-2009 minus 1979-1998 precipitation shift

Two most recent dry winters  
partly SST forced but the  
97/98 shift to more La Niña-  
like tropical Pacific state has  
also favored drying across  
southwest North America



# Climate models project for California wetter winters/drier springs due to rising greenhouse gases. For DJF, wet-getting-wetter and wave response with southwesterly anomaly at coast.

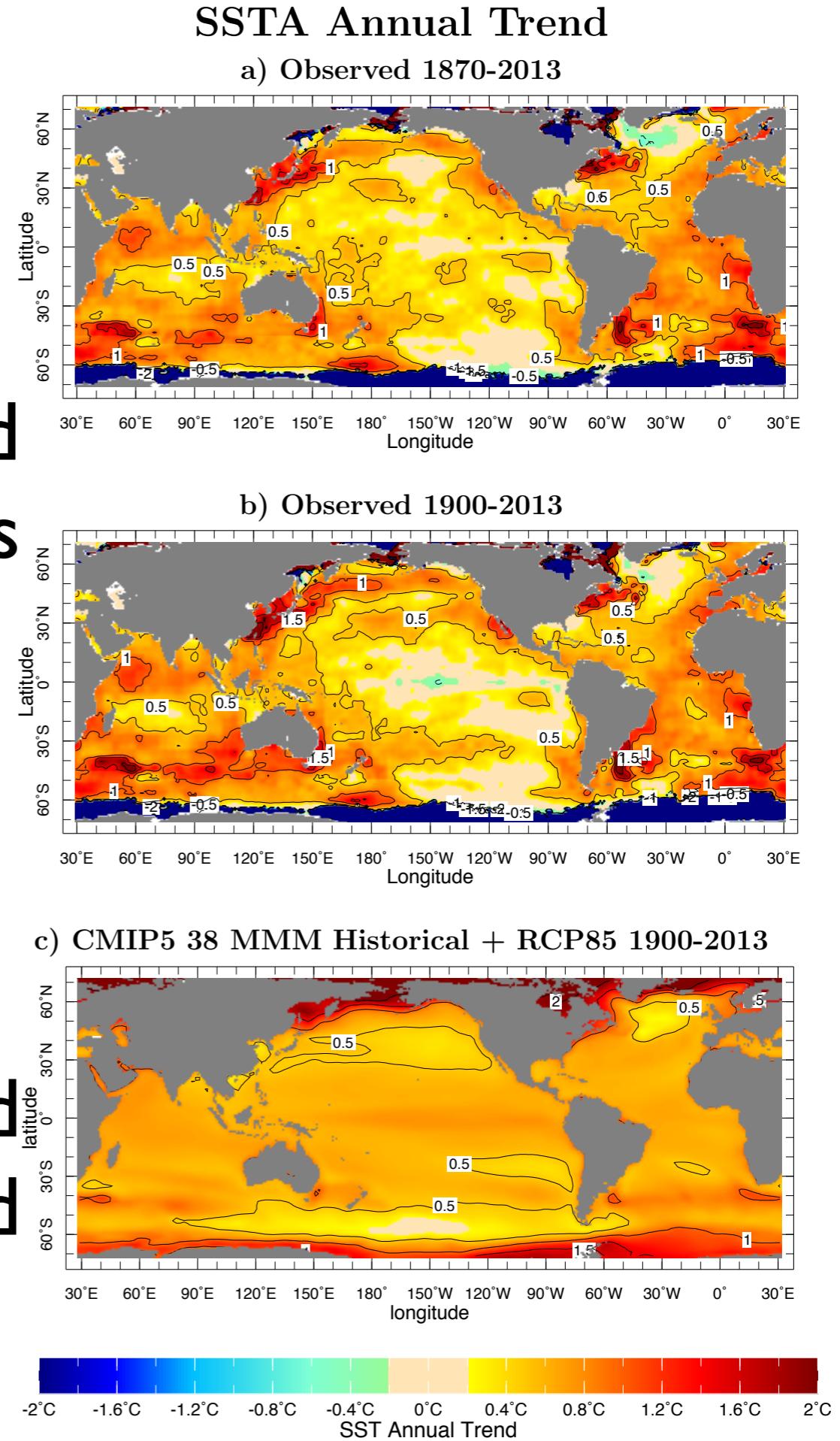
CMIP5, (2021-2040) - (1979-2005)



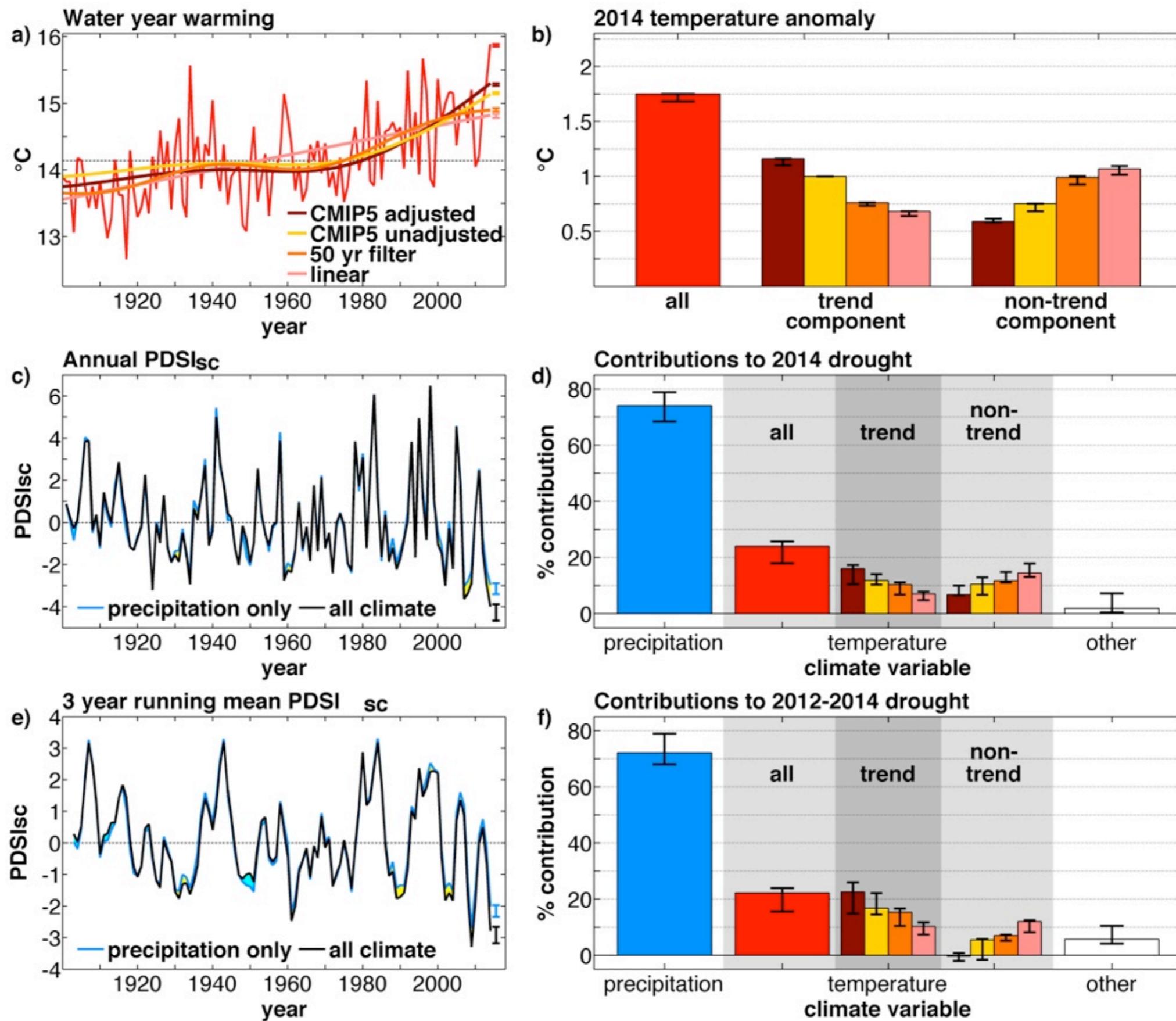
and all this raises the question of what caused the west Pacific warm SST anomaly?

Despite the lowly regard in which the “ocean dynamical thermostat” is held, Nature refuses to preferentially warm the eastern equatorial Pacific. The contrast with CMIP5 models is as stark now as at the time of Cane et al. (1997).

Observed trends  
Modeled trend



# The role of temperature variability and change from the Penman-Monteith PDSI perspective



# Conclusions on CA drought

Ongoing California drought driven by precipitation drop associated with a persistent eastern North Pacific-west coast ridge. SST-forced models get this.

California droughts almost this serious have occurred before. No clear P trends.

Droughts largely related to internal atmosphere variability. Wet winters tend to be El Nino winters. Link not strong: 1976/77 was both an El Nino winter and a drought!

The drought partly forced by La Nina and ENSO-neutral tropical Pacific SST anomalies.

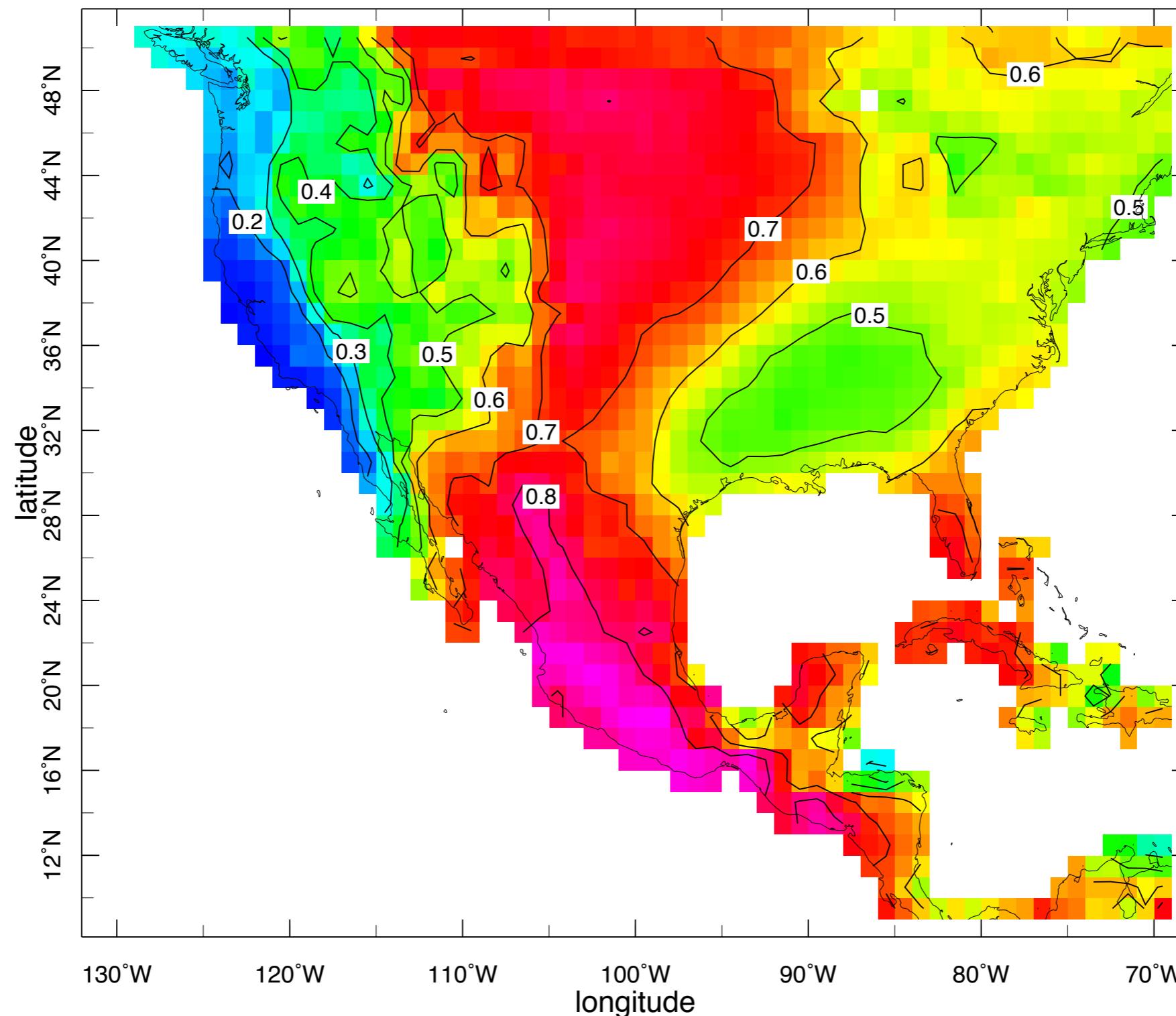
1997/98 Pacific decadal shift has favored dry conditions in SW since.

Models project rising GHGs will increase precipitation in winter for central to northern CA and decrease it in spring, unlike current drought (but CA does face real climate change problems).

*But can we trust model projections of tropical SST change?*

Away from CA the North American Monsoon is of importance to water resources, agriculture, ecosystems ...

Apr-Sep  $P$  as % of annual



# The North American Drought Atlas (NADA, Cook et al. 2004, 2007, 2010) targets late spring/early summer surface moisture - not a NAM proxy.

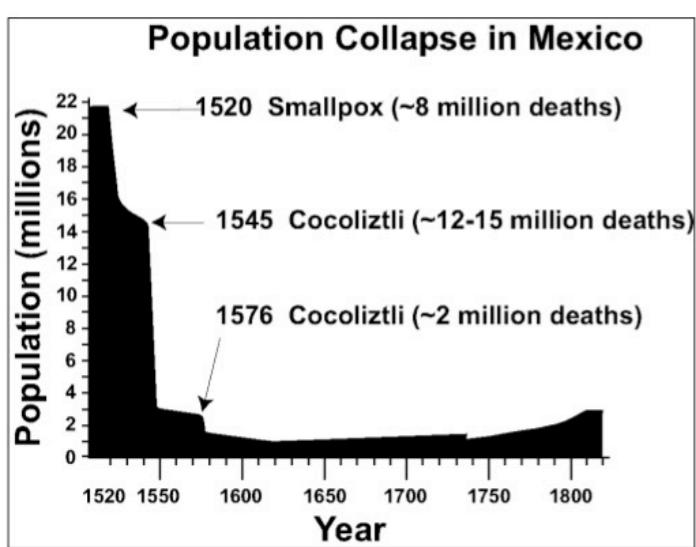
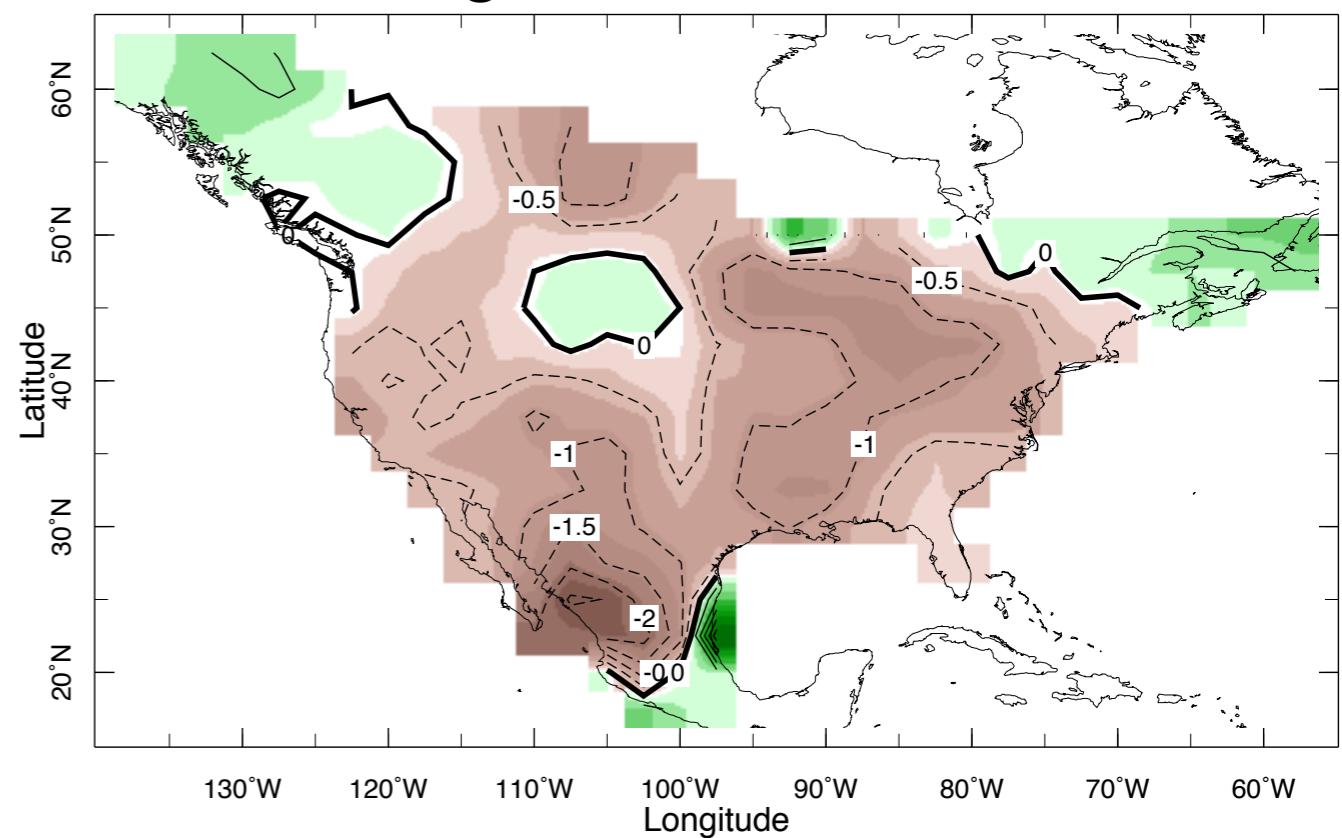
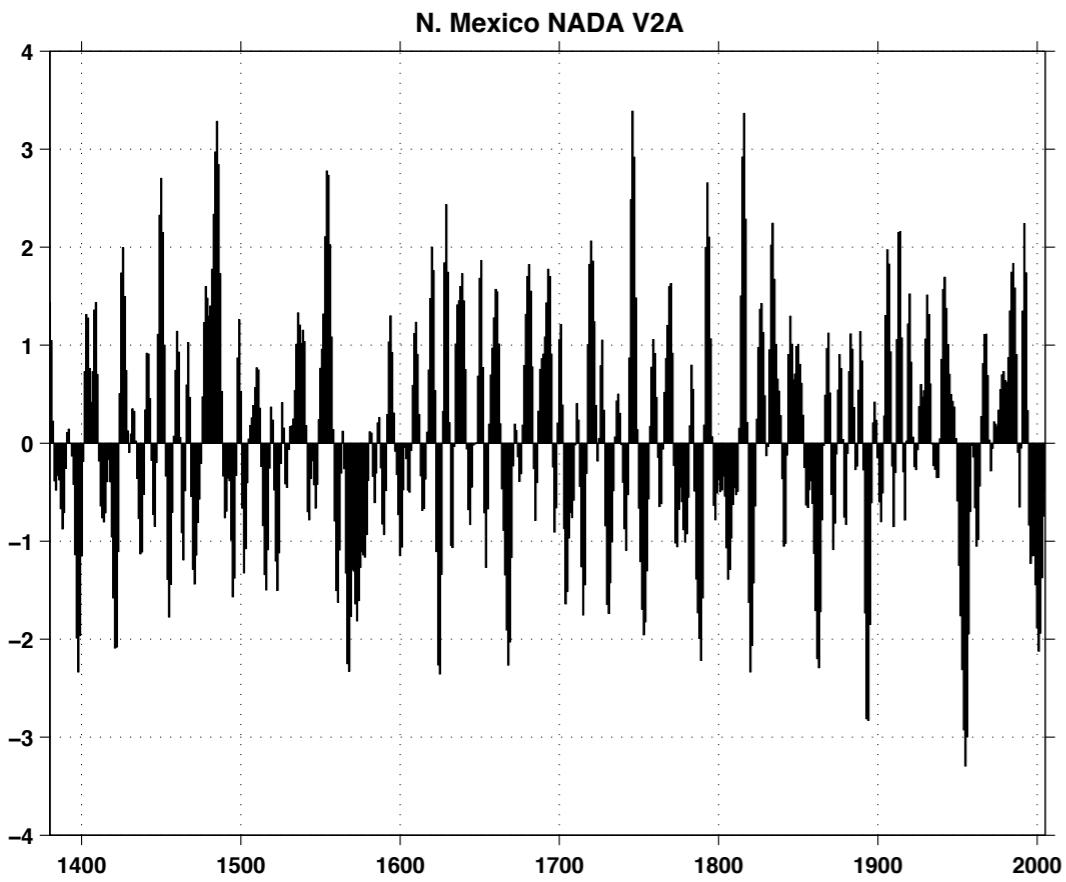
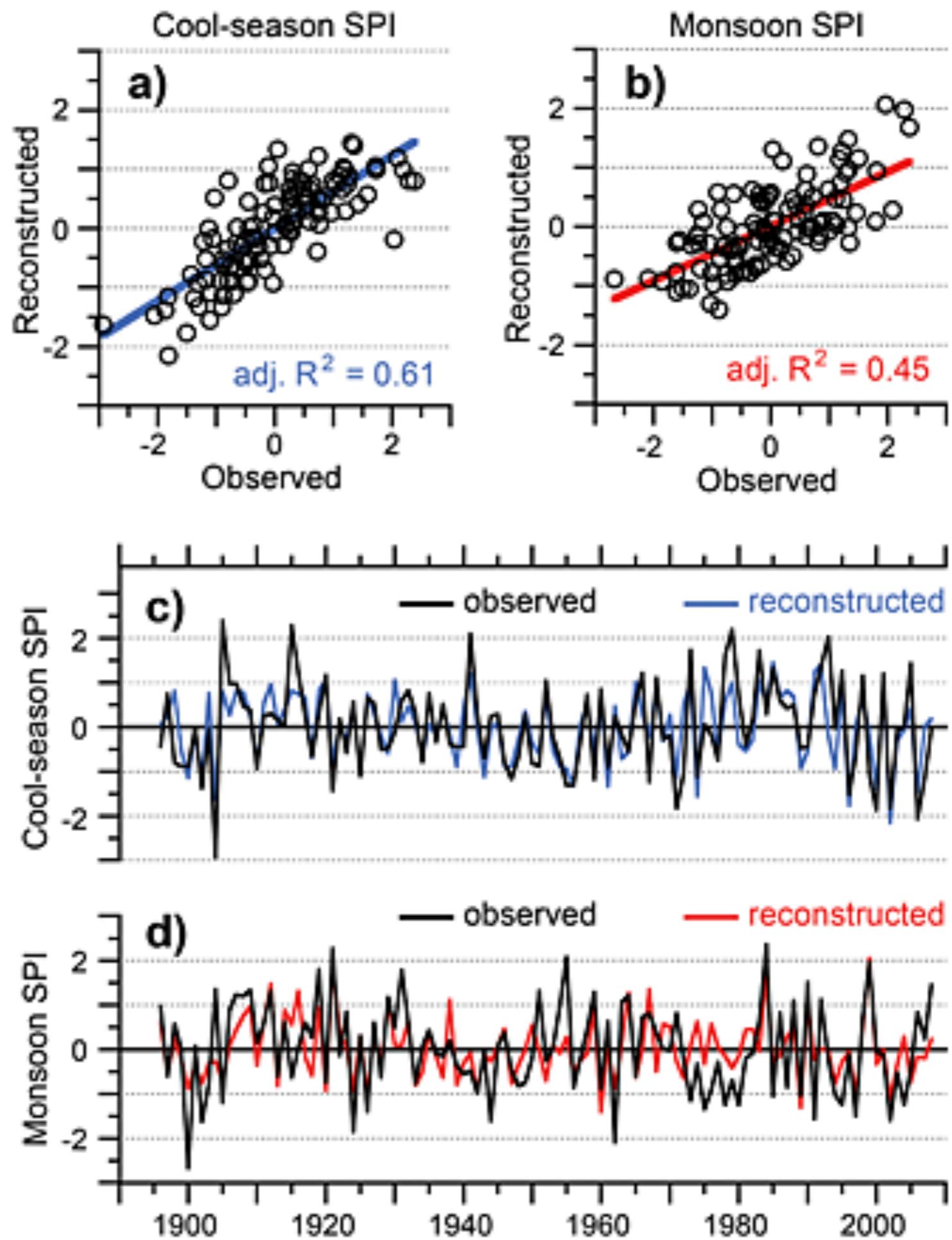


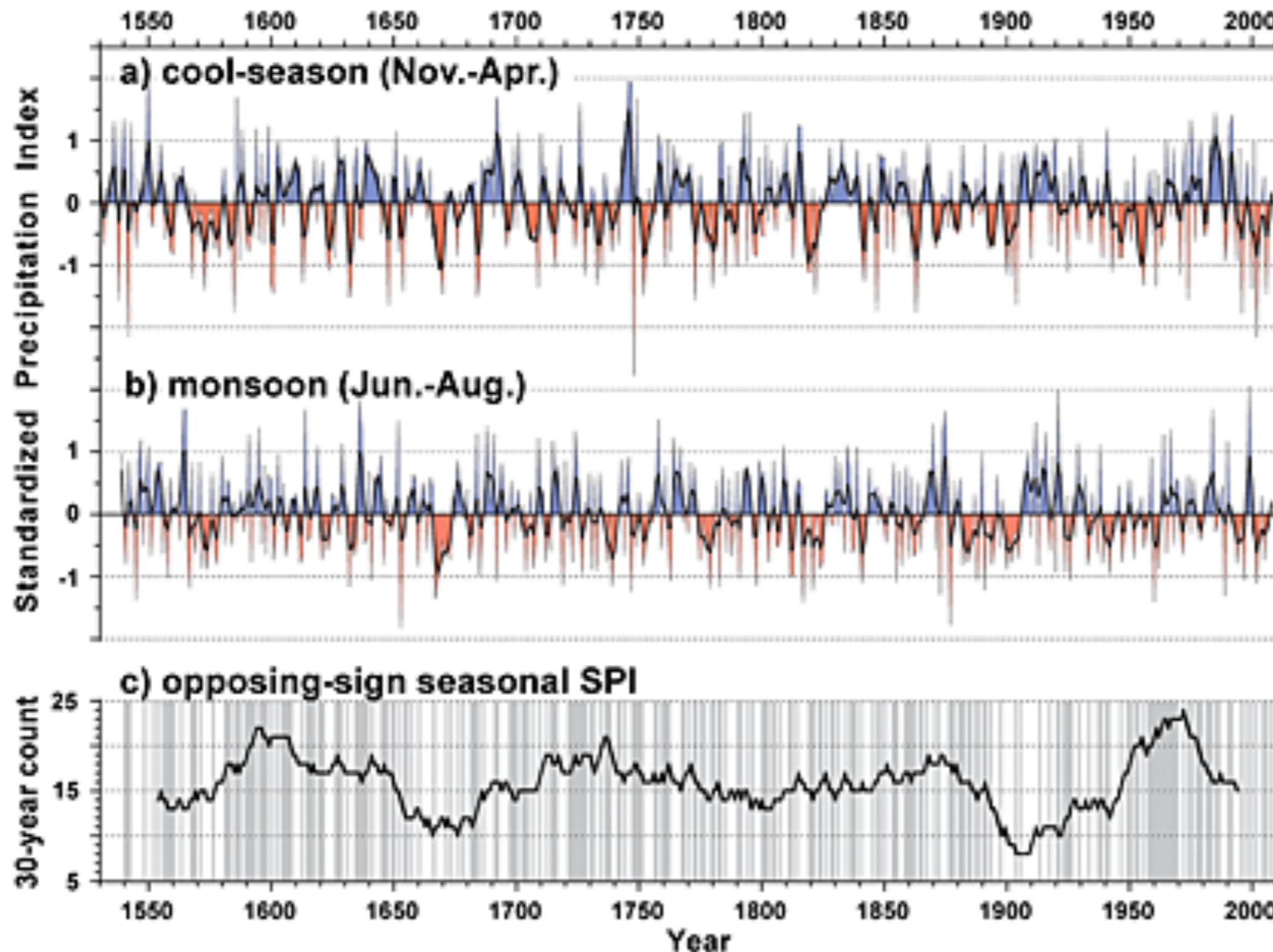
Figure 1. The 16th-century population collapse in Mexico, based on estimates of Cook and Simpson (1). The 1545 and 1576 cocoliztli epidemics appear to have been hemorrhagic fevers caused by an indigenous viral agent and aggravated by unusual climatic conditions. The Mexican population did not recover to pre-Hispanic levels until the 20th century.

## 16th Century megadrought and megadeath stands out (Acuna-Soto et al.)

Griffin et al.  
(2013) use  
subseasonal  
banding to divide  
early (late) wood  
into record of  
winter  
(monsoon)  $P$  and  
it works (for  
northern NAM)

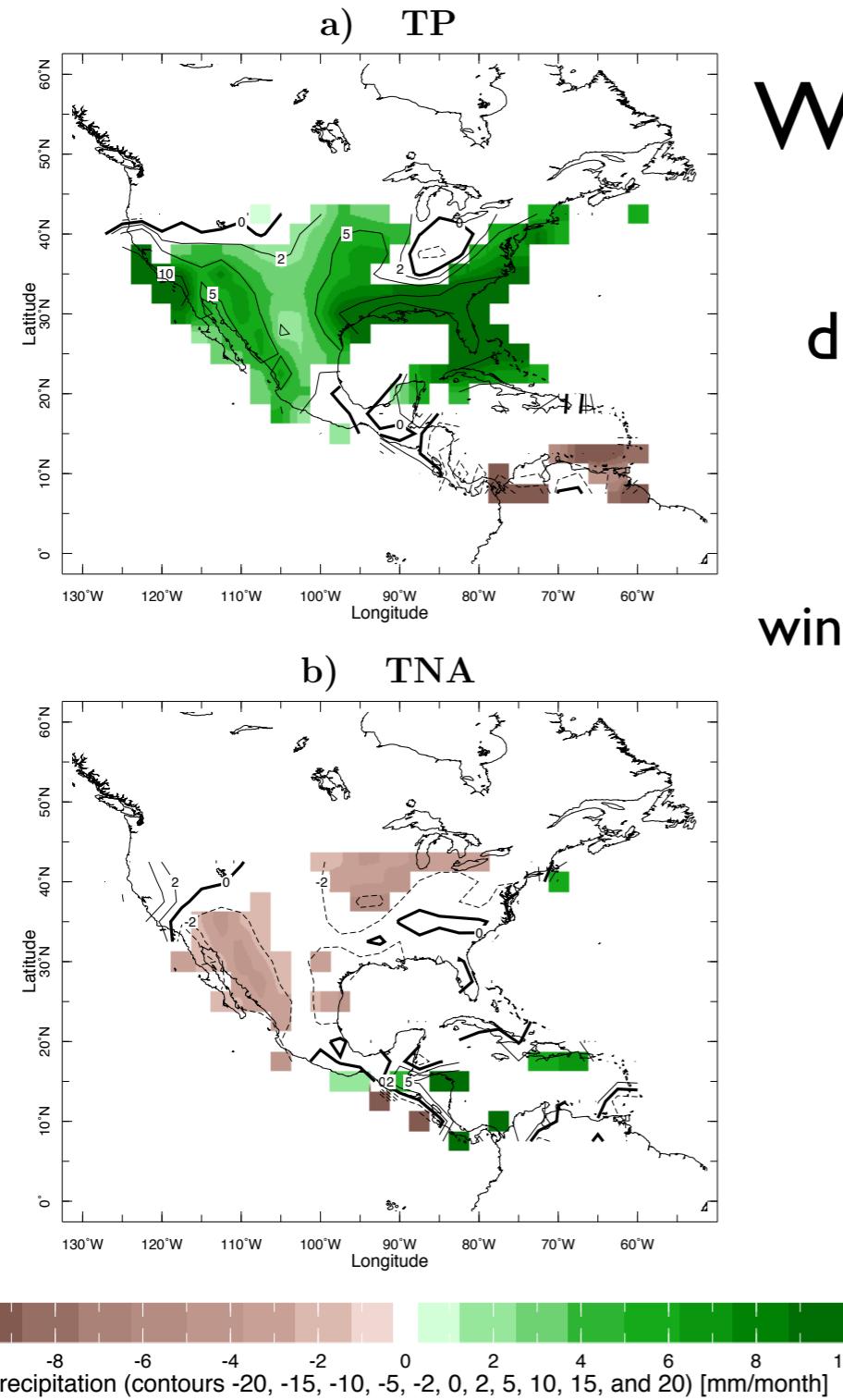


Late 16th Century megadrought was “dual season”.  
But winter and monsoon P anomalies can just as likely be  
of opposite sign.



# Multiple regressions of observed P on tropical Pacific and tropical North Atlantic SST indices

Multiple Regr of TP and TNA on UNAM Precip for Nov-Apr 1945-2002, Significant areas (colors)



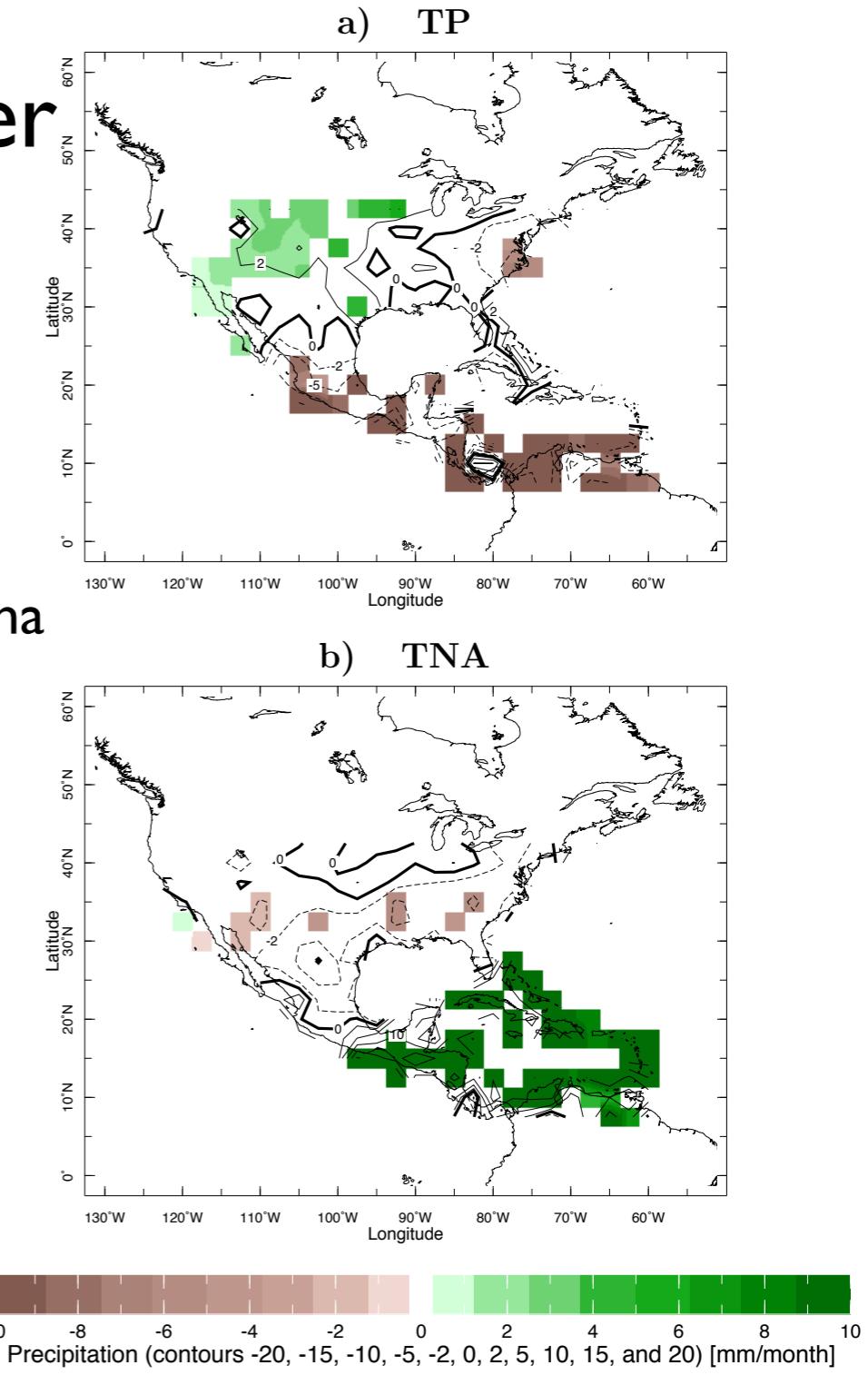
Multiple Regr of TP and TNA on UNAM Precip for May-Oct 1945-2002, Significant areas (colors)

Winter      Summer

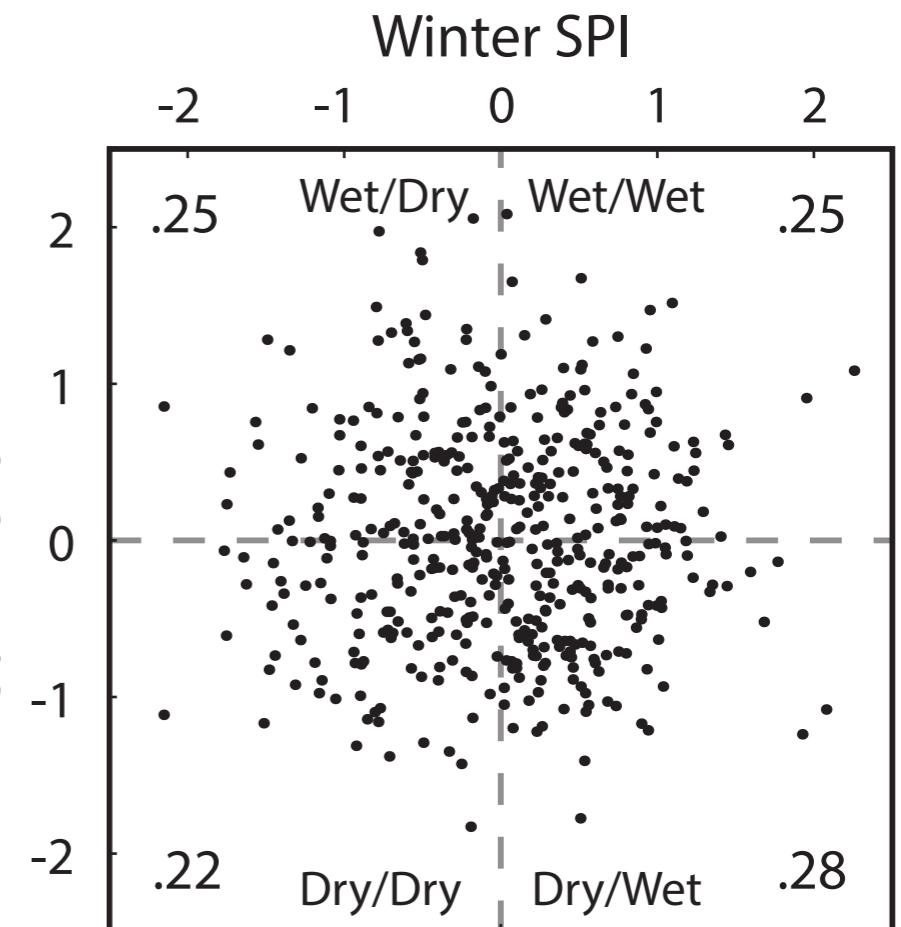
dual season drought:

North NAM:  
warm TNA,  
winter and summer La Nina

South NAM:  
warm TNA,  
winter La Nina,  
summer El Nino

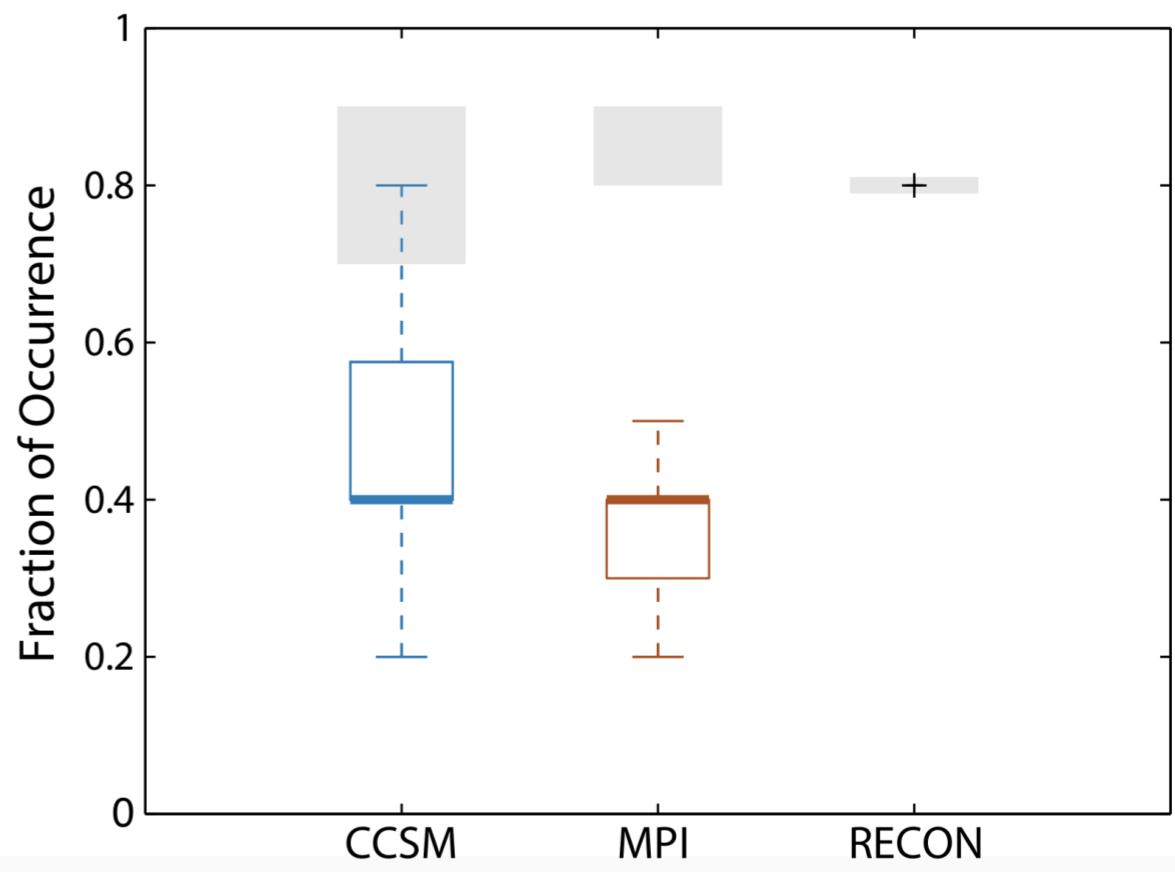


On interannual timescale, the reconstruction suggests no tendency to same or opposing sign winter and NAM  $P$  anomalies



But, measured by fraction of most severe persistent droughts in each season, dual season megadroughts common over last millennium in nature but not in two models.

Coats et al. (2015)



# **Conclusions on paleo-North American Monsoon**

Dendroclimatology (Griffin, Stahle, Cook and Cook) is only just beginning to work out how to reconstruct North American Monsoon hydroclimate

Indications to date are that the NAM region can also experience decadal scale megadroughts

Also in the north, dual season megadroughts seem possible (though not in CMIP5 models!)

Mechanisms of paleo-NAM variability not understood

# Models:

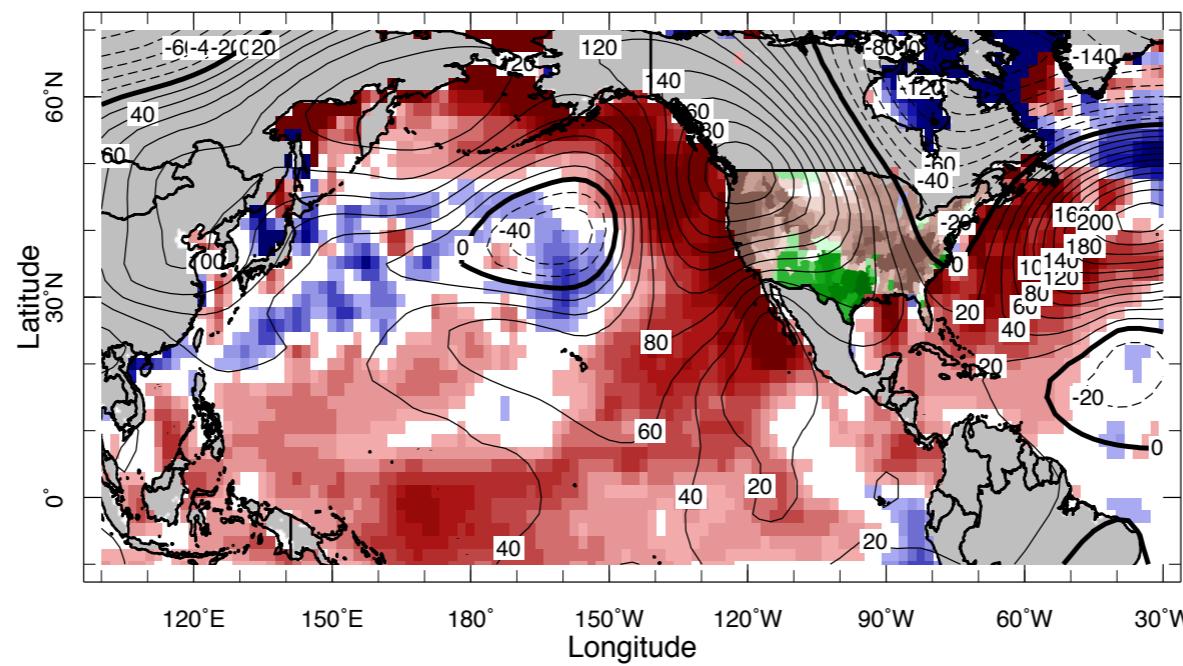
## Seven SST-forced GCMs

### from Lamont, IRI, NASA, NOAA CPC and ESRL

Model	Contributor	Ensemble	Resolution	SST, sea ice	trace gases	Time period
CCM3	LDEO	16	T42L18	Hadley, ice fixed	fixed	1856-2014
ECHAM4.5	IRI	24	T42L19	ERSST, ice fixed	fixed	1950-2014
ECHAM5	NOAA ESRL	20	T159L31	Hurrell	varying GHGs	1979-2014
GEOS-5	NASA GSFC	12	$1^\circ \times 1^\circ$ L72	Hurrell	varying	1871-2014
ESRL GFSv2	NOAA ESRL	50	T126L64	Hurrell	varying $CO_2$	1979-2014
NCEP GFSv2	NOAA CPC	18	T126L64	Hurrell	varying $CO_2$	1957-2014
CAM4	NOAA ESRL	20	$0.94^\circ \times 1.25^\circ$ L26	Hurrell	varying	1979-2014

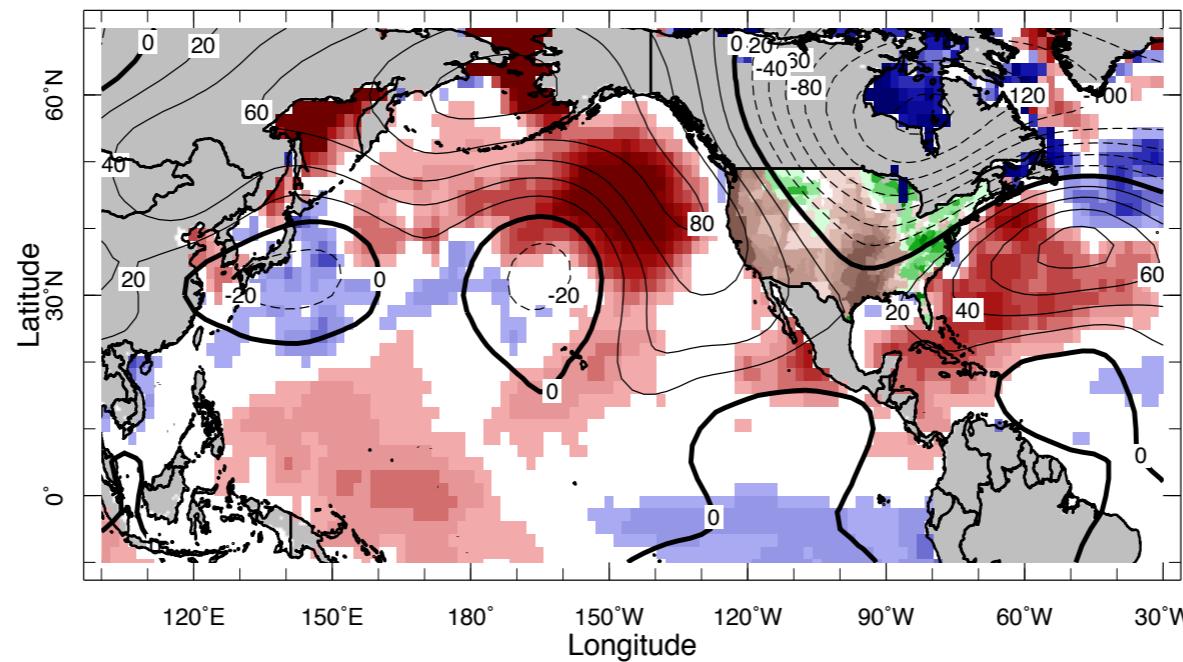
# Winter SSTAs (ocean), Precip (land), 200 mb Height (contour)

(a) Jan 2015



Jan 2015

(b) Nov-Apr 2013-2014



Nov 2013 - Apr 2014

