TEXAS SAND STORM Feb. 20th. 1894.

Climate and Drought: The State of the Science

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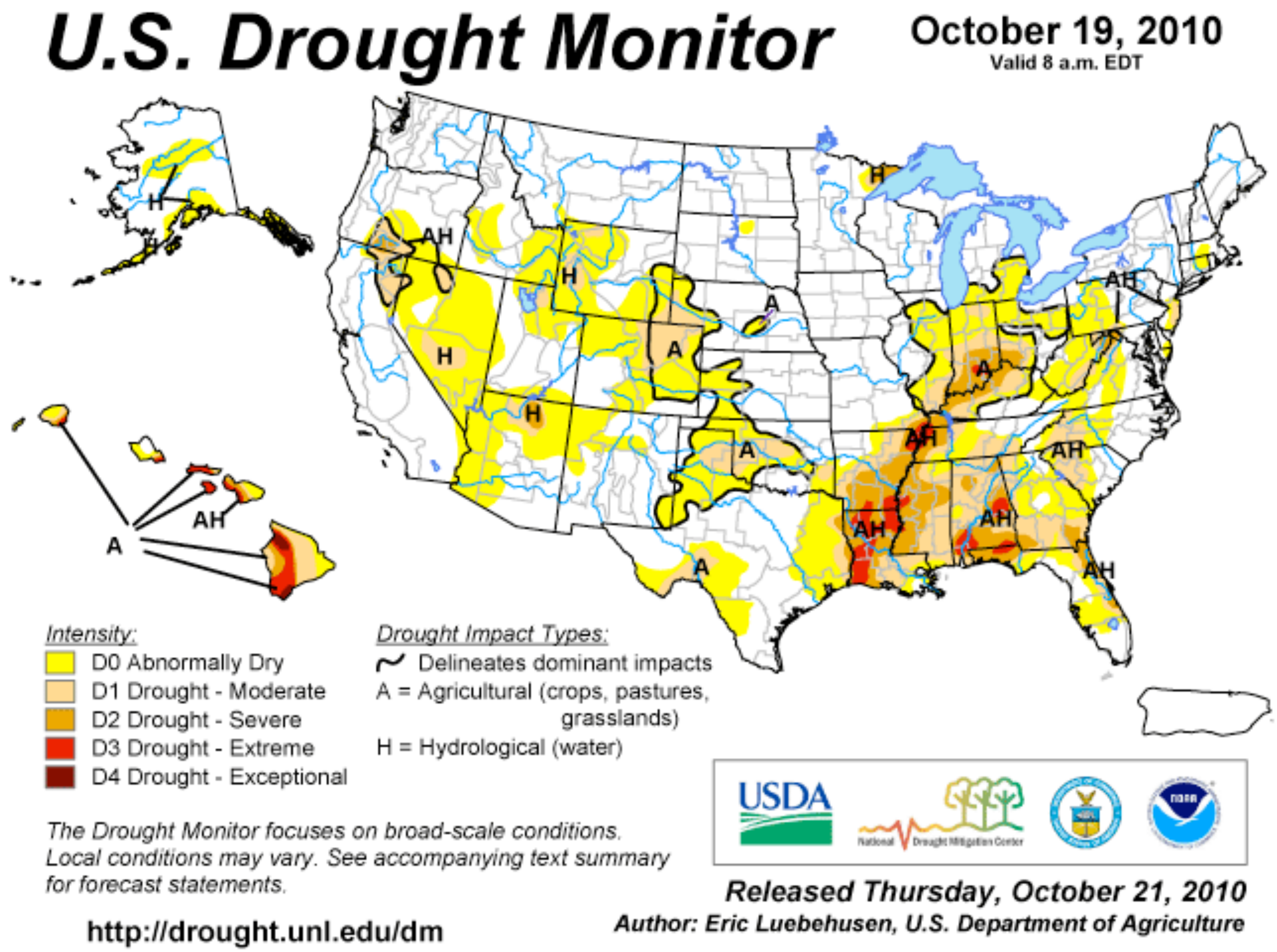
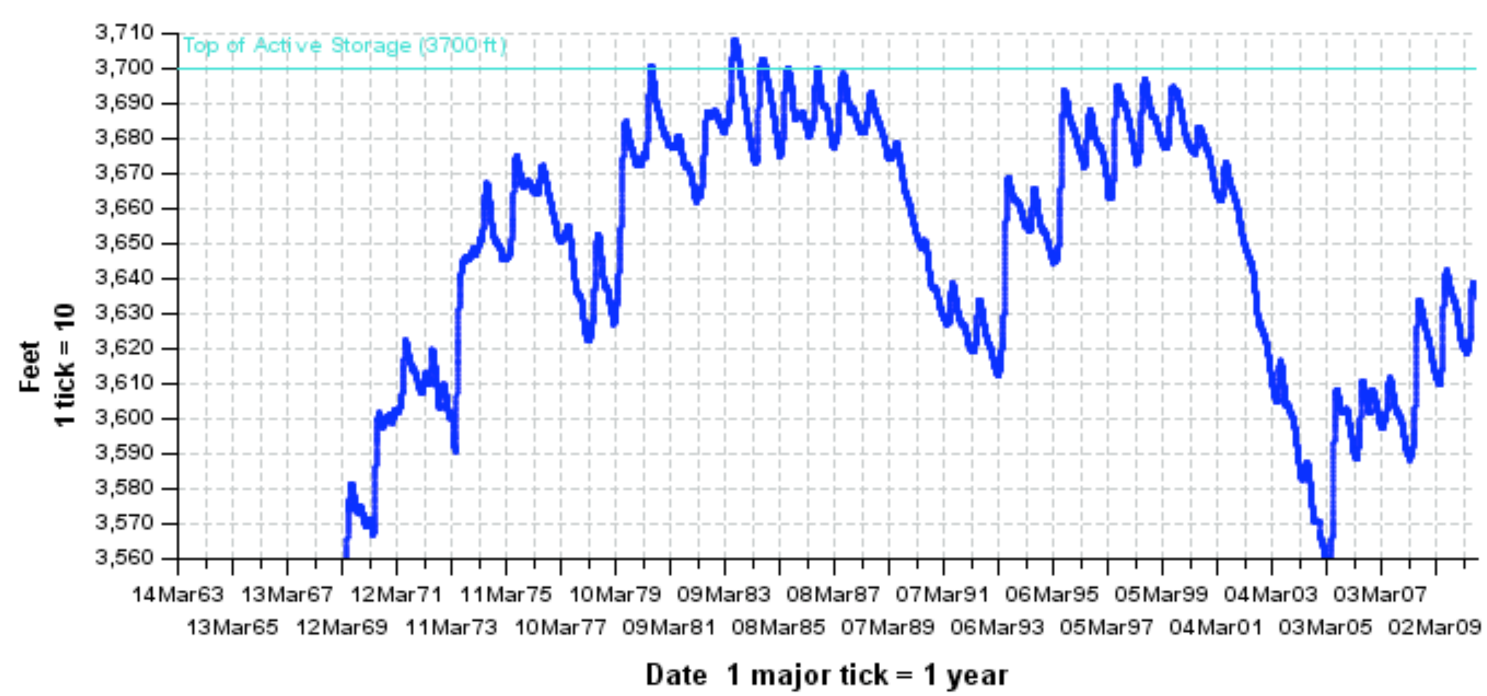
Western Governors' Association Drought and Climate Workshop
Washington DC, Sept. 14-15, 2010

Where are we now?

Coming out of the deep 'turn-of-the-century' drought but with water storage still low

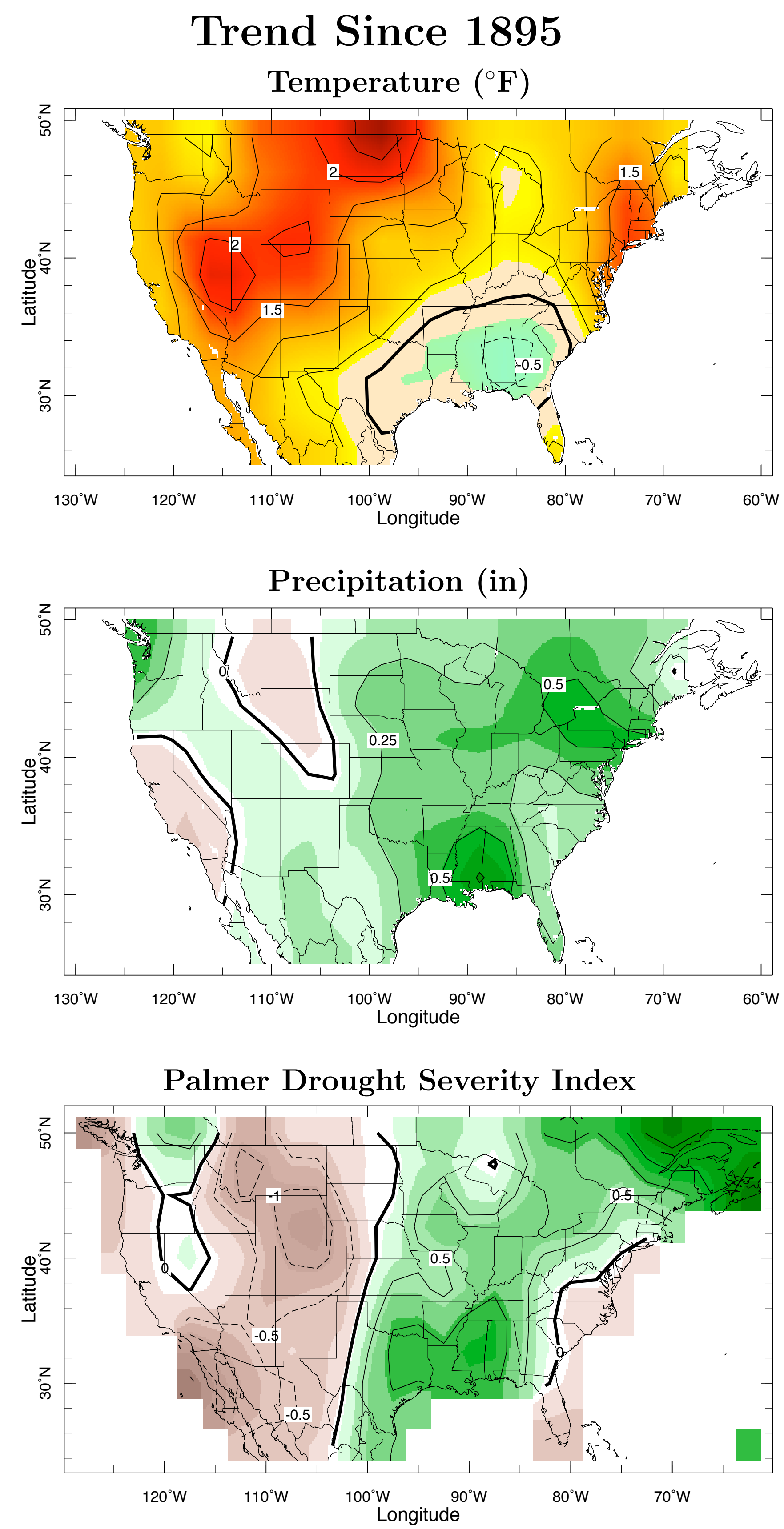


Lake Powell pool elevation



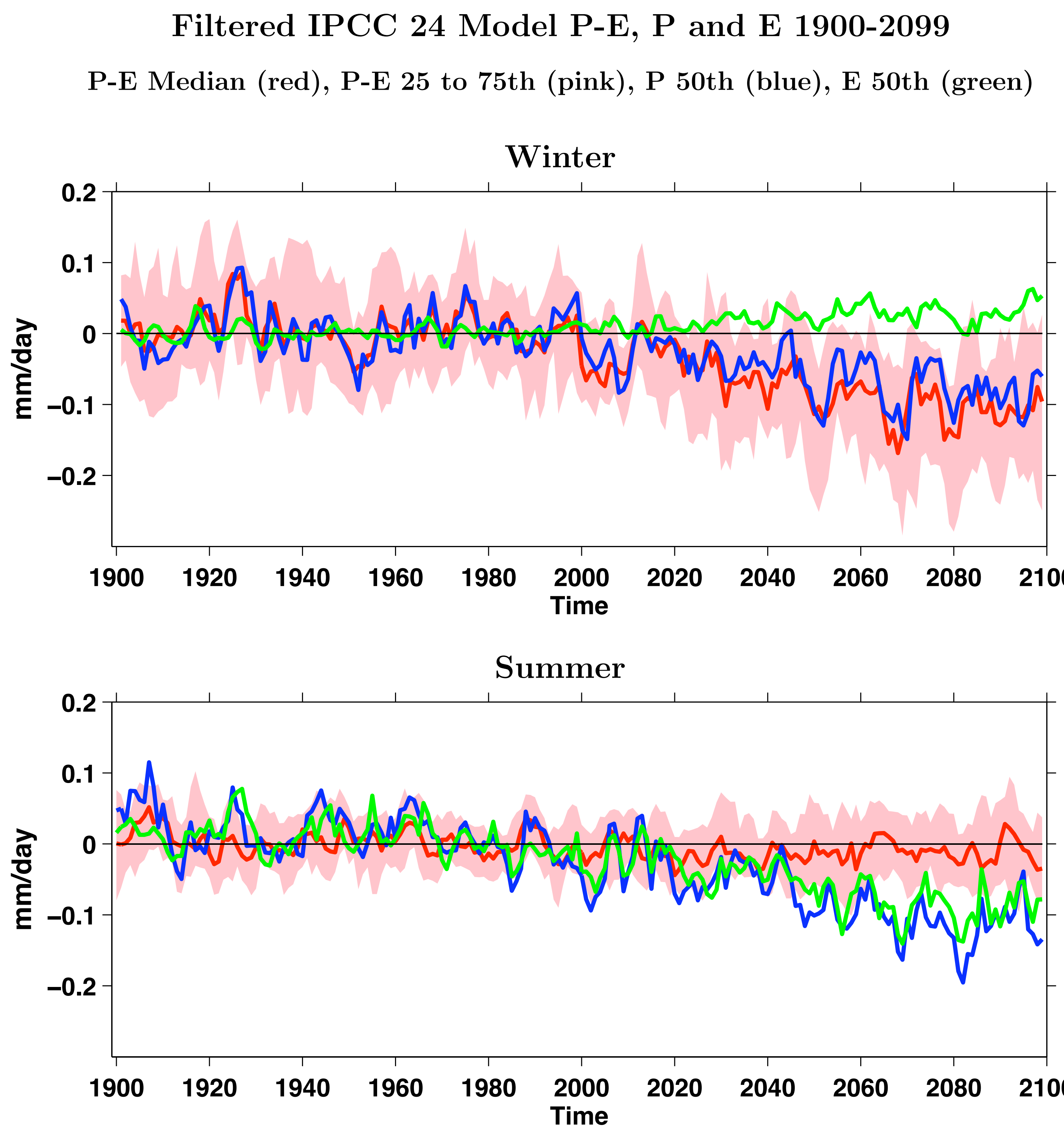
Where have we come from?

Over last 115 years, the West has warmed, the east has got wetter, and aridity has intensified in the West and lessened in the east



And where are we, supposedly, heading?

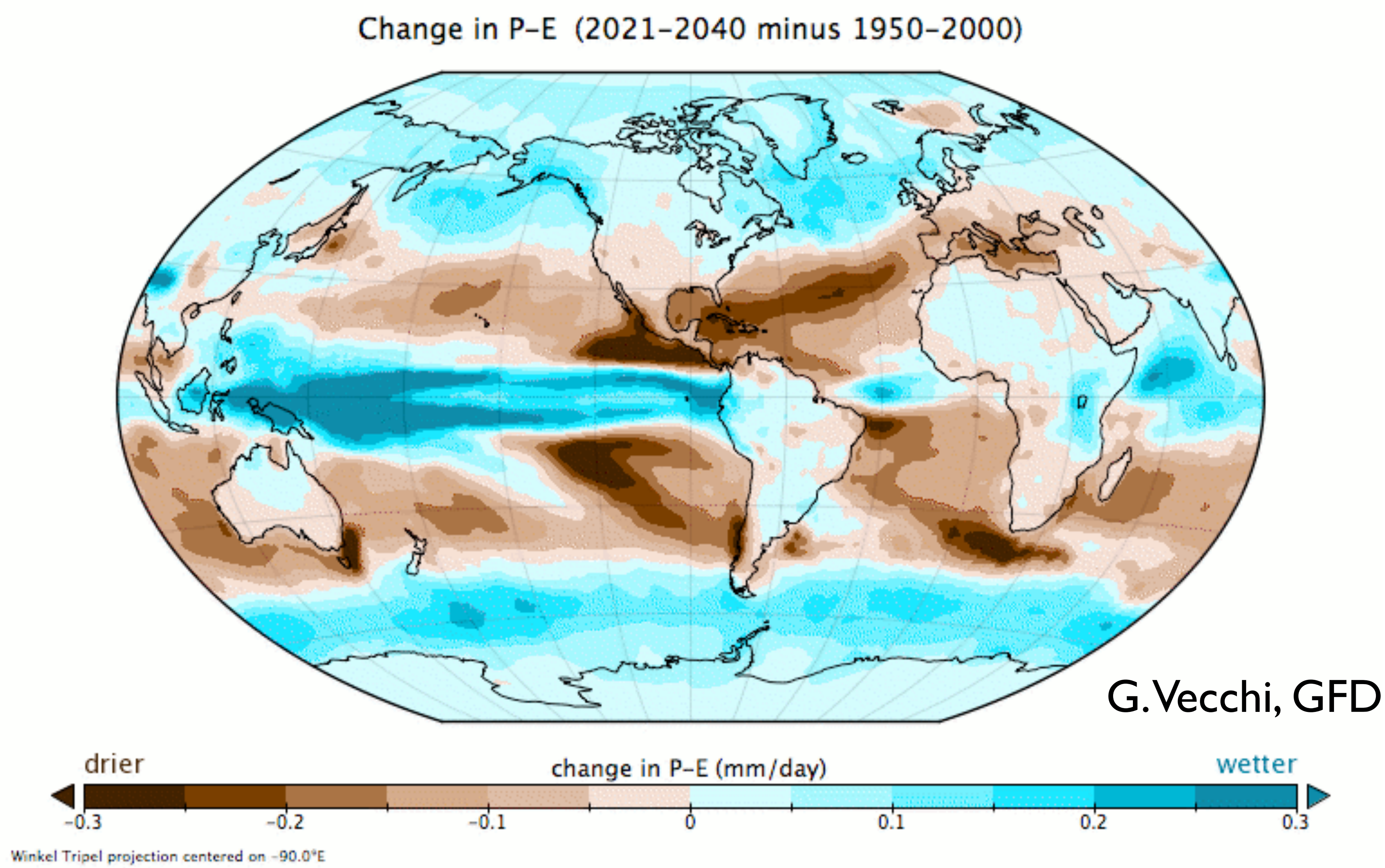
Climate models robustly project a drop in precipitation minus evaporation (P-E) driven by a drop in winter precipitation



Seager et al. (2007)

The projected drying of the Southwest is not a regional peculiarity but part of a planetary-scale change in the hydrological cycle

- ***wet areas get wetter, dry areas get drier***



G.Vecchi, GFDL

A consequence of GHG-driven warming leading to stronger atmospheric water vapor transports, a poleward expanded Hadley Cell and a poleward shifted storm track

In addition to the projected decline in precipitation, warming will:

1. Cause increased evaporative demand and stress on plants
2. Reduce winter snow
3. Cause earlier spring snow melt

Late 20th Century trends in April 1 snow water equivalent

Mote et al. (2005), Mote (2006)

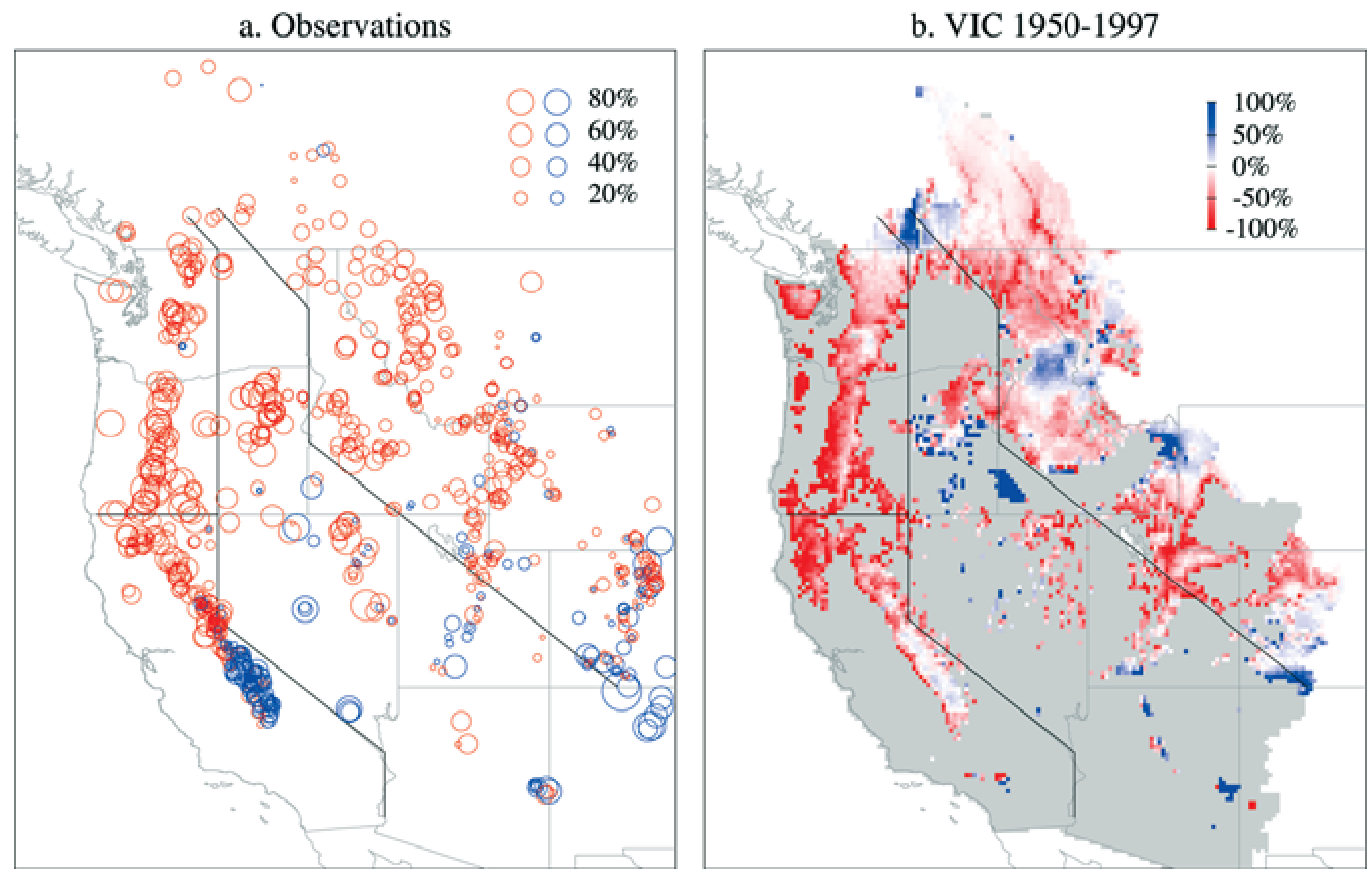


Fig. 1. Linear trends in 1 Apr SWE relative to the starting value for the linear fit (i.e., the 1950 value for the best-fit line): (a) at 824 snow course locations in the western United States and Canada for the period 1950–97, with negative trends shown by red circles and positive by blue circles; (b) from the simulation by the VIC hydrologic model (domain shown in gray) for the period 1950–97. Lines on the maps divide the West into four regions for analysis shown in subsequent figures.

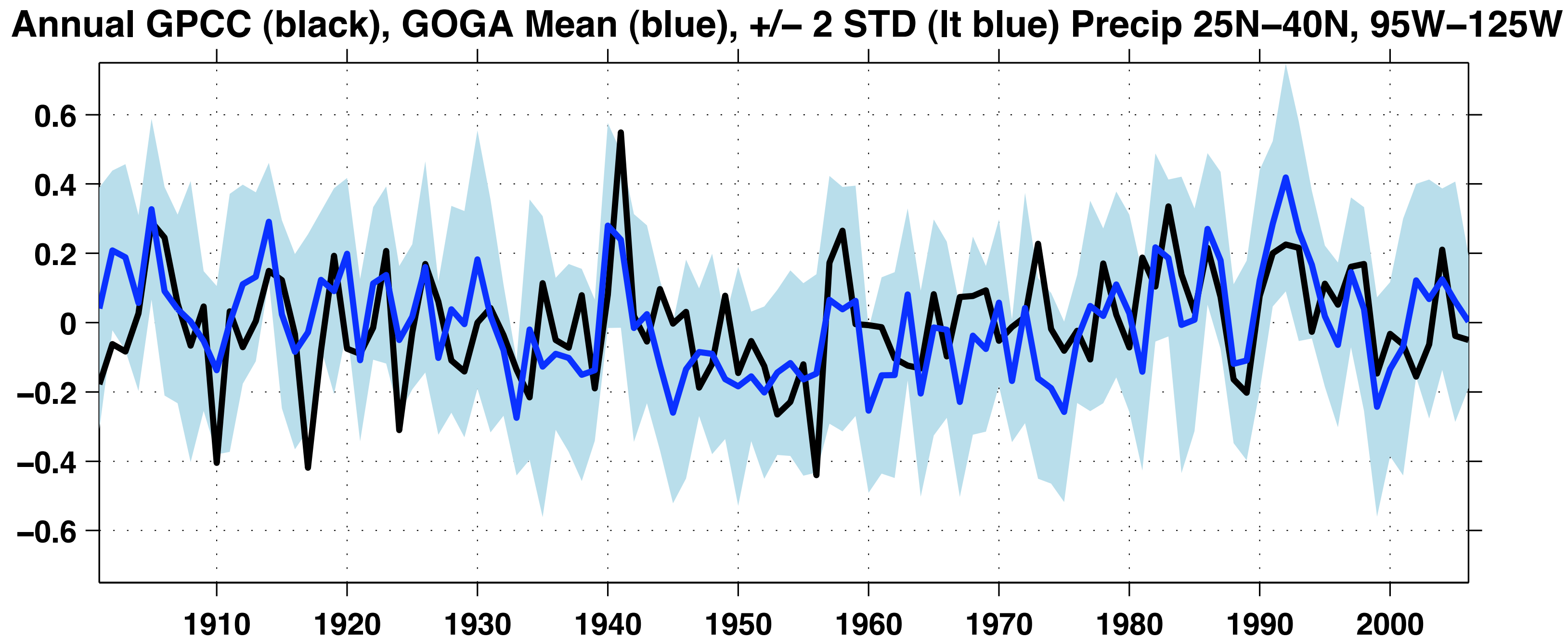
Can we assess whether the anthropogenic drying is already occurring?

The problem is that the natural variability of precipitation across North America, on seasonal to multi-decadal timescales, is enormous.

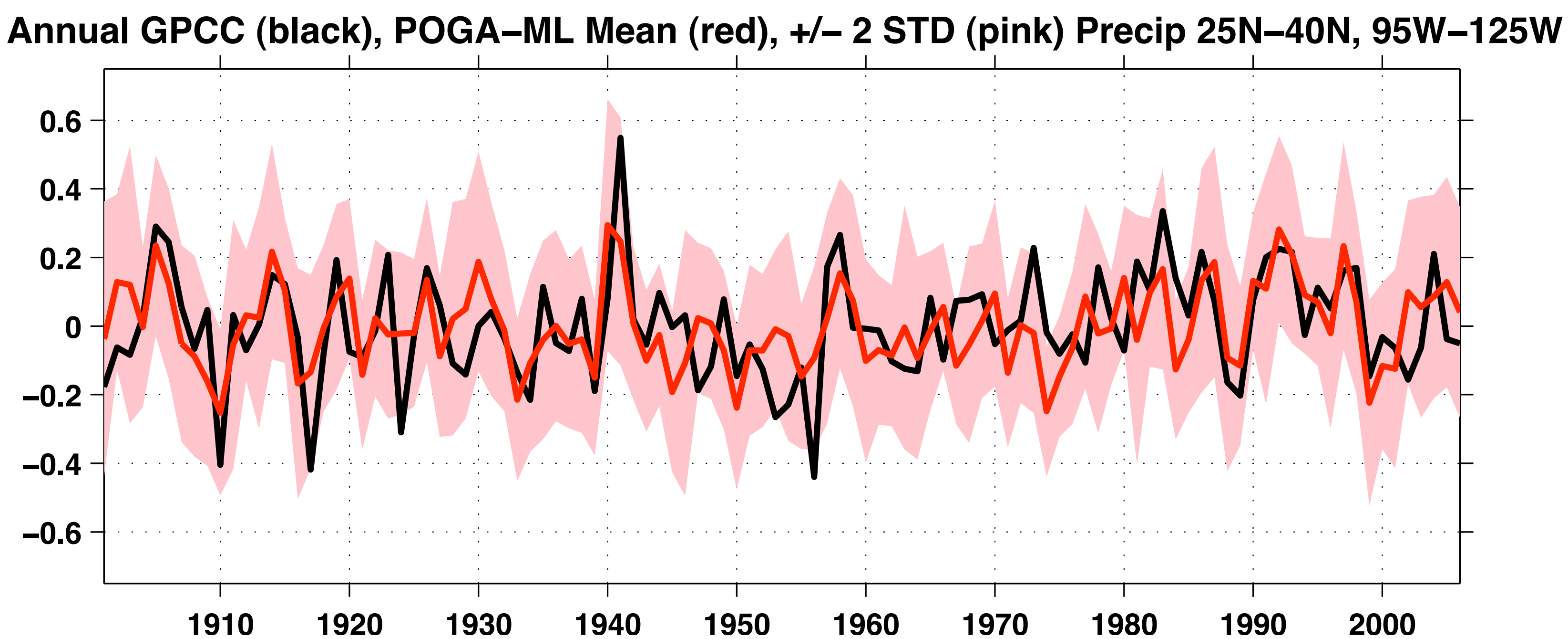
Natural variations can, for now, mask any underlying anthropogenic drying trend.

Observed SW precipitation history quite well explained as an atmospheric response to naturally-varying tropical sea surface temperature (SST) anomalies

Observed (black) and modeled (blue) SW precipitation with *global* SST forcing



Observed (black) and modeled (blue) SW precipitation with *tropical Pacific* SST forcing alone



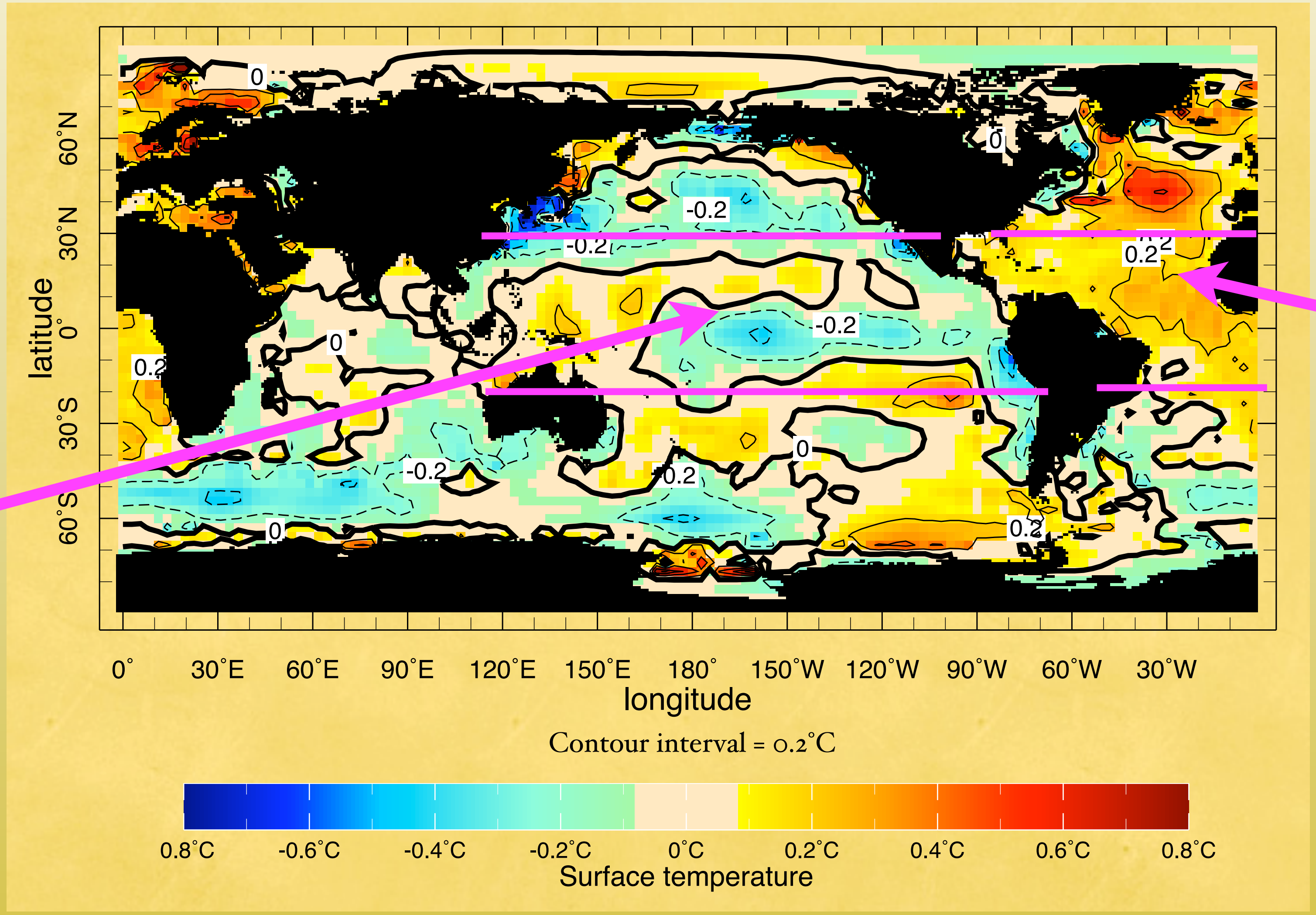
The Dust Bowl drought of the 1930s …

A monumental environmental and social disaster was ultimately triggered by tiny changes in sea surface temperature (SST) …

Modeling methodology

GOGA: *SST prescribed everywhere*

POGA-ML: SST prescribed *only in the tropical Pacific & calculated elsewhere with a 2 layer OML*

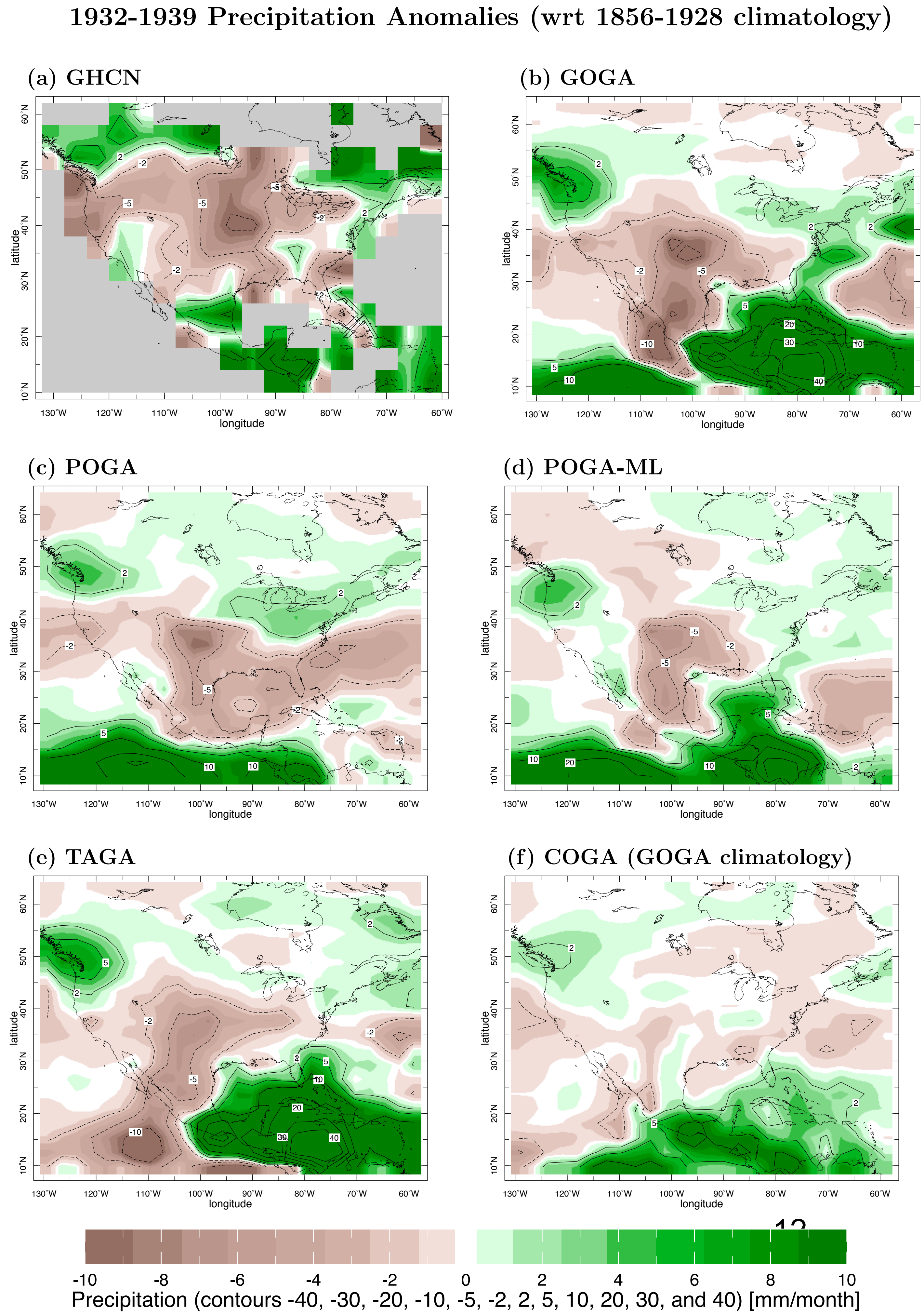


TAGA: SST prescribed *only in the tropical Atlantic & climo elsewhere*

Figure shows SST anomaly 1932-39

All the experiments conducted using an ensemble of CCM3 runs integrated from 1856 to 2007

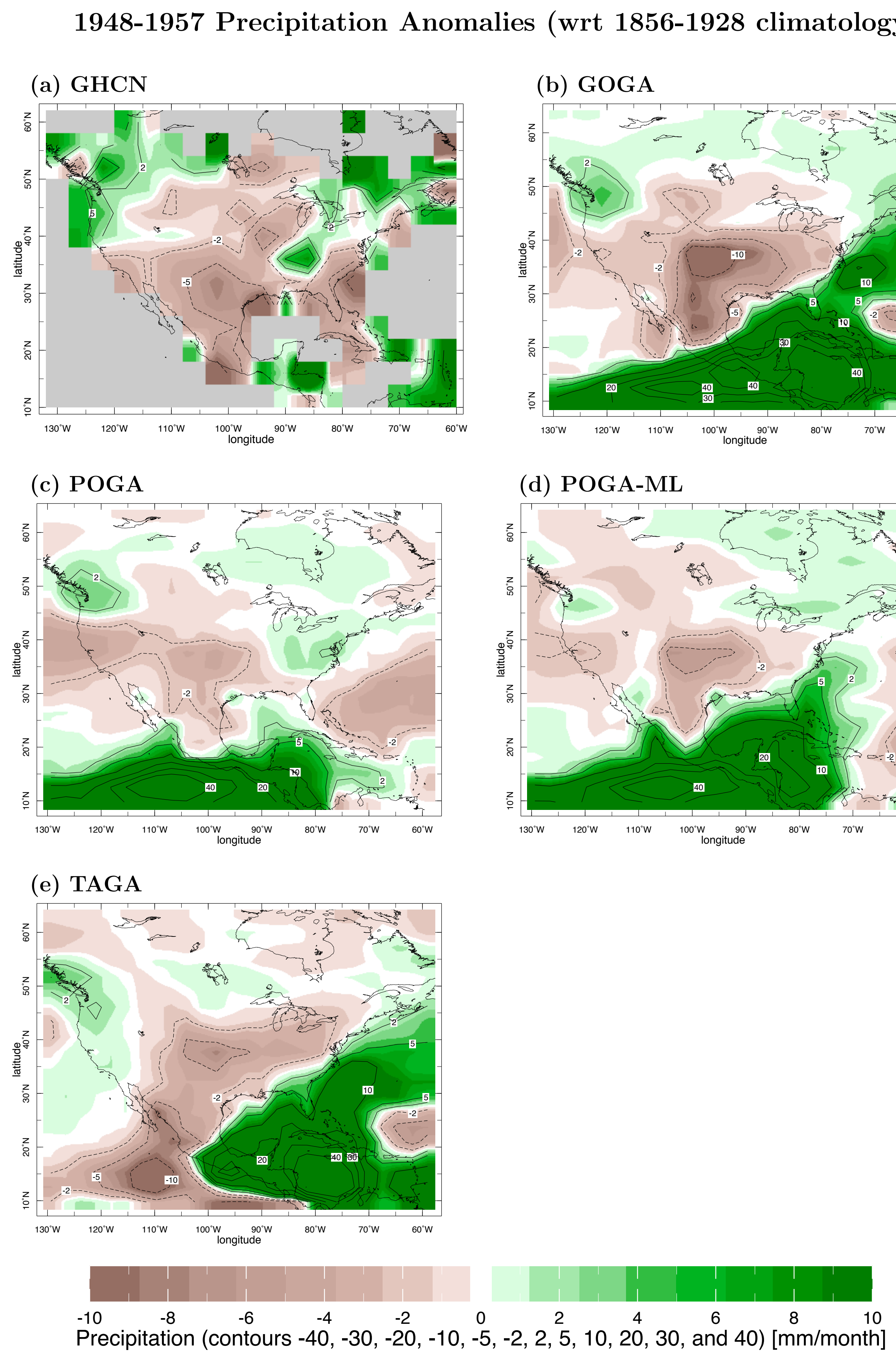
The Dust Bowl: a case of cooperative Pacific and Atlantic SST anomalies



But the pure SST-forced model simulations place Dust Bowl drought too far south

Can naturally-occurring droughts be forecast in advance?

Atmosphere models show they could if we could forecast the sea surface temperatures that force the droughts



1950s SW drought, observed and with global SST forcing

Tropical Pacific SST forcing alone

Tropical Atlantic SST forcing alone

Alas, SST forecasting limited to at most one year (in the tropical Pacific) and little progress on multiyear prediction

Seager et al. (2008)

The Dust Bowl drought was unique in not being a purely natural phenomena ...

Wind erosion was caused by poor land use practices causing horrific dust storms

The dust storms worsened the drought and moved its center northward

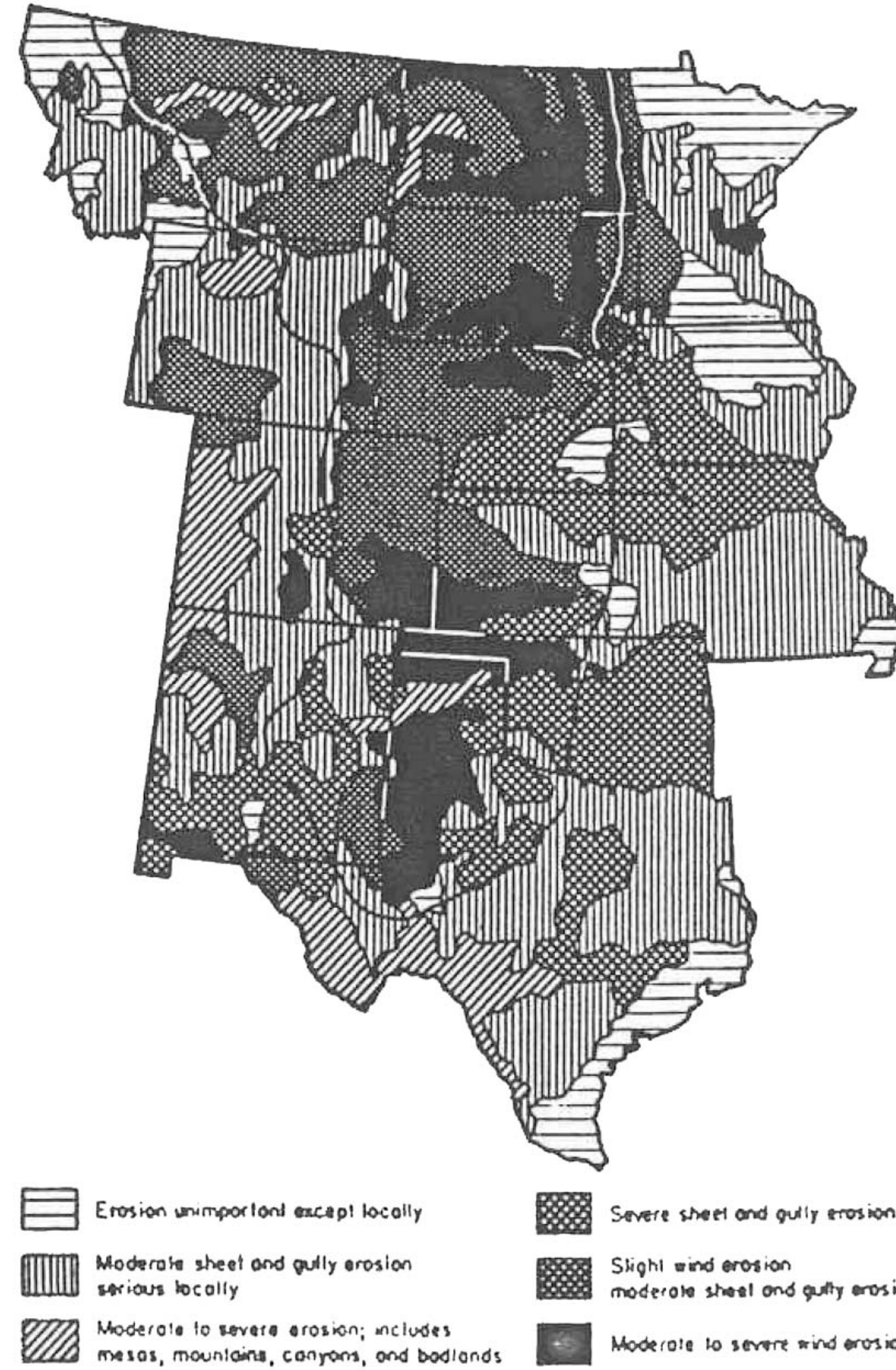
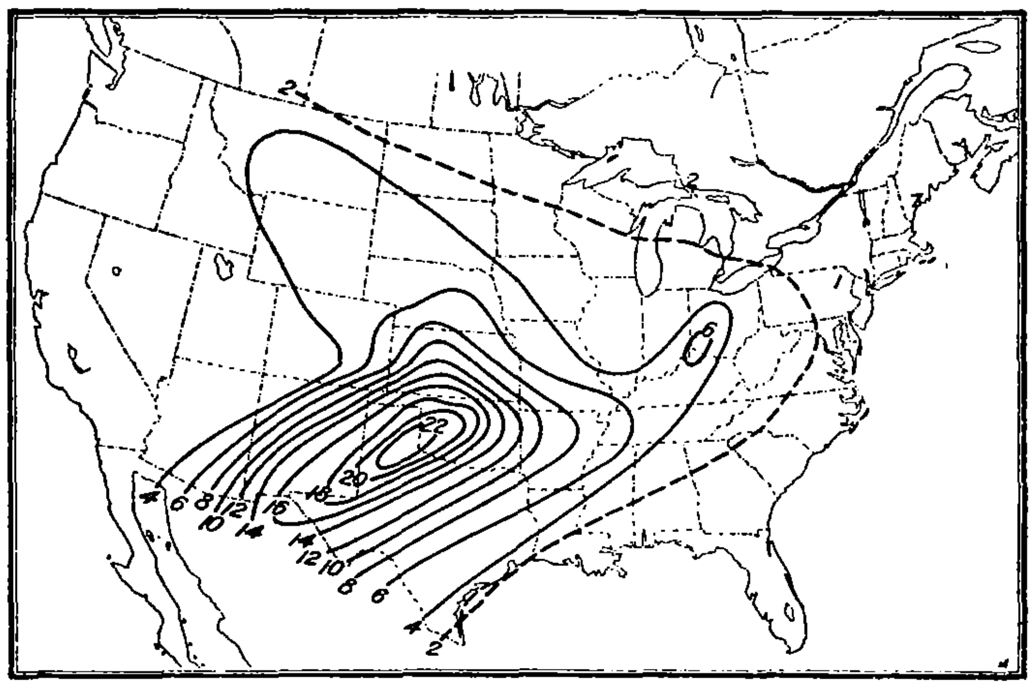


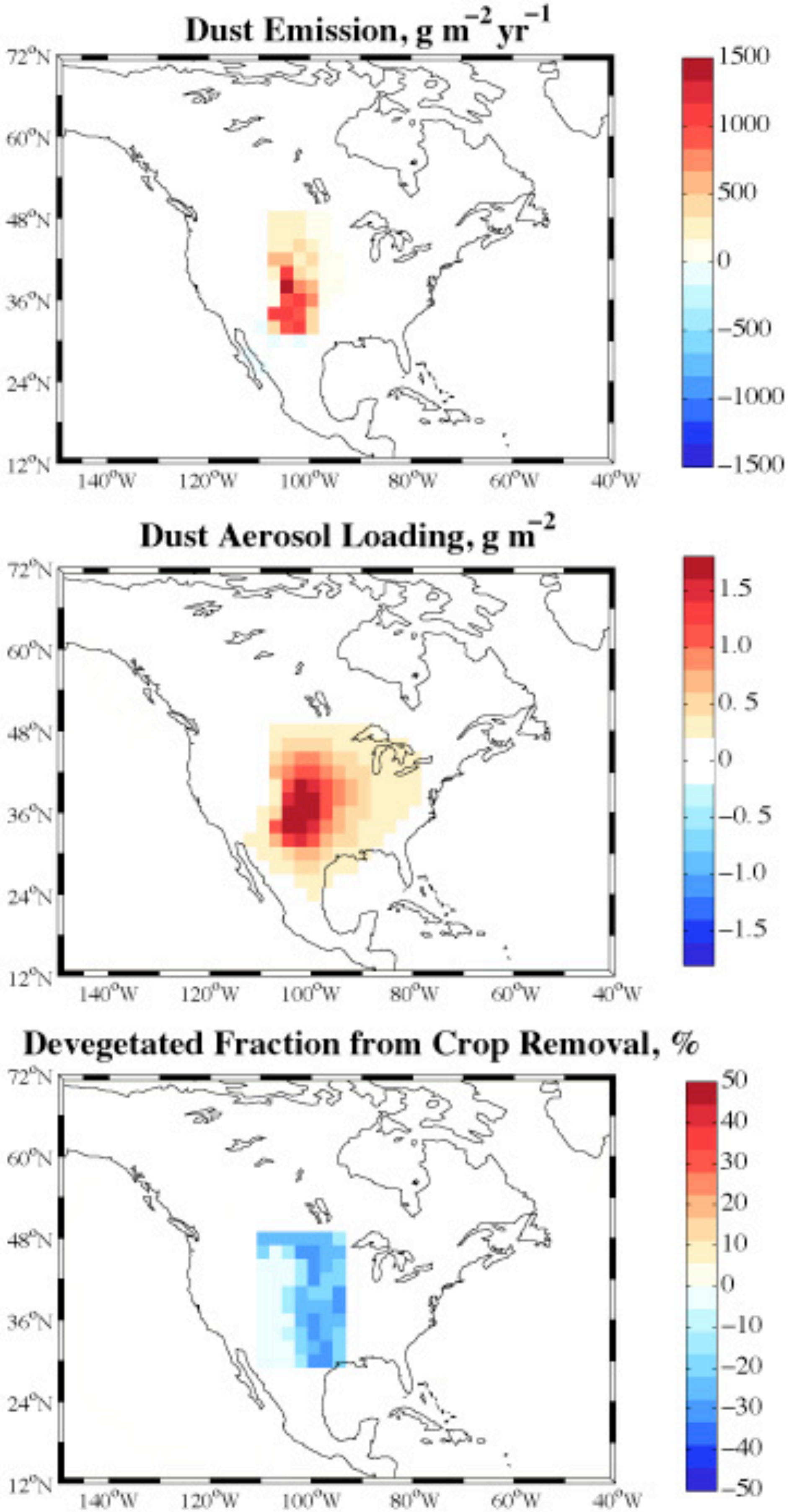
Fig. 1.—Wind erosion in the Great Plains in the 1930s. An irregular line bounds the Great Plains region as delimited by the Great Plains Committee. Source: Adapted from "General Distribution of Erosion" (U.S. Dept. Agriculture, Soil Conservation Service, August 1936).

contemporary observations of dust storms and modeled dust storms
(GISS model, Cook, Miller and Seager (2008, 2009))



Number of days with duststorms, or dusty conditions, March 1936.—W. A. M

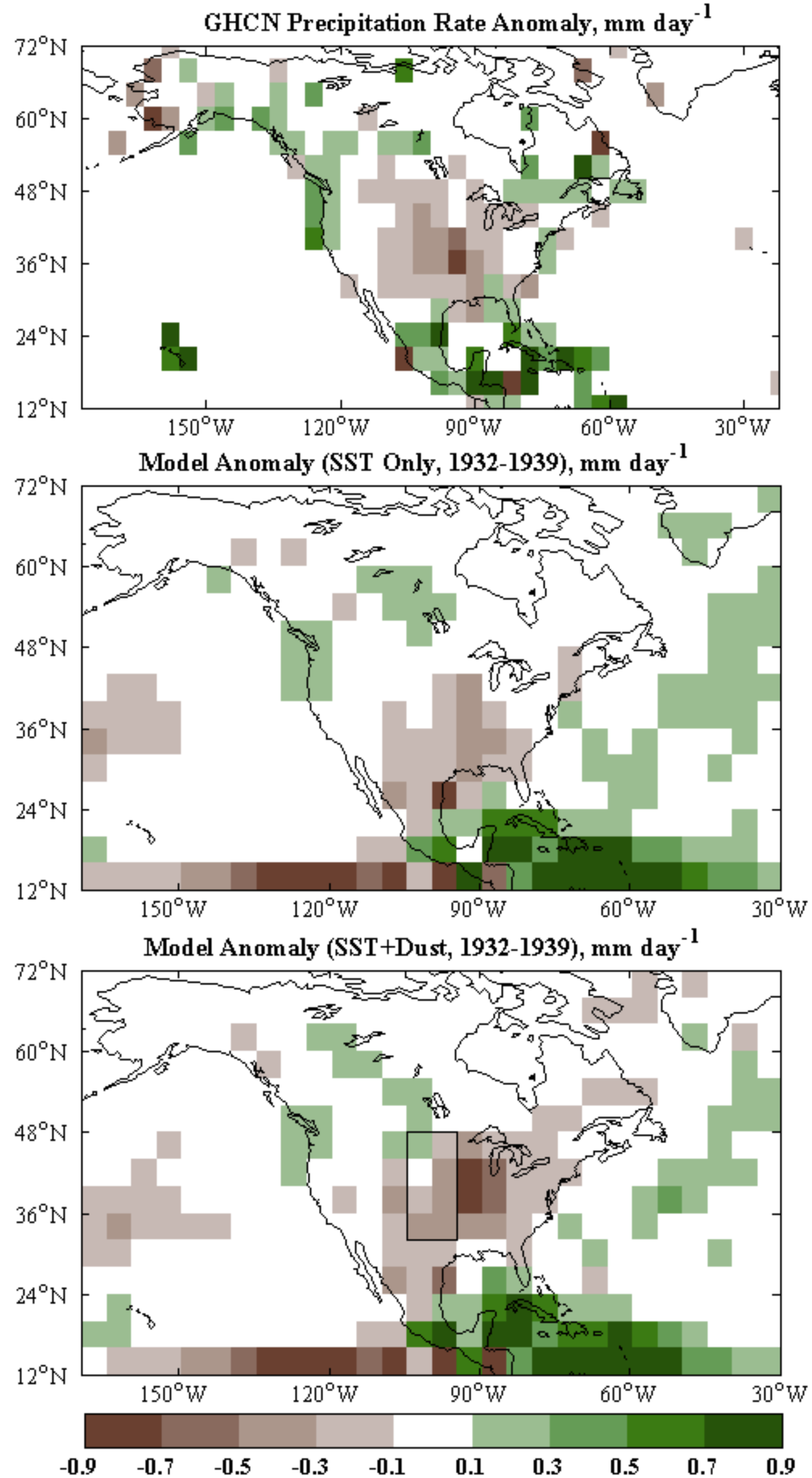
Martin, 1936



Based on wind erosion maps convert portions of model grid boxes to bare soil

Model created dust storms, the dust interacted with solar and longwave radiation intensifying the drought and moving it north

Dust Bowl was a coupled human-natural disaster .... with clear lessons for the future



Observed 1930s precipitation anomaly

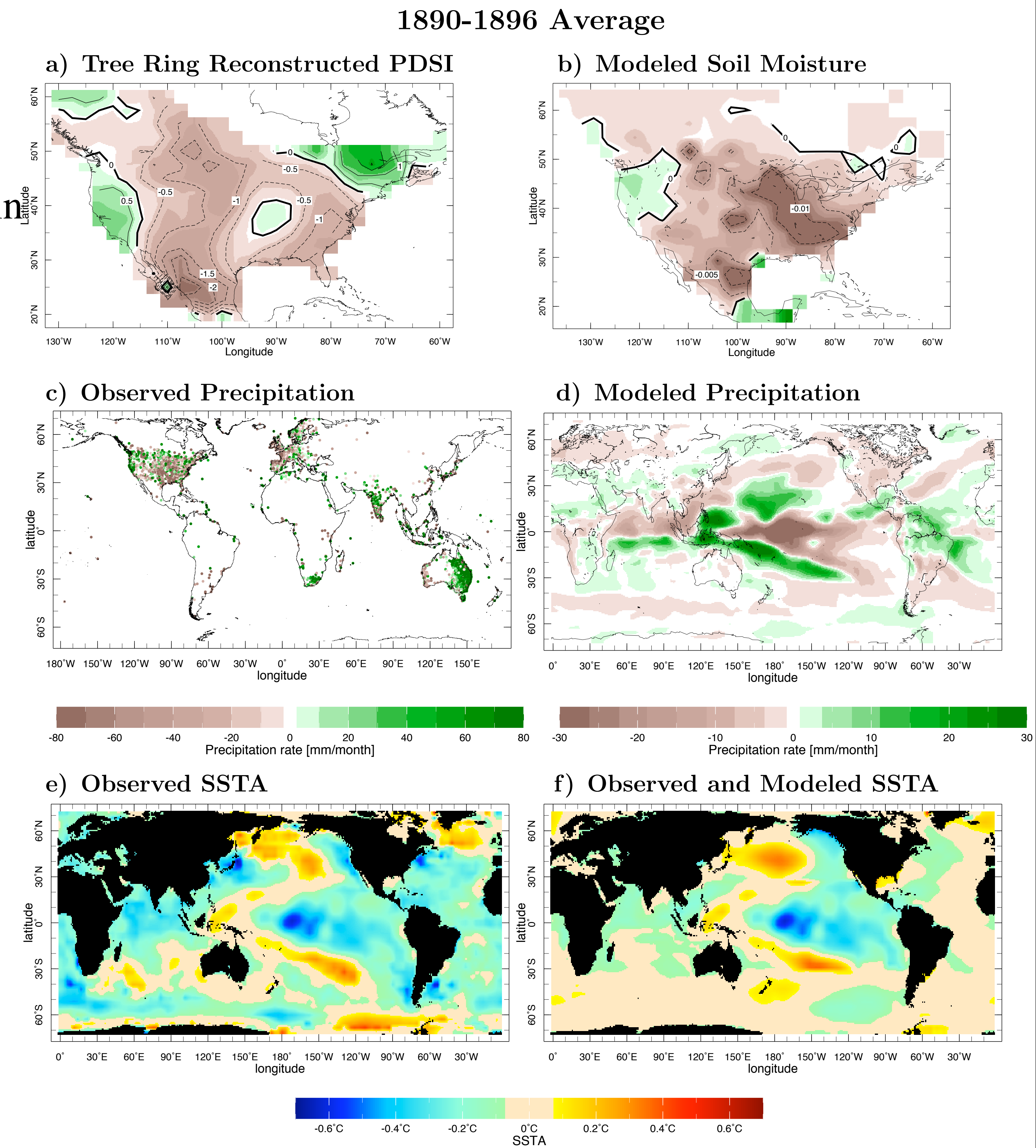
Modeled with SST forcing only

Modeled with SST forcing and interactive dust

The 1890s drought -

-Massive abandonment of homesteads in the high plains

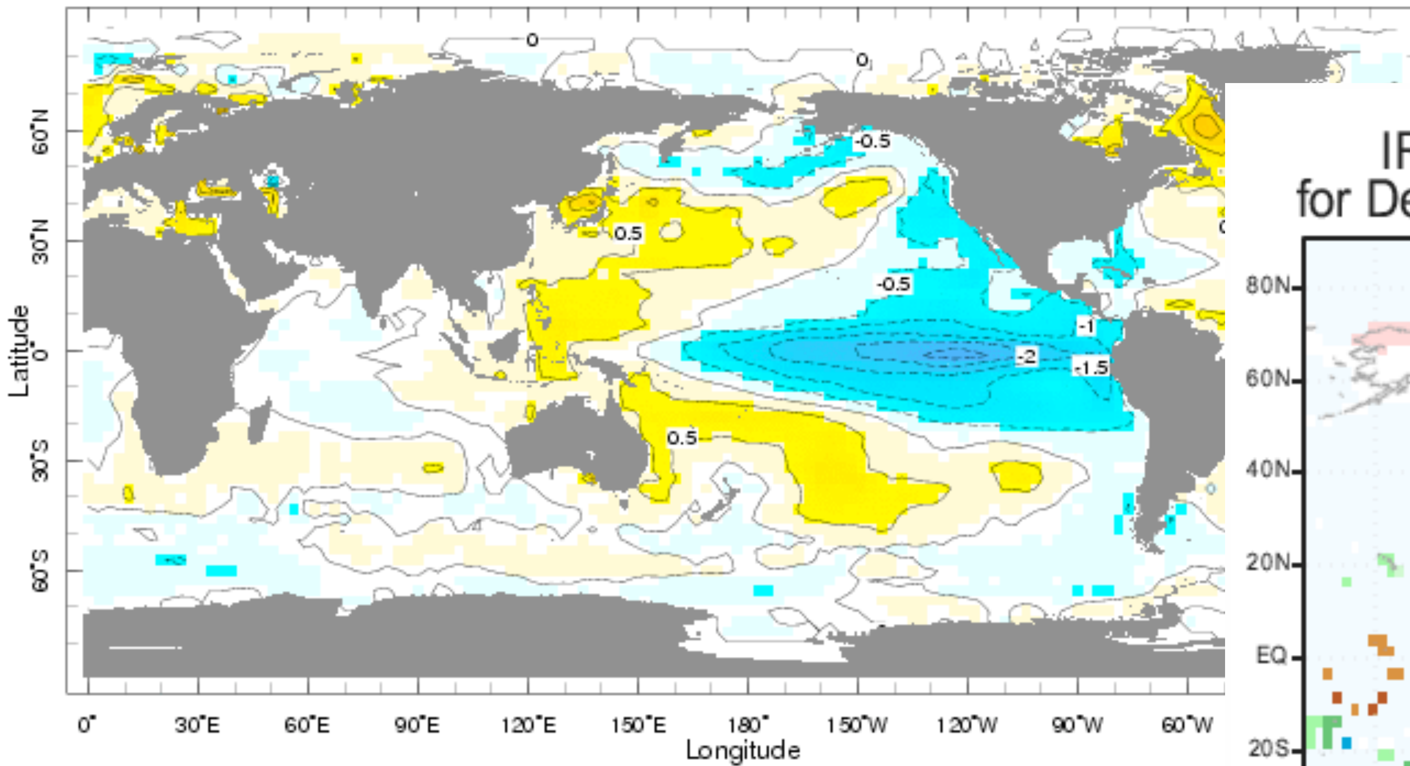
-led to Reclamation Act of 1902, federalization of western development and the 'hydraulic society'



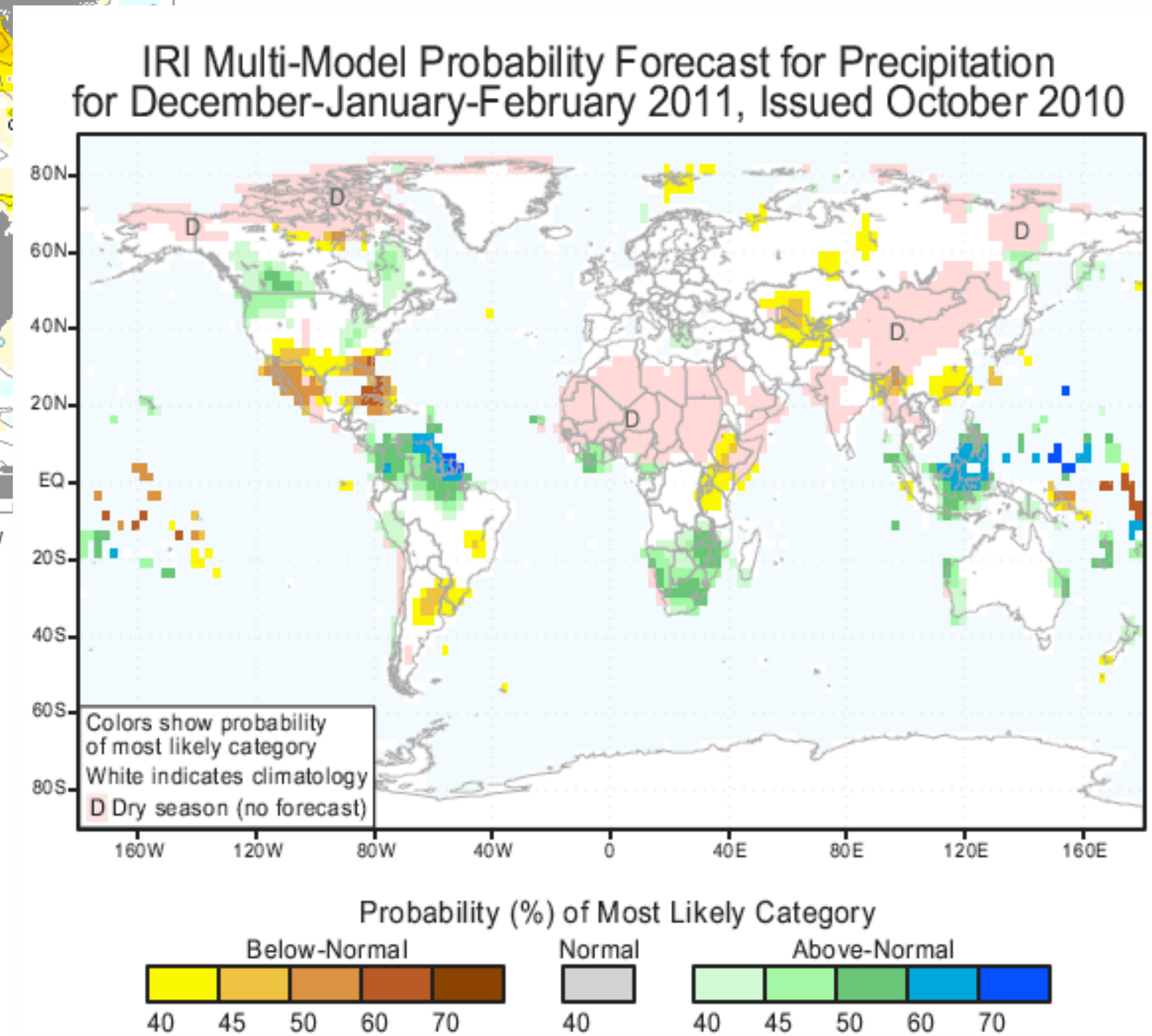
Once more, La Nina-forced
(model has tropical Pacific SST forcing only)

SST anomalies outside tropical Pacific created ***as a response to tropical Pacific SSTs***

For now we are limited to seasonal to interannual prediction based on forecasts of El Ninos and La Ninas

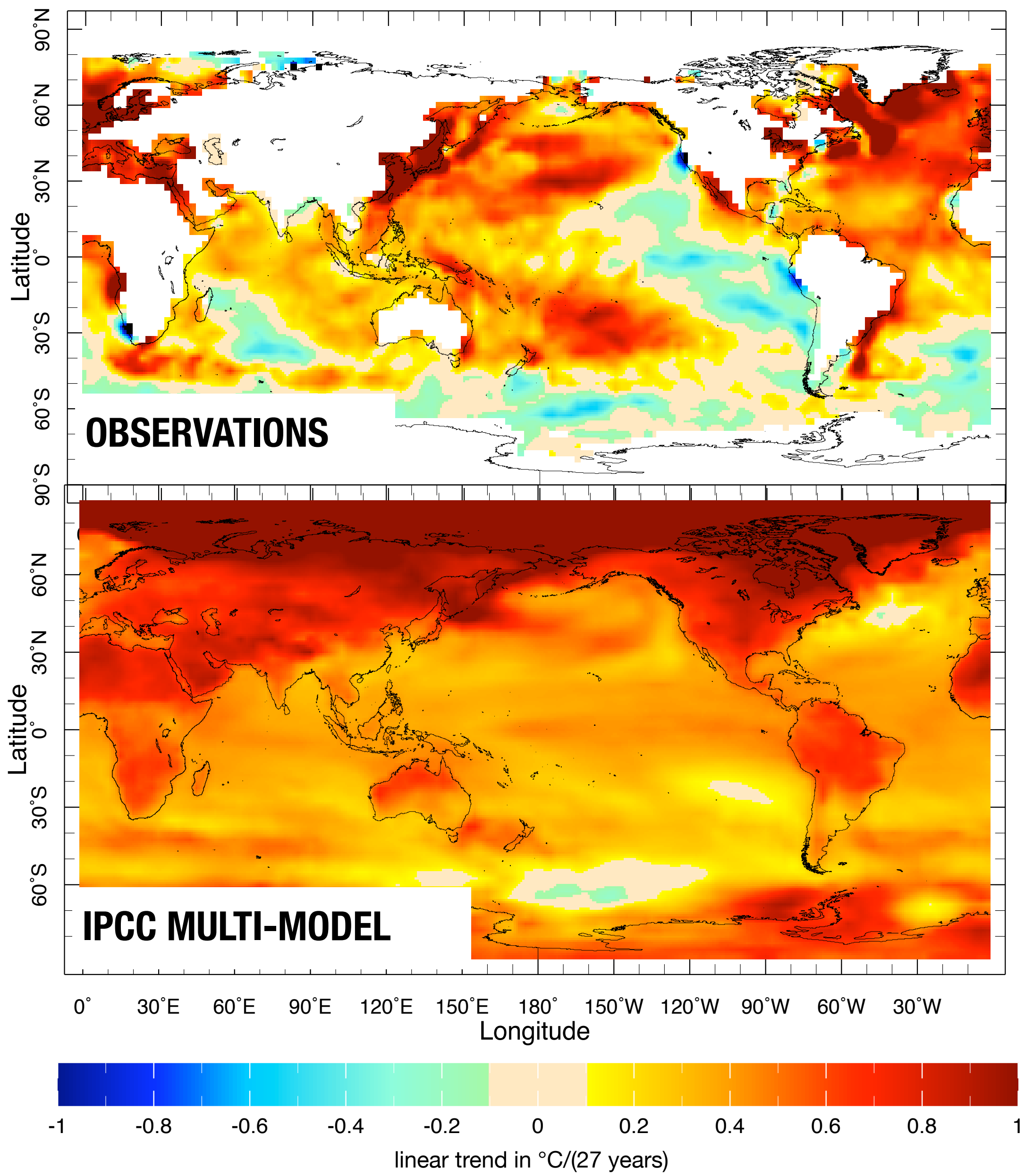


Dec 2010 - Feb 2011 IRI seasonal Forecast SSTA issued 0000 1 Sep 2010

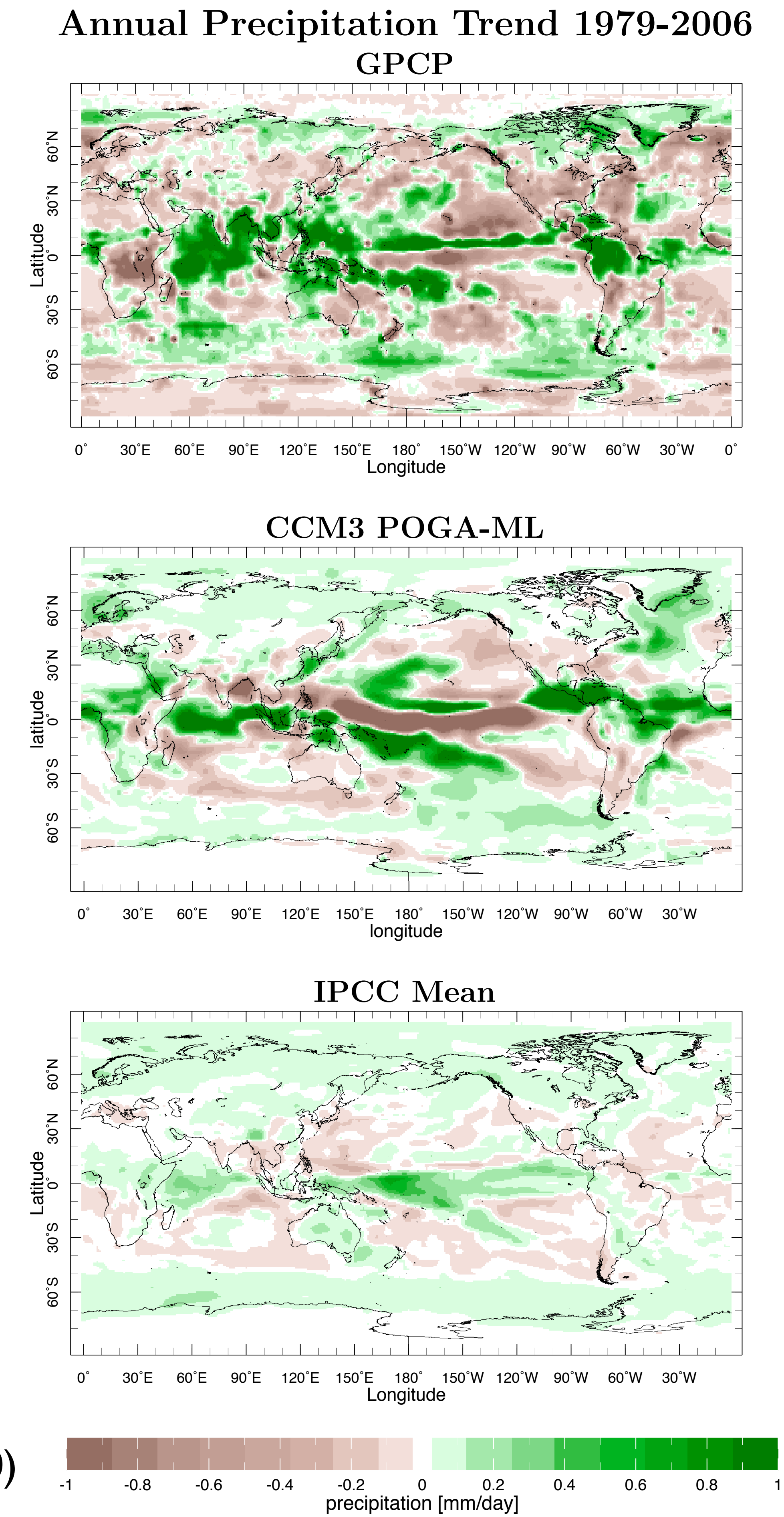


Forecast for DJF 2010/11 is a strong La Nina and high probability of a dry Southwest winter

Recent, post 1979, trends do show subtropical drying but this is strongly influenced by trend to La Nina SST pattern (presumed natural) rather than GHG-forcing



Seager and Vecchi (2010)



observed trend

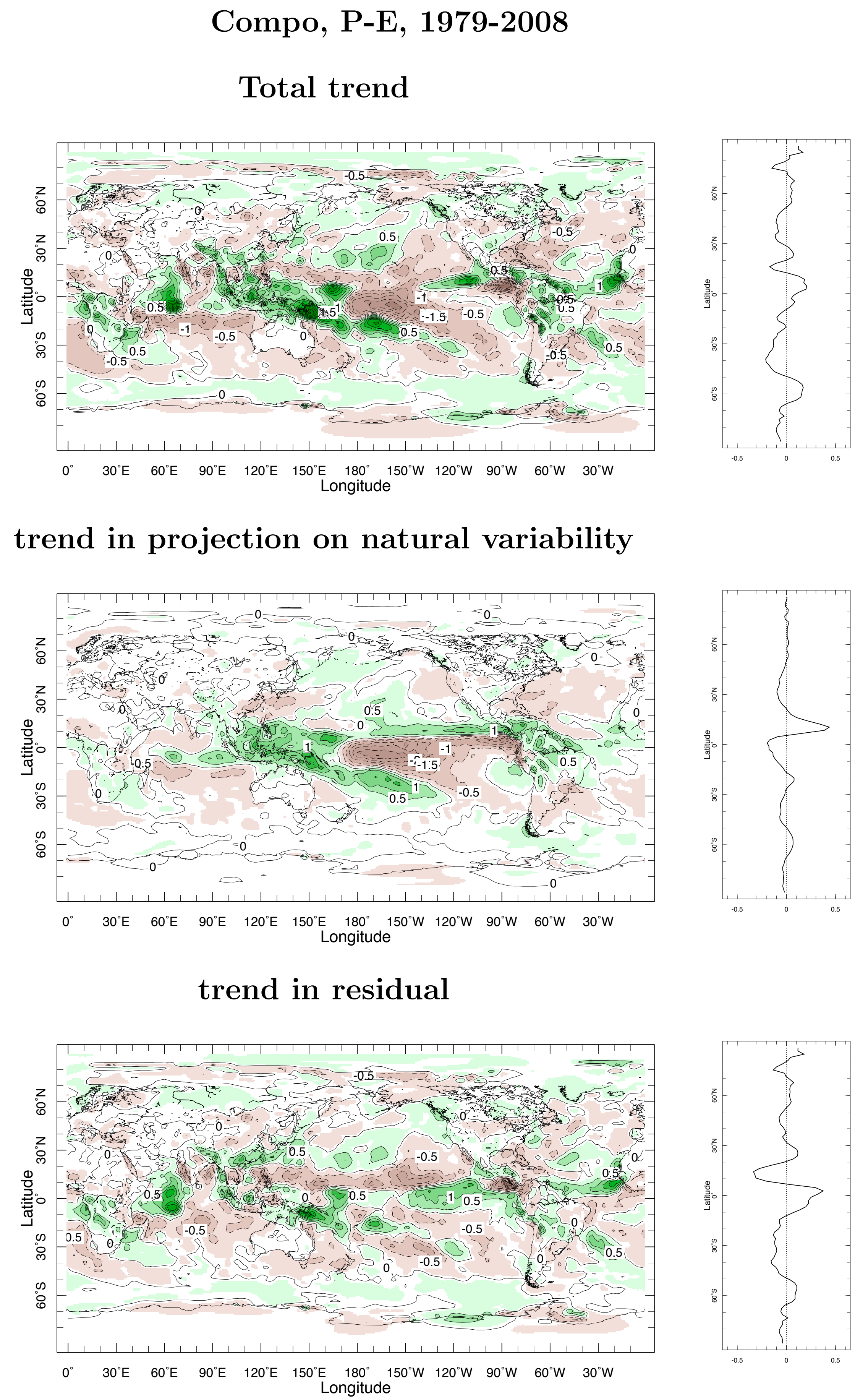
forced by observed tropical Pacific SST trend

IPCC AR4 radiatively-forced trend

One way to determine natural and anthropogenic contributions to recent change is to compute the ENSO-related variability and subtract it from the total.

The residual has non-ENSO climate variability and any climate change.

Here we used the Compo et al. (2010) 20th Century Reanalysis data

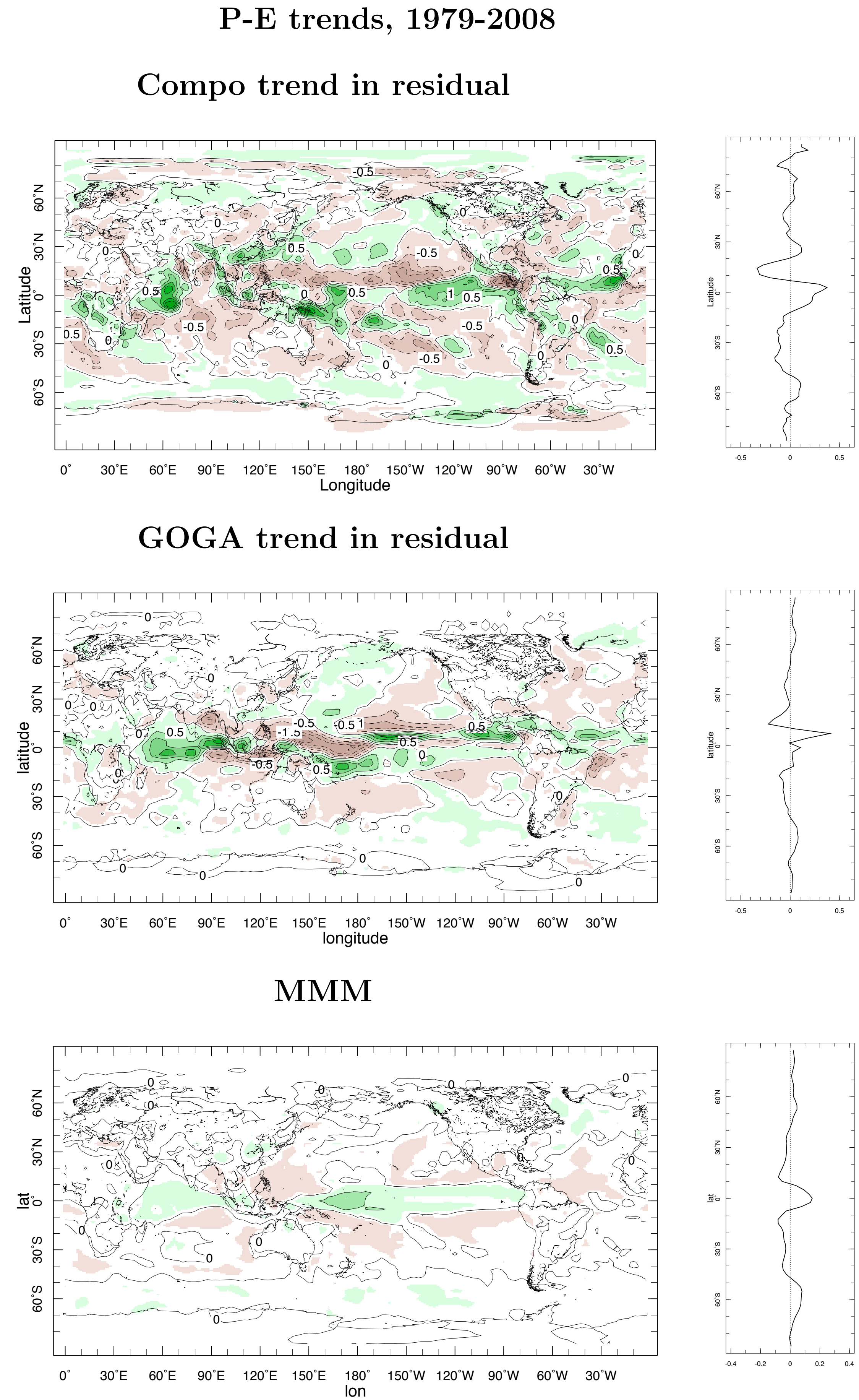


ENSO-removed residual trends for:

The 20th C Reanalysis

and an SST-forced atmosphere model

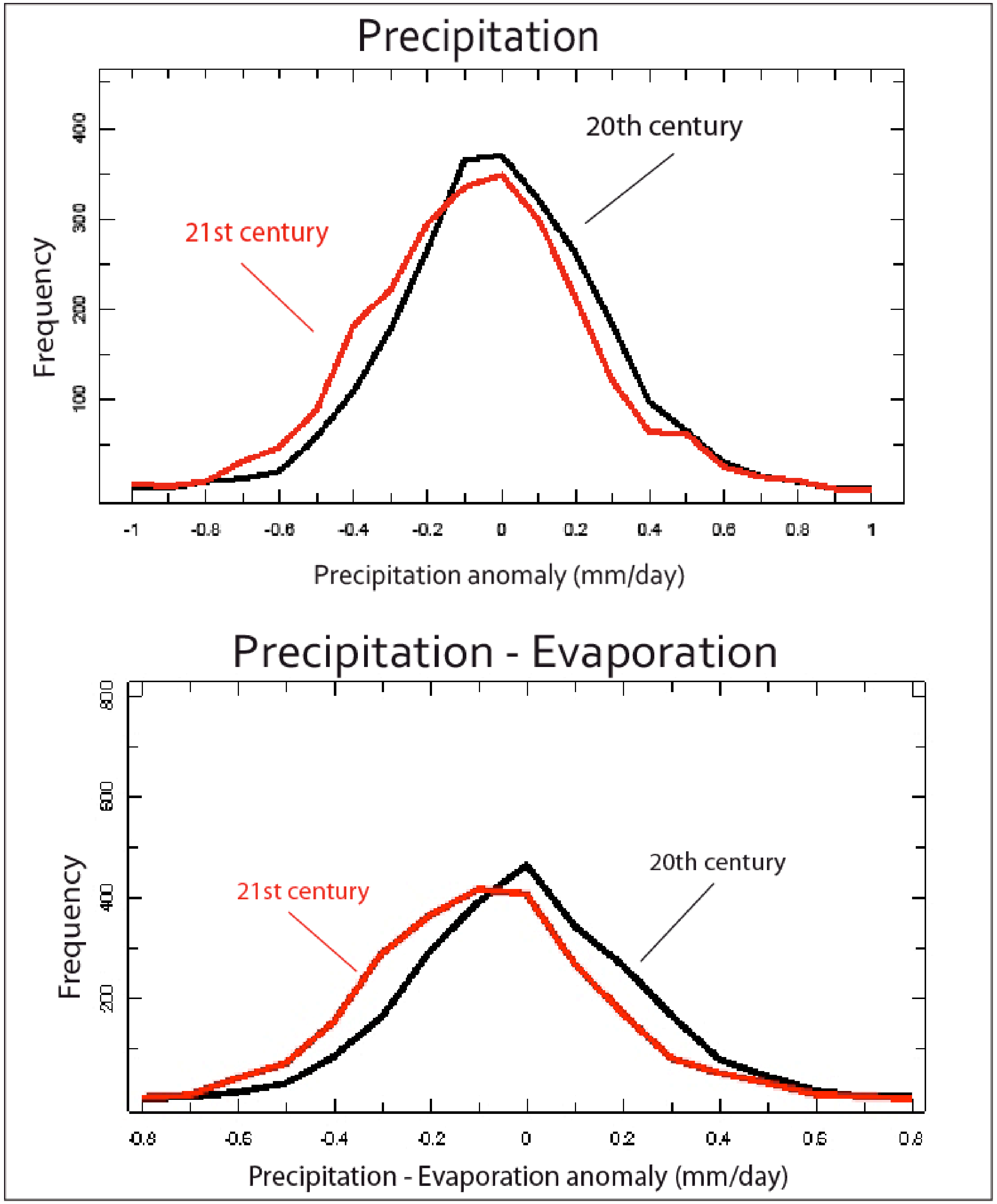
As compared to the average of IPCC AR4 models' simulation of radiative-forced change



P and P-E histograms for interannual variability in Southwest N. America

Do seasonal P, or P-E, anomalies get more extreme in a warmer climate?

NO. The magnitude of seasonal to interannual variability remains the same but around a drier mean

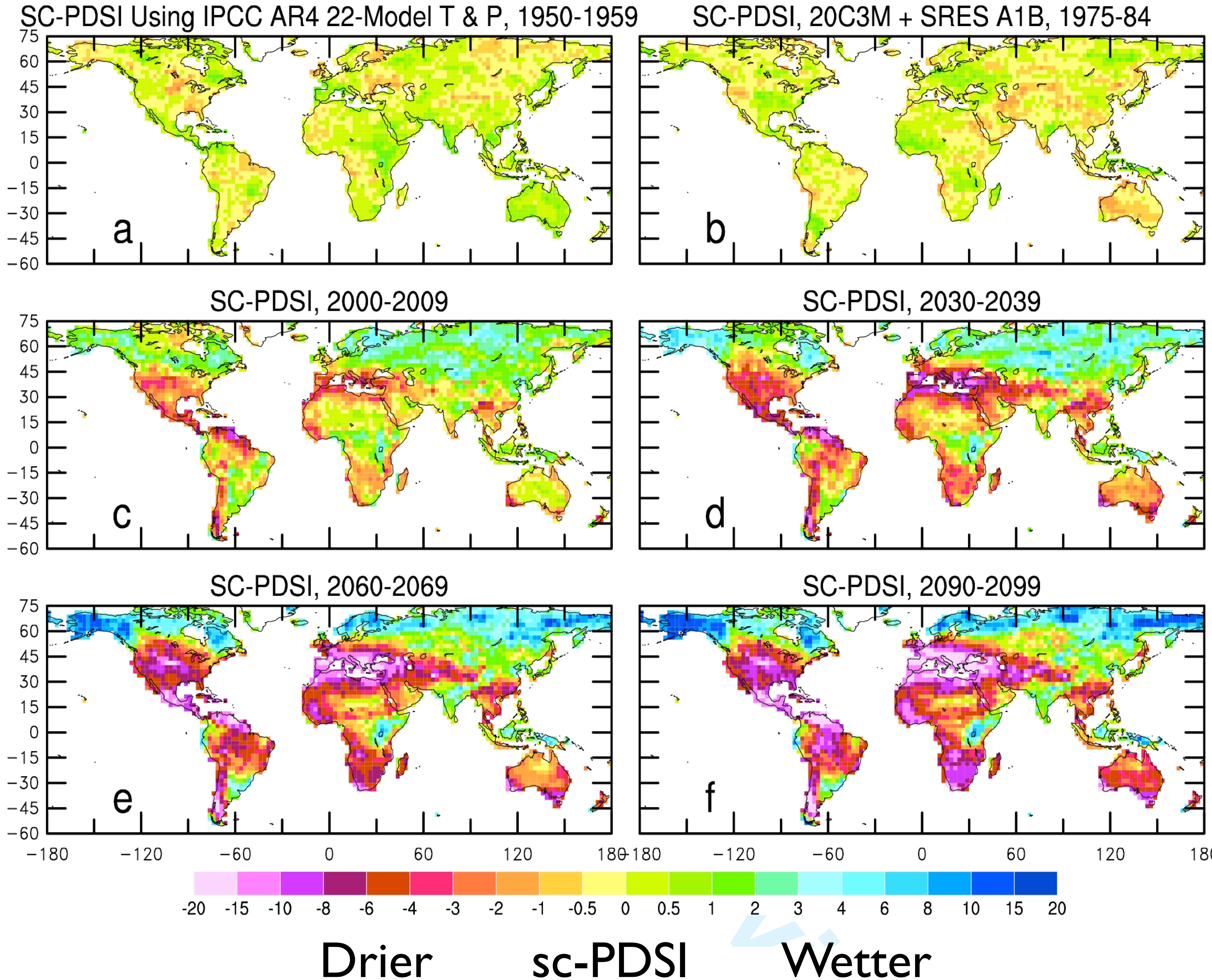


courtesy, Laura Vogel

Dai (2010)

The onward march of subtropical-mid-latitude drying.

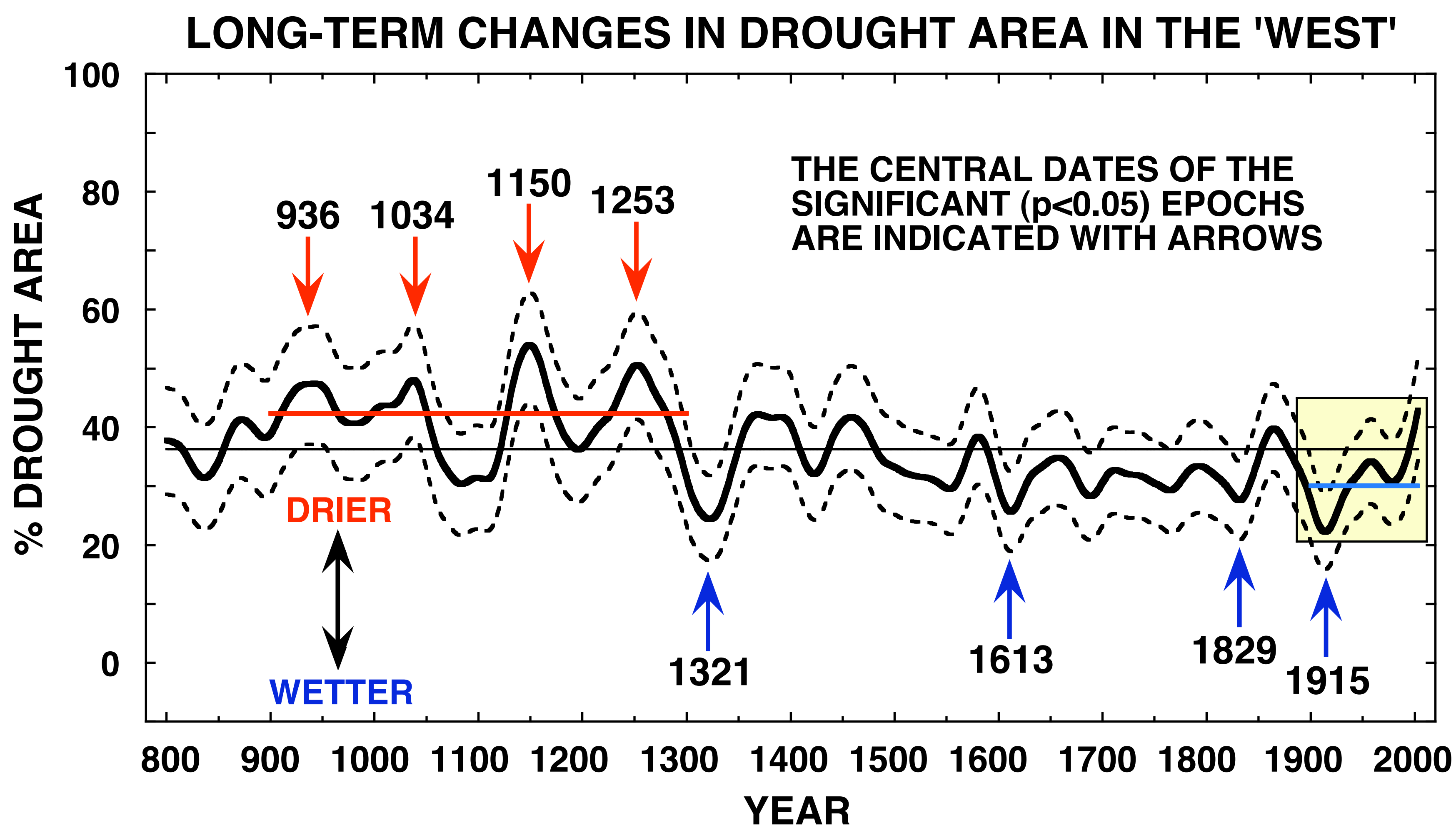
A large part of this is driven by warming and increased evaporative demand



Turning to the trees …..

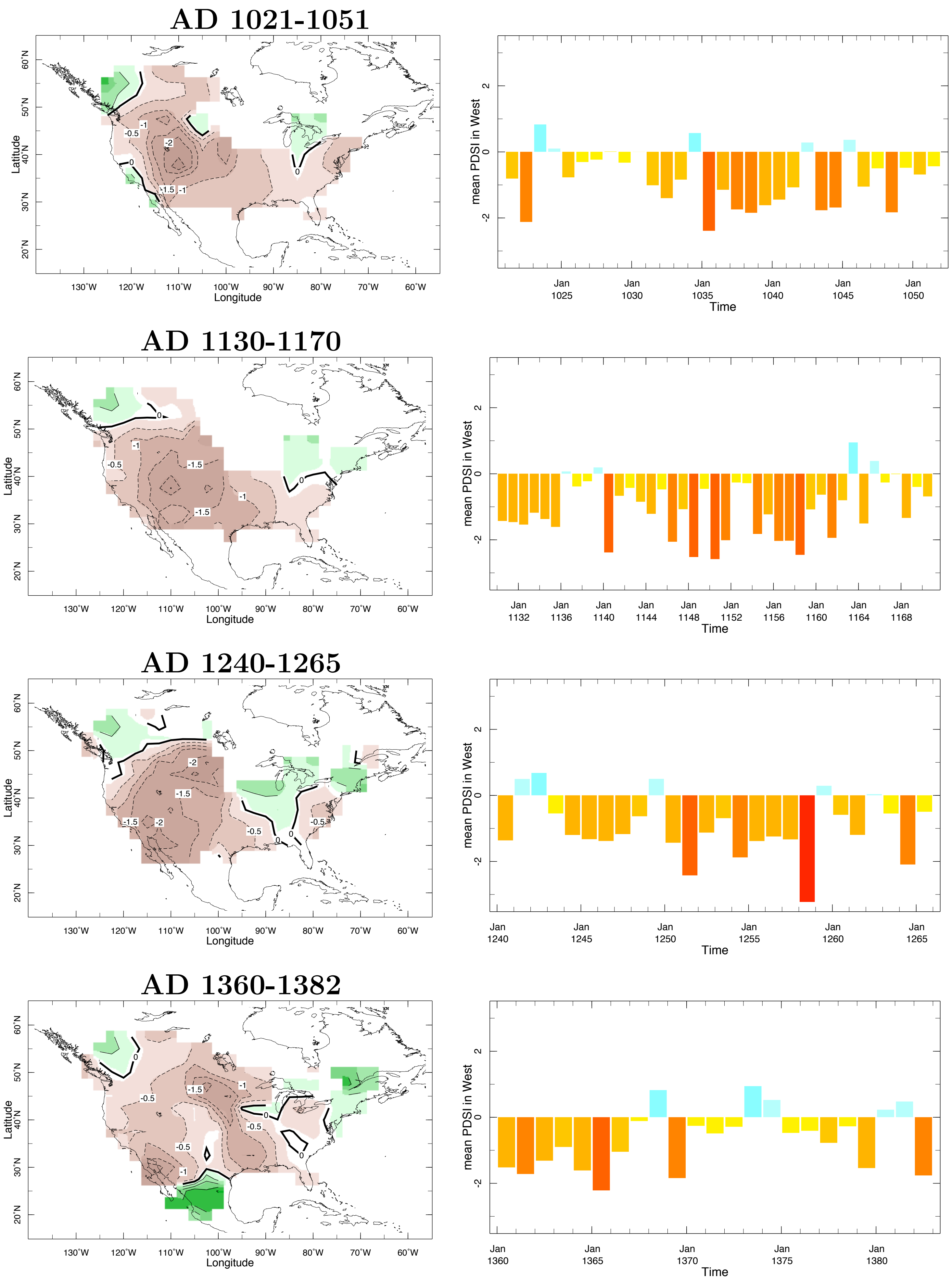
…a millennial perspective on North American drought

(the past is scary)



***Cook et al., Science* (2004)**

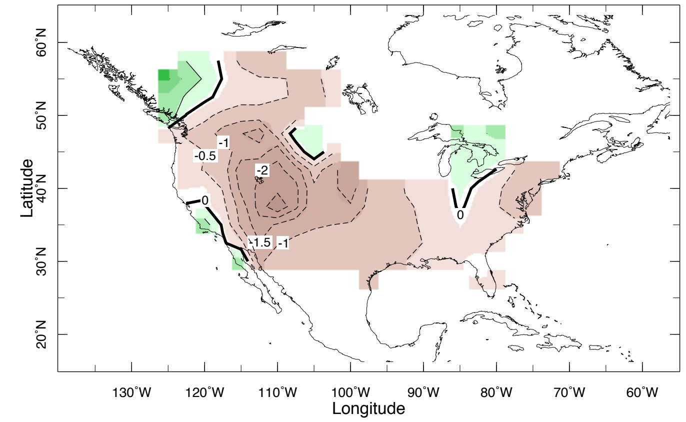

Stumps of trees killed by rising waters
after end of medieval megadroughts

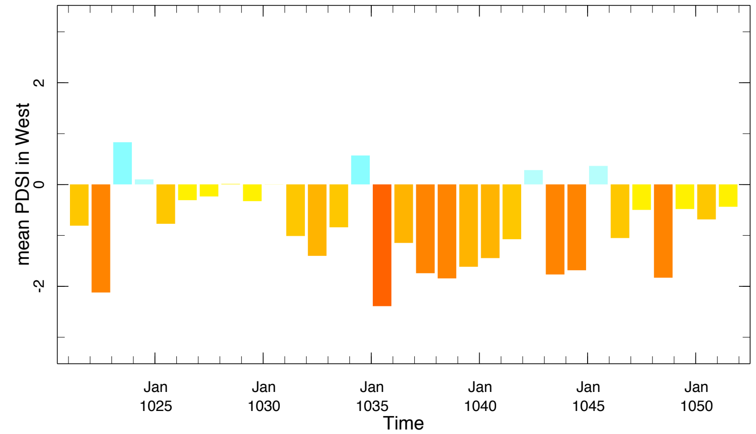


Herweijer et al. (2007)

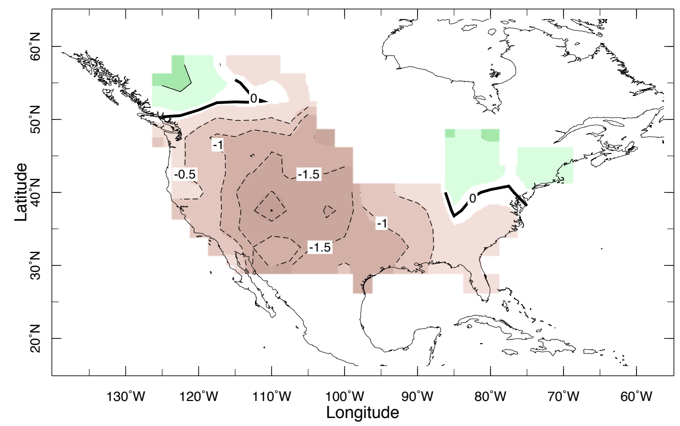
Droughts of Medieval Times reconstructed from tree rings

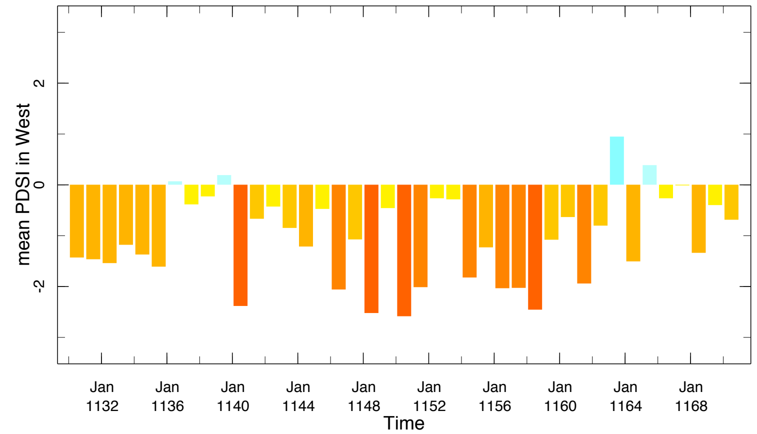
AD 1021-1051





AD 1130-1170





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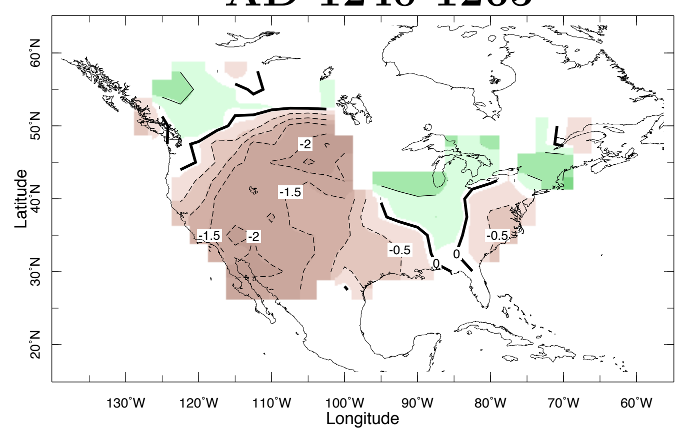
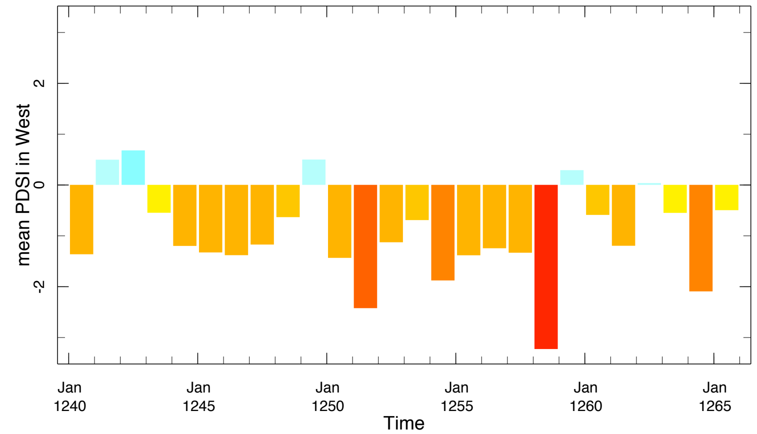
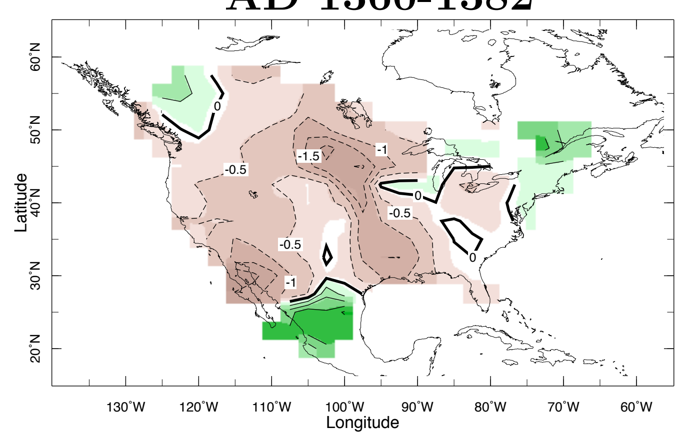
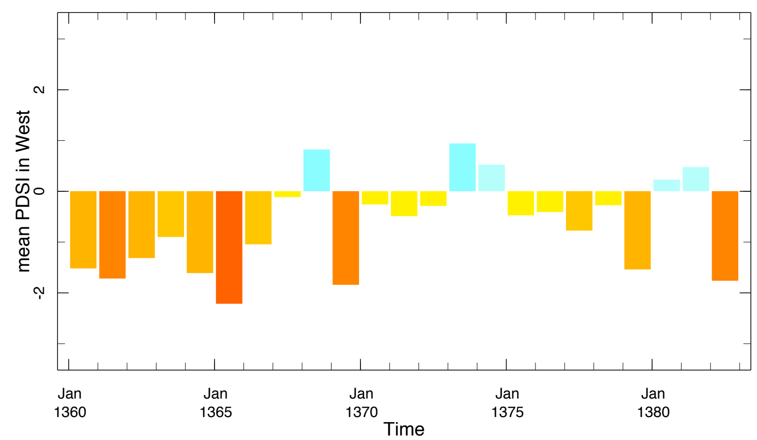




AD 1360-1382





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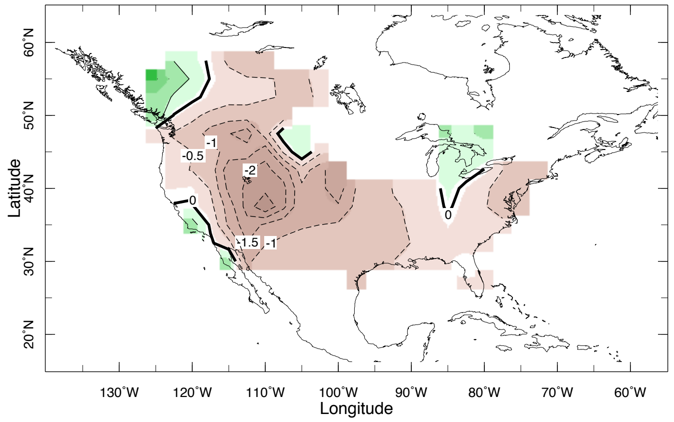

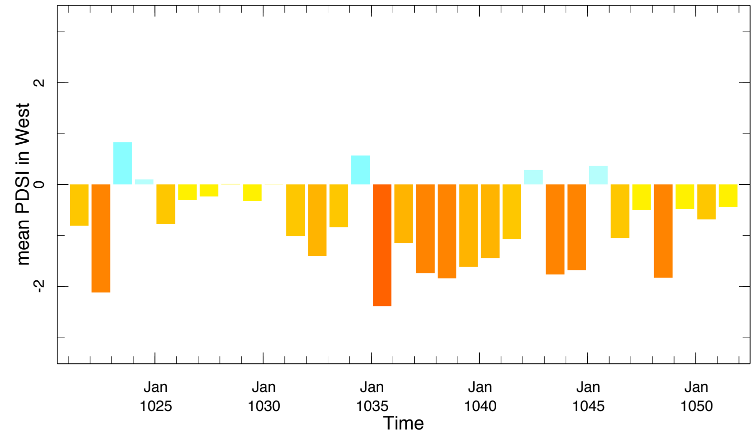

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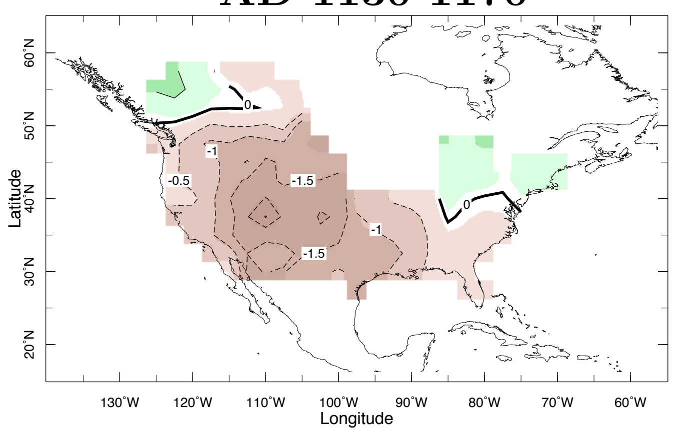
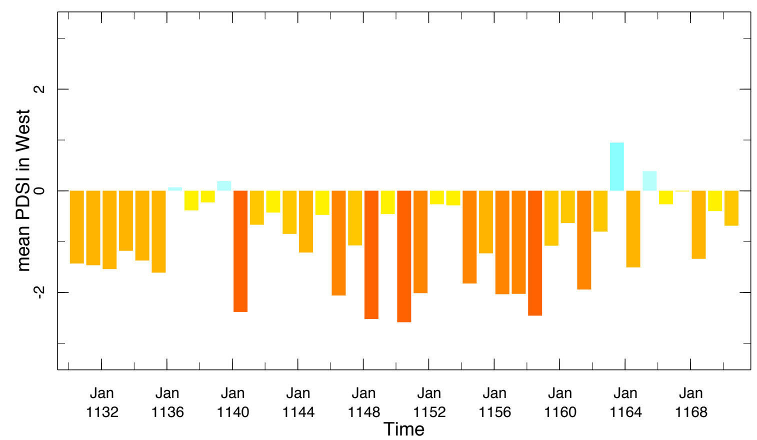
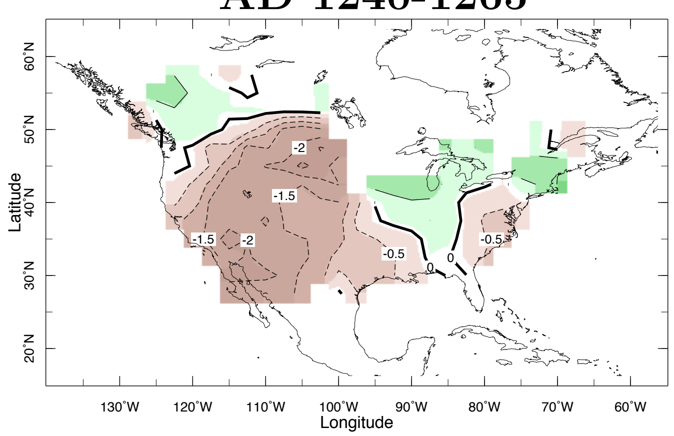
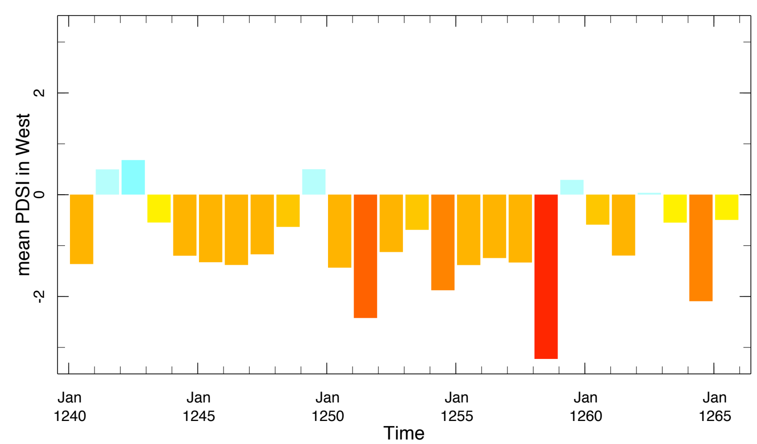




AD 1240-1265





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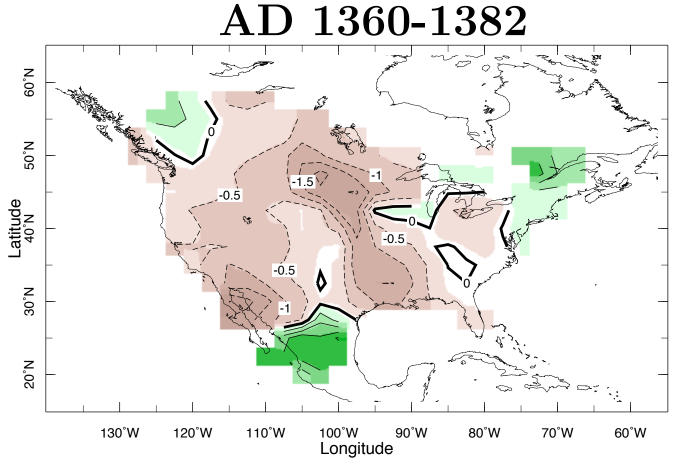

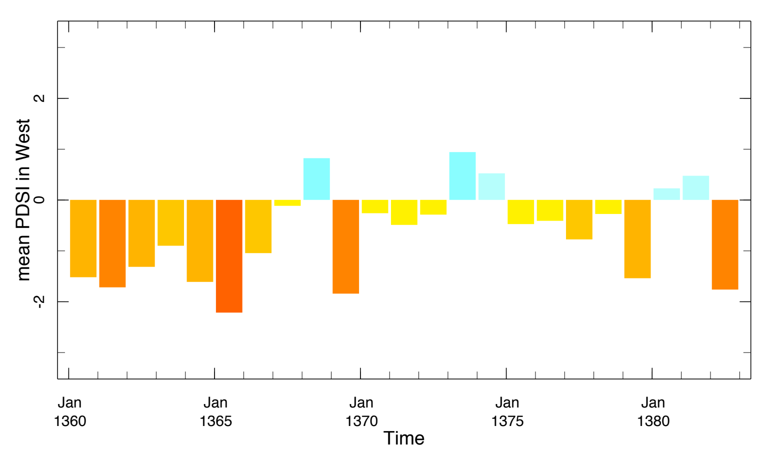

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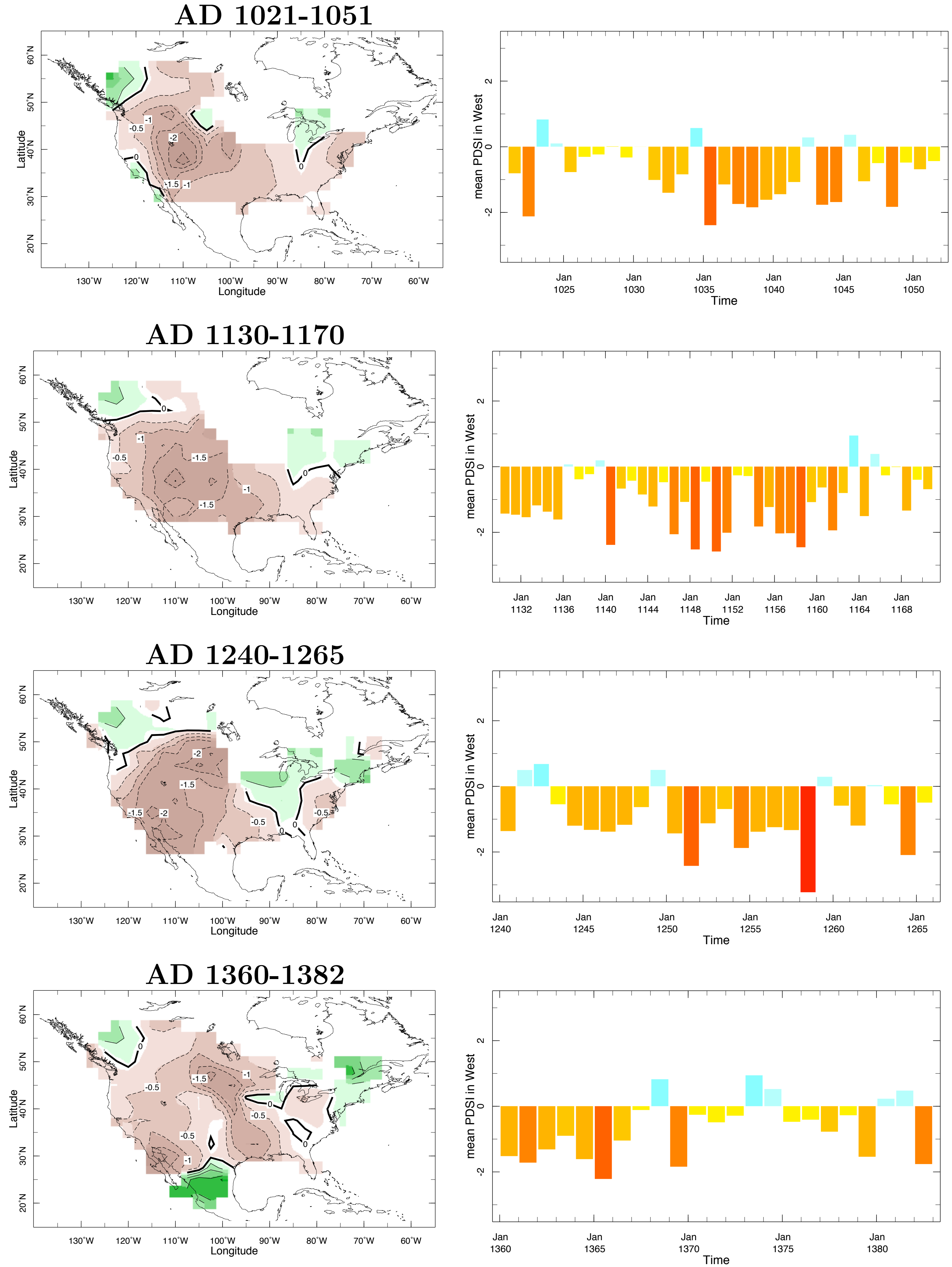

Droughts of Medieval Times reconstructed from tree rings

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Conditions persisted **MUCH** longer (20-40yrs)

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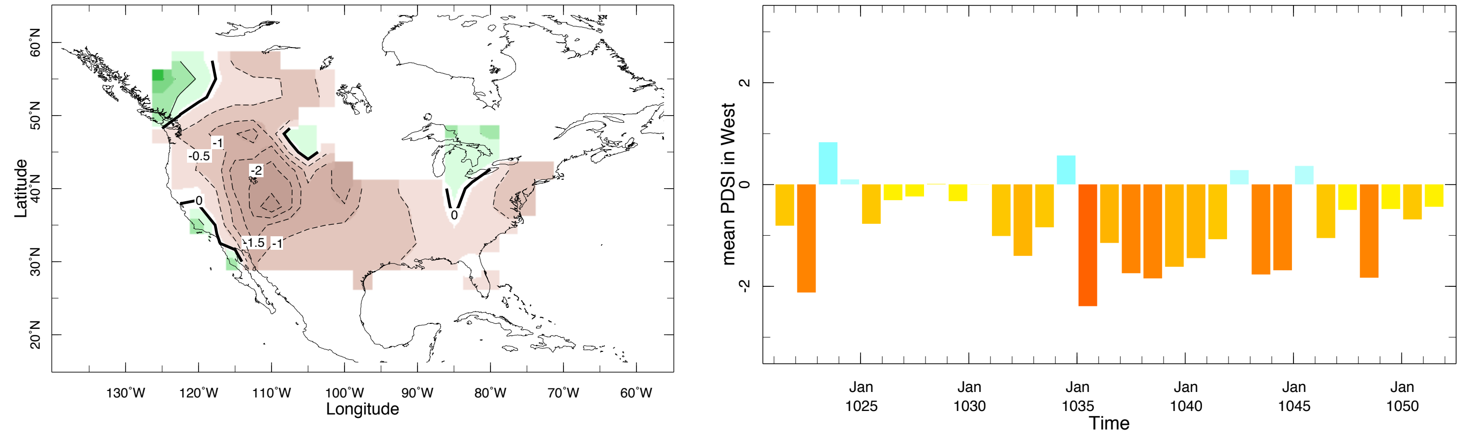

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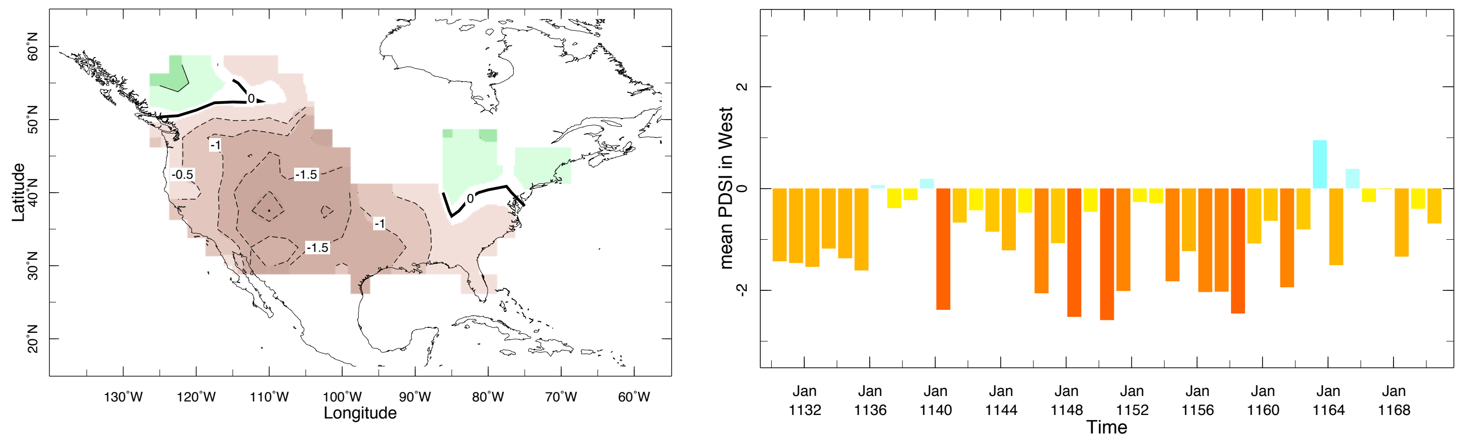

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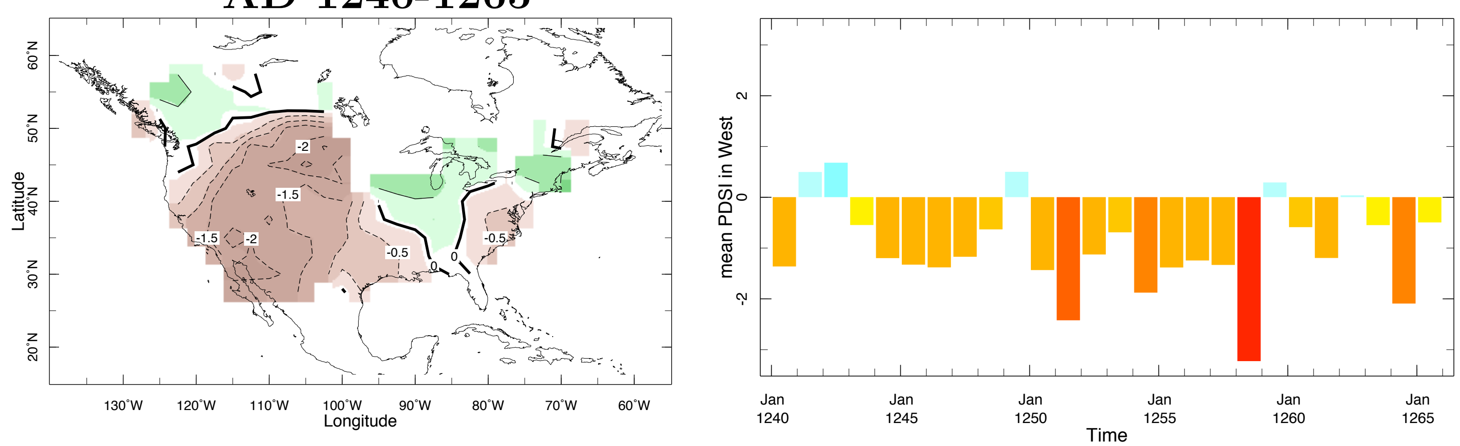

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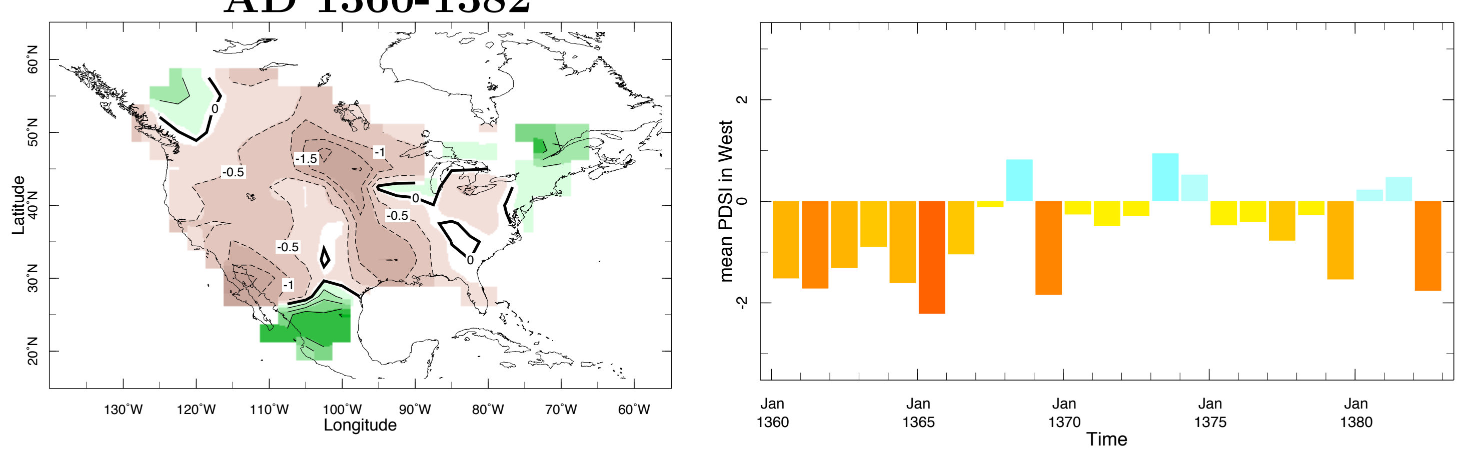

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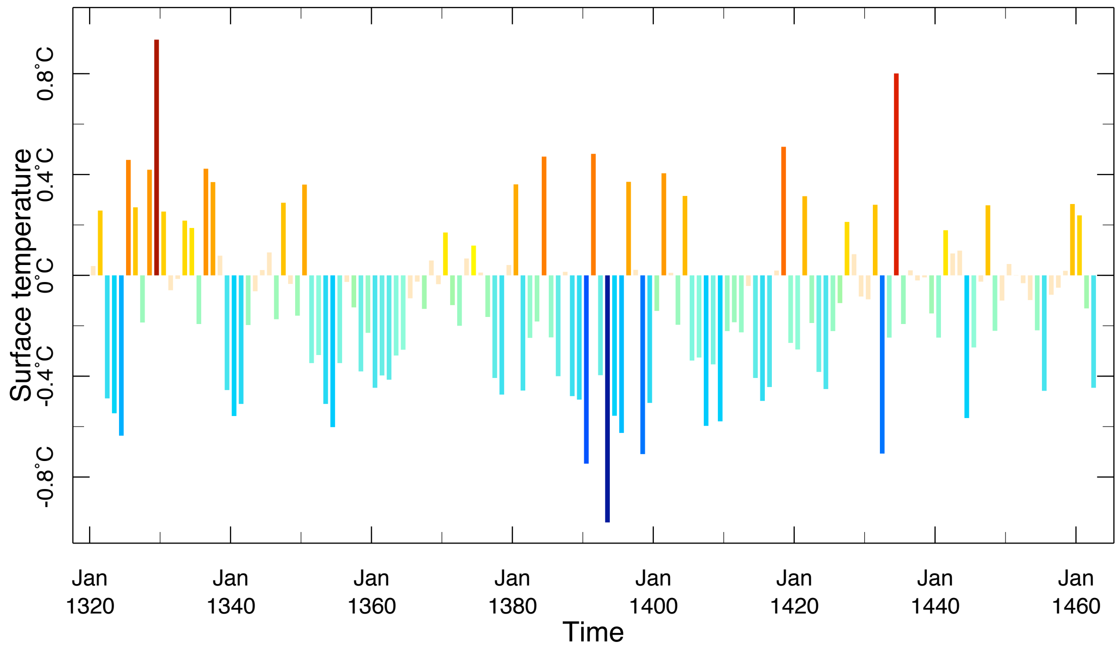
I.E. MEDIEVAL 'MEGA-DROUGHTS'

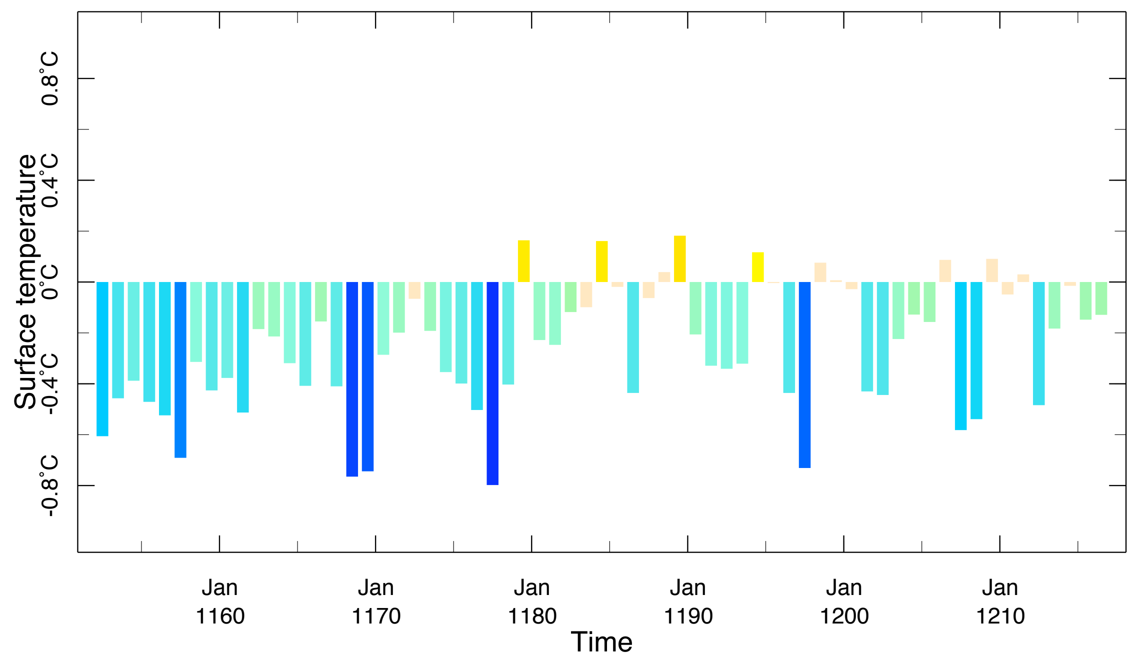
Herweijer et al. (2007)

Coral support for Medieval La Nina ....

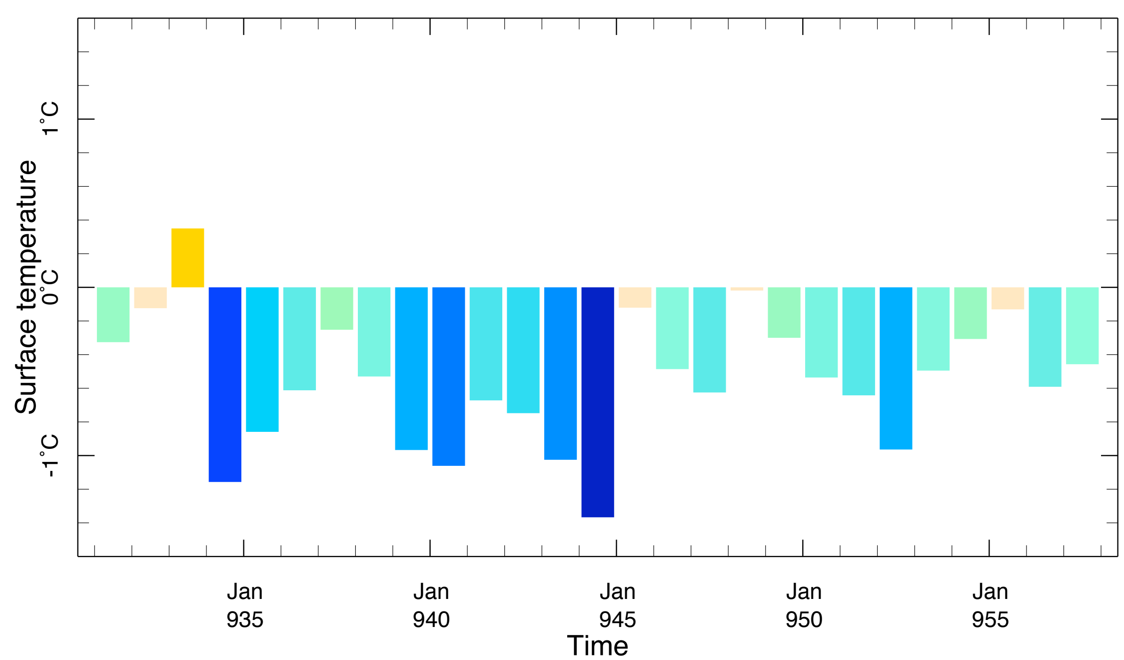


Tropical Pacific SST index 1320-1462 A.D.

Fossil corals from Palmyra suggest more La Nina-like Medieval period (Cobb et al., 2003)



1152-1216 A.D.



931-957 A.D.

Use these corals to create SSTs to force atmosphere model simulations

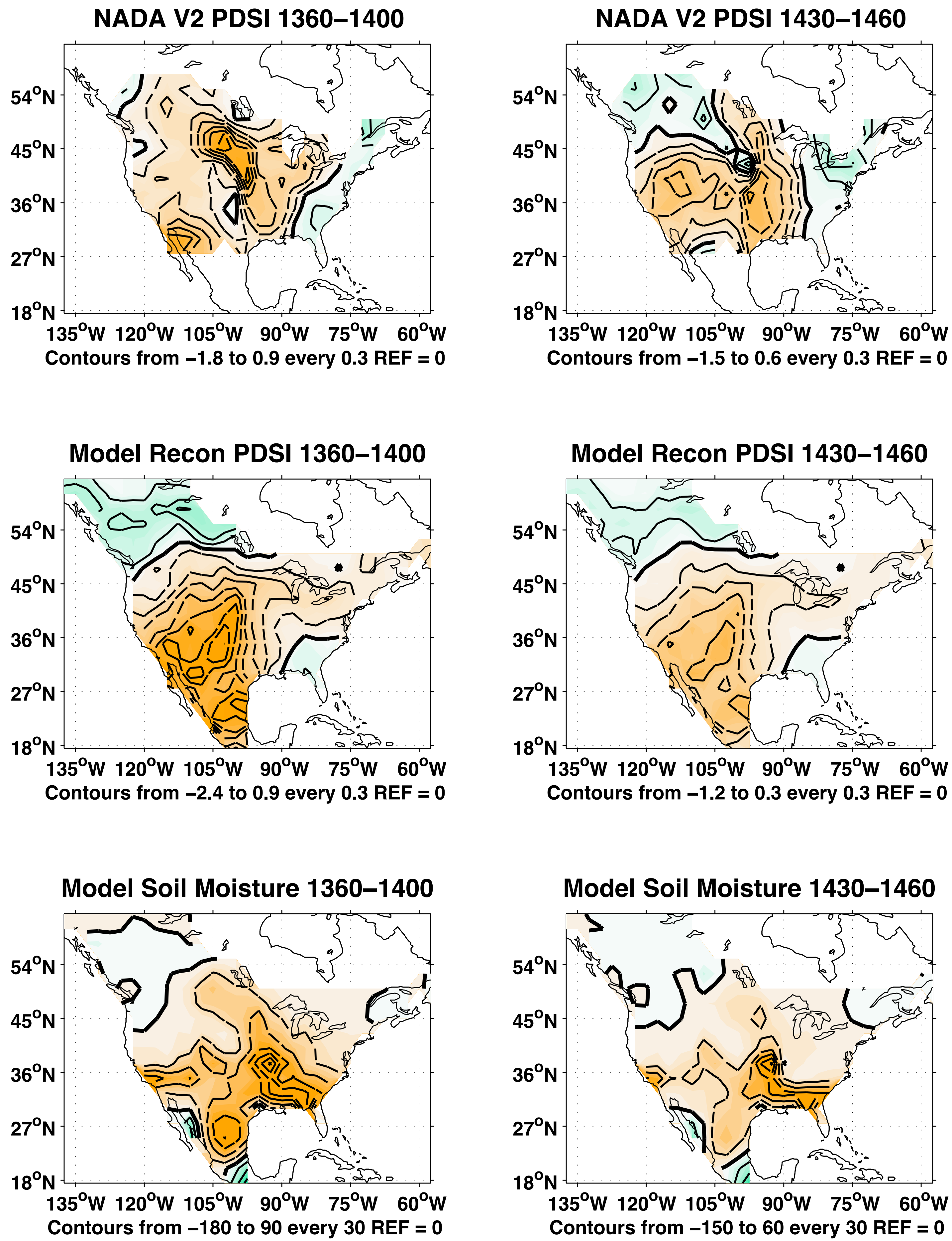
Comparison of tree ring and modeled spatial patterns of two megadroughts

suggestive of a tropical Pacific link to Medieval drought ..

Tree ring PDSI

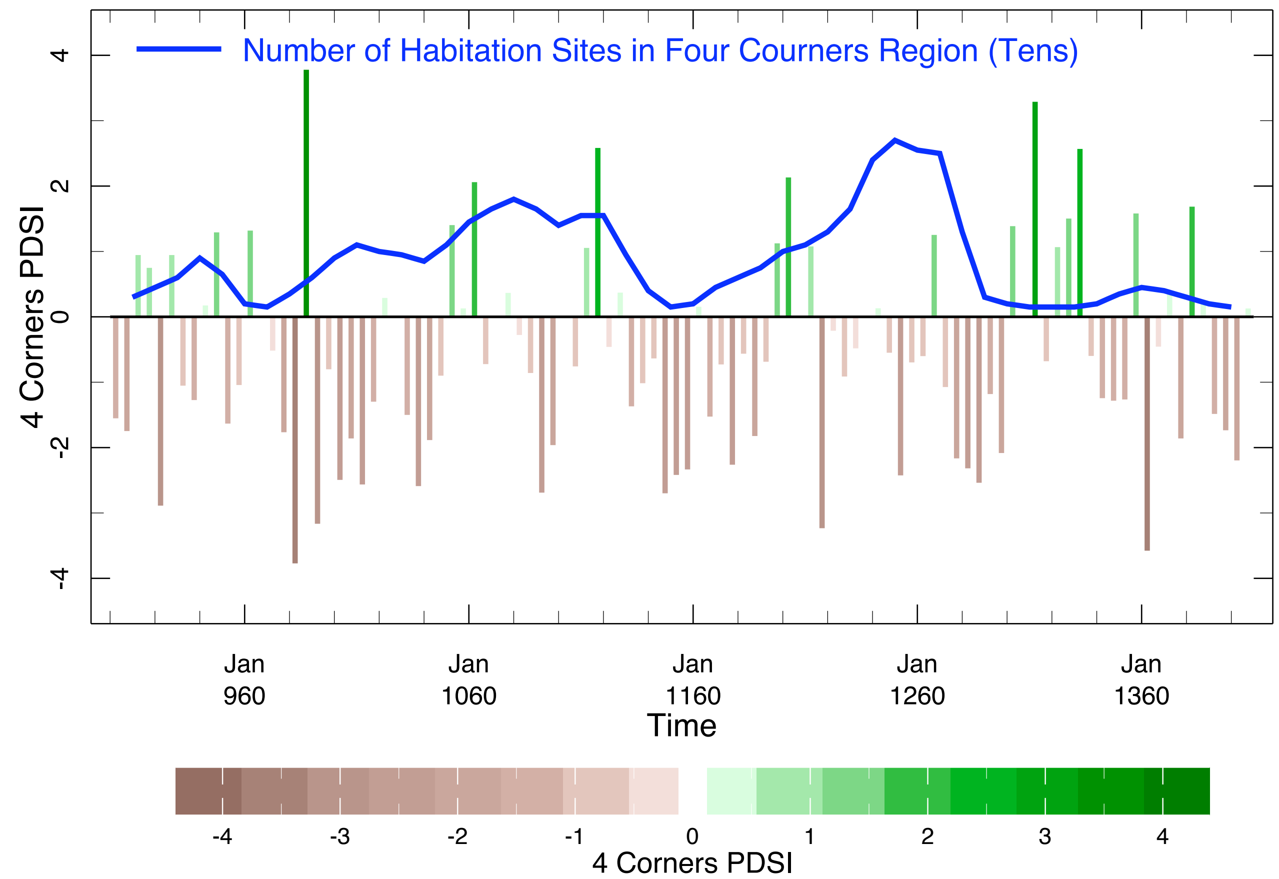
model PDSI

model soil moisture

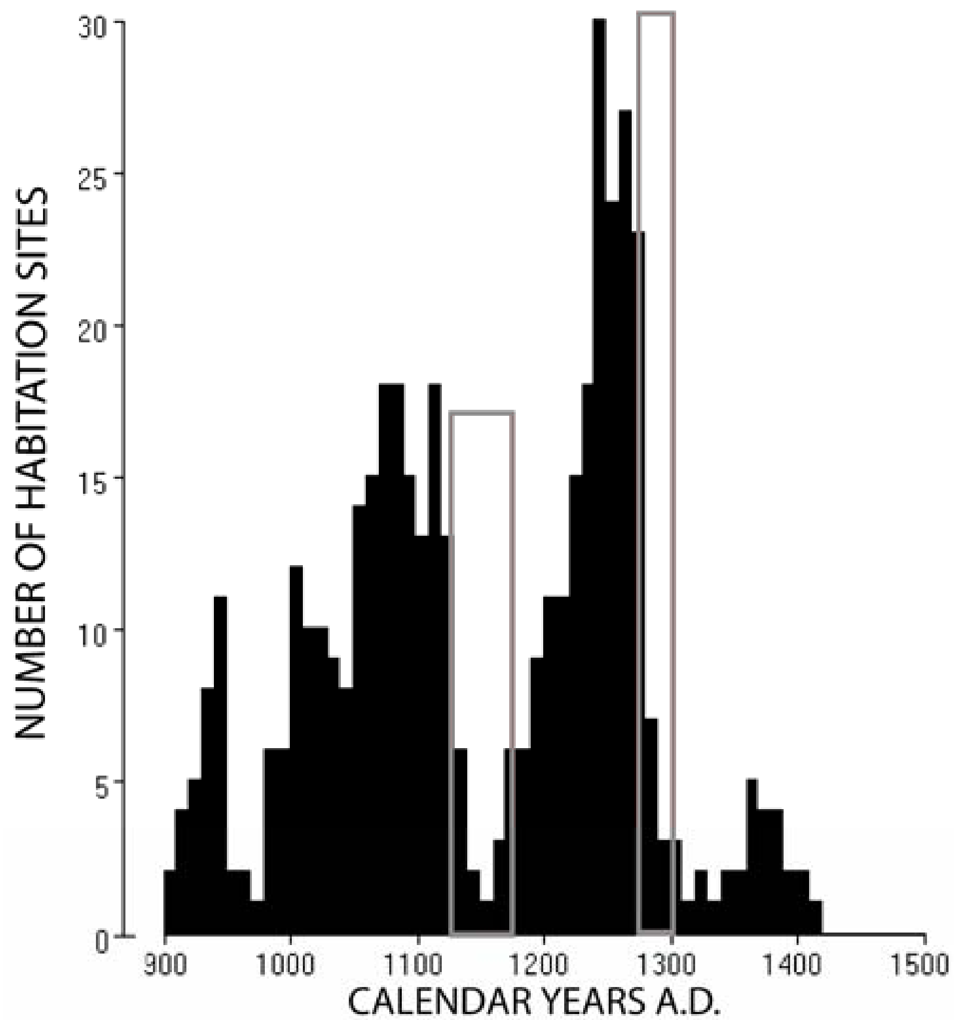


Drought and the ancestral Pueblo Indians

Number of Habitation Sites in Four Corners Region (line) and PDSI (bars)



Seager and Cook (unpubl.)

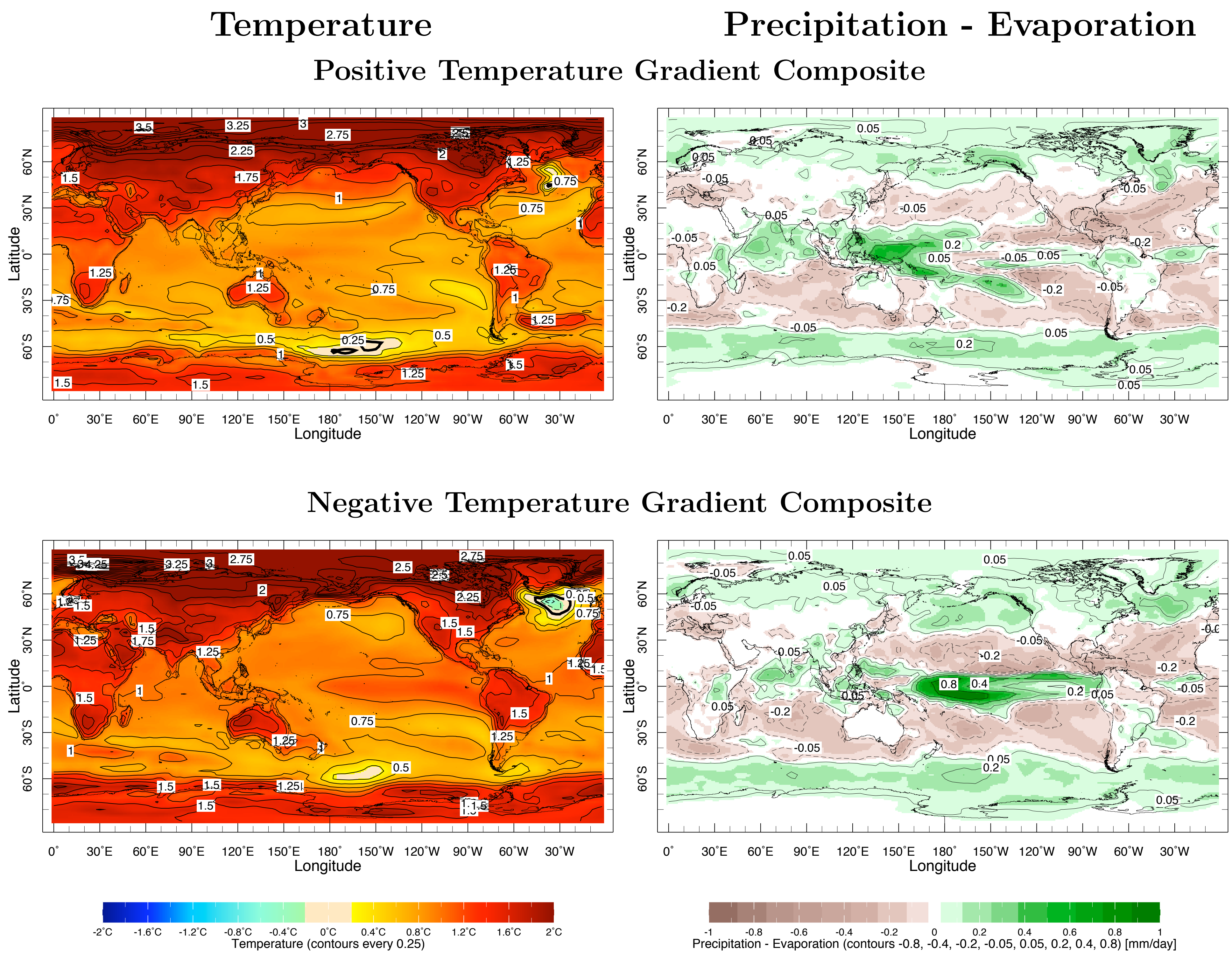


Studies of the Four Corners region show population related to megadroughts

Benson et al. (2007)

IPCC (2021 to 2040) - (1950 to 1999)

A further wrinkle is that the amplitude of future drying of southwest is greatest in models that become more La Nina-like in response to rising GHGs, but tropical Pacific SST response is highly uncertain



Seager and Vecchi (2010)

Conclusions

Multiyear drought in Southwest North America always forced by small variations in tropical SSTs.

Predictability of the SSTs limited to one year, longer term prediction still a research problem (but it just may not be possible).

Models project that rising GHGs and global warming will steadily turn Southwest North America more arid - akin to permanent drought by mid-century - as part of a global-scale change in the hydrological cycle. Worst case and best case scenarios but hard to think that this will not occur. Looks like it is occurring.

Year to year variability does not change but occurs around this drying mean state - dry years will get drier, wet years less wet.

Current climate models not up to task of providing detailed projections of river flows and won't be for years/decades.

The short, instrumental record does not contain all that can happen - during the Medieval period SW N. America was struck by a series of multi-decadal droughts whose origins - internal climate variability or forced by solar and volcanism variations are unknown