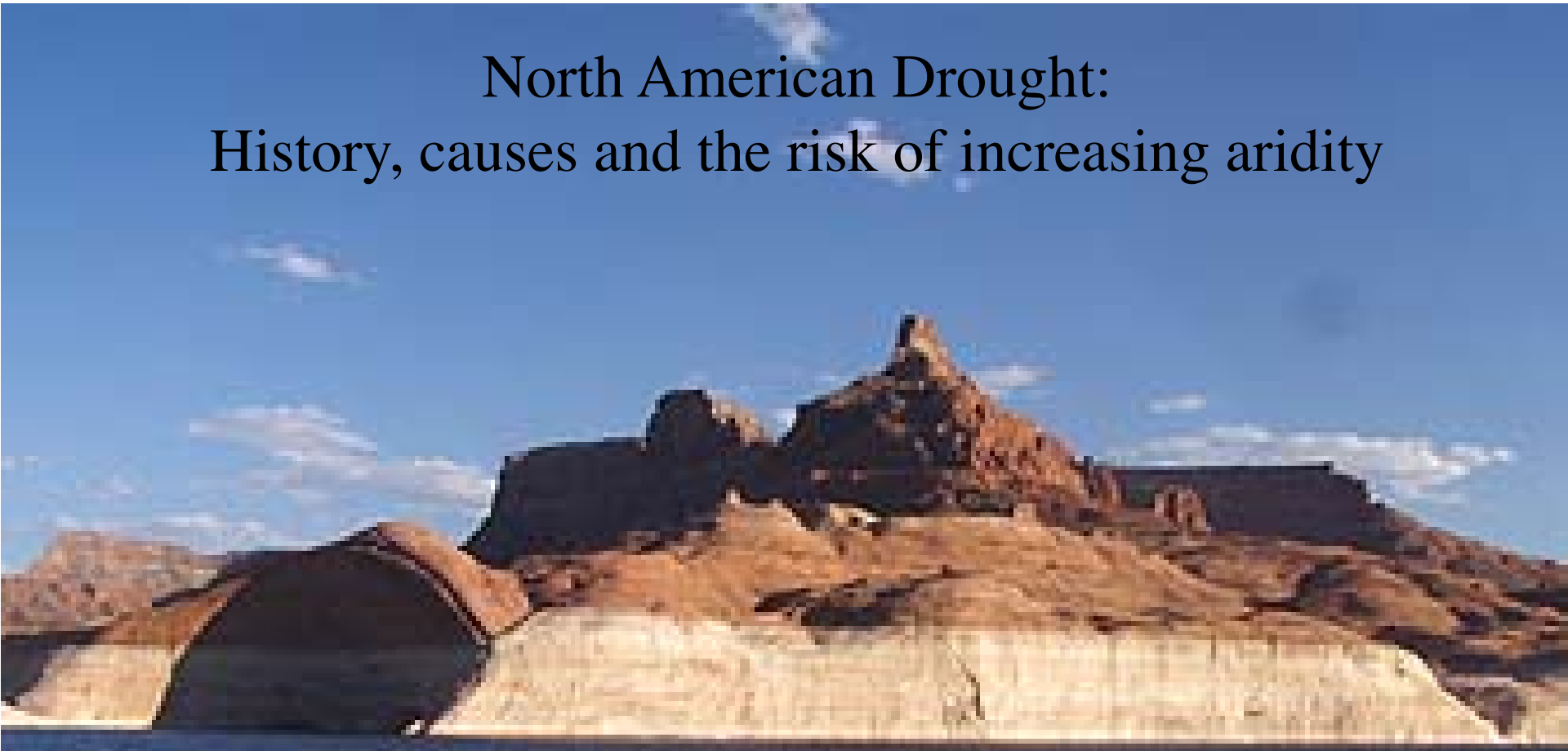
North American Drought:
History, causes and the risk of increasing aridity



Richard Seager

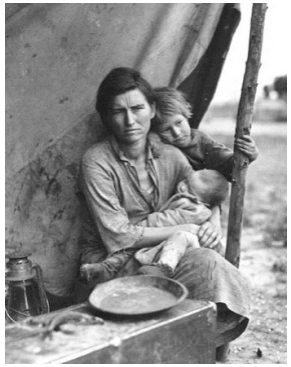
Yochanan Kushnir, Celine Herweijer, Ed Cook and Mingfang Ting

Lamont Doherty Earth Observatory of Columbia University

Plus:

Nili Harnik (U. Tel Aviv), Walter Robinson (U. Illinois), Huei-Ping Huang (LDEO)

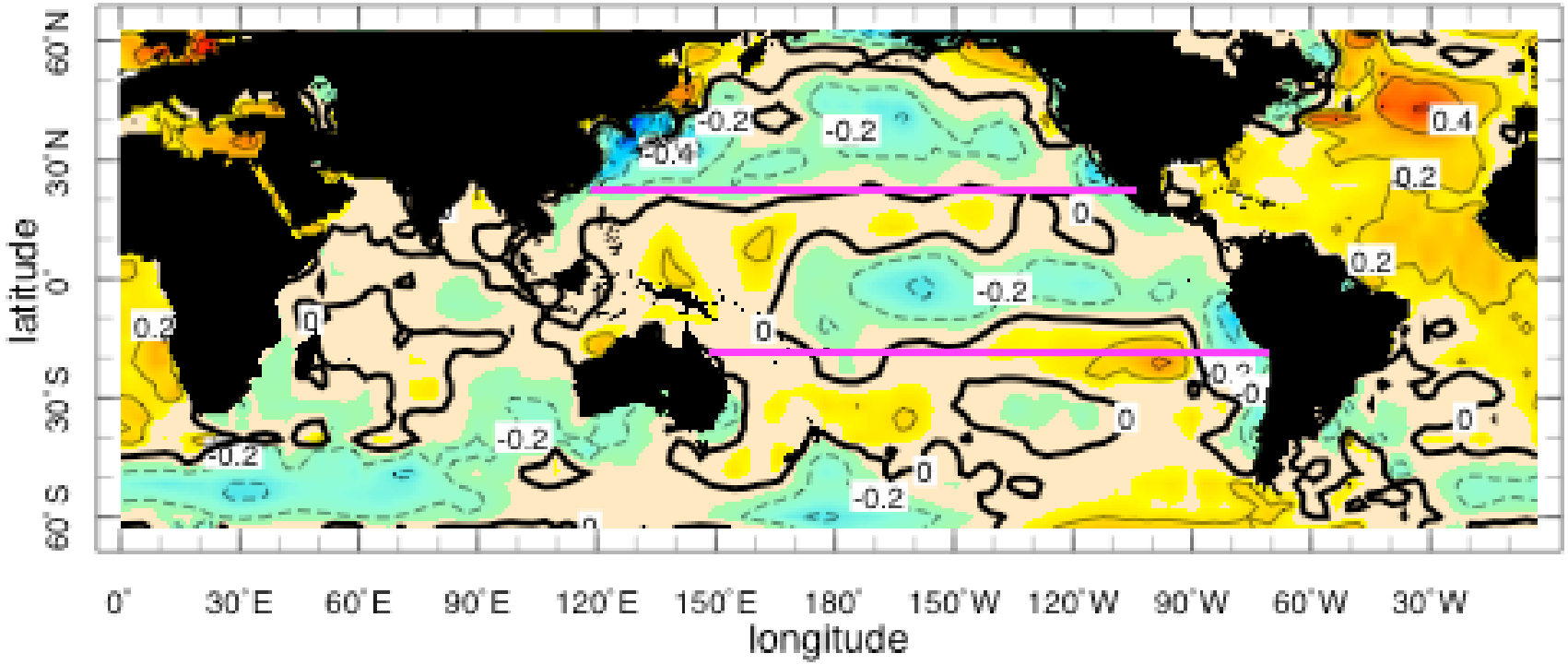
The Dust Bowl drought of the 1930s …



Was caused by …

Sea Surface Temperature Anomaly 1932-1939

OBSERVED



Contour interval = 0.2°C

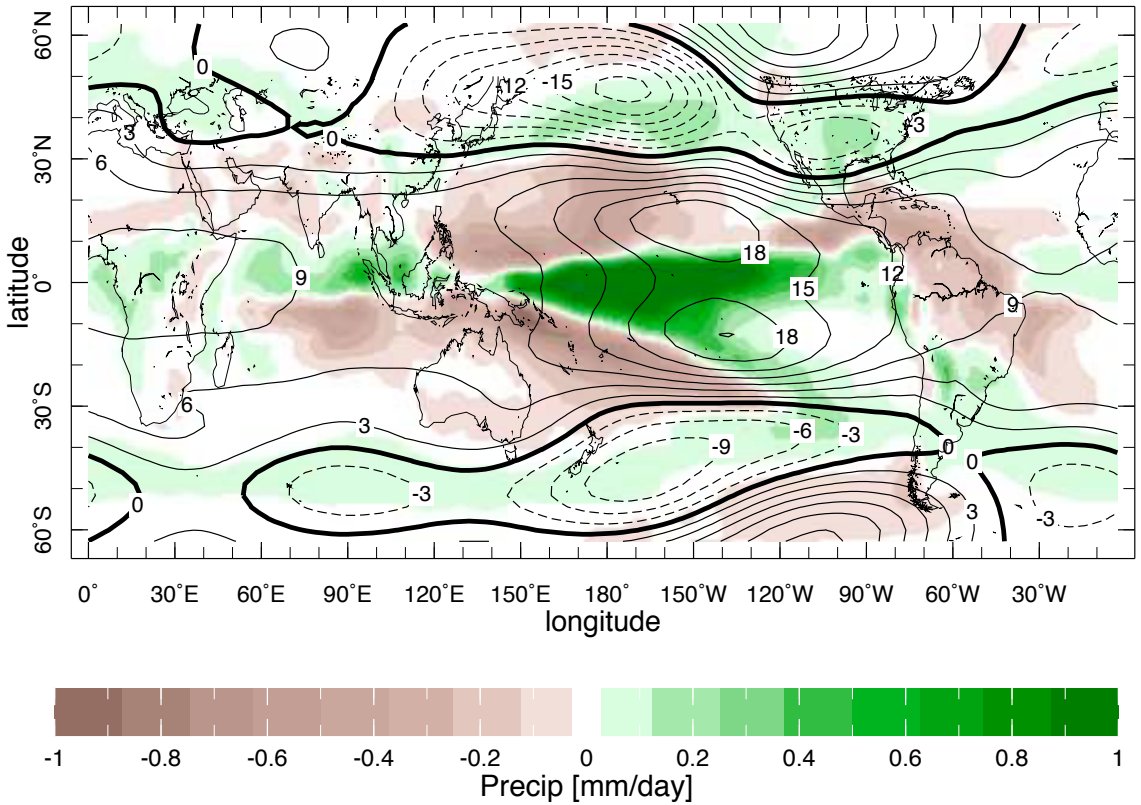
Critically, a cold, La Nina-like, tropical Pacific Ocean

Simulation of variability of precipitation over the West: 1856-2005

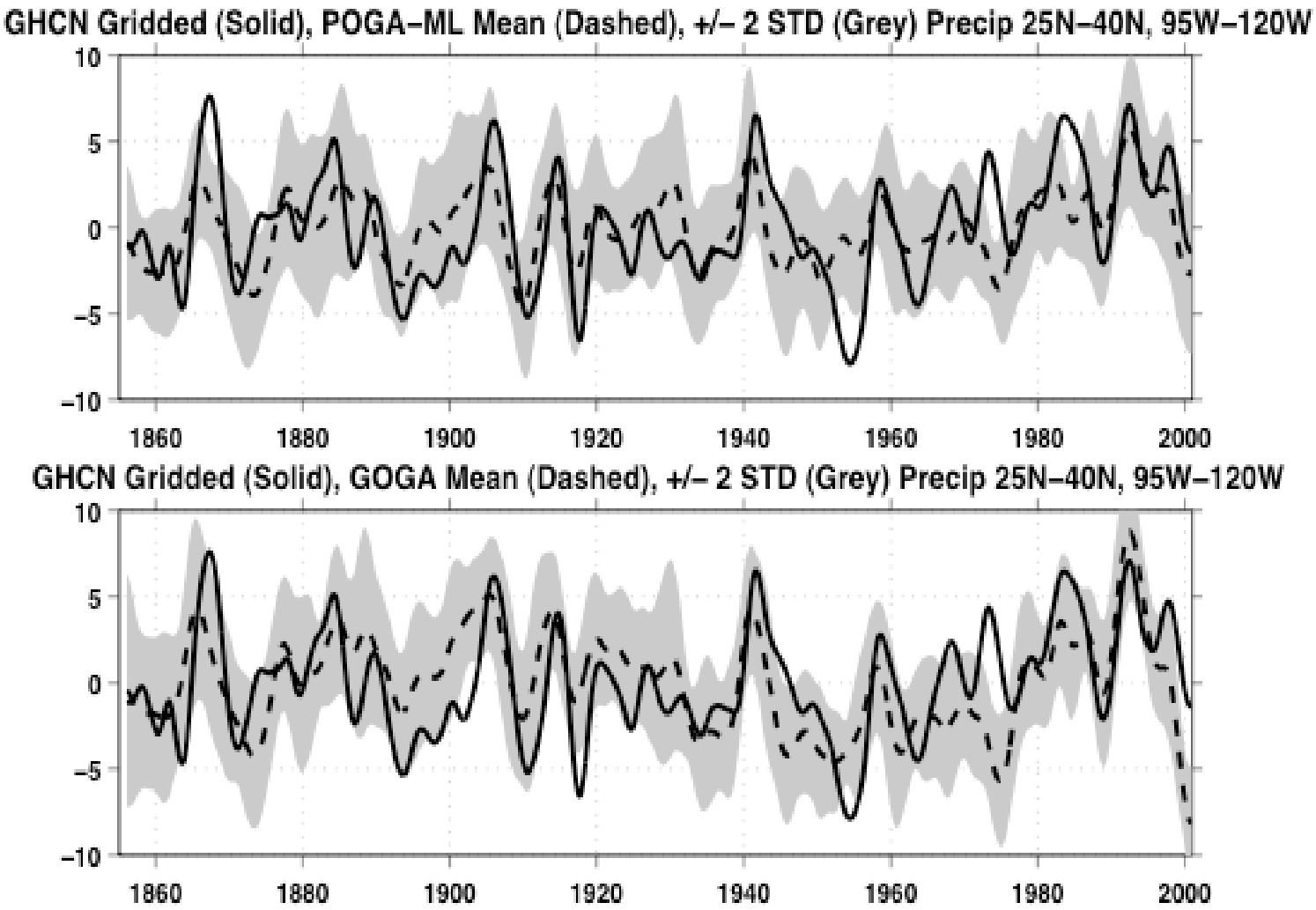
Results based on atmospheric GCM forced by:

1. *historical tropical Pacific SSTs, coupled to mixed layer ocean elsewhere (POGA-ML)*
2. *global SSTs since 1856 (GOGA)*
3. *Tropical Atlantic SSTs, climatology elsewhere (TAGA)*

200 mb Height and Precip Regression on Great Plains Precip Index 1856-2000

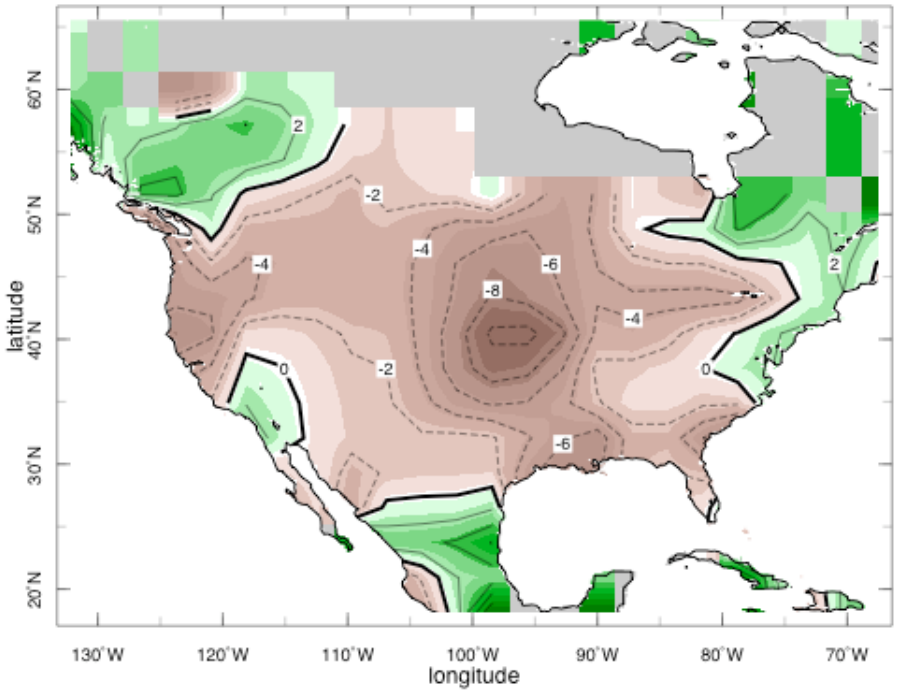


Modeled and observed Southwest precipitation:1856-2000



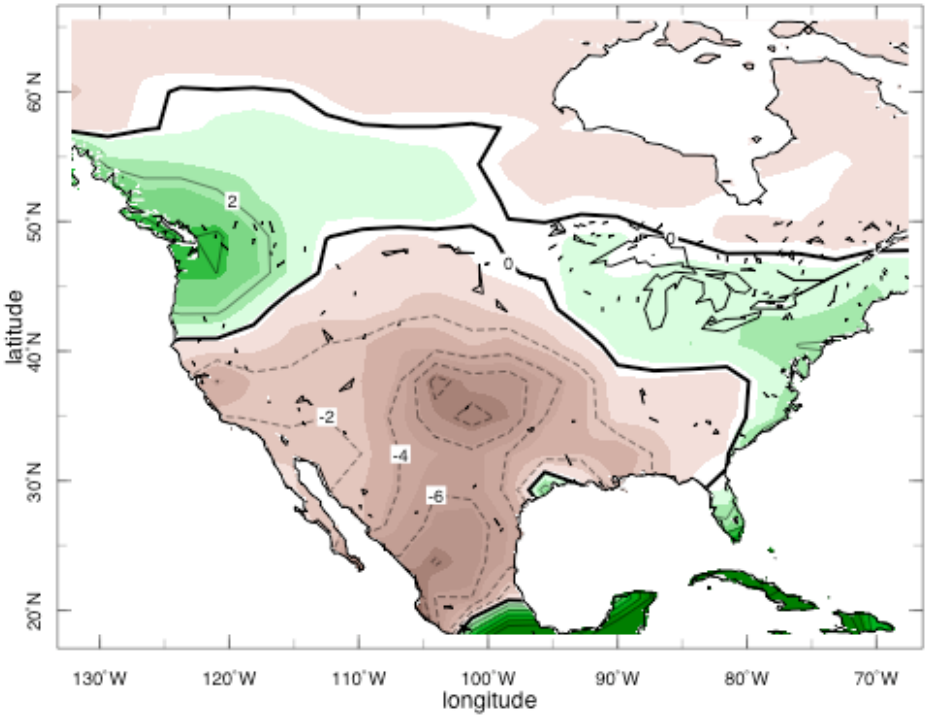
The Dust Bowl
Precipitation Anomaly 1932-1939

OBSERVED



Contour interval = 2 mm/month

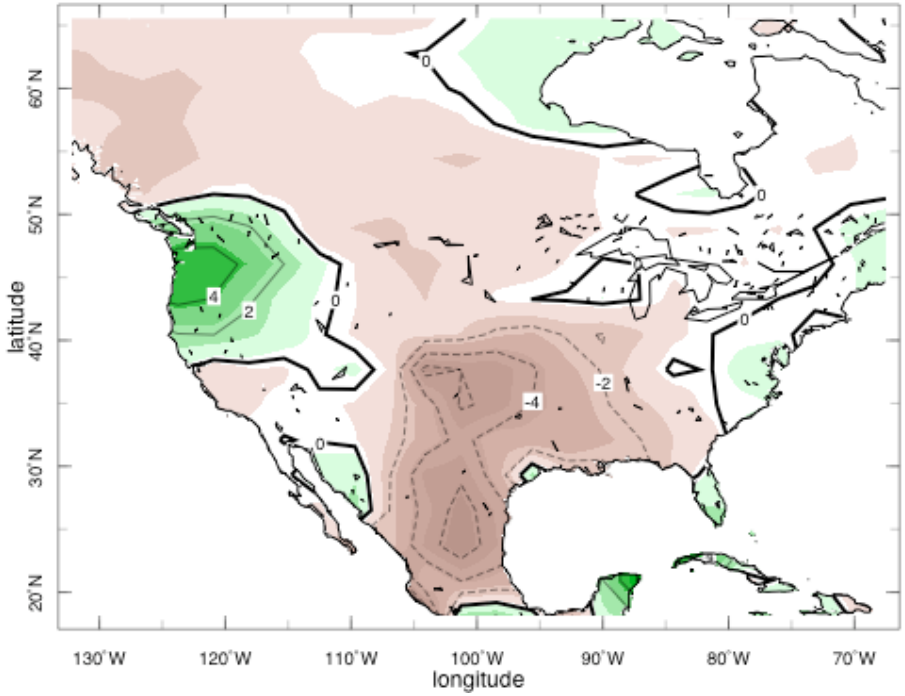
GOGA MODEL



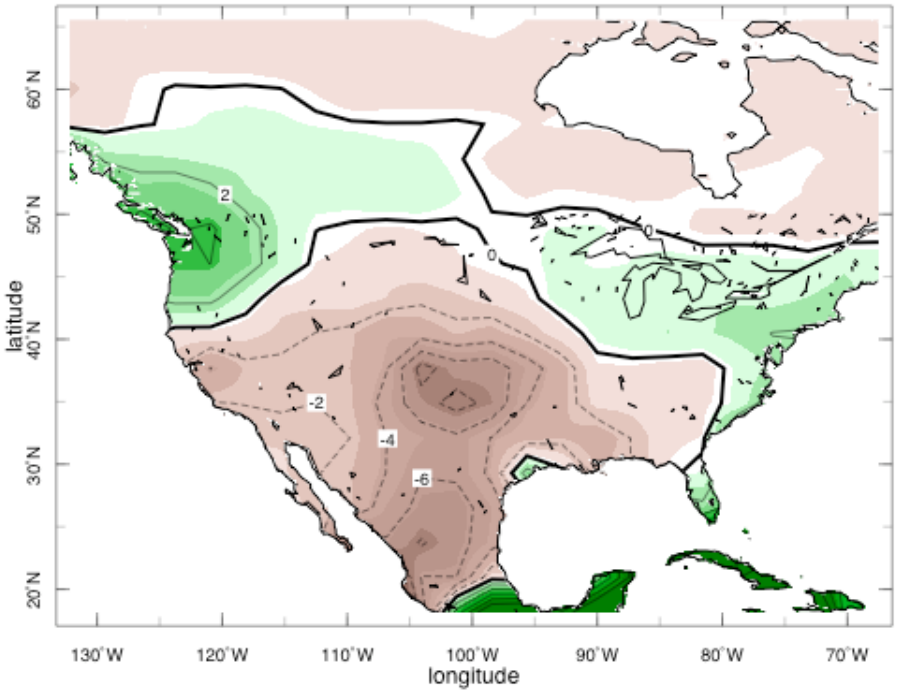
GOGA MODEL = Global Sea Surface Temperature Specified

Precipitation Anomaly 1932-1939

POGA-ML MODEL



GOGA MODEL



POGA-ML MODEL = Only Tropical Pacific Sea Surface Temperature Specified

GOGA MODEL = Global Sea Surface Temperature Specified

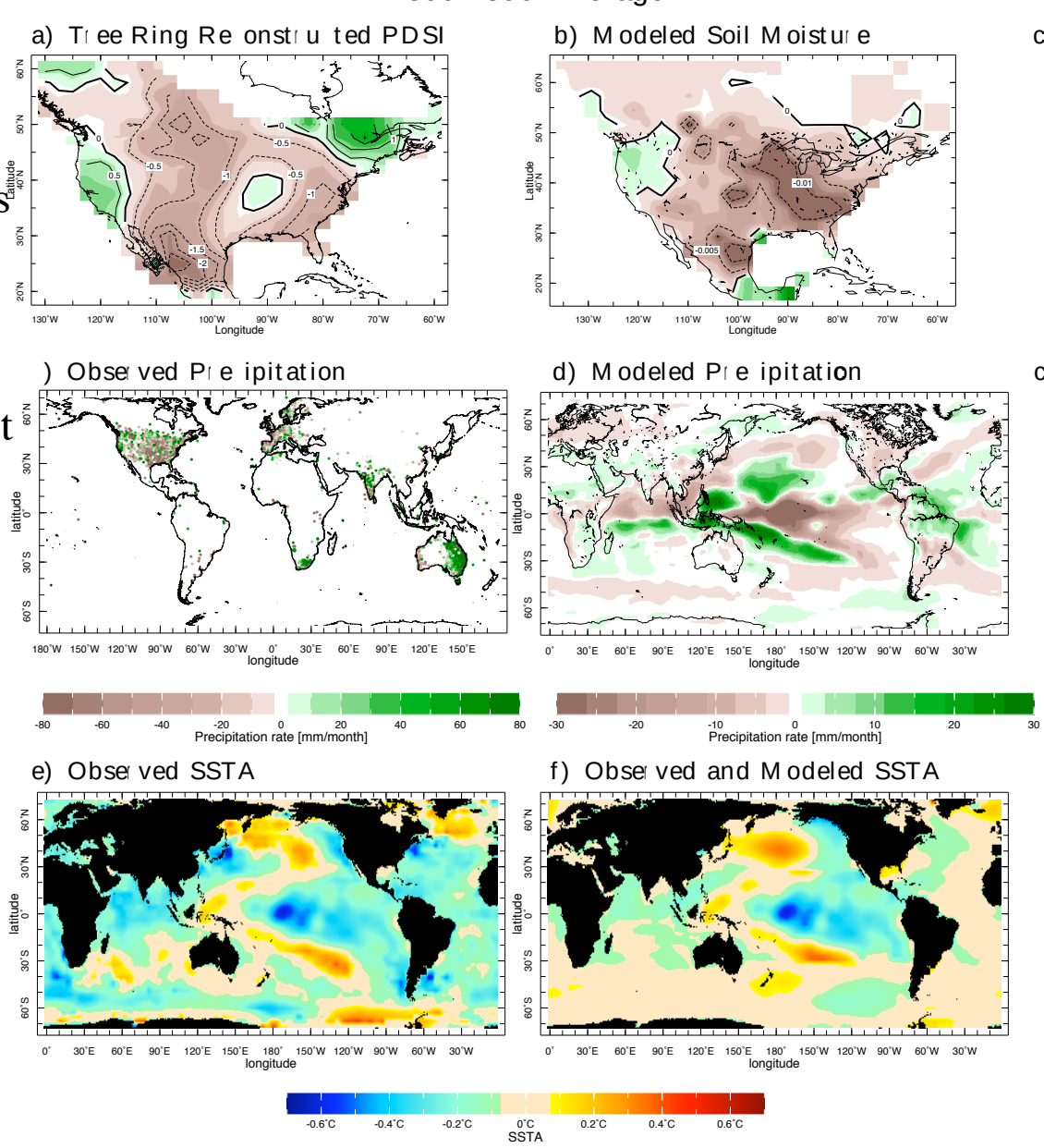
The 1890s drought -

-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)

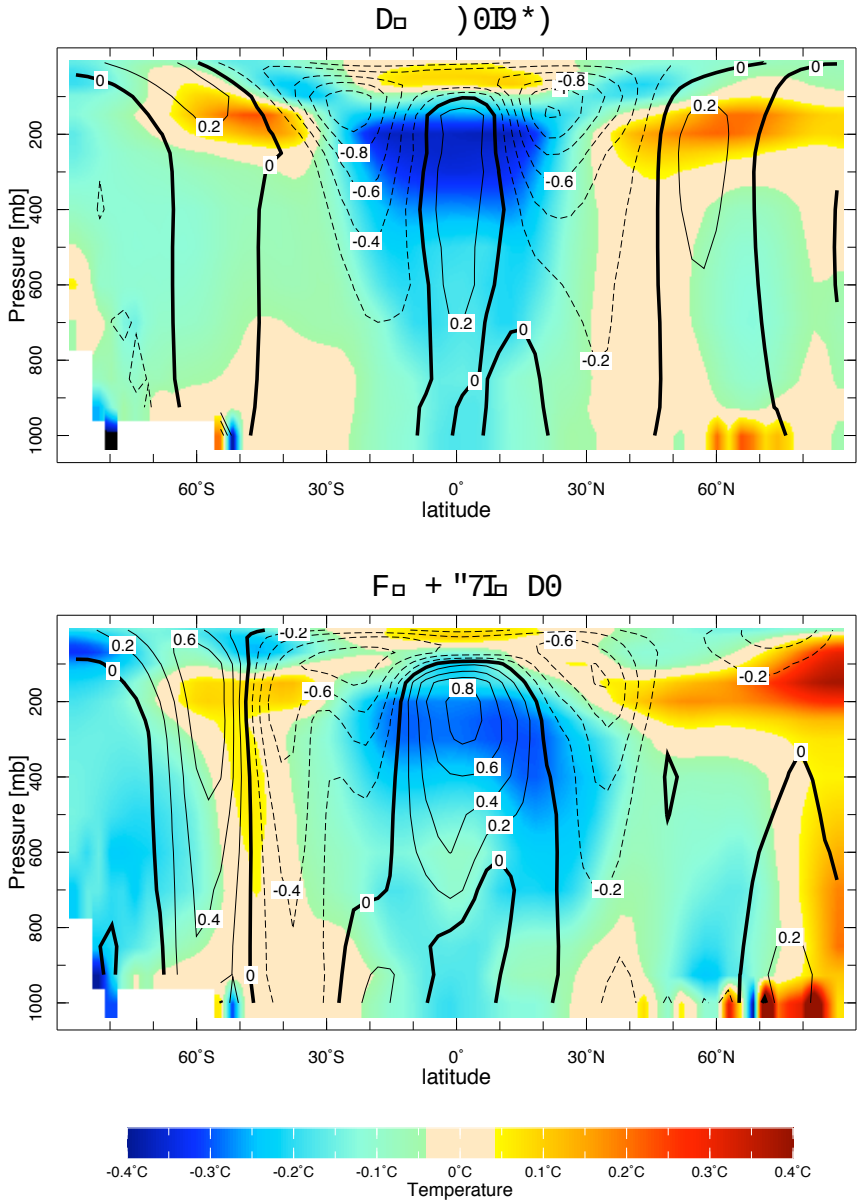
SST anomalies outside tropical Pacific created ***as a response to tropical Pacific SSTs***



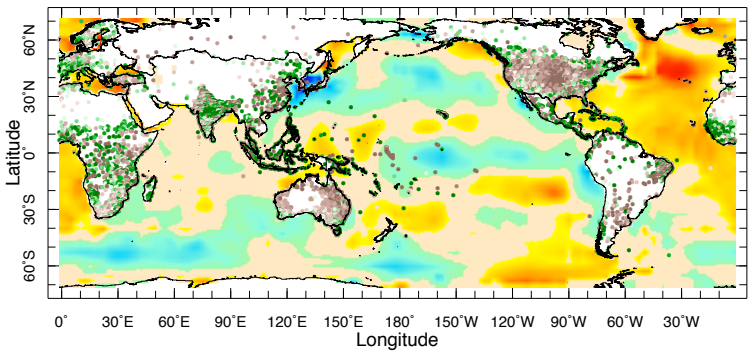
Zonal mean dynamical context of mid-latitude hydroclimate regimes

During drought regimes:

-cold tropical troposphere
-warm mid-latitudes
-poleward shifted subtropical jet stream

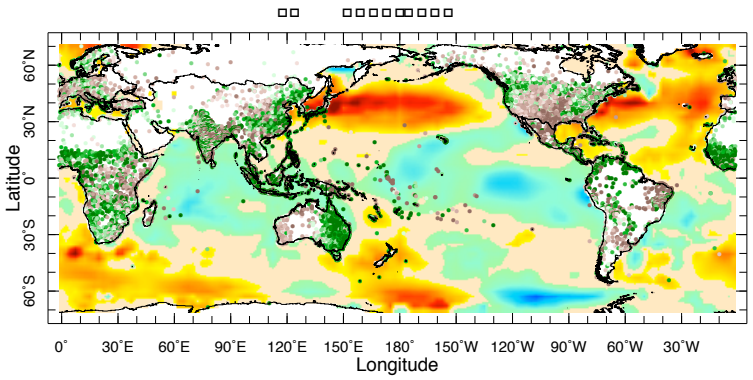


The Dust Bowl



North American droughts of the 20thC fit into a consistent global pattern …

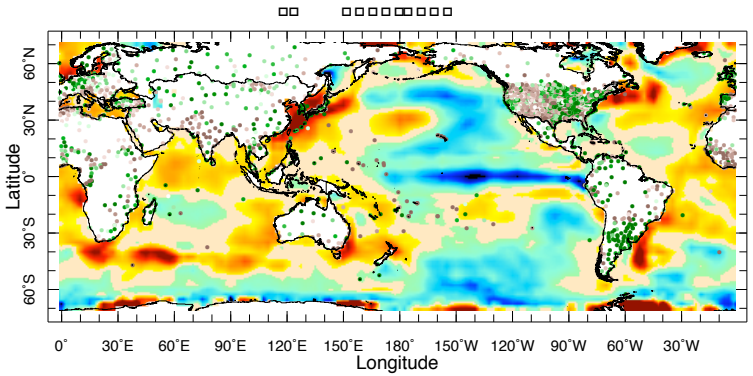
The 1950s

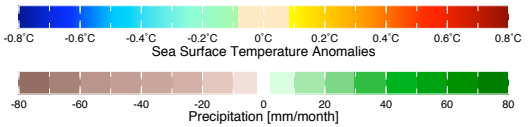


-Widespread drought in northern and southern mid-latitudes

- In the SST, the common feature is a cold equatorial Pacific - La Nina

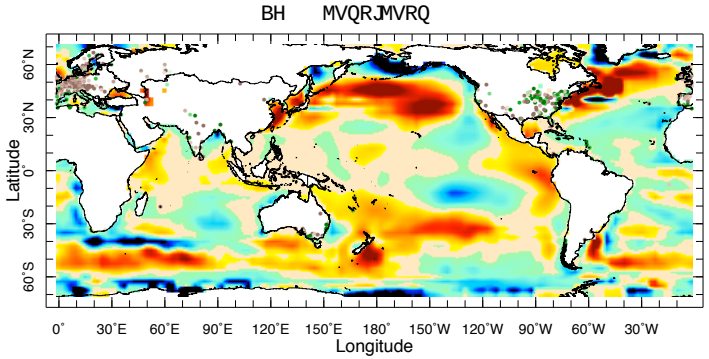
The most recent



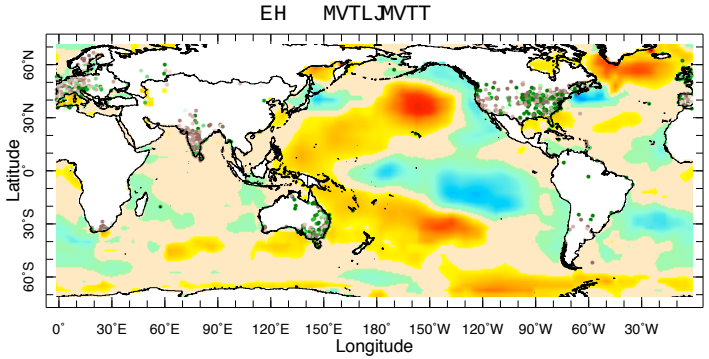


SST from ships, rain from gauges

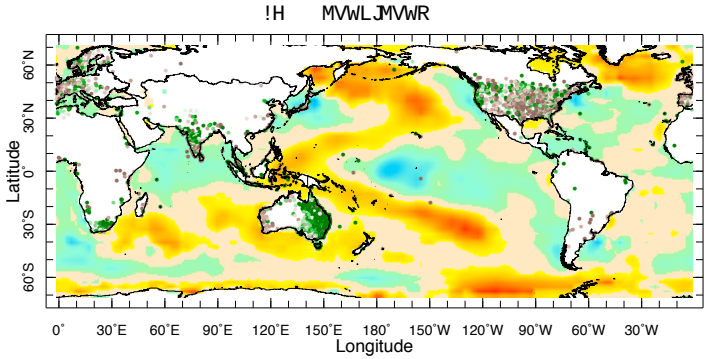
The Civil War drought

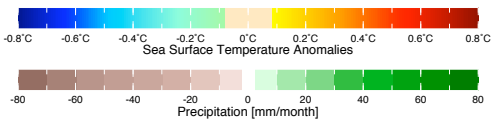


The 1870s



The 1890s



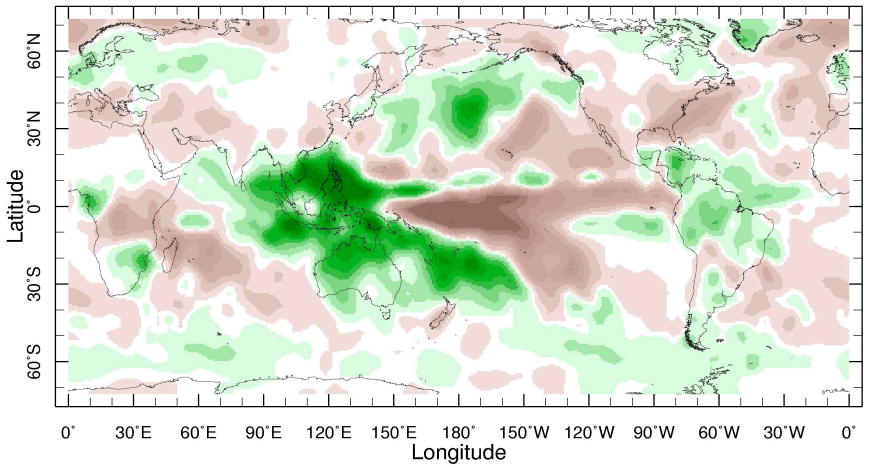


The same global hydroclimate regimes are seen in the mid to late 19thC North American droughts

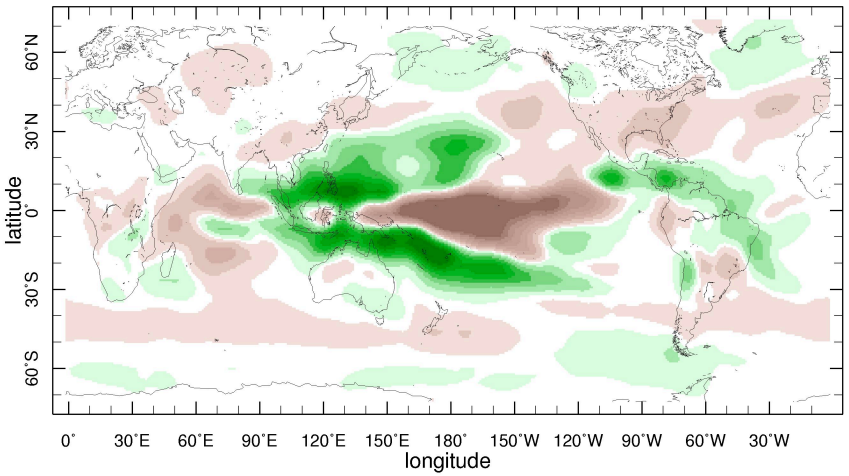
SST from ships (1856 on), rain from gauges (few in 19thC)

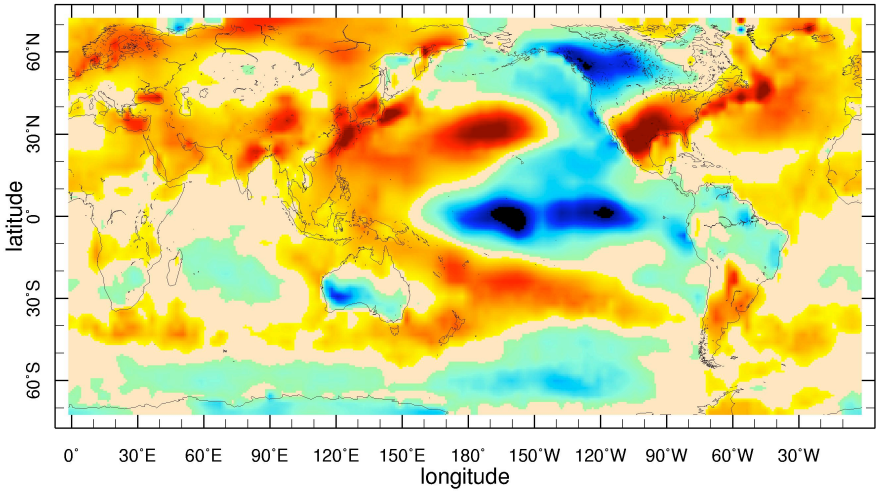
TEXAS SAND STORM Feb. 20th. 1894.

Observed precipitation



Modeled precipitation, tropical Pacific SST forcing only





Observed (ocean) and modeled (land) surface temperature anomaly

The 1998-2002 years of the 'turn of the century' drought

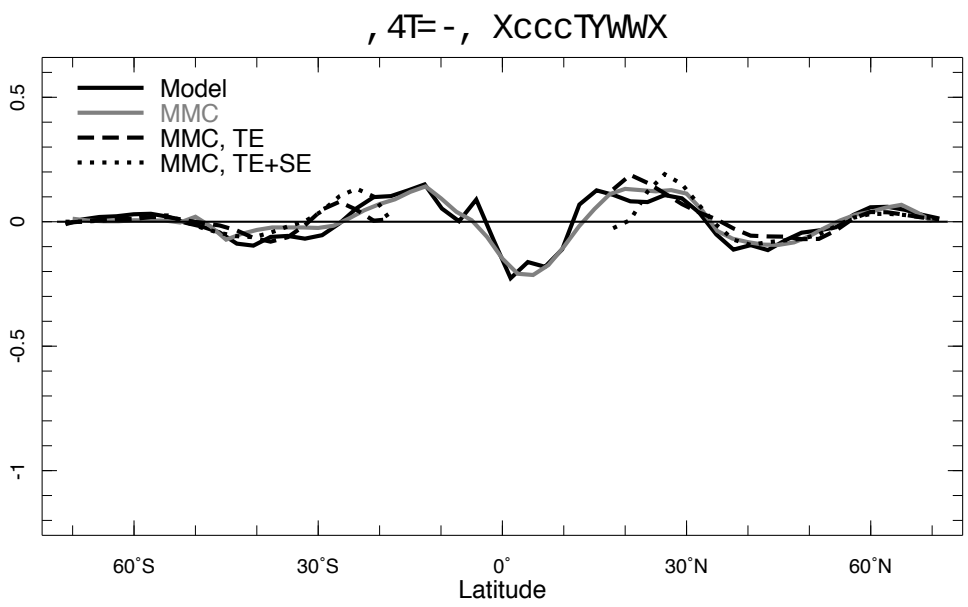
- a classic case of forcing by a persistent La Nina

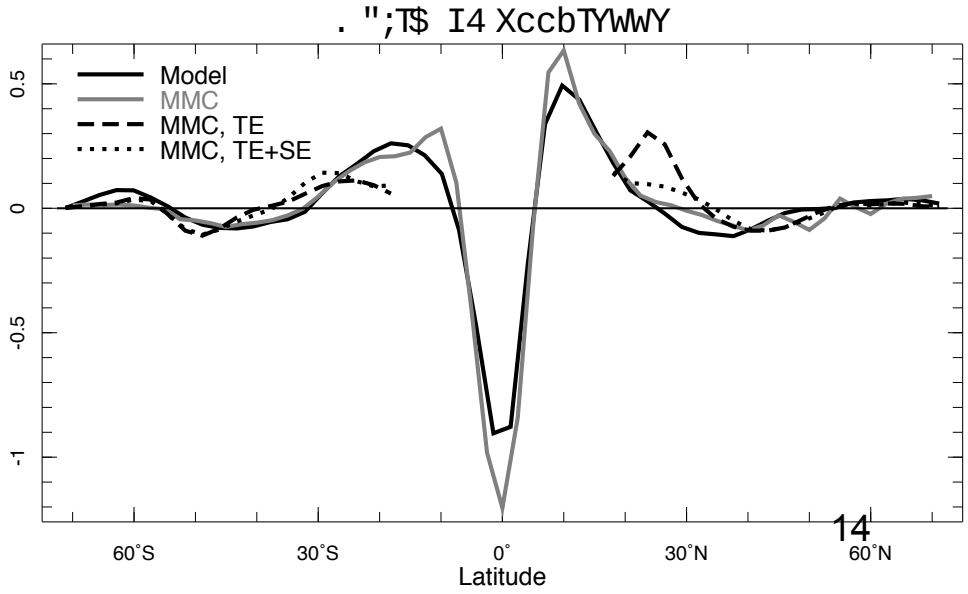
... but 2002-2004 was different

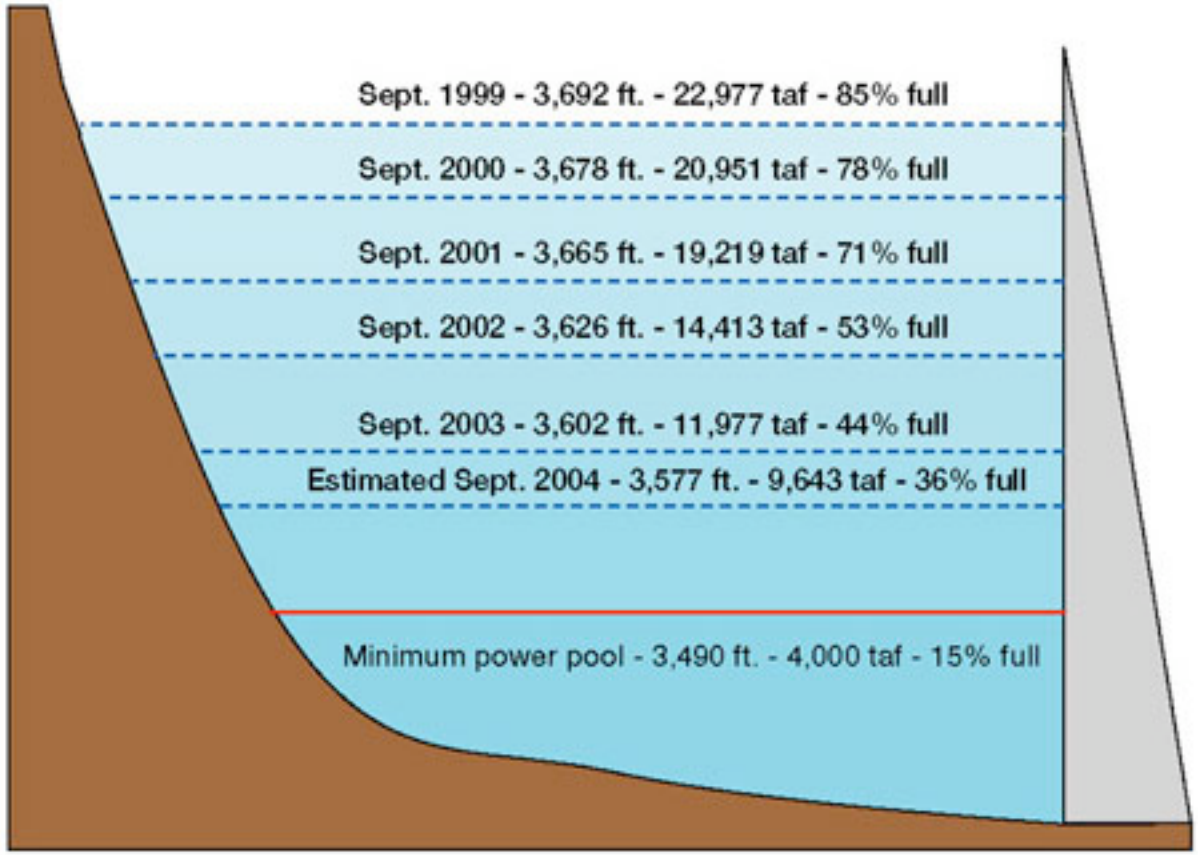
Zonal mean P-E (mm/day) in turn-of-century drought

- accounted for by MMC

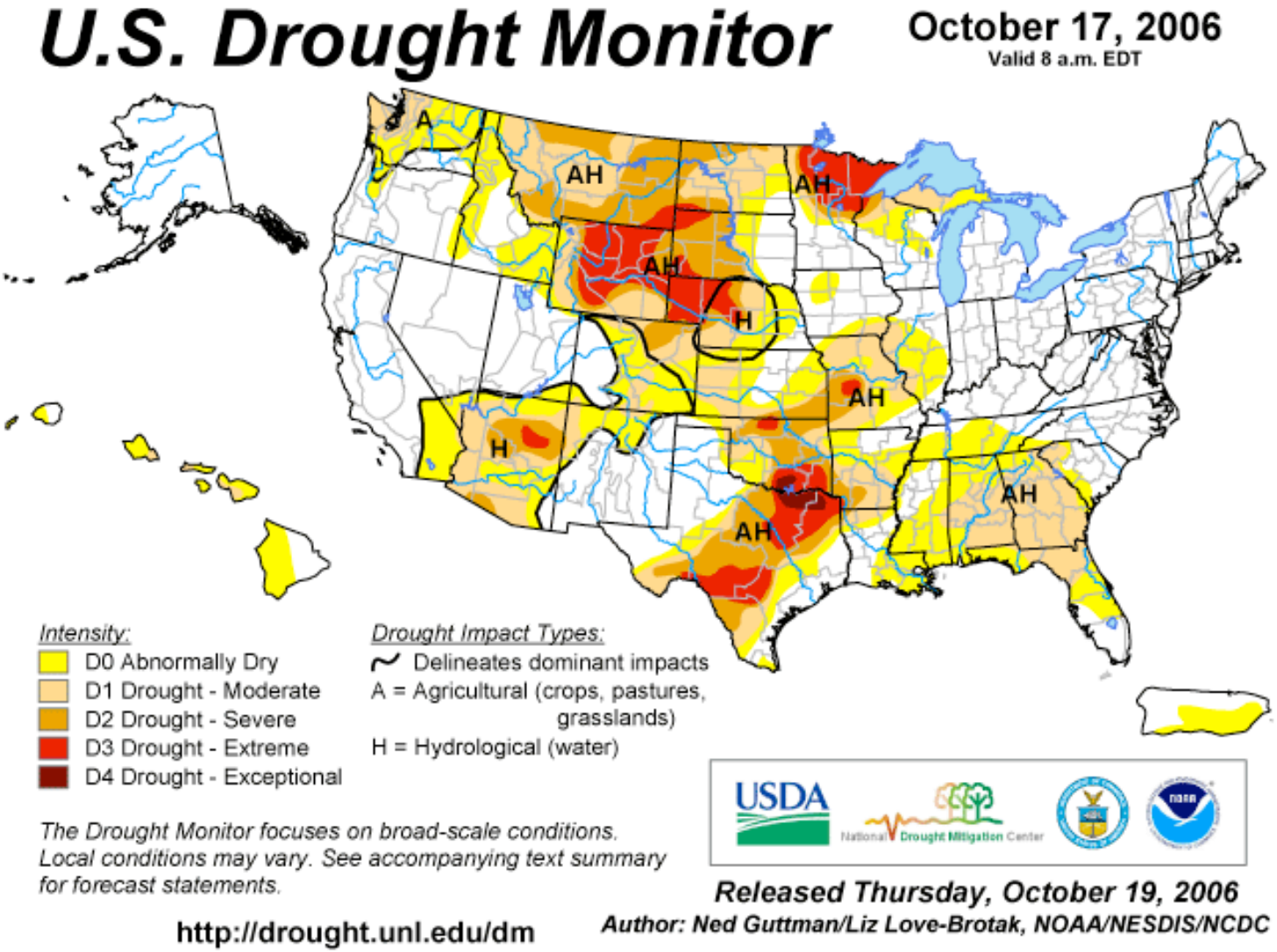
- transient eddy-driven MMC does the most



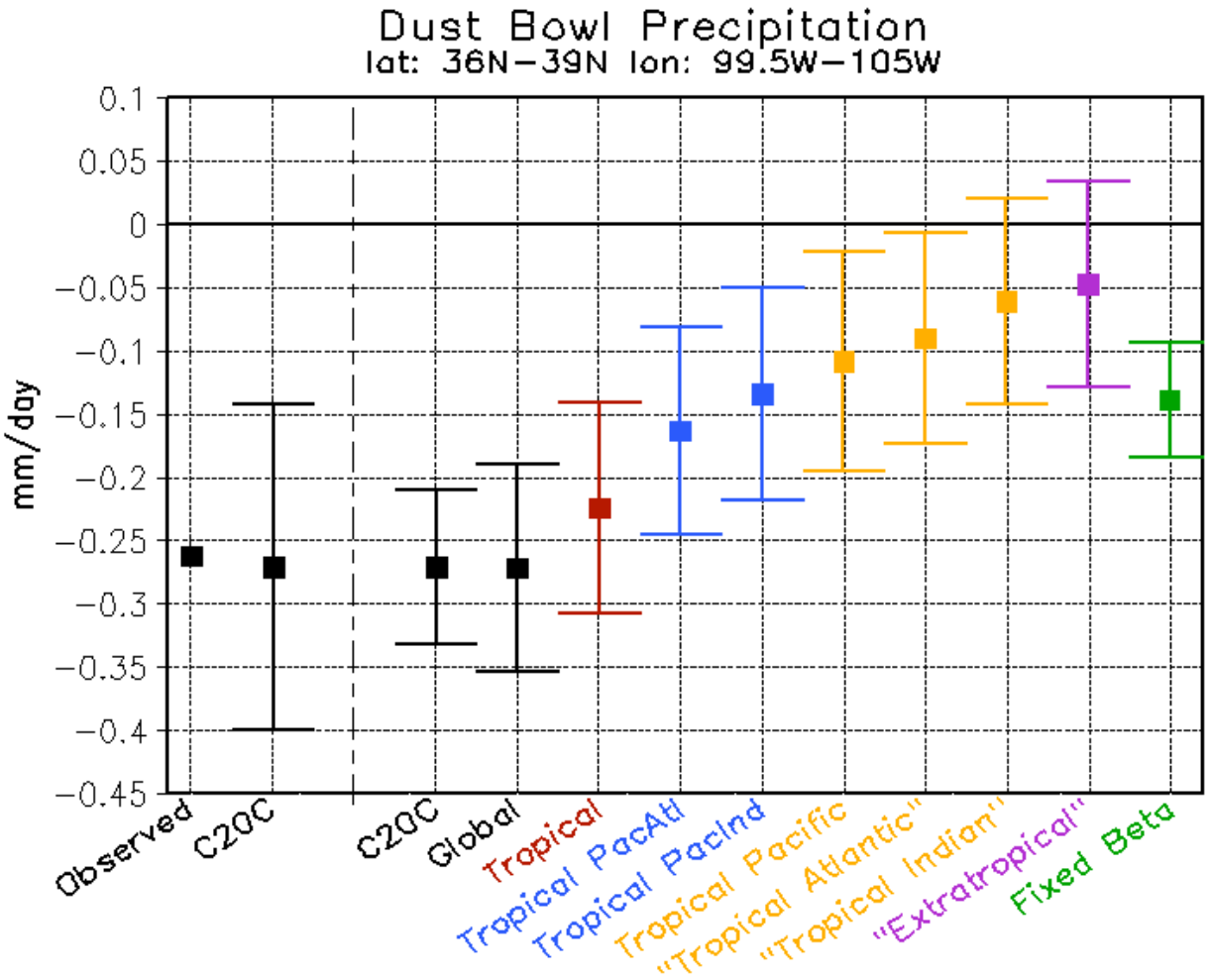



Sept. 1999 - 3,692 ft. - 22,977 taf - 85% full
Sept. 2000 - 3,678 ft. - 20,951 taf - 78% full
Sept. 2001 - 3,665 ft. - 19,219 taf - 71% full
Sept. 2002 - 3,626 ft. - 14,413 taf - 53% full
Sept. 2003 - 3,602 ft. - 11,977 taf - 44% full
Estimated Sept. 2004 - 3,577 ft. - 9,643 taf - 36% full
Minimum power pool - 3,490 ft. - 4,000 taf - 15% full

Current conditions show drought continuing, despite on again-off again El Nino-La Nina conditions ...



But what about the Atlantic?



Schubert et al. (2004)

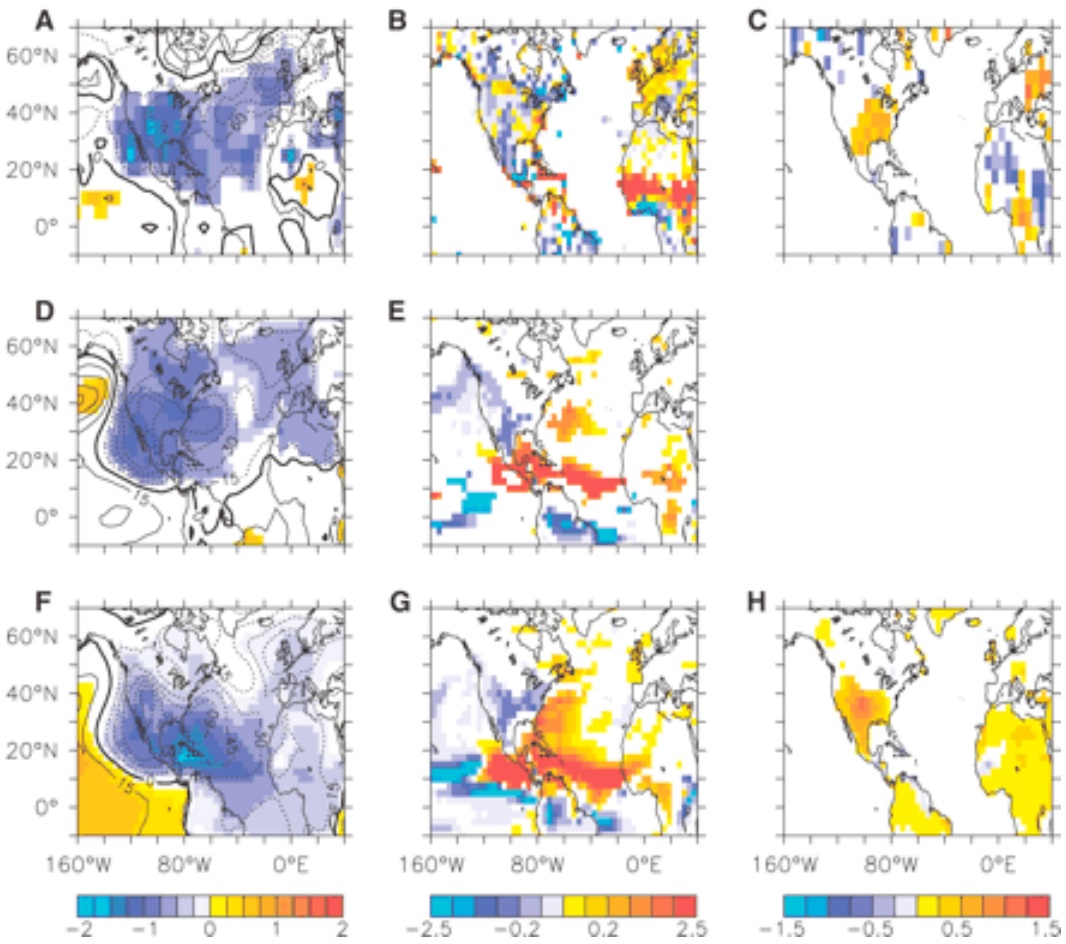
JJA (1930-1960) - (1960-1990)

SLP | Precip | air T

Obs

HadAM3, forced by obs SST

HadAM3 forced by AMO SST



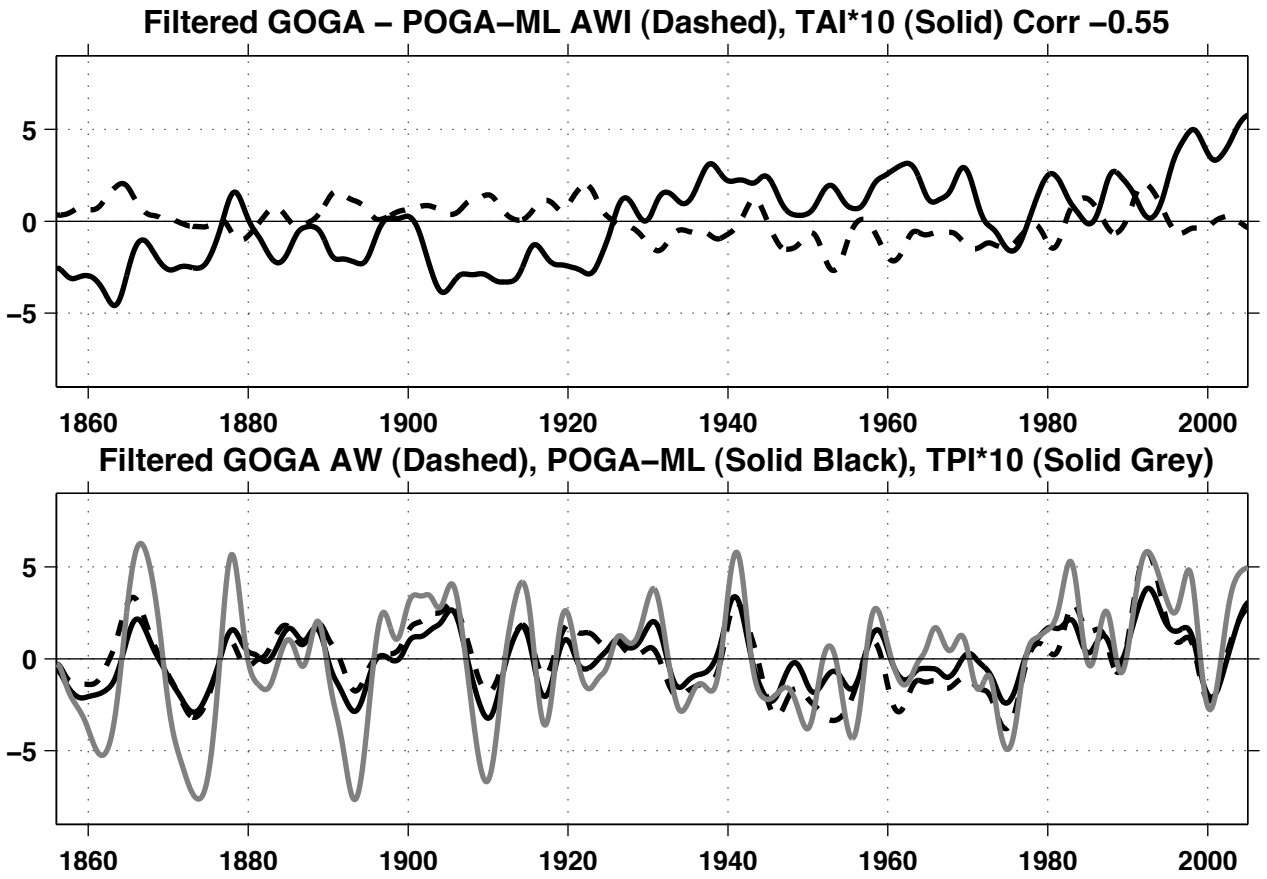
Sutton and Hodson (2005)

Is there a role for SSTs outside of the tropical Pacific?

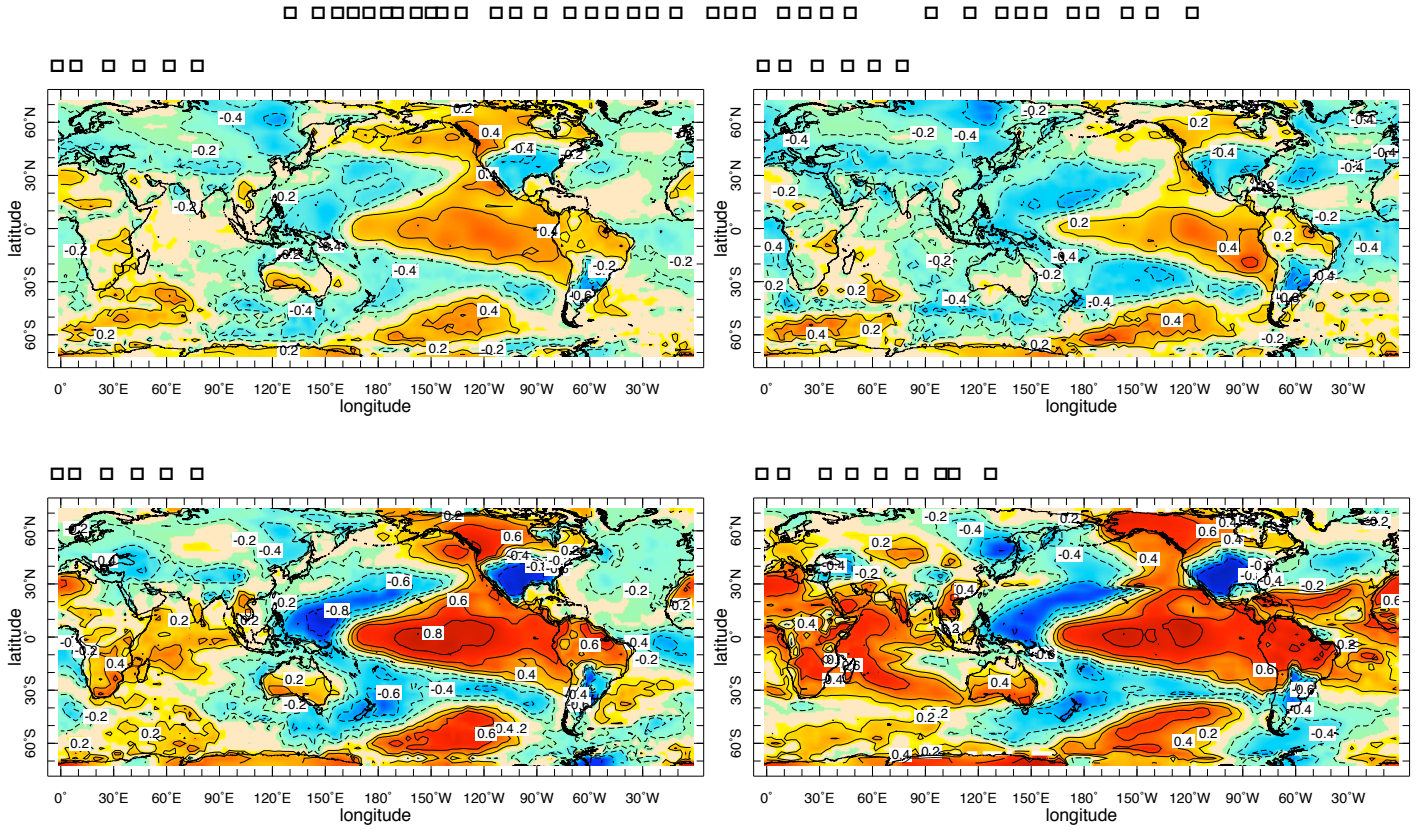
Difference in precip over the West between global and TP SST forcing ..

.. explained by TA SST forcing but …

… NA precip closely follows TP SSTS



So, yes, but secondary

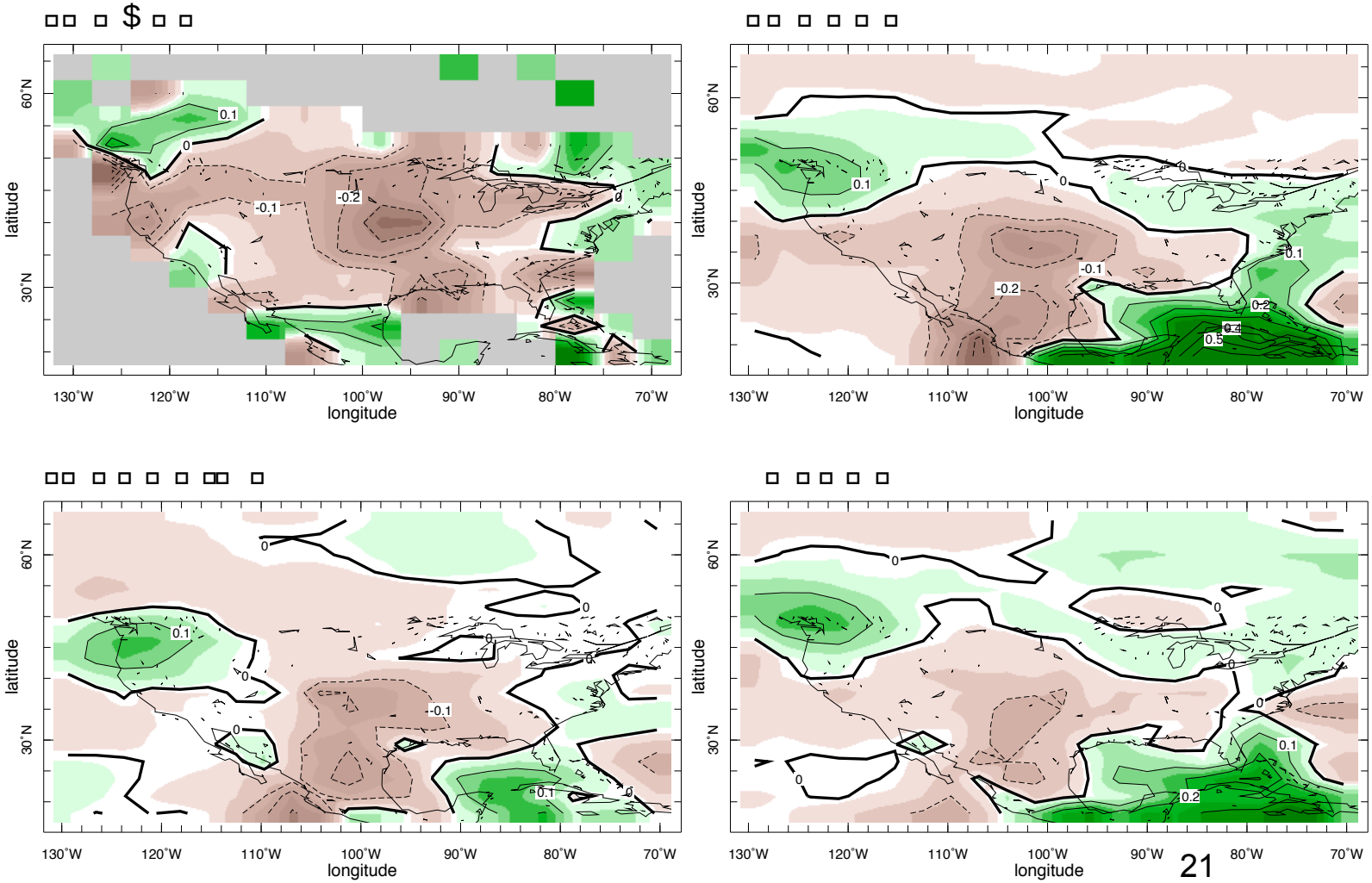


So, cold tropical Pacific and warm N Atlantic ideal for drought

(a configuration the POGA-ML ensemble-mean cannot create)

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

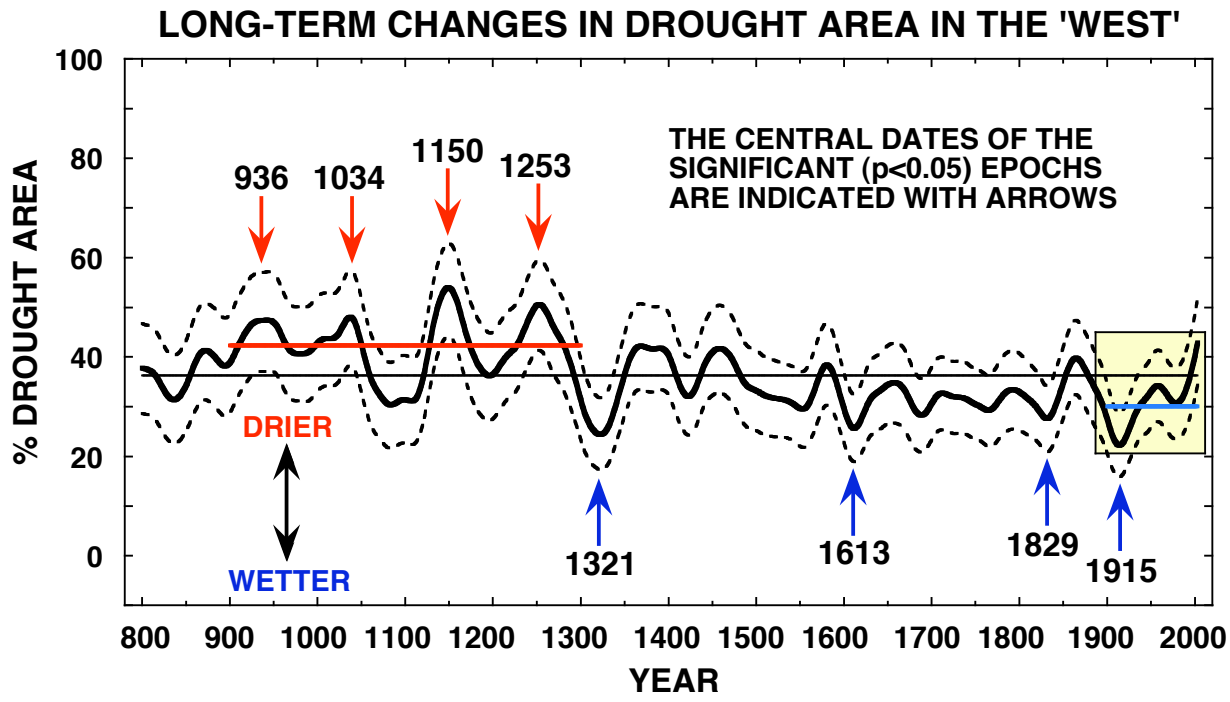
□ □ □□ #□#□□□ □□□□□□□□□



Turning to the trees …..

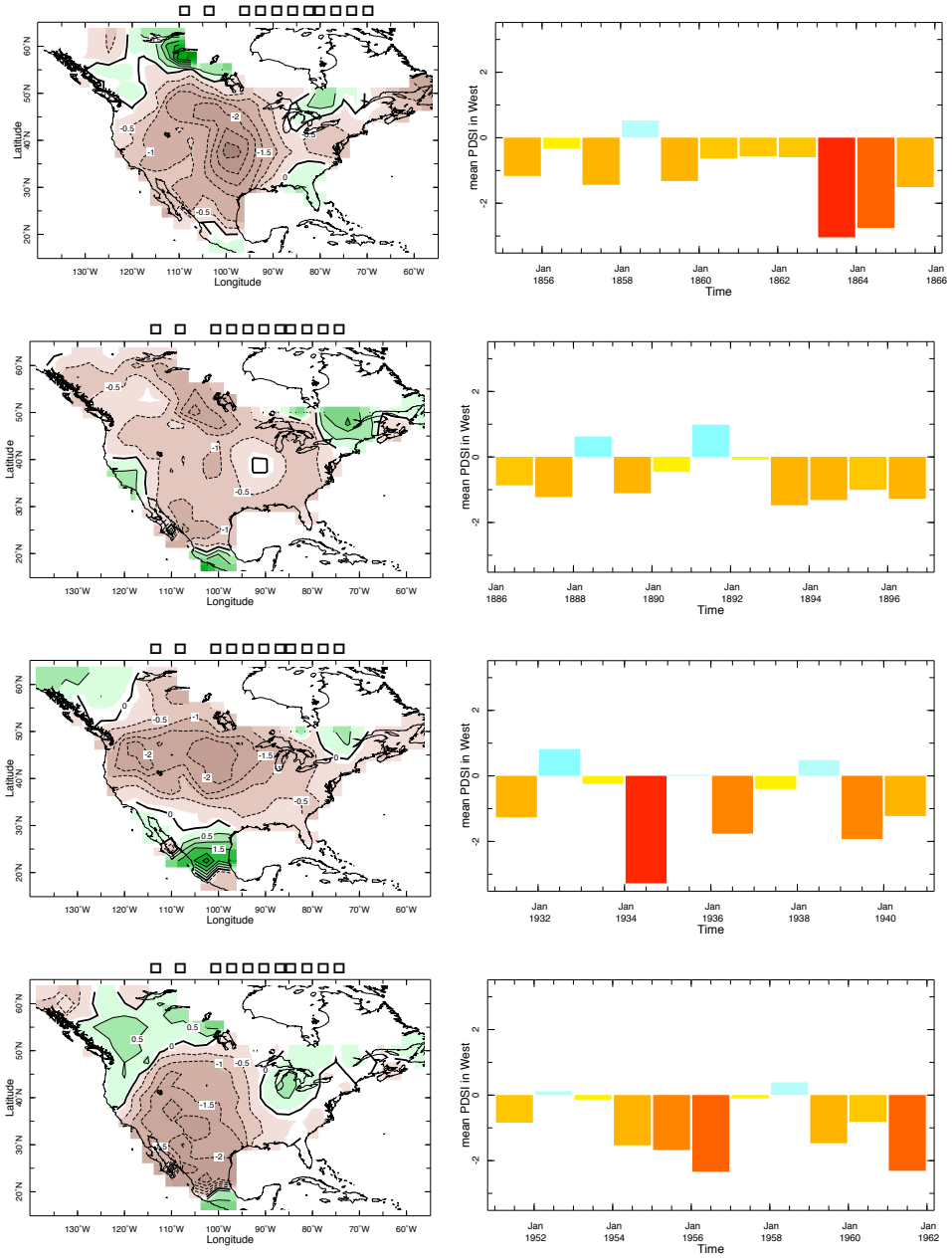
…a millennial perspective on North American drought

(the past is scary)



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

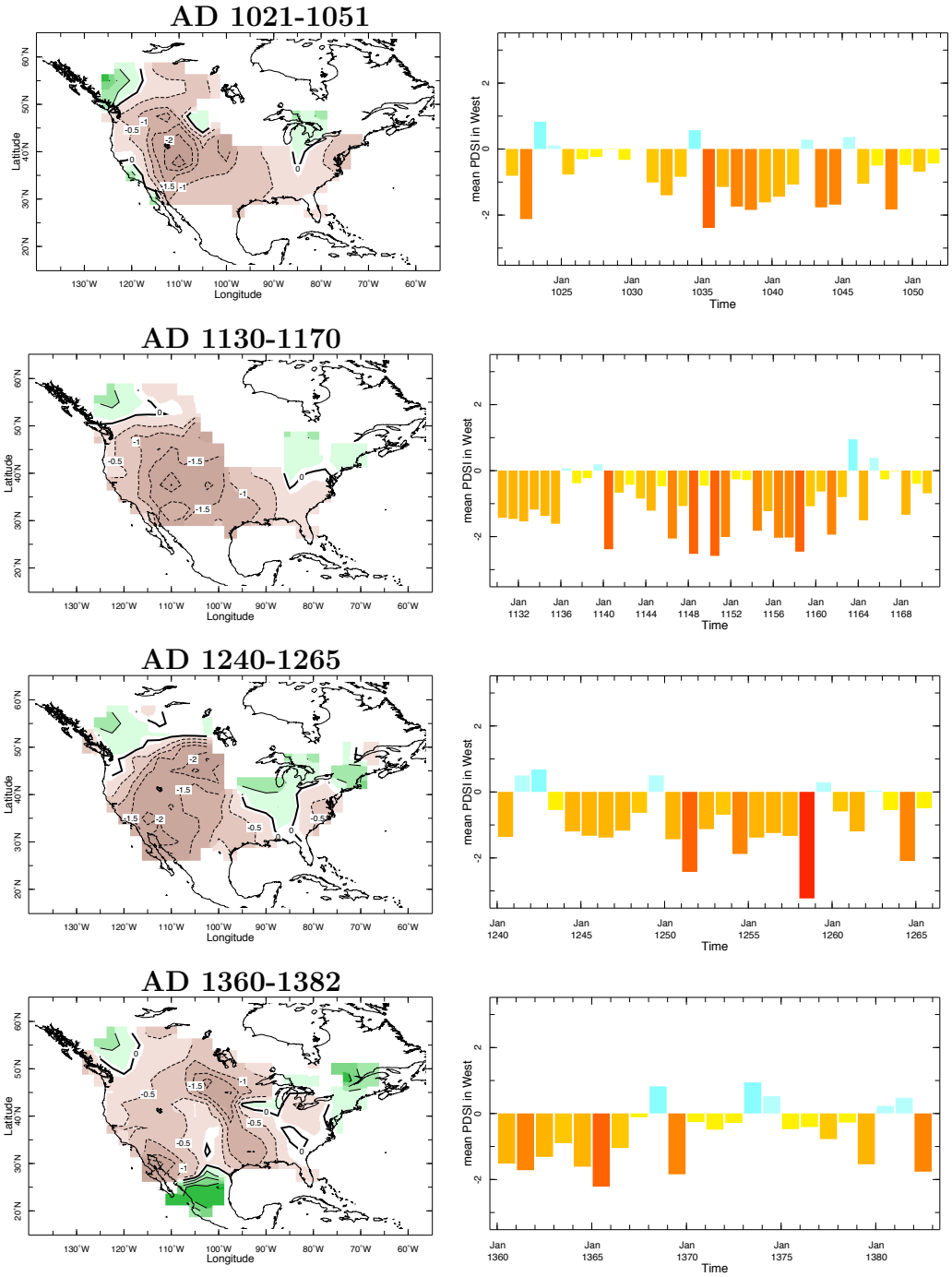

Stumps of trees killed by rising waters
after end of medieval megadroughts



Tree ring records of modern droughts

LHS = spatial distribution

RHS = PDSI history over the ‘West’



Droughts of Medieval Times

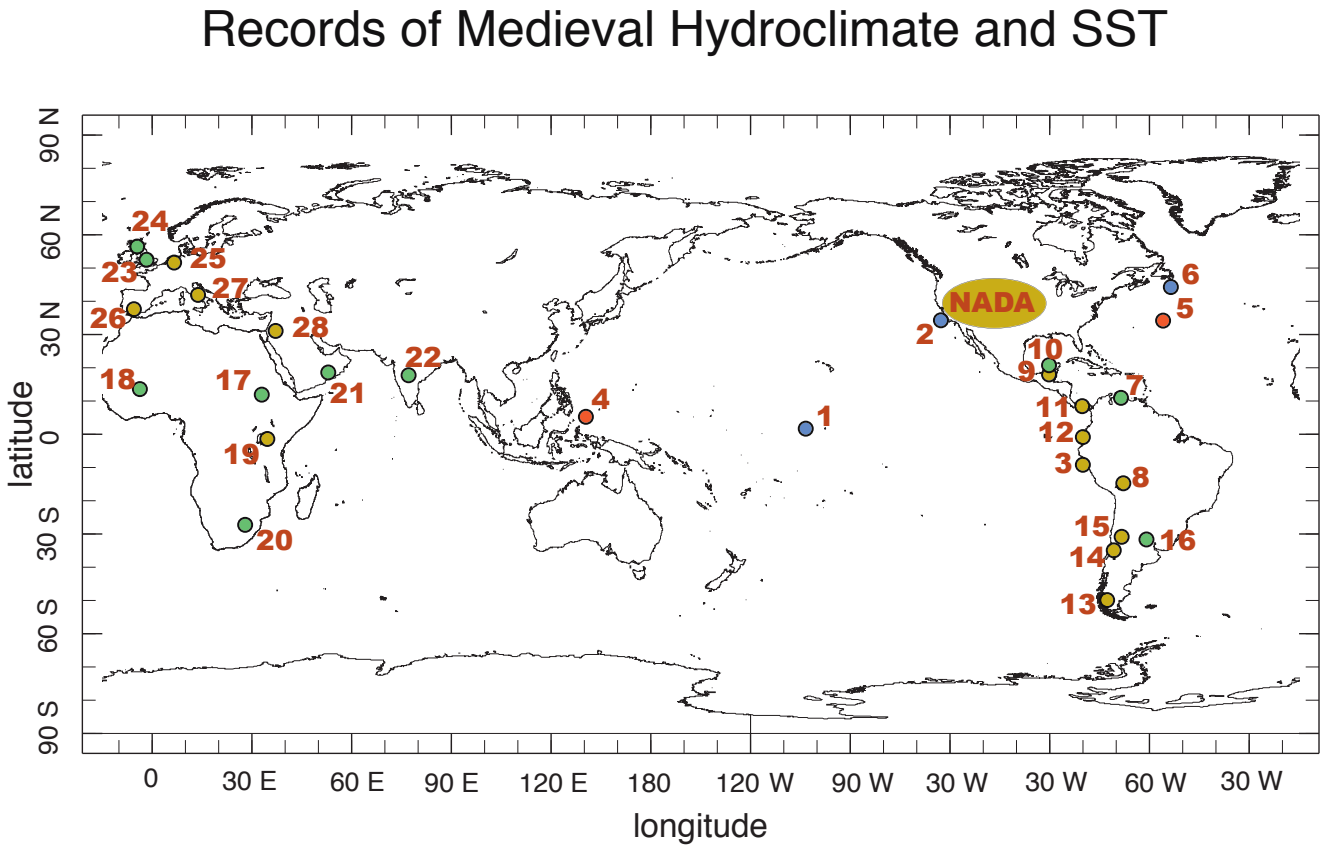
Similar spatial pattern of drought to modern-day: widespread with drought centers in the continental interior, either in the SW and Rockies, or in the Plains, or both.

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

I.E. MEDIEVAL 'MEGA-DROUGHTS'

Did permanent La Nina cause the medieval megadroughts?

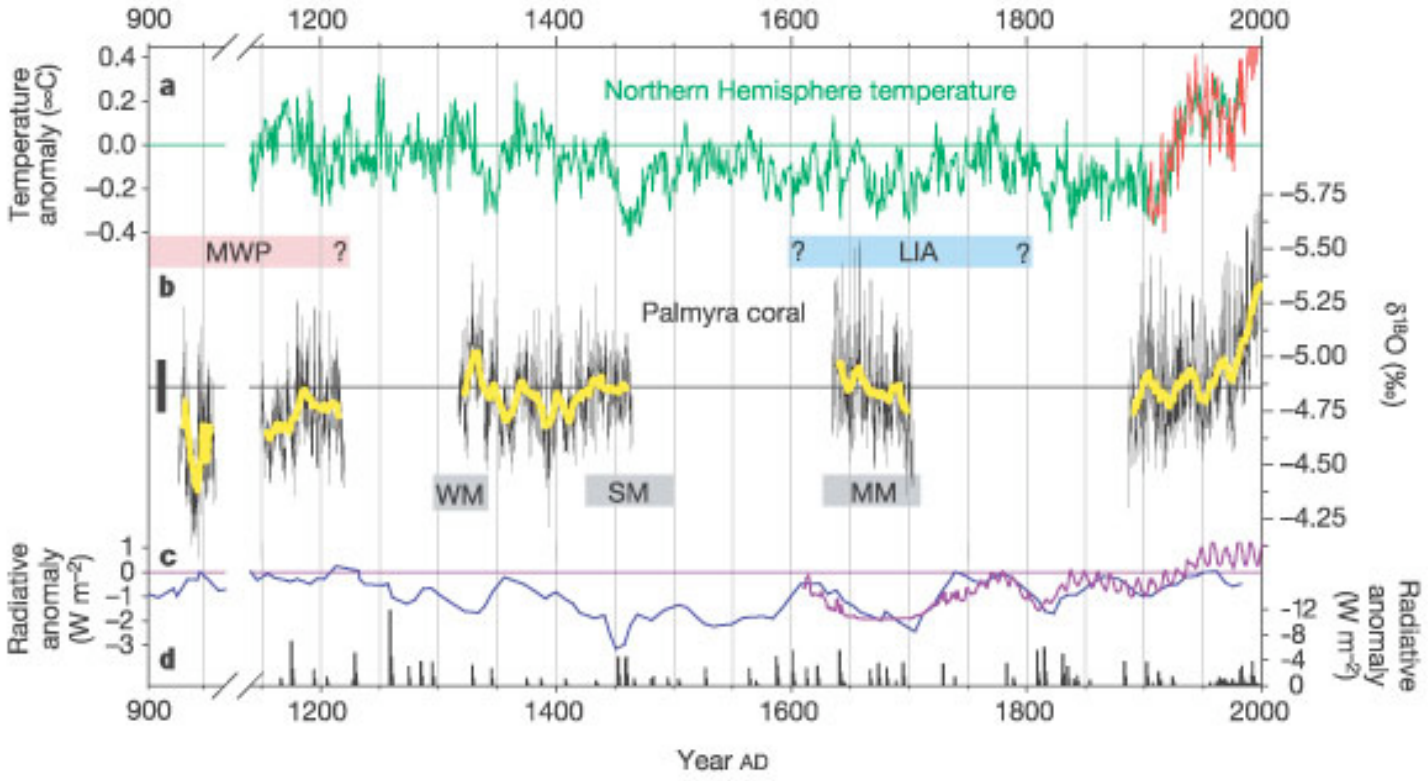
- pattern suggests, yes, but with +ve AMO (stronger THC) also contributing



warm SST- red *Dry - brown*

cold SST - blue *Wet - green*

Coral support for Medieval La Nina ....



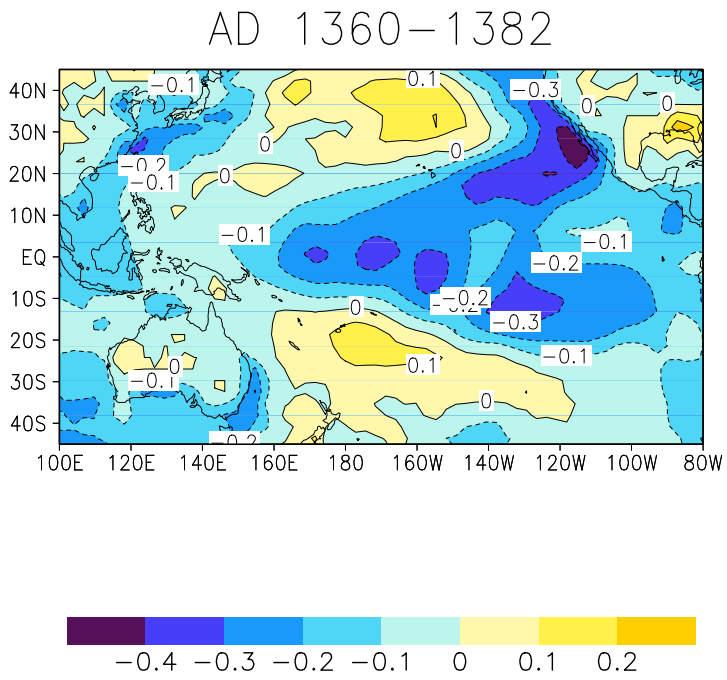
single Pacific, medieval, fossil coral suggests more La Nina-like than during subsequent LIA.

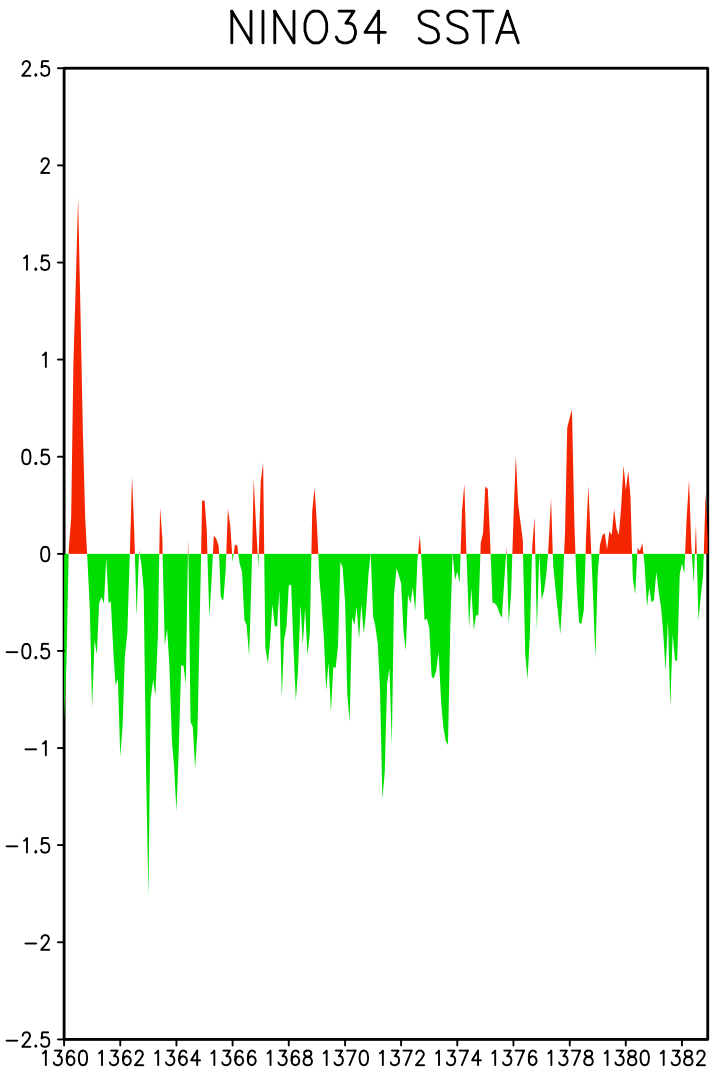
20th C, however, a problem (coral may be recording something else than ENSO.)

Cobb et al., Nature, 2003

SSTA reconstructed from coral $\partial^{18}O$ for a 14th Century megadrought

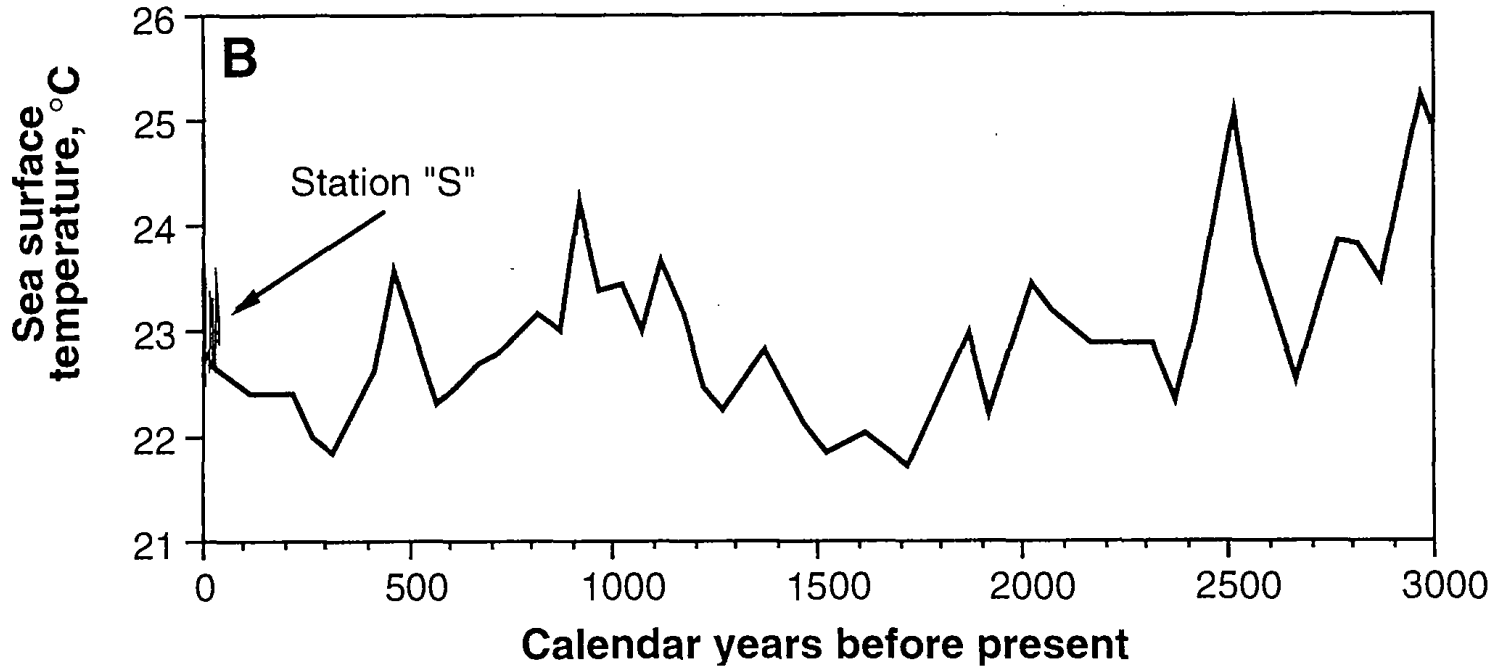
now being used to force a climate model ensemble 1319 - 1461 A.D.





Burgman and Clement (ARCHES co-PI, RSMAS) with Seager (LDEO), and thanks to Kim Cobb (Georgia Tech)

... and oxygen isotope evidence for a warm Medieval subtropical North Atlantic Ocean



Keigwin (1996)

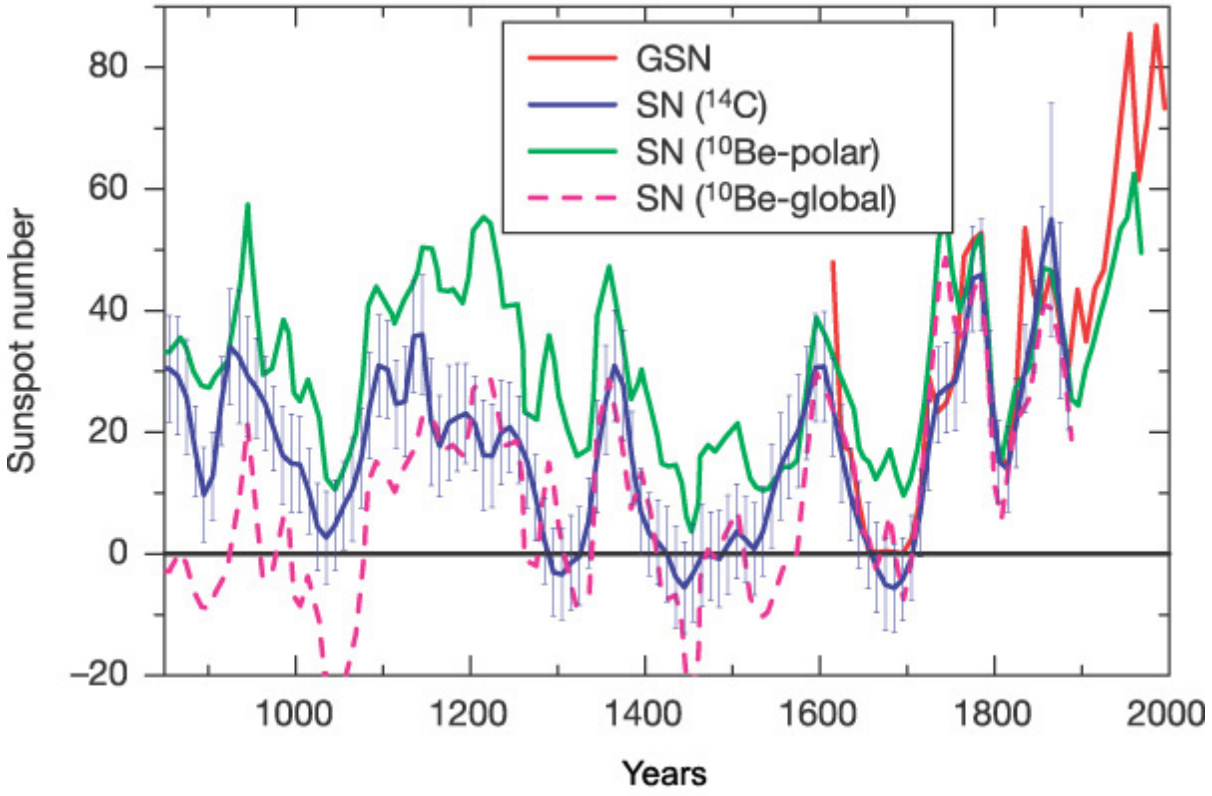
What caused the permanent Medieval La Nina?

Two possible contributors:

- increased solar irradiance
- decreased volcanism → increased surface solar

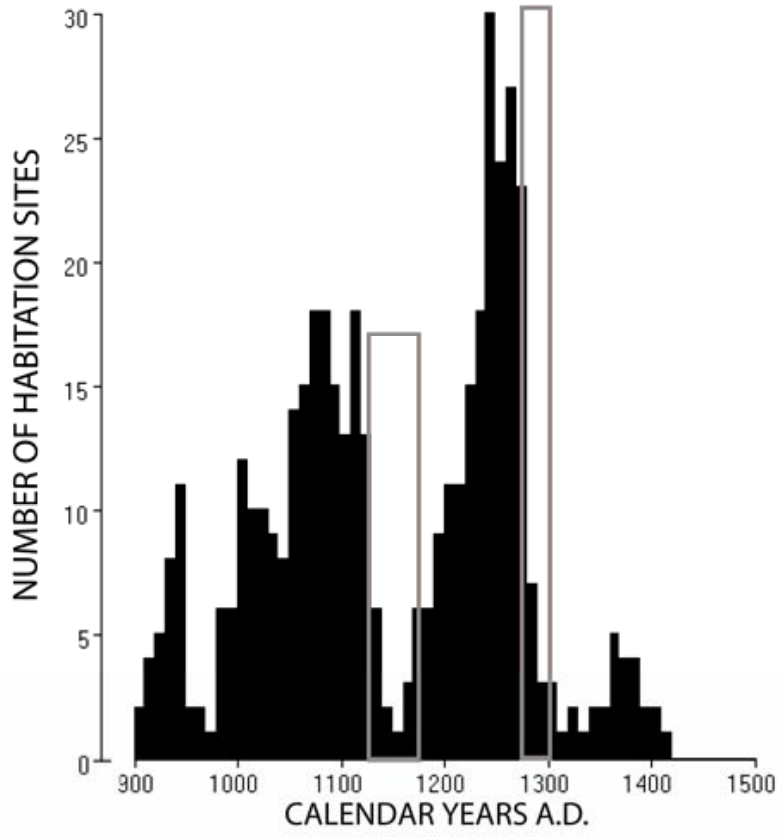
But this leaves 20thC a problem …

Solar irradiance increases with number of sunspots



Solanki et al. Nature, 2004

Drought and the ancestral Pueblo Indians



Studies of the Four Corners region show
population boom and bust related to megadroughts

Benson et al. (2006)

CONCLUSIONS

North American droughts since the mid 19th Century forced by
1. Persistent La Nina-like conditions
2. Secondarily, a warm subtropical North Atlantic

Fit into a global pattern of hydroclimate with notable hemispheric and zonal symmetry

Dynamics of the Pacific influence (on both zonal symmetric and asymmetric response) well understood but Atlantic influence is not

Medieval megadroughts were likely similarly forced (but need to explain the Medieval SSTs)

But the past can only teach us so much - the future is likely to present some new dynamics for subtropical drying

SCIENTIFIC QUESTIONS

1. drought prediction requires tropical SST prediction

- what is the SST predictability on interannual to decadal timescales?
- given the SSTs, how accurate is the drought prediction (precip, soil moisture, river flow ...)?
- but what happened from 2002 to 2006?

2. even for S/I, can no longer ignore climate change and must move towards CLIMATE CHANGE PREDICTION

assimilated and initialized global coupled model prediction-projections of next decade or two with forcing scenarios to account for:

i. Evolution of natural variability
ii. Anthropogenic change
iii. The interaction between them