

A modeling perspective on past, present and future of drought in southwestern North America

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AAAS Meeting, February 2013, Boston

North American drought as of now

North American Drought Monitor

December 31, 2012

Released: Tuesday, January 15, 2013

<http://www.ncdc.noaa.gov/nadm.html>

Analysts:
Canada - Trevor Hadwen
Richard Rieger
Mexico - Adelina Albalil
Reynaldo Pascual
U.S.A. - Richard Heim
Brad Rippey*
Mark Brusberg*

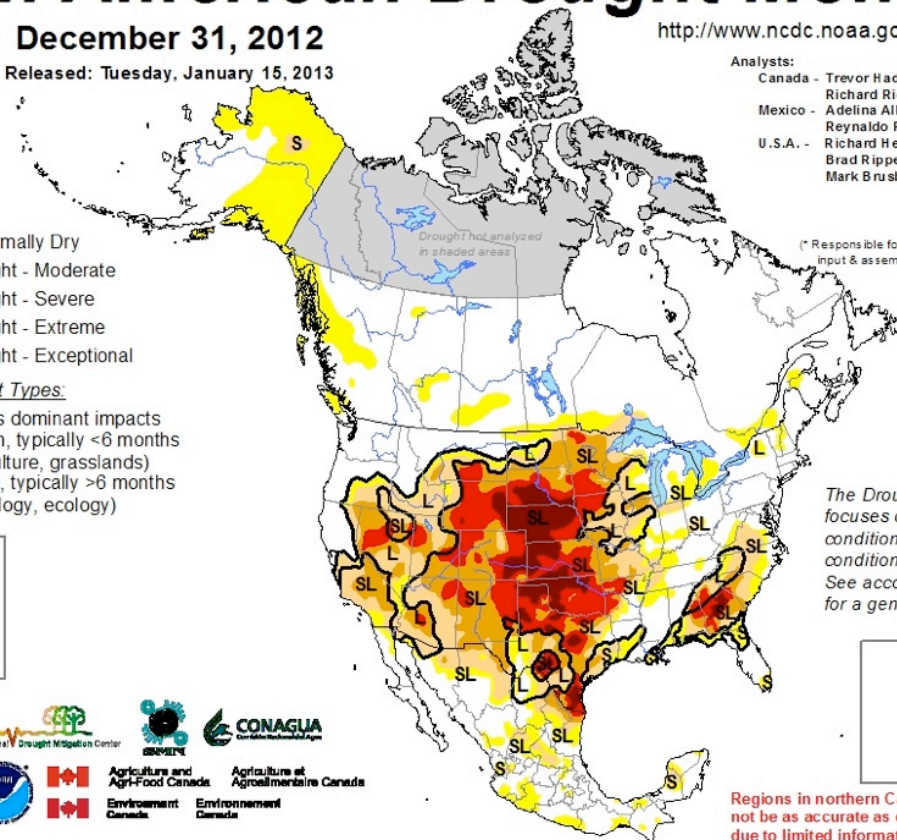
(* Responsible for collecting analysts' input & assembling the NA-DM map)

Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

- ~ Delineates dominant impacts
- S = Short-Term, typically <6 months (e.g. agriculture, grasslands)
- L = Long-Term, typically >6 months (e.g. hydrology, ecology)



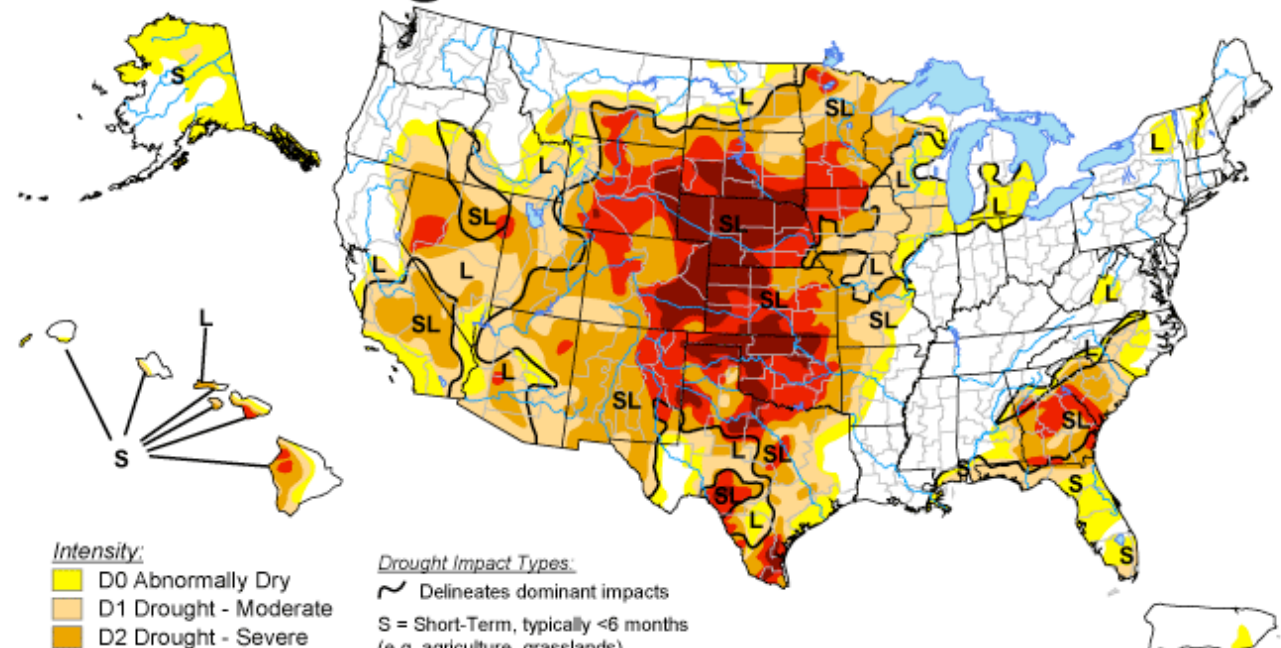
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text for a general summary.

Regions in northern Canada may not be as accurate as other regions due to limited information.

U.S. Drought Monitor

February 12, 2013

Valid 7 a.m. EST



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The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

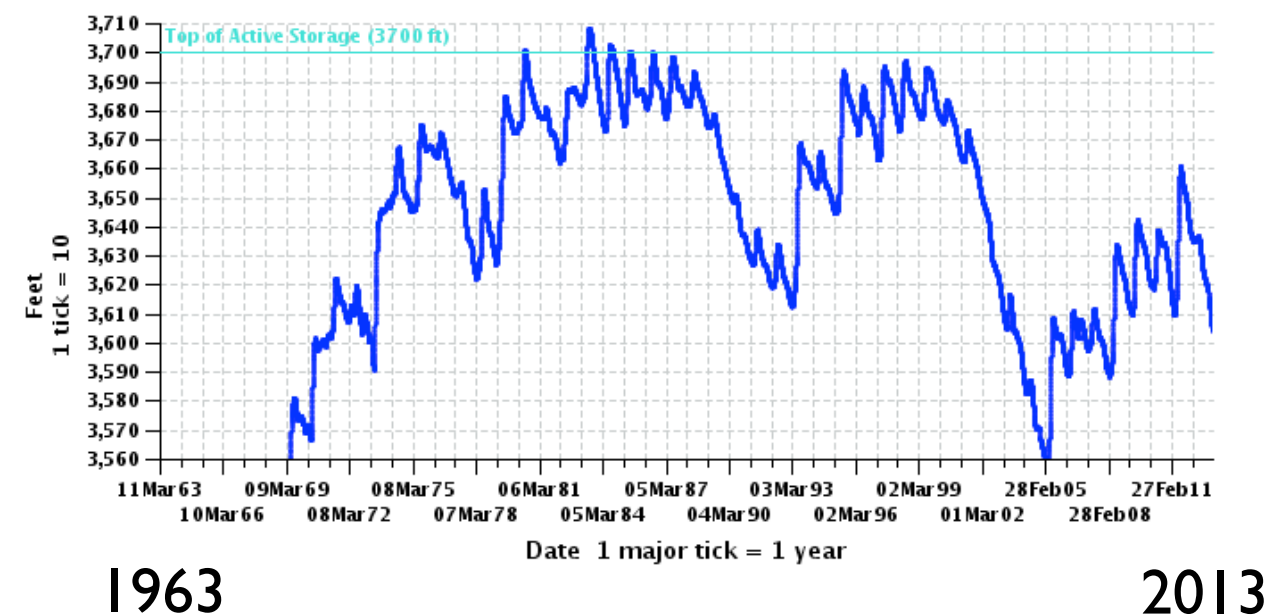
<http://droughtmonitor.unl.edu/>



Released Thursday, February 14, 2013

Author: Michael Brewer/L. Love-Brotak, NOAA/NESDIS/NCDC

Widespread severe to exceptional droughts in Plains and West. Continued long term (since 1998) shortfall of water storage on Colorado River



Lake Powell pool elevation

North American Drought Monitor

October 31, 2011

Released: Thursday, November 10, 2011

<http://www.ncdc.noaa.gov/nadm.html>

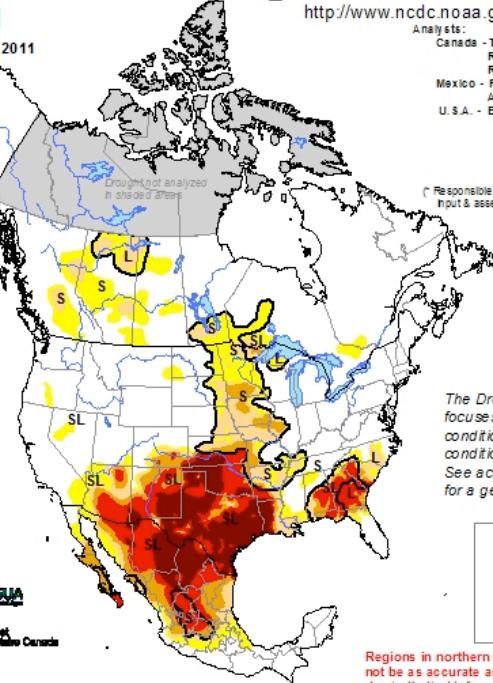
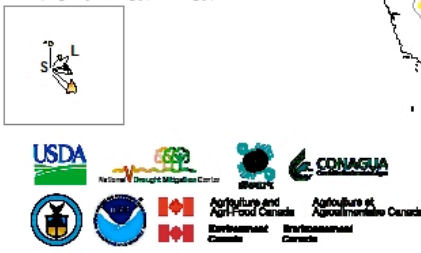
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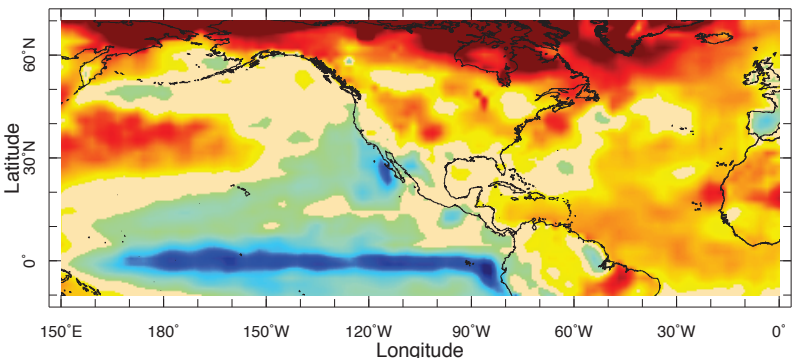
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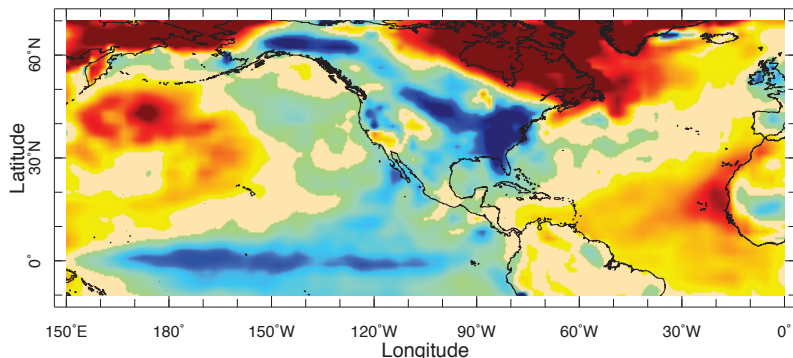


SSTA (ocean), Surface Air Temp (land)

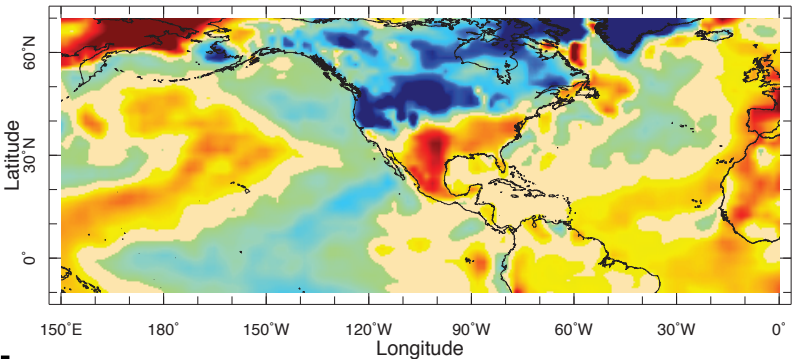
SON 2010



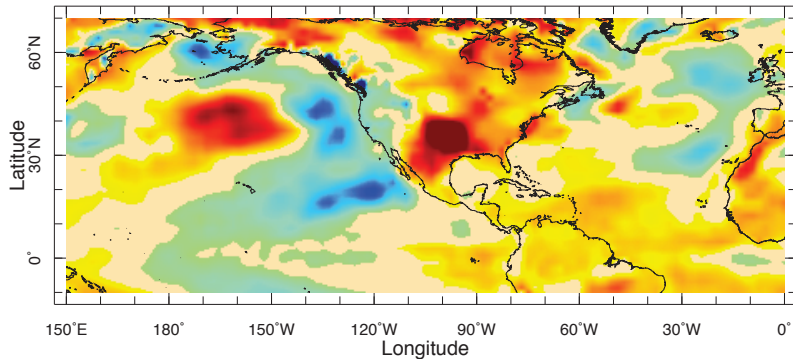
DJF 2010/2011



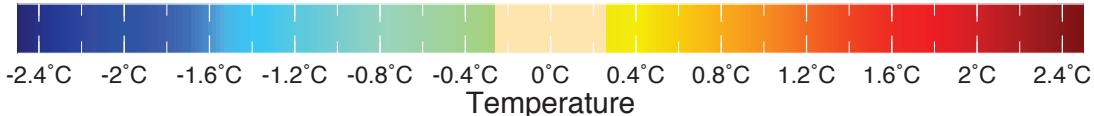
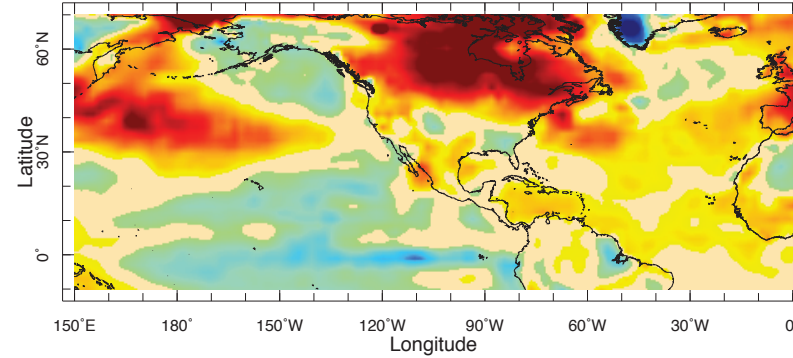
MAM 2011



JJA 2011

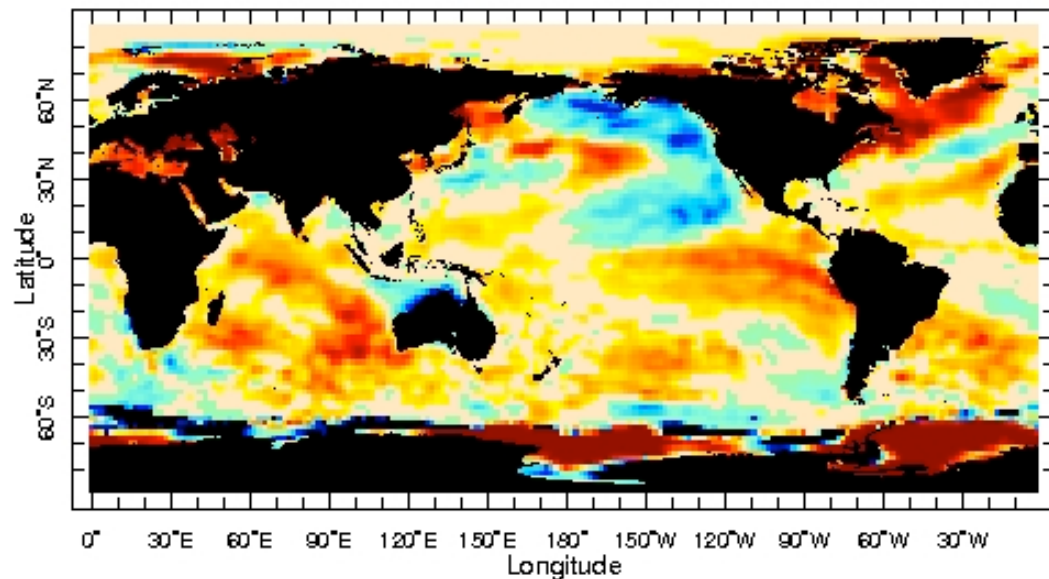
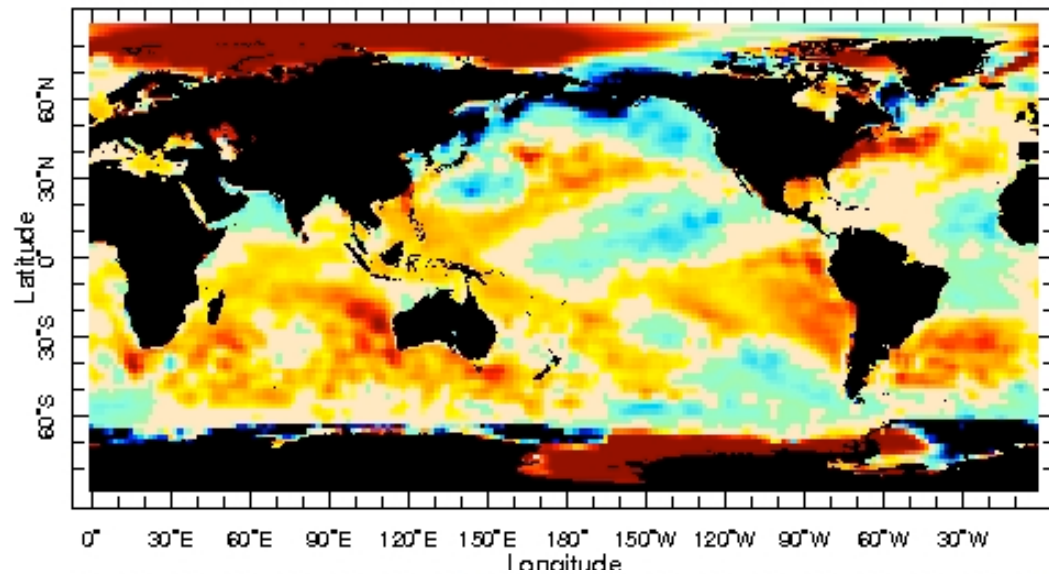
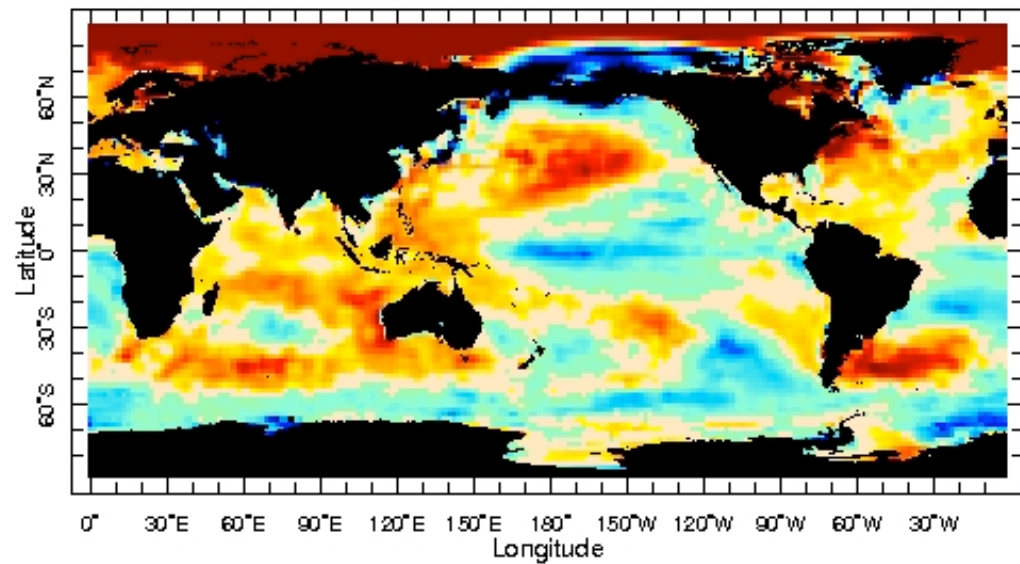


SON 2011



The current TexMex drought emerged in fall 2010 along with a cold tropical Pacific-warm tropical Atlantic SST pattern. By fall 2011 severe TexMex drought.

SST anomaly



DJF
2011/2

Continued
La Nina

MAM
2012

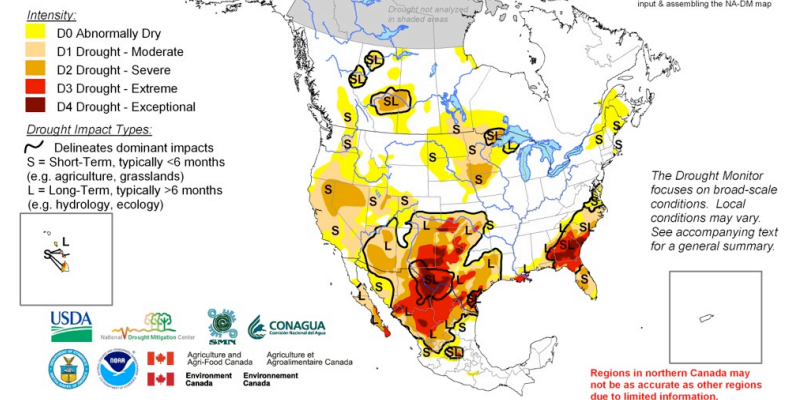
atmosphere-only
variability?

JJA
2012

North American Drought Monitor

February 29, 2012
Released: March 13, 2012

<http://www.ncdc.noaa.gov/nadm.html>

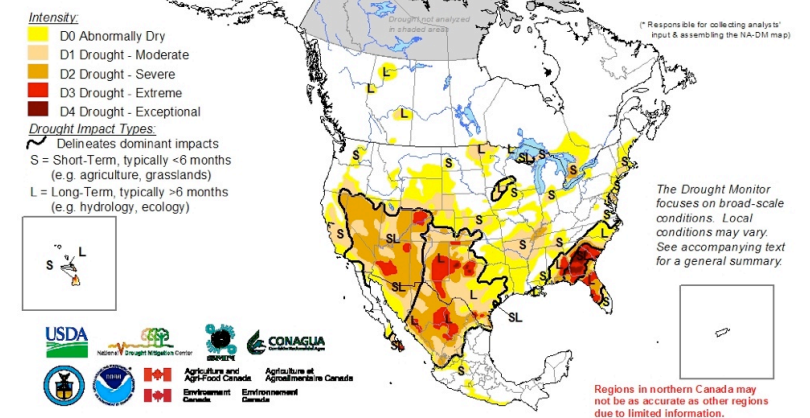


North American Drought Monitor

May 31, 2012

Released: Tuesday, June 12, 2012

<http://www.ncdc.noaa.gov/nadm.html>

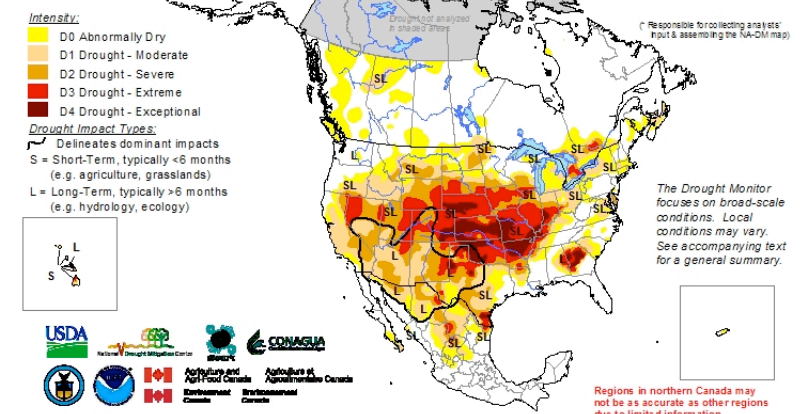


North American Drought Monitor

August 31, 2012

Released: Thursday, September 13, 2012

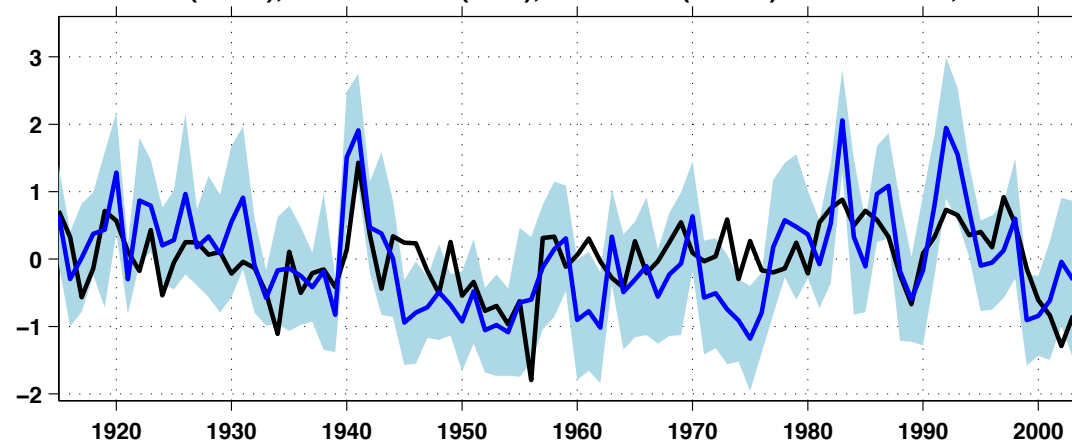
<http://www.ncdc.noaa.gov/nadm.html>



Association of NA drought with cold tropical Pacific - La Nina - SST anomalies is typical - has worked for more than a century

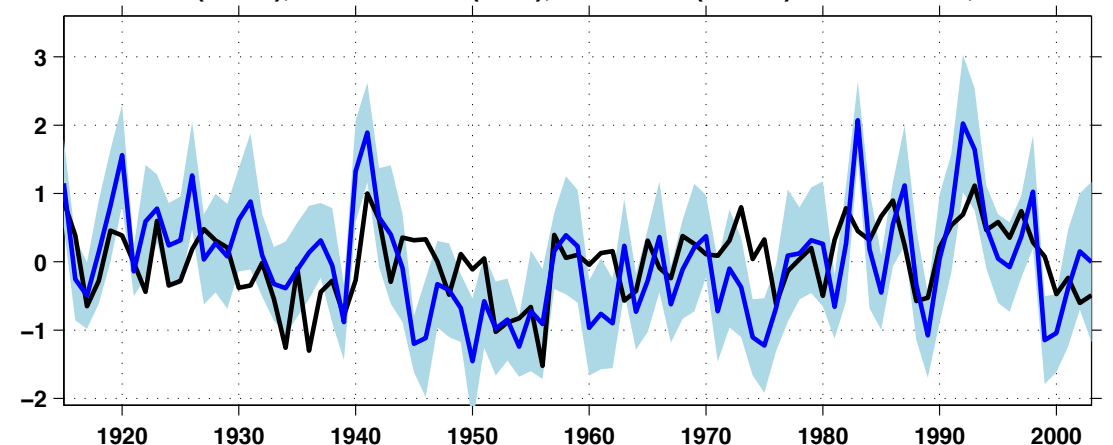
Soil moisture anomalies - 'observations based' and from global climate model

Std Annual VIC (black), GOGA Mean (blue), ± 2 STD (lt blue) SM 25N-40N, 95W-125W US

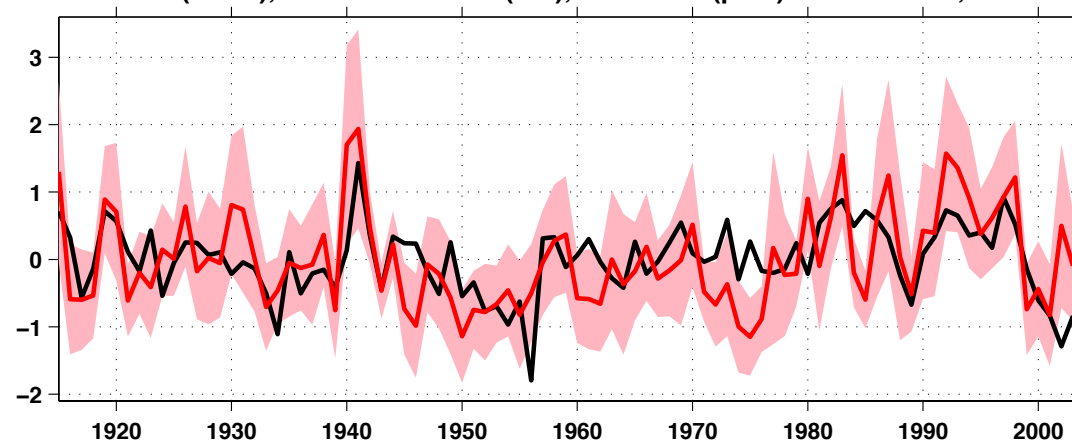


Global
SST
forcing

Std Annual VIC (black), GOGA Mean (blue), ± 2 STD (lt blue) SM 30N-50N, 90W-110W US

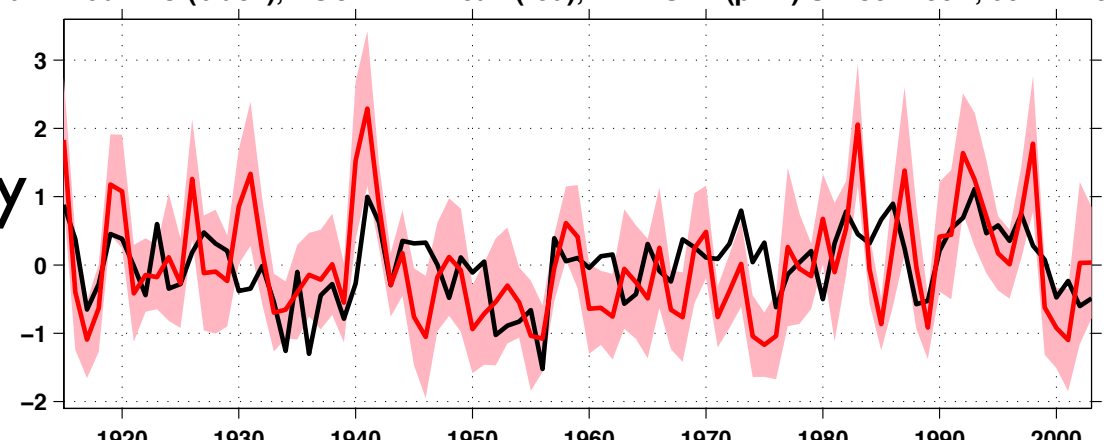


Std Annual VIC (black), POGA-ML Mean (red), ± 2 STD (pink) SM 25N-40N, 95W-125W US



Tropical
Pacific only
SST
forcing

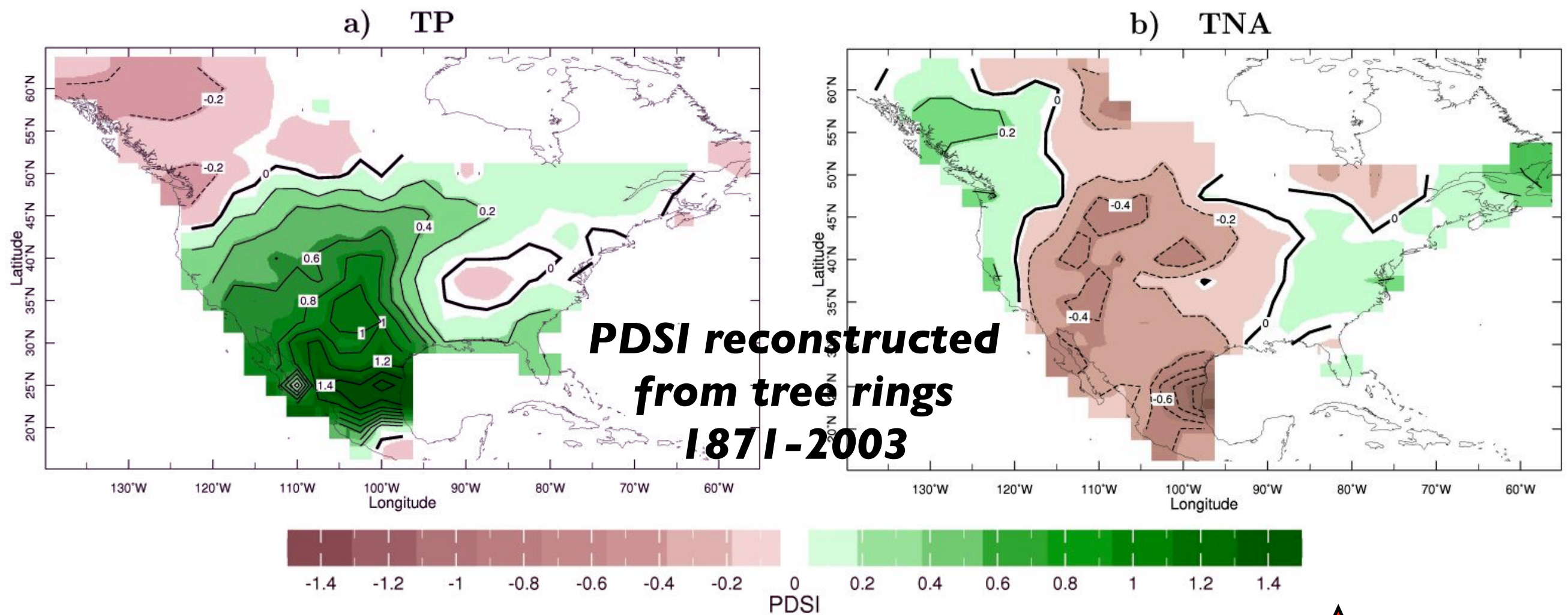
Std Annual VIC (black), POGA-ML Mean (red), ± 2 STD (pink) SM 30N-50N, 90W-110W US



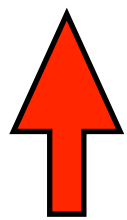
Great Plains

southwest NA

Tree ring reconstructions of Palmer Drought Severity Index allow determination of SST-drought link back into 19th Century



Tropical Pacific SST



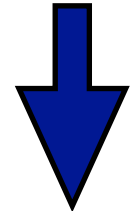
SW PDSI



Tropical North Atlantic SST

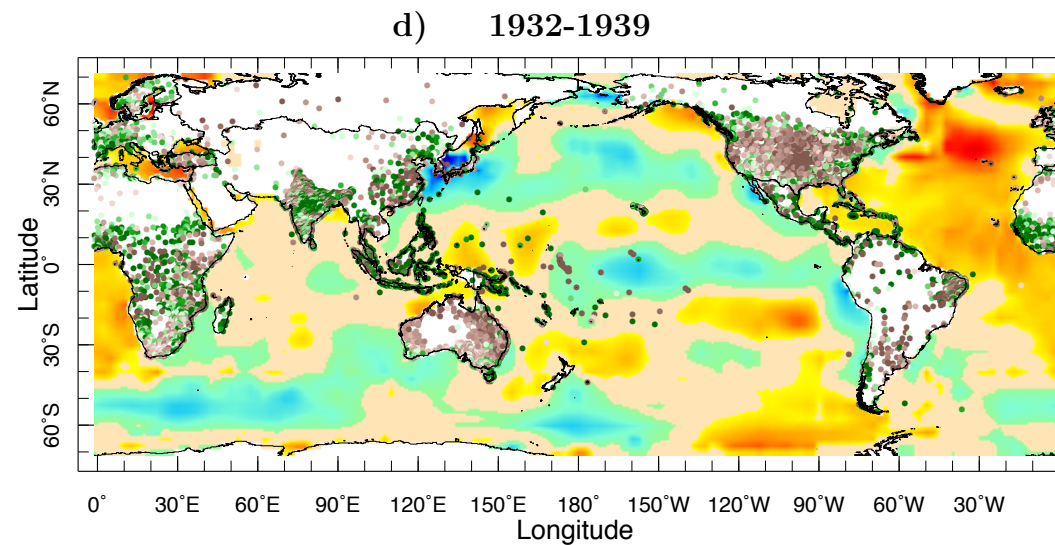


SW PDSI



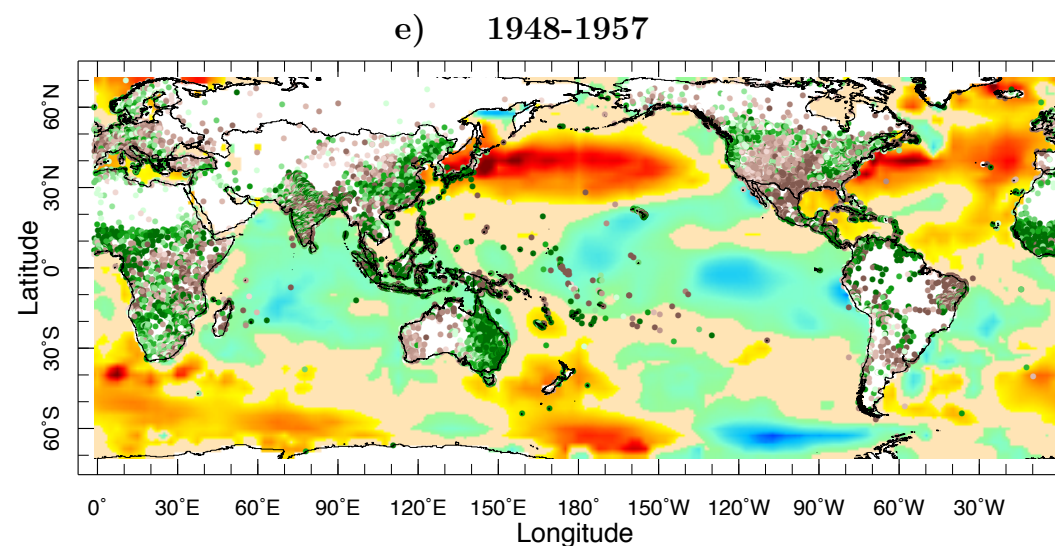
Cold tropical Pacific - warm tropical North Atlantic
perfect ocean for drought

The Dust Bowl



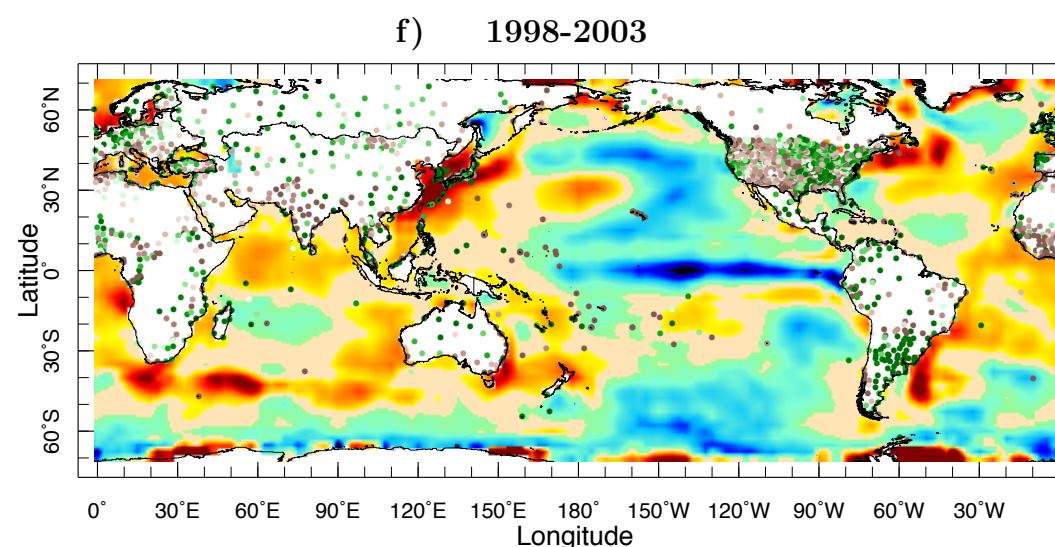
North American droughts of the 20thC fit into a consistent global pattern ...

The 1950s

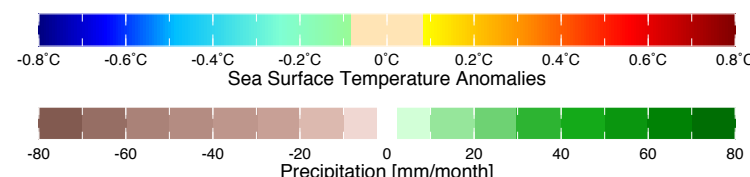


-Widespread drought in northern and southern mid-latitudes

Turn-of-the-century

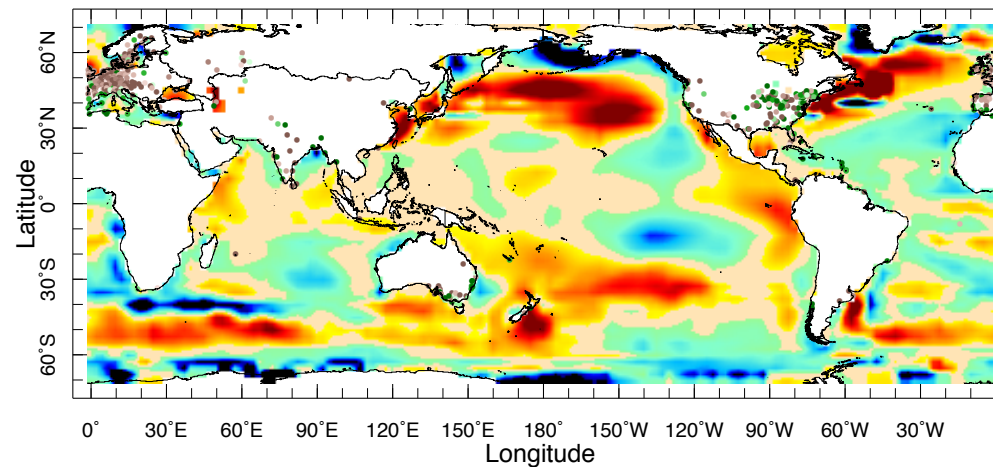


- In the SST, the common feature is a cold equatorial Pacific - La Nina



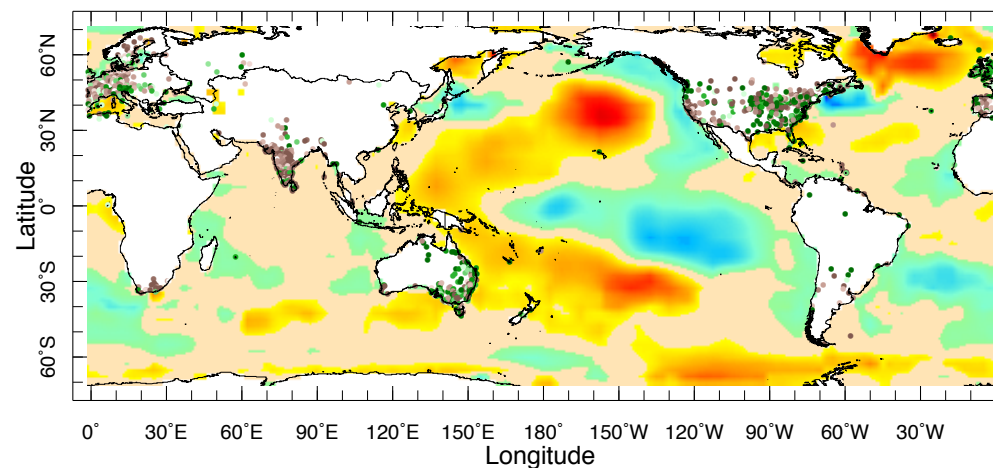
SST from ships, rain from gauges

a) 1856-1865



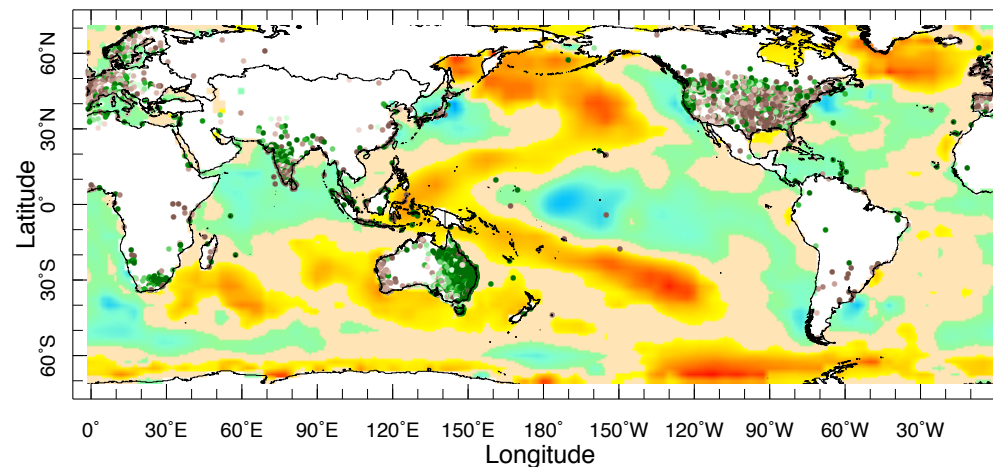
**The Civil War
drought**

b) 1870-1877

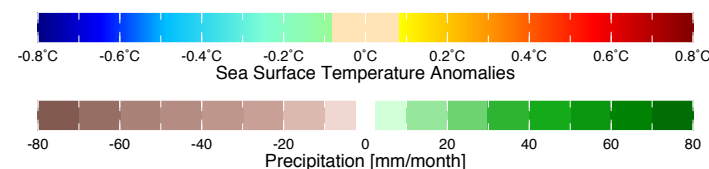


The 1870s

c) 1890-1896



The 1890s



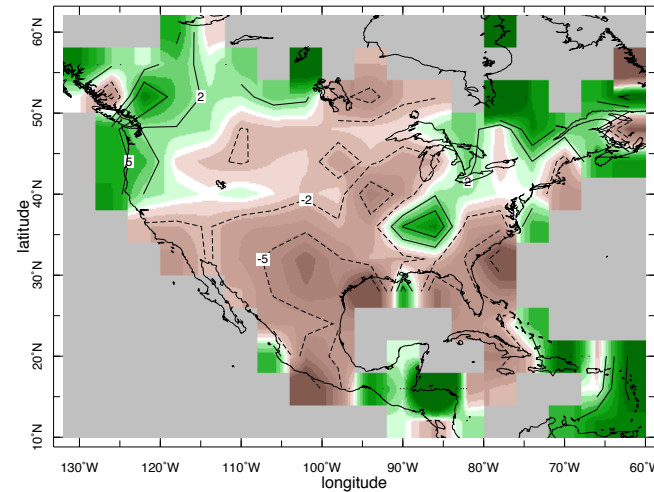
The same global hydroclimate regimes are seen in the mid to late 19thC North American droughts

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

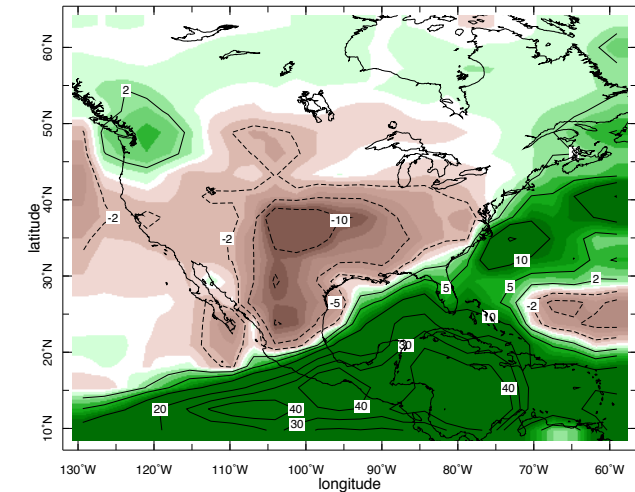
Models simulate well the 1950s drought. This was centered in southwest N. America - typical of SST-forced drought (also case for Civil War, 1870s, 1890s and 1998-2004 droughts) - and was worst SW and Mexico have experienced.

The Dust Bowl was different ...

(a) GHCN

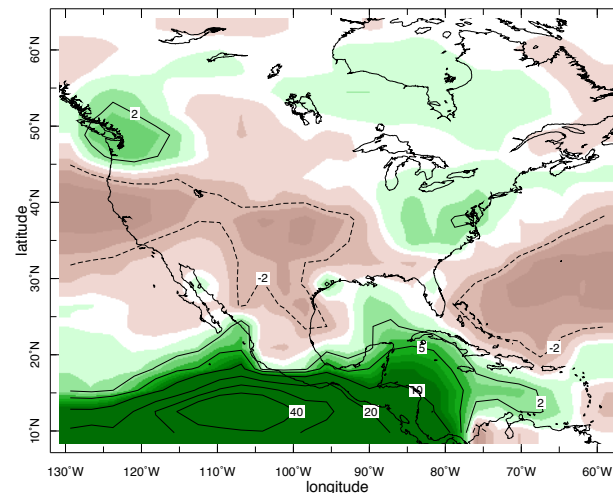


(b) GOGA

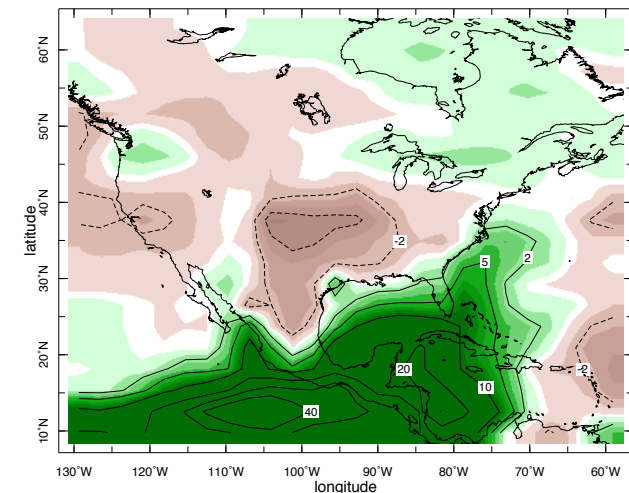


*model
global
SST
forcing*

(c) POGA

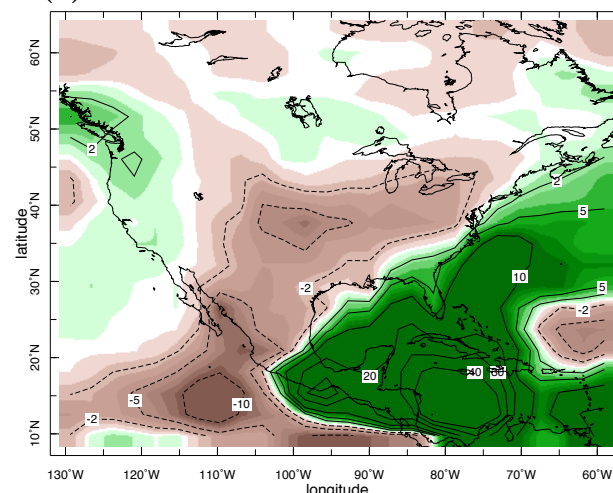


(d) POGA-ML

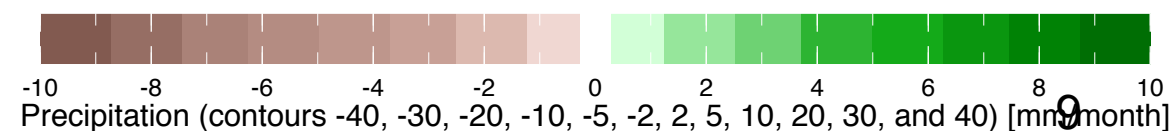


*model
tropical
Pacific
SST
forcing*

(e) TAGA



*model
tropical
Atlantic
SST
forcing*

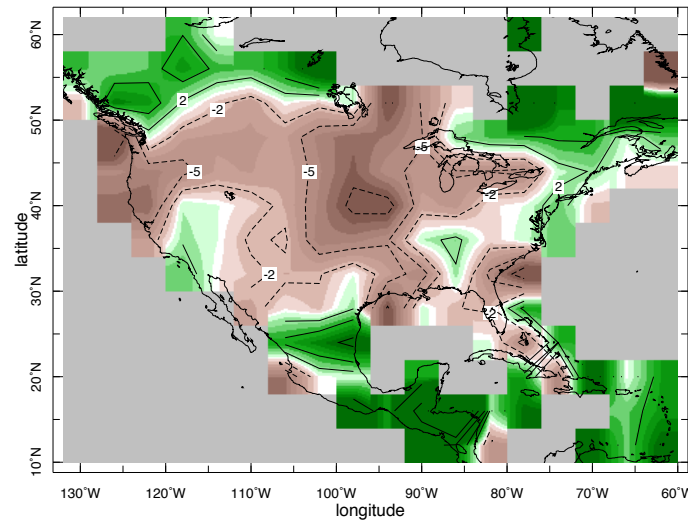


The Dust Bowl was also a case of cooperative Pacific and Atlantic SST anomalies

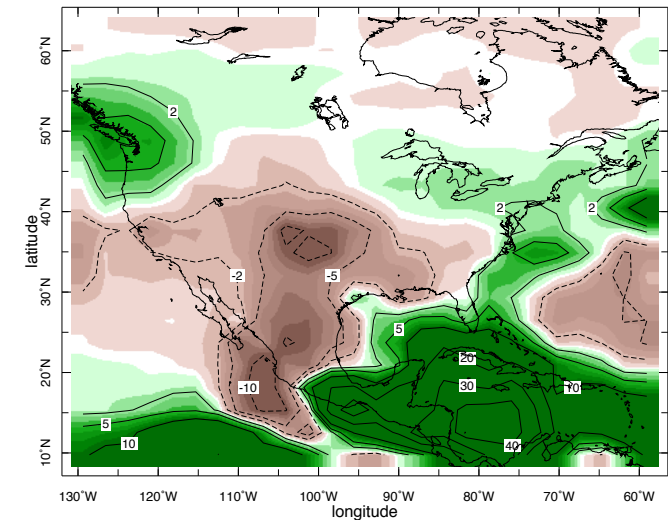
but modeled drought centered too far south

observed

(a) GHCN

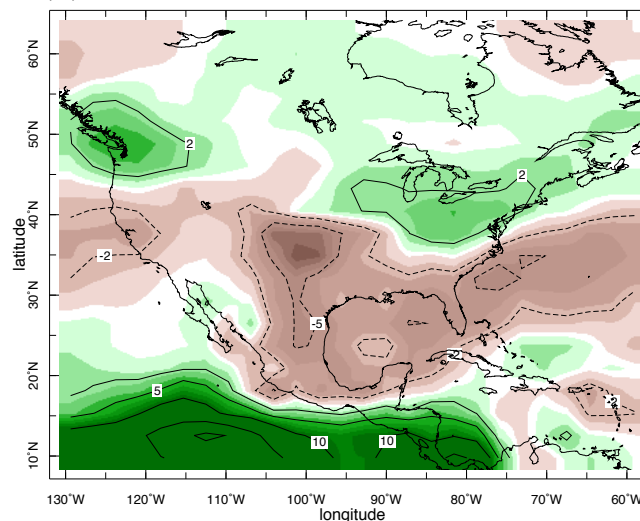


(b) GOGA

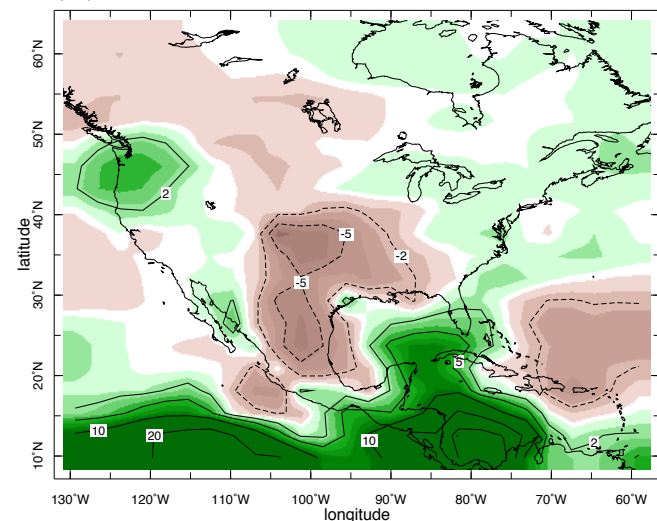


*model
global
SST
forcing*

(c) POGA

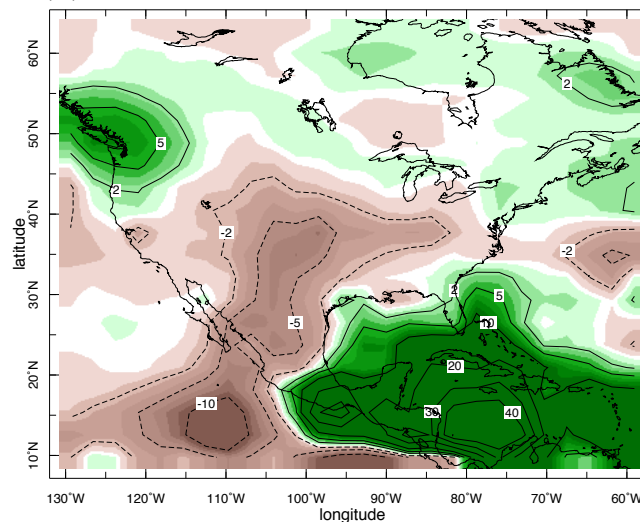


(d) POGA-ML



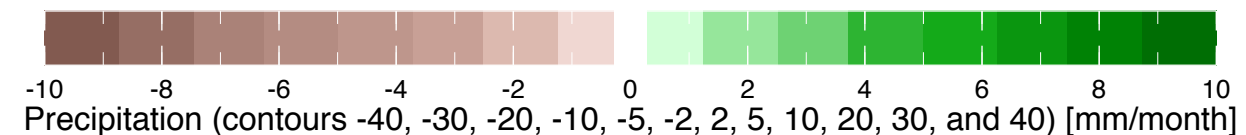
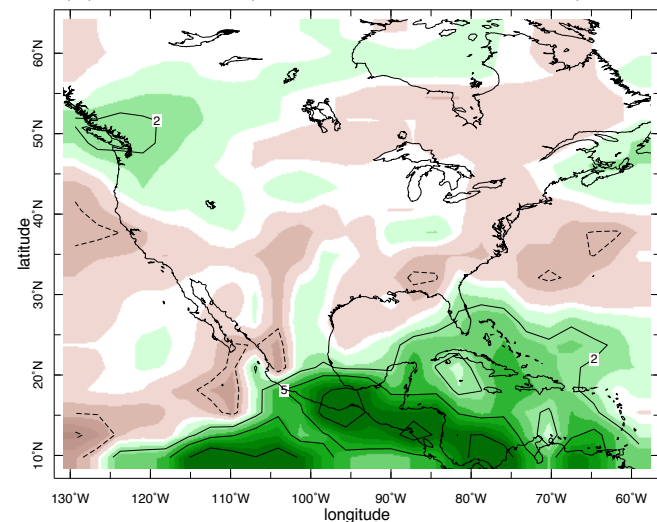
*model
tropical
Pacific
SST
forcing*

(e) TAGA



*model
tropical
Atlantic
SST
forcing*

(f) COGA (GOGA climatology)

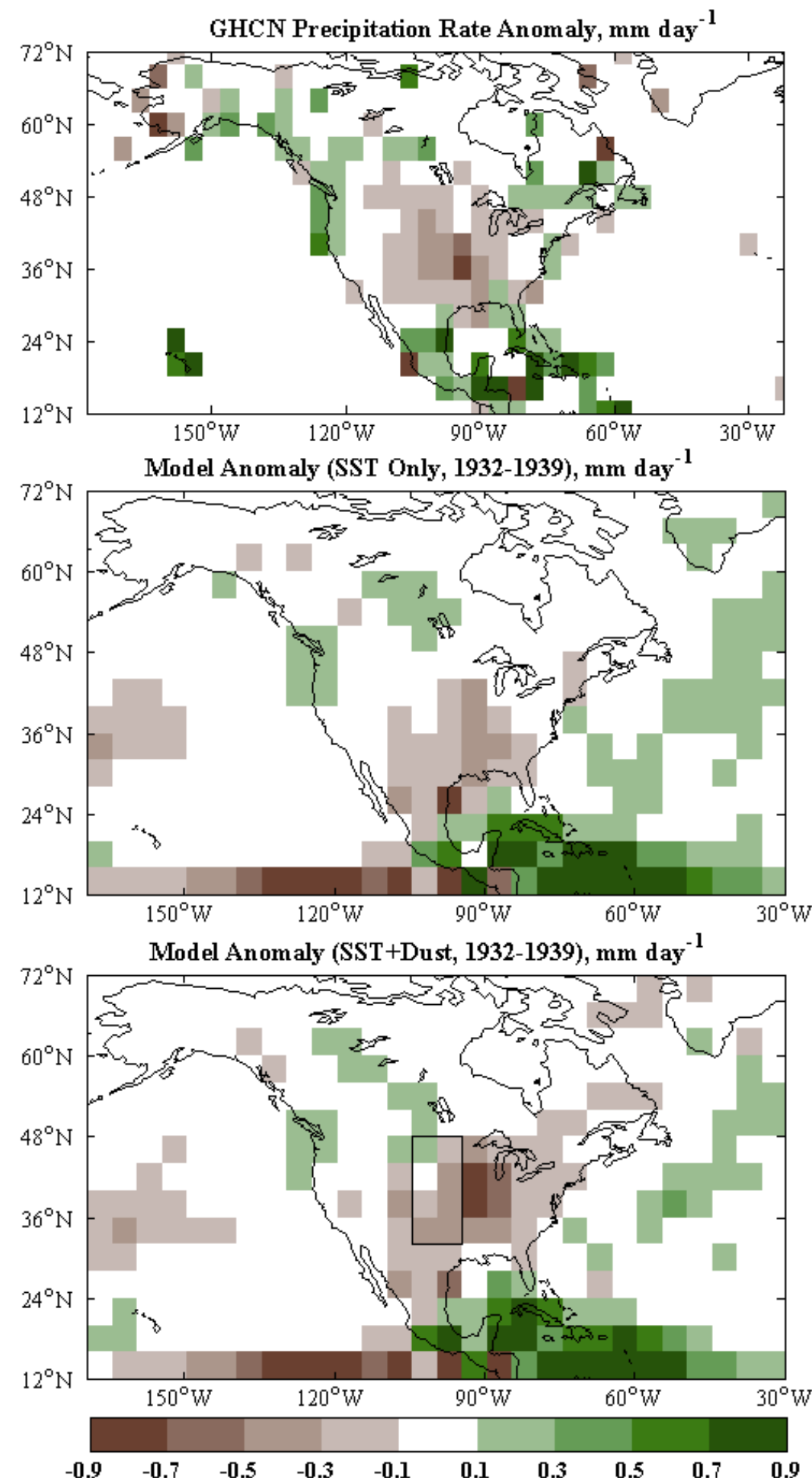


1930s Dust Bowl drought only one that went along with soil erosion and dust storms due to farming practices.

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

Model created dust storms, the dust interacted with 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

North America has an excellent network of tree ring records of past hydroclimate.

The Southwest and, especially, the Plains experienced a series of multidecadal megadroughts before the 17th Century.

The southeast U.S. has been getting wetter for a millennium.

Cook et al. 2013

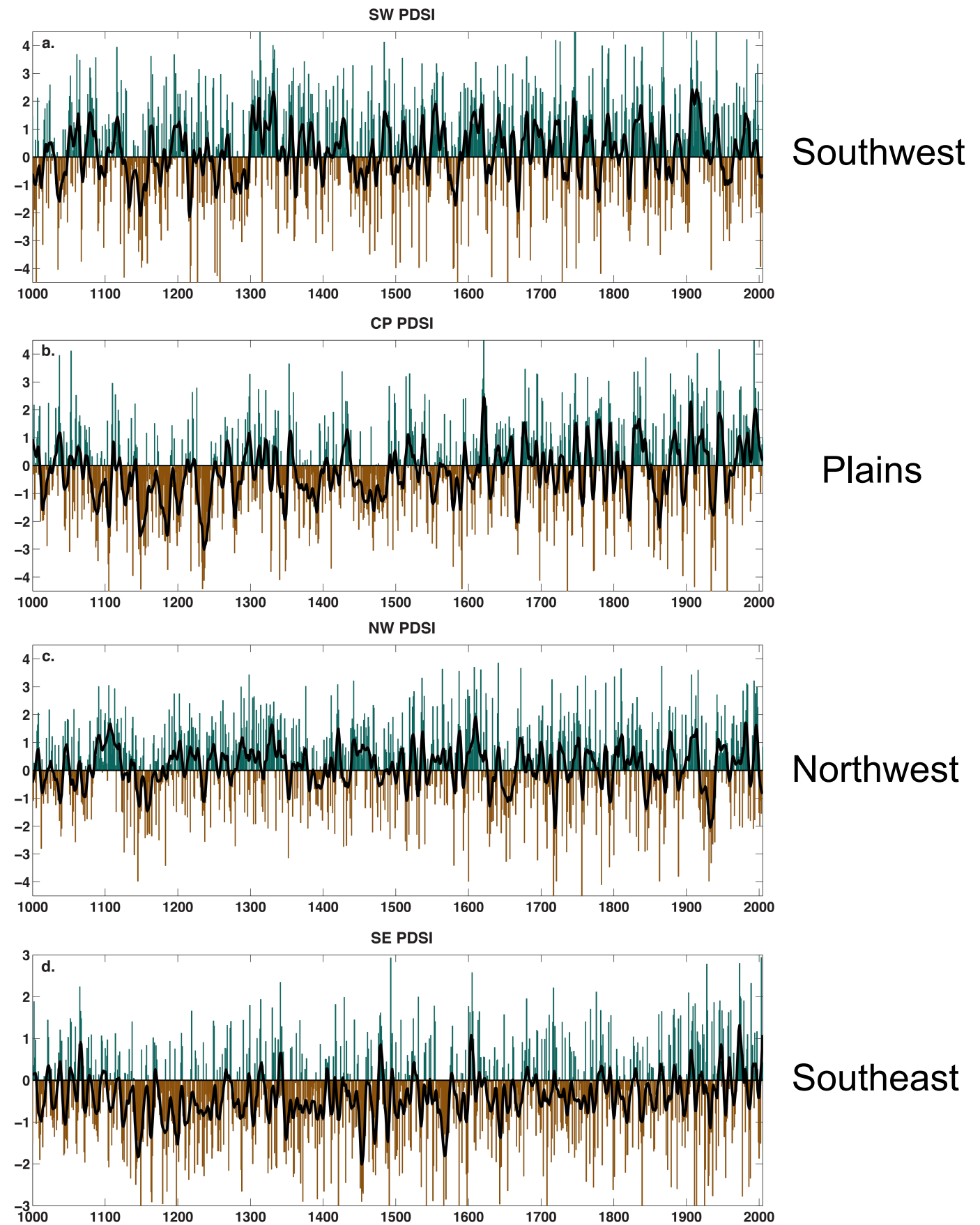


FIG. 3. Area averaged PDSI from the NADA for the SW (a), CP (b), NW (c), and SE (d) regions, as shown in Figures 1 and 2. Green and brown bars are the original data, and dark black lines are a smoothed version of the time series using a 10-year LOWESS spline.

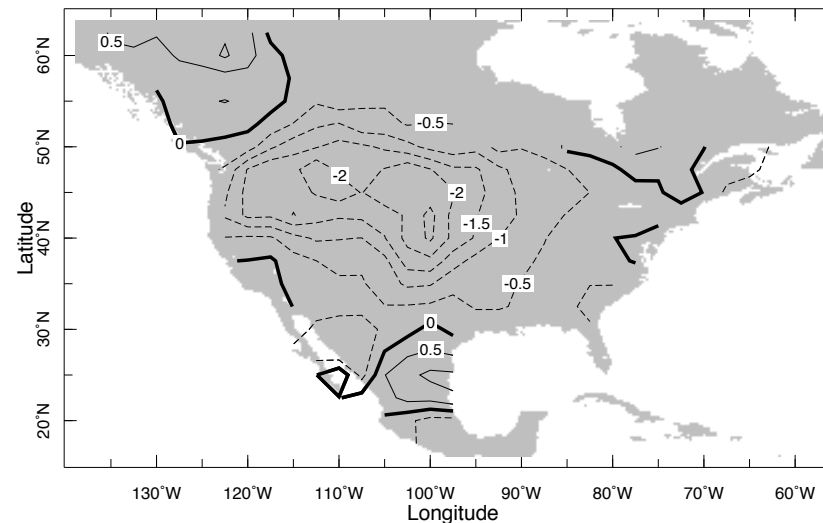
The Medieval megadroughts were often pan-continental and of multidecadal duration. Causes?

- Very long timescale SST variations, possibly solar or volcanic-forced?
- Internal atmosphere variability?

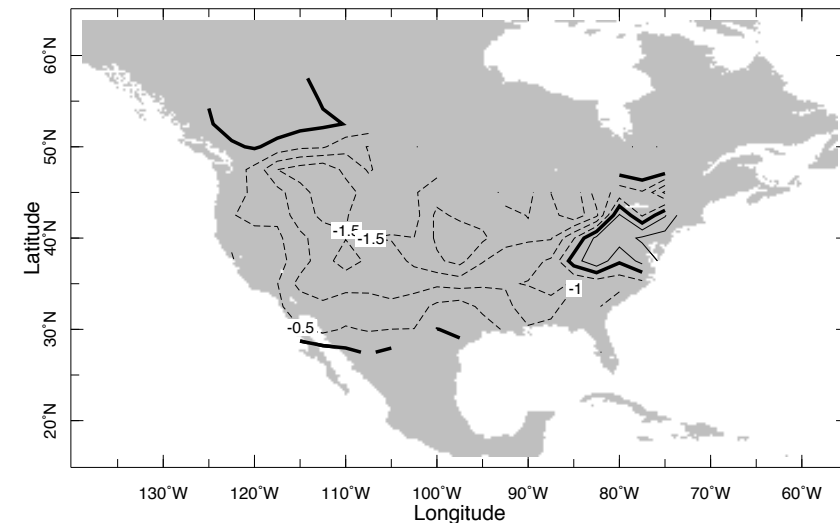
NADA V2

*Tree ring
reconstructed
summer
Palmer
Drought
Severity
Index*

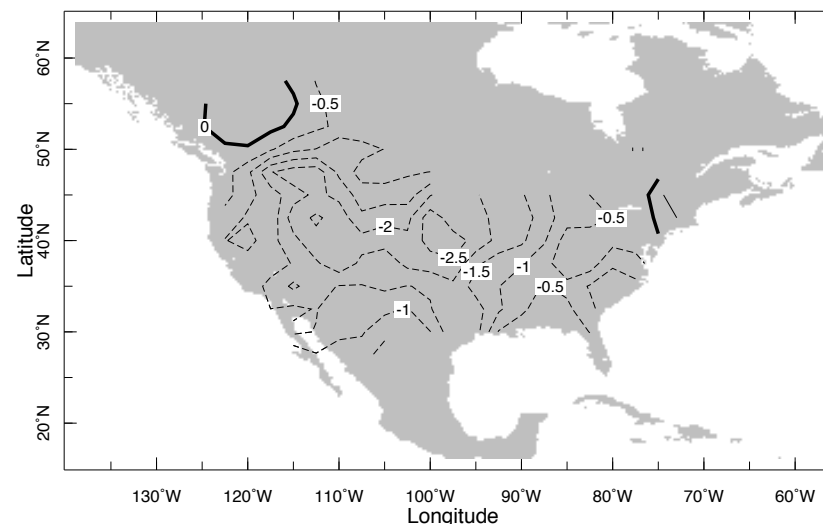
a) 1932-1939



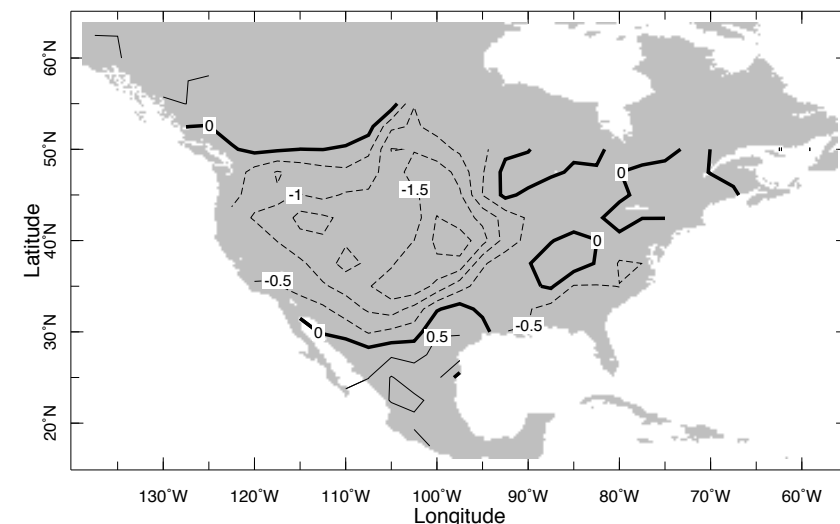
b) 1011-1019



c) 1145-1160



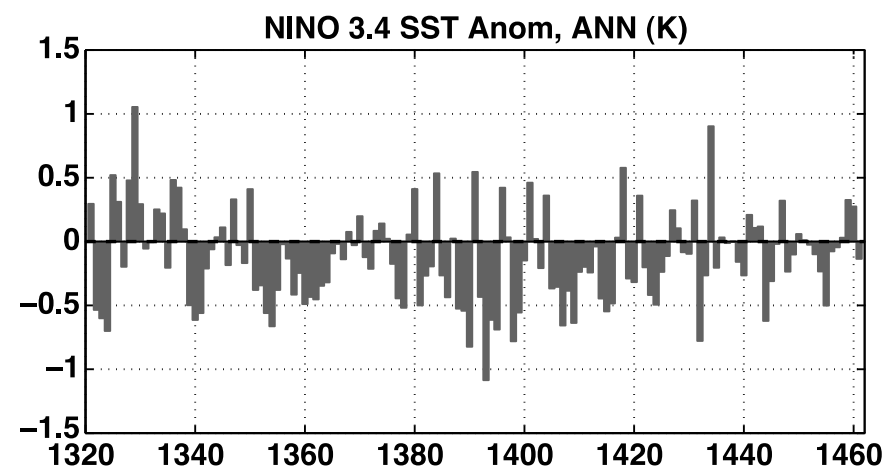
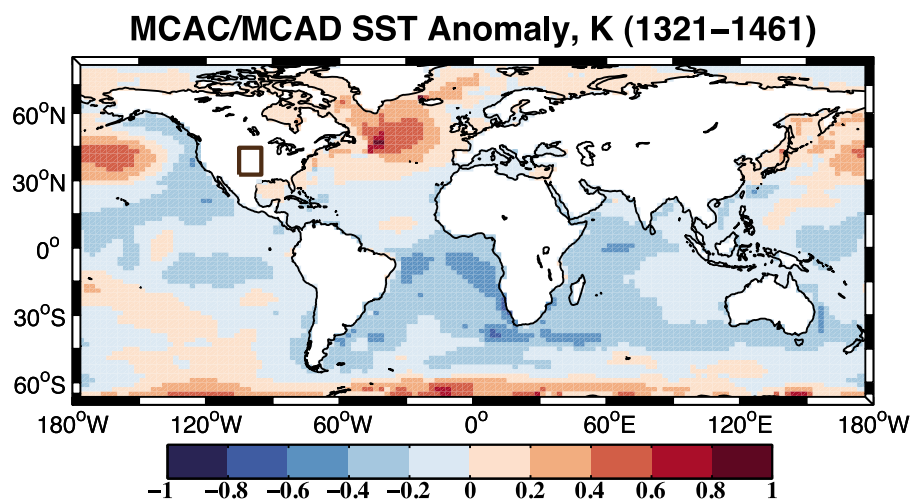
d) 1468-1481



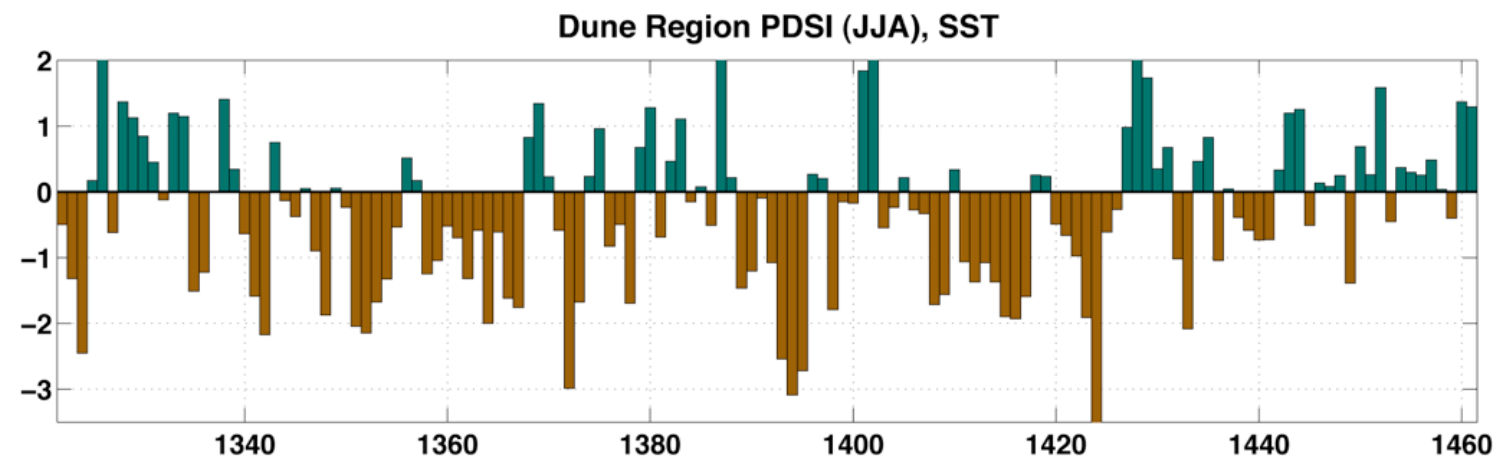
The only analogs of the Dust Bowl spatial pattern were the Medieval megadroughts during the 800-1500A.D. period - also a time of dune activity.

Force model ensemble with tropical Pacific SST
reconstructed for 1320-1462 from Cobb et al. (2003)
Palmyra coral (mixed layer ocean elsewhere).

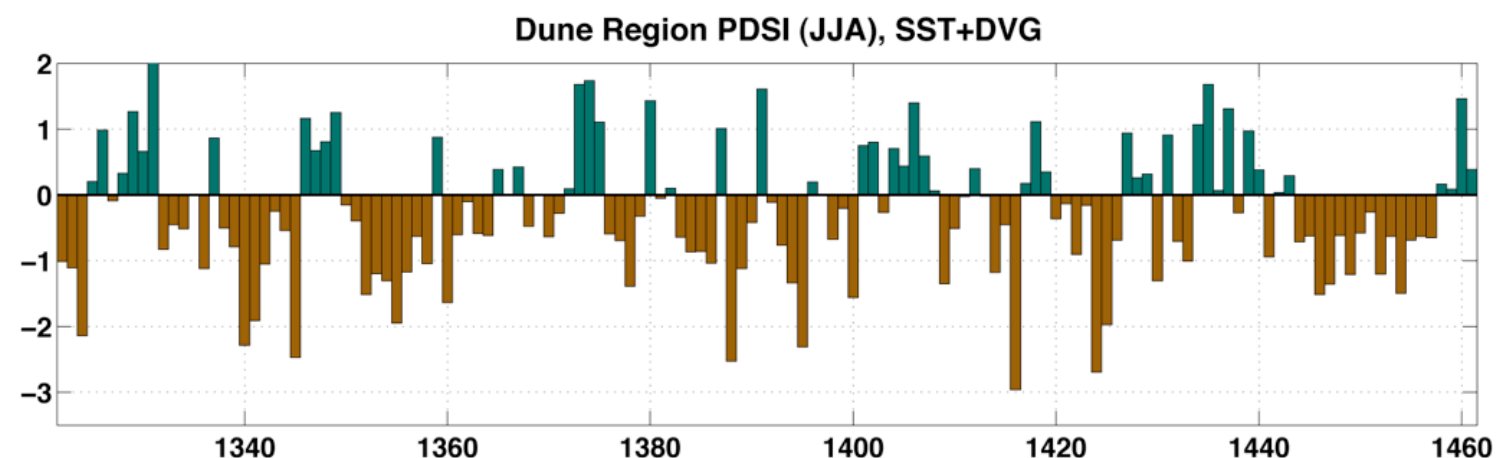
SST and NINO3.4



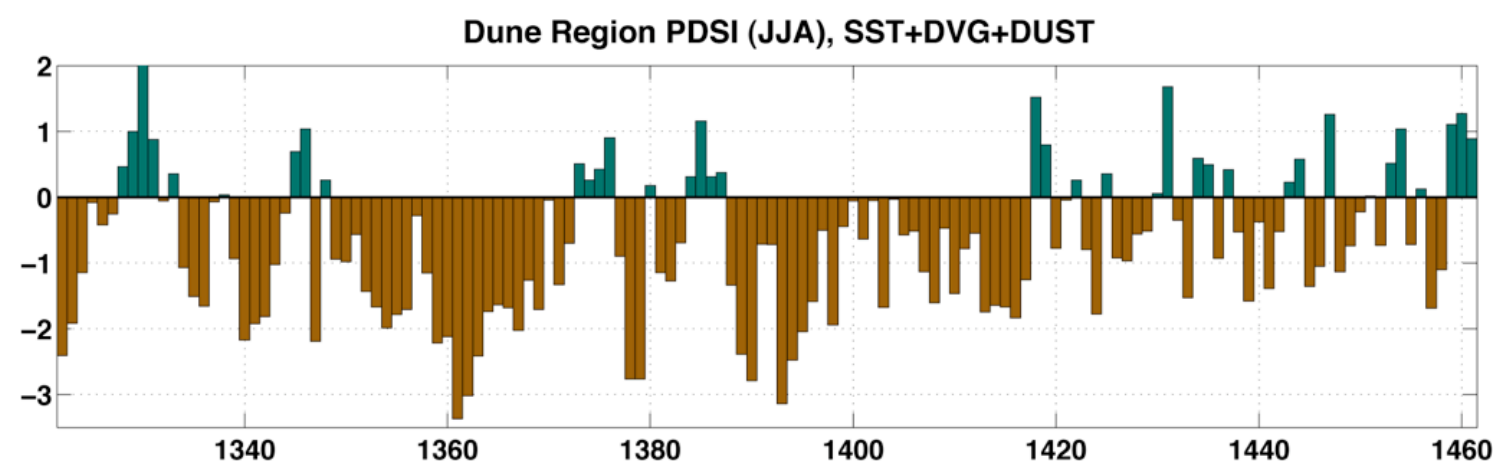
Ben Cook et al. (2011b, 2012)



SST
forcing
only



SST +
dunes



SST +
dunes
+ dust

active dunes turned Medieval droughts into megadroughts

Historical droughts caused by patterns of tropical SST anomalies.

Medieval megadroughts are of unknown origin - though tropical SST forcing remains the leading hypothesis (Graham et al. 2007, 2010; Seager et al. 2007, 2008; Burgman et al. 2010, Seager and Burgman 2011, Feng et al. 2008, Oglesby et al. 2011).

GHG-driven global warming is introducing a new type of North American drought driven by global changes in the hydrological cycle and atmospheric circulation (that do not depend on *patterns* of SST change).

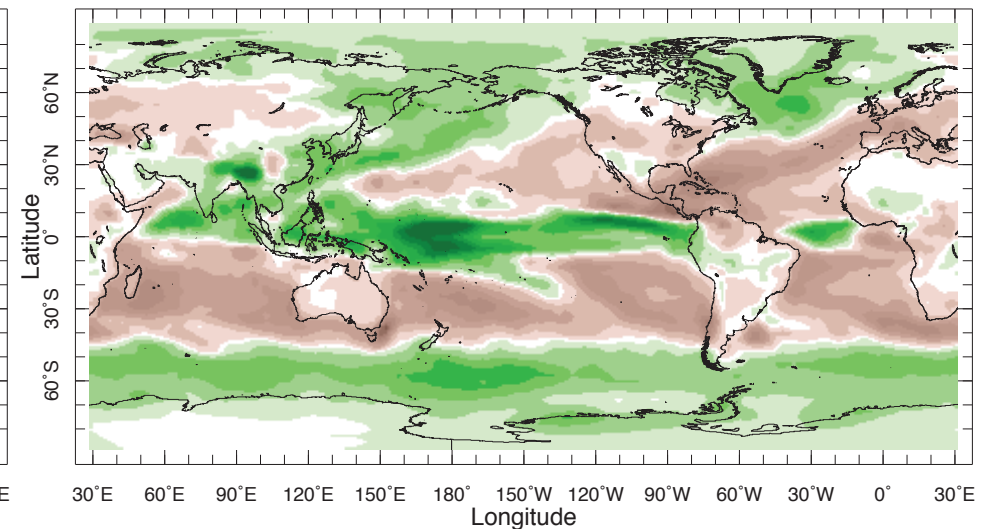
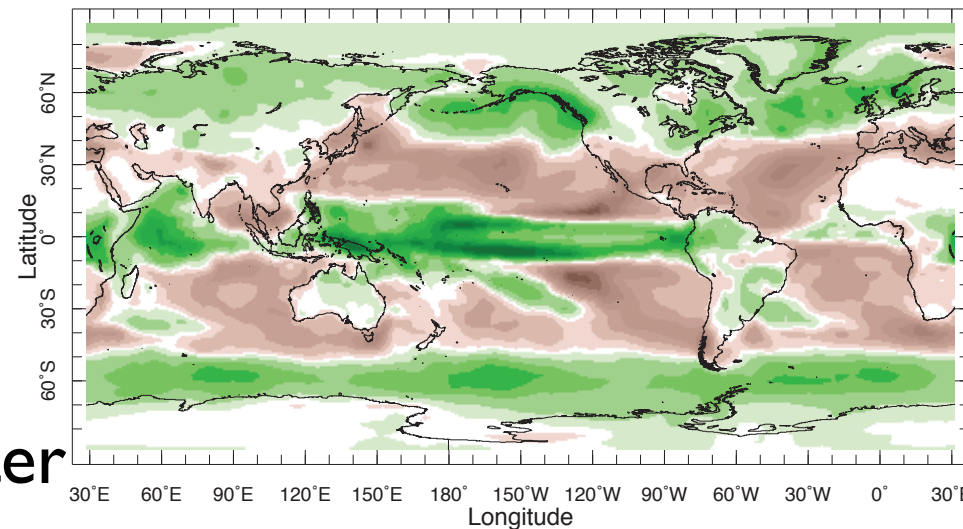
Greenhouse warming will impact patterns of precipitation across the planet

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

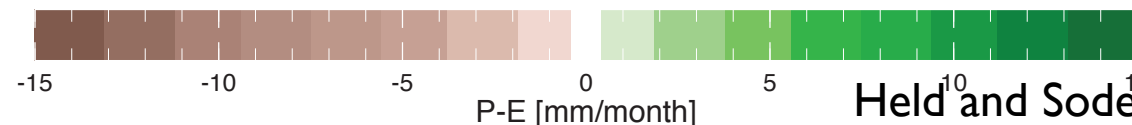
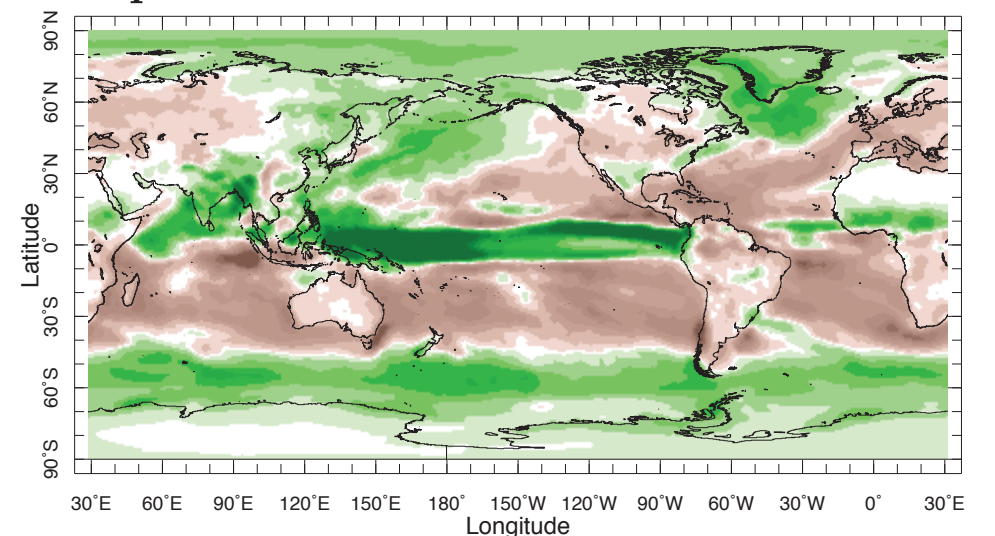
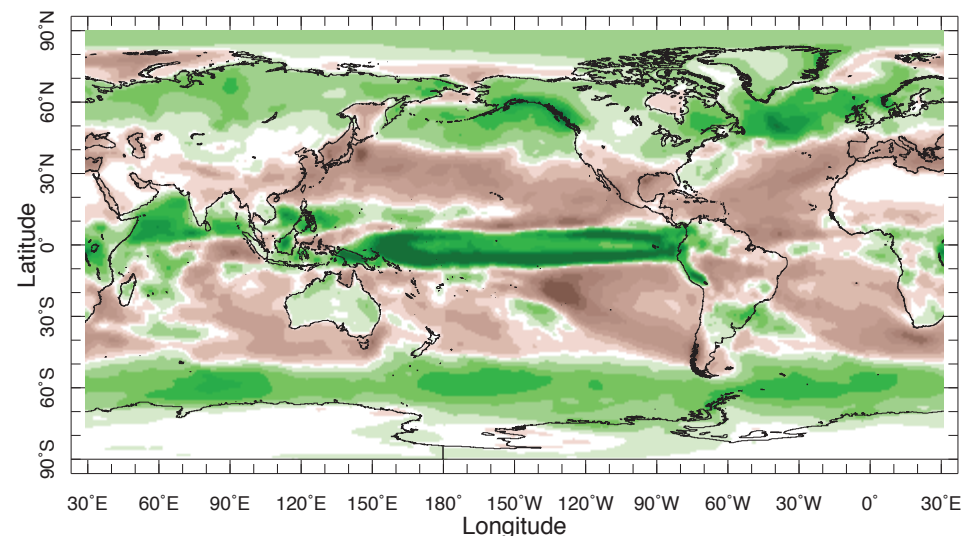
Oct-Mar

Apr-Sep

CMIP3 sresa1b



CMIP5 rcp85



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

Projected change in
mean hydroclimate:

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

Southwest N.
America dries in
winter. Northern
monsoon region
and TX have
increased P-E in
summer.

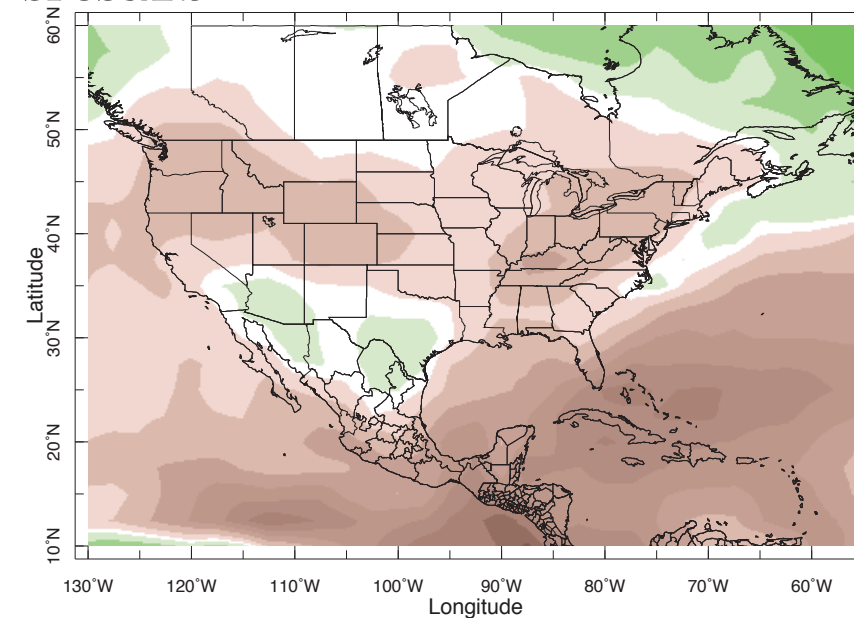
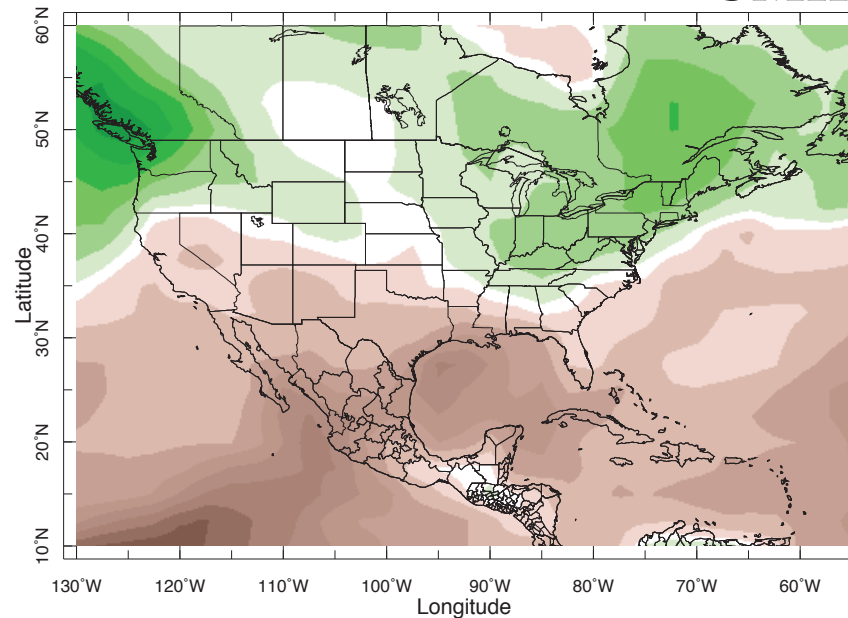
Impacts on
agricultural
production
(irrigated, rain-fed),
water resources,
ecosystems etc..

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

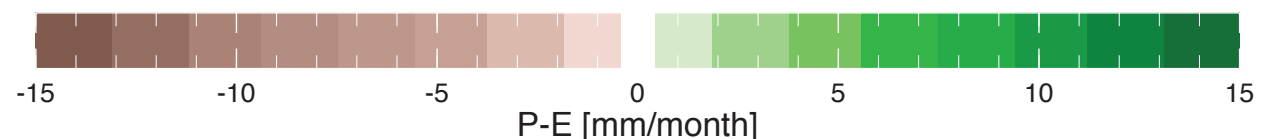
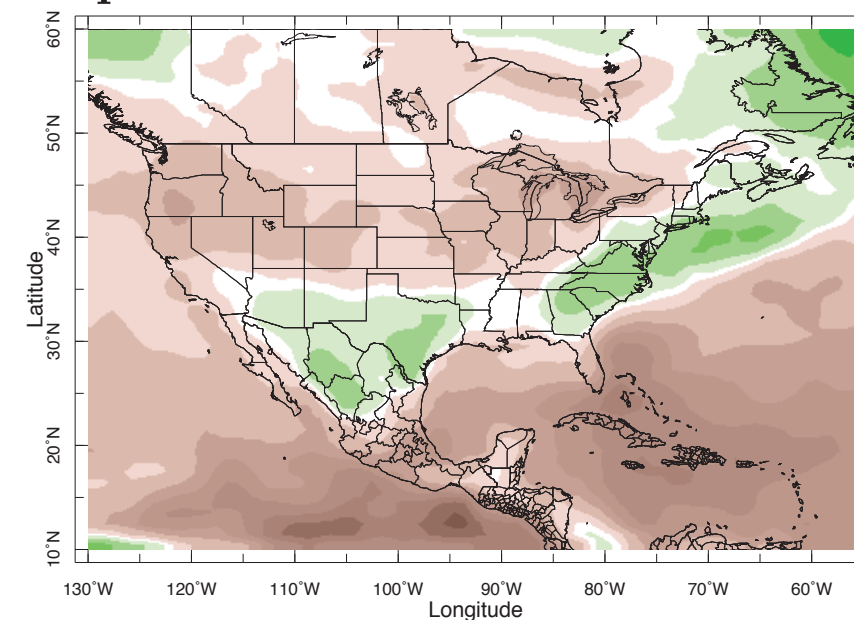
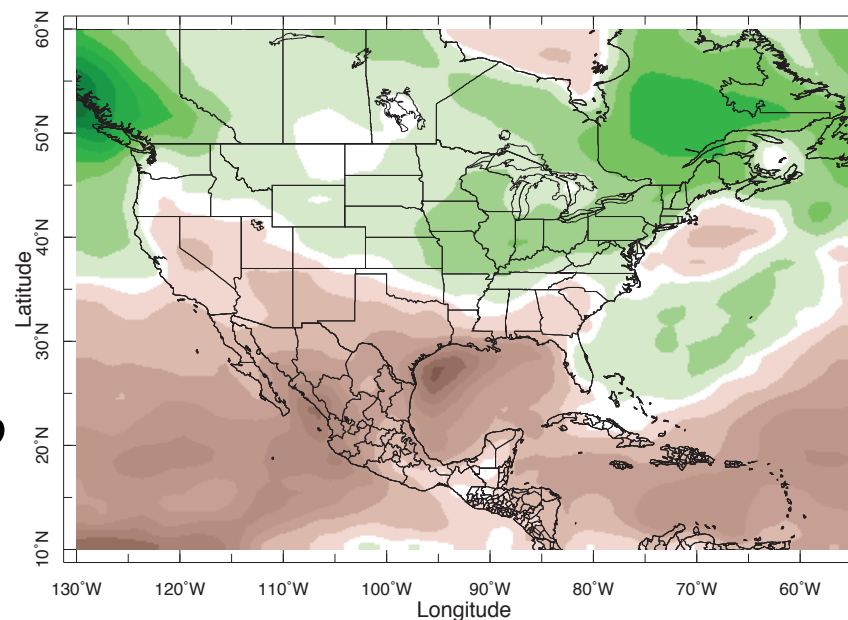
Oct-Mar

Apr-Sep

CMIP3 sresa1b



CMIP5 rcp85



CMIP5 model projected changes in P-E relative to 1950-2000

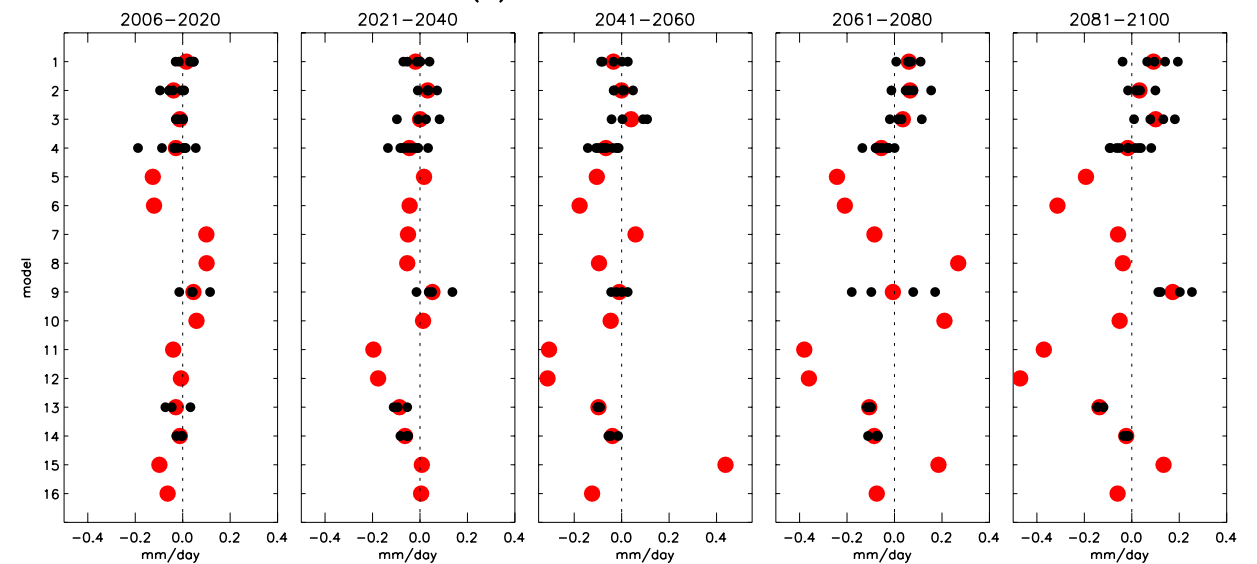
CA&NV

Colorado River
headwaters

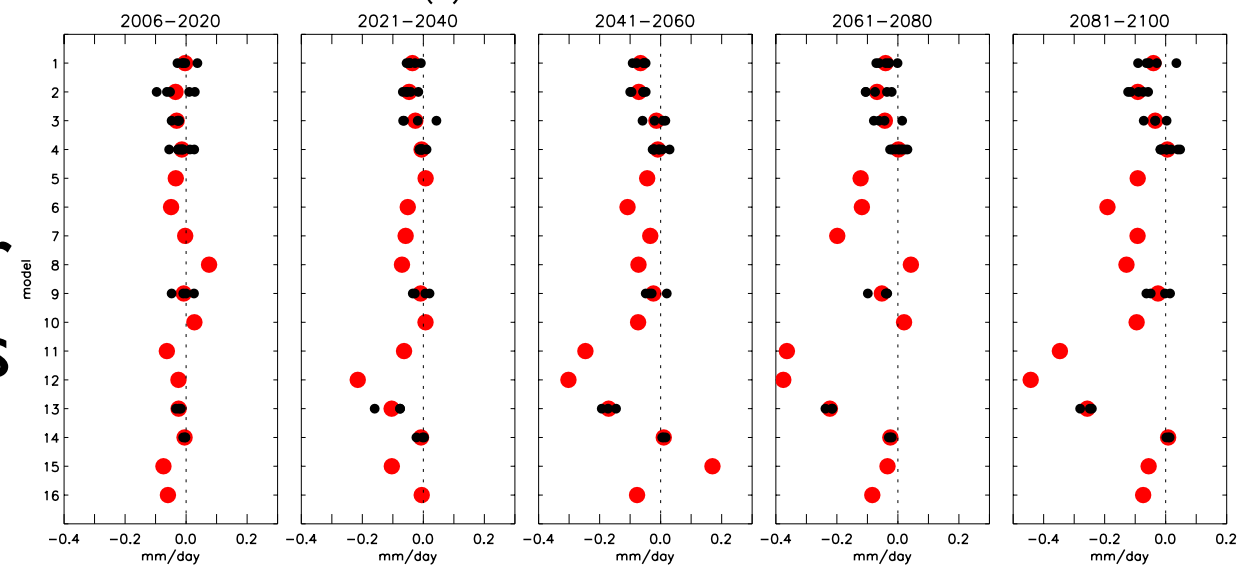
Texas

Precipitation – Evaporation Anomaly (CMIP5/rcp85)

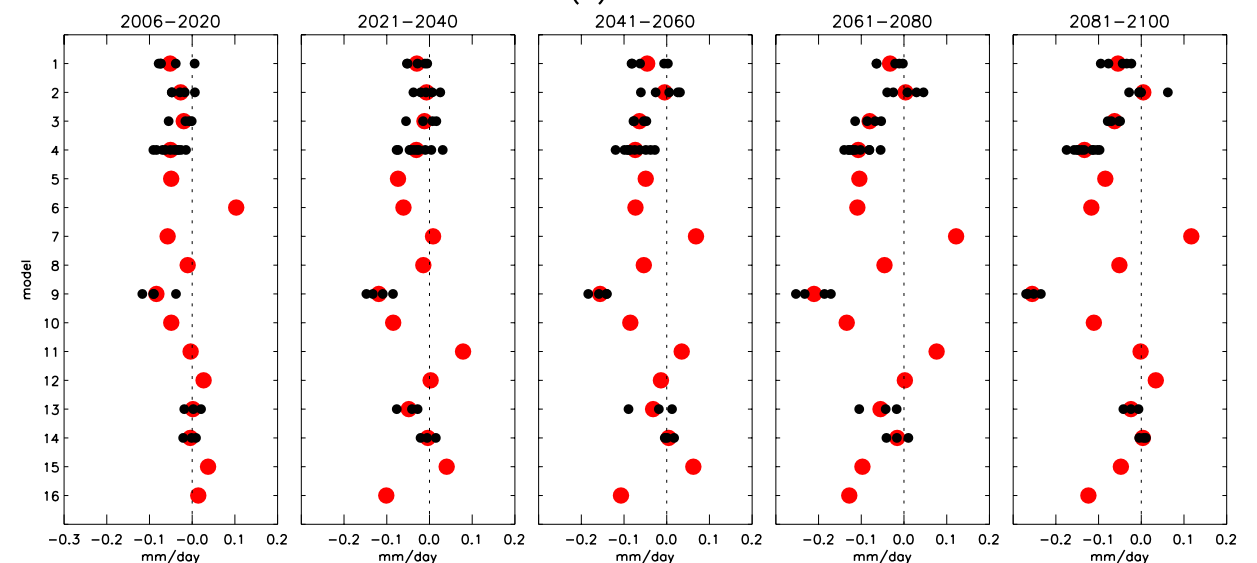
(a). California & Nevada



(b). Colorado River Headwaters

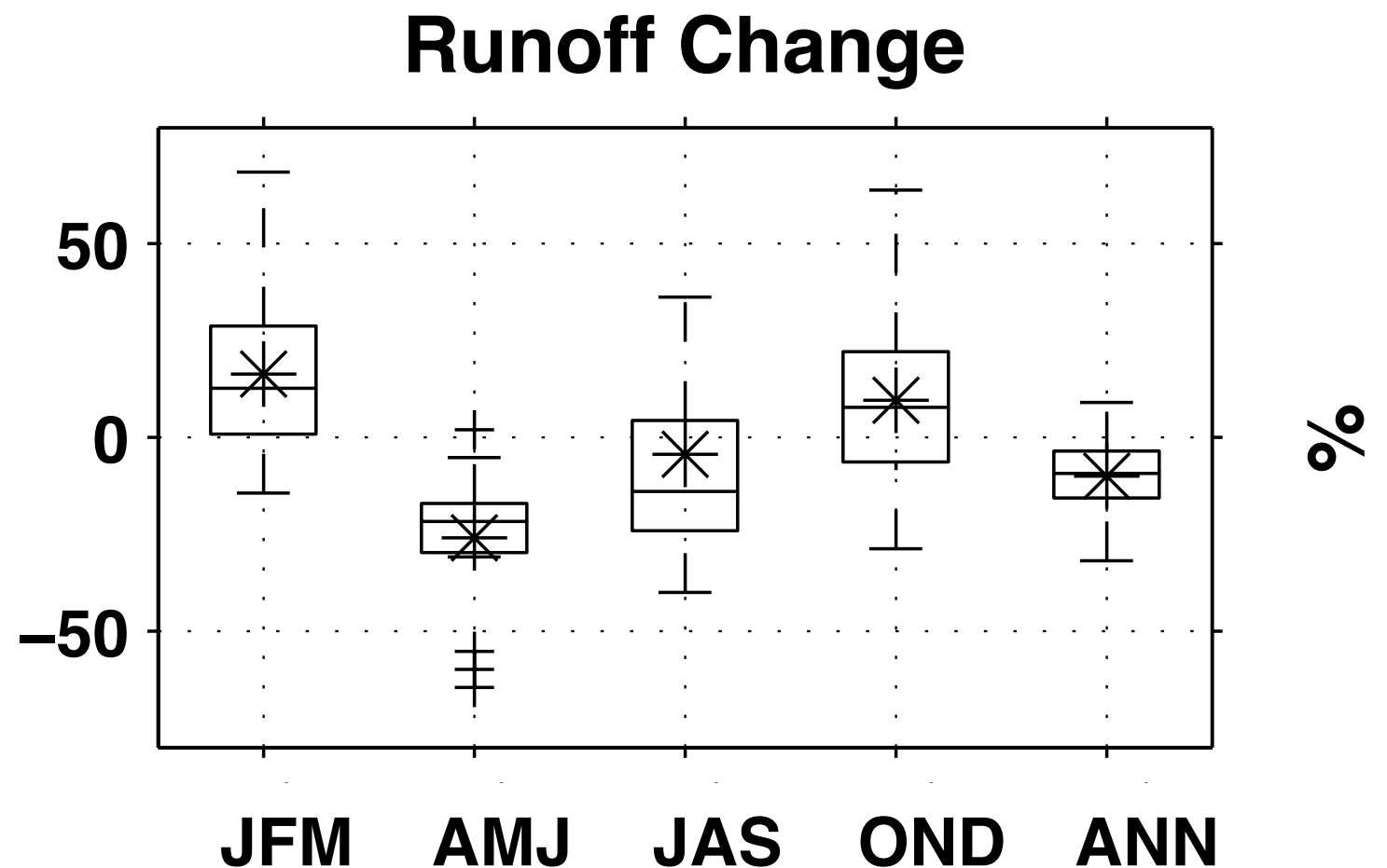


(c). Texas

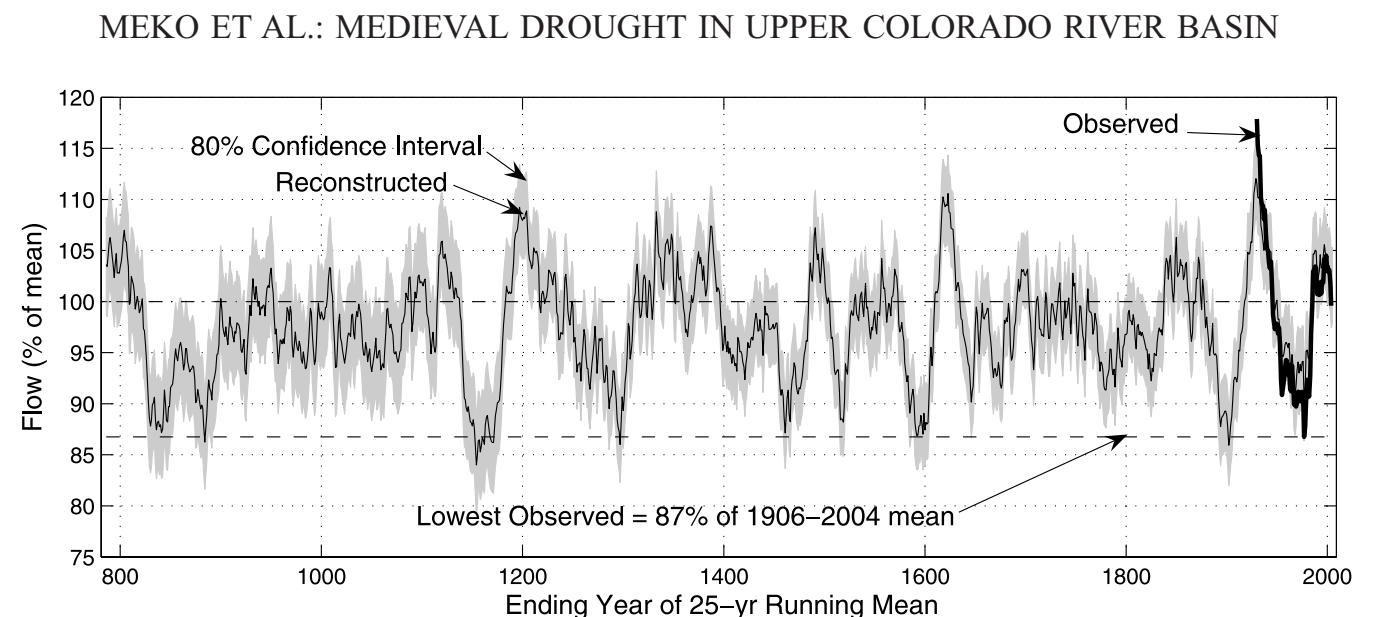


2021-2040 2041-2060 2061-2080 2081-2100

CMIP5 model
projected change in
Colorado River runoff
for 2021-2040 relative
to 1950-2000



Tree ring
reconstructed
Colorado River flow
800-2000

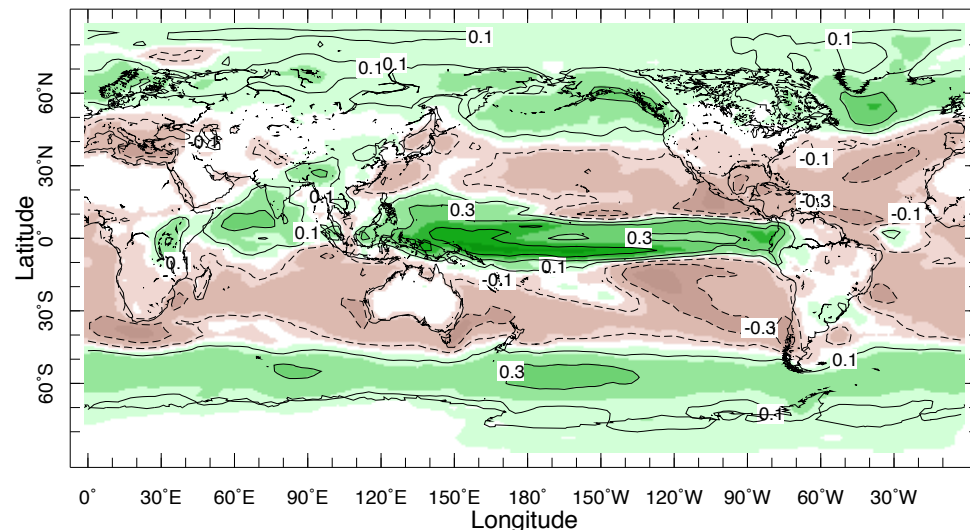


Near term human-induced flow reduction roughly equivalent to
the temporary drop in the 12th Century megadrought

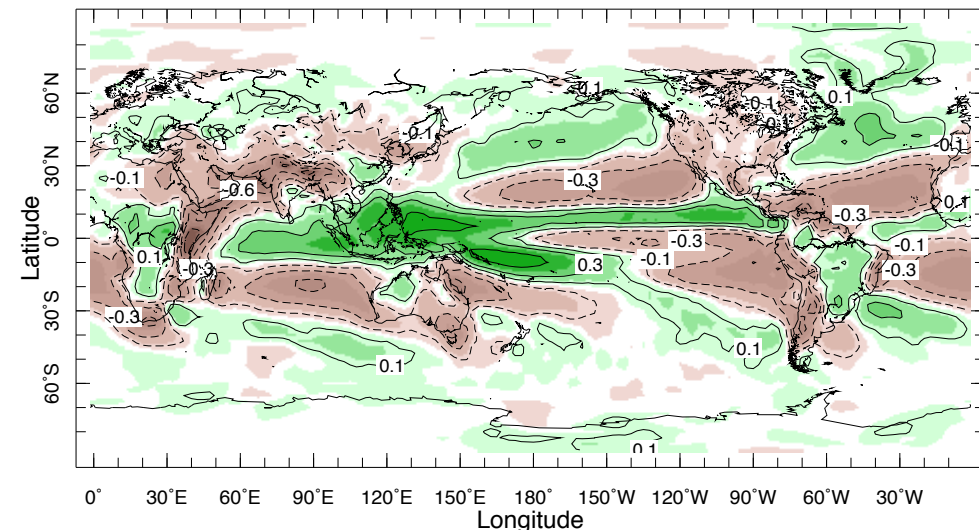
Mechanisms of modeled hydroclimate **change**

MMM - Climate Change

$$\delta(P - E)$$

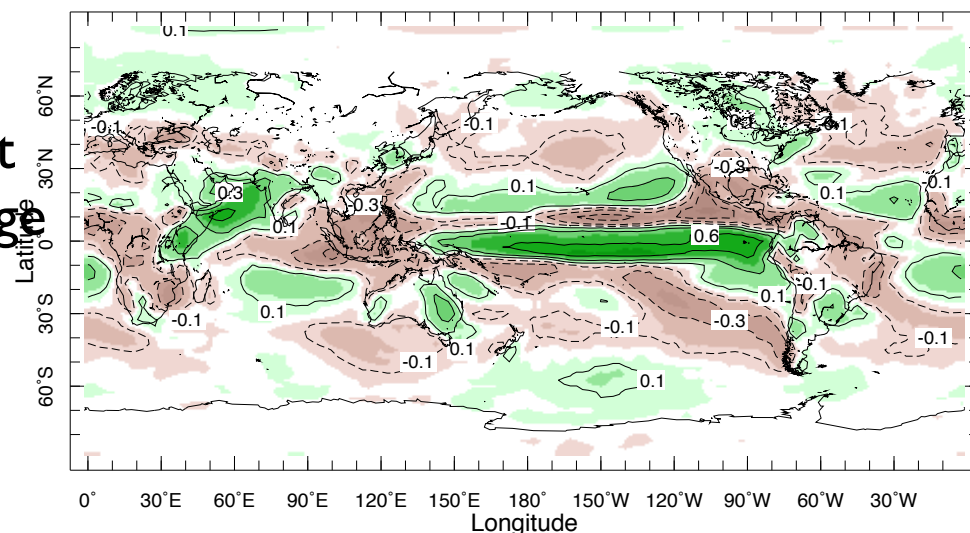


$$\delta TH$$



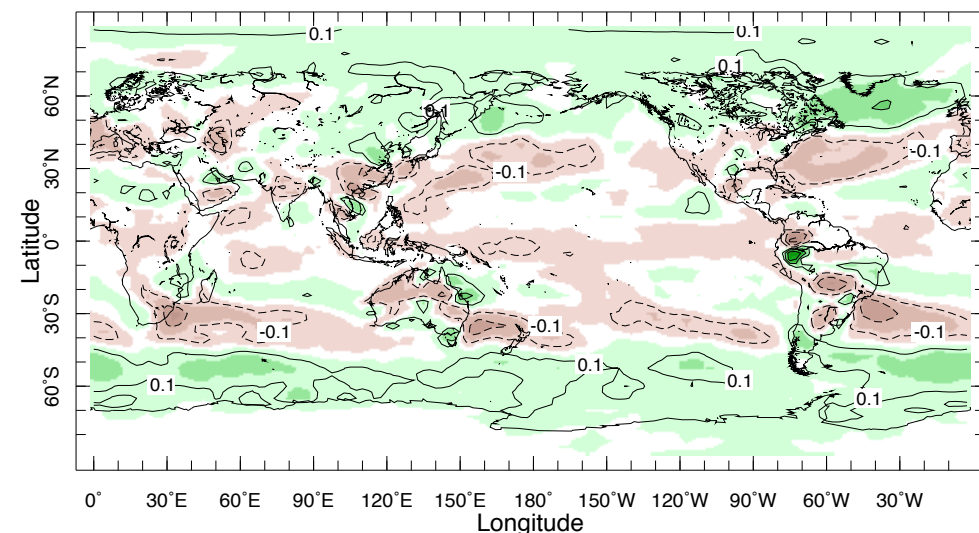
component
due to rising
humidity

$$\delta MCD$$



component
due to change
in mean
circulation

$$\delta TE$$



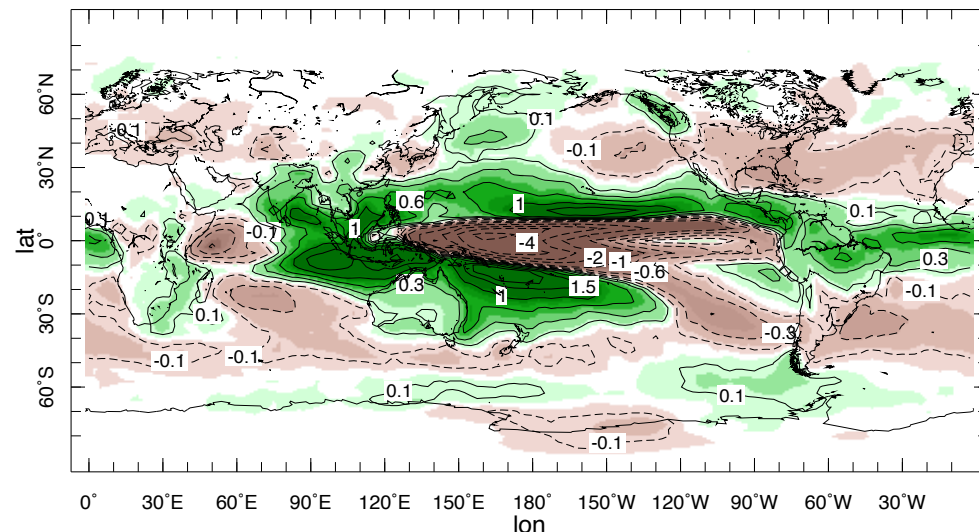
component
due to change
in transient
eddy
transports

Tropical wetting, subtropical drying strongly influenced by rising q and intensified moisture convergence and divergence. Mean circulation change - weaker tropical circulation, Hadley Cell expansion - also important as well as TE intensification and poleward shift. ***‘Thermodynamics mediated.’***

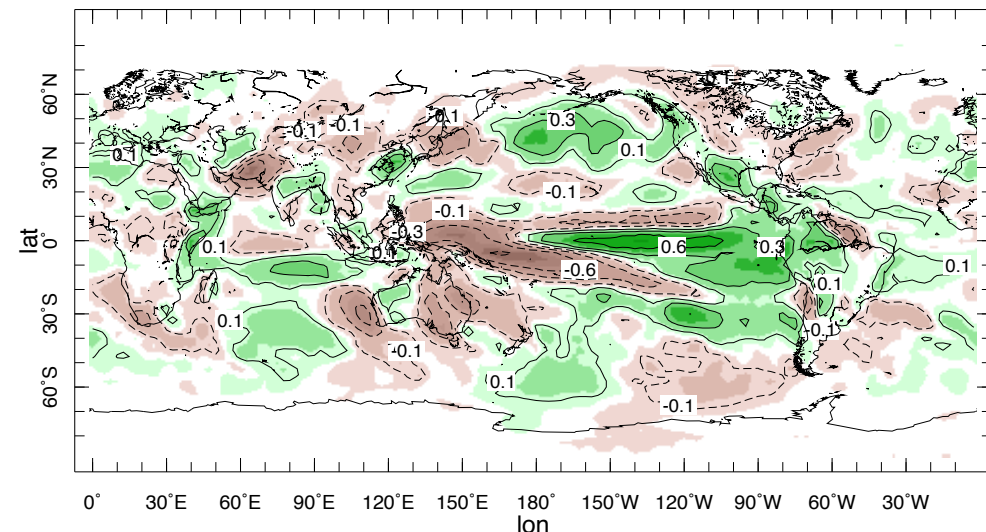
Mechanisms of modeled hydroclimate **variability**

MMM - Natural Variability

$$\delta(P - E)$$

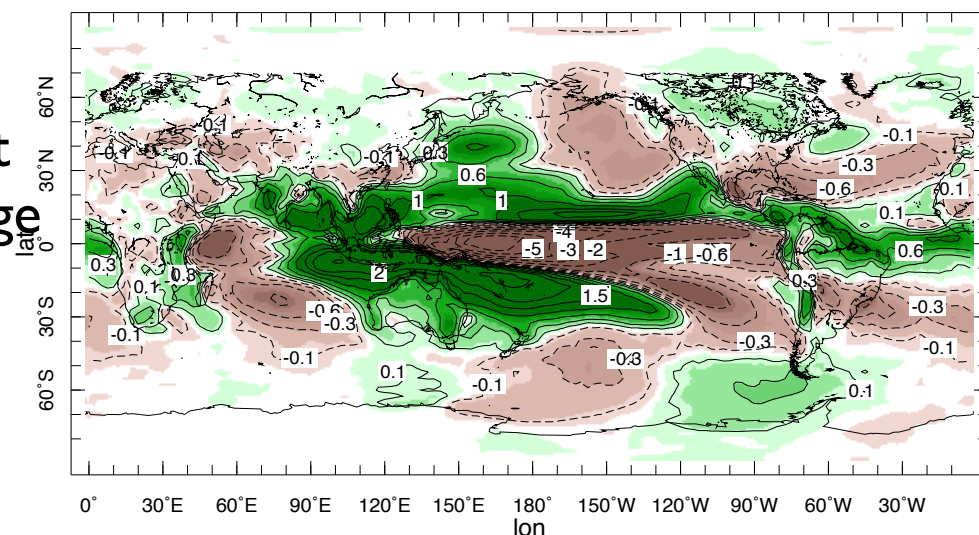


$$\delta TH$$



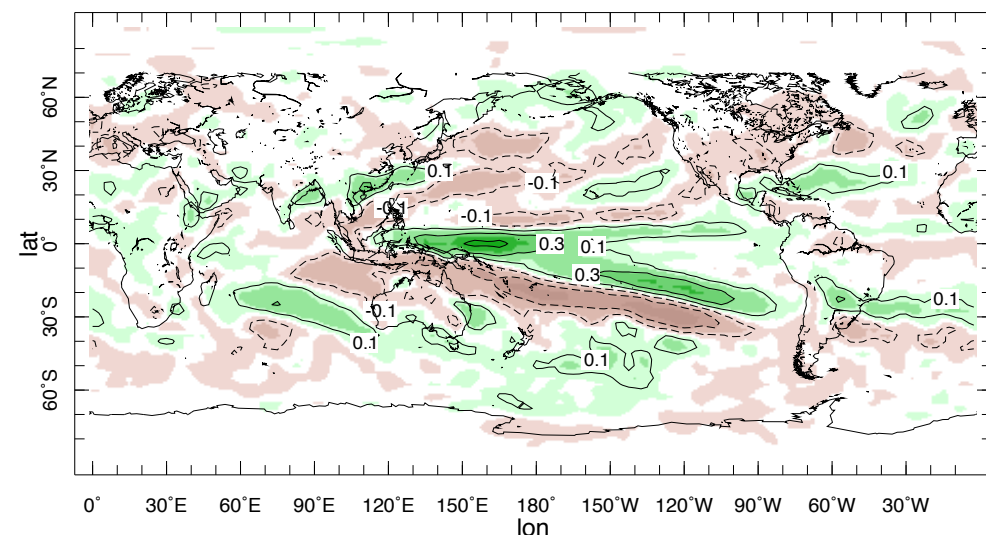
component
due to rising
humidity

$$\delta MCD$$



component
due to change
in mean
circulation

$$\delta TE$$



component
due to change
in transient
eddy
transports

For internal model (and observed) variability - mostly ENSO - thermodynamic contribution is weak and $P-E$ is ***‘Dynamics dominated’***.

Using mechanisms to understand recent hydroclimate variations in atmospheric data sets

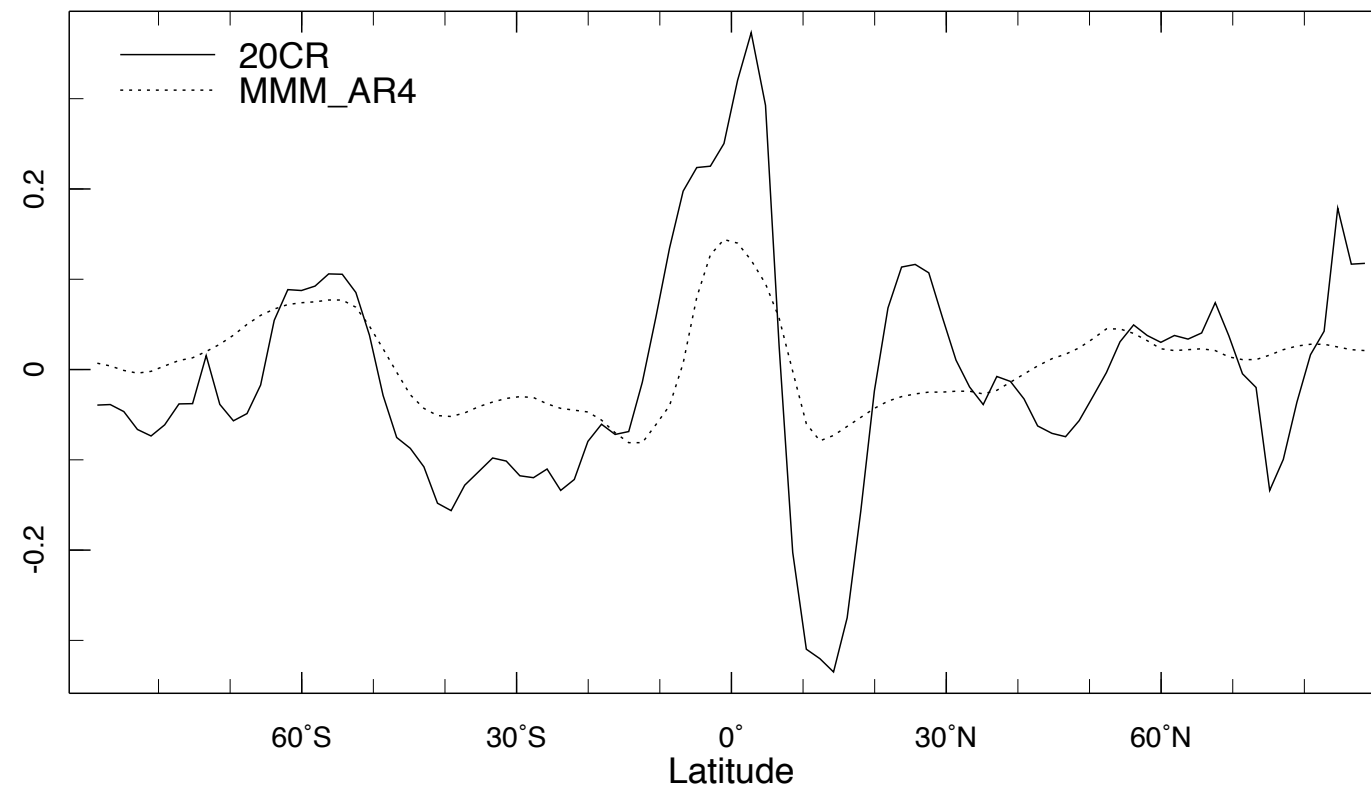
Observations-based atmospheric data sets - the 20th Century Reanalysis (20CR) - support the models' indication that natural variability of P-E is 'dynamics dominated' i.e. caused by circulation anomalies.

- Remove ENSO variability from the 20CR
- Examine trend in residual
- Compare it - and its driving mechanisms - with what models predict the radiatively-driven trend to date should have been

Radiatively-forced models (IPCC AR4) and ENSO-removed 20CR residual 1979-2008 trends

Zonal mean trends for 20CR residuals and AR4 MMM

$P - E$



‘Observed’ and modeled $P-E$ trends have some agreement
(agreement on importance of circulation change in tropics, thermodynamic contribution to wet-get-wetter, dry-get-drier)

I.e., at the planetary scale, the hydrological cycle over is evolving as models predict it should due to changing CO₂, CH₄, O₃ etc.
Regional attribution much harder.

Conclusions

Historical multiyear droughts forced by tropical Pacific (always) and Atlantic (sometimes) multiyear SST anomalies.

Crop failure and dust storms made Dust Bowl drought worse and shifted it northward.

Medieval megadroughts also influenced by active dunes and dust. Also tropical SST-forced? Need better SST reconstructions for last millennium!

GHG-driven drying of southwest North America mechanistically distinct from natural drought.

GHG-driven climate change will reduce runoff across SW including CA/NV, Colorado headwaters, Texas by appreciable amounts in near term future.

Global subtropical drying and expansion of subtropical dry zones is underway consistent with IPCC AR4 model projections.