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

Richard Seager
Lamont Doherty Earth Observatory of Columbia University, Palisades, New York

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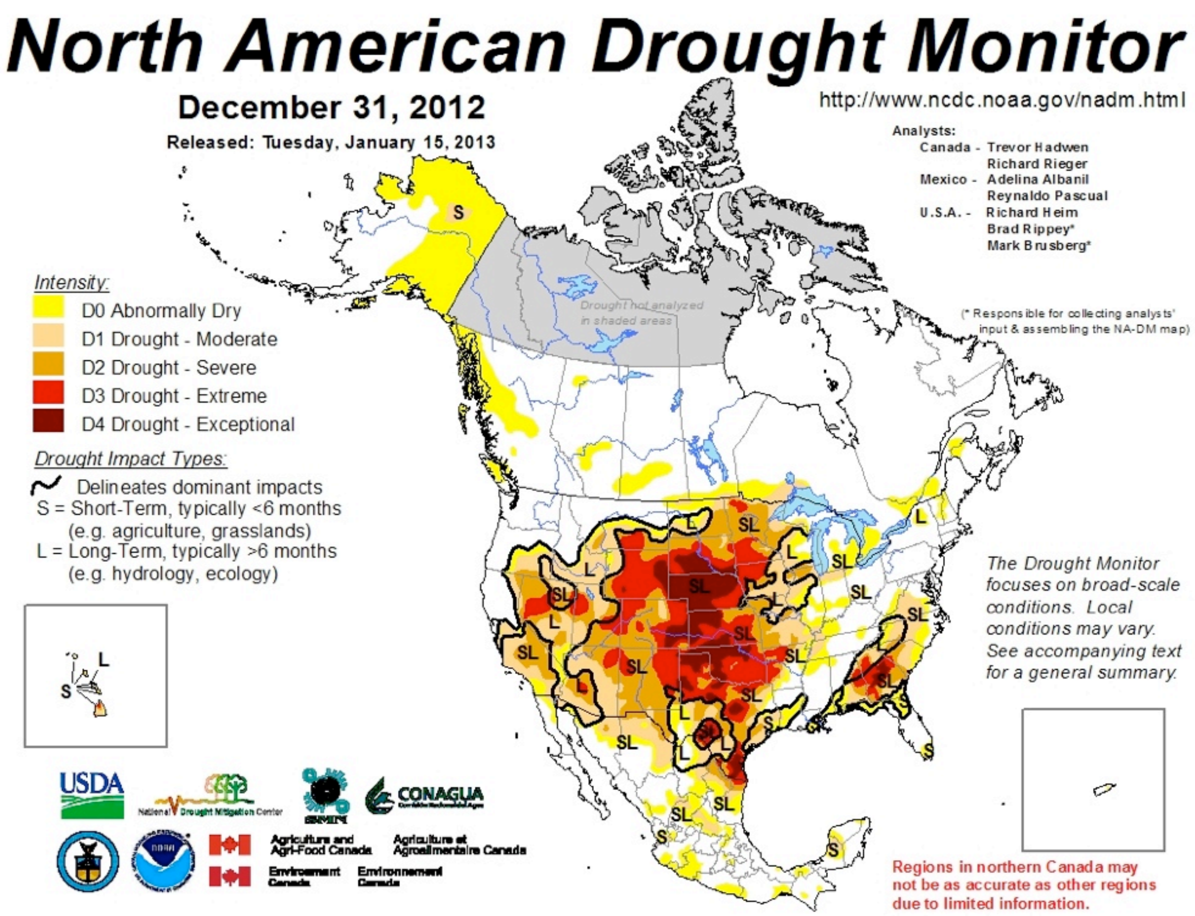
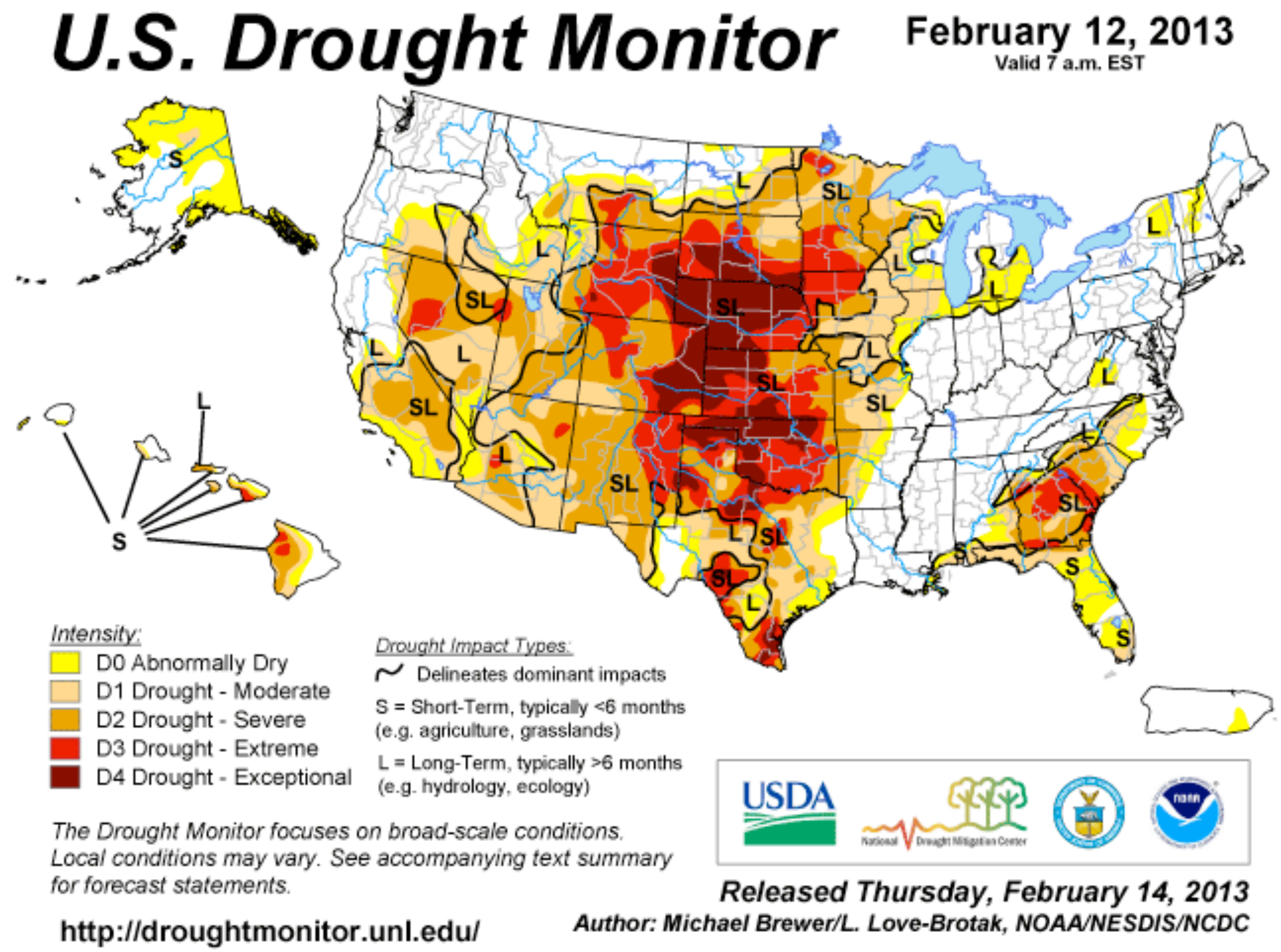
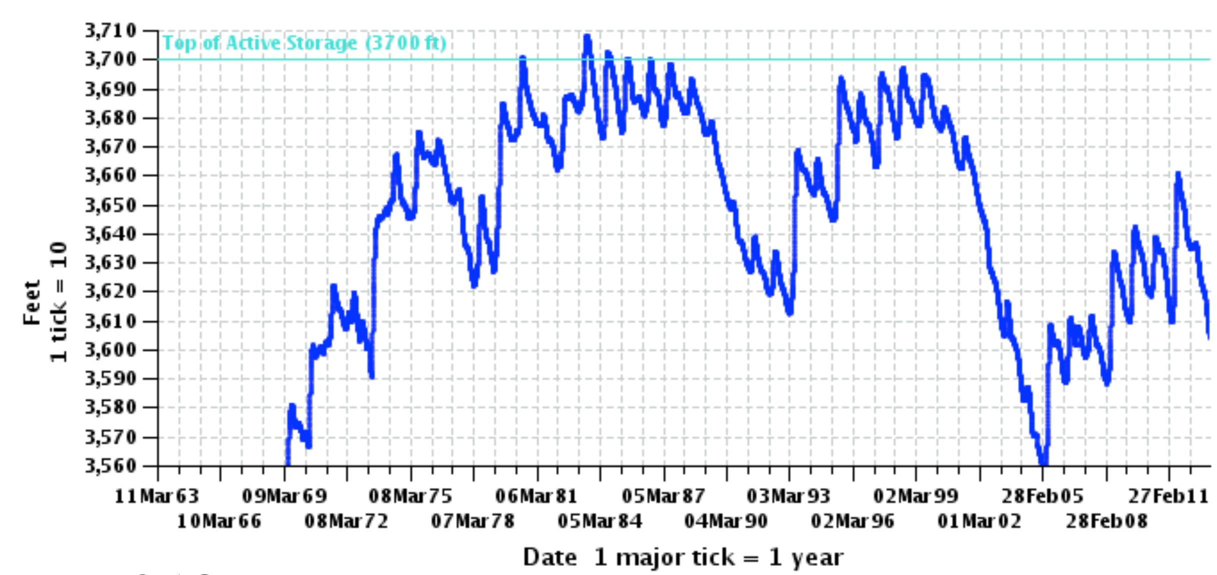
North American drought as of now



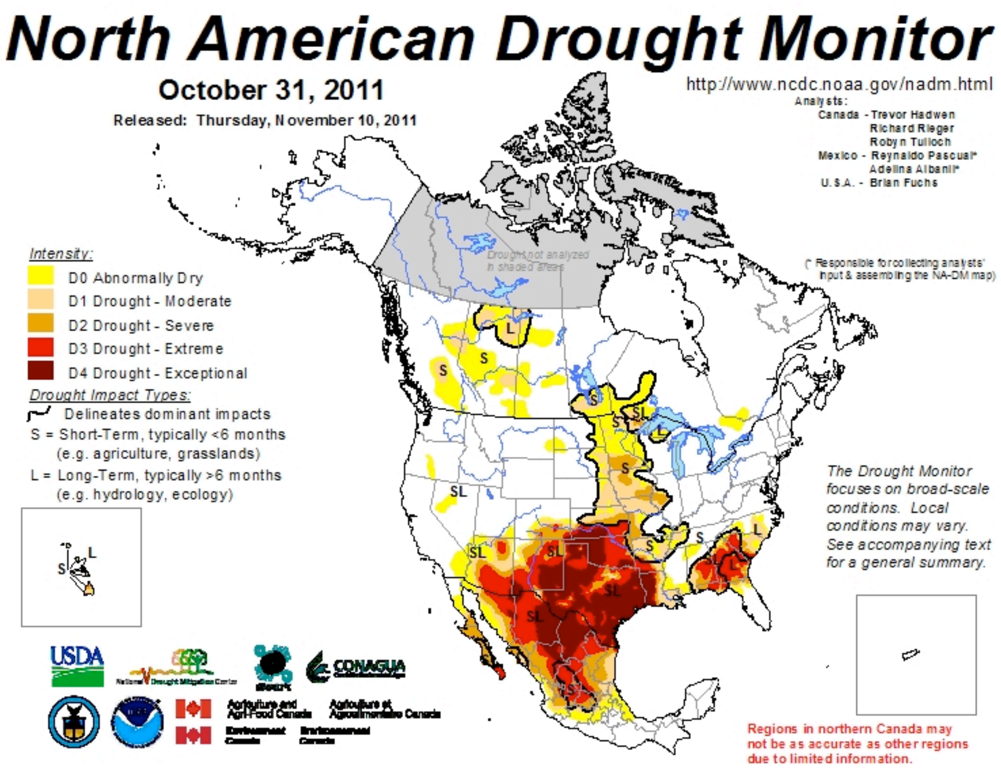


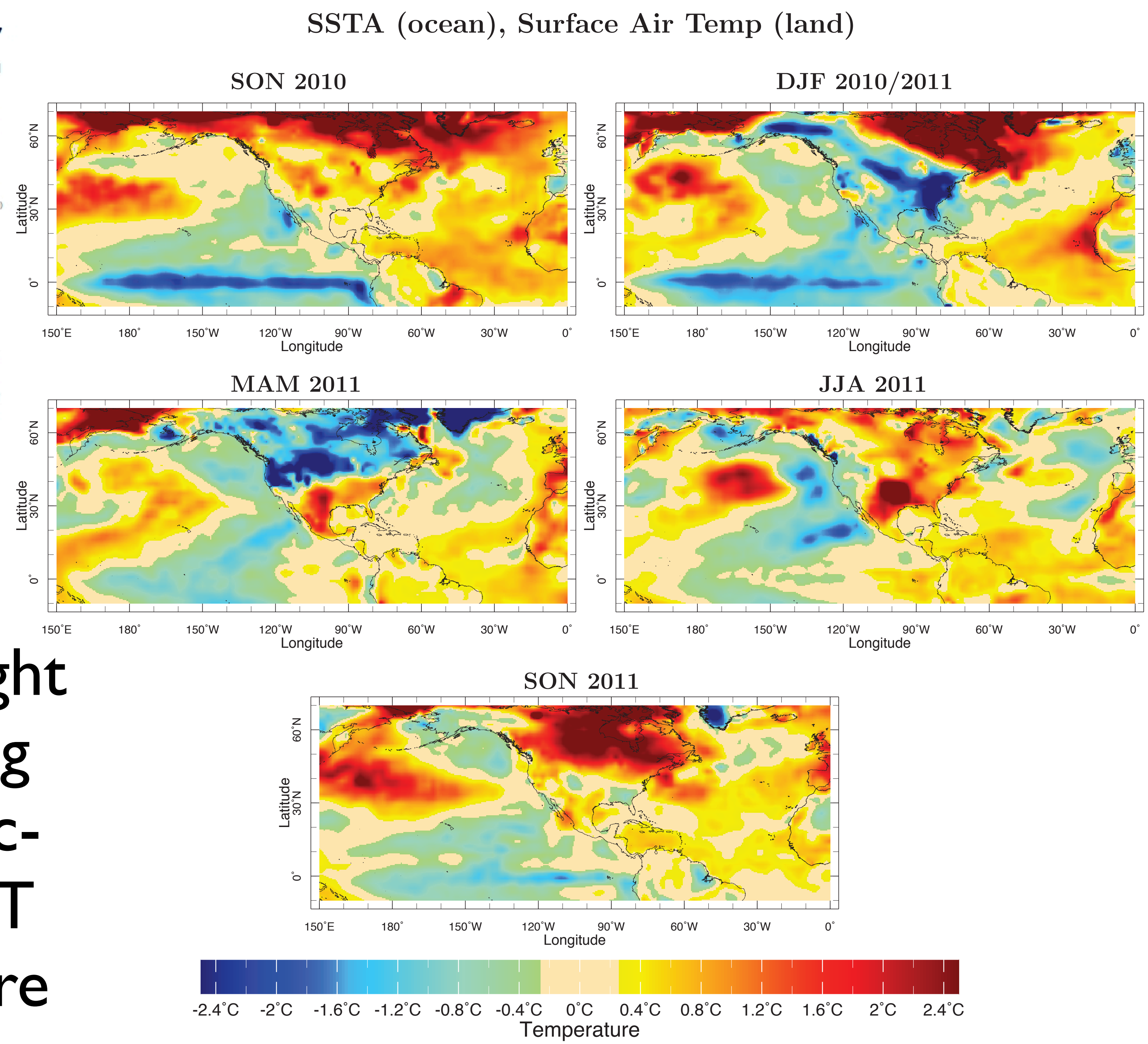
Widespread severe to exceptional droughts in Plains and West. Continued long term (since 1998) shortfall of water storage on Colorado River



1963 2013

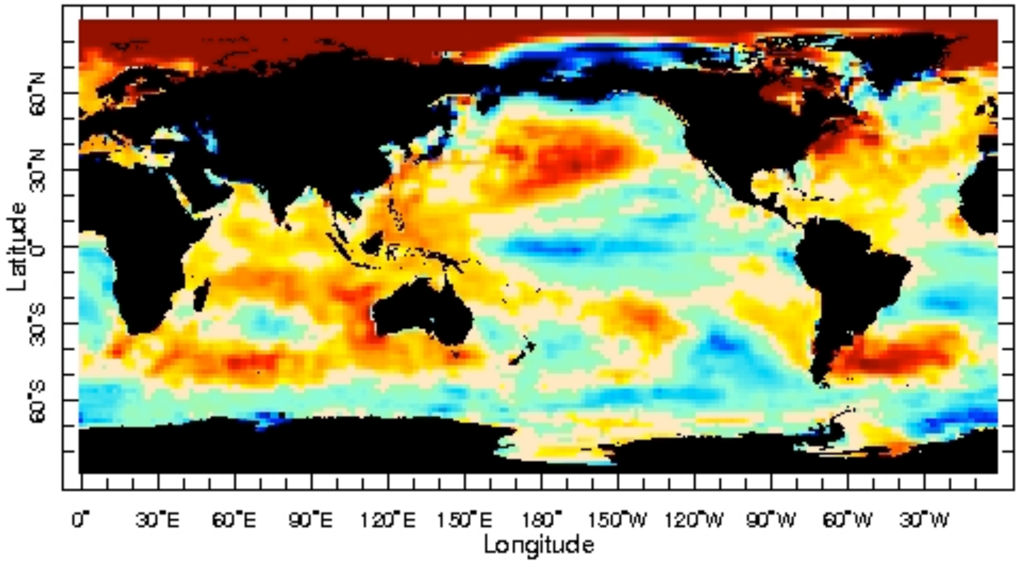
Lake Powell pool elevation



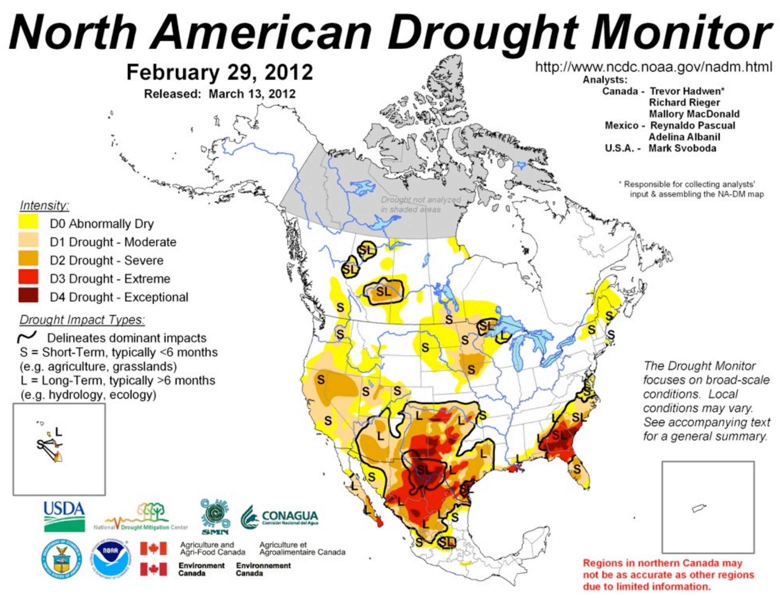


The current TexMex drought emerged in fall 2010 along with a cold tropical Pacific-warm tropical Atlantic SST pattern. By fall 2011 severe TexMex drought.

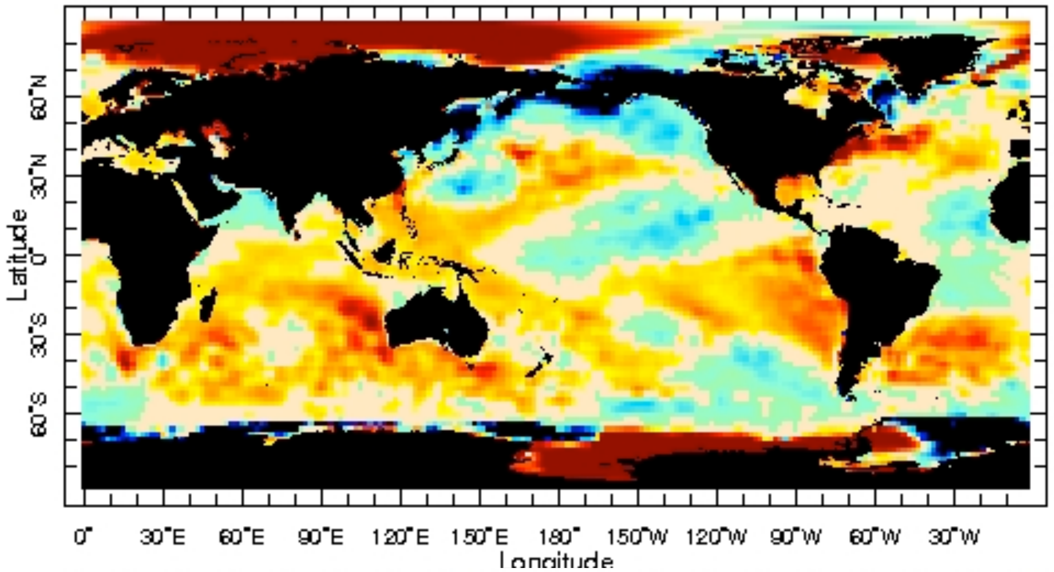
SST anomaly



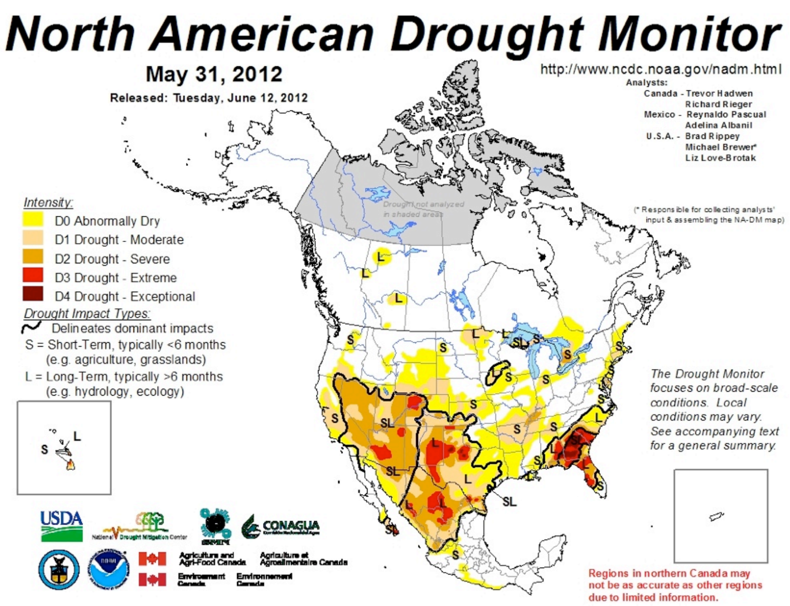
DJF
2011/2



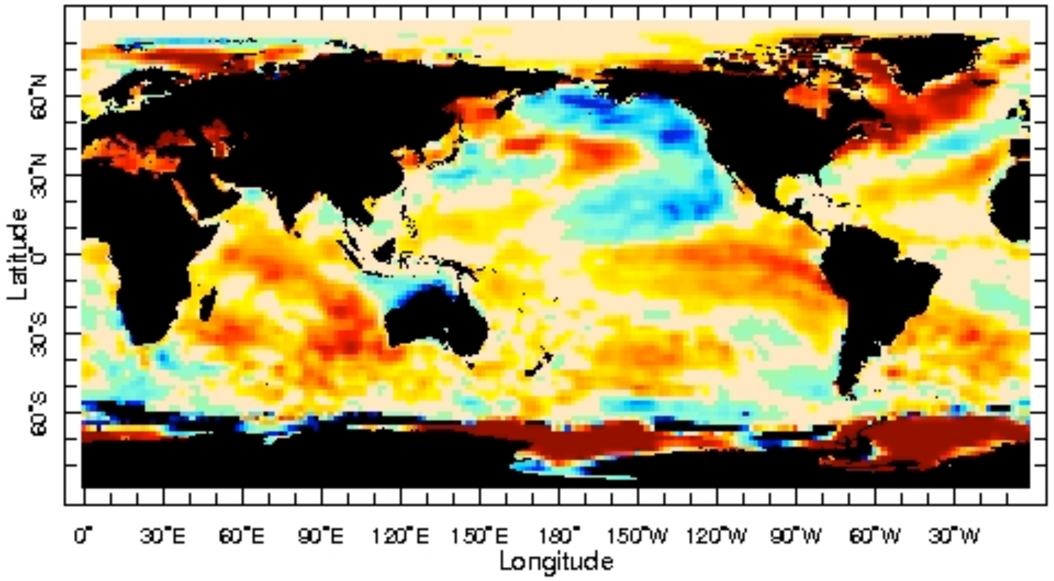
Continued La Nina



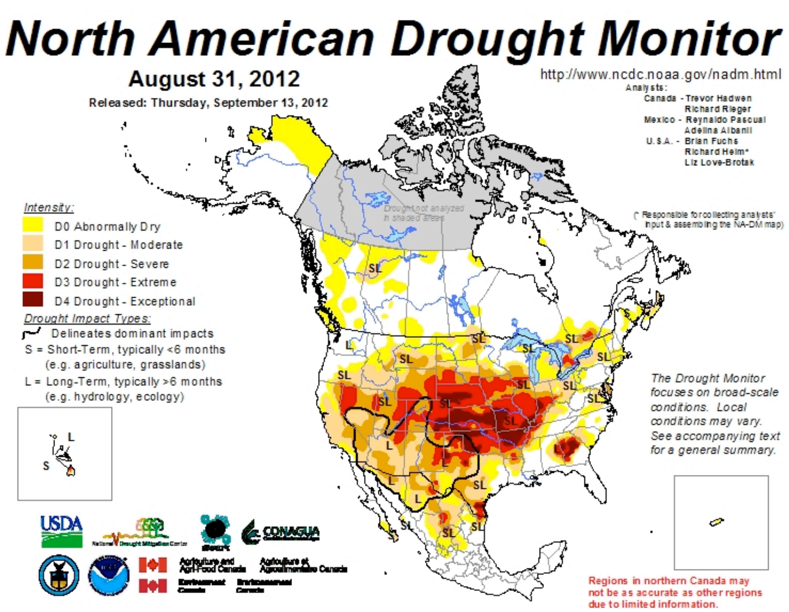
MAM
2012



atmosphere-only variability?

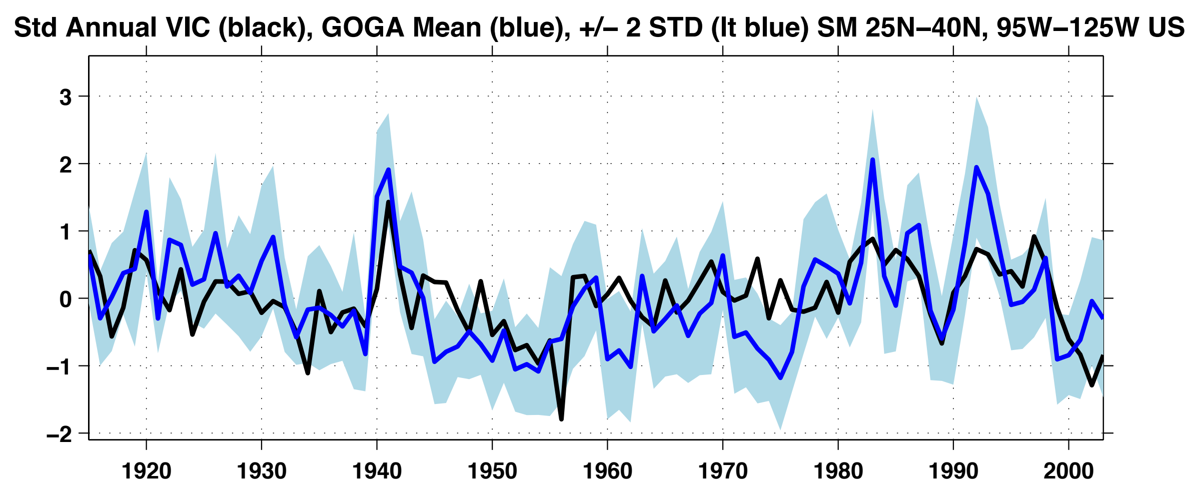


JJA
2012

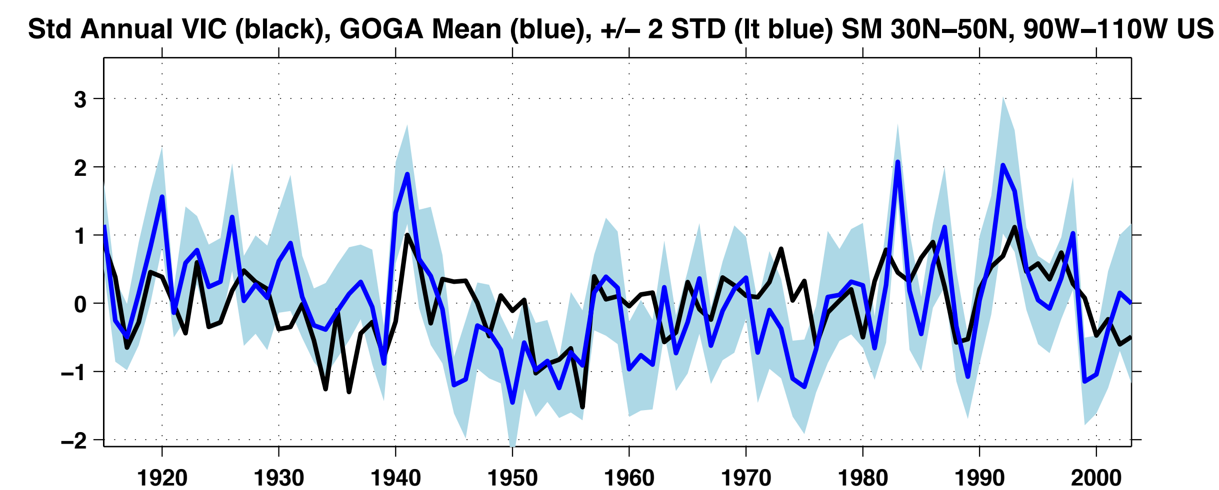


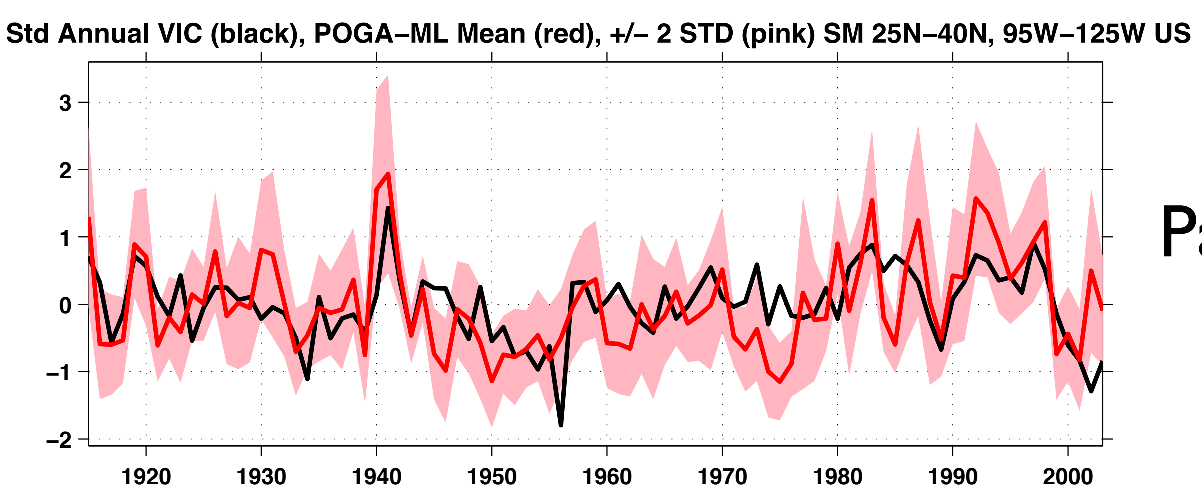
Association of NA drought with cold tropical Pacific - La Nina - SST anomalies is typical - has worked for more than a century

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

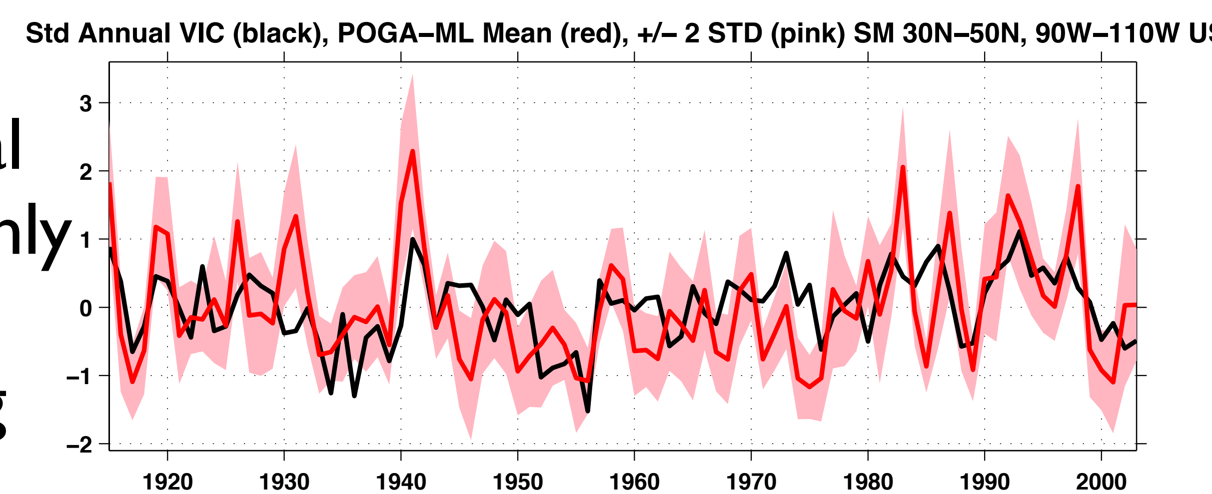


Global SST forcing





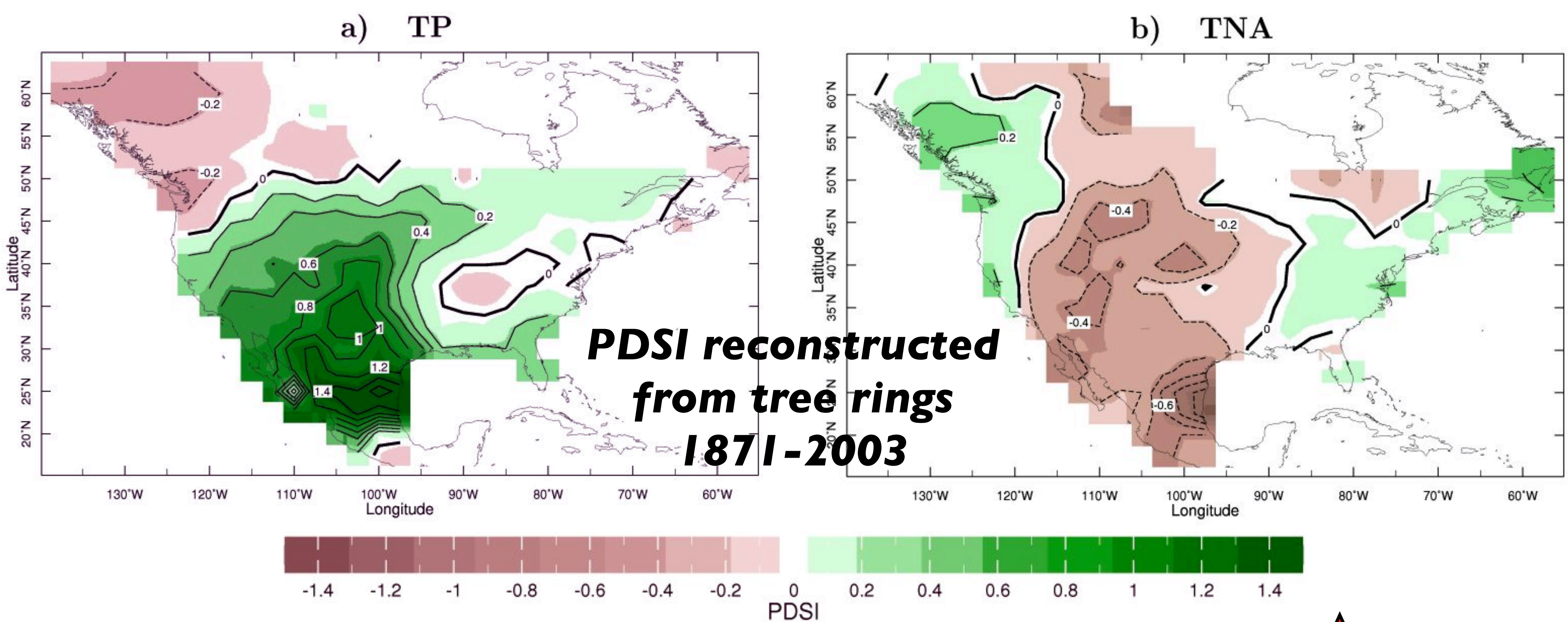
Tropical Pacific only SST forcing



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 ↑

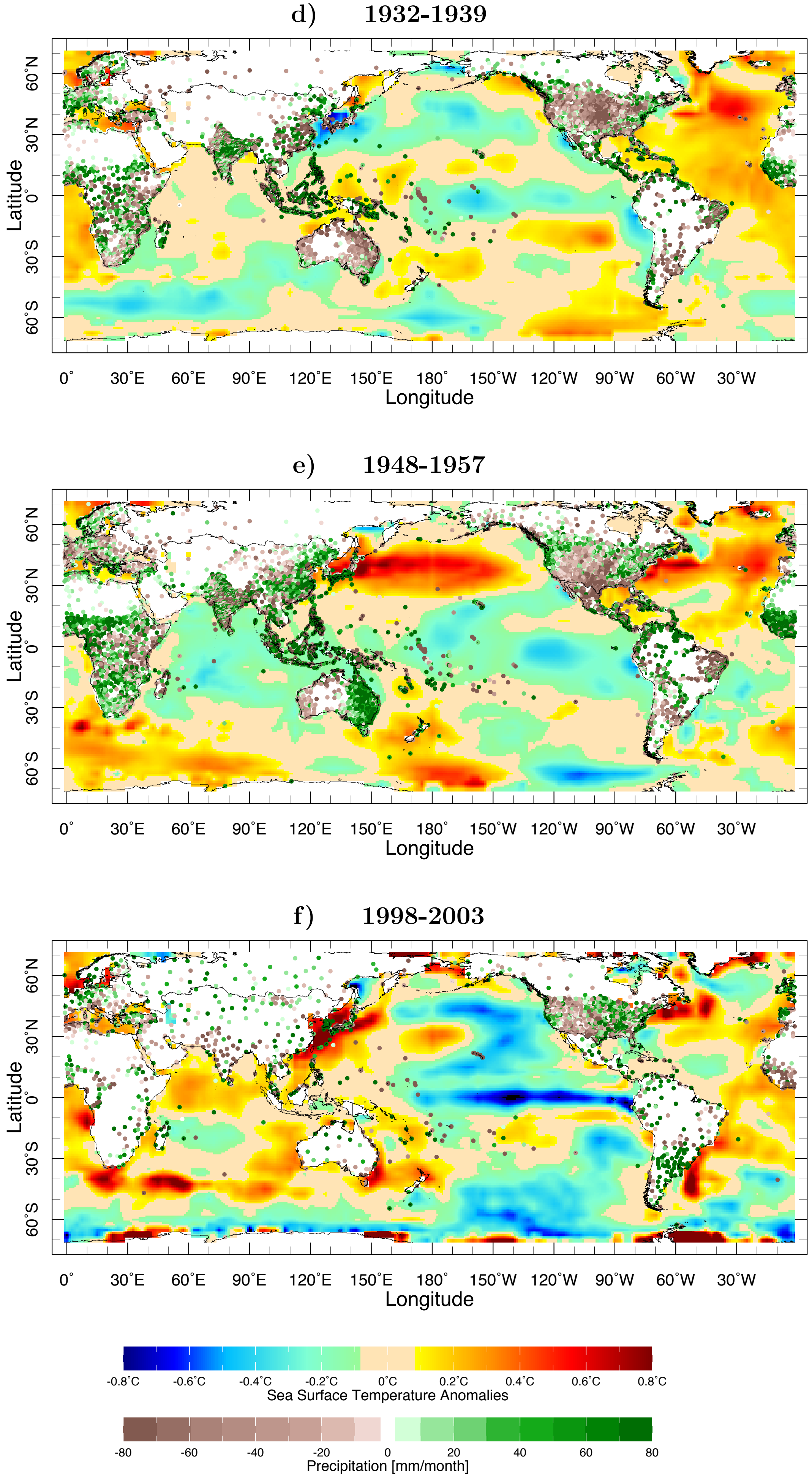
Tropical North Atlantic SST ↑

SW PDSI ↓

Cold tropical Pacific - warm tropical North Atlantic

perfect ocean for drought

GOGA SSTA (global mean removed) and GHCN station precipitation



The Dust Bowl

The 1950s

Turn-of-the-century

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

-Widespread drought in northern and southern mid-latitudes

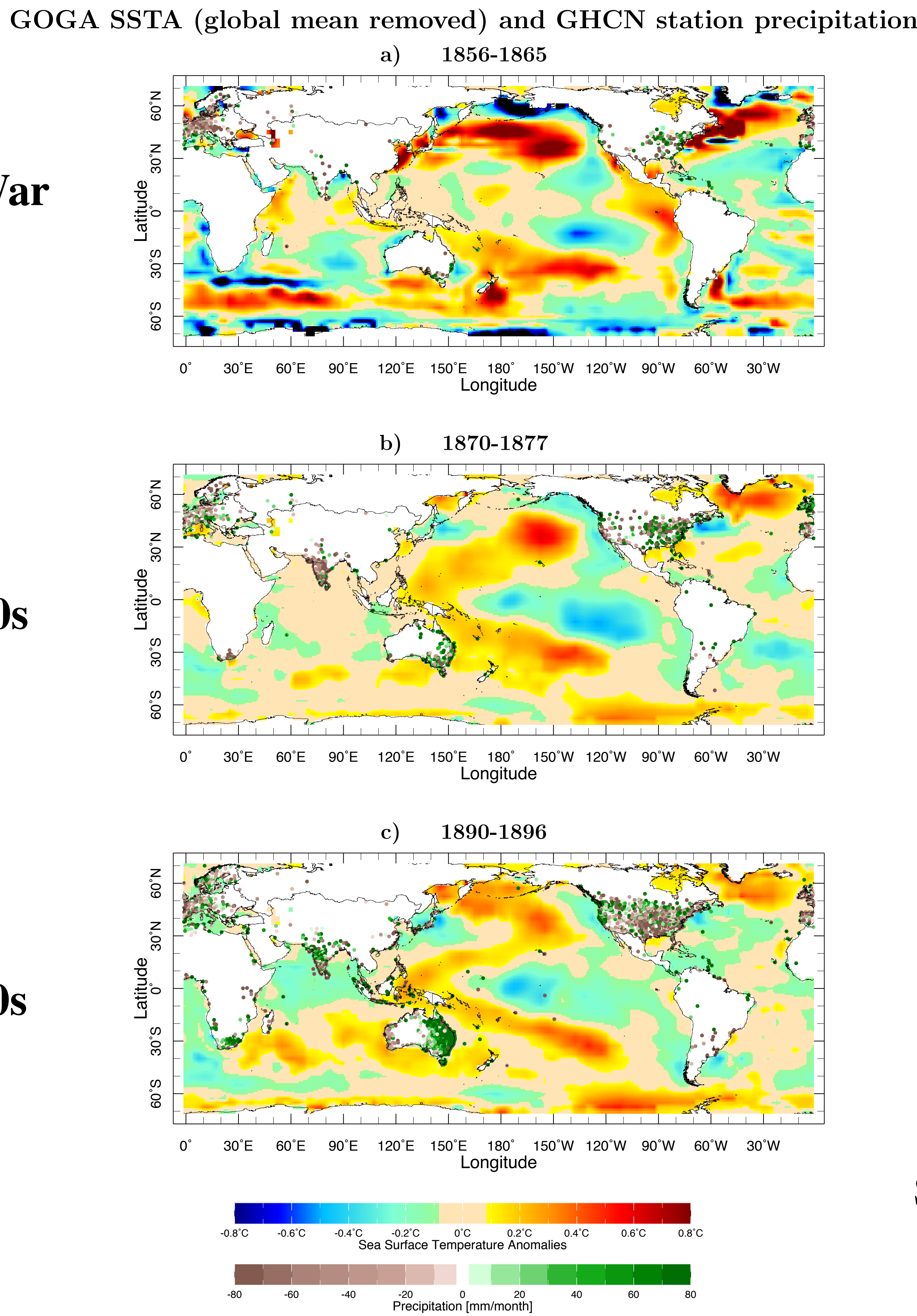
- In the SST, the common feature is a cold equatorial Pacific - La Nina

SST from ships, rain from gauges

The Civil War drought

The 1870s

The 1890s

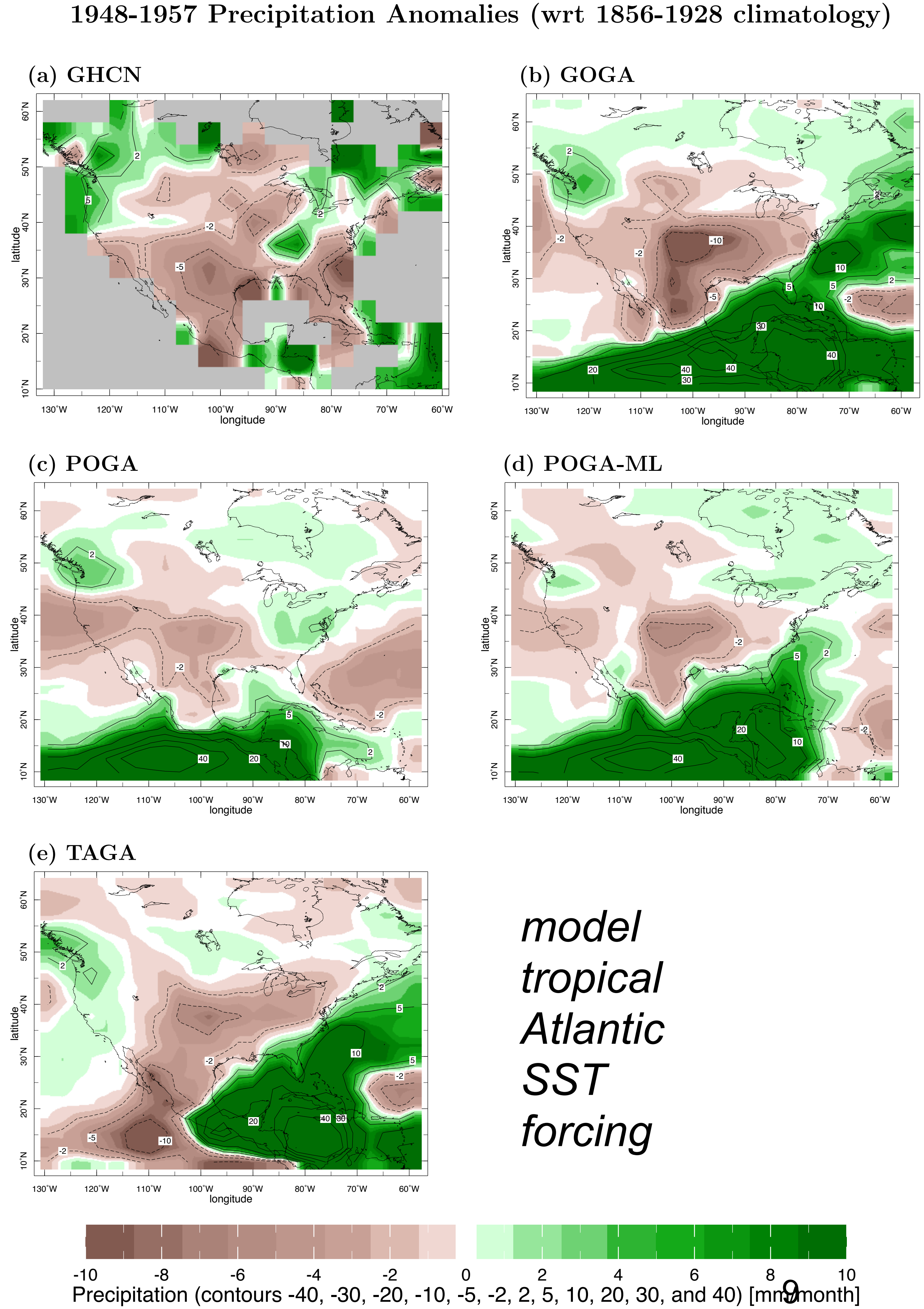


The same global hydroclimate regimes are seen in the mid to late 19thC North American droughts

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

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 ...



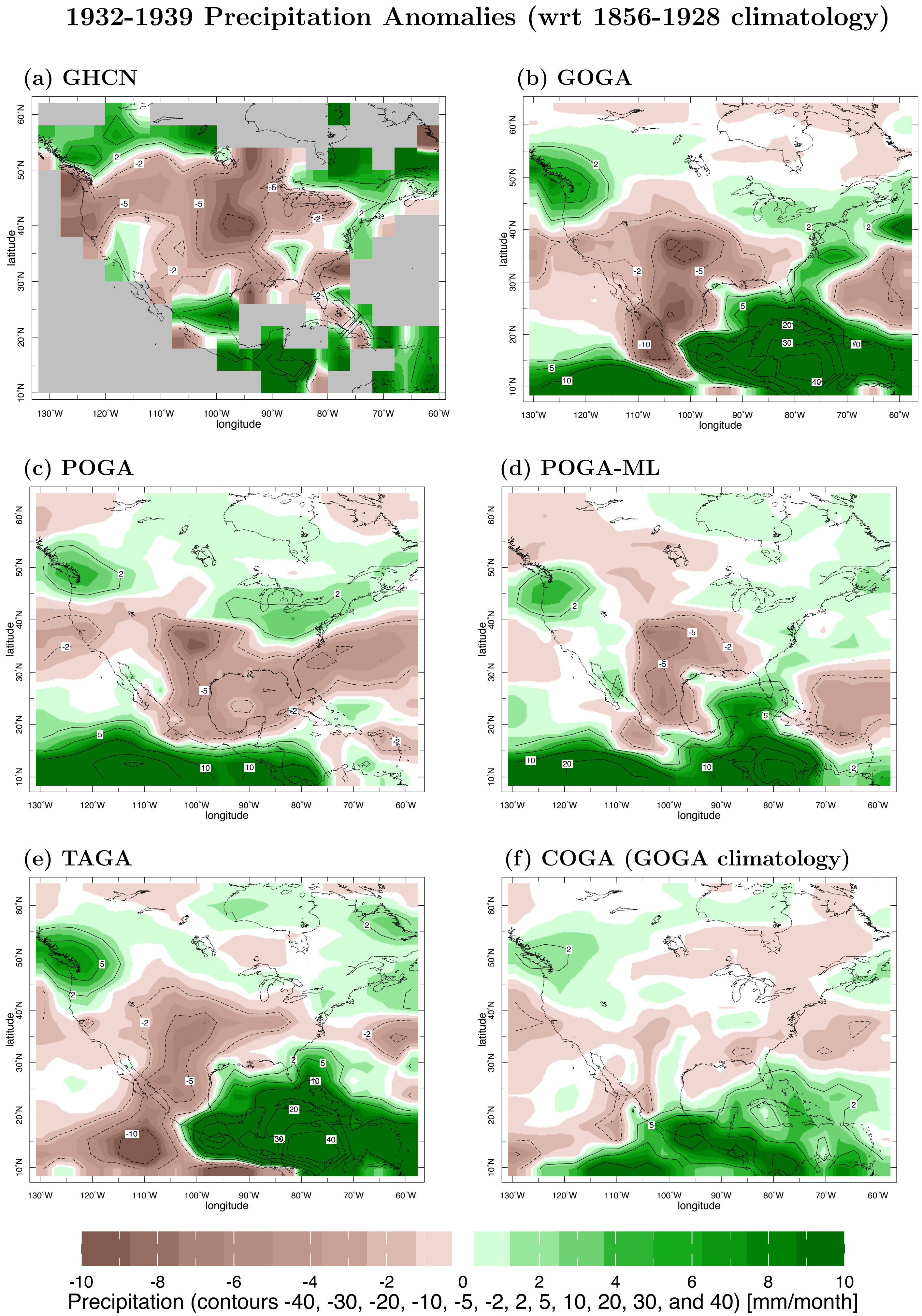
model global SST forcing

model tropical Pacific SST forcing

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

model global SST forcing

model tropical Pacific SST forcing

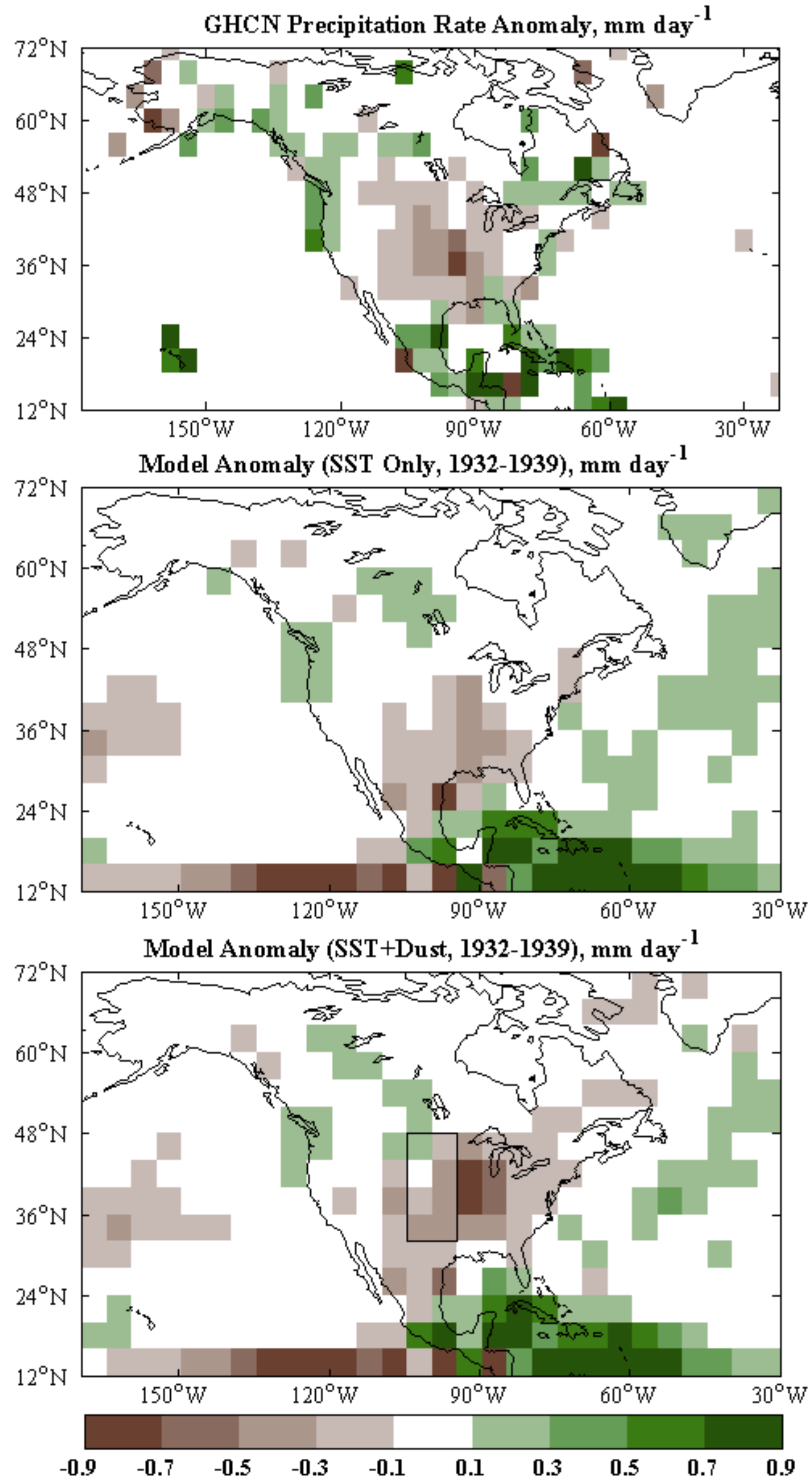
model tropical Atlantic SST forcing

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

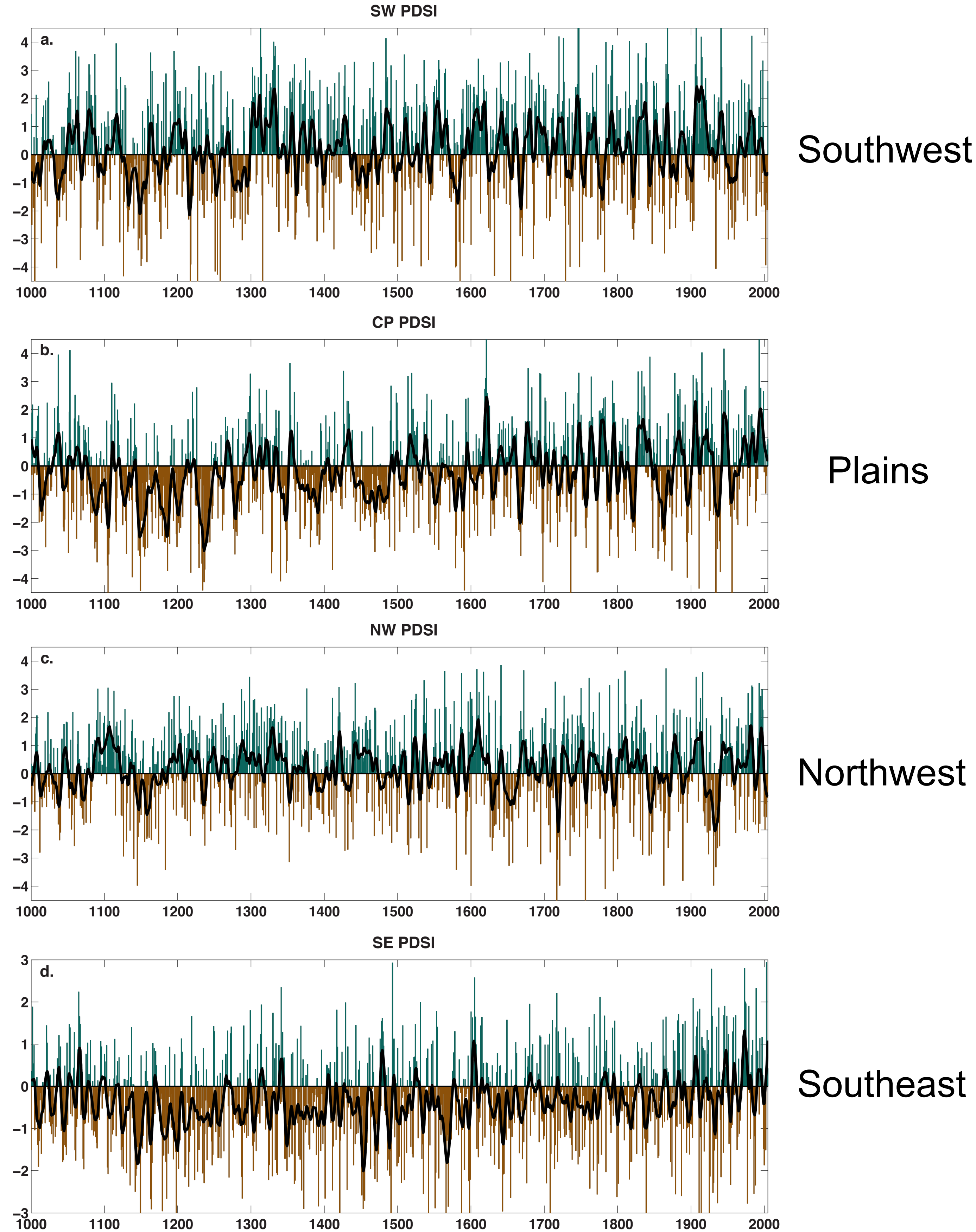
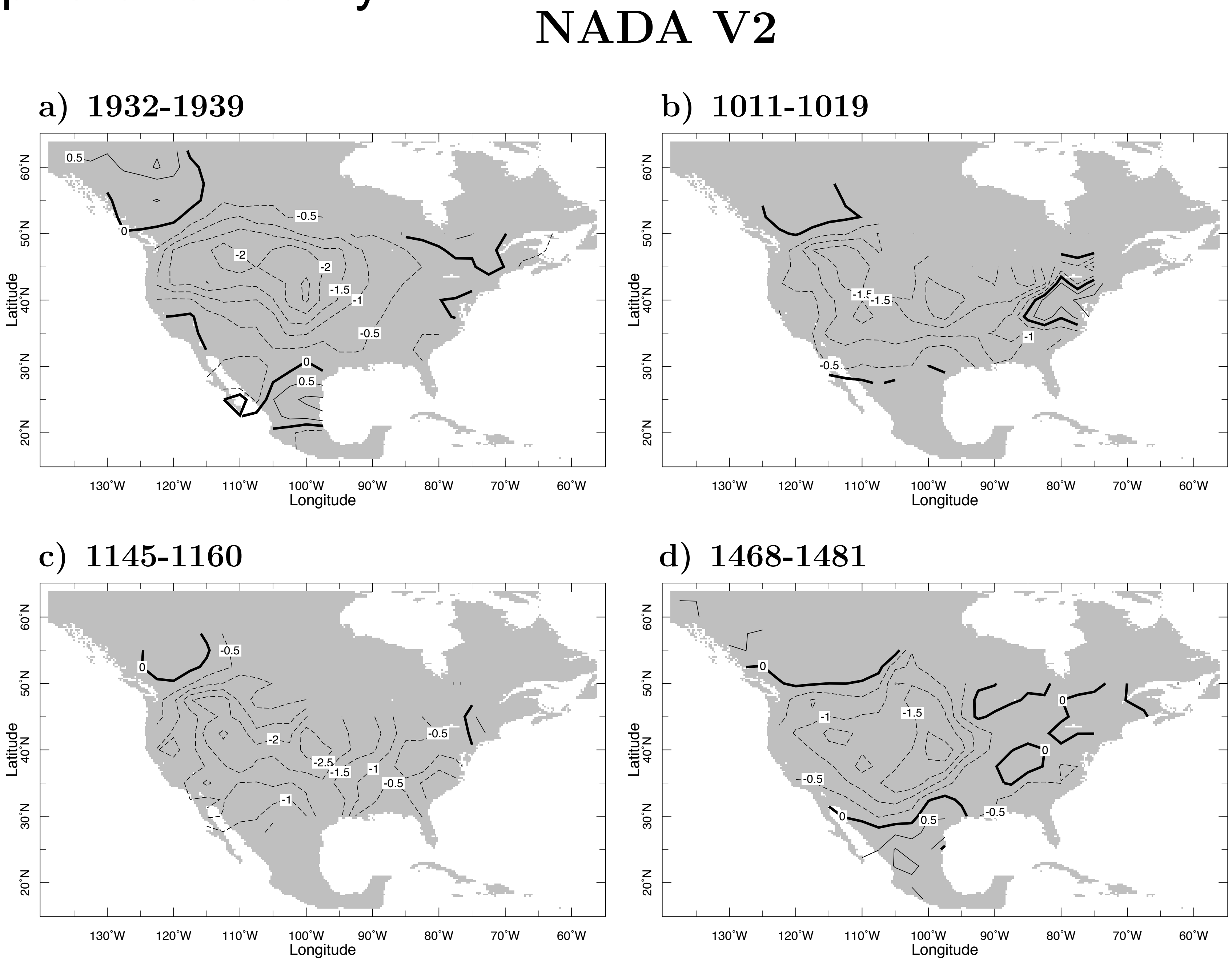


Fig. 3. Area averaged PDSI from the NADA for the SW (a), CP (b), NW (c), and SE (d) regions, as shown in Figures 1 and 2. Green and brown bars are the original data, and dark black lines are a smoothed version of the time series using a 10-year LOWESS spline.

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?

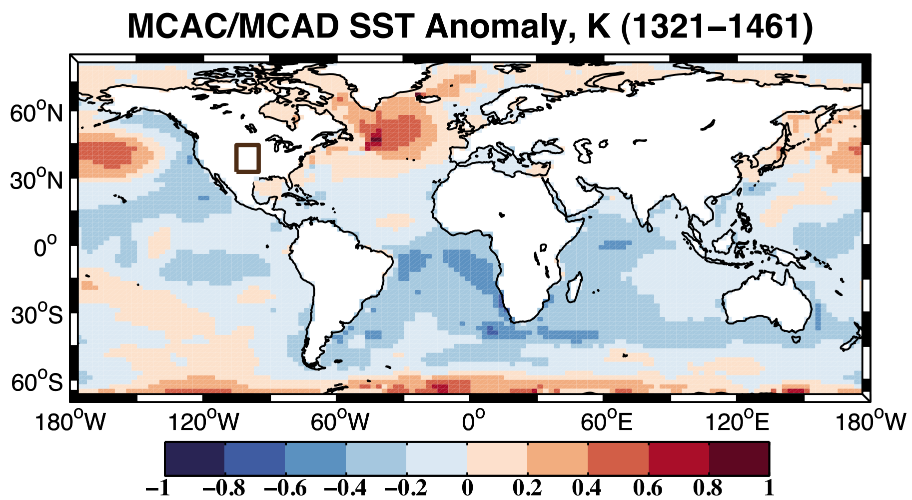
Tree ring reconstructed summer Palmer Drought Severity Index

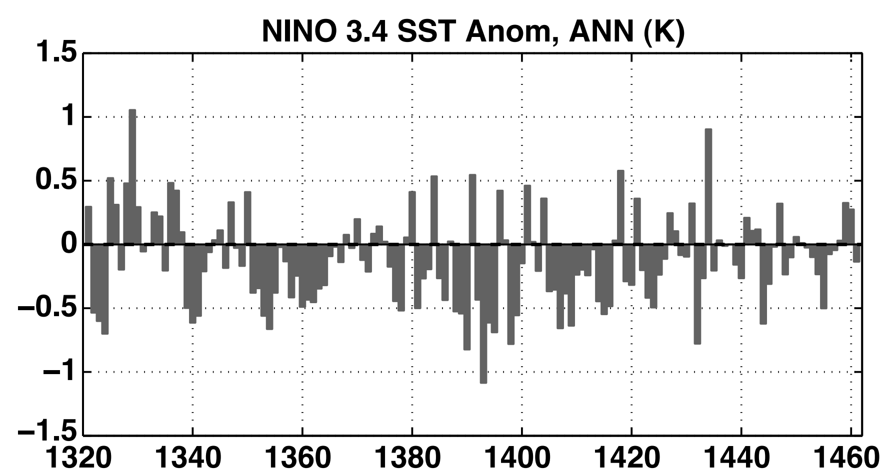


The only analogs of the Dust Bowl spatial pattern were the Medieval megadroughts during the 800-1500A.D. period - also a time of dune activity.

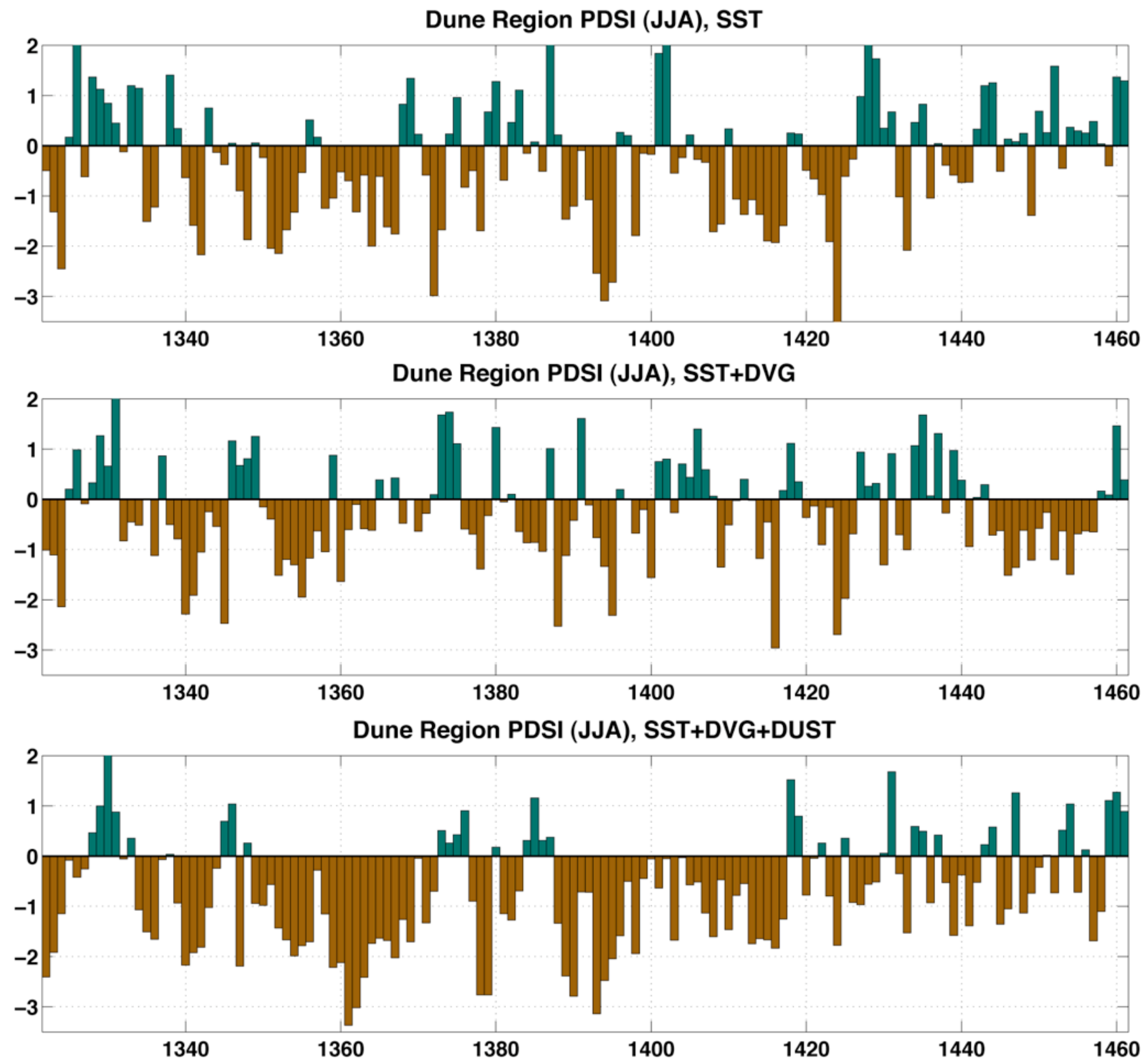
Force model ensemble with tropical Pacific SST reconstructed for 1320-1462 from Cobb et al. (2003) Palmyra coral (mixed layer ocean elsewhere).

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.

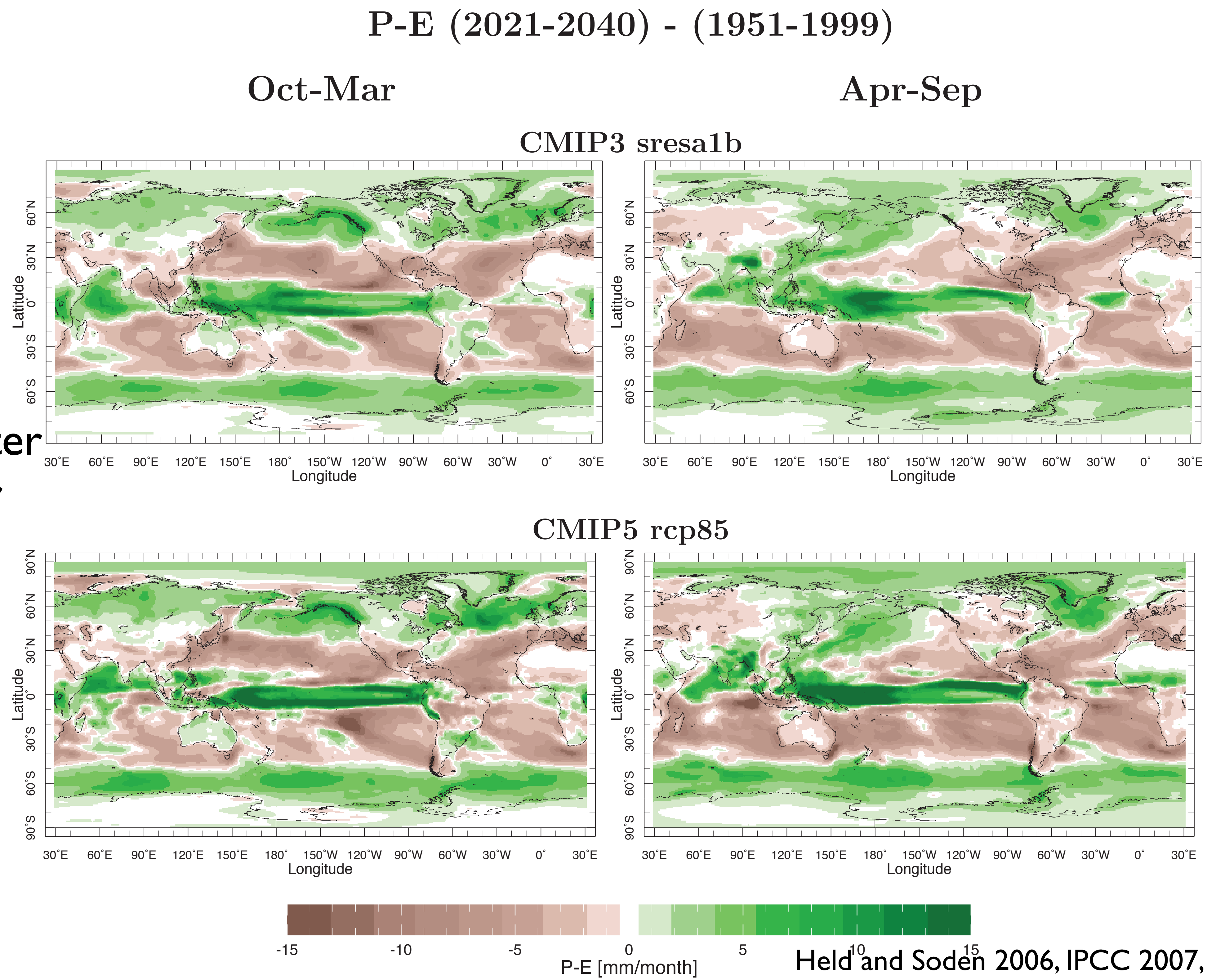
Medievel megadroughts are of unknown origin - though tropical SST forcing remains the leading hypothesis (Graham et al. 2007, 2010; Seager et al. 2007, 2008; Burgman et al. 2010, Seager and Burgman 2011, Feng et al. 2008, Oglesby et al. 2011).

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

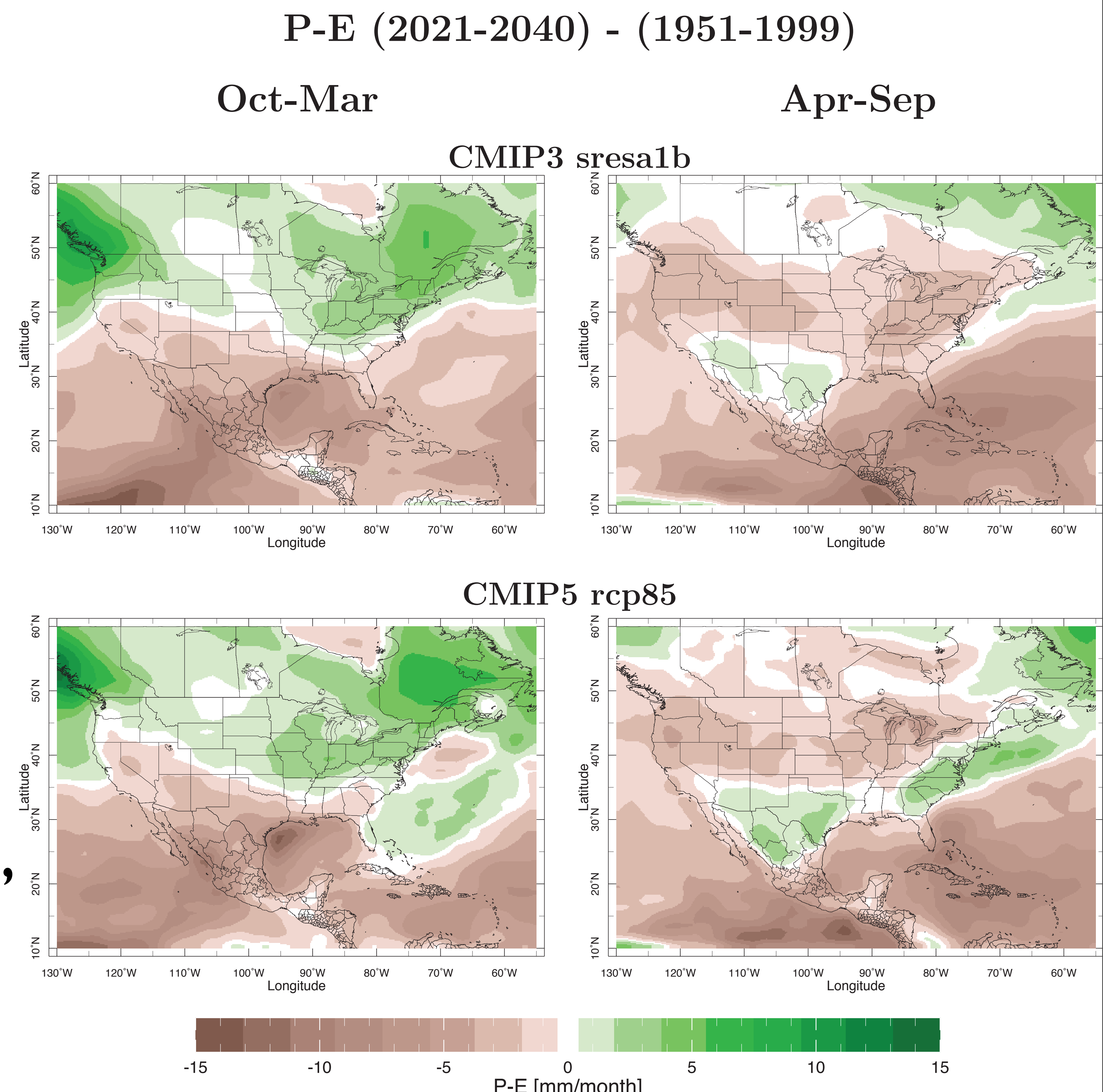
Projected change in mean hydroclimate:

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



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

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..

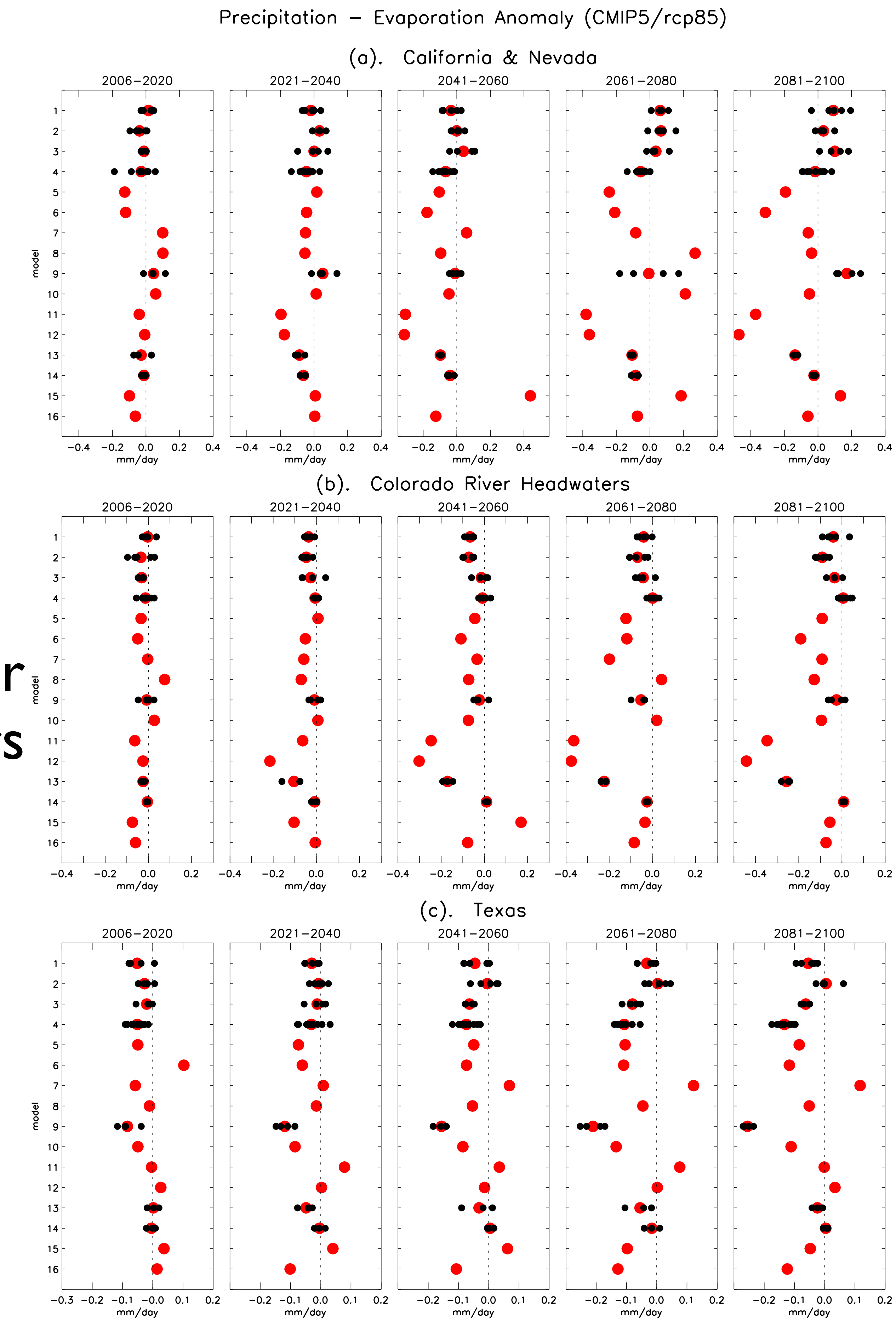


CMIP5 model projected changes in P-E relative to 1950-2000

CA&NV

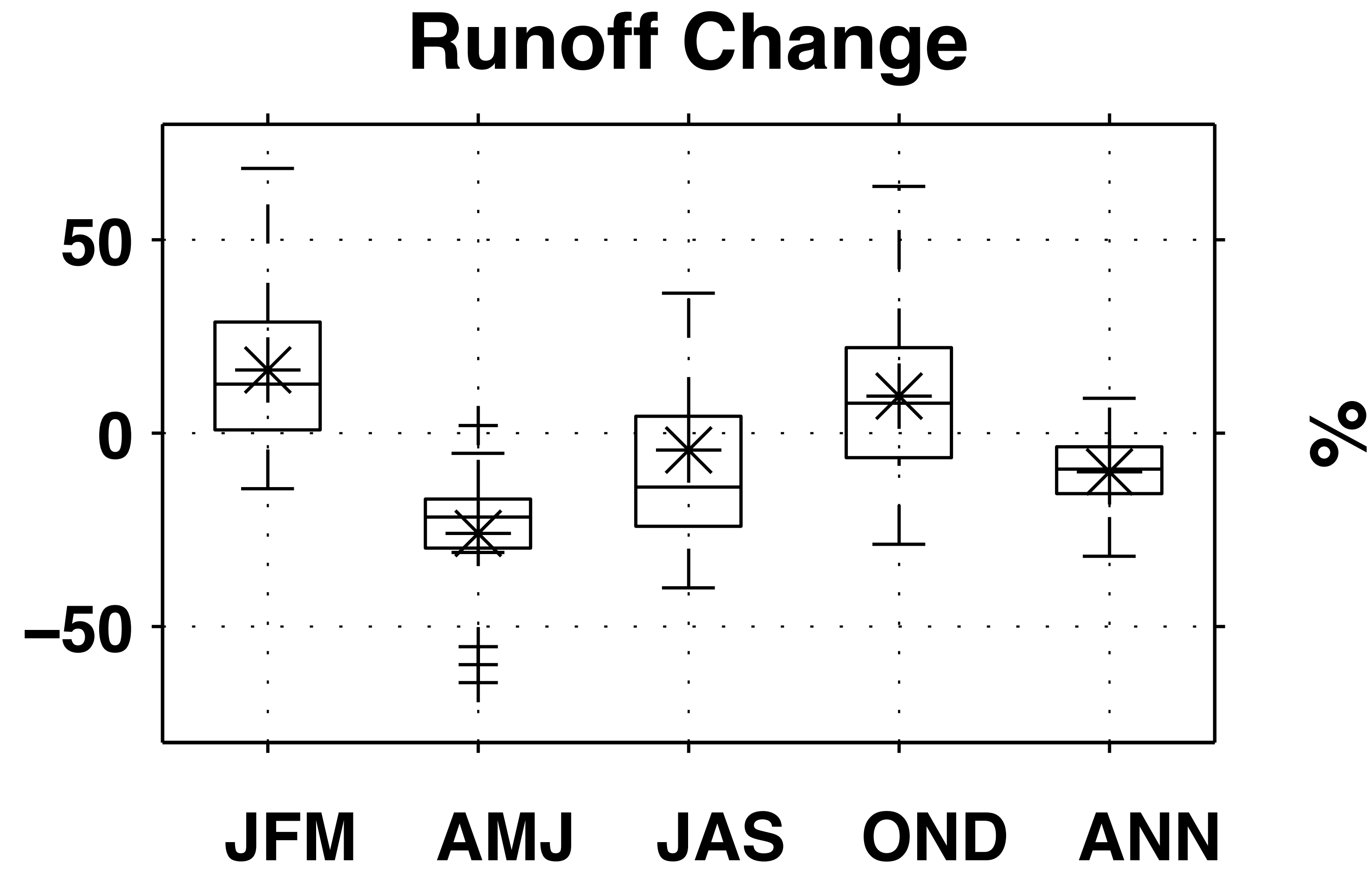
Colorado River headwaters

Texas

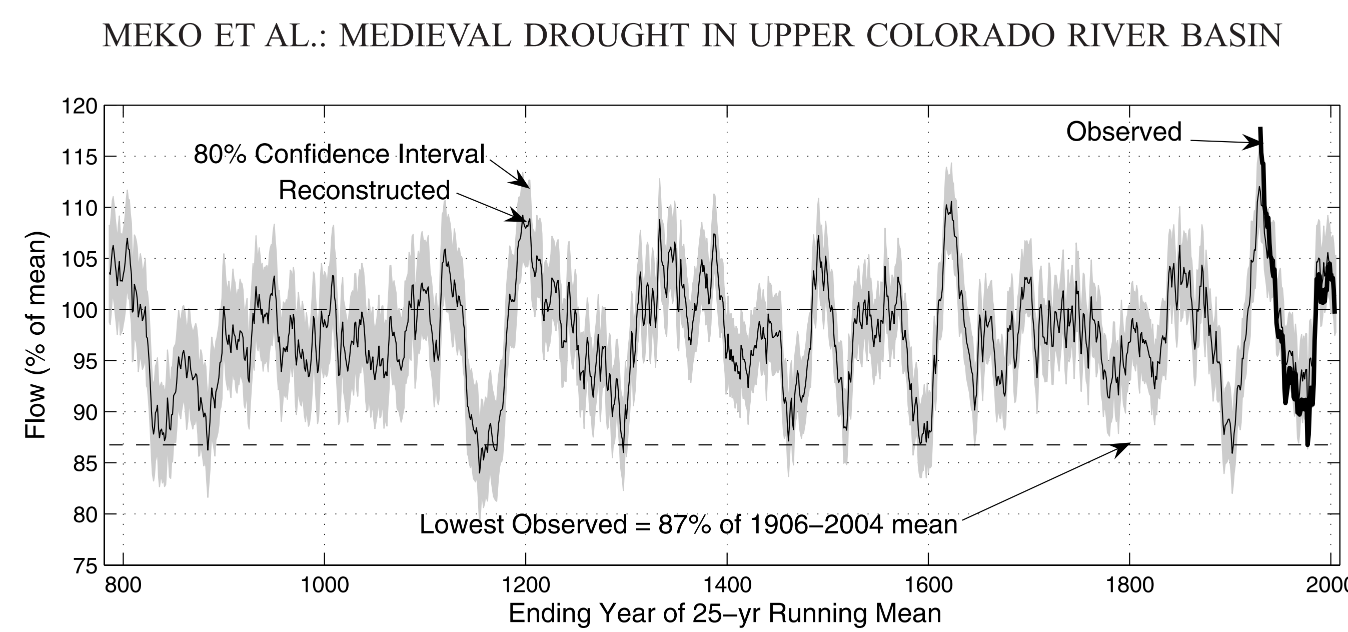


2021-2040 2041-2060 2061-2080 2081-2100

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

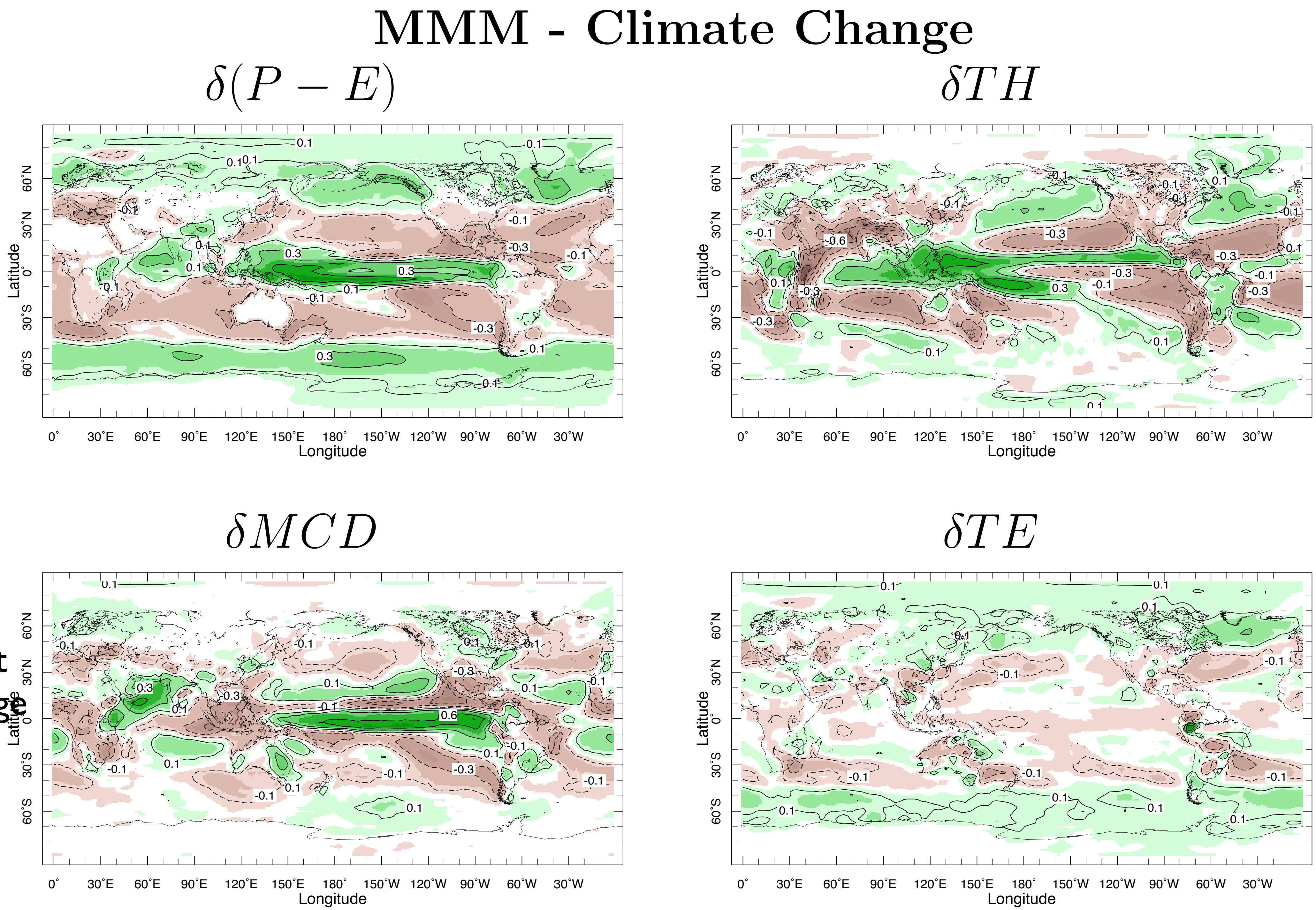


Tree ring reconstructed Colorado River flow 800-2000



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

Mechanisms of modeled hydroclimate **change**



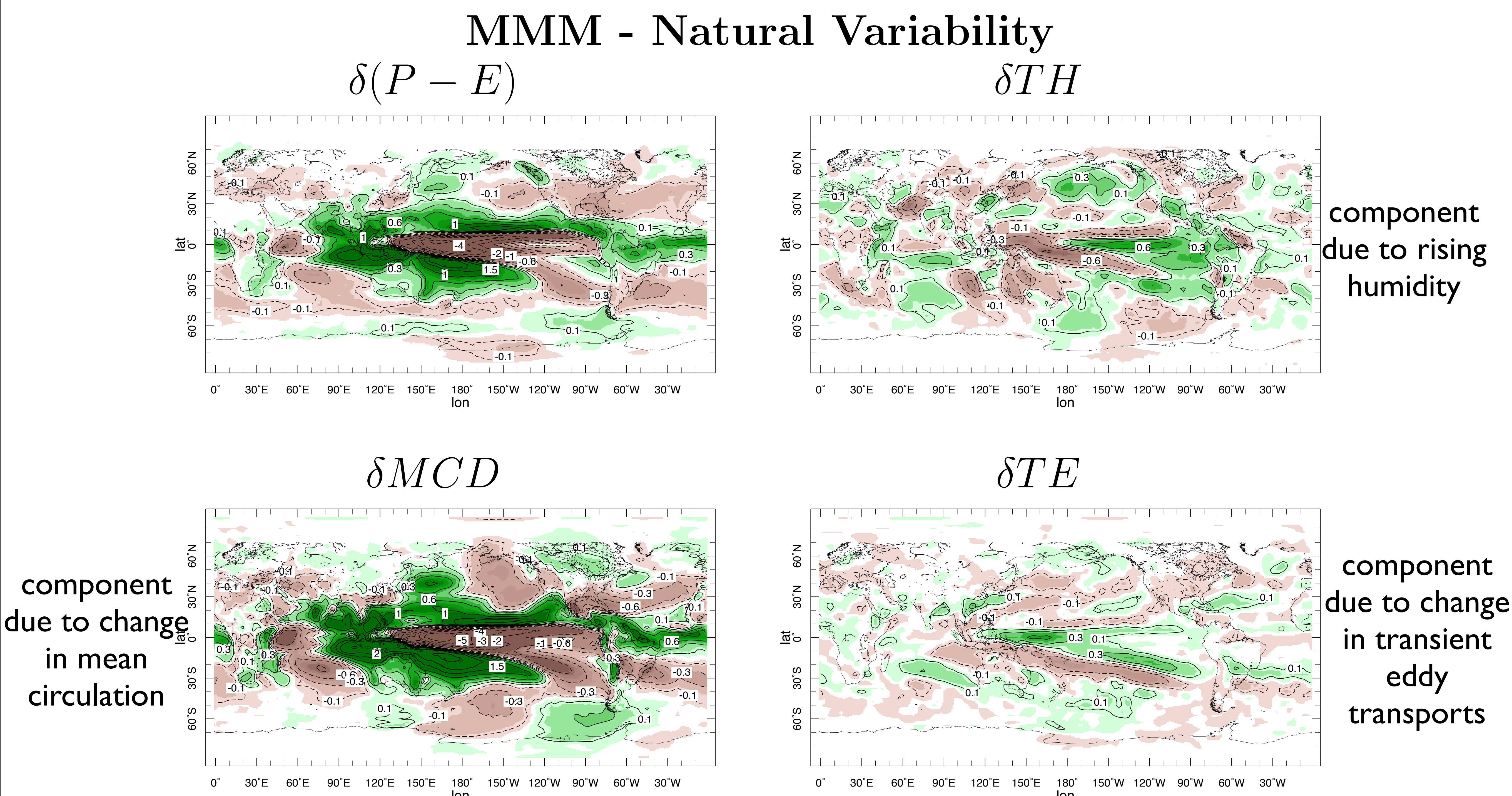
component due to rising humidity

component due to change in mean circulation

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**



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

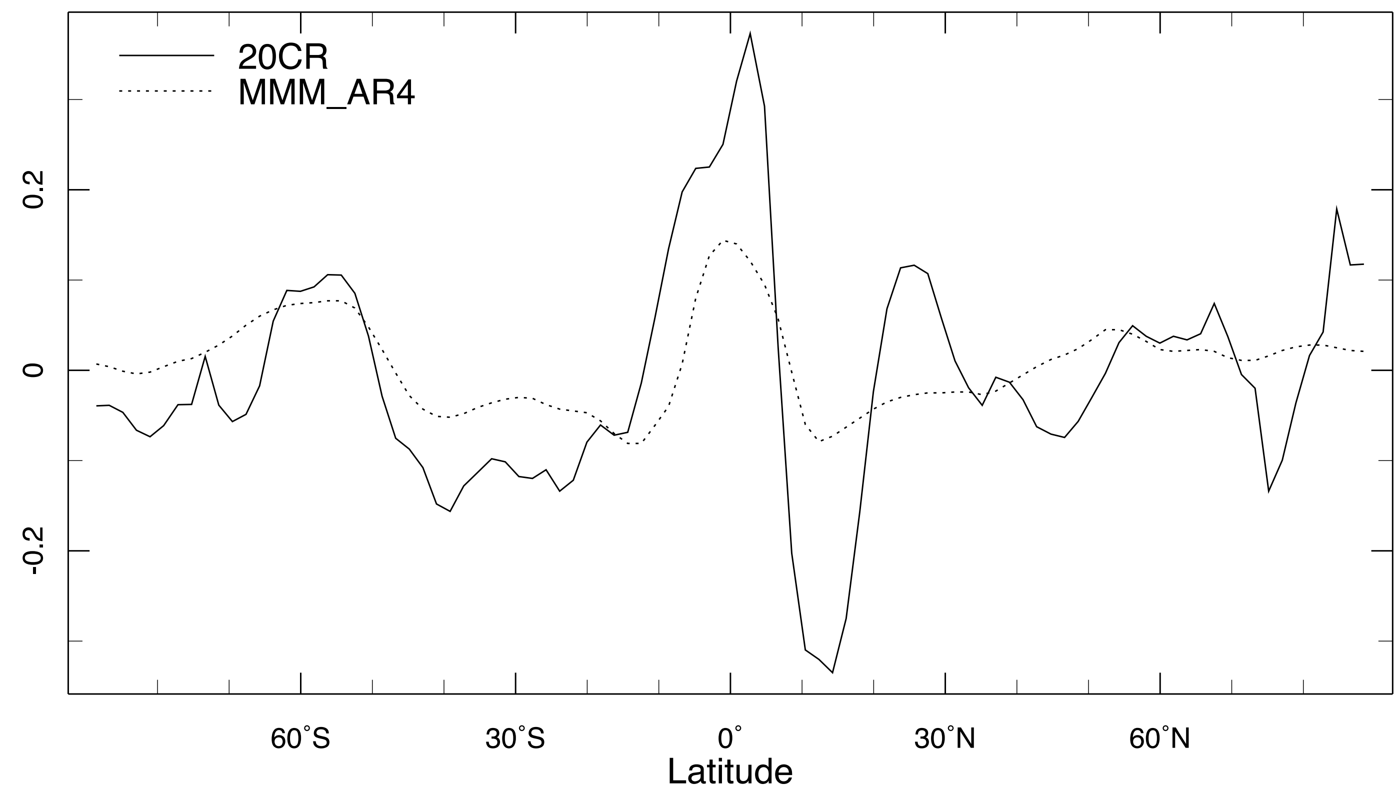
Observations-based atmospheric data sets - the 20th Century Reanalysis (20CR) - support the models' indication that natural variability of P-E is 'dynamics dominated' i.e. caused by circulation anomalies.

- 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.