Mechanisms of North American Drought as diagnosed with models and the 20th Century Reanalysis

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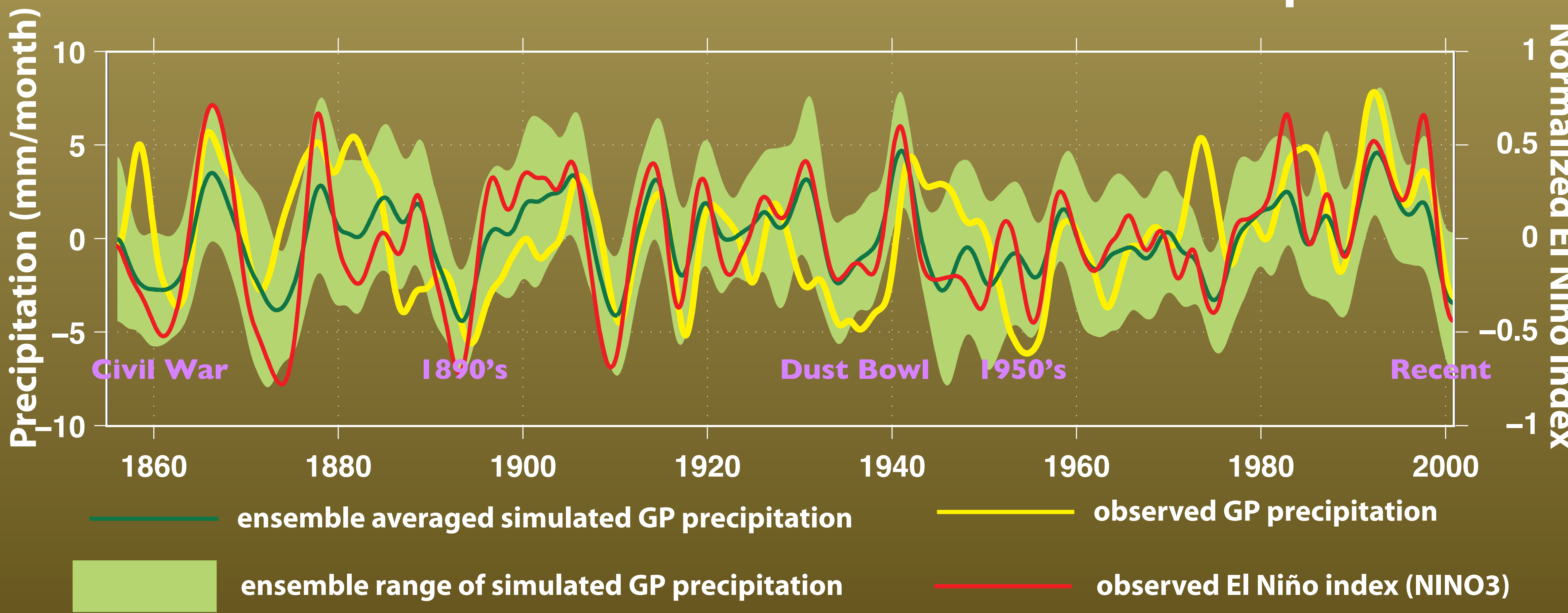
Models have established oceanic causes of N. American drought: e.g. Great Plains precipitation variability since 1856

Seager et al. (2005)

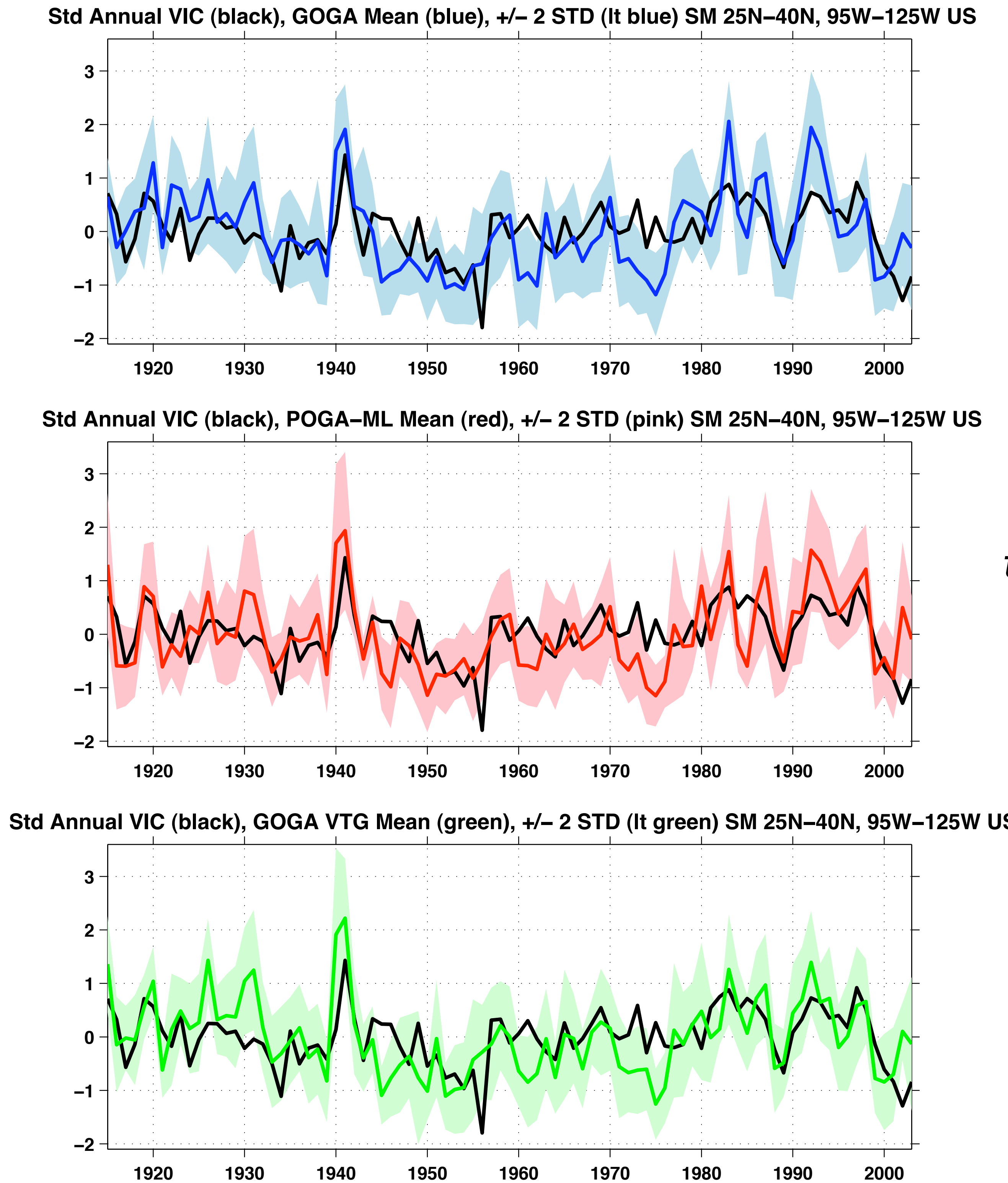
Climate Model Simulation[1] of U.S. Great Plains[2] Precipitation



1. An ensemble of 16 model runs with observed SST prescribed in the equatorial Pacific Ocean (20°S-20°N) and calculated elsewhere, using a two-layer slab ocean model
2. Great Plains are defined as the area between110° W– 90° W and 30°N–50°N

VIC and CCM3 simulations of soil moisture

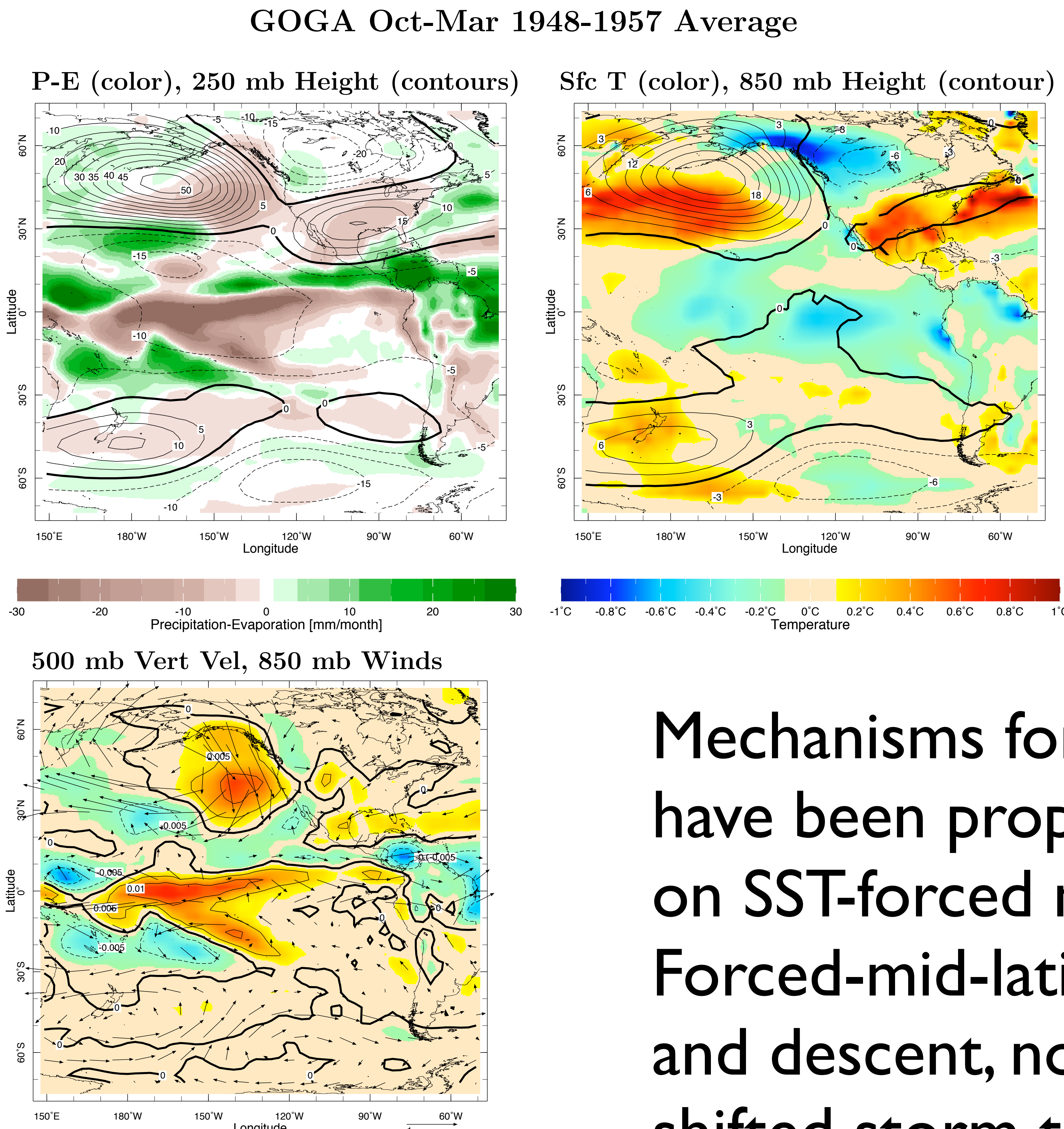
Tropical Pacific SSTs are dominant, as seen in simulation of last century of soil moisture in SWNA.



global SST forcing

tropical Pacific SST forcing

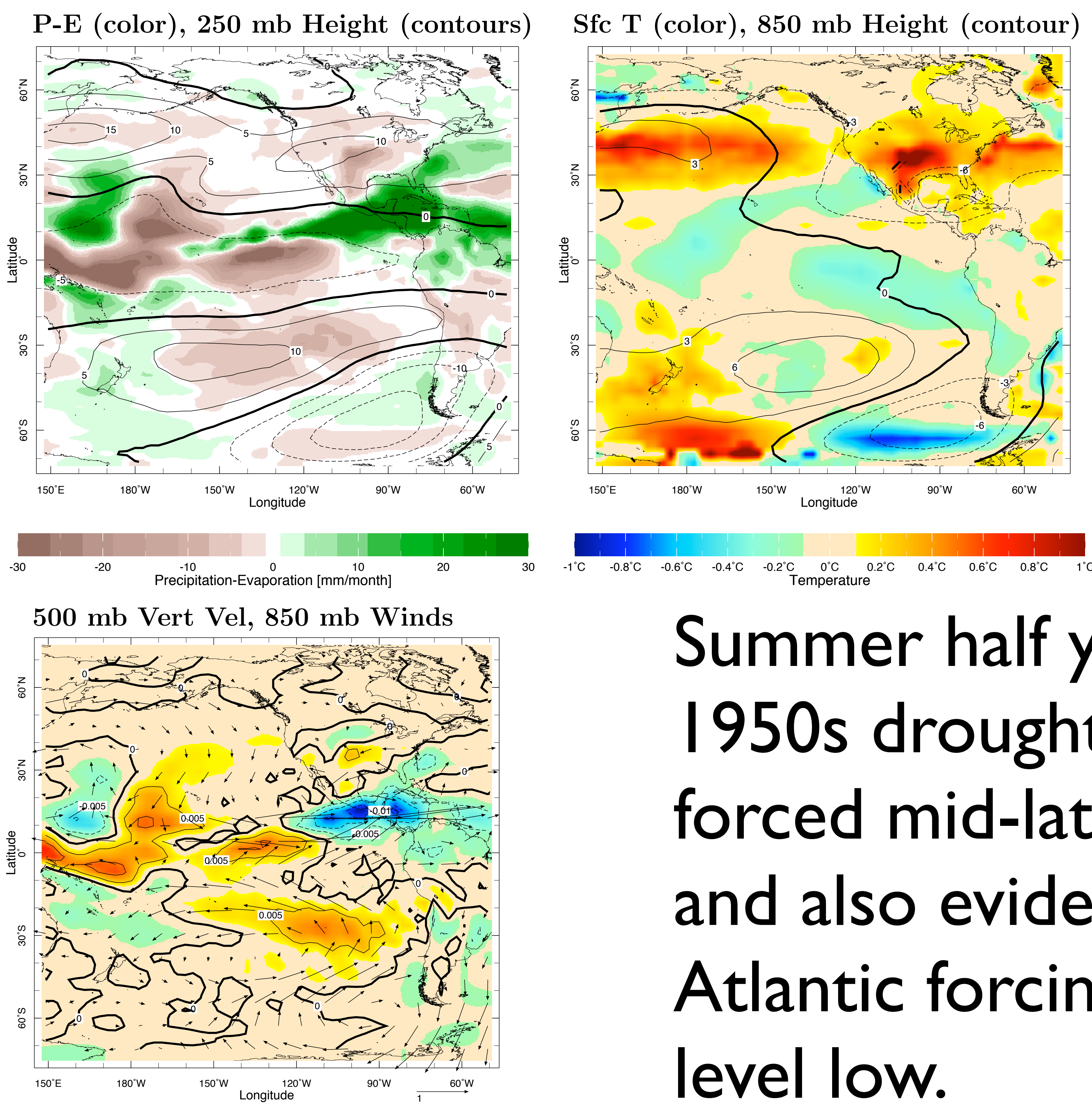
global SST forcing plus variable trace gases



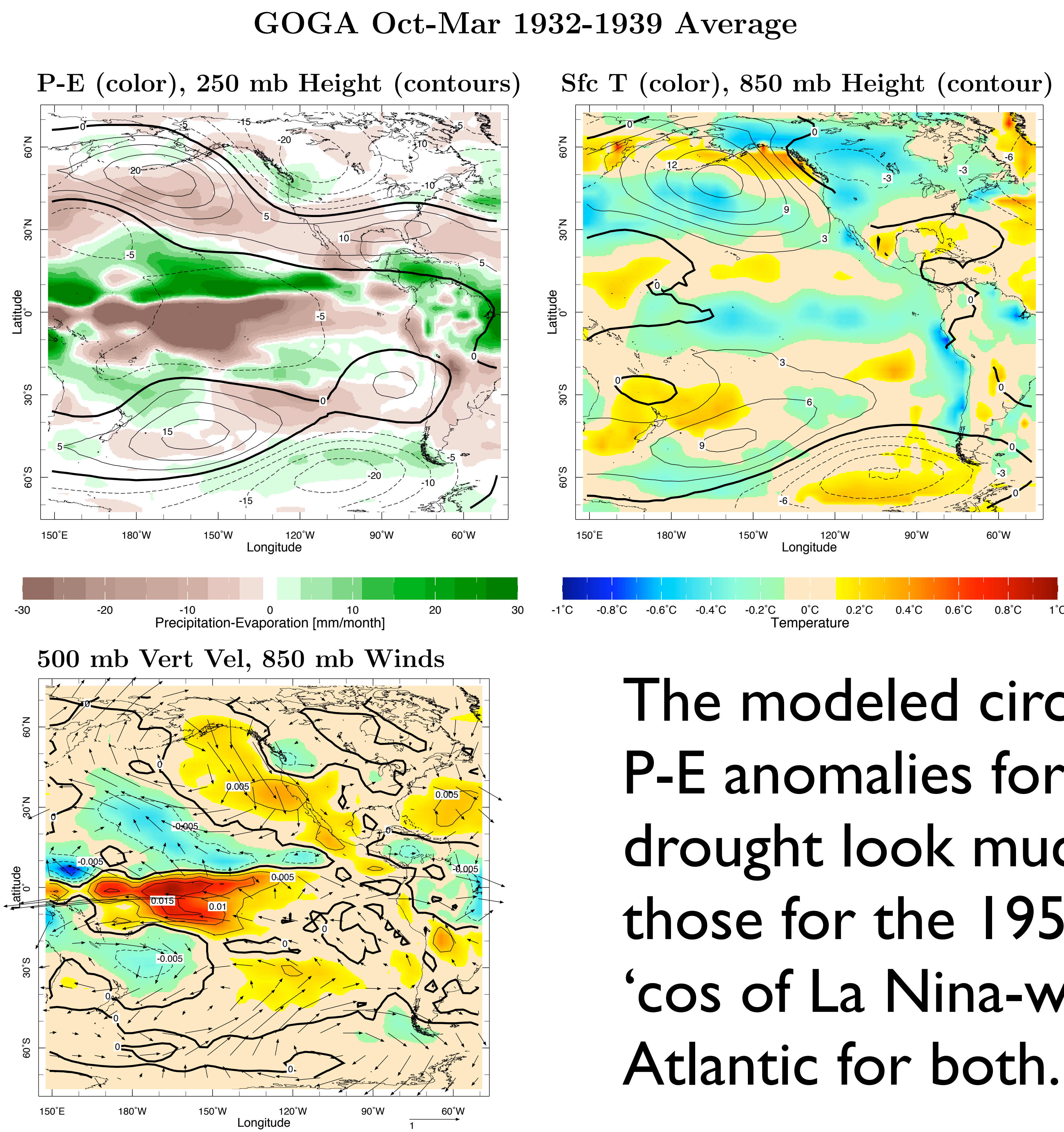
winter half years of 1950s drought

Mechanisms for drought have been proposed based on SST-forced models. Forced-mid-latitude ridge and descent, northward shifted storm track.

GOGA Apr-Sep 1948-1957 Average



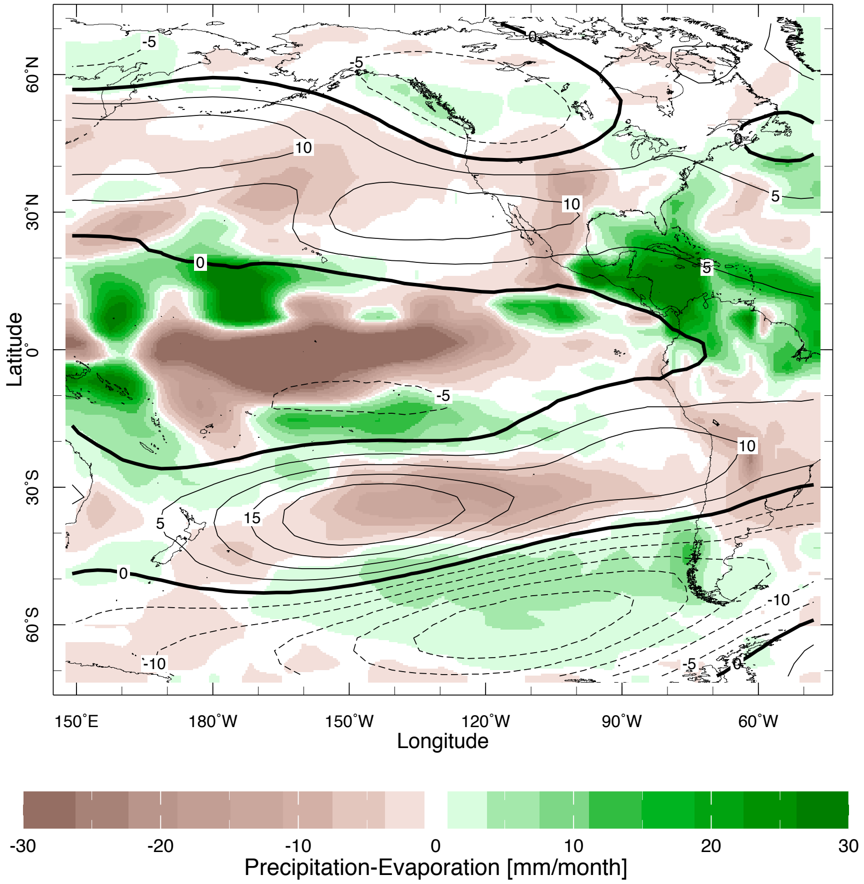
Summer half years of the 1950s drought. SST-forced mid-latitude ridge and also evidence of N. Atlantic forcing of low level low.



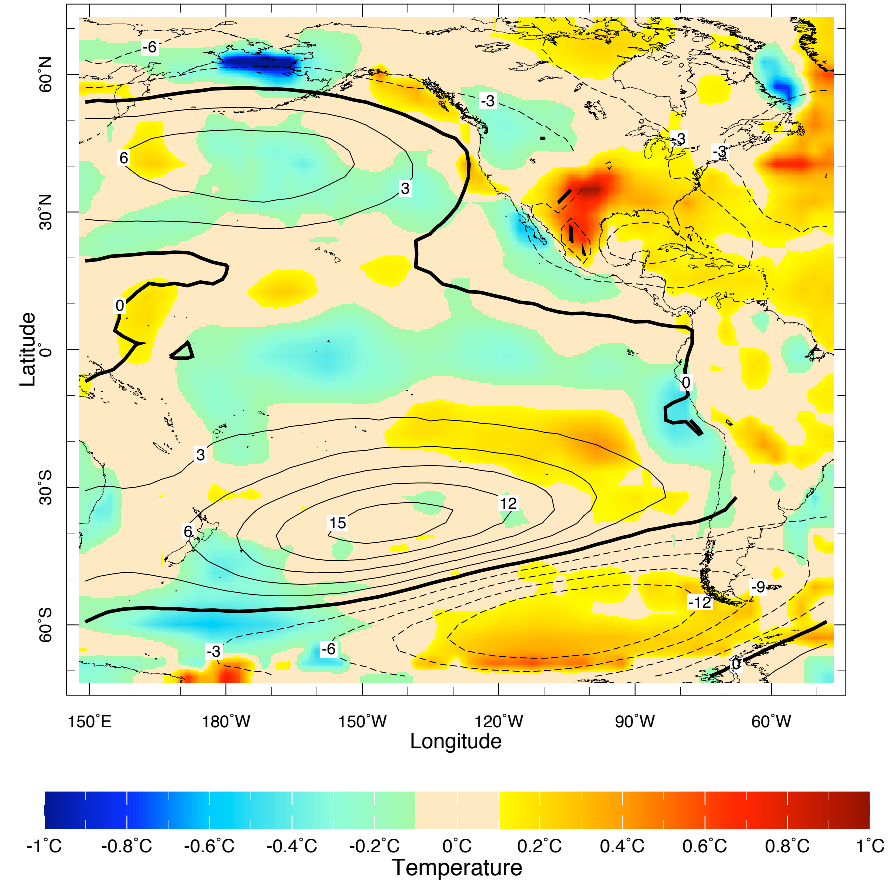
The modeled circulation and P-E anomalies for the 1930s drought look much like those for the 1950s drought ‘cos of La Nina-warm N. Atlantic for both.

GOGA Apr-Sep 1932-1939 Average

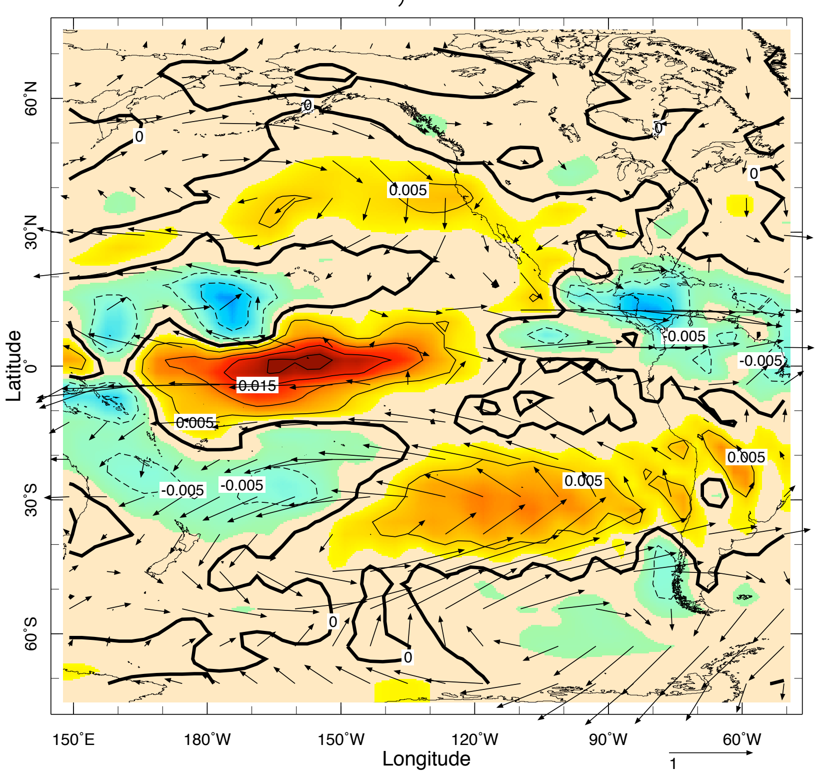
P-E (color), 250 mb Height (contours)



Sfc T (color), 850 mb Height (contour)



500 mb Vert Vel, 850 mb Winds

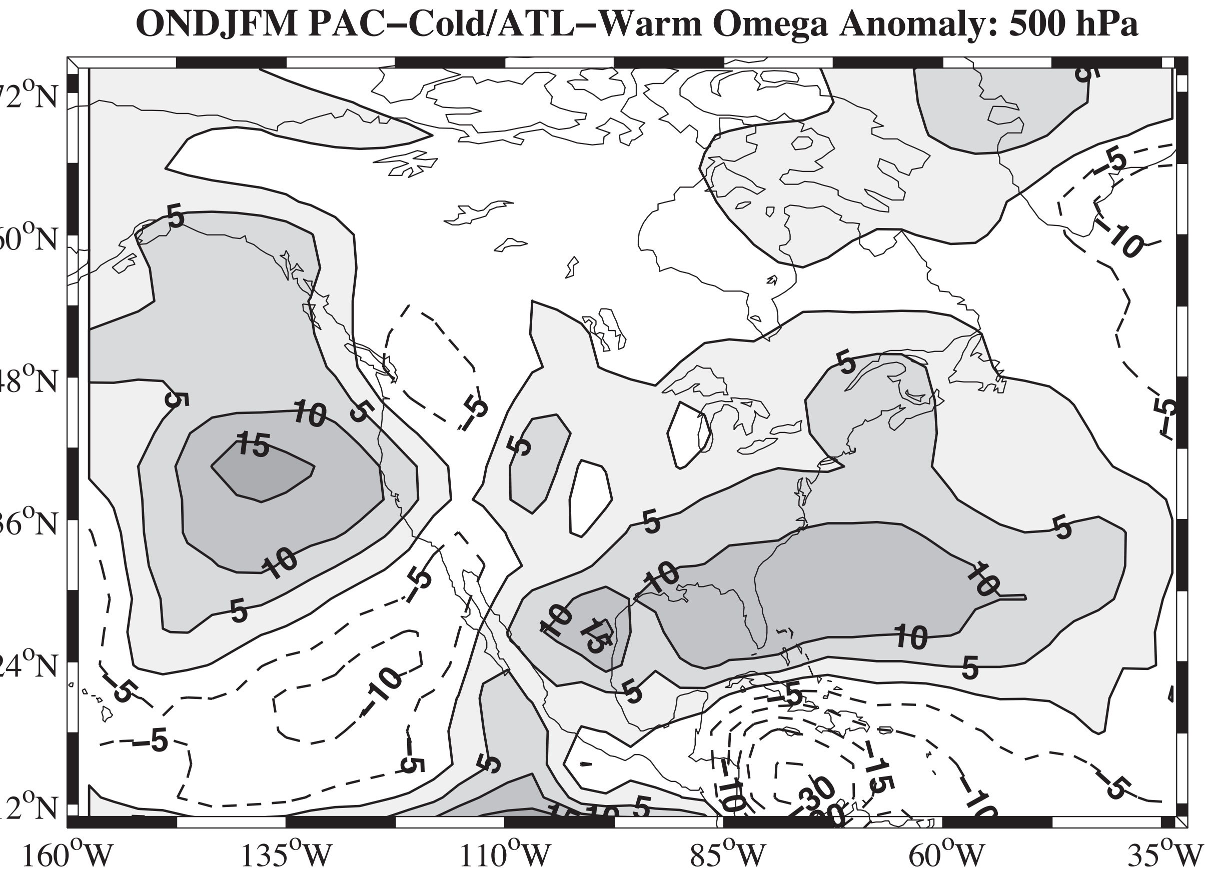


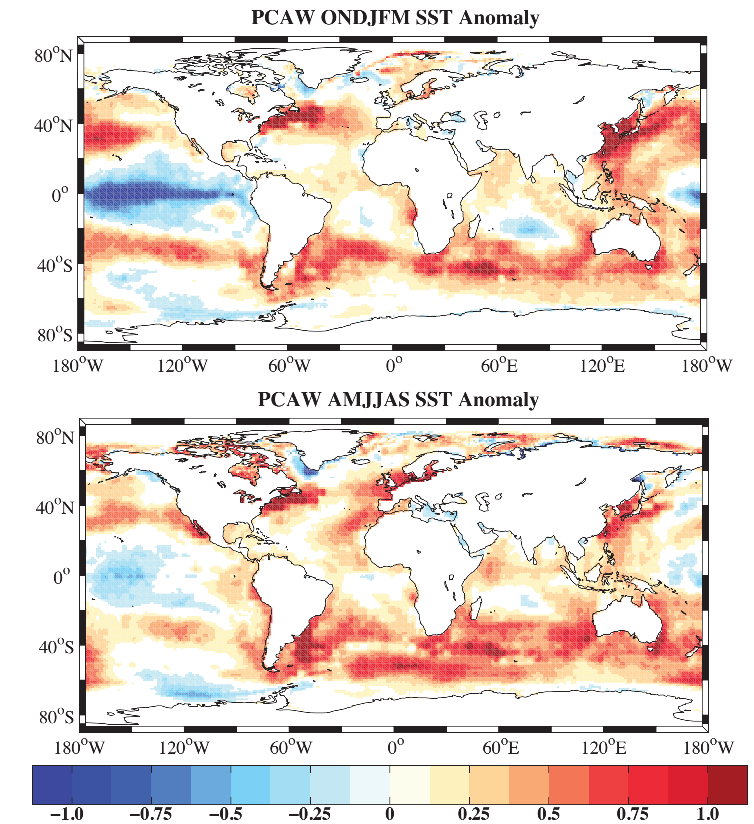
1930s and 1950s similarity is in summer half years as well

Despite the modeling progress the lack of long atmospheric data sets made validation of the mechanisms of drought difficult. In particular how similar really were the Dust Bowl and 1950s droughts given the more northward center of the Dust Bowl?

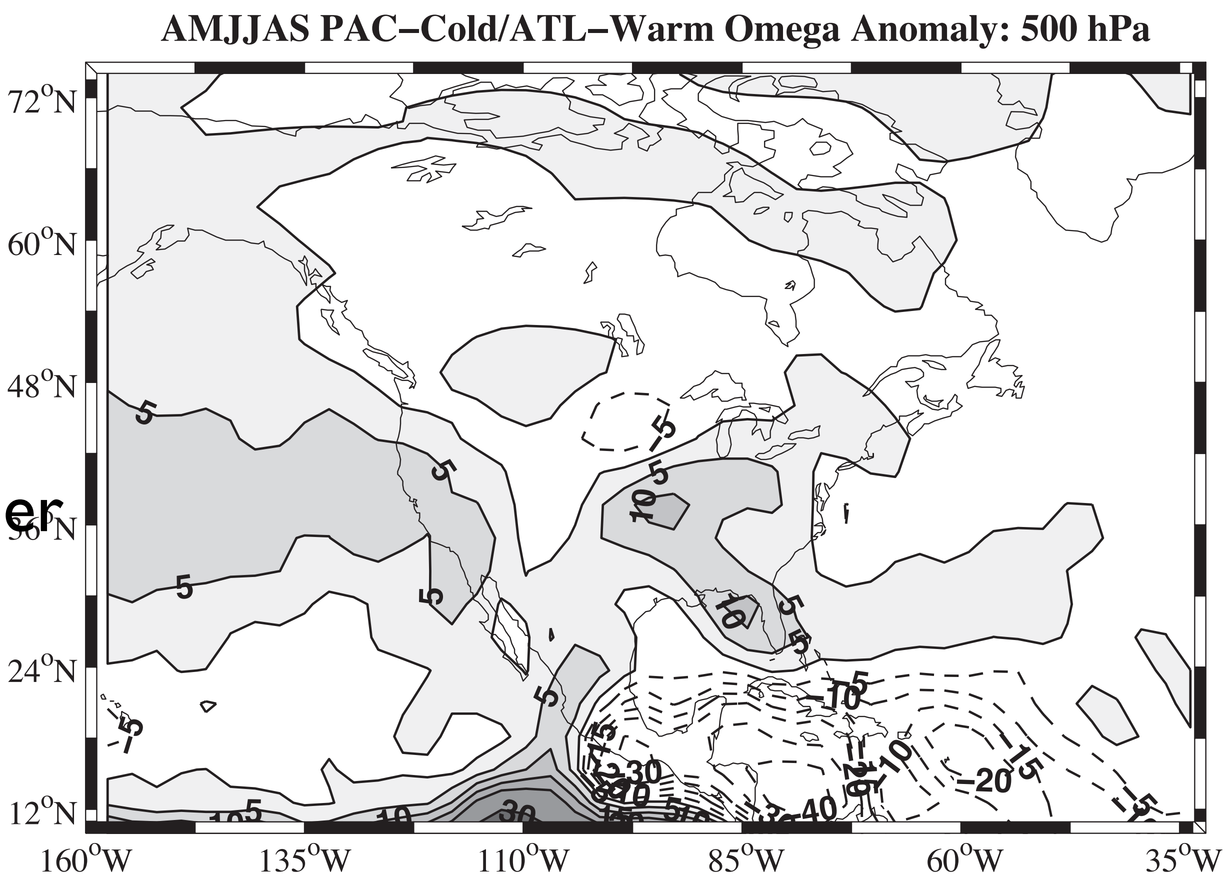
Enter: The 20th Century Reanalysis!
And the US CLIVAR Drought WG experiments.

winter



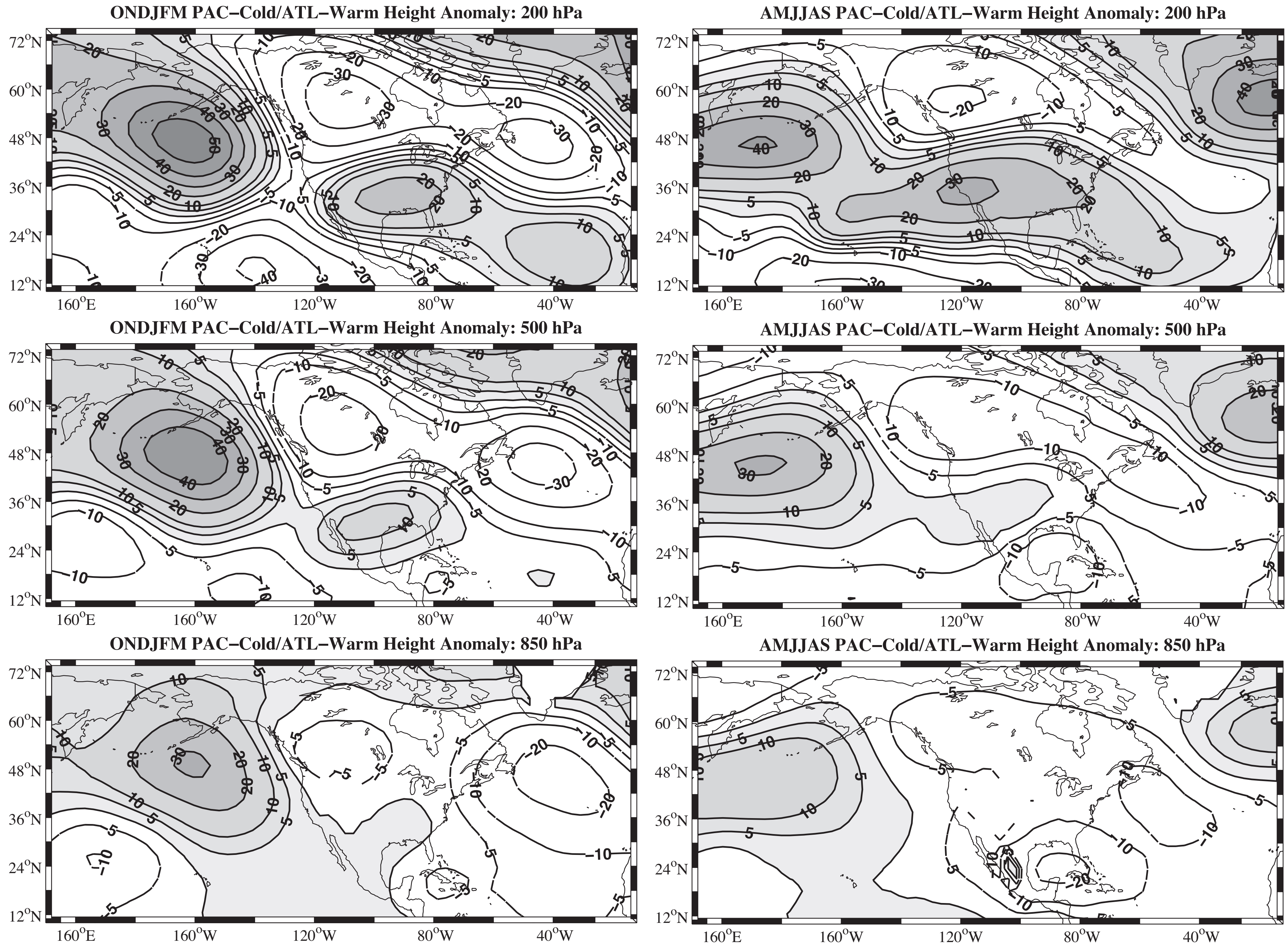


summer



The multimodel mean 500mb omega for cold Pacific-warm N. Atlantic SSTA. Subsidence off W. Coast and over Gulf of Mexico, Florida ...

Cold Pacific-warm Atlantic height anomalies



200mb

500mb

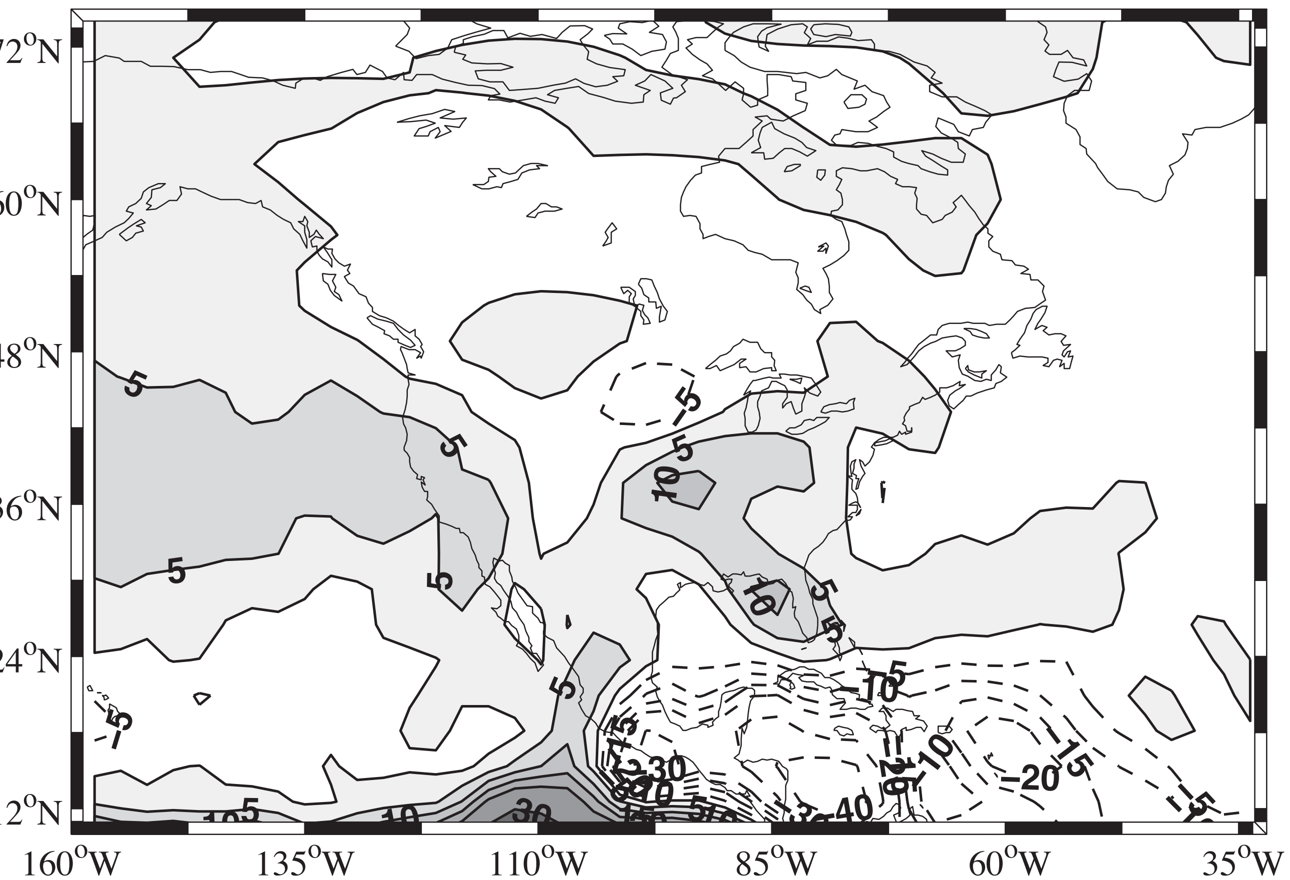
850mb

Winters

Summers

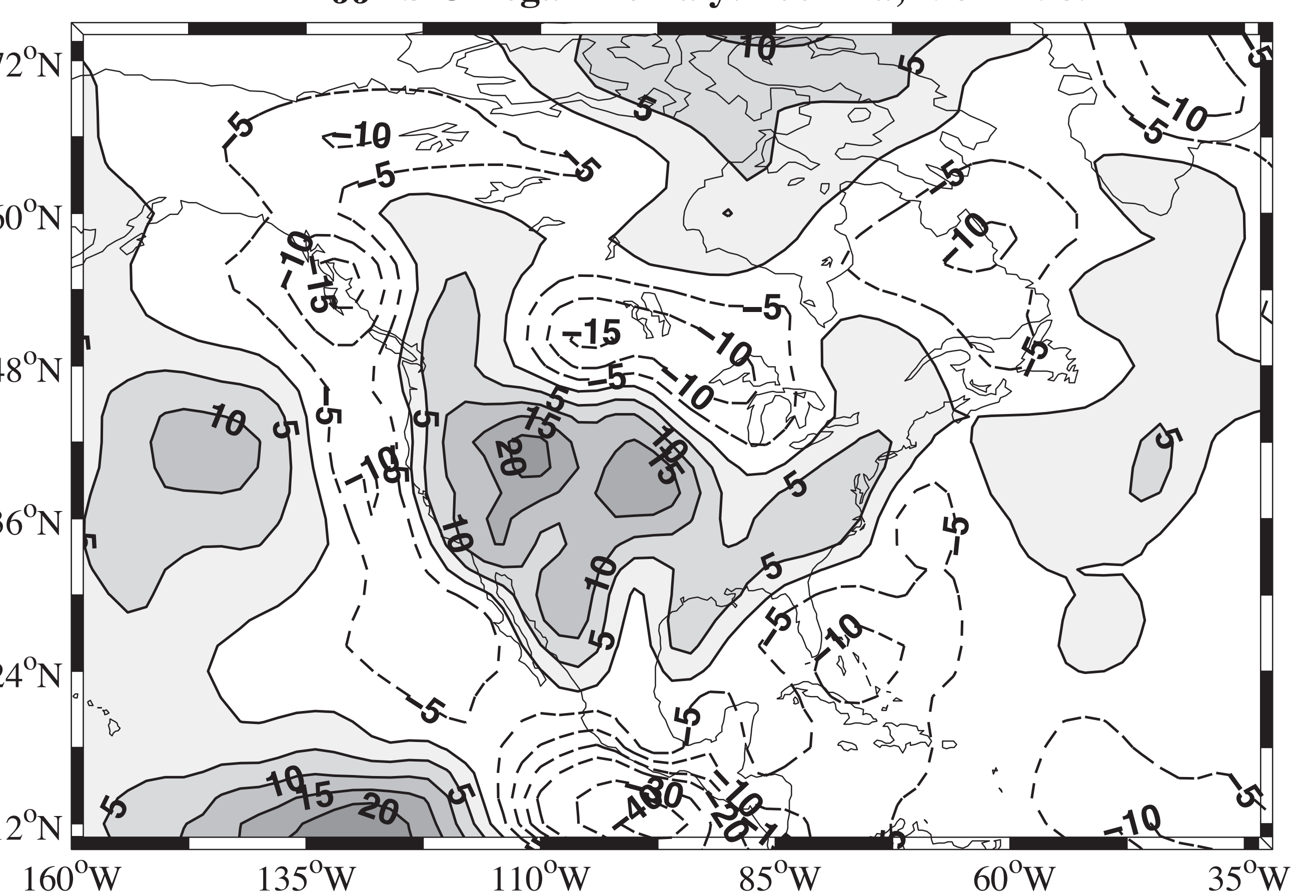
note low level summer Gulf of Mexico low

AMJJAS PAC–Cold/ATL–Warm Omega Anomaly: 500 hPa



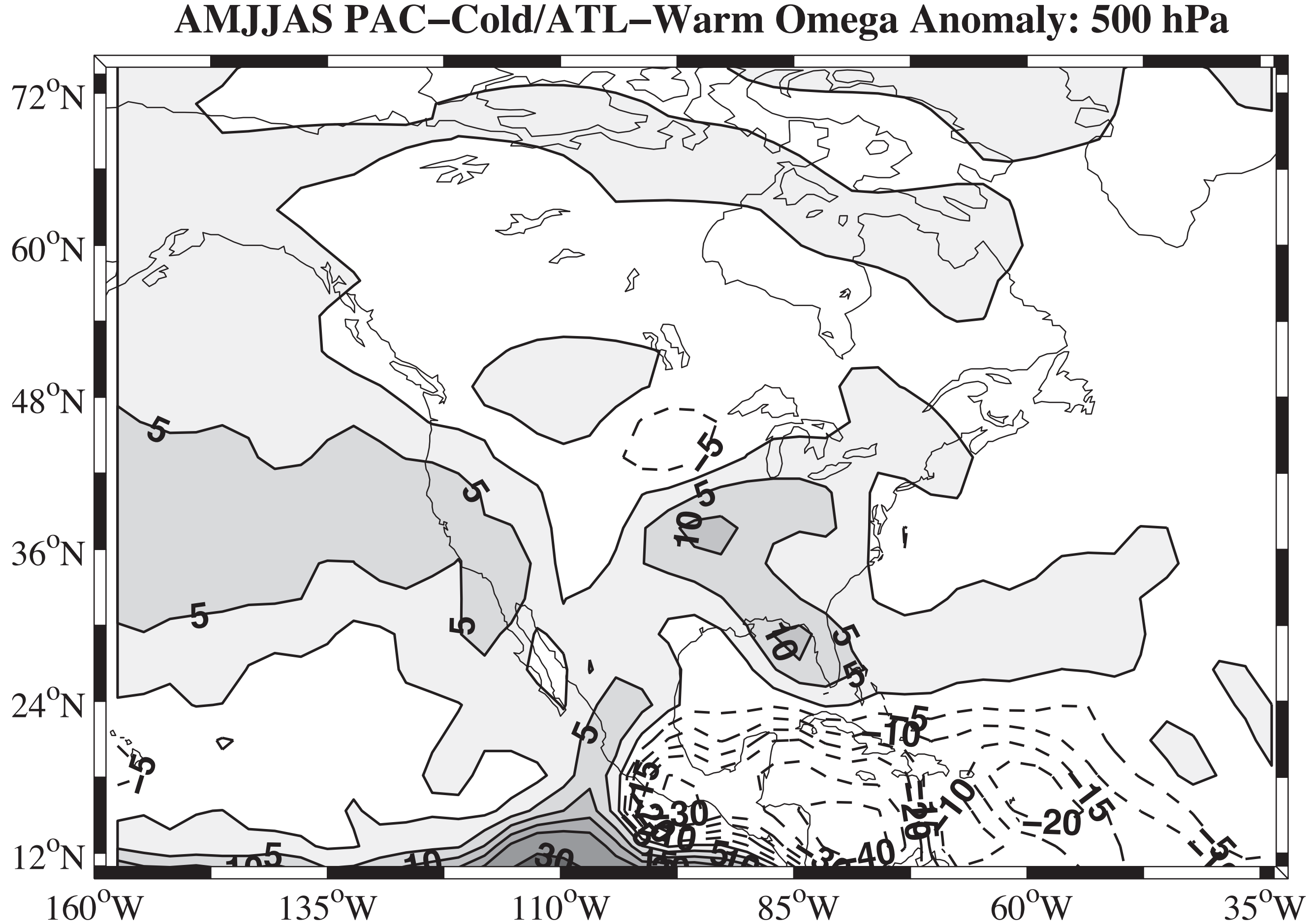
SST-forced
'expected' 500mb
summer omega

AMJJAS Omega Anomaly: 500 hPa, 1932–1939



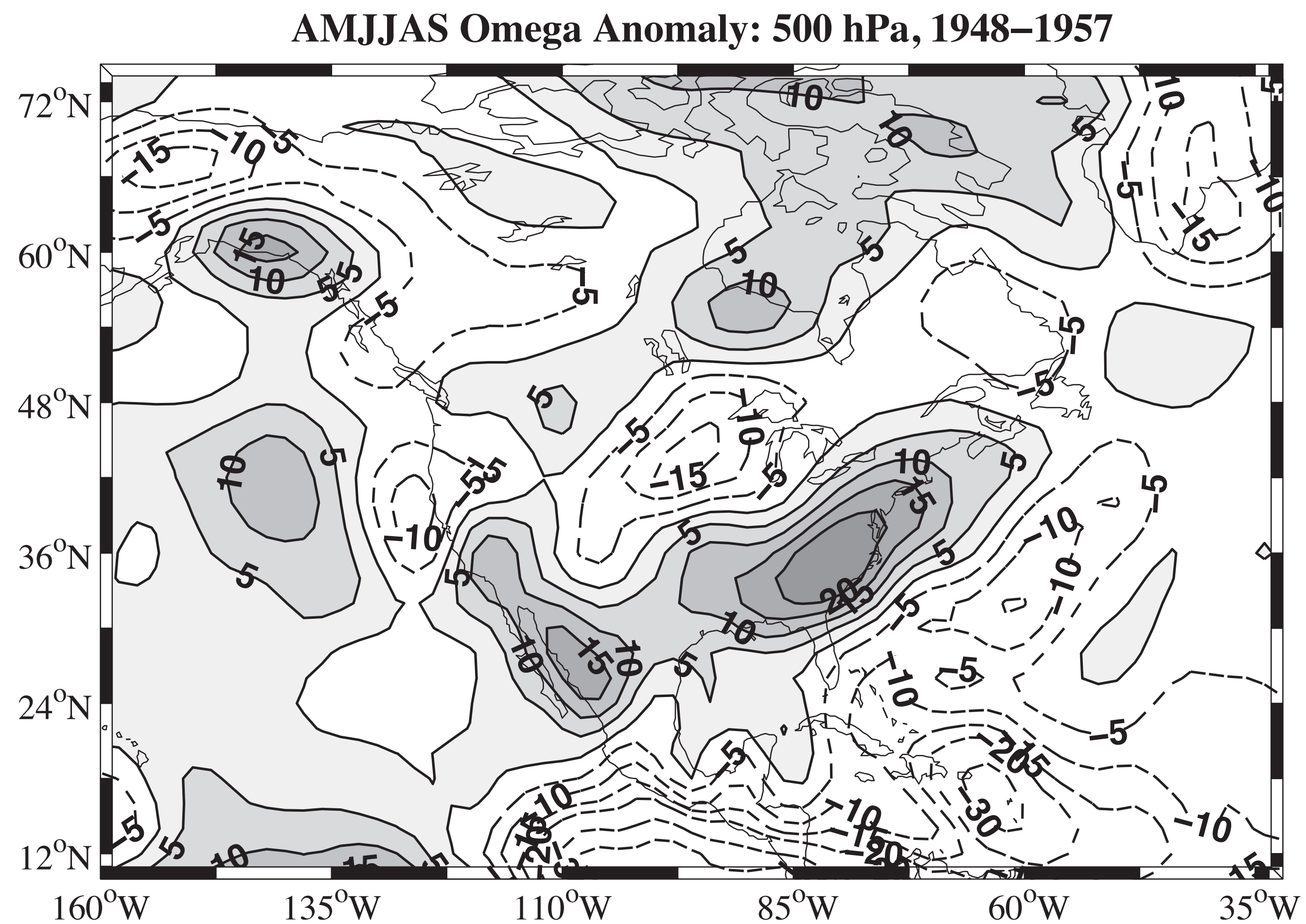
During the Dust Bowl, strong continental-centered subsidence at variance with that expected from 1930s SST forcing

'actual' 20CR
500mb omega in
1930s summers.



SST-forced 'expected' 500mb summer omega

Better agreement between expected and actual 500mb omega during the 1950s drought.



'actual' 20CR 500mb omega in 1950s summers.

What explains Dust Bowl departure from normal pattern?

Hoerling et al. (2009) appeal to internal atmospheric variability.

But the Dust Bowl drought was unique in that wind erosion, caused by poor land use practices, created vast dust storms

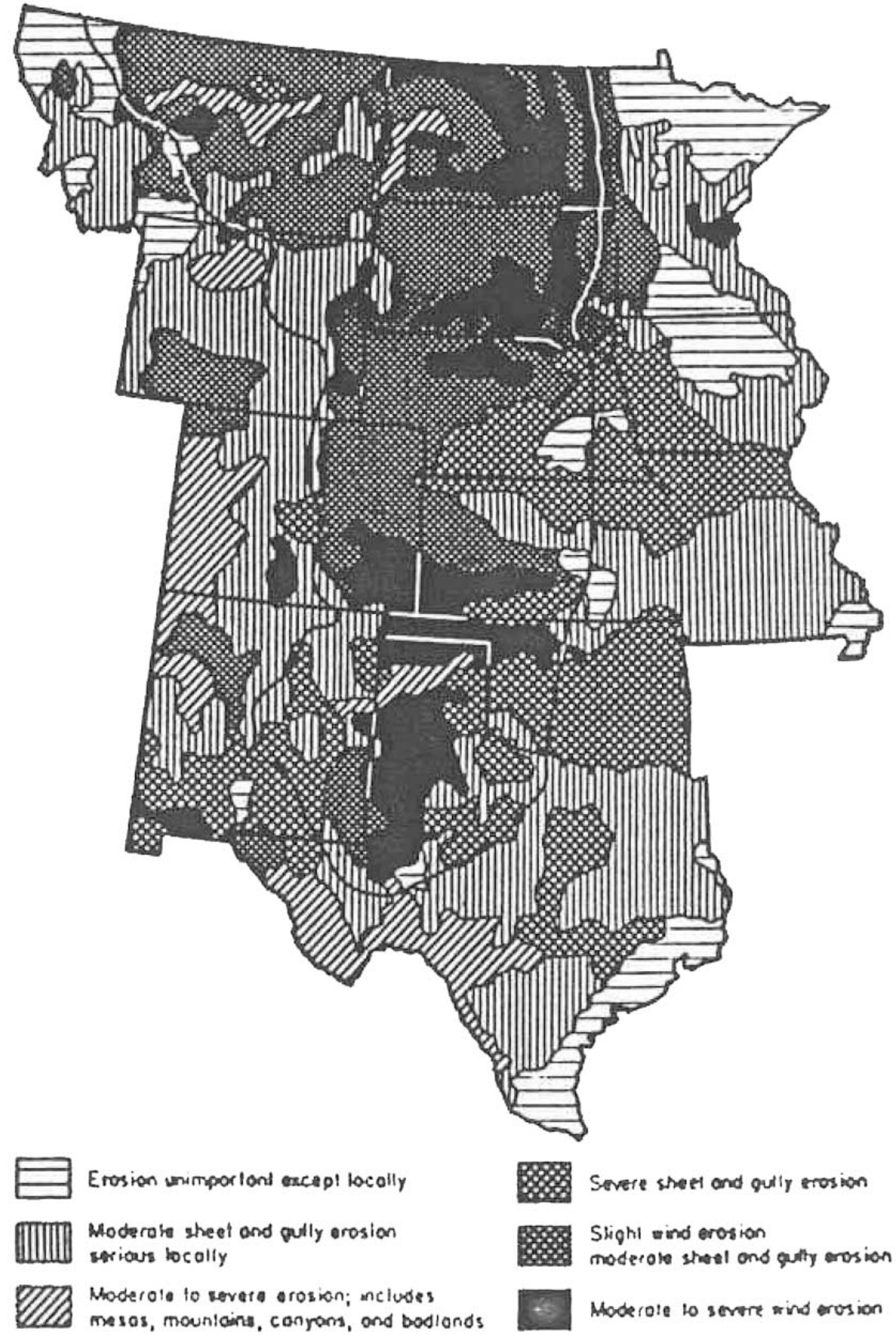
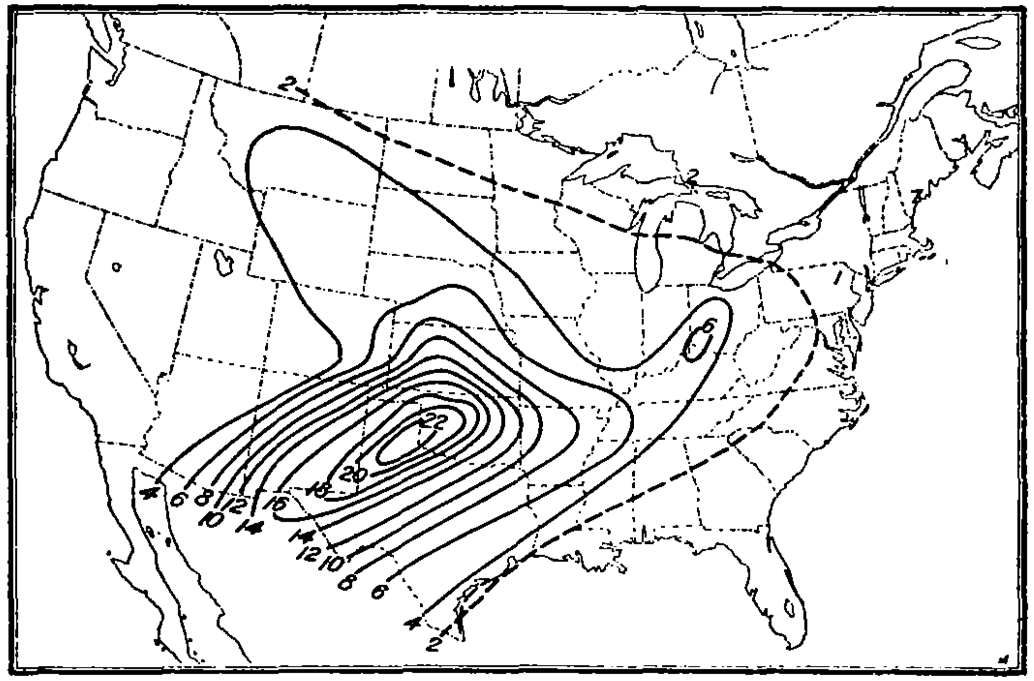


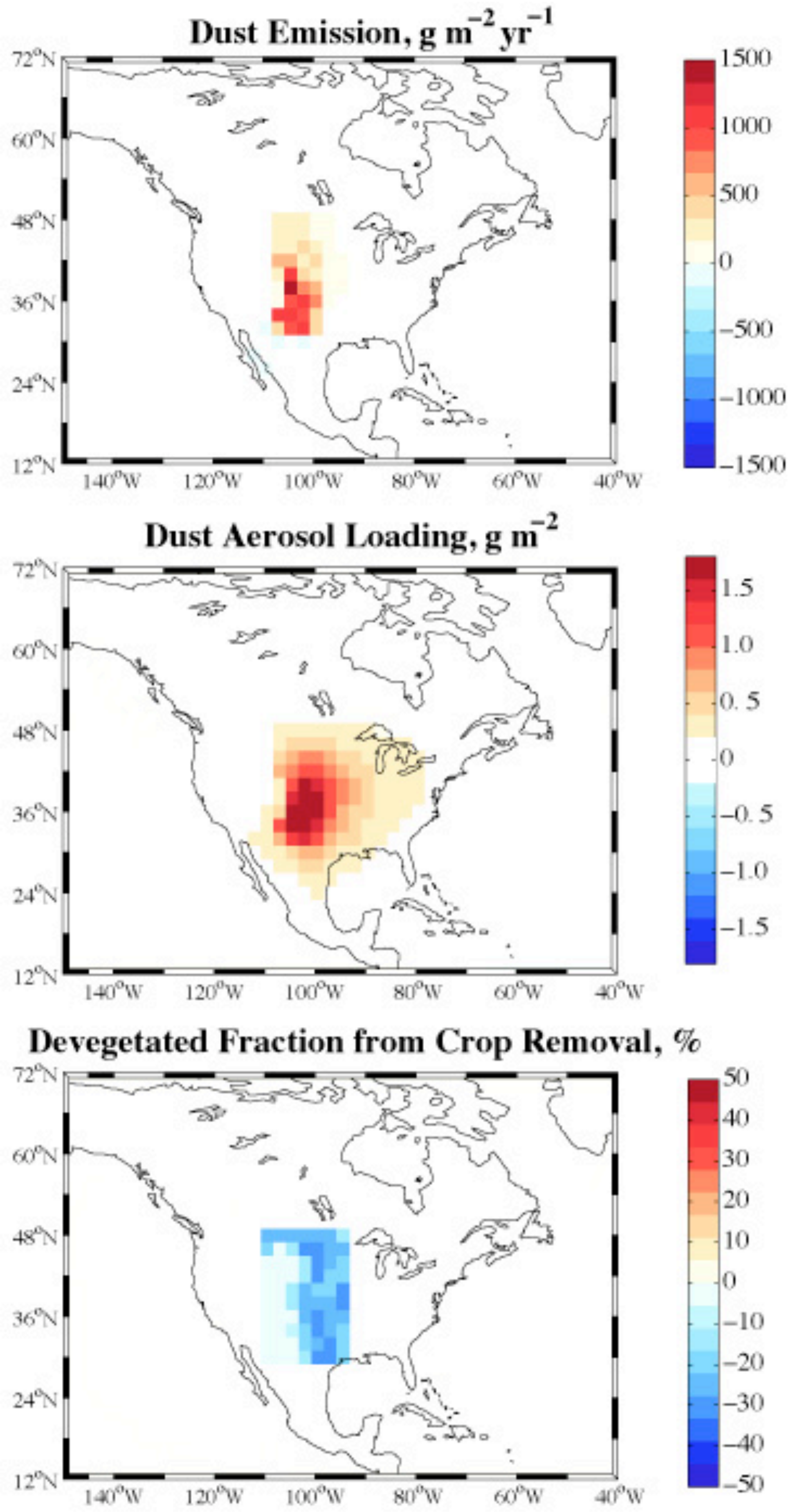
FIG. 1.—Wind erosion in the Great Plains in the 1930s. An irregular line bounds the Great Plains region as delimited by the Great Plains Committee. Source: Adapted from "General Distribution of Erosion" (U.S. Dept. Agriculture, Soil Conservation Service, August 1936).

contemporary observations of dust storms and modeled dust storms
(GISS model, Cook et al. (2008, 2009))



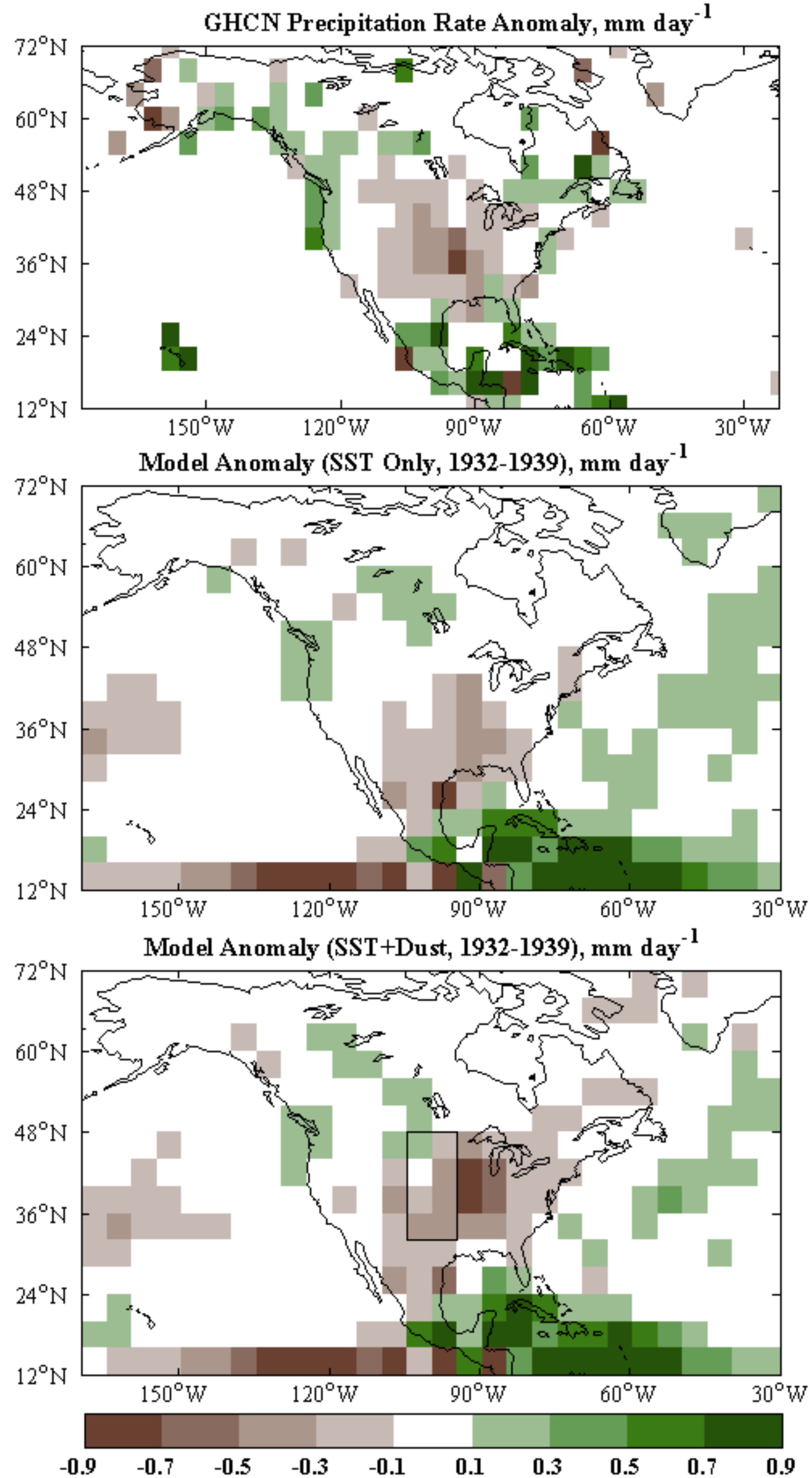
Number of days with duststorms, or dusty conditions, March 1936.—W. A. M

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



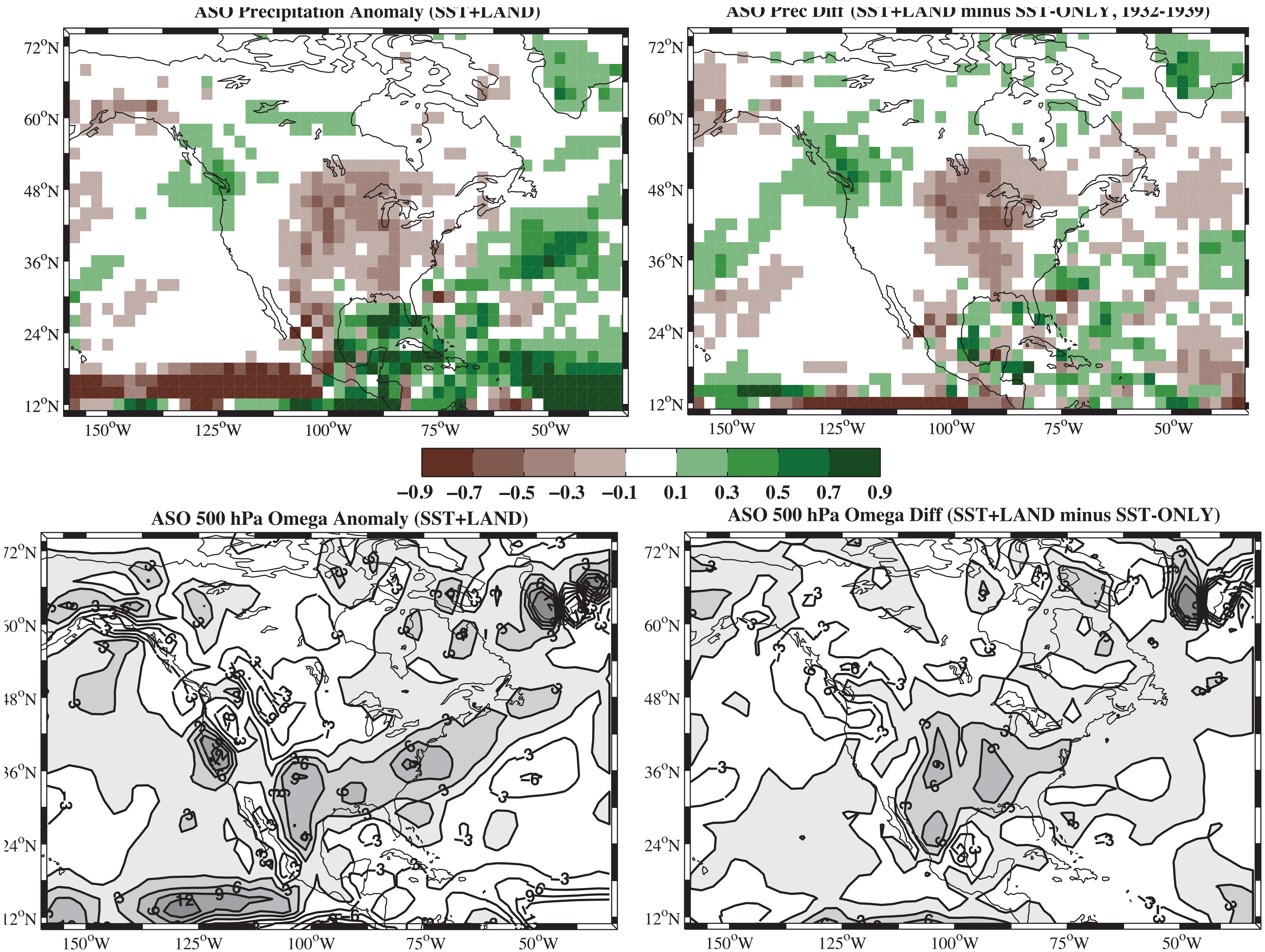
Observed 1930s precipitation anomaly

Modeled with SST forcing only

Modeled with SST forcing and interactive dust

GISS model simulation of Dust Bowl drought:

SST + dust + crop failure — *Impact of dust and deveg*



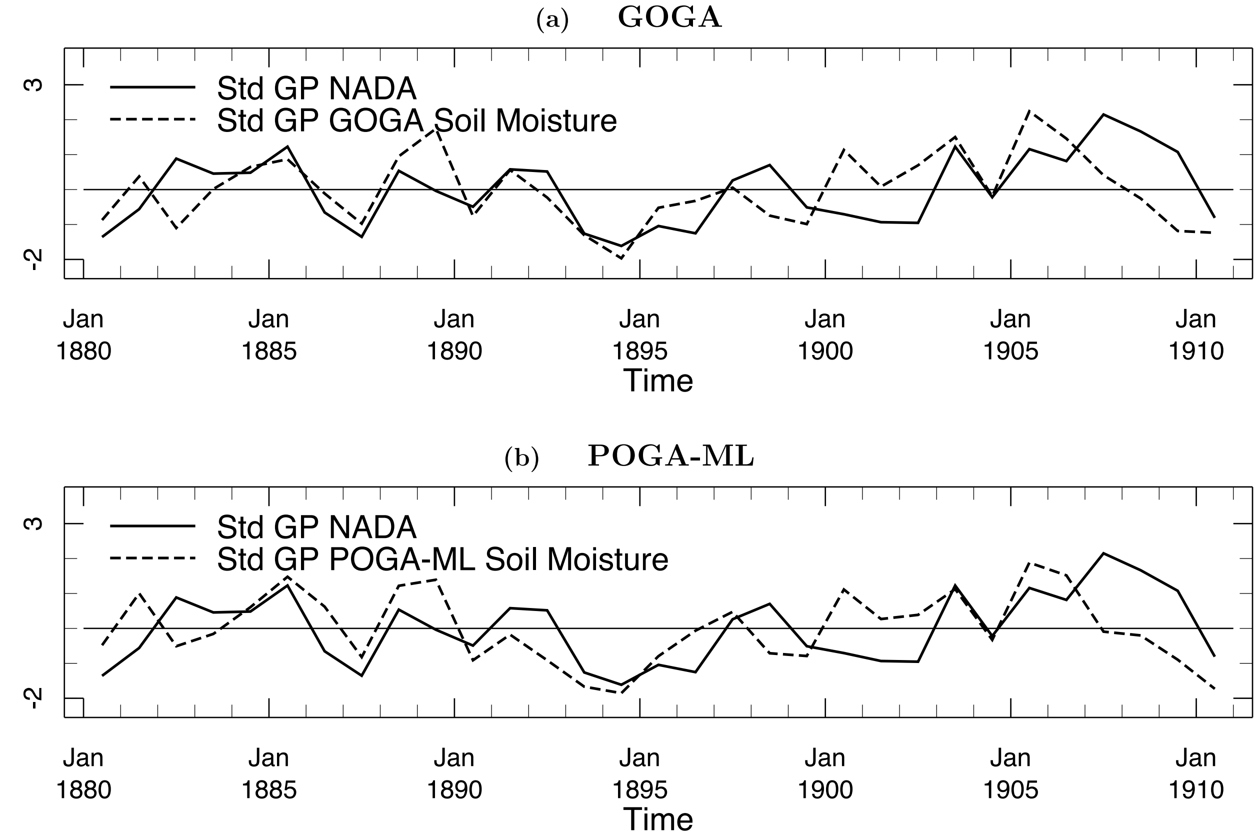
Precip

Dust and crop failure create observed drought pattern and matching continent-centered subsidence

500mb omega

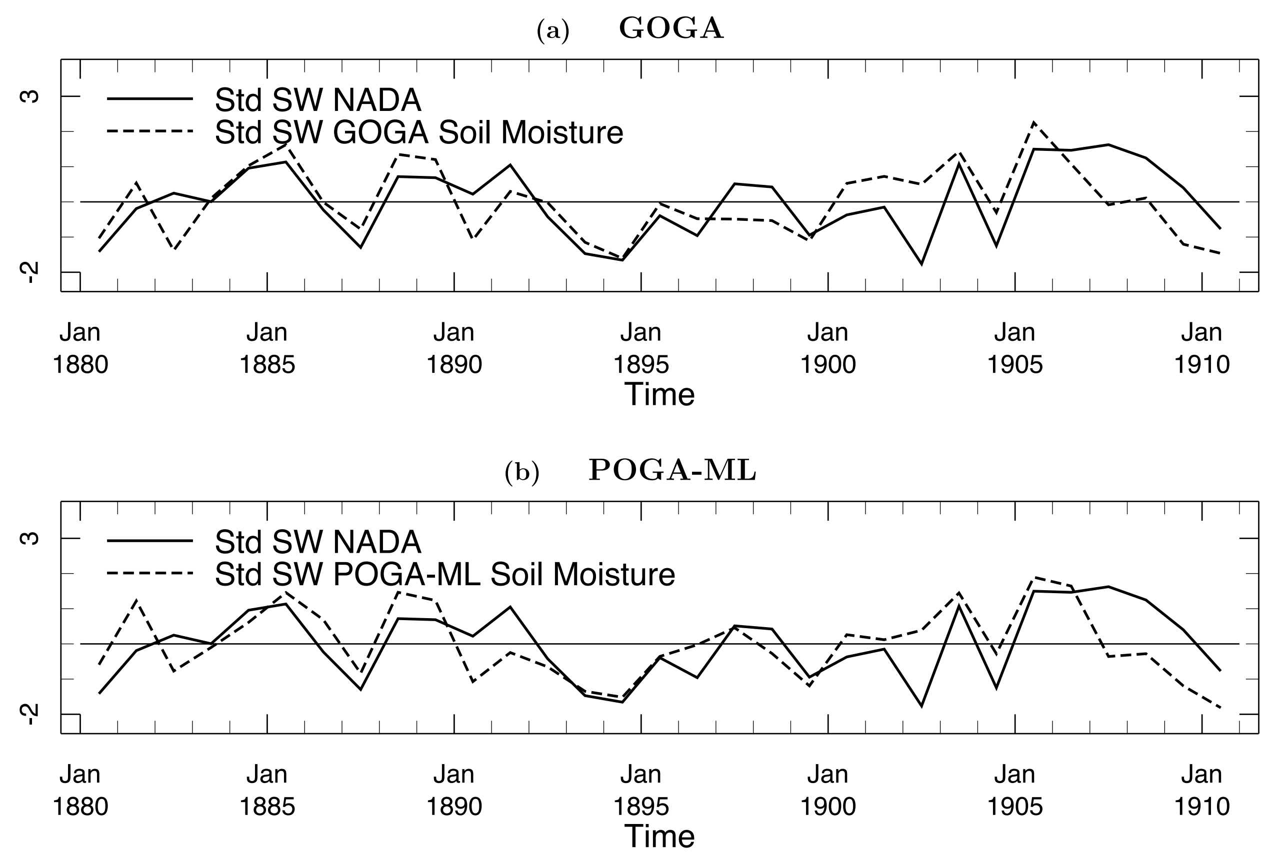
The 1890s drought, relatively brief, is quite well modeled with tropical Pacific forcing dominant.

Annual GP Indices, Std NADA V2A (solid) Model Mean (dashed)



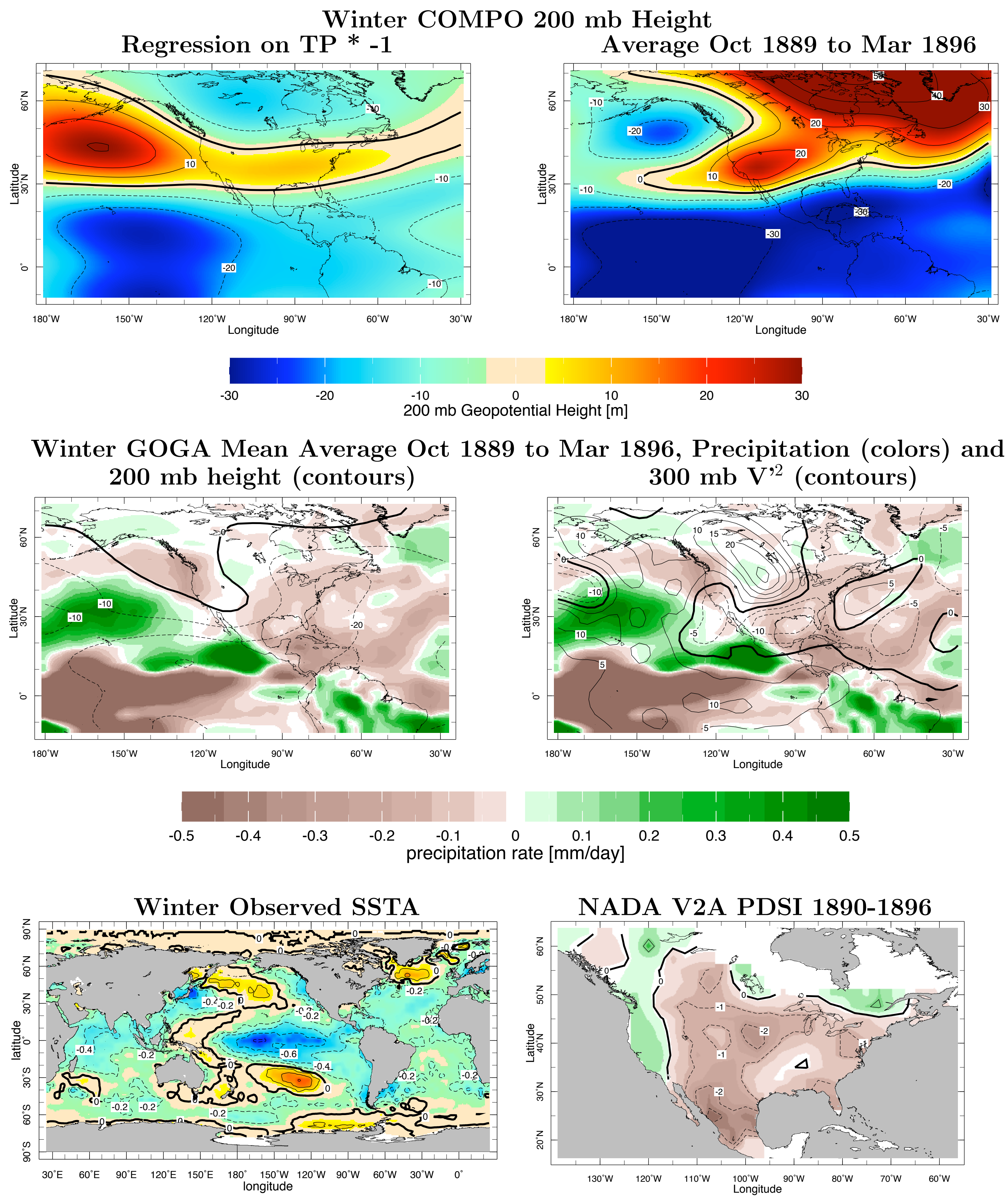
Great Plains, modeled soil moisture and tree ring PDSI

Annual SW Indices, Std NADA V2A (solid) Model Mean (dashed)

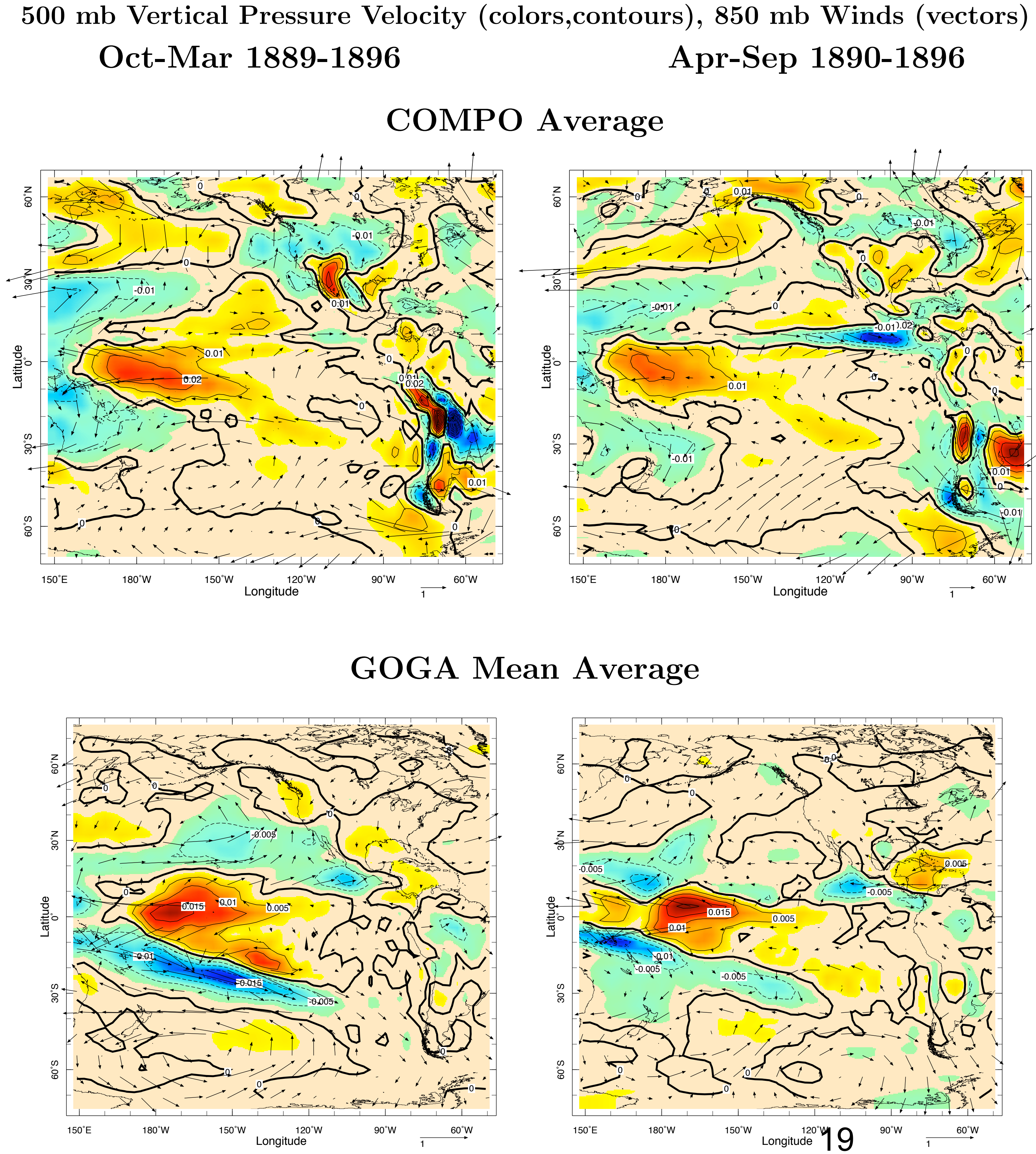


As above but for Southwest

1890s drought was associated with a La Nina but the circulation anomalies were not very typical in 20CR or model.



20CR and the model circulation match well in the tropics but not so well over N. America. In the model there is general southerly flow and descent forcing the drought.

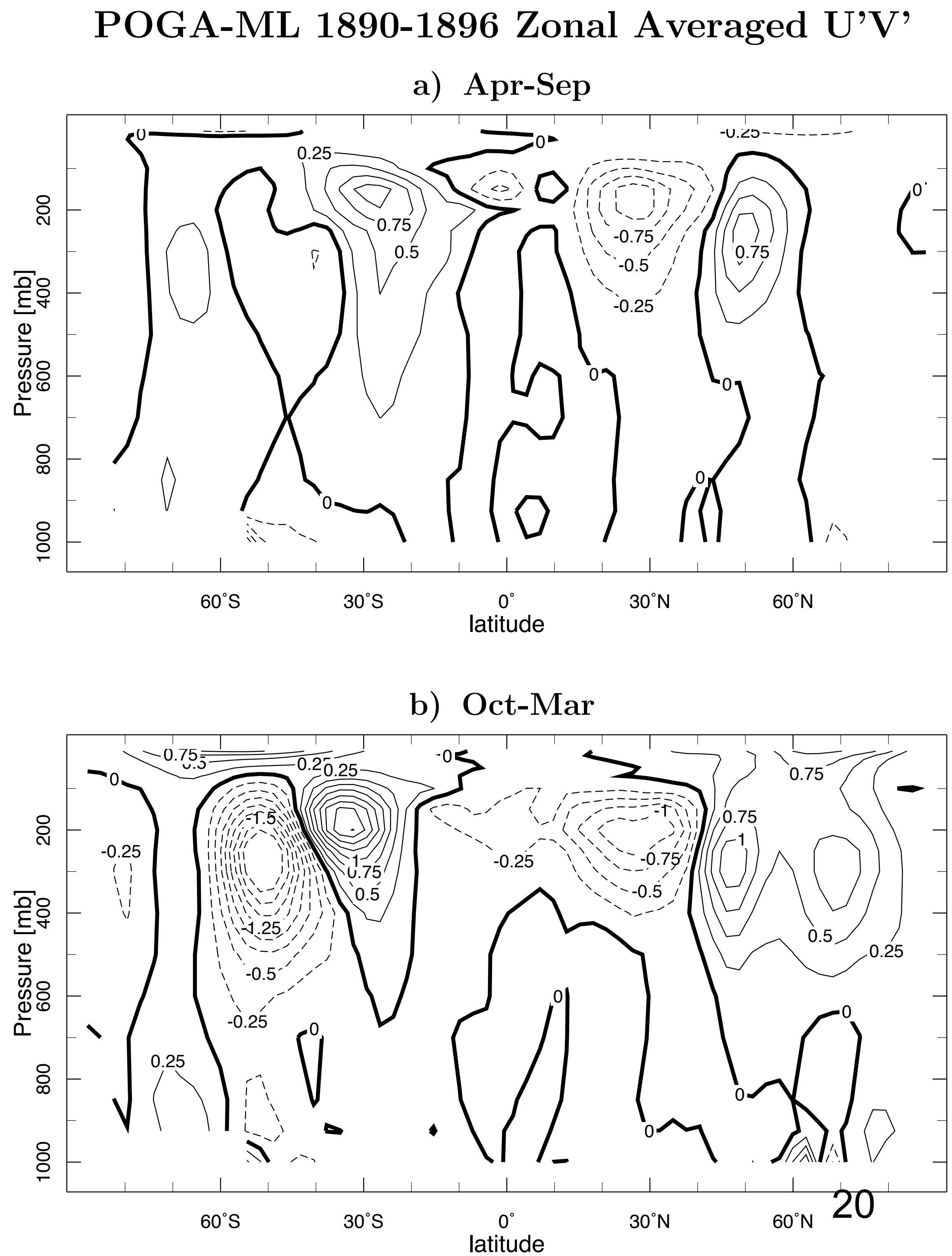


At least in the tropical Pacific SST-forced model the familiar pattern of tropically organized transient eddy-driven descent is clear in the 1890s.

For drought regimes:

1. Tropical tropospheric cooling ⇒poleward shift of subtropical jet
2. jet shift ⇒ shift in the pattern of eddy momentum transport
3. Balancing Coriolis torque ⇒eddy-induced upper troposheric flow subtropics to mid-latitudes.
4. Mass convergence in the mid-latitudes ⇒ descent ⇒suppressed precipitation.

Need to see ensemble members in 20CR to check this



Conclusions

1. 20CR allows examination of the similarities and differences of the 20th Century droughts and moving beyond SST-forced model simulations to validate proposed mechanisms.

2. 1950s drought akin to that expected from cold tropical Pacific-warm subtropical North Atlantic SST forcing.

3. 1930s Dust Bowl drought has, unlike SST forced droughts, massive continental-centered subsidence.

4. The Dust Bowl subsidence is consistent with dust aerosol forcing following crop failure. Dust forcing worsened drought and moved it northwards explaining its unique spatial pattern.

5. 1890s drought - more work needed!