Mechanisms of tropical Pacific and tropical Atlantic forcing of North American hydroclimate

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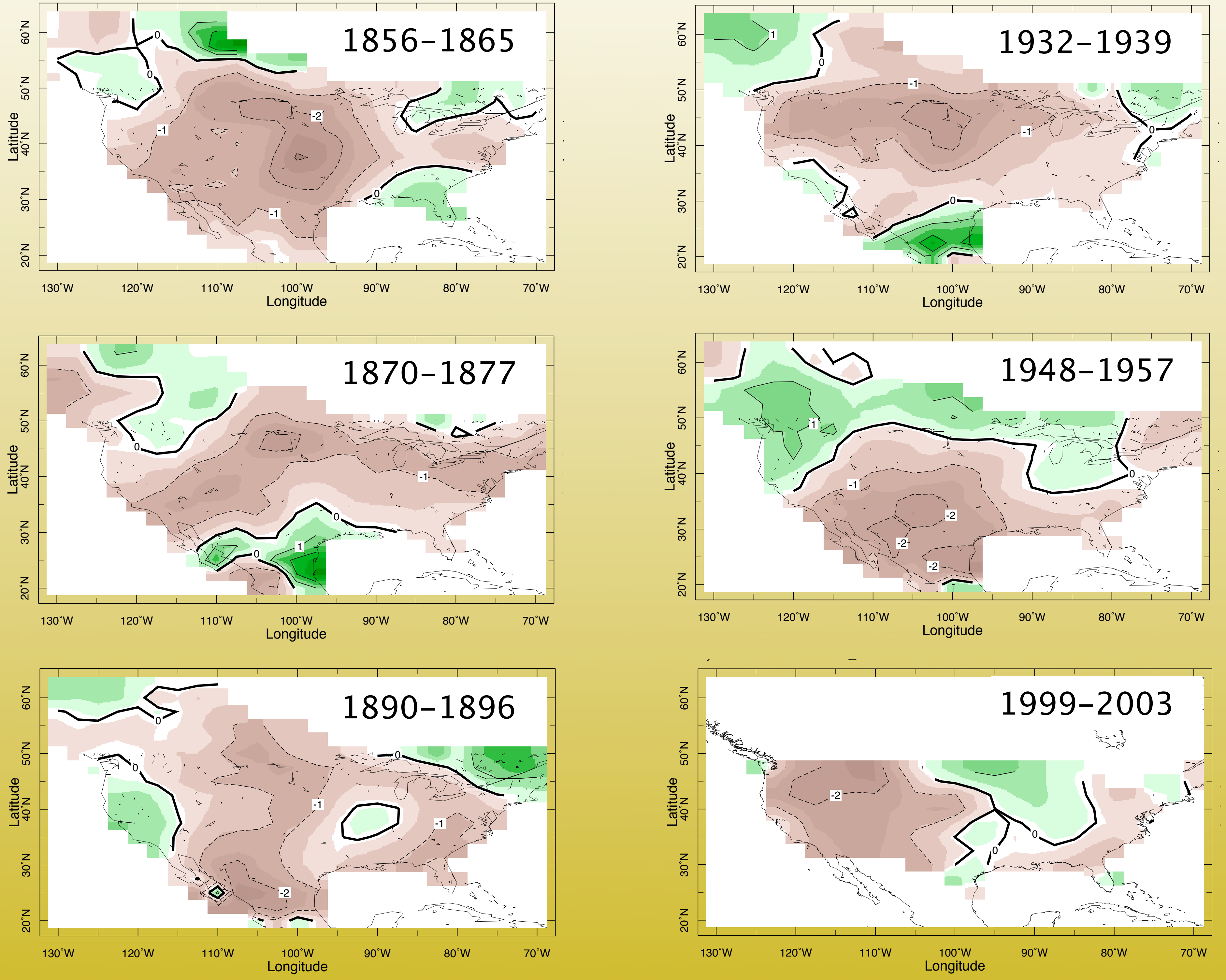
Historical Droughts



PDSI

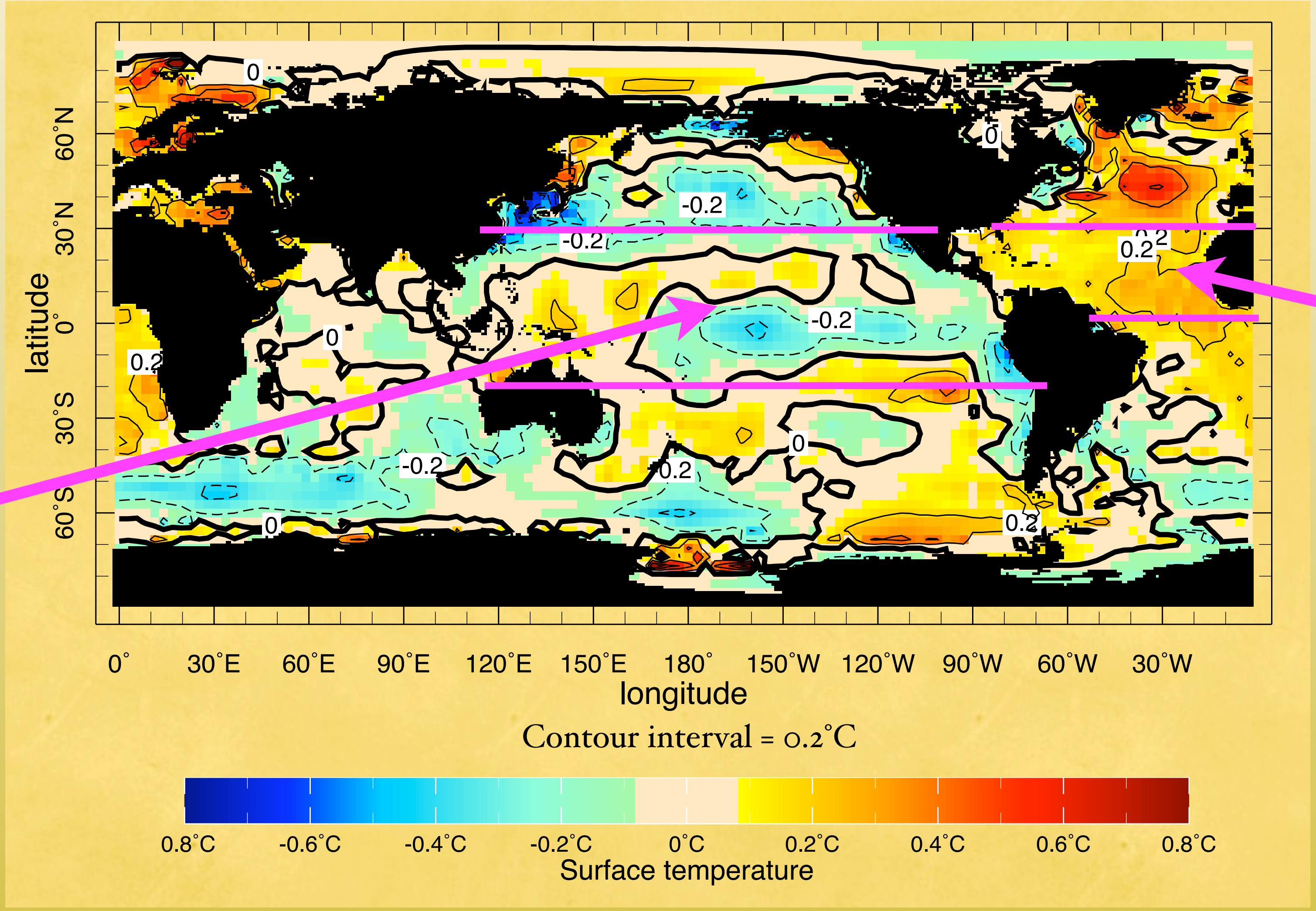
North American Drought Atlas

http://iridl.ldeo.columbia.edu/SOURCES/.LDEO/.TRL/.NADA2004/.pdsi-atlas.html

Modeling methodology

GOGA: *SST prescribed everywhere*

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



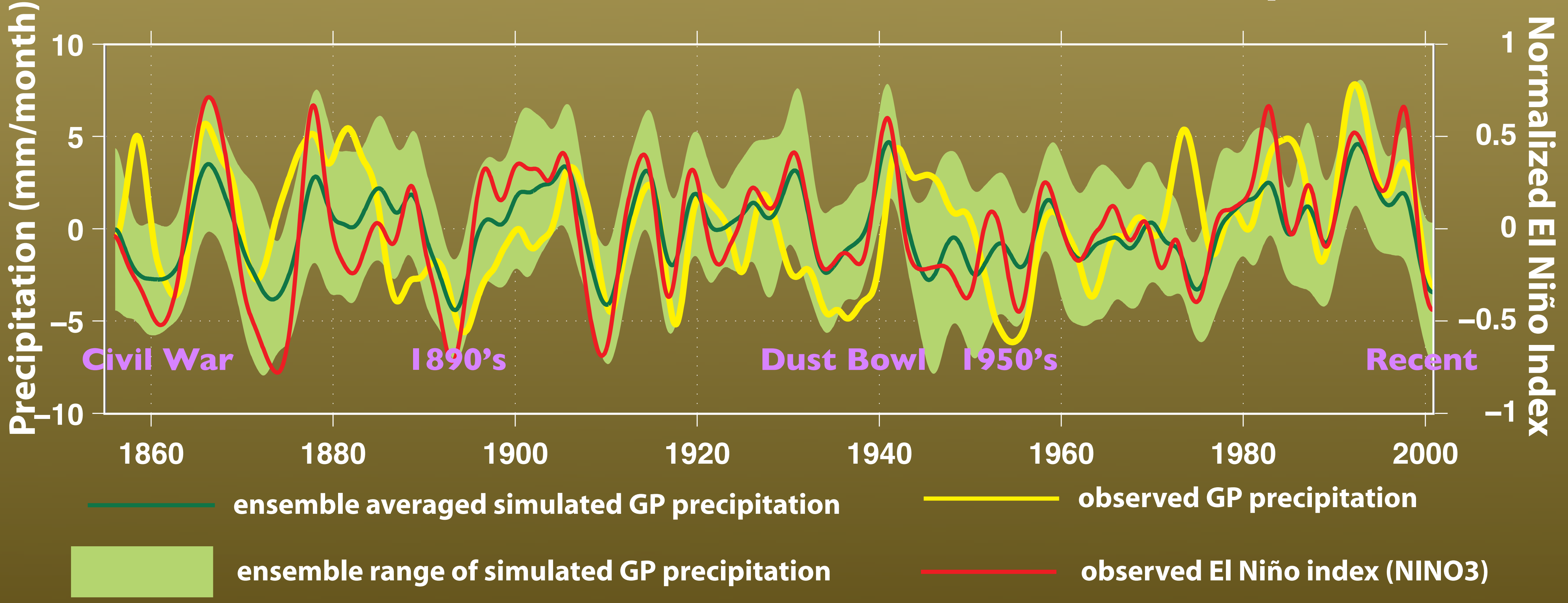
TAGA: SST prescribed *only in the tropical Atlantic & climo elsewhere*

Figure shows SST anomaly 1932-39

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

GP rainfall variability 1850’s to present

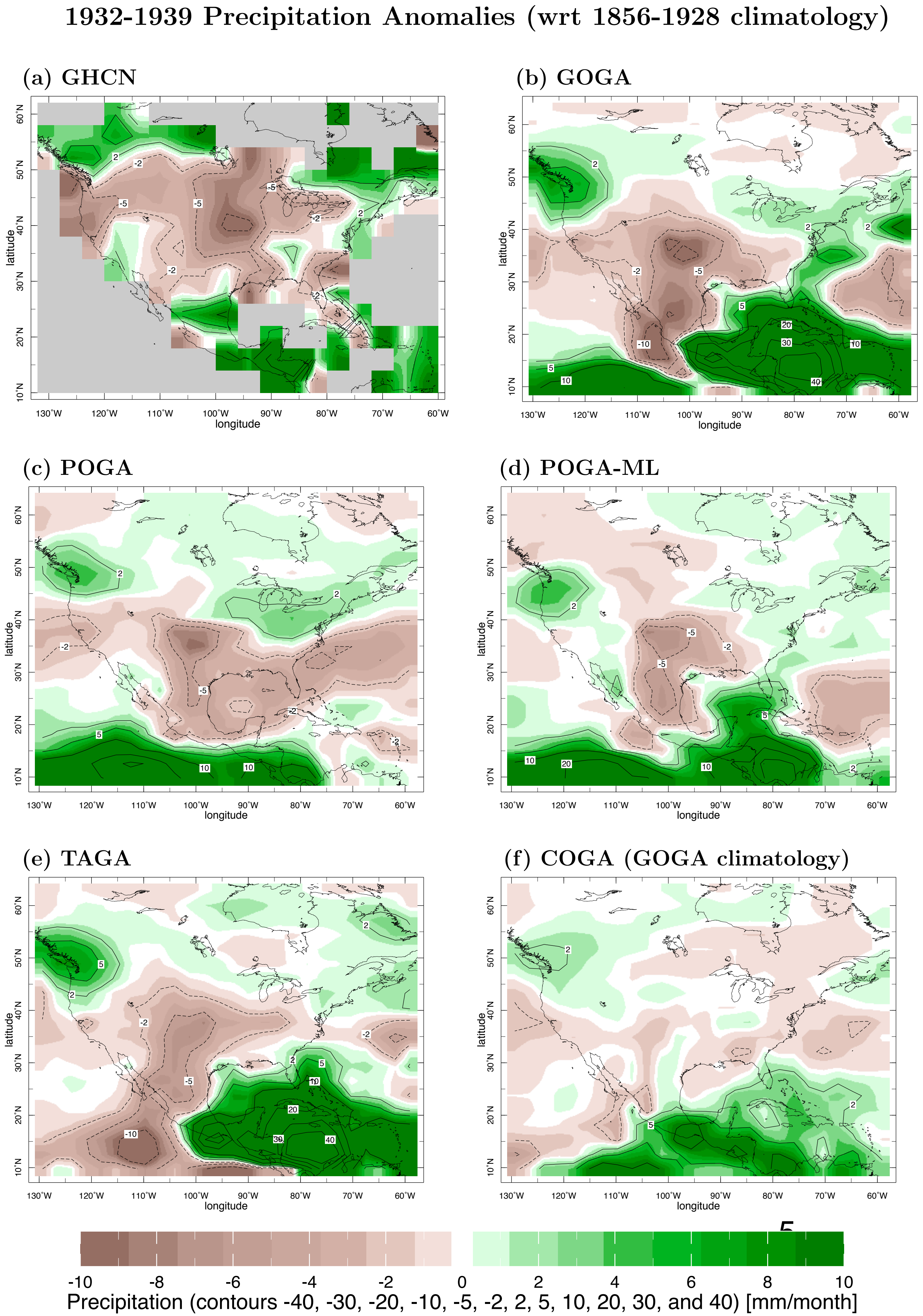
Seager et al. (2005)



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

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

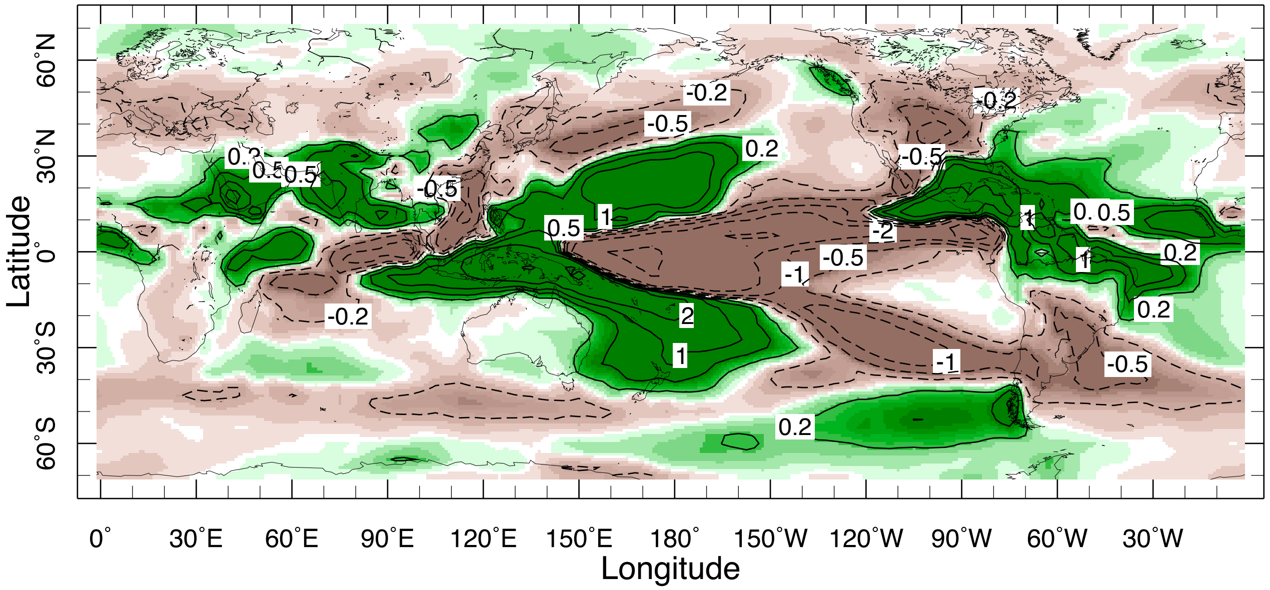


Drought WG 5 model composite Pac Cold minus Pac warm (both Atl neutral)

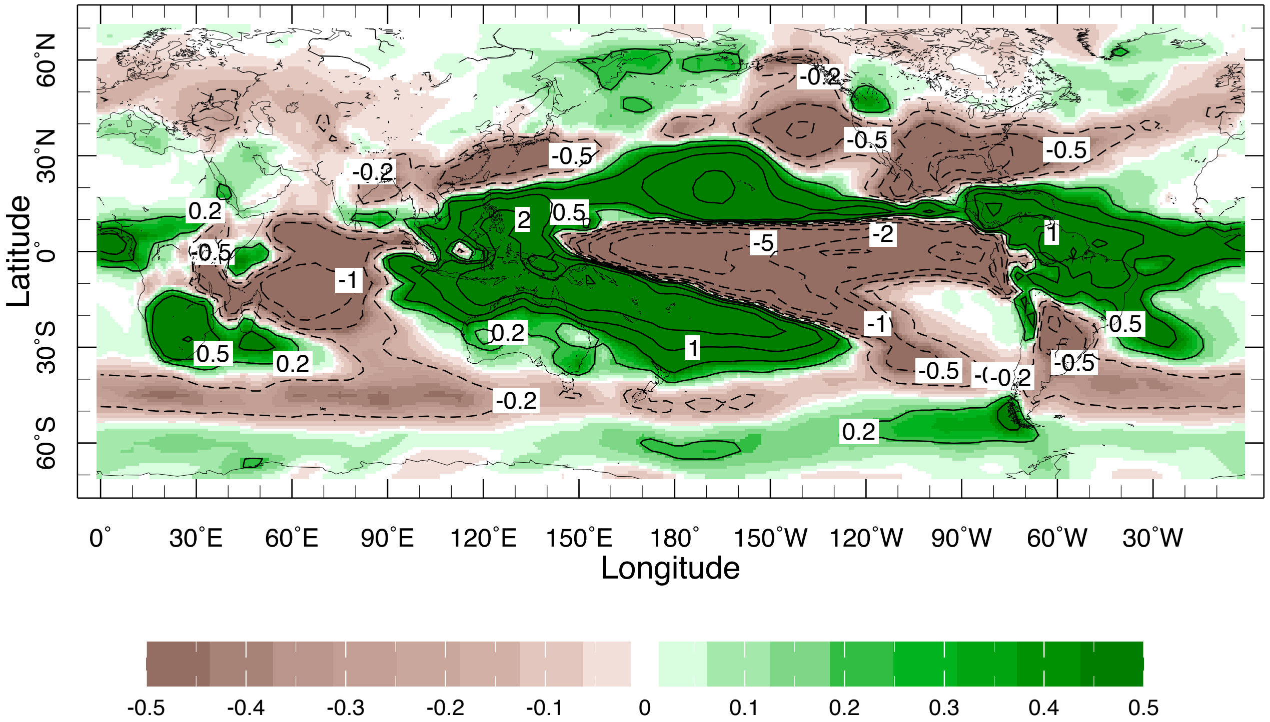
precipitation

Clivar 5 Model Composite PcAn - PwAn Last 35 Years Precipitation

a) Summer



b) Winter

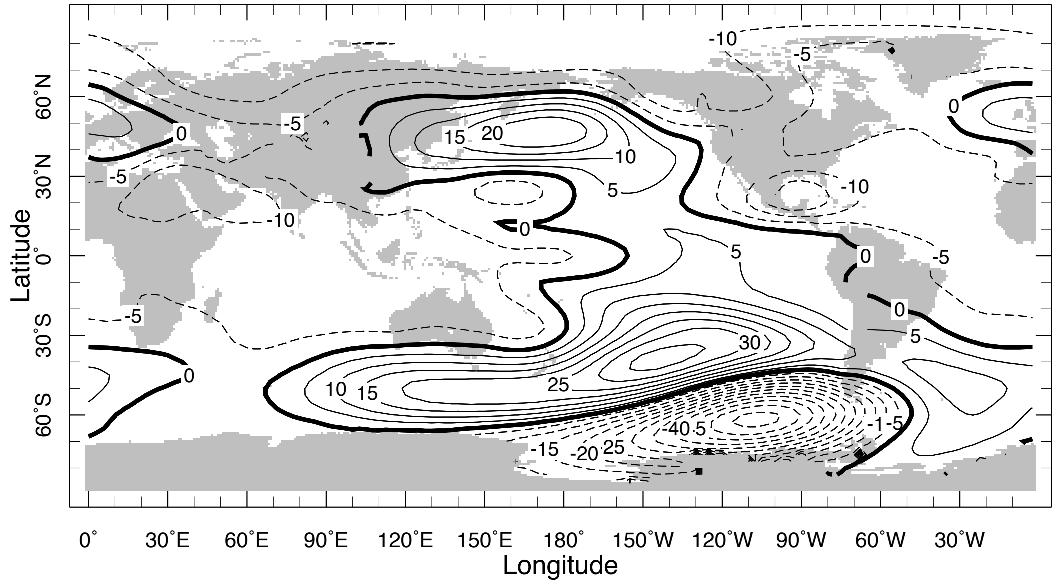


Precipitation (contours -5, -2, -1, -0.5, -0.2, 0.2, 0.5, 1, 2, and 5) [mm/day]

850 mb height

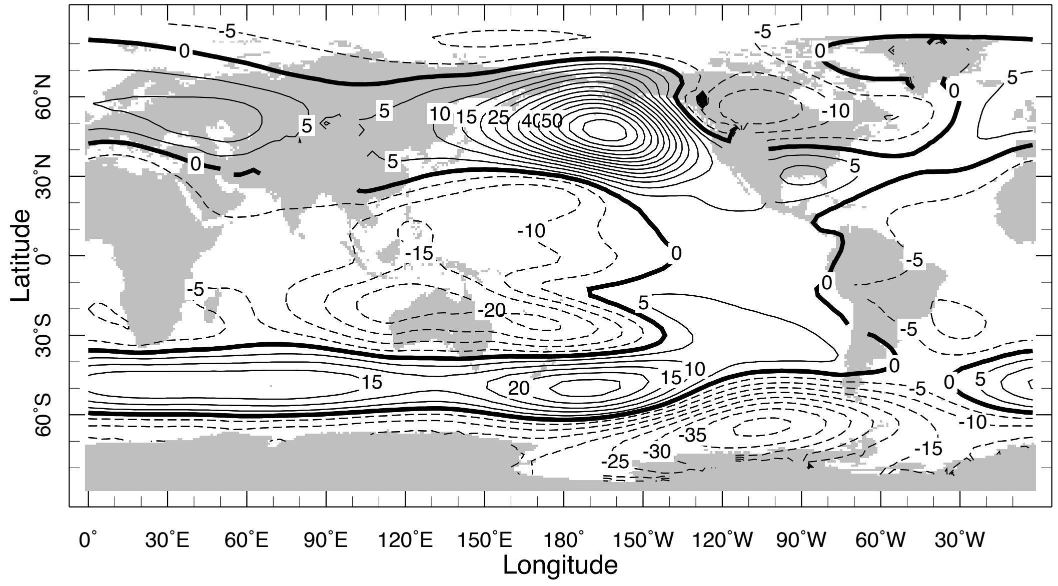
Clivar 4 Model Comp PcAn - PwAn Last 45 Years 850 mb Heights

a) Summer



850. hPa

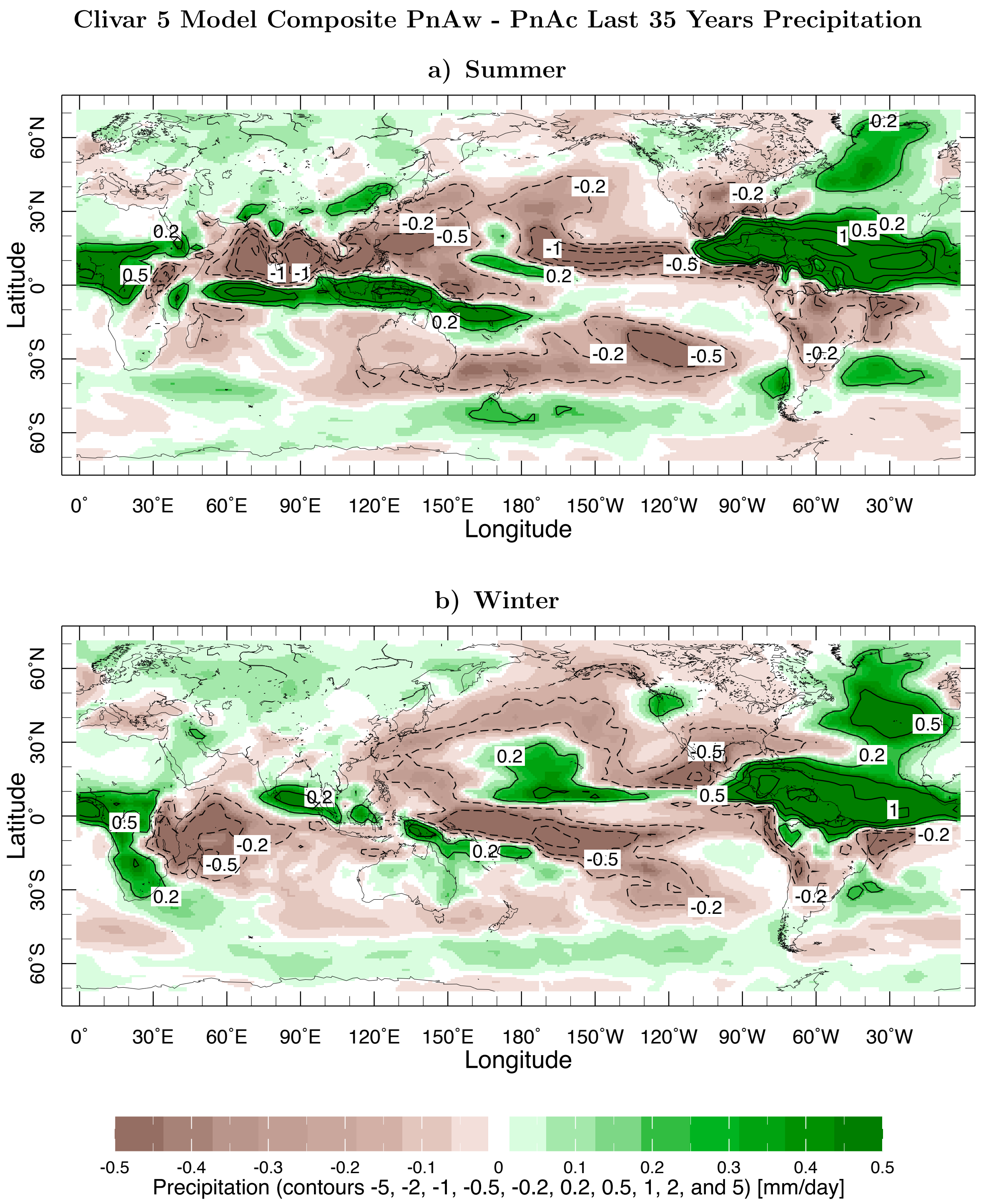
b) Winter



850. hPa

Drought WG 5 model composite Atl warm minus Atl cold (both Pac neutral)

precipitation



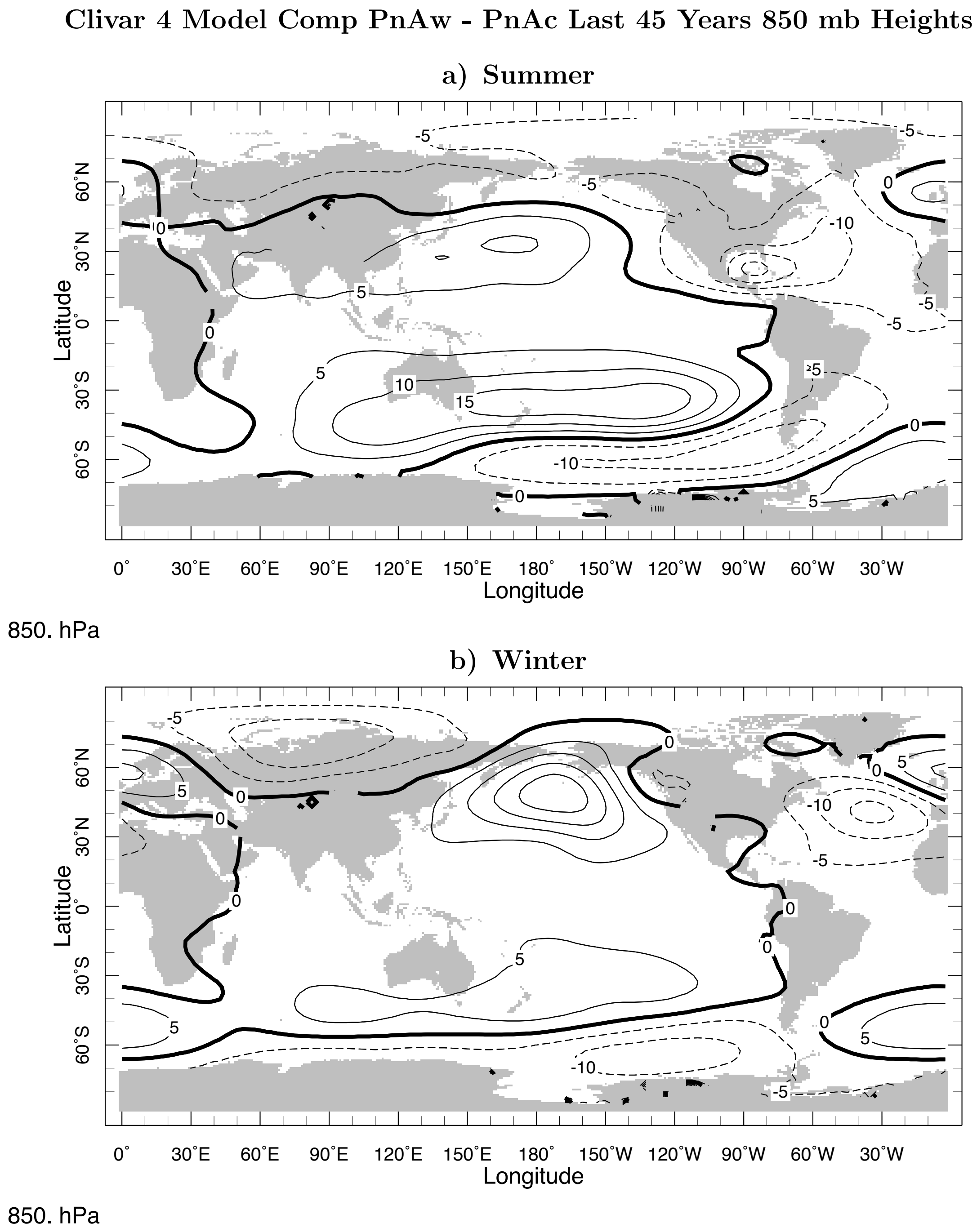
Clivar 5 Model Composite PnAw - PnAc Last 35 Years Precipitation

a) Summer

b) Winter

Precipitation (contours -5, -2, -1, -0.5, -0.2, 0.2, 0.5, 1, 2, and 5) [mm/day]

850 mb height



Clivar 4 Model Comp PnAw - PnAc Last 45 Years 850 mb Heights

a) Summer

850. hPa

b) Winter

850. hPa

Model and observational consensus:

both tropical Pacific cold and tropical Atlantic warm
dry Mexico and most of U.S. with Pacific influence
winning in terms of mm/day/K.

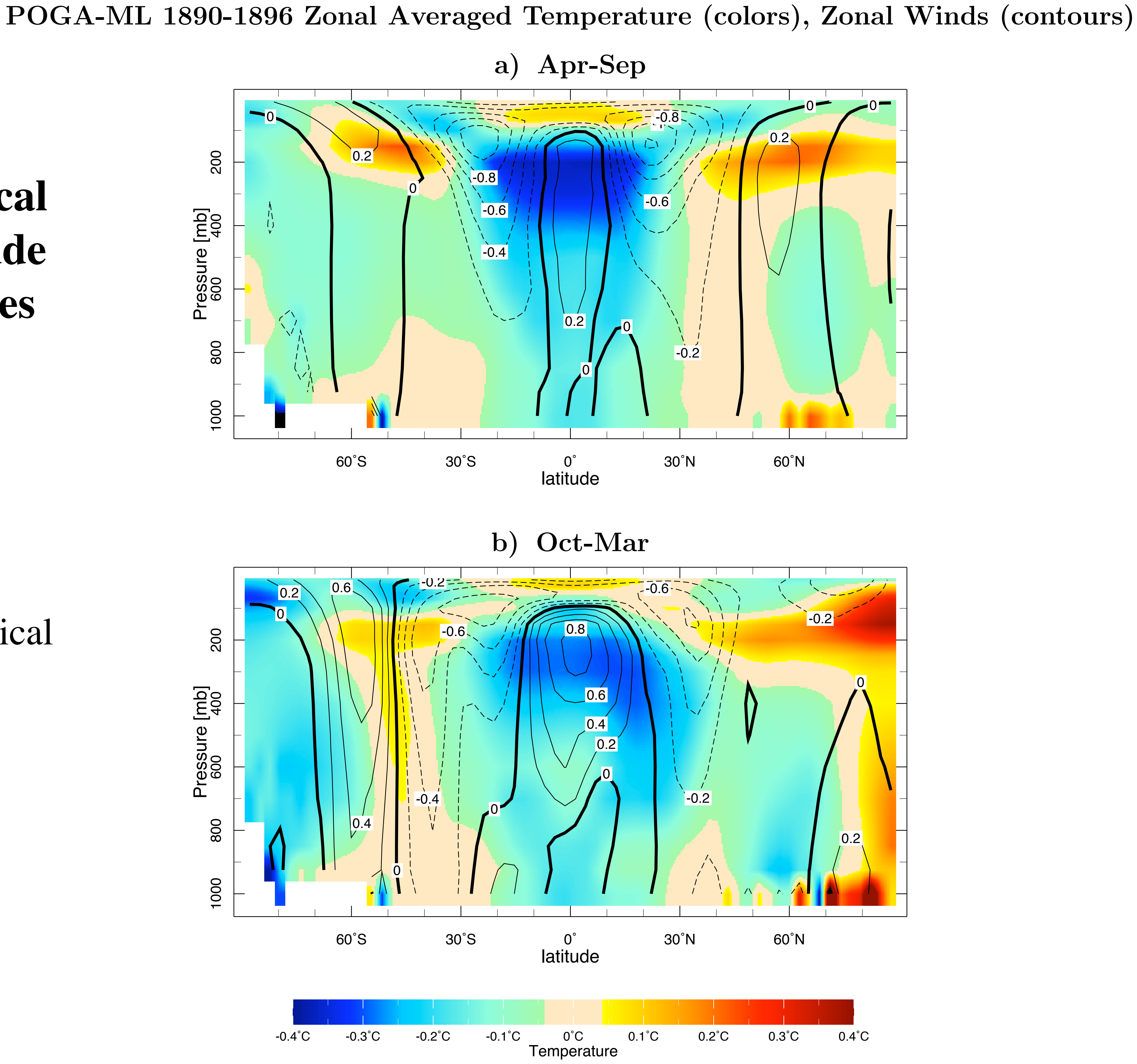
Need to understand mechanisms of both

Mechanisms of the tropical Pacific forcing of North American hydroclimate ....

Zonal mean dynamical context of mid-latitude hydroclimate regimes

During drought regimes:

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



POGA-ML 1890-1896 Zonal Averaged Temperature (colors), Zonal Winds (contours)

a) Apr-Sep

b) Oct-Mar

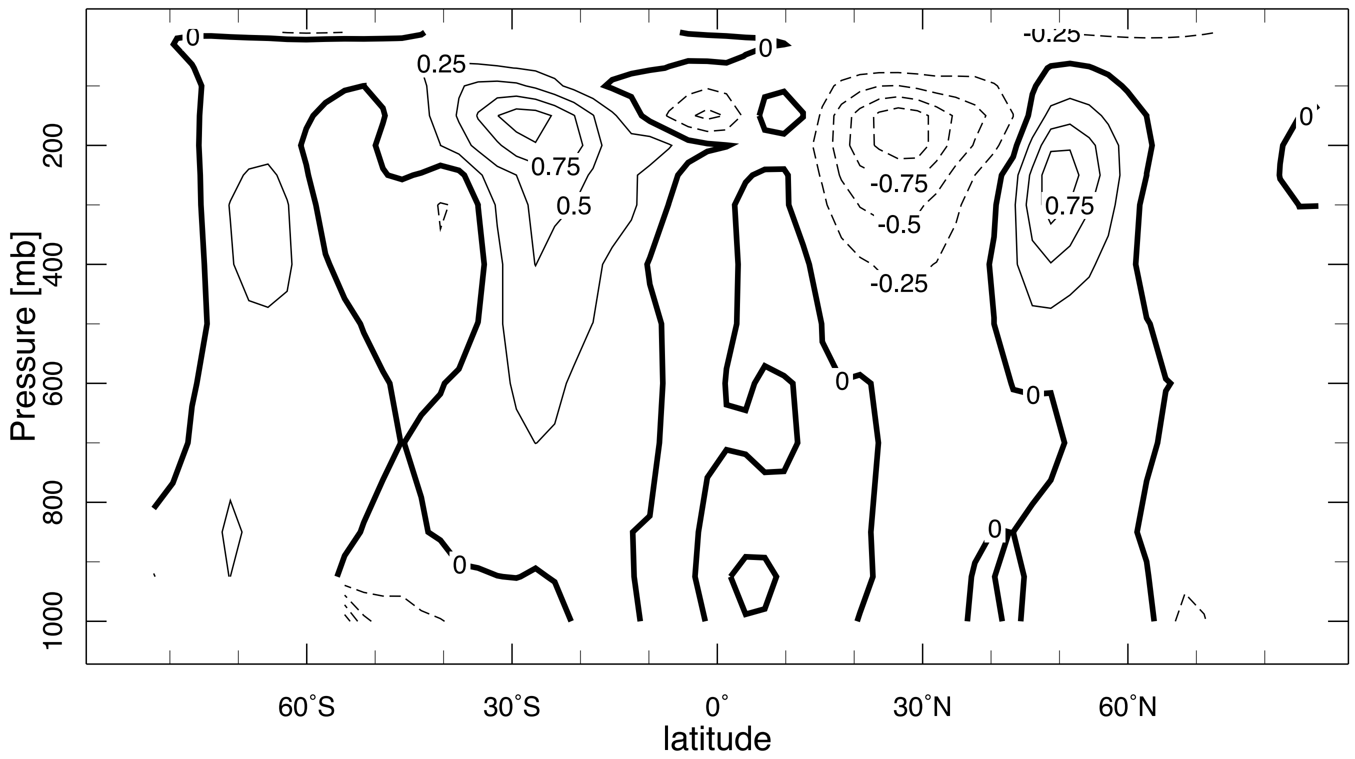
The zonally symmetric dynamics according to Seager et al. (2003) …

For drought regimes:

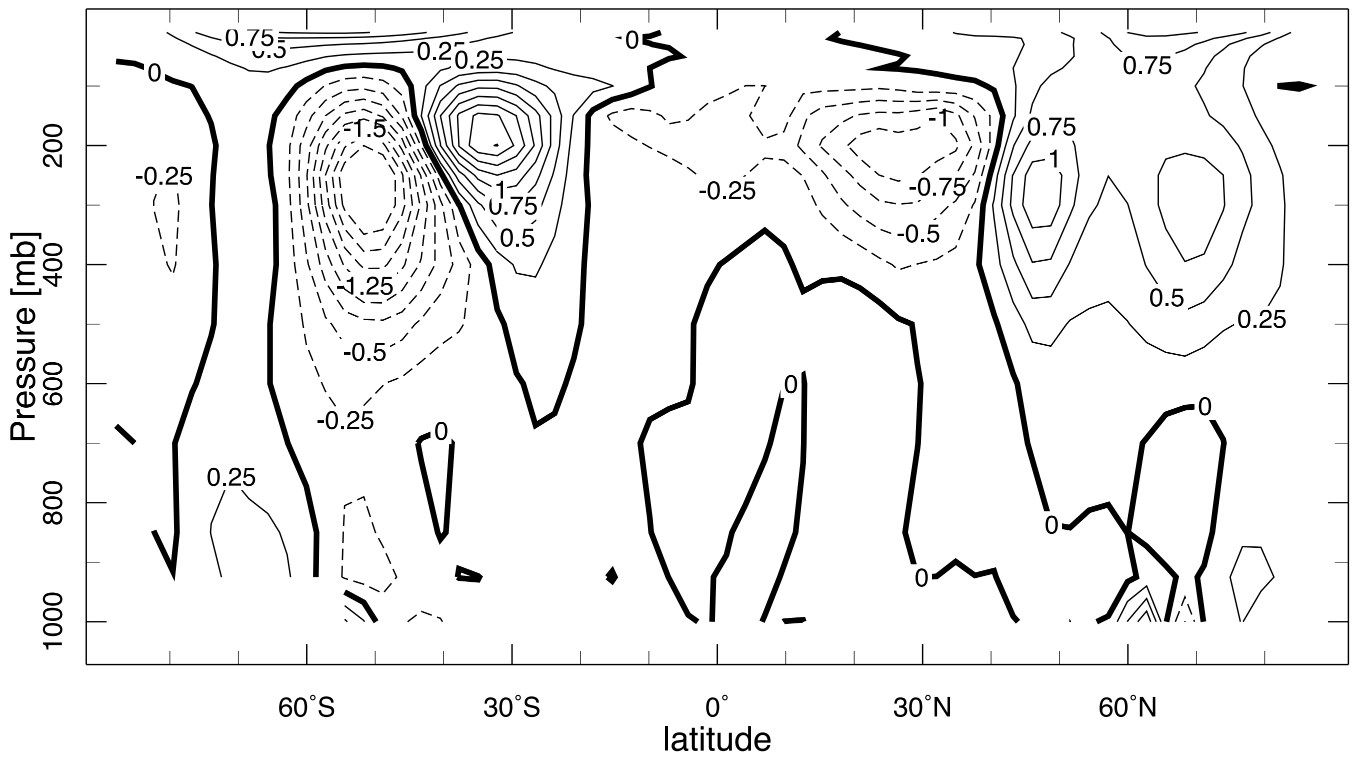
1. Tropical tropospheric cooling ⇒poleward shift of subtropical jet
2. jet shift ⇒ shift in the pattern of eddy momentum transport
3. Balancing Coriolis torque ⇒eddy-induced upper tropospheric flow subtropics to mid-latitudes.
4. Mass convergence in the mid-latitudes ⇒ descent ⇒suppressed precipitation.

POGA-ML 1890-1896 Zonal Averaged U'V'

a) Apr-Sep



b) Oct-Mar



Consistent with eddy-driving of an anomalous MMC ....

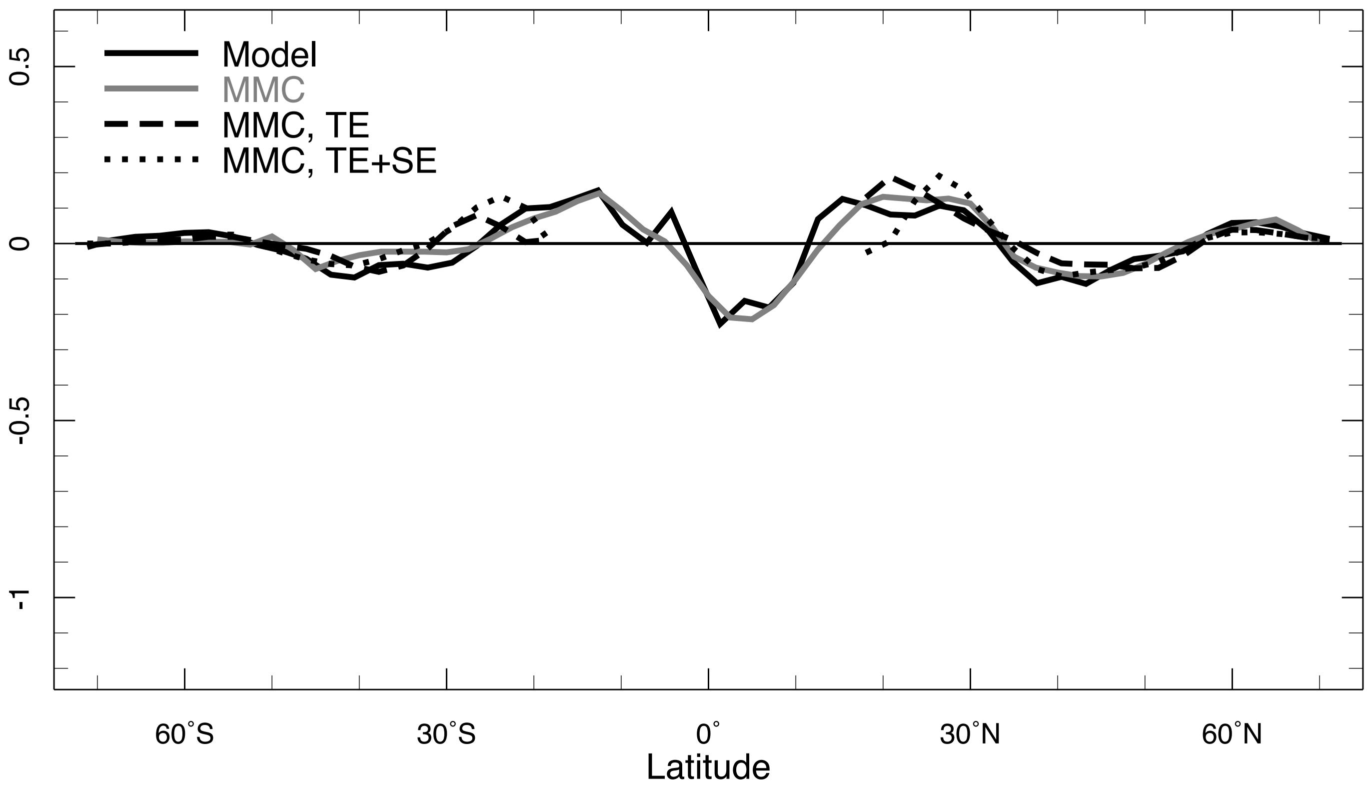
Zonal mean P-E (mm/day) in turn-of-century drought

- accounted for by MMC anomaly working on climatological humidity field

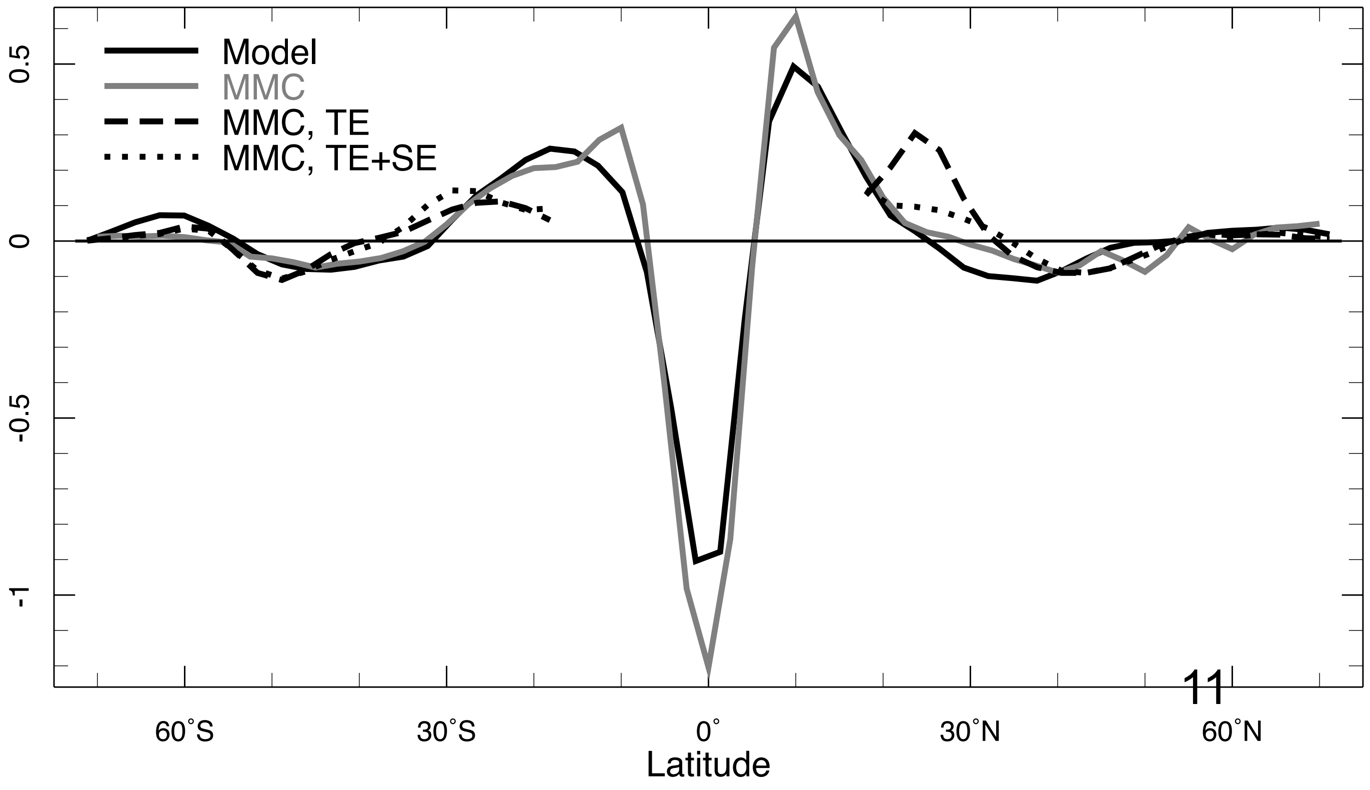
- transient eddy-driven MMC does the most

Zonal Average GOGA P-E

Apr-Sep 1999-2001



Oct-Mar 1998-2002



Diagnosing tropical-extratropical interactions with a linear quasi-geostrophic model of transient eddies (Harnik and Lindzen 2001):

$$\frac{a^2 f^2}{N^2}\frac{\partial^2 \varphi}{\partial z^2} + \frac{f}{\cos\phi}\frac{\partial}{\partial\phi}\left[\cos\phi\frac{\partial}{\partial\phi}\left(\frac{\varphi}{f}\right)\right] + \left[\frac{a\langle\overline{q_\phi}\rangle}{\langle\overline{u}\rangle - \dfrac{\sigma a\ \cos\phi}{s}} - \frac{s^2}{\cos^2\phi} + a^2 f^2 F(N^2)\right]\varphi = \text{damping.}$$

Solve for geopotential of a wave of specified zonal wavenumber and frequency, then for u’, v’, <u’v’>, MMC, T’

Solution depends on specified zonal mean flow and PV gradient
specify 1) climatological and 2) El Nino conditions

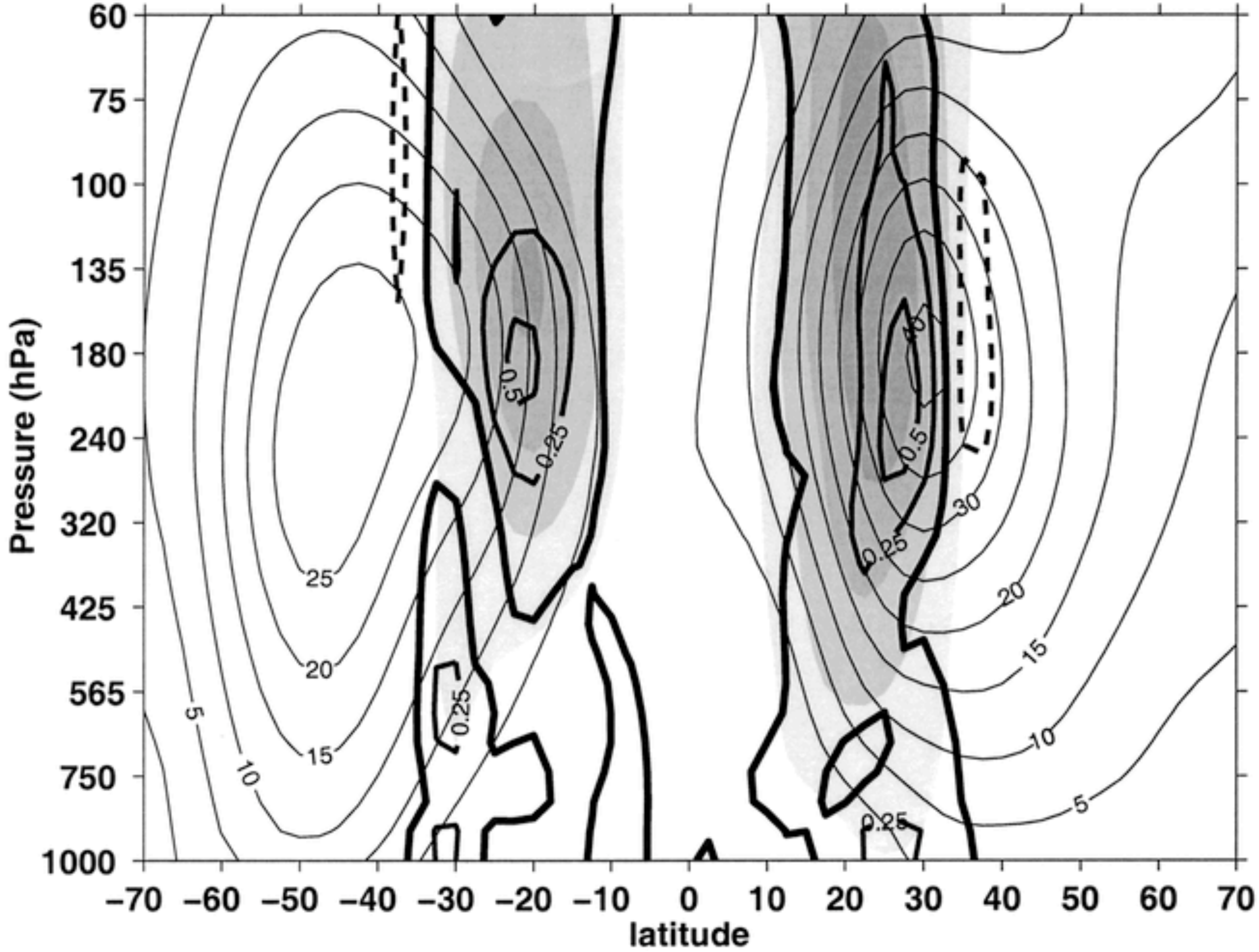


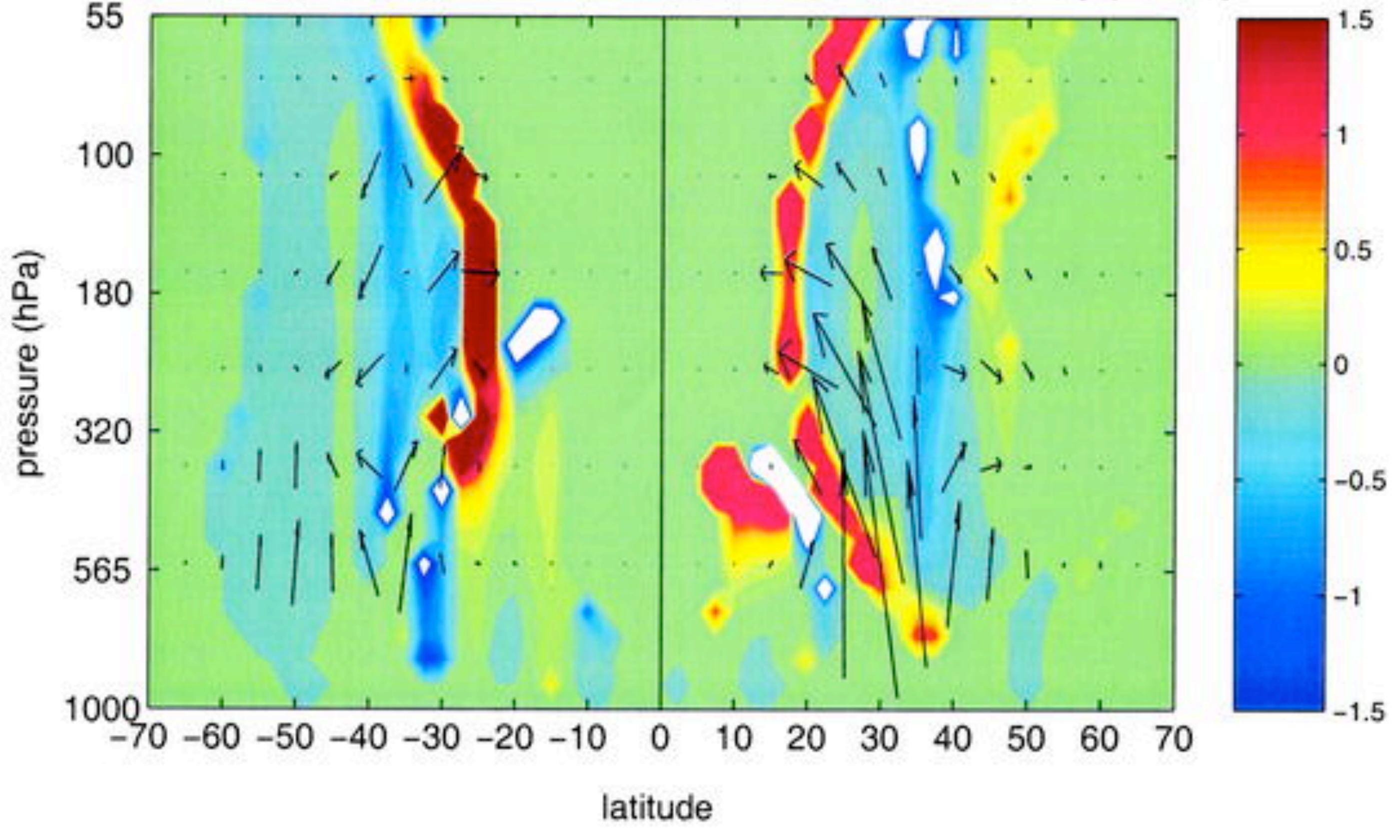
Fig. 12. DJF climatological zonal-mean wind (thin contours, intervals of 5 m s^{-1}), the El Niño wind anomalies used in our calculation (shaded, values between 0.5 and 3 m s^{-1}, at intervals of 0.5), and the corresponding meridional PV gradient anomalies (thick lines, zero line thickest, negative values dashed, contour interval of 0.25×10^{-11} m^{-1} s^{-1}).

The zonal mean basic state and the imposed El Nino anomaly

Modeled El Nino anomaly of:

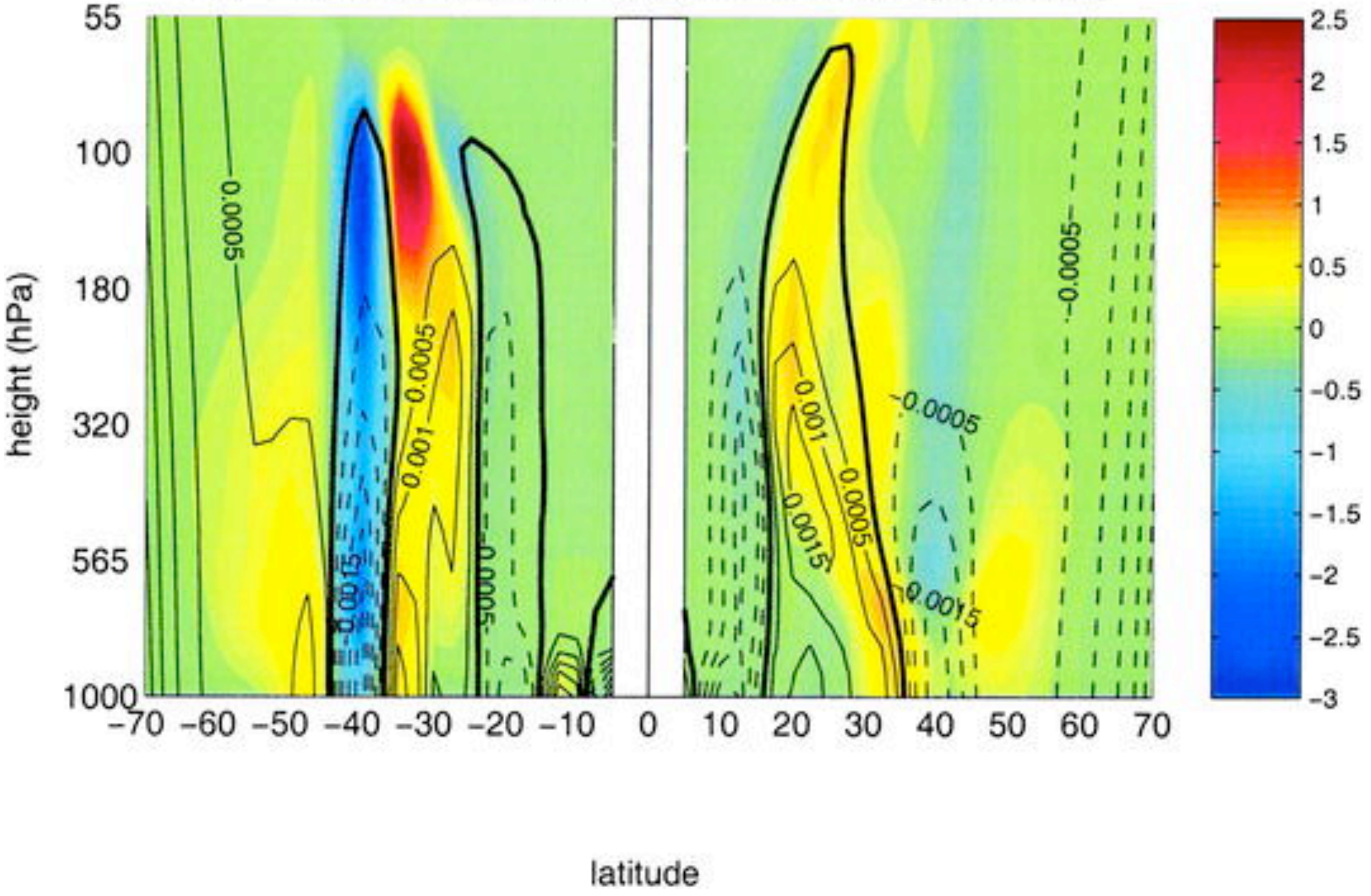
EP fluxes

(a) meridional wavenumber anomaly (colors), EP flux anomaly (arrows)



vertical velocity (contours) and T (color)

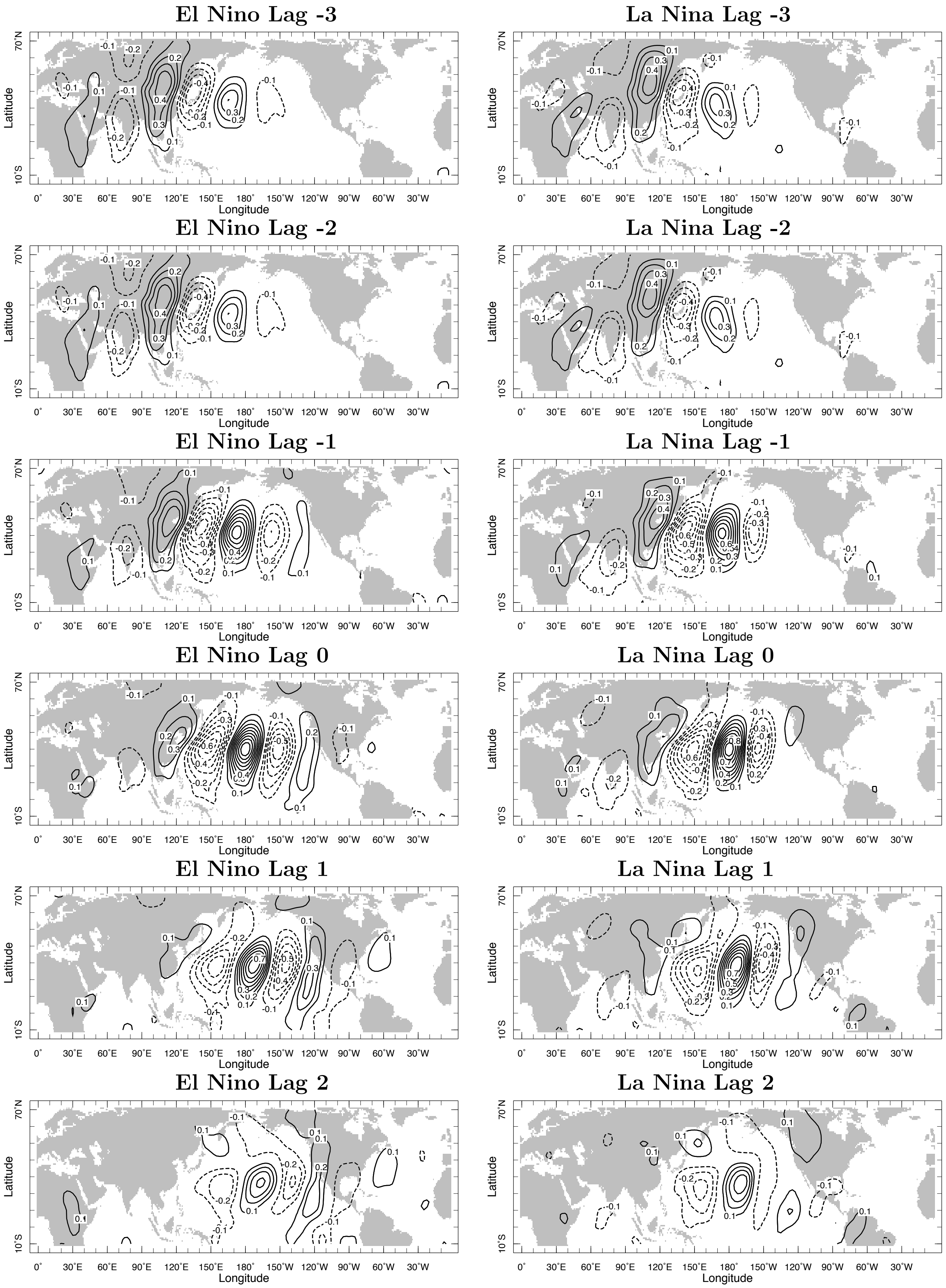
(b) T anomaly (colors), vertical pressure velocity (contours)



problem with this calculation (Seager et al. 2003) is that the specified mean flows were from NCEP Reanalysis and already include potential effects of eddy-driving

however, check the daily NCEP data for evidence of altered patterns of transient eddy propagation during El Nino and La Nina winters ....

NCEP Dec01-Feb28 Daily Corr V (300mb) and V (300mb, 30N, 180E)



El Nino Lag -3

La Nina Lag -3

El Nino Lag -2

La Nina Lag -2

El Nino Lag -1

La Nina Lag -1

El Nino Lag 0

La Nina Lag 0

El Nino Lag 1

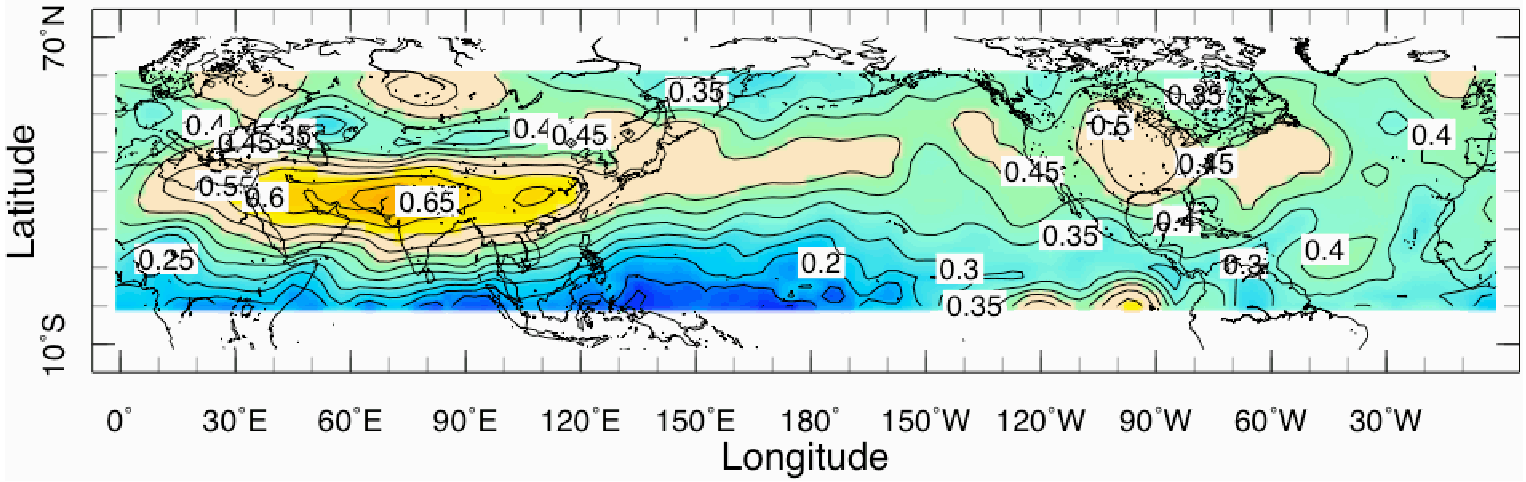
La Nina Lag 1

El Nino Lag 2

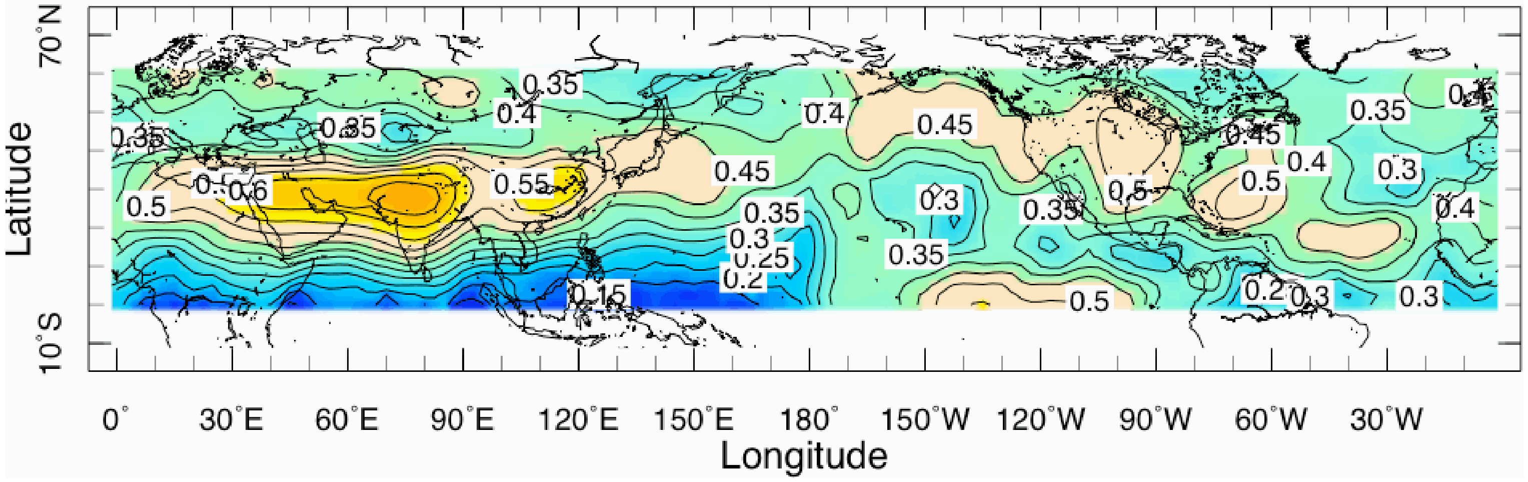
La Nina Lag 2

El Nino - La Nina changes in storm track supported by analysis of NCEP eddy meridional velocity with daily data and 1 point correlation maps

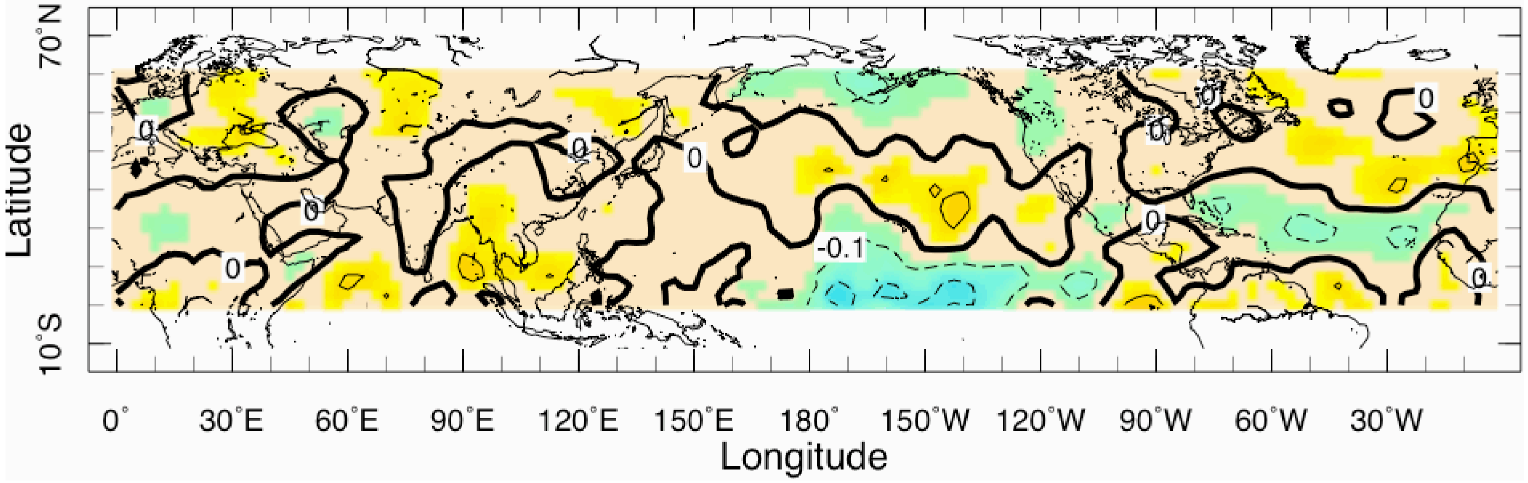
Note for El Nino a strong storm track into SW N. America and a split into S and N routes for La Nina



NCEP WCI - ElNino, daily v300mb, DJF



NCEP WCI - LaNina, daily v300mb, DJF



ElNino - LaNina

Compute wave coherence index as in Chang and Yu (1999)

shows for El Nino winters a strong zonal wave guide

for La Nina winters a northern wave guide plus a leak into the tropics

Identifying cause and effect in eddy-mean flow interaction using short, large ensembles with step function changes in SST on Dec 01

Dec 01 I.C. # 1 - El Nino SSTA
- climo SSTA
- La Nina SSTA

Dec 01 I.C. #2 - El Nino SSTA
- climo SSTA
- La Nina SSTA

Dec 01 I.C. #3 - El Nino SSTA
- climo SSTA
- La Nina SSTA

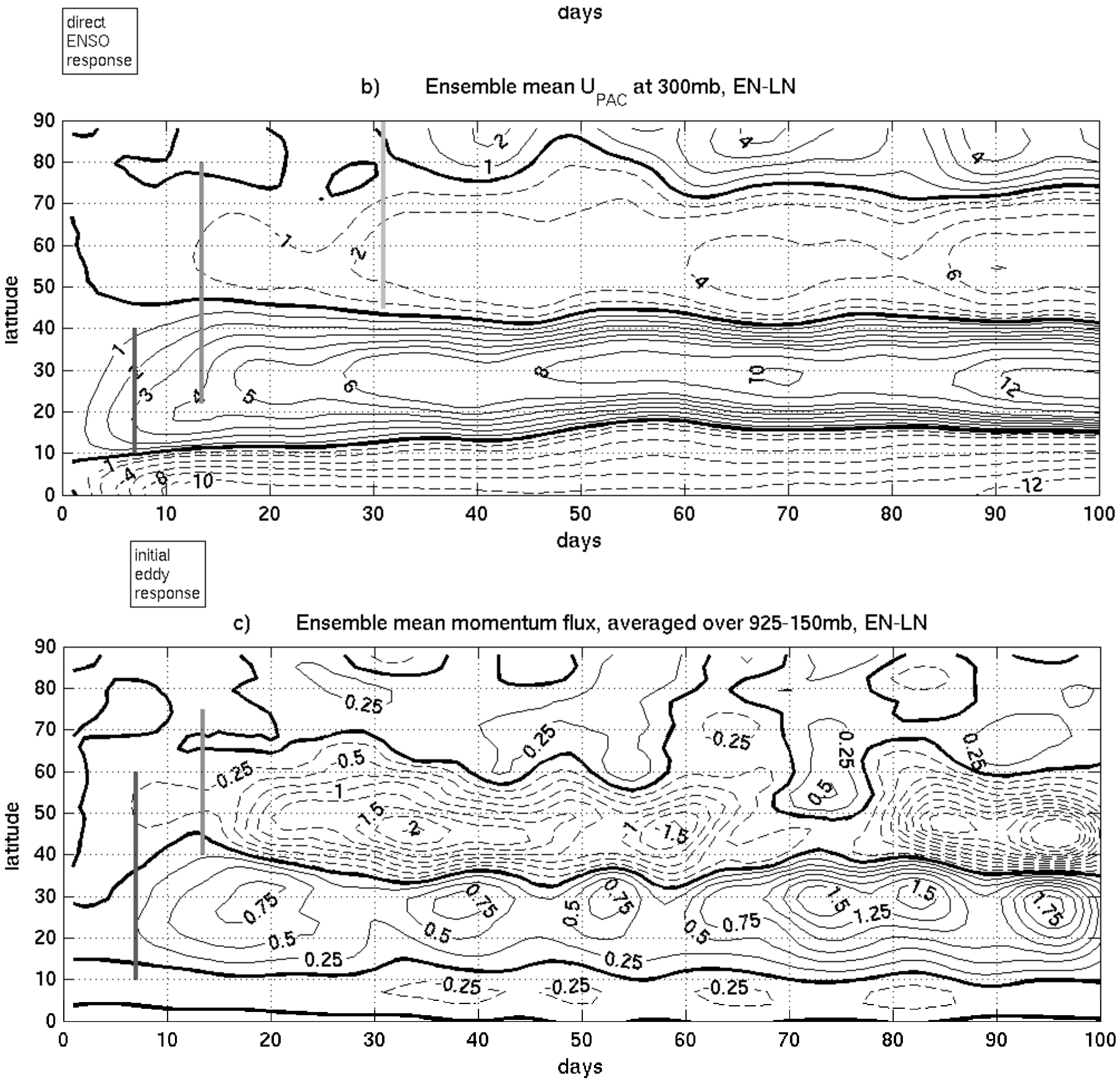
....

Dec 01 I.C. #100 - El Nino SSTA
- climo SSTA
- La Nina SSTA

run all for 100 days, through February.

Average over 100 member ensemble to see day by day SST anomaly forced adjustment of mean and transient circulation

100 member ensemble mean response to El Nino minus La Nina SST anomaly



latitude

u

latitude

u’v’

days after SSTA turned on

direct mean flow response to tropical SSTs

↓

eddy propagation path and u’v’ pattern response

↓

eddy-driven mean flow response in extra-tropics

↓

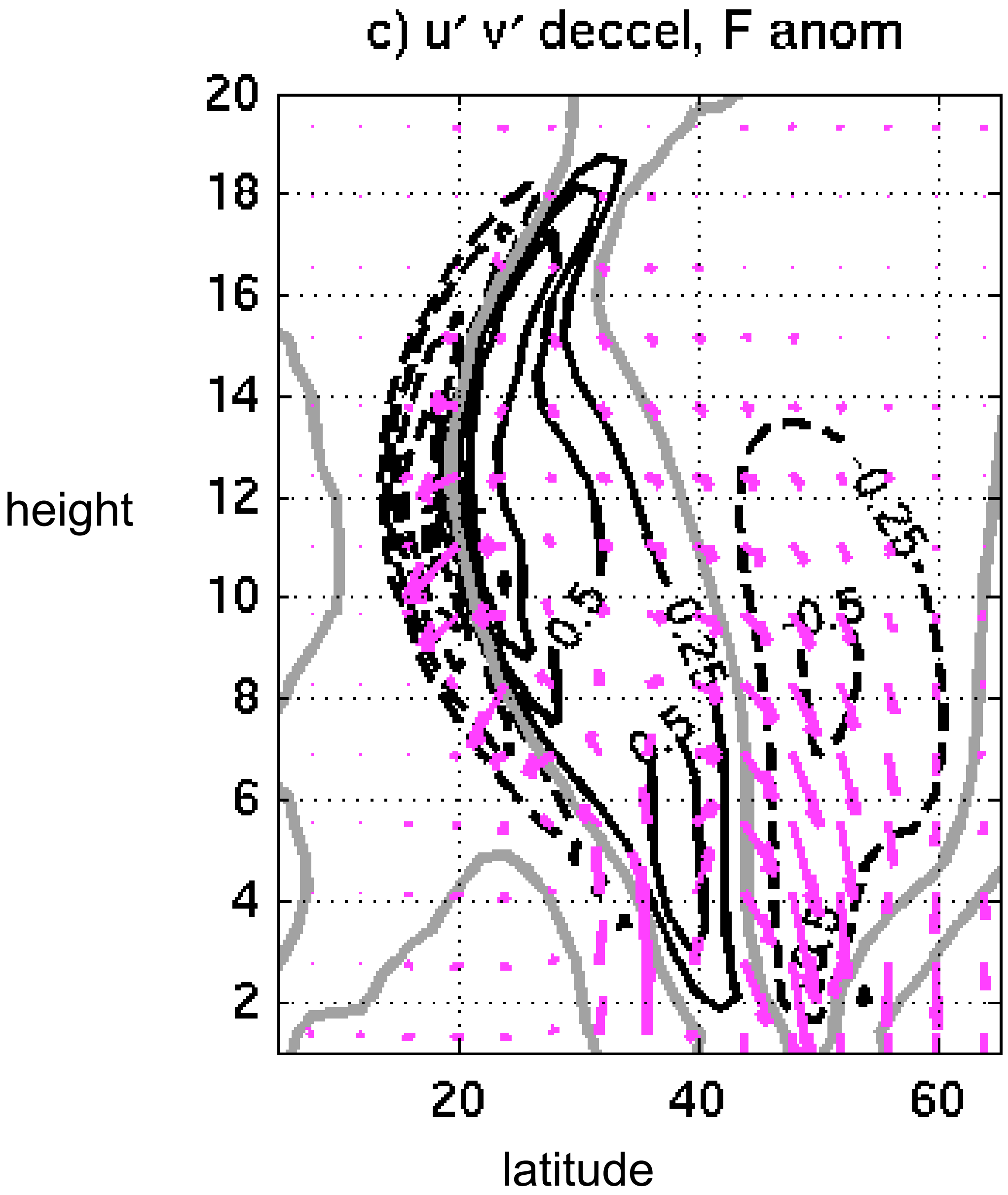
....

To prove this GCM-based contention:

solve the linear QGPV equation for transient eddies of specified zonal wavenumber and frequency and calculate u’v’

mean flows specified from the first days of the 100 member ensembles (when direct tropical-forcing dominates)

examine **El Nino minus La Nina** case



-d(u’v’)/dy response of QGPV model to immediate tropically-forced mean flow anomalies forces:

- zonal wind acceleration 20-40N
- zonal wind deceleration 40-60N
- after equilibration, zonal mean mid-latitude ascent (-f<v> = - d<u’v’>/dy)

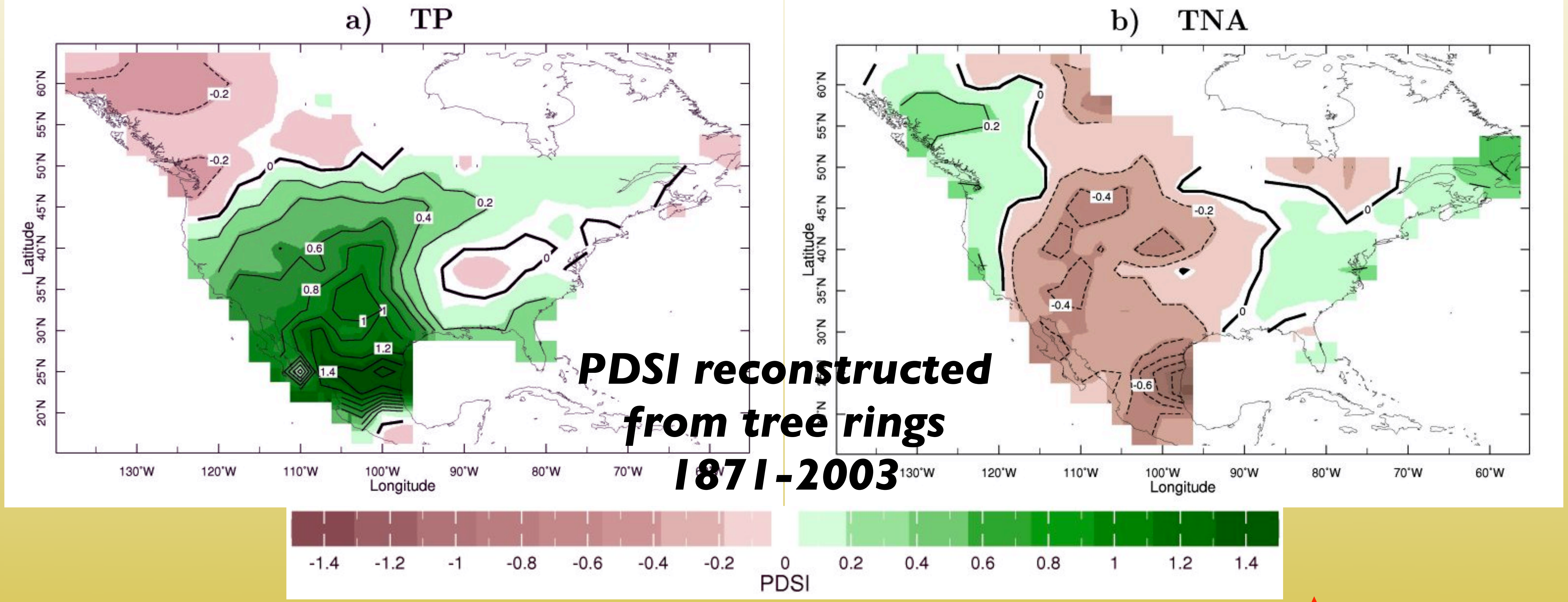
Response to Pacific SST anomalies involves:

stationary Rossby wave propagation but, perhaps more critically,

an impact of direct, tropically, forced circulation (subtropical jet) anomalies on the pattern of transient eddy propagation (storm track path) in PNA sector and subsequent impact on the mid-latitude mean flow.

Mechanisms of tropical Atlantic forcing of North American hydroclimate ....

PDSI Regression on TP & TNA



PDSI reconstructed from tree rings 1871-2003

TP SST ↑

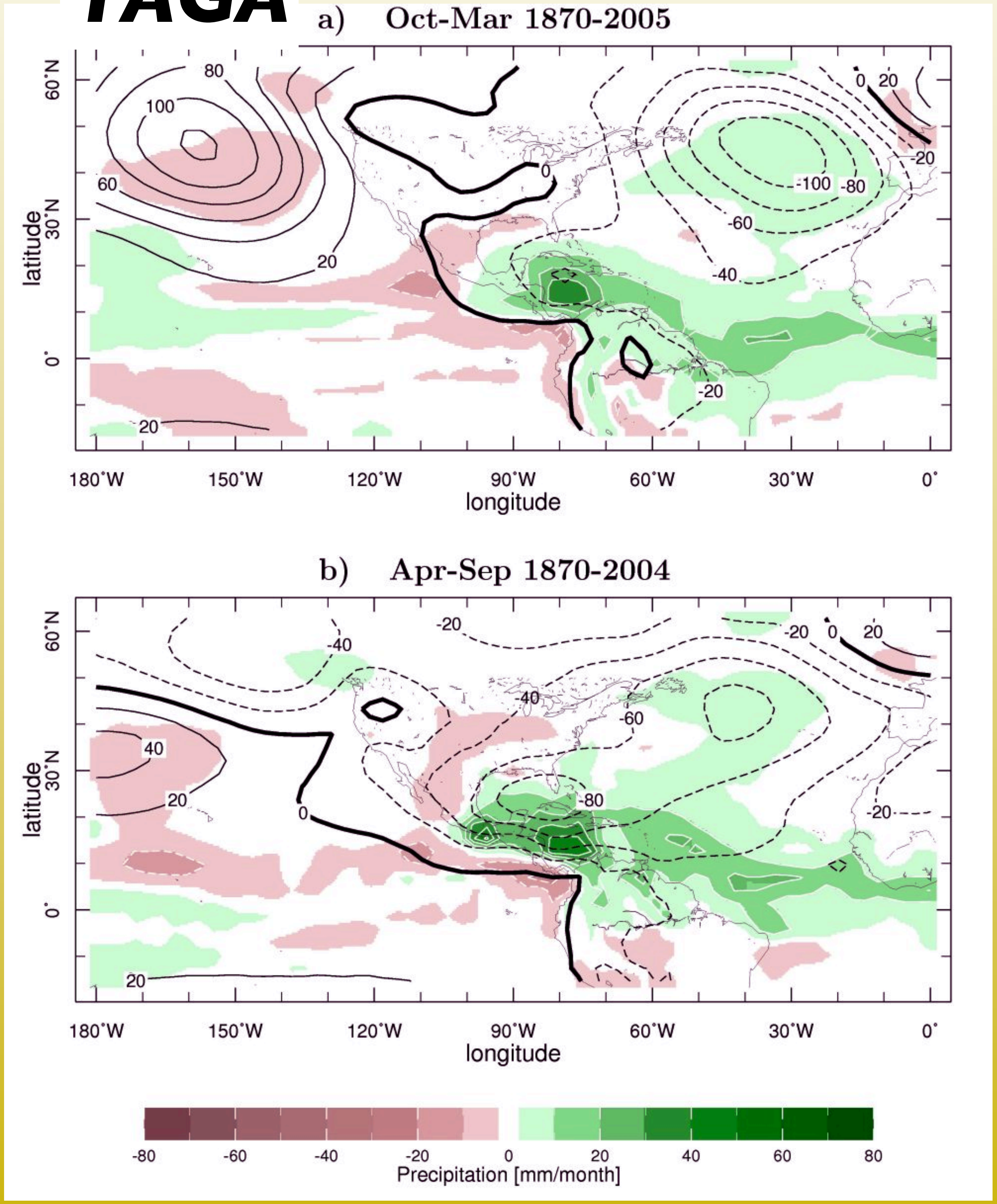
GP PDSI ↑

TNA SST ↑

GP PDSI ↓

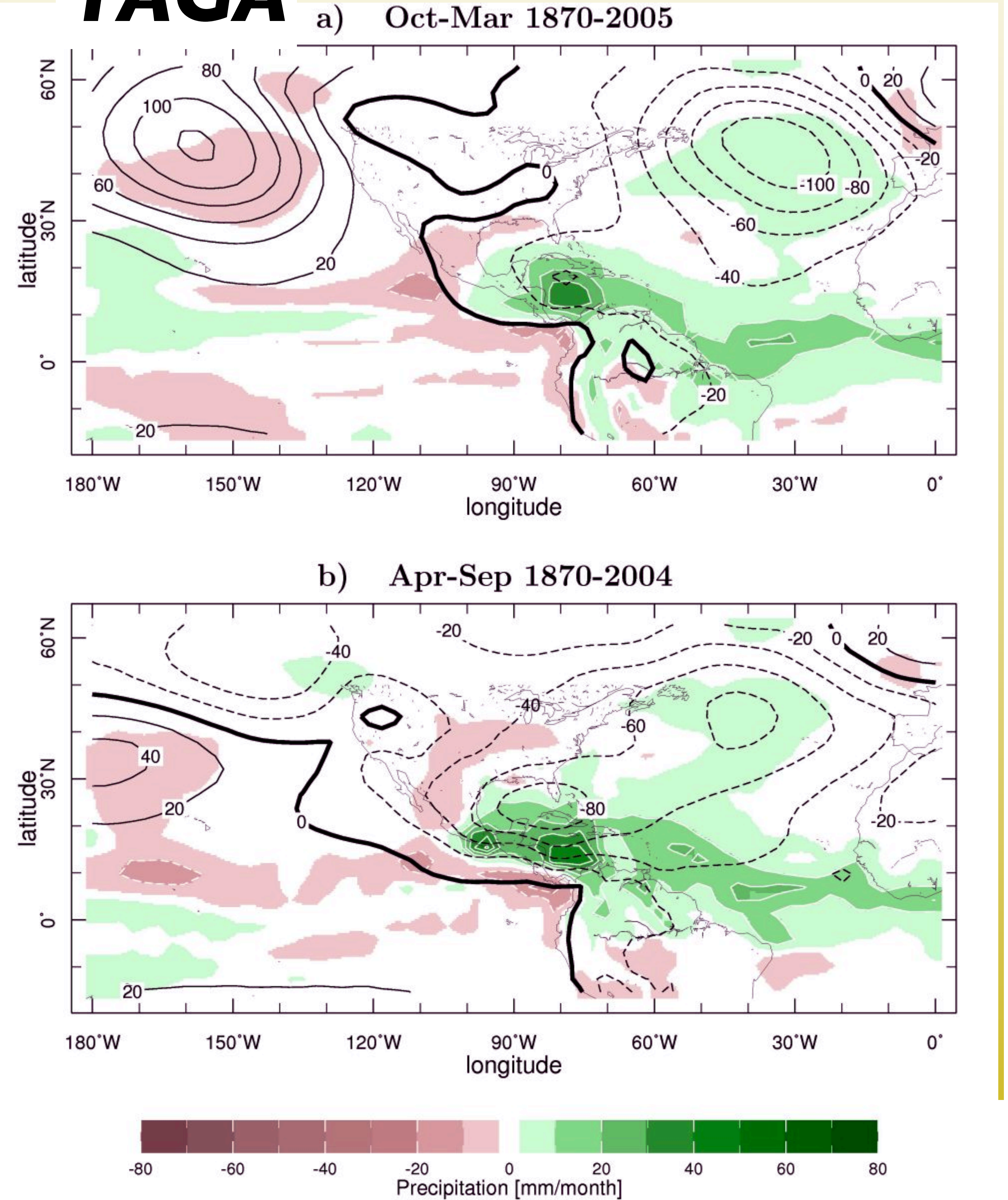
TAGA and GOGA results

TAGA

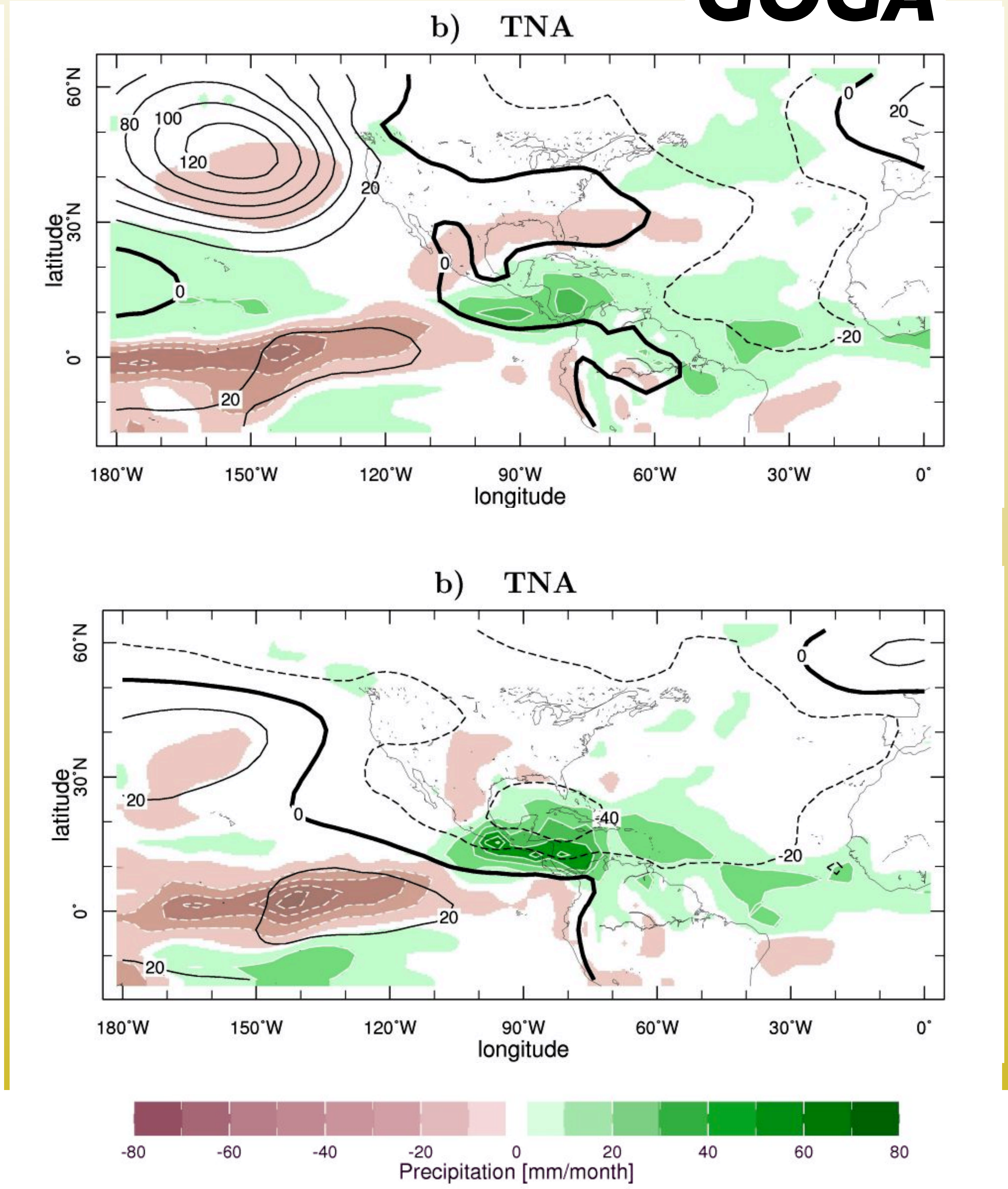


TAGA and GOGA results

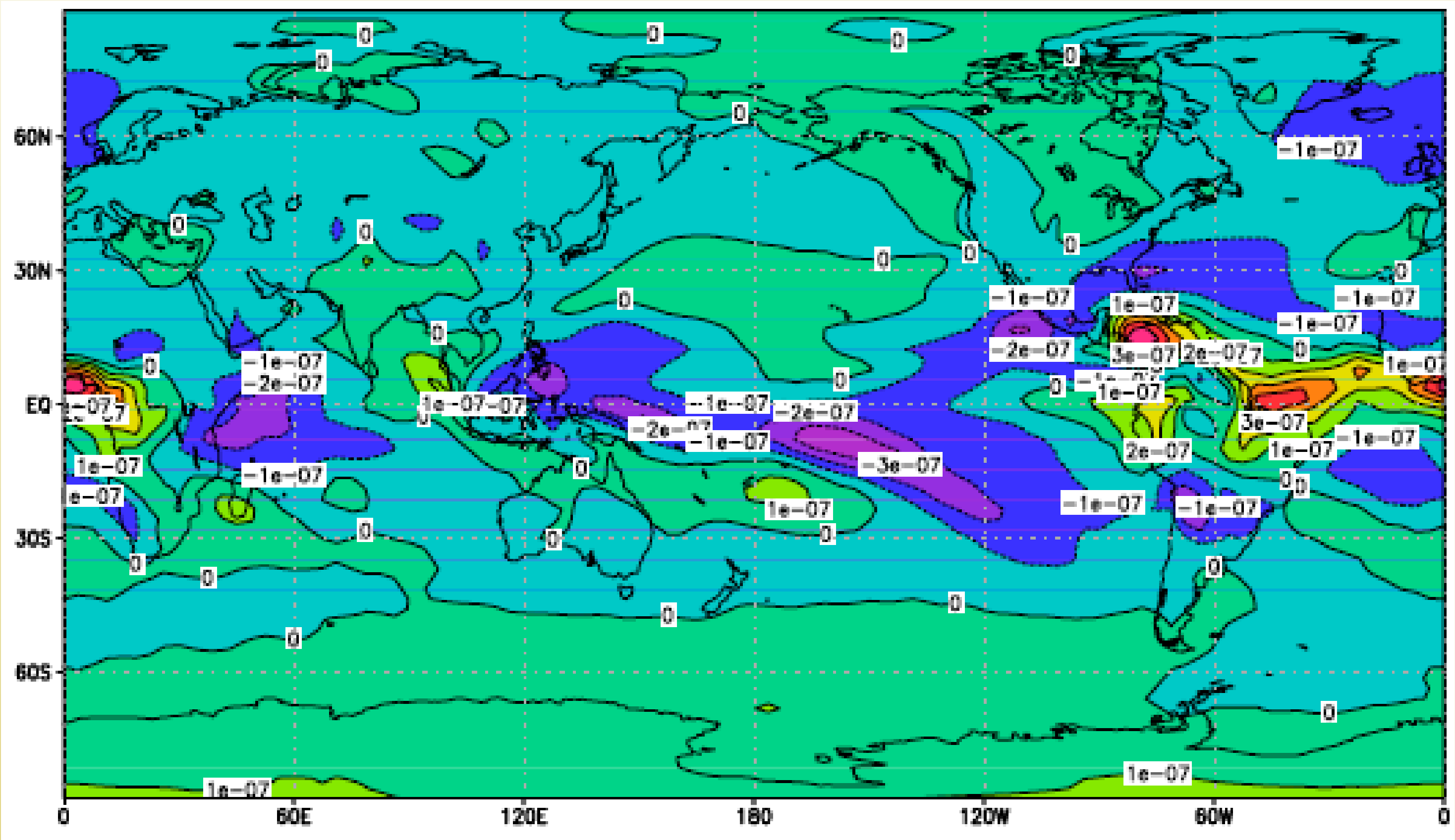
TAGA



GOGA

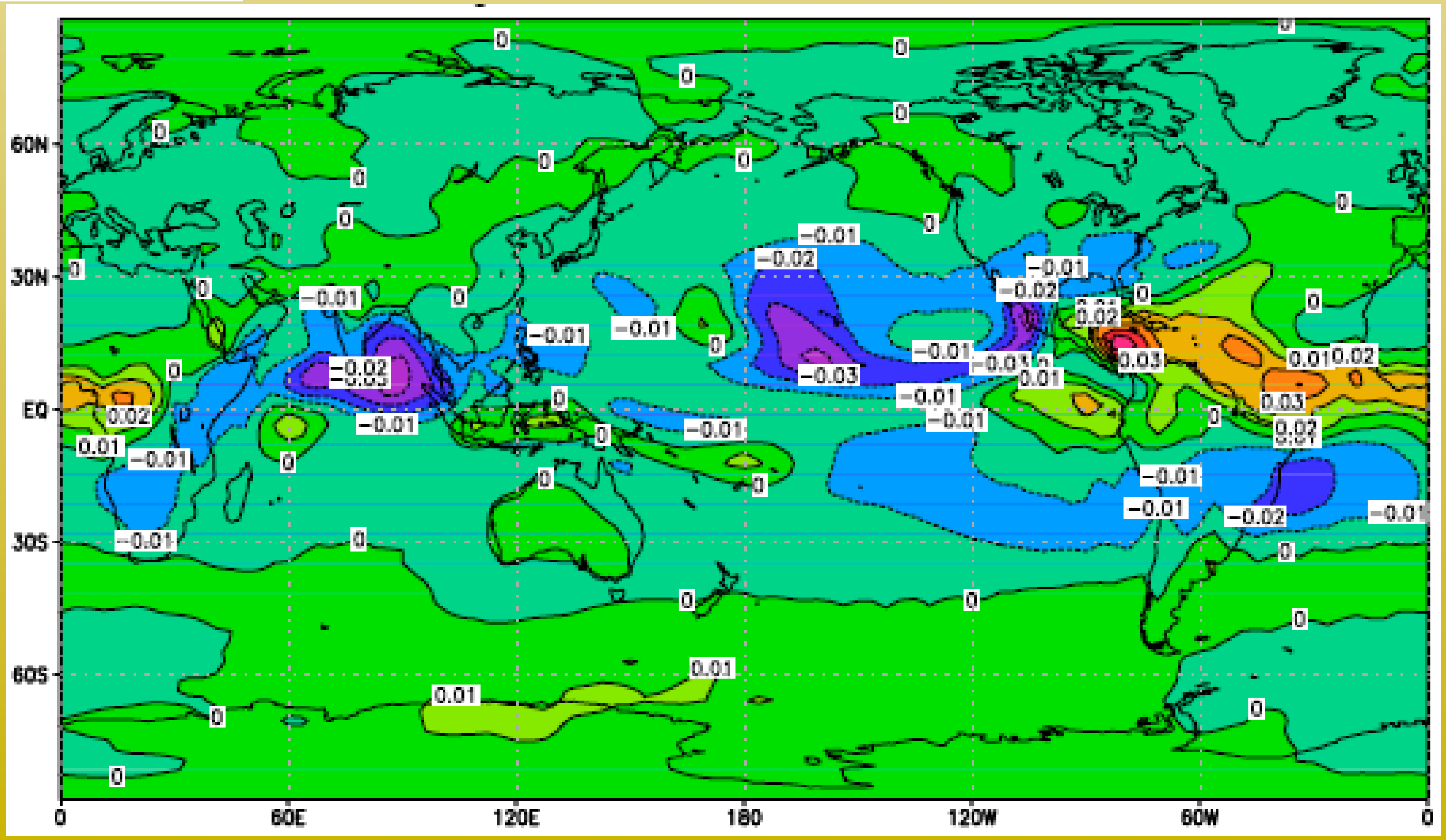


Linear Model Experiments



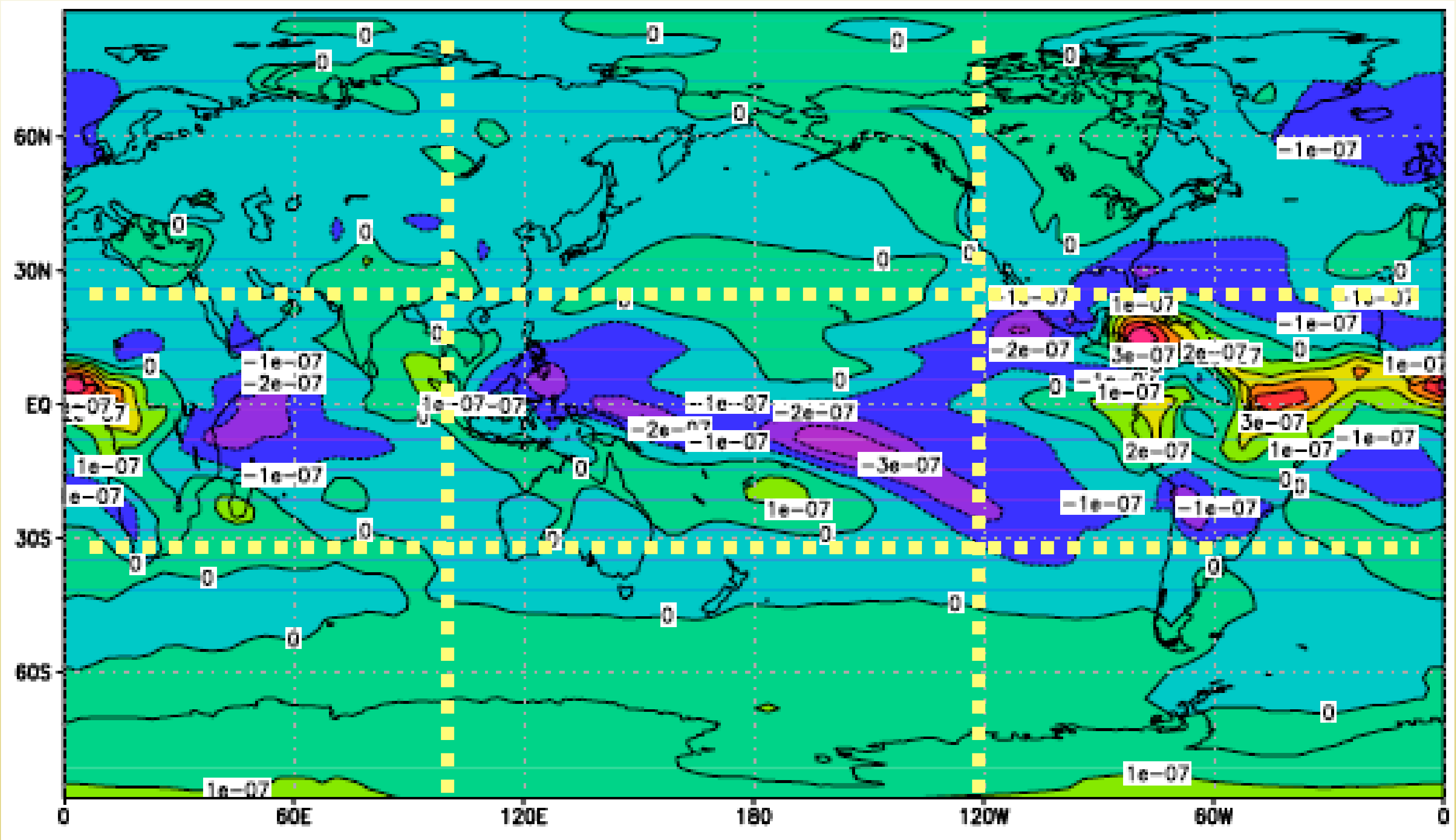
Winter diabatic heating from TAGA

Summer diabatic heating from TAGA



To understand the dynamical elements of the Atlantic influence we forced a linear, PE model with the heating field derived from TAGA, specified in different sectors.

Linear Model Experiments



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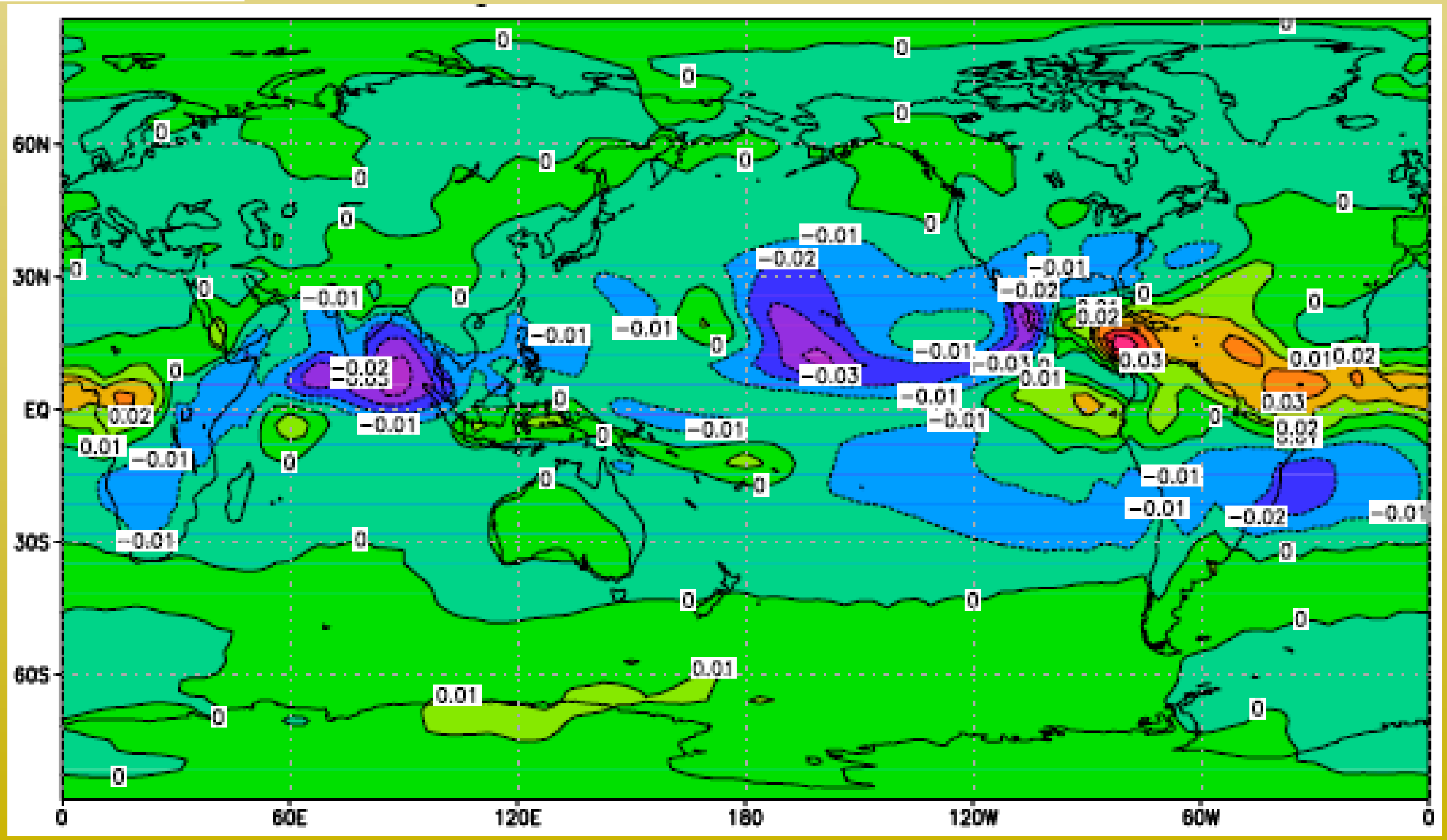

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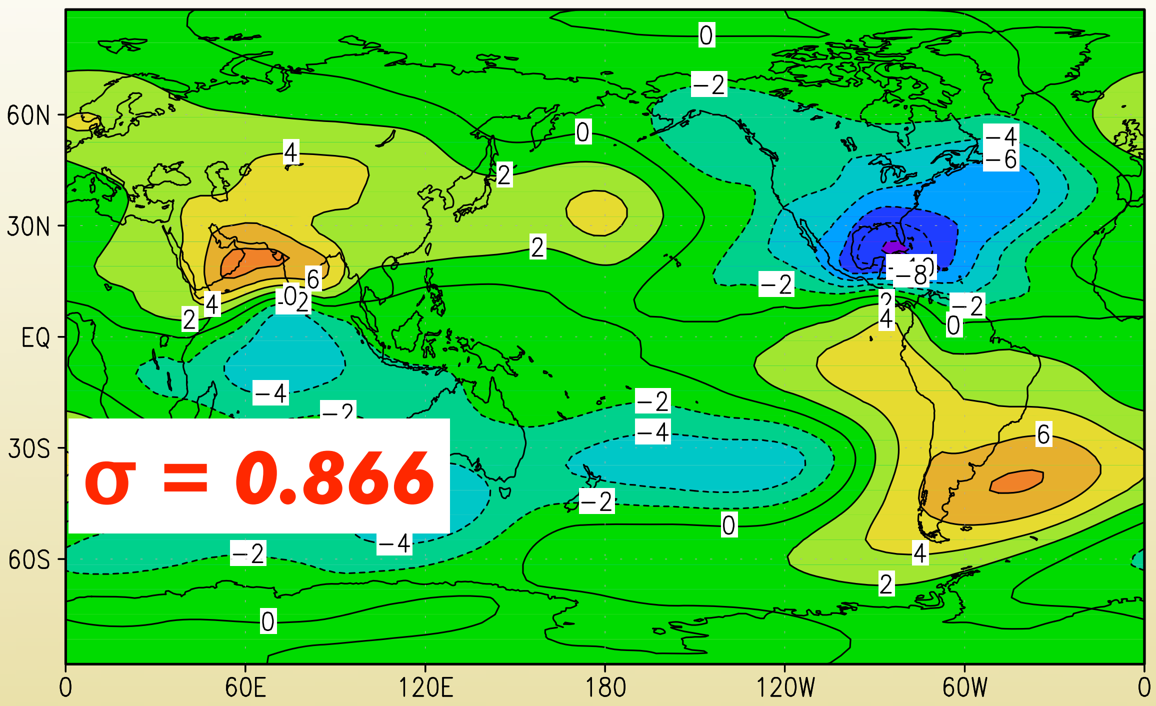
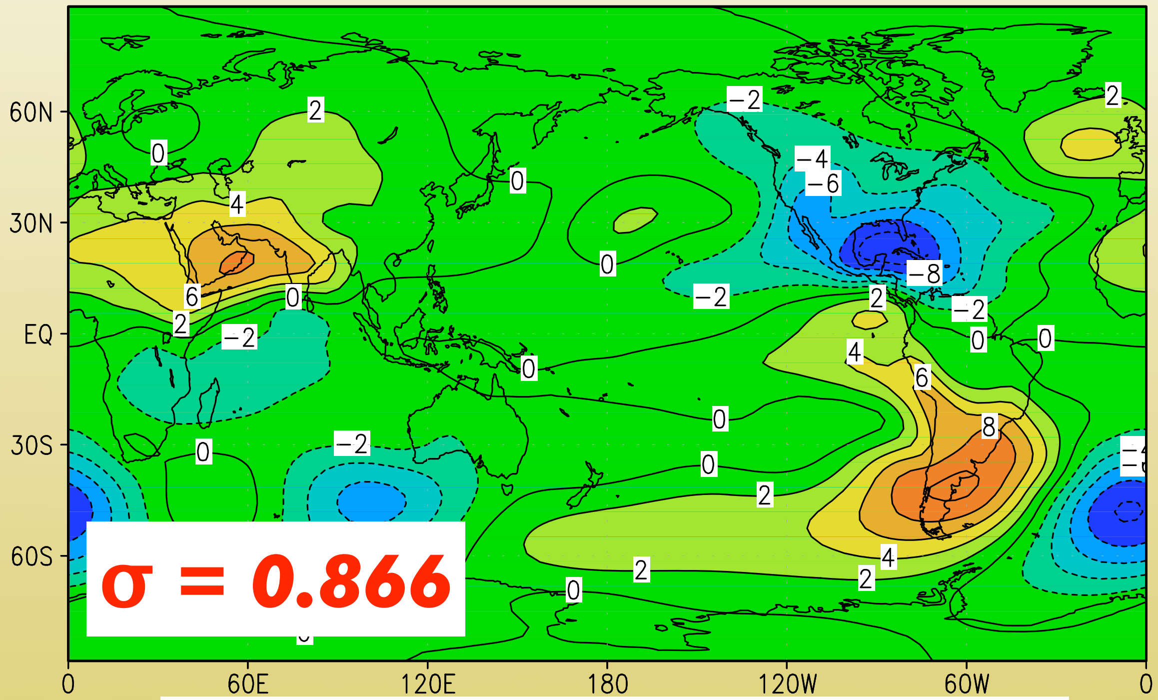
Linear Model, Summer (Apr.-Sep.)



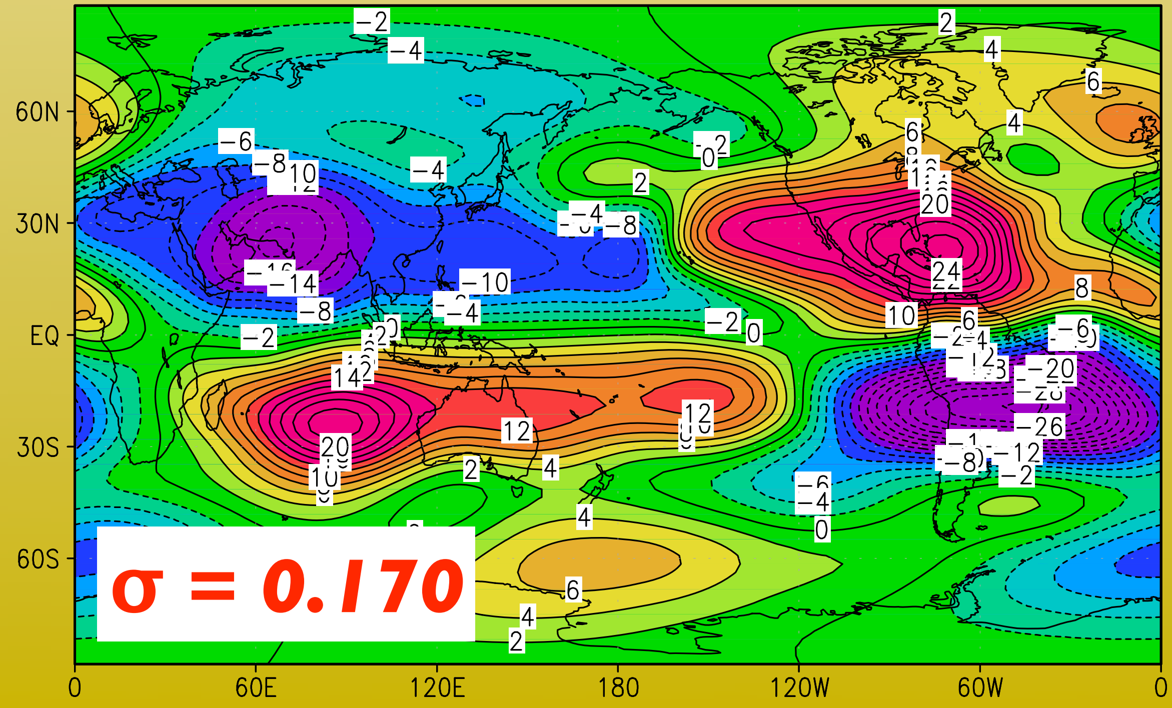
σ = 0.866

TAGA regression on TNA SST



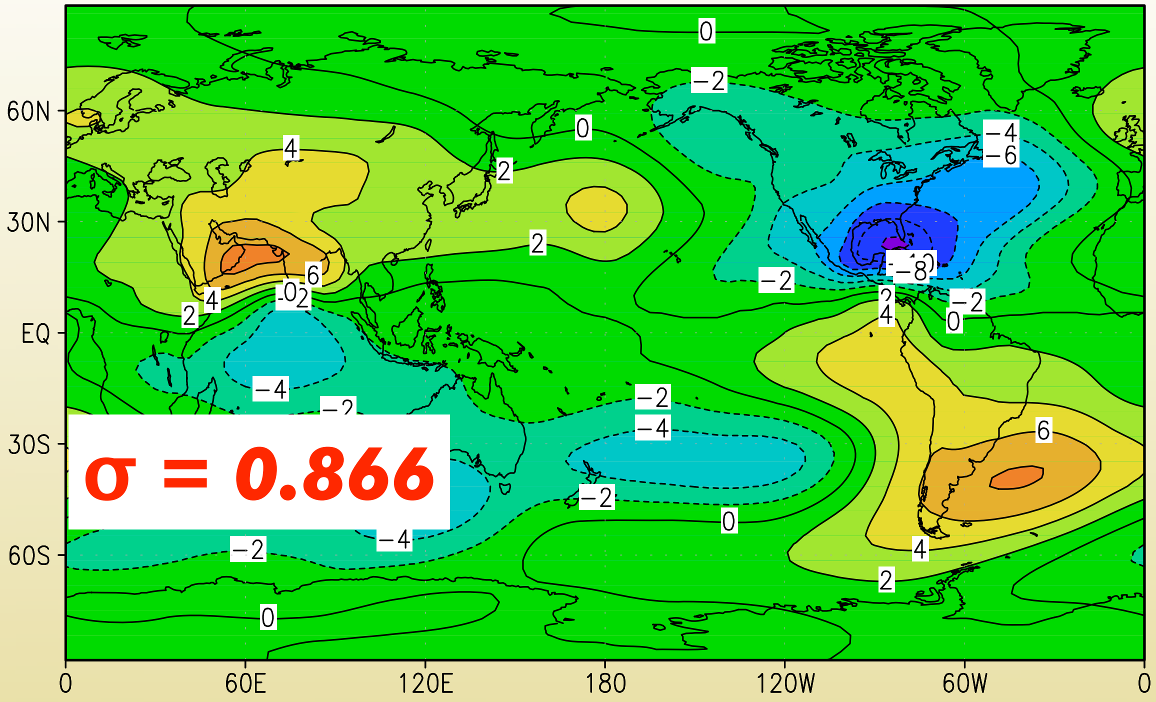
σ = 0.866

response to trop. Atl. Heating



σ = 0.170

Linear Model, Summer (Apr.-Sep.)



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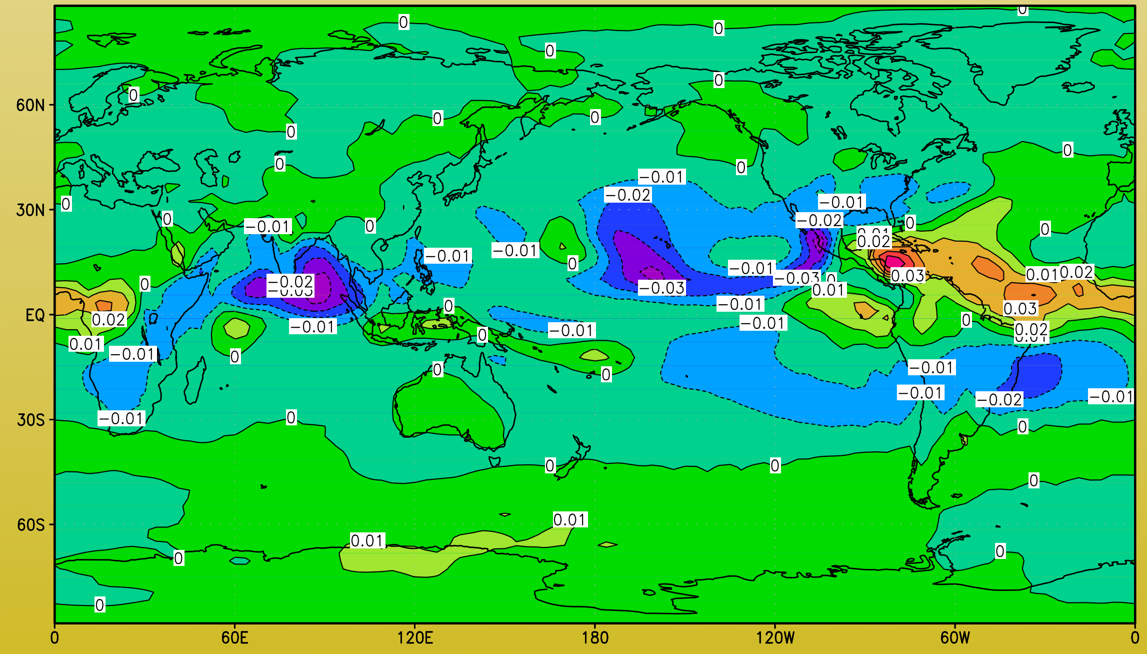
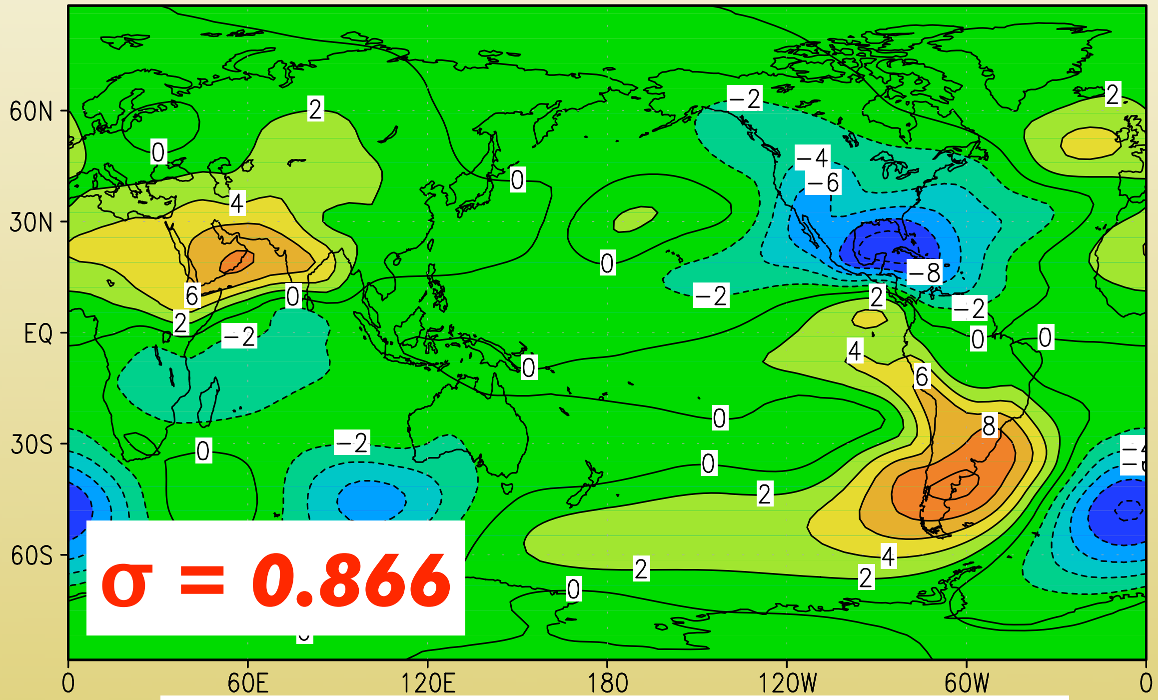
TAGA regression on TNA SST

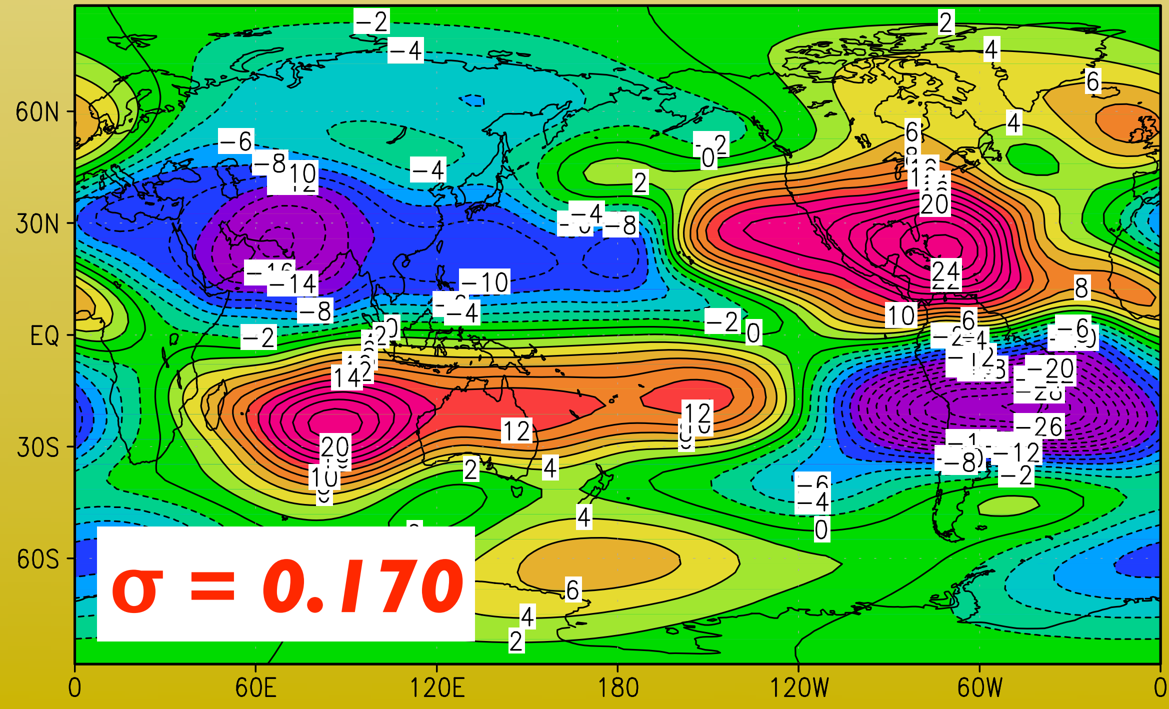
TAGA Diabatic Heating





σ = 0.866

response to trop. Atl. Heating



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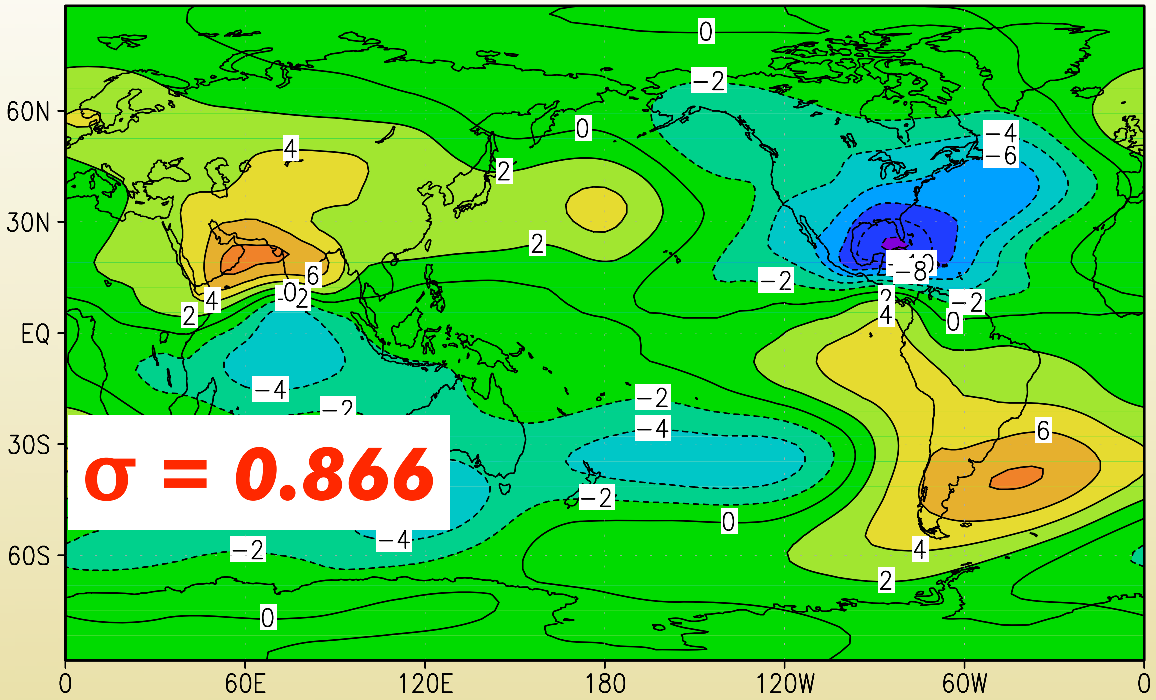
Linear Model, Summer (Apr.-Sep.)



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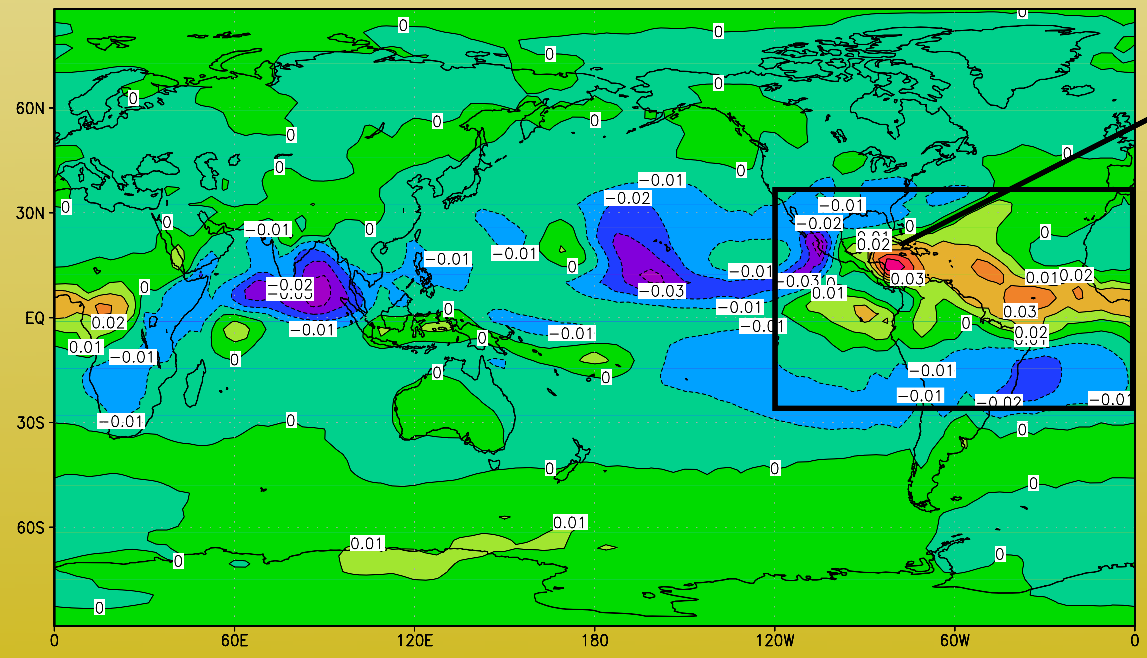
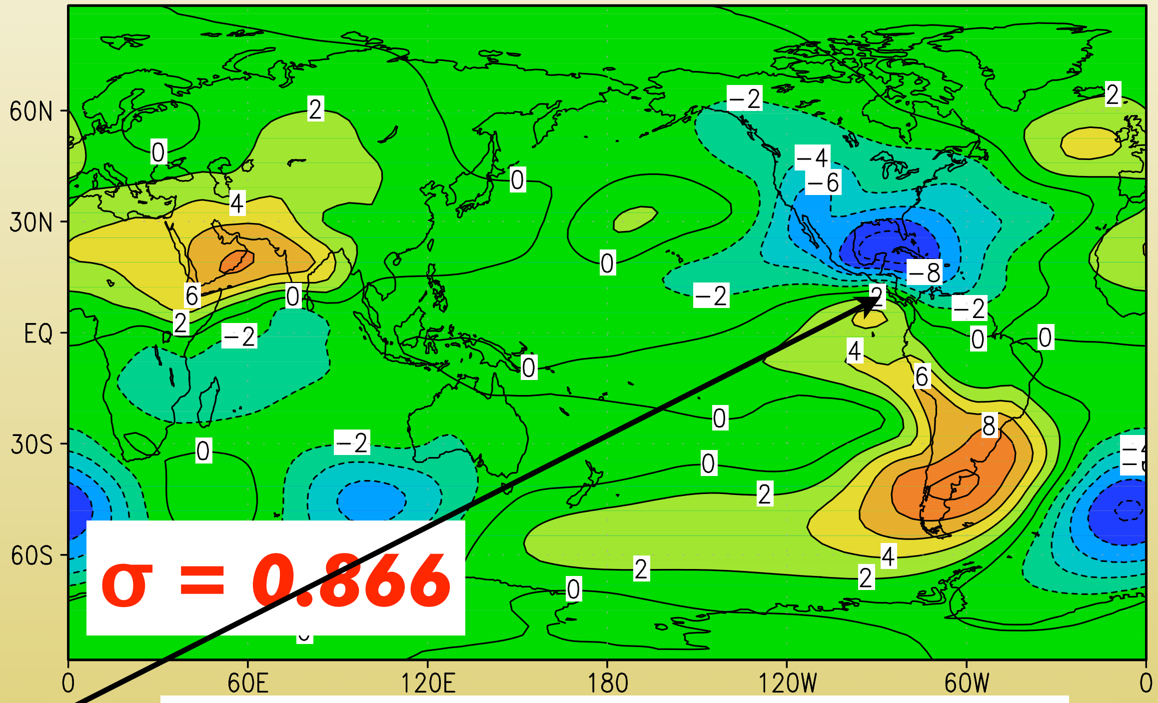
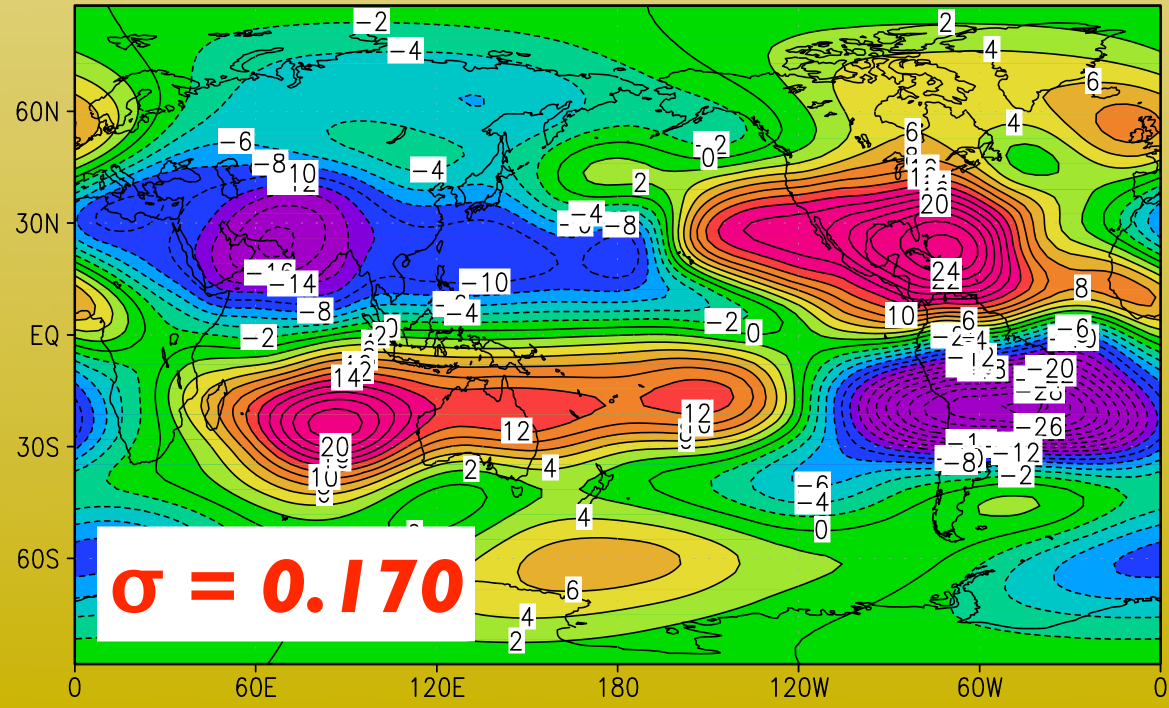
TAGA Diabatic Heating





σ = 0.866

response to trop. Atl. Heating



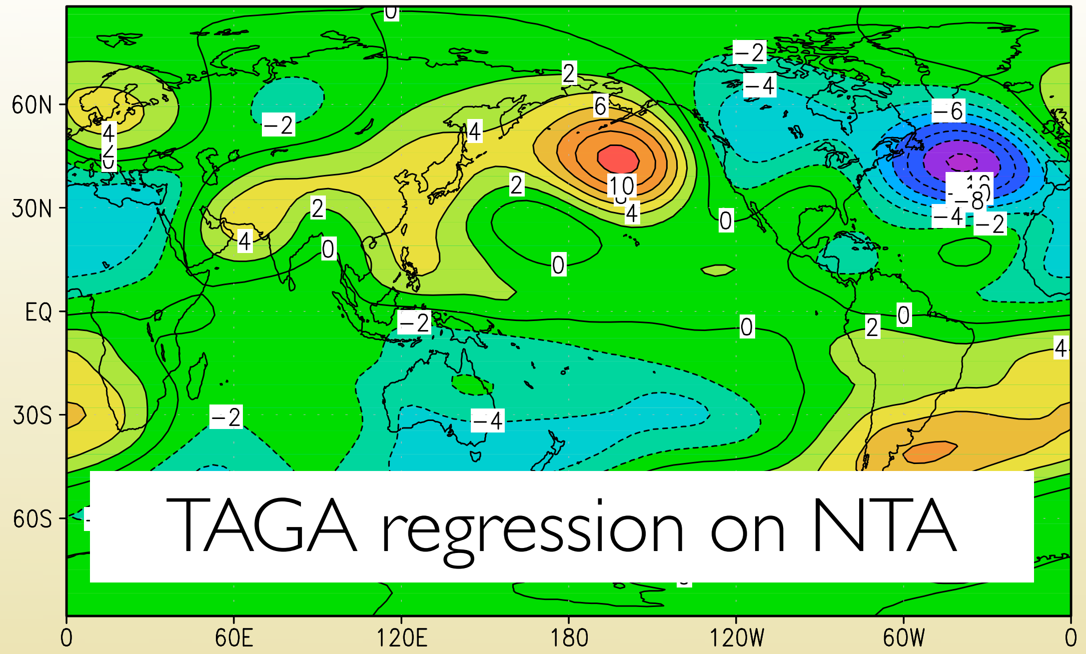
σ = 0.170

Summer response to tropical Atlantic SSTAs is Gill-like - northerly-subsiding (drying) flow over Plains and SW North America

Winter response is not so simple ....

Linear Model, Winter (Oct.-Mar.)

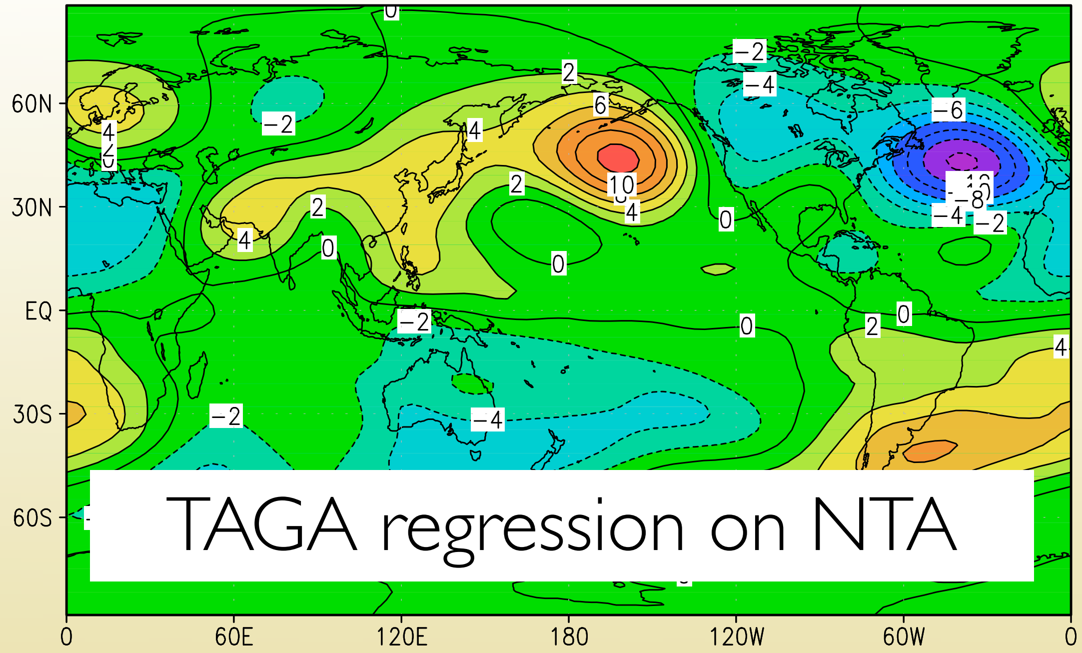
results on σ = 0.568



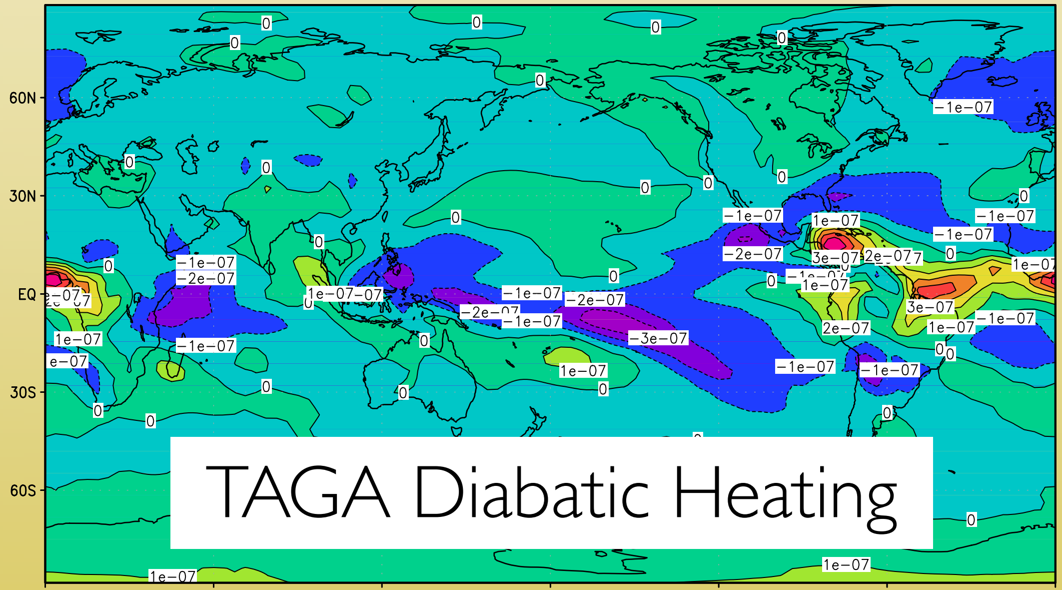
TAGA regression on NTA

Linear Model, Winter (Oct.-Mar.)

results on σ = 0.568



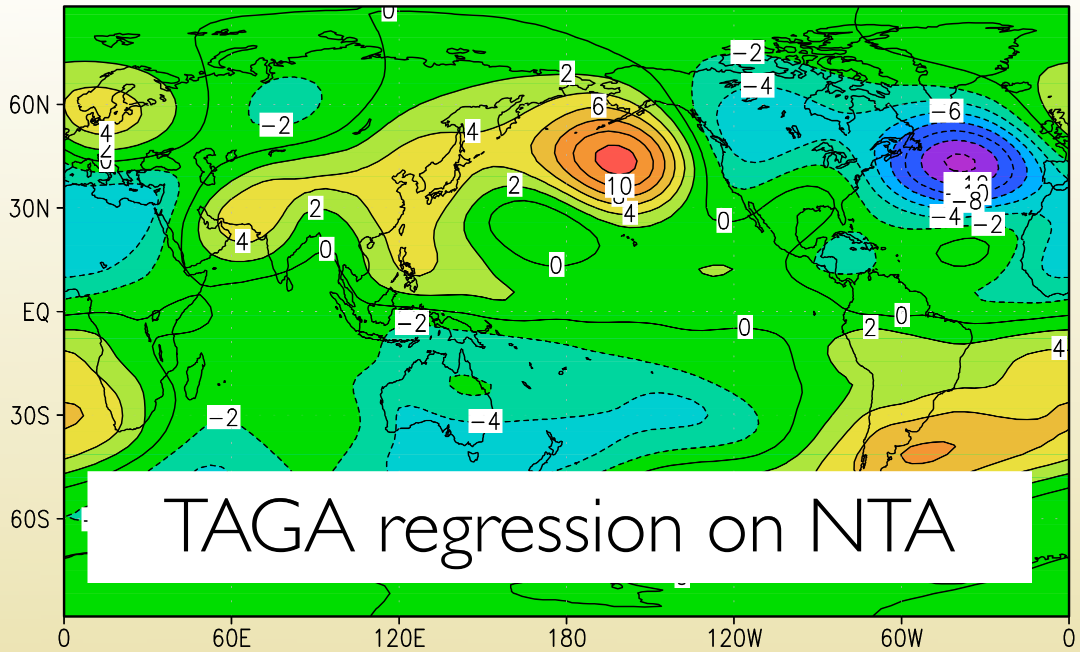
TAGA regression on NTA

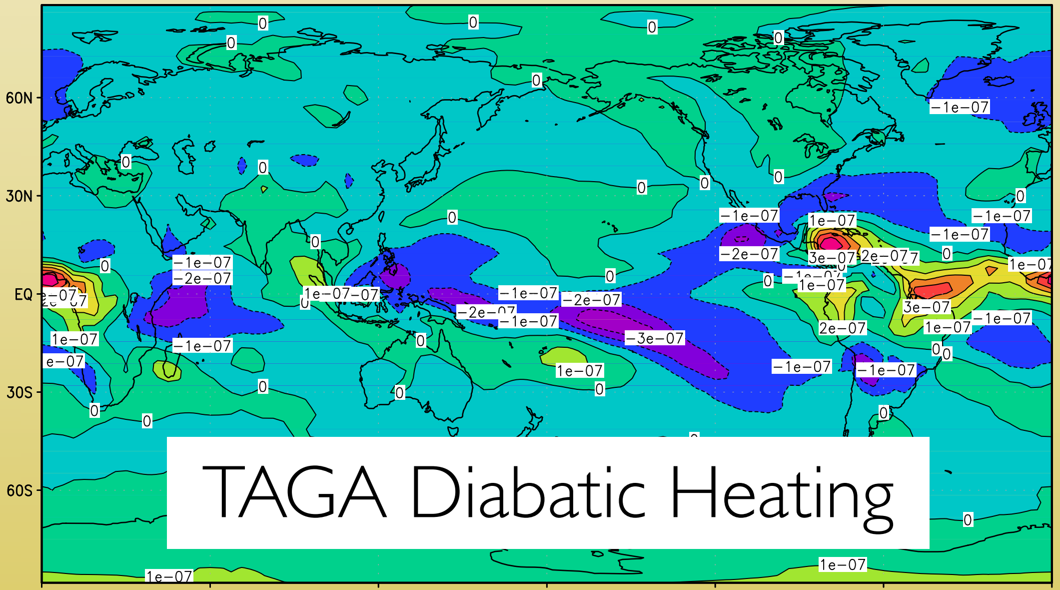


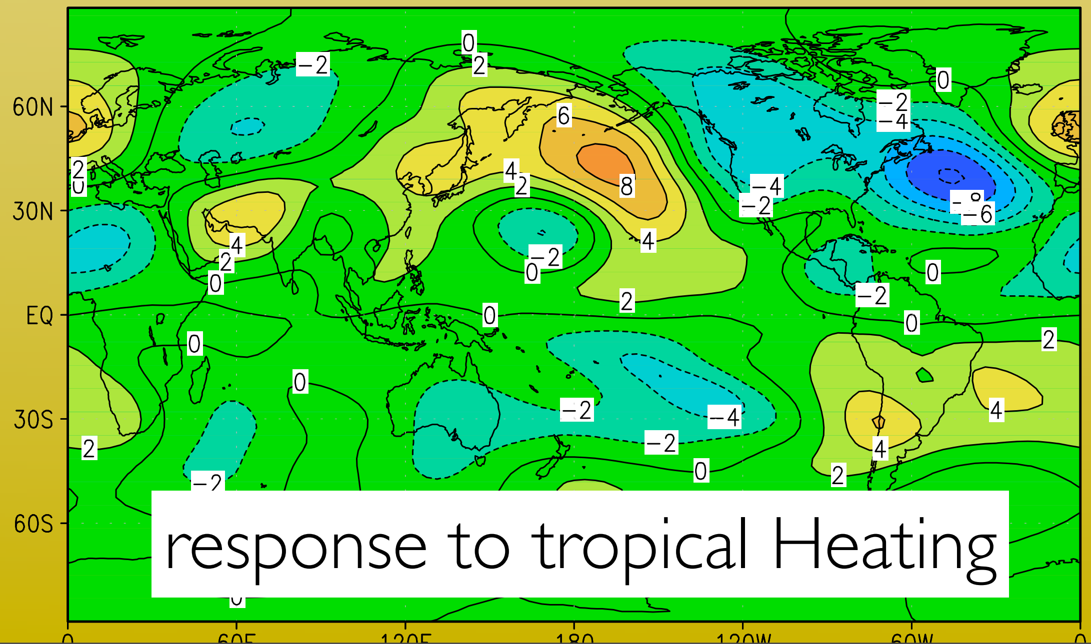
TAGA Diabatic Heating

Linear Model, Winter (Oct.-Mar.)

results on $\sigma = 0.568$

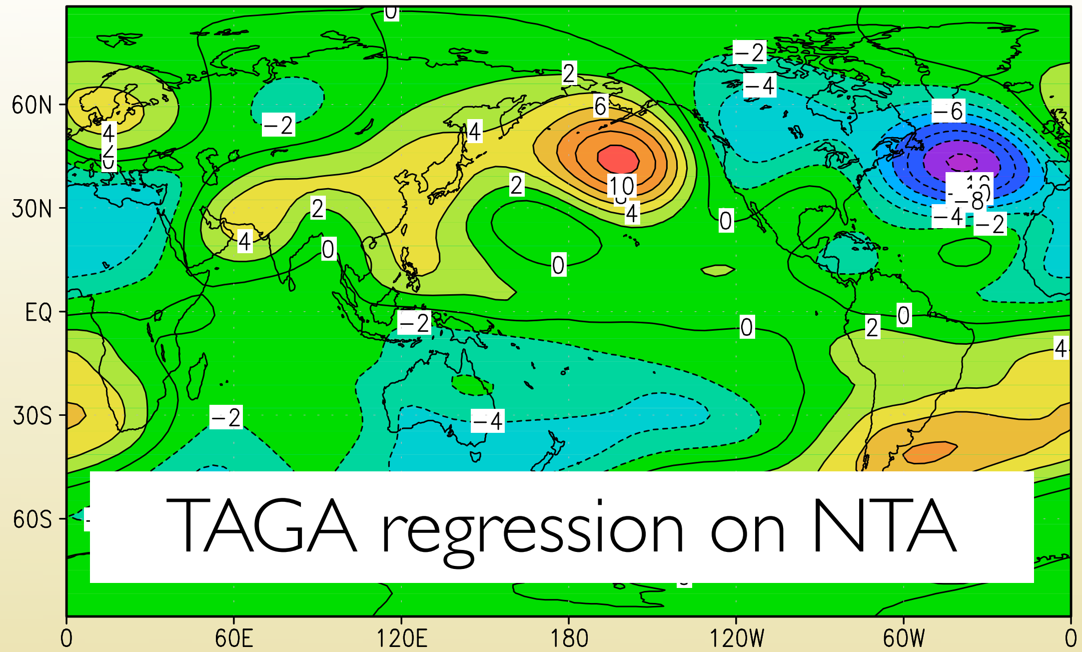

TAGA regression on NTA


TAGA Diabatic Heating

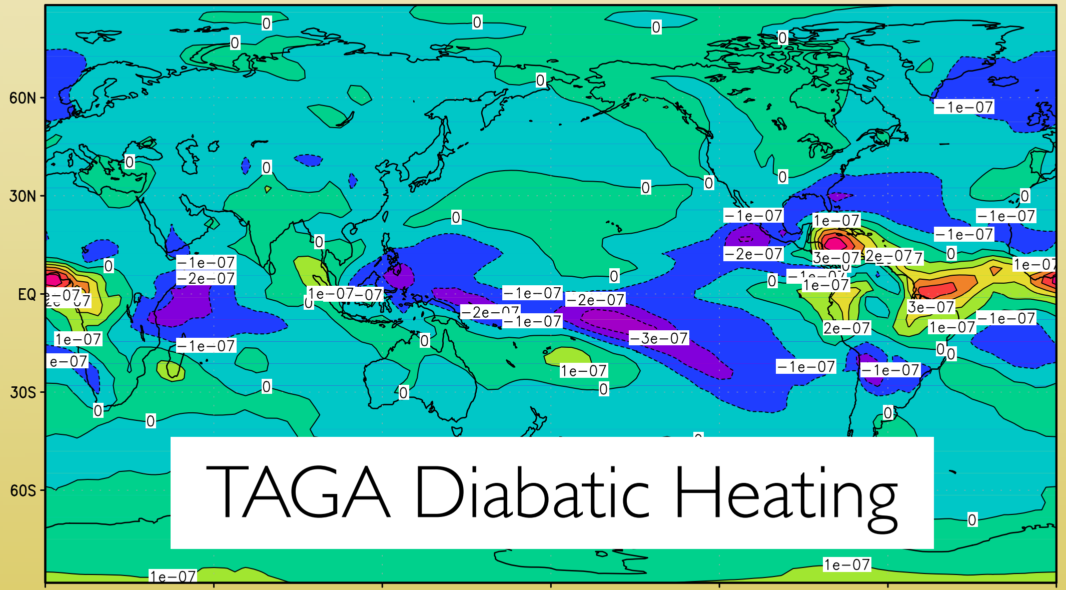

response to tropical Heating

Linear Model, Winter (Oct.-Mar.)

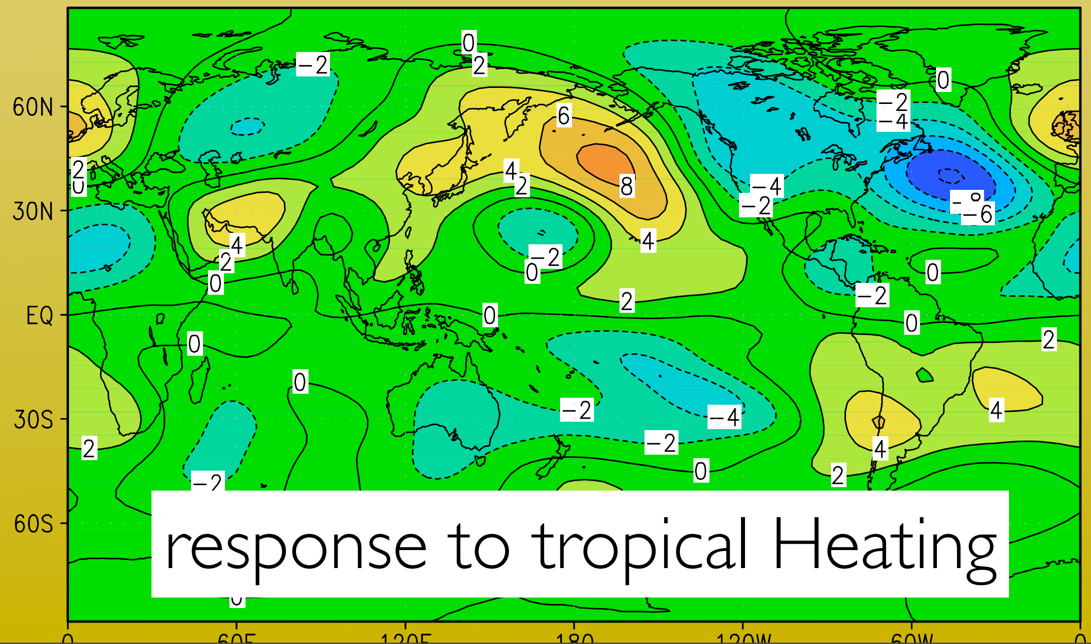
results on σ = 0.568



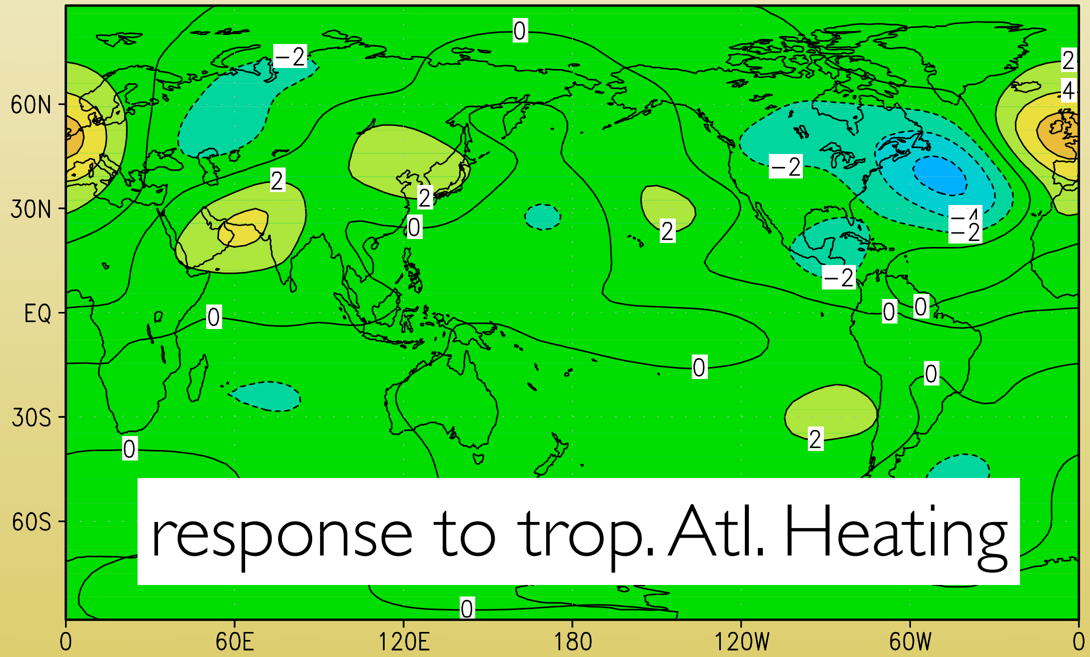
TAGA regression on NTA



TAGA Diabatic Heating



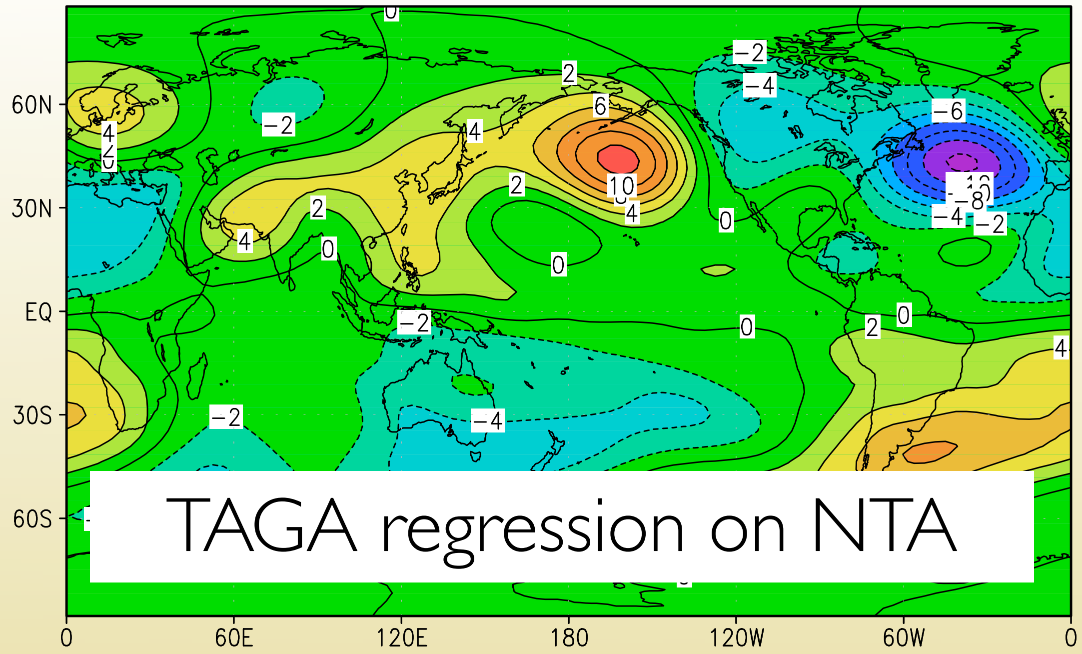
response to tropical Heating



response to trop. Atl. Heating

Linear Model, Winter (Oct.-Mar.)

results on σ = 0.568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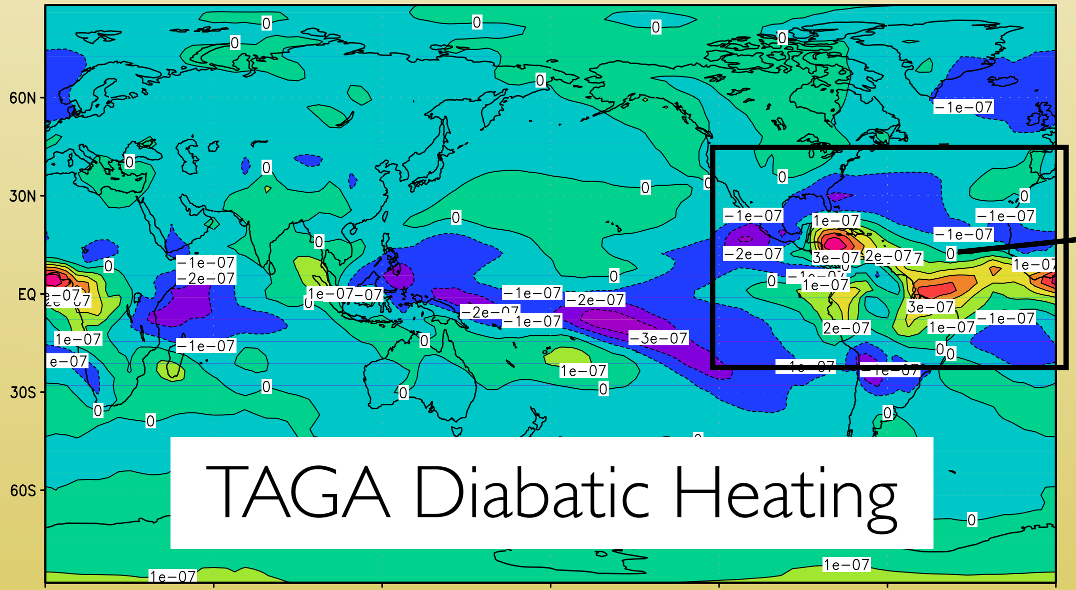
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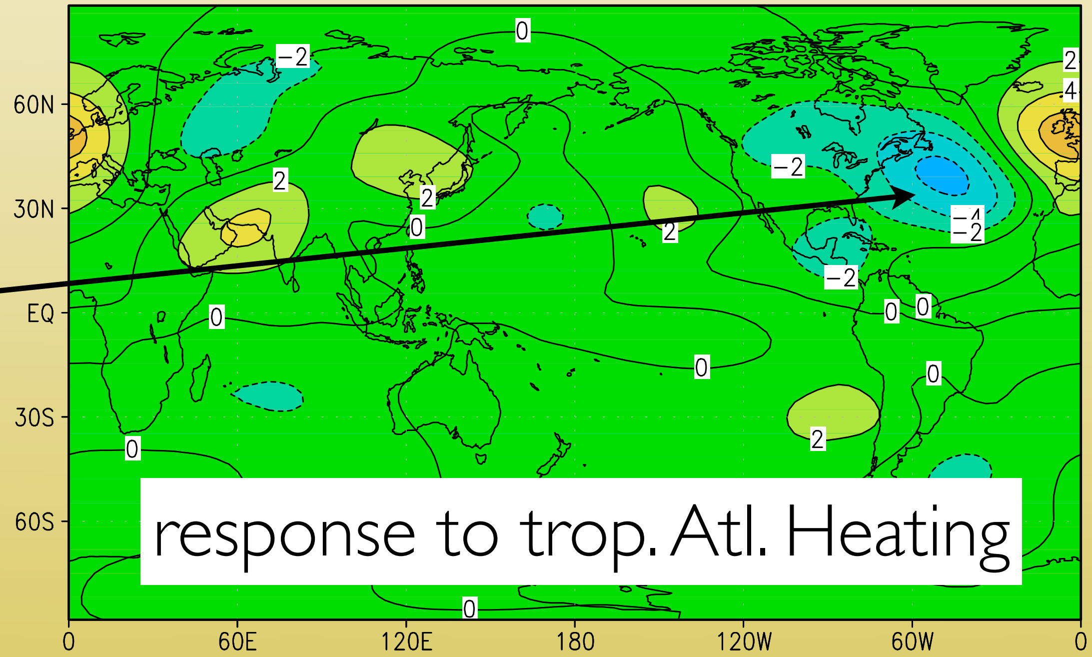
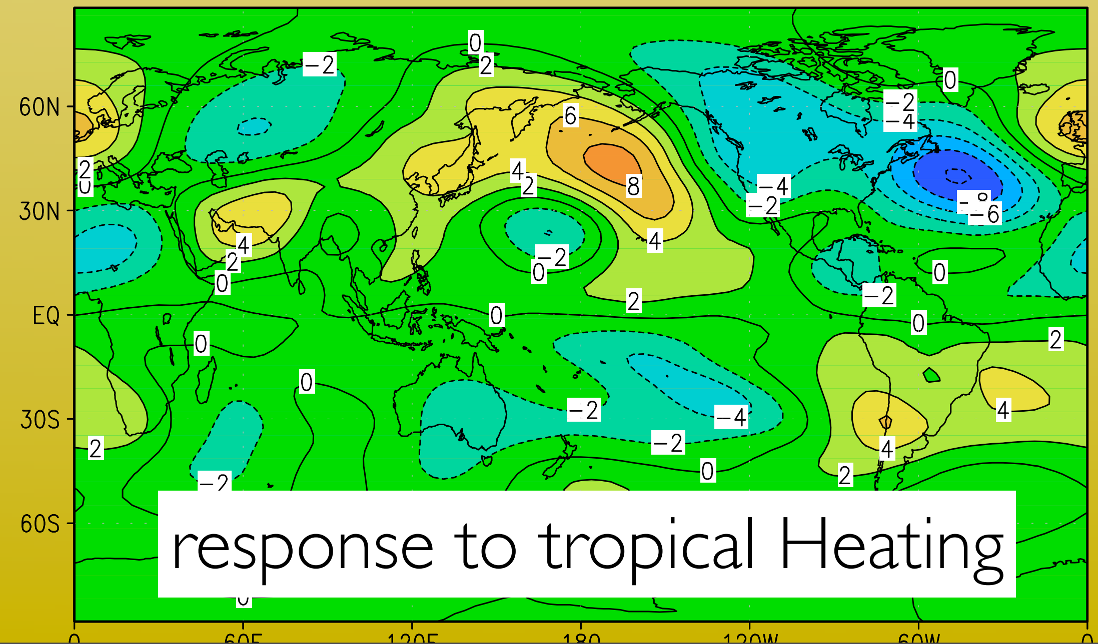
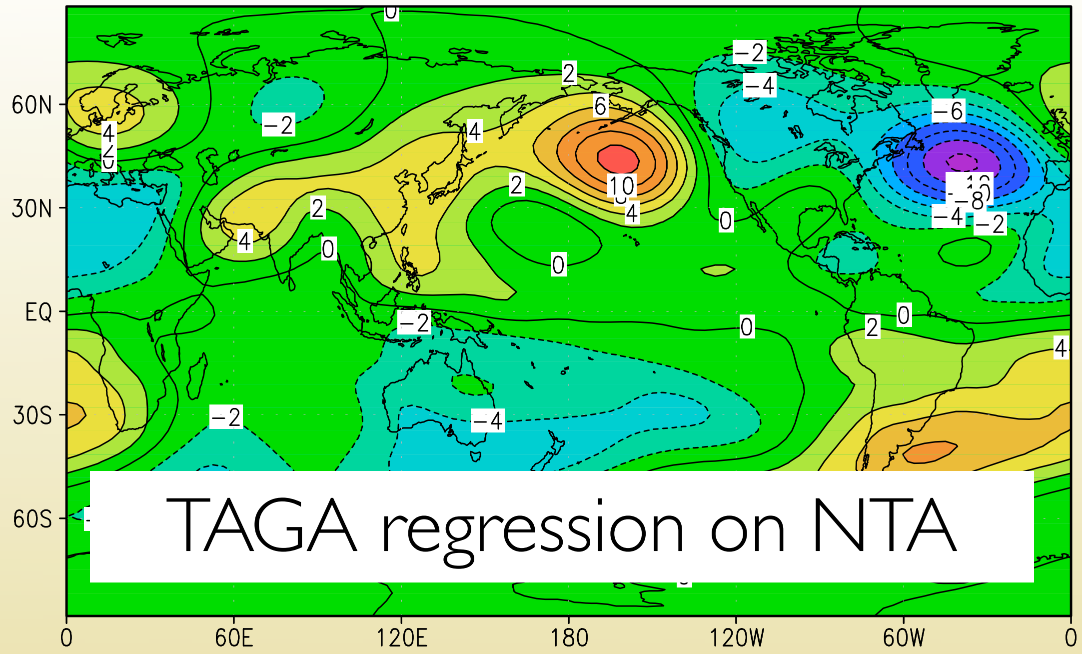

response to trop. Atl. Heating


response to tropical Heating

Linear Model, Winter (Oct.-Mar.)

results on σ = 0.568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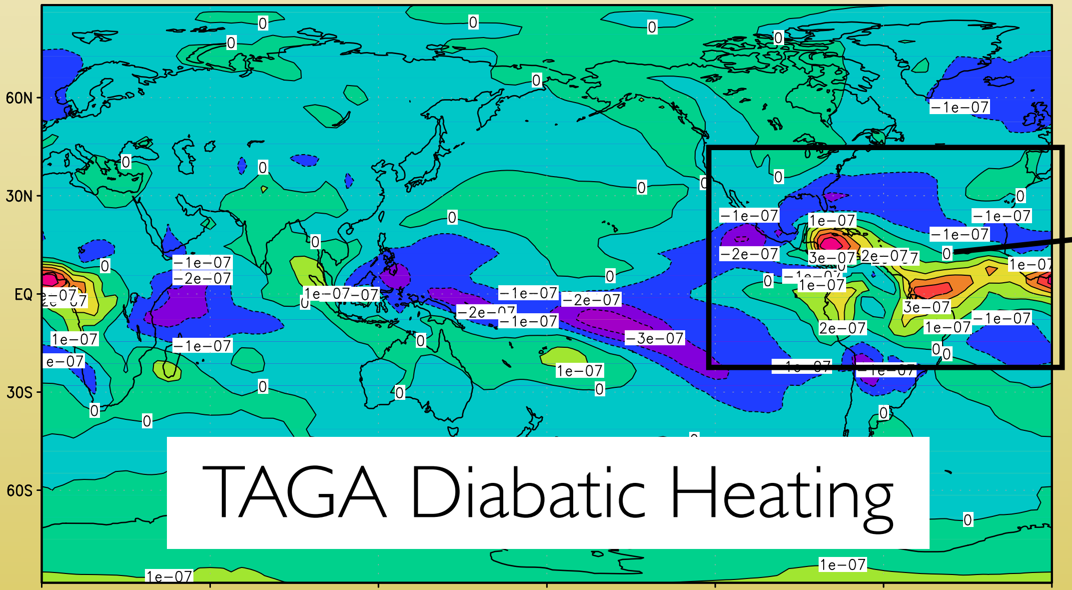
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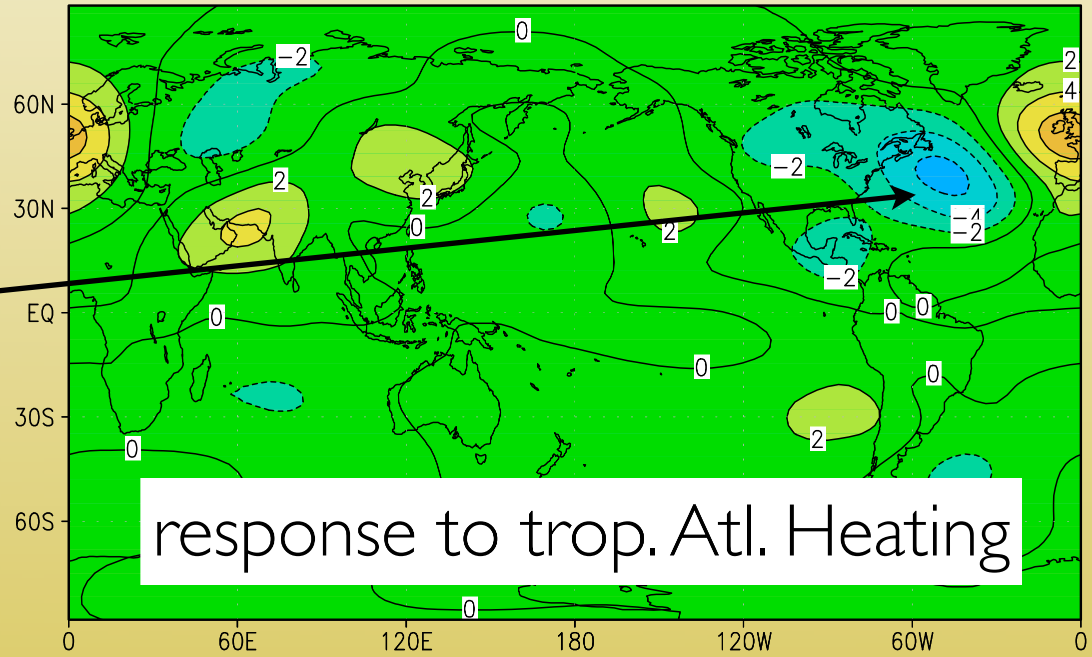
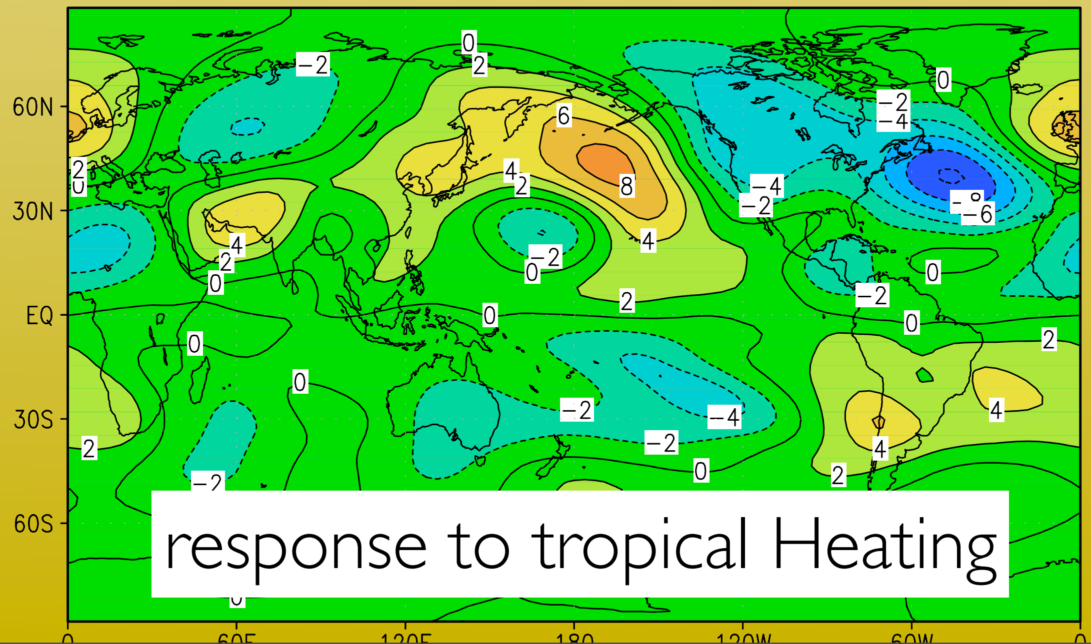
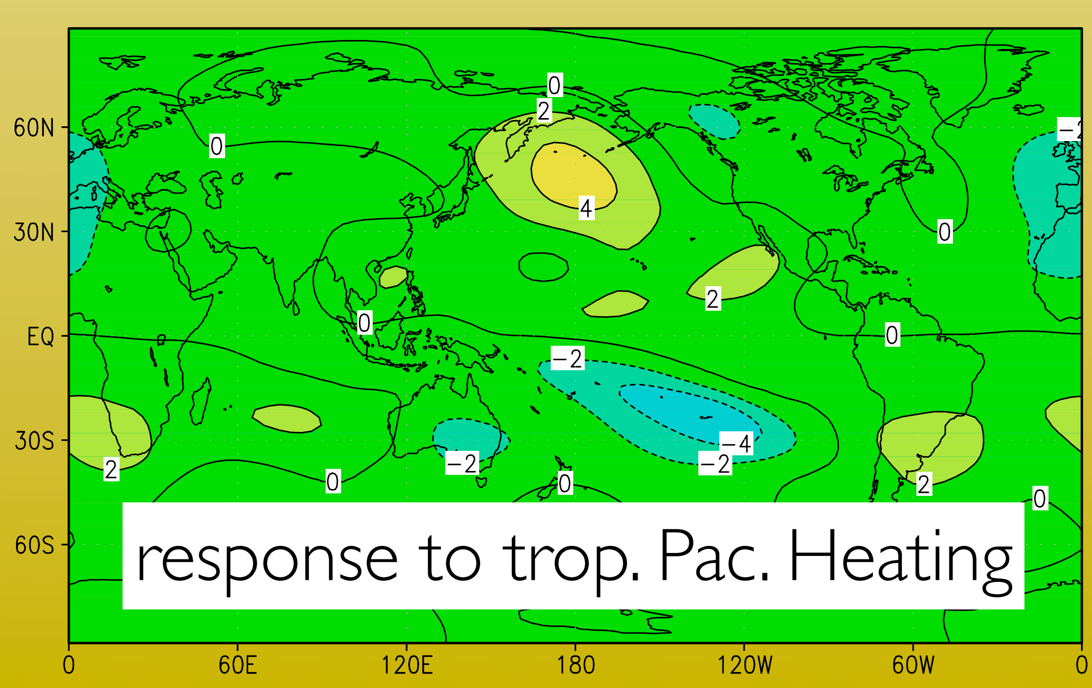
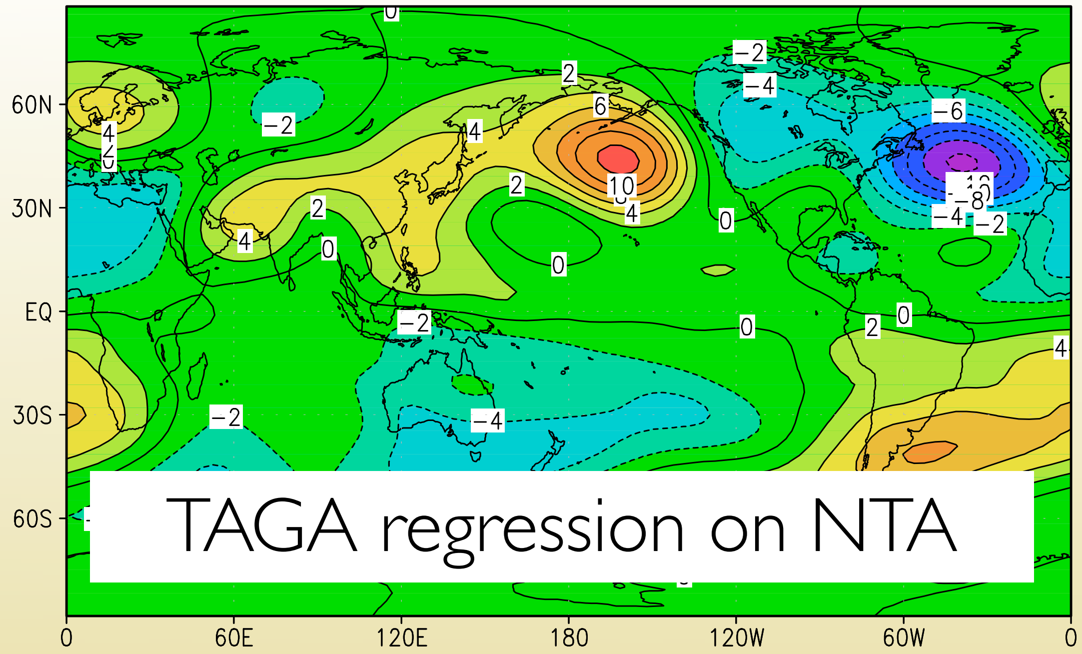

response to trop. Atl. Heating

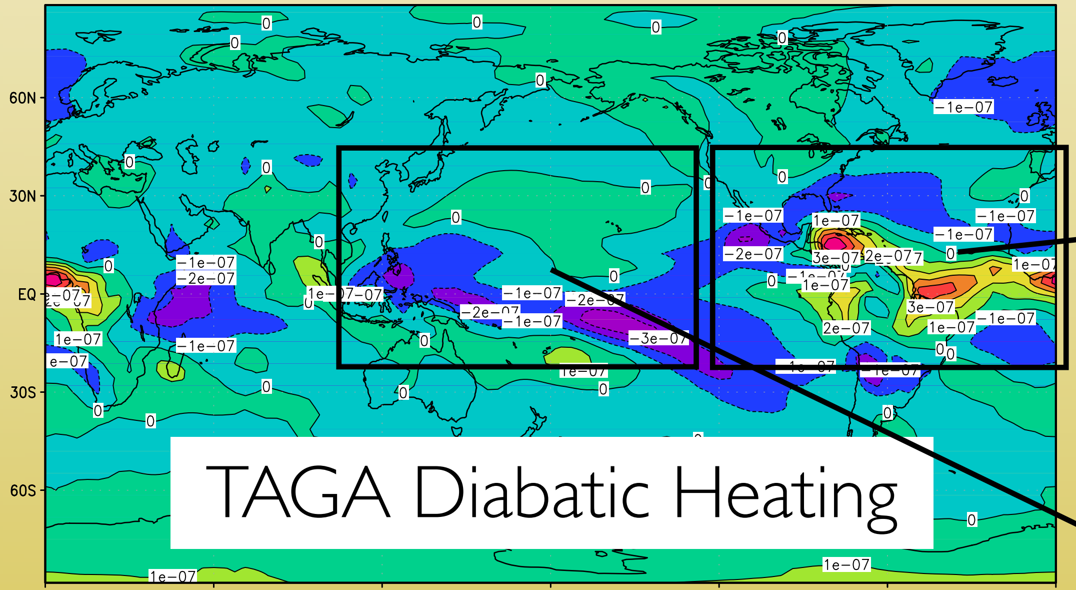

response to tropical Heating


response to trop. Pac. Heating

Linear Model, Winter (Oct.-Mar.)

results on σ = 0.568


TAGA regression on NTA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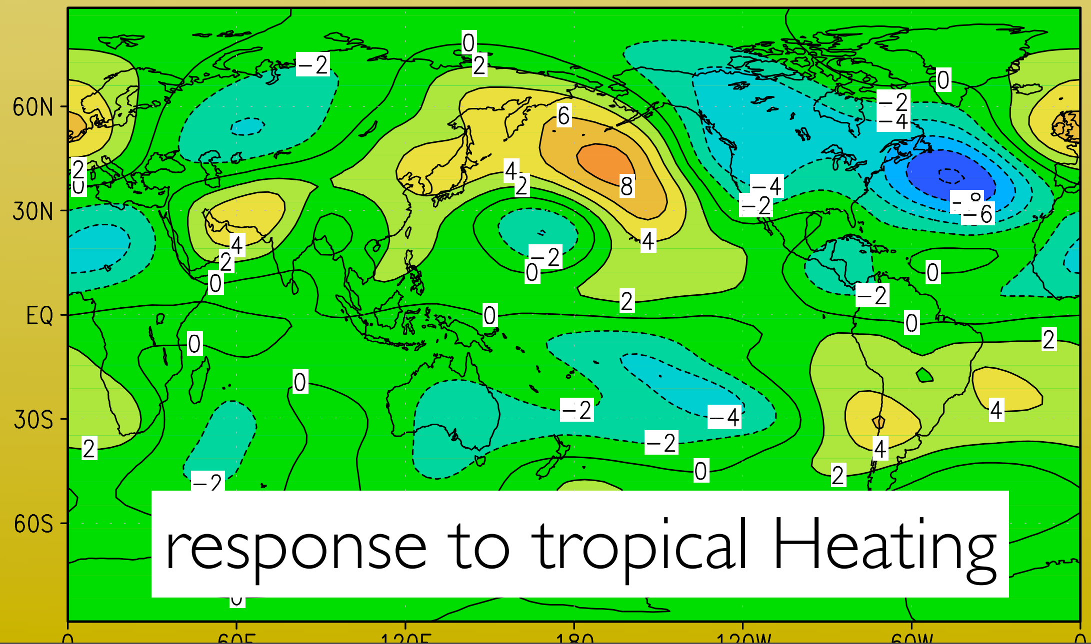
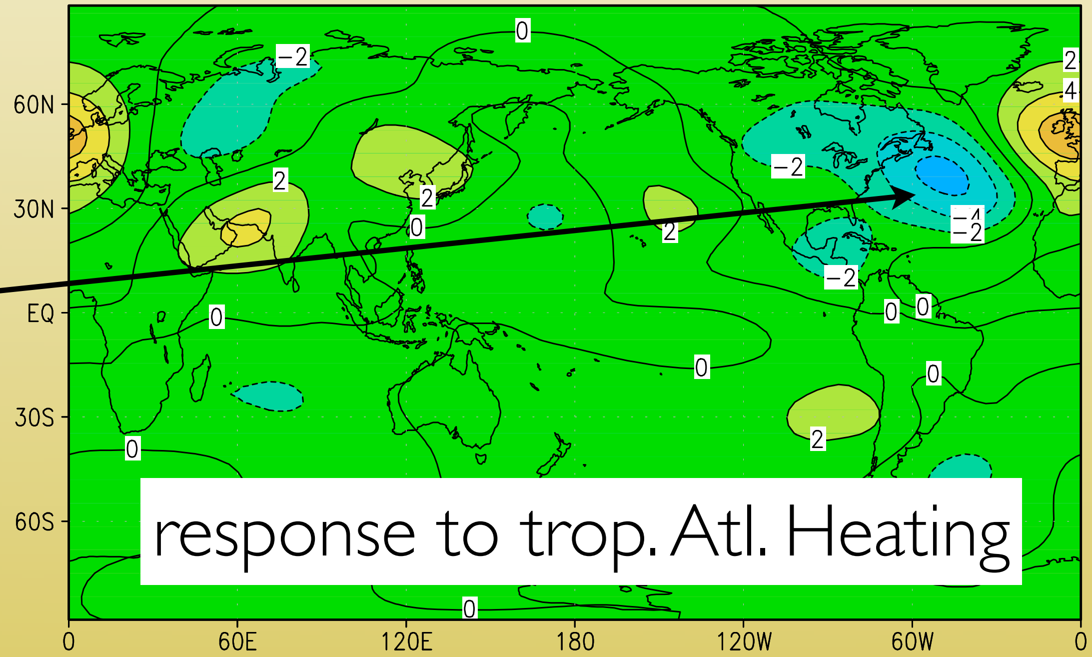
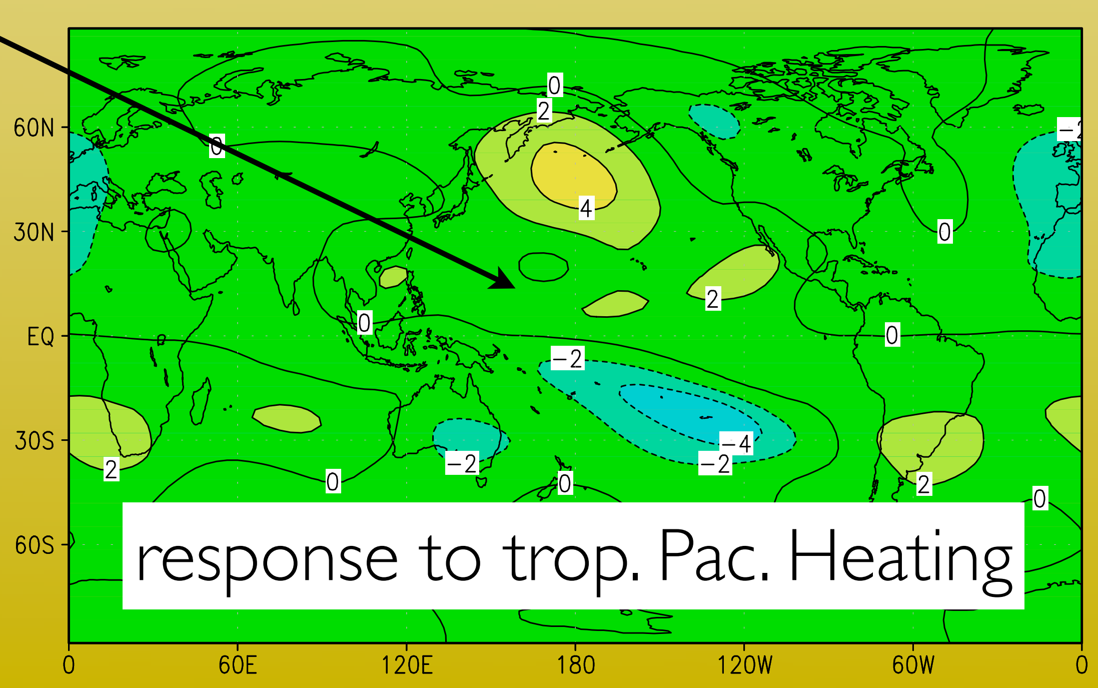
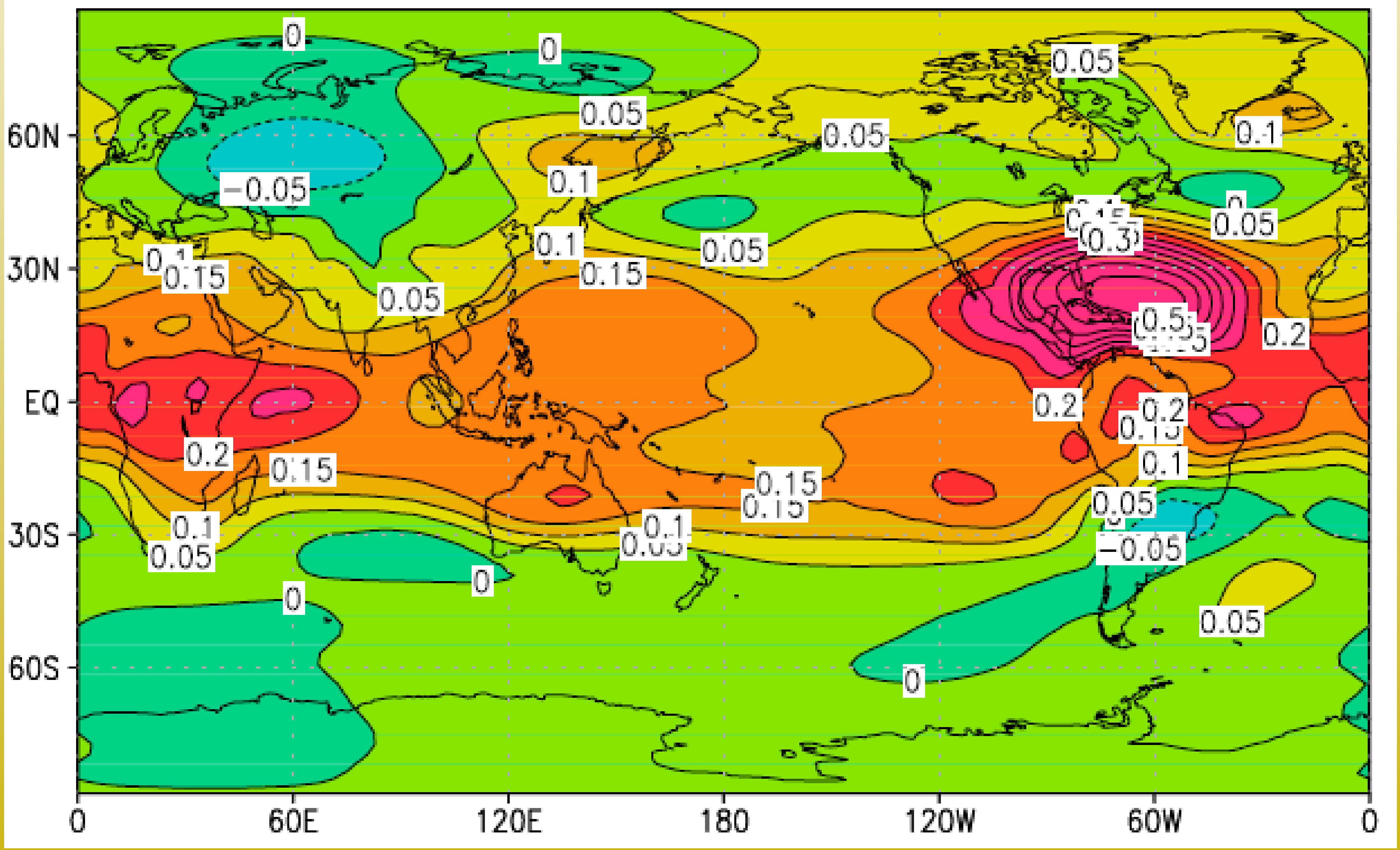

response to tropical Heating


response to trop. Atl. Heating


response to trop. Pac. Heating

Linear Model Results

warm TA induces tropical stabilization and suppresses precipitation elsewhere in the tropics



Winter response to tropical Atlantic SSTAs involves:

1) a locally generated Rossby wave train that arches northeastward towards Europe

2) warming of tropical upper troposphere and stabilization of Pacific atmosphere

3) a remote response to suppressed heating over the Pacific that influences North Pacific and North America

But it appears that 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

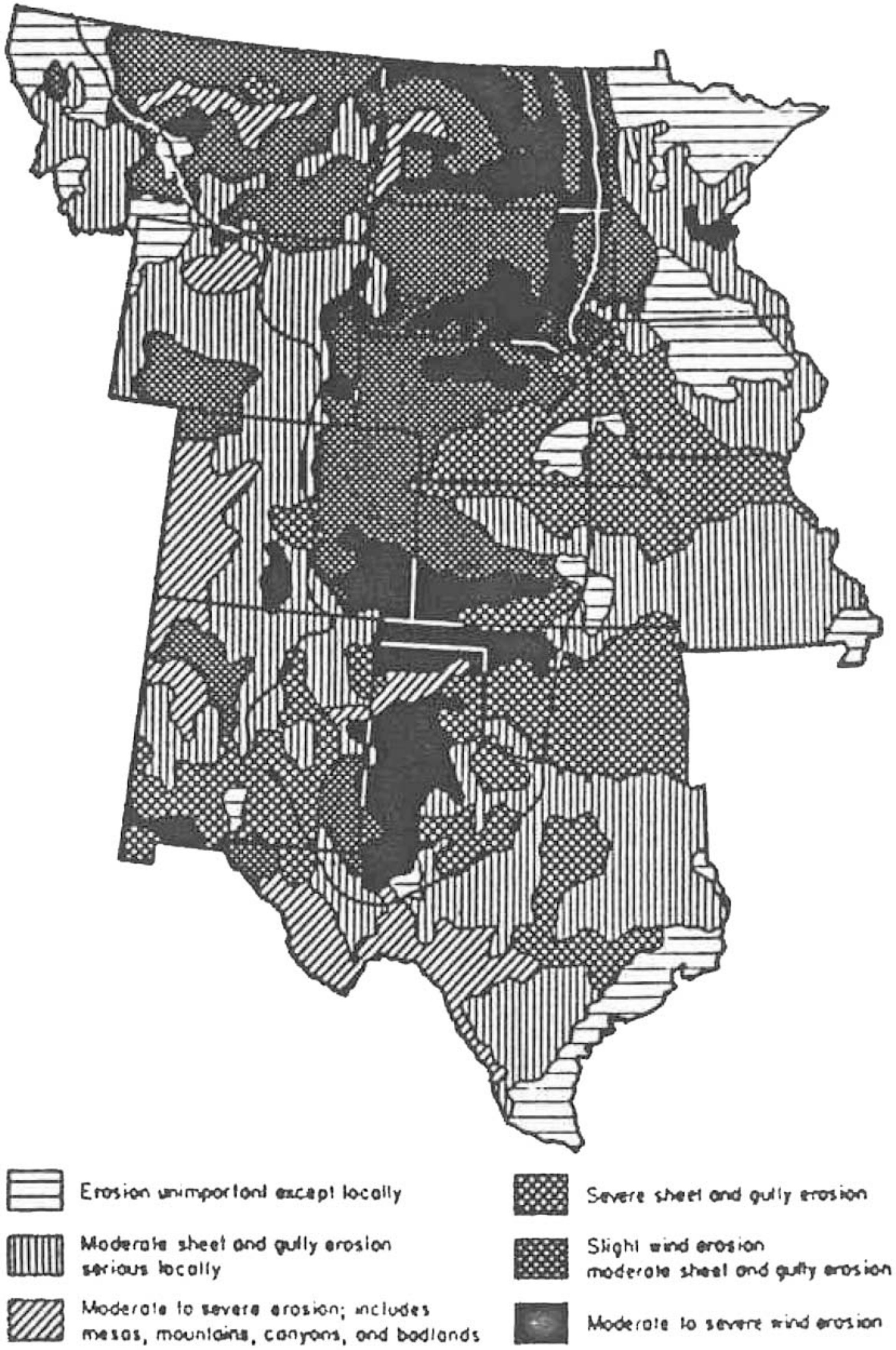
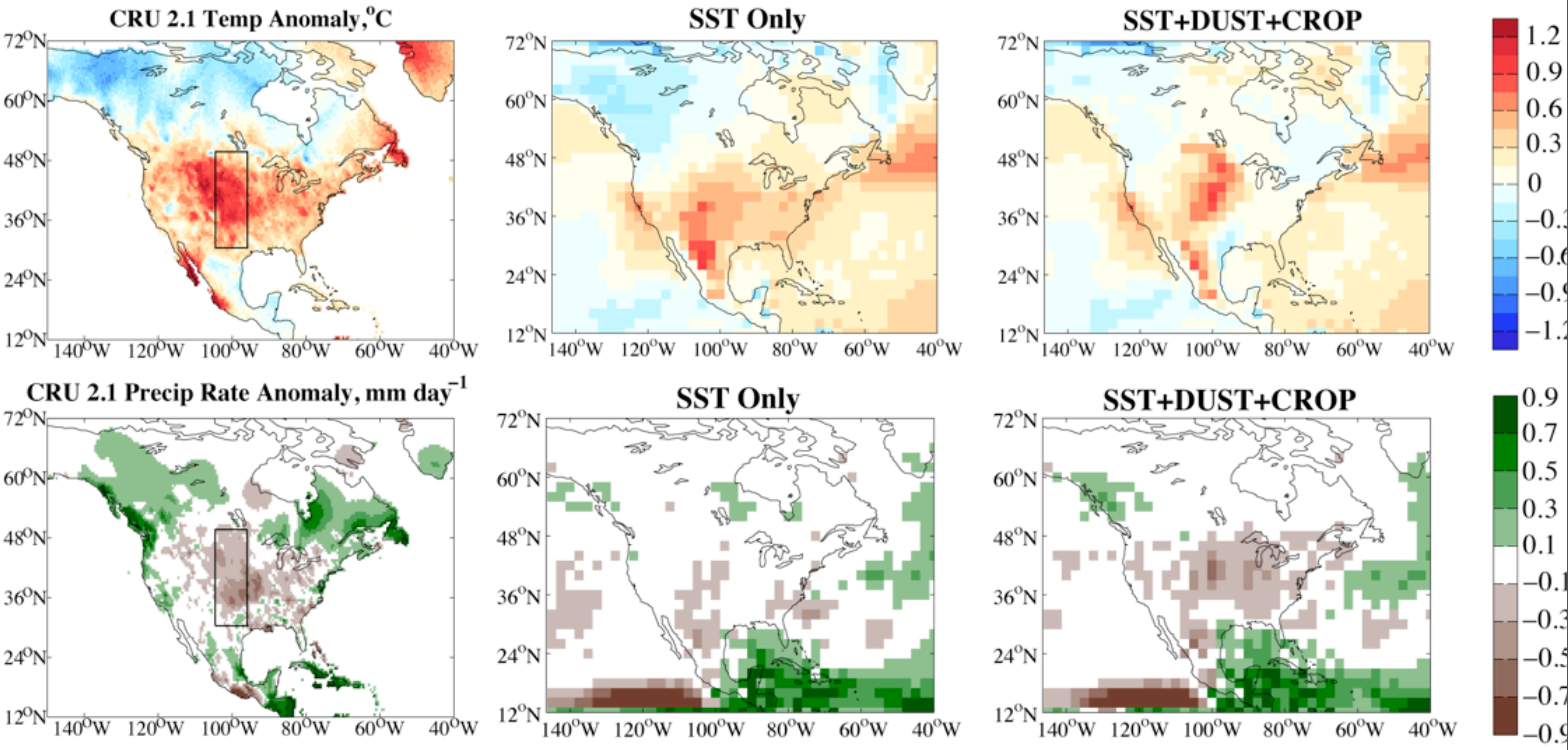


FIG. 1.—Wind erosion in the Great Plains in the 1930s. An irregular line bounds the Great Plains region as delimited by the Great Plains Committee. Source: Adapted from "General Distribution of Erosion" (U.S. Dept. Agriculture, Soil Conservation Service, August 1936).

The Dust Bowl: Human modification and amplification of a natural SST triggered drought. (Crop failure and dust storms.)



Conclusions

Both tropical Pacific and tropical North Atlantic play a role in forcing North American hydroclimate

Pacific-North America link involves impact of direct tropically forced flow on wave refraction as well as (more familiar) stationary waves

Summer response to Atlantic is explained by subtropical stationary waves

Winter response to Atlantic involves inter-basin interaction ... and needs a lot more attention

At least for the Dust Bowl, human-induced land surface transformation intensified and moved the drought