Is anthropogenic subtropical drying and expansion already occurring?

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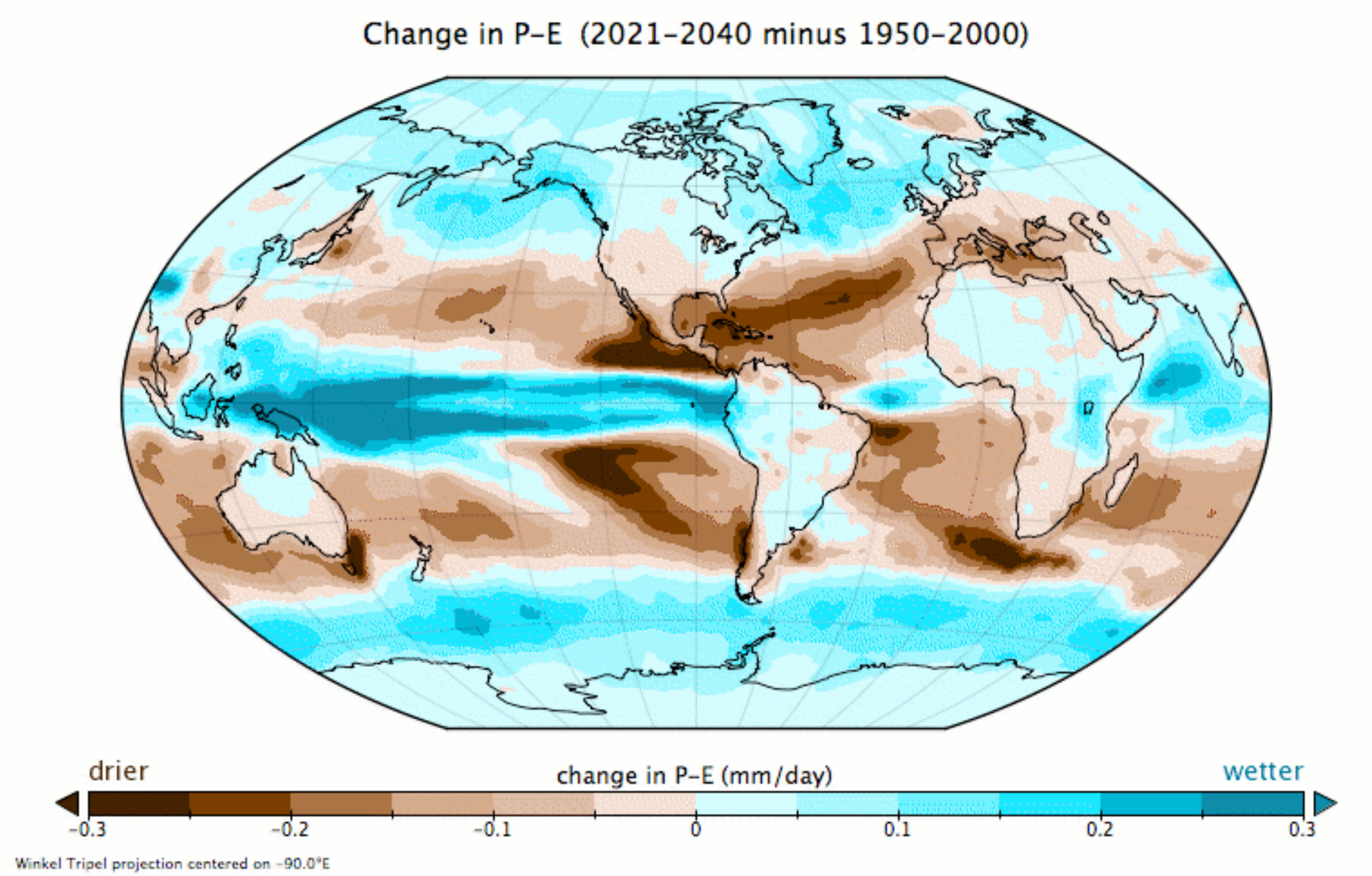
Seager, R., N. Naik and G. Vecchi, 2010: Thermodynamic and dynamic mechanisms for large-scale changes in the hydrological cycle in response to global warming. *J. Climate*, **23**, 4651-4668.

Seager, R. and N. Naik, 2011: A mechanisms-based approach to detecting recent anthropogenic hydroclimate change. *J. Climate*, in press.

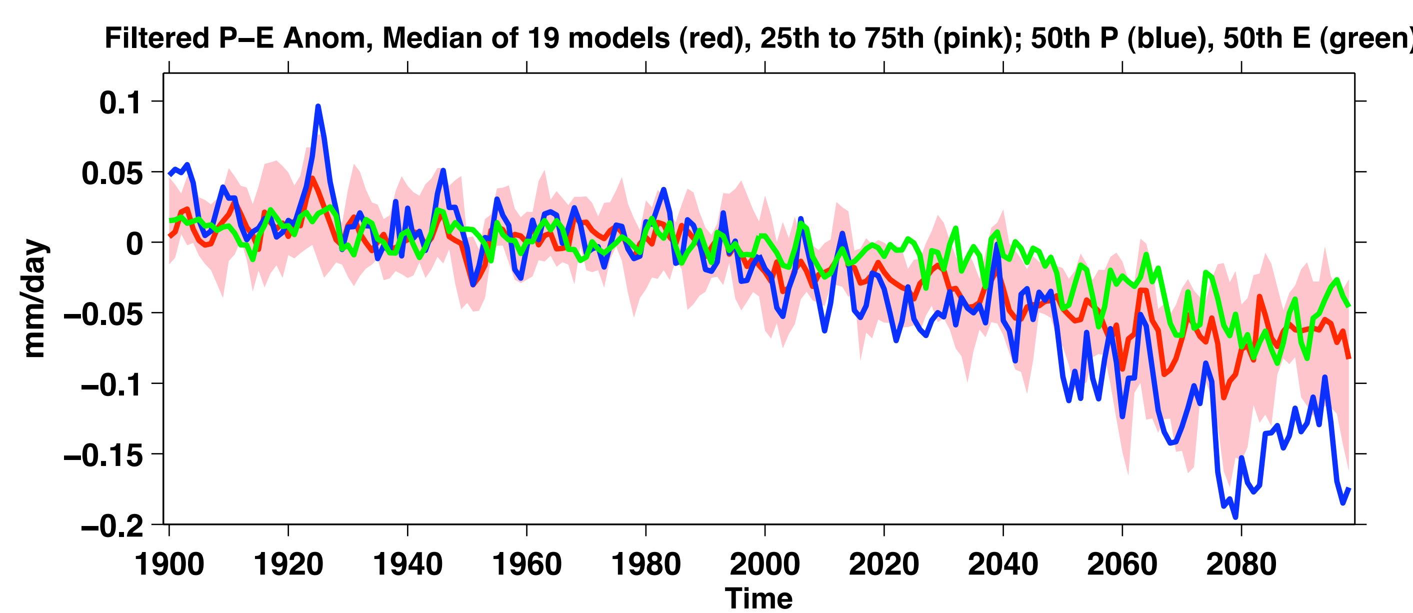
Also:
Wu, Y. et al. 2011 Atmospheric circulation response to an instantaneous doubling of carbon dioxide, Parts I and II. *J. Climate*, submitted.
See poster session

IPCC AR4 models project - a robust, potent, imminent, drying of the global subtropics and latitudinal expansion of subtropical dry zones



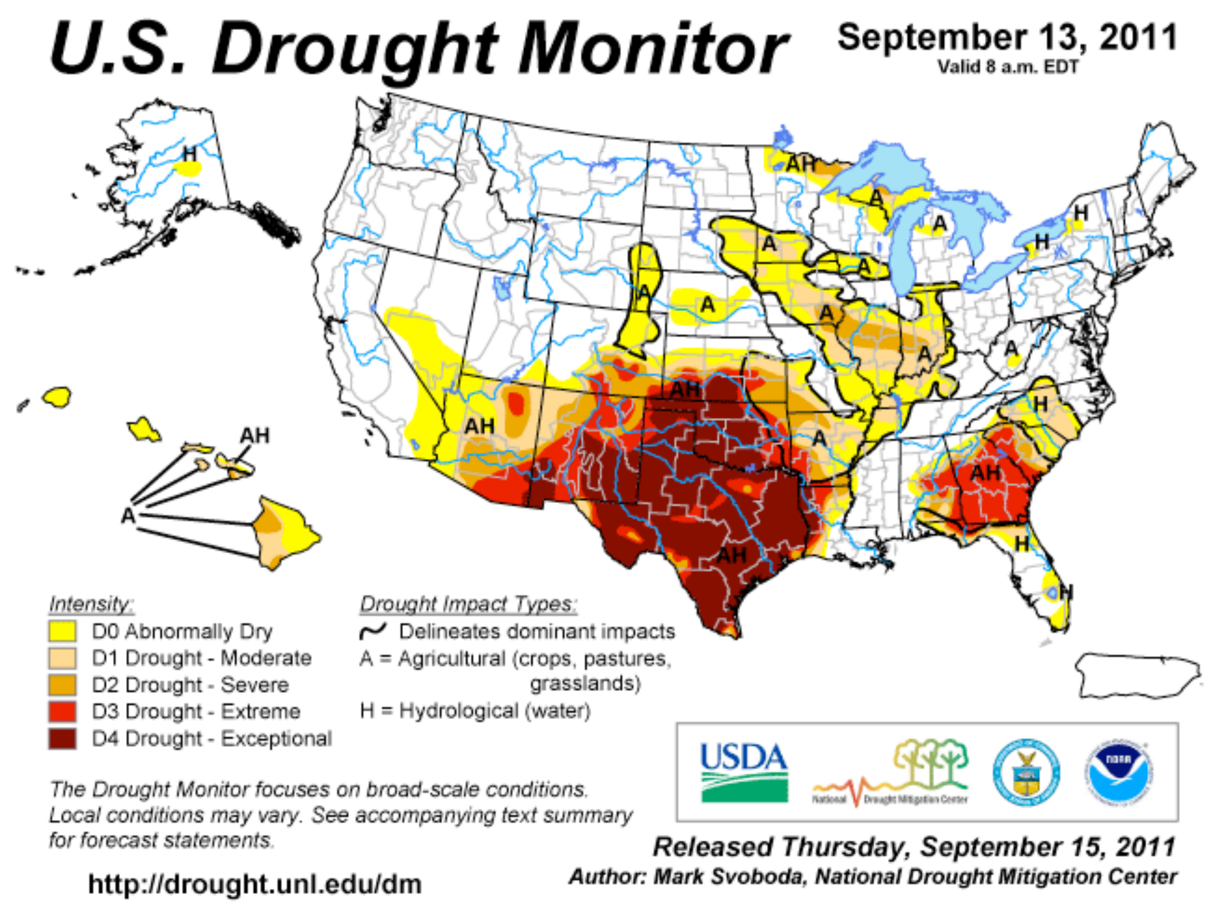
That will impact southwest North America

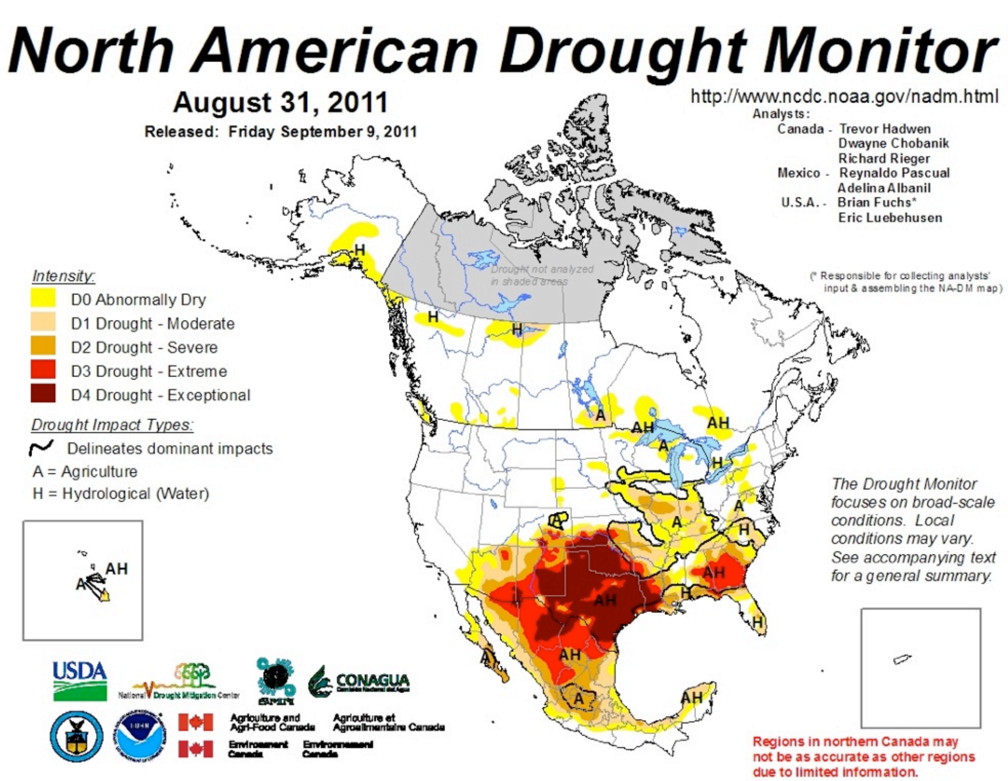
Is this happening?



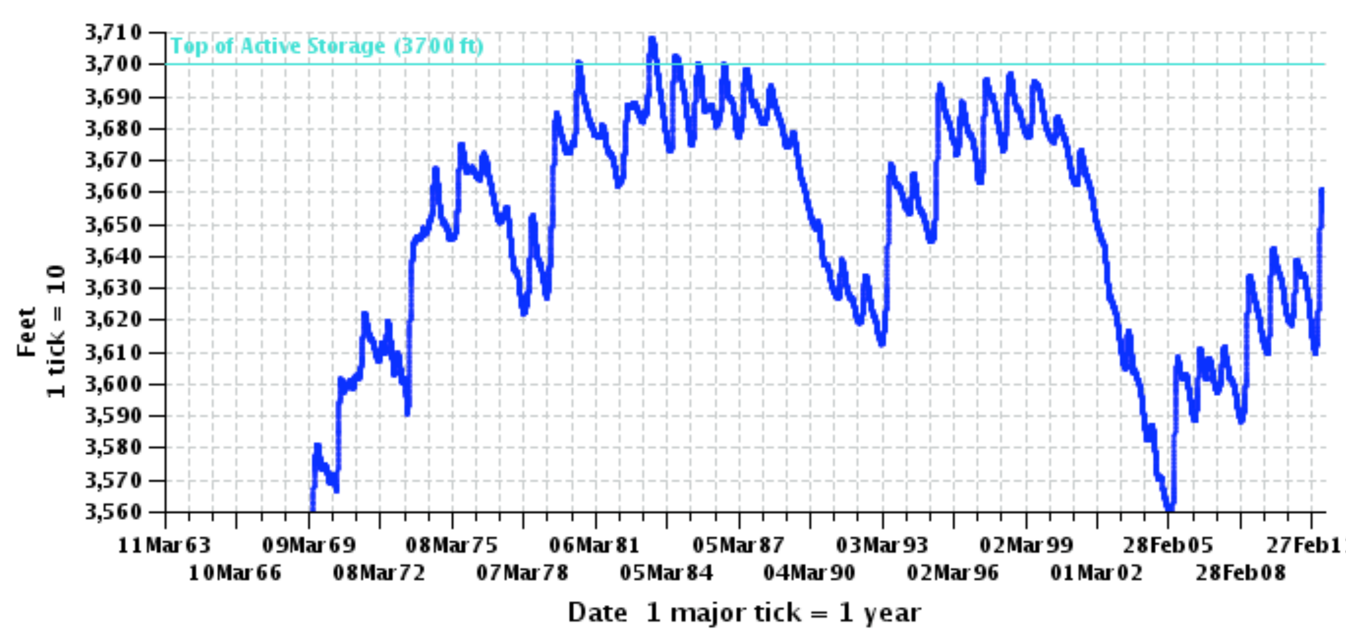
Where are we now?

Coming out of the deep 'turn-of-the-century' drought across the West but with intense La Nina + warm tropical Atlantic induced drought in south and Mexico. Is the drought in part human-caused?



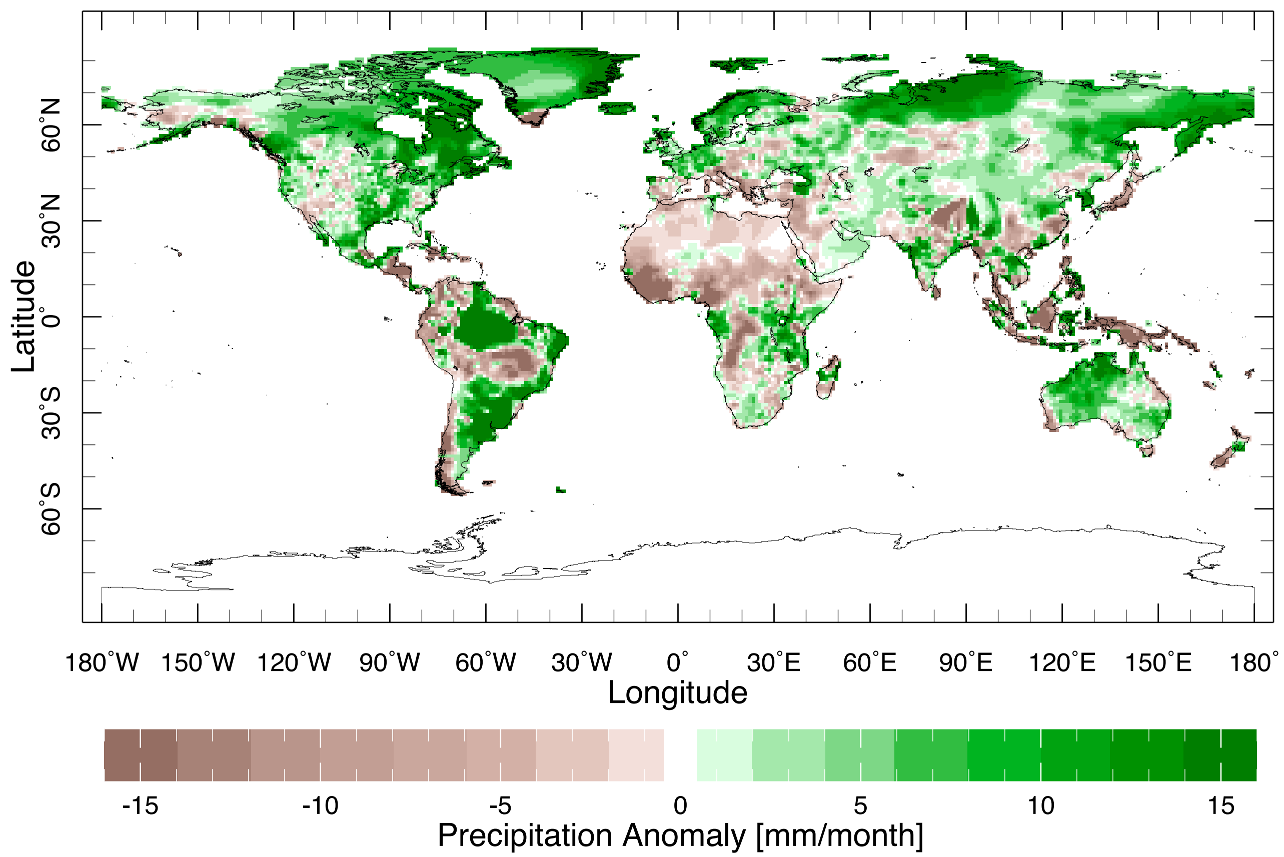


Lake Powell pool elevation



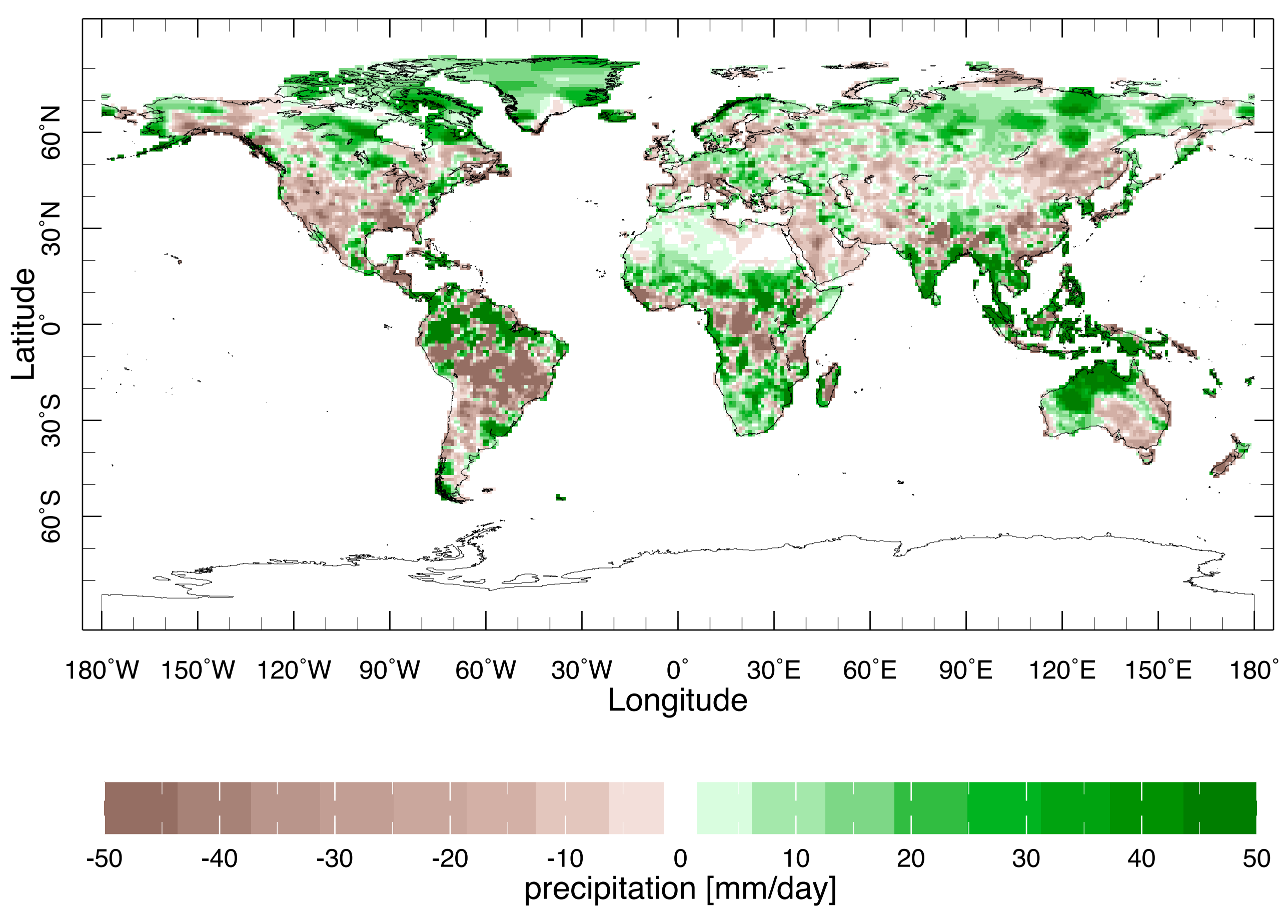
GPCC station data precipitation trends

1901-2007

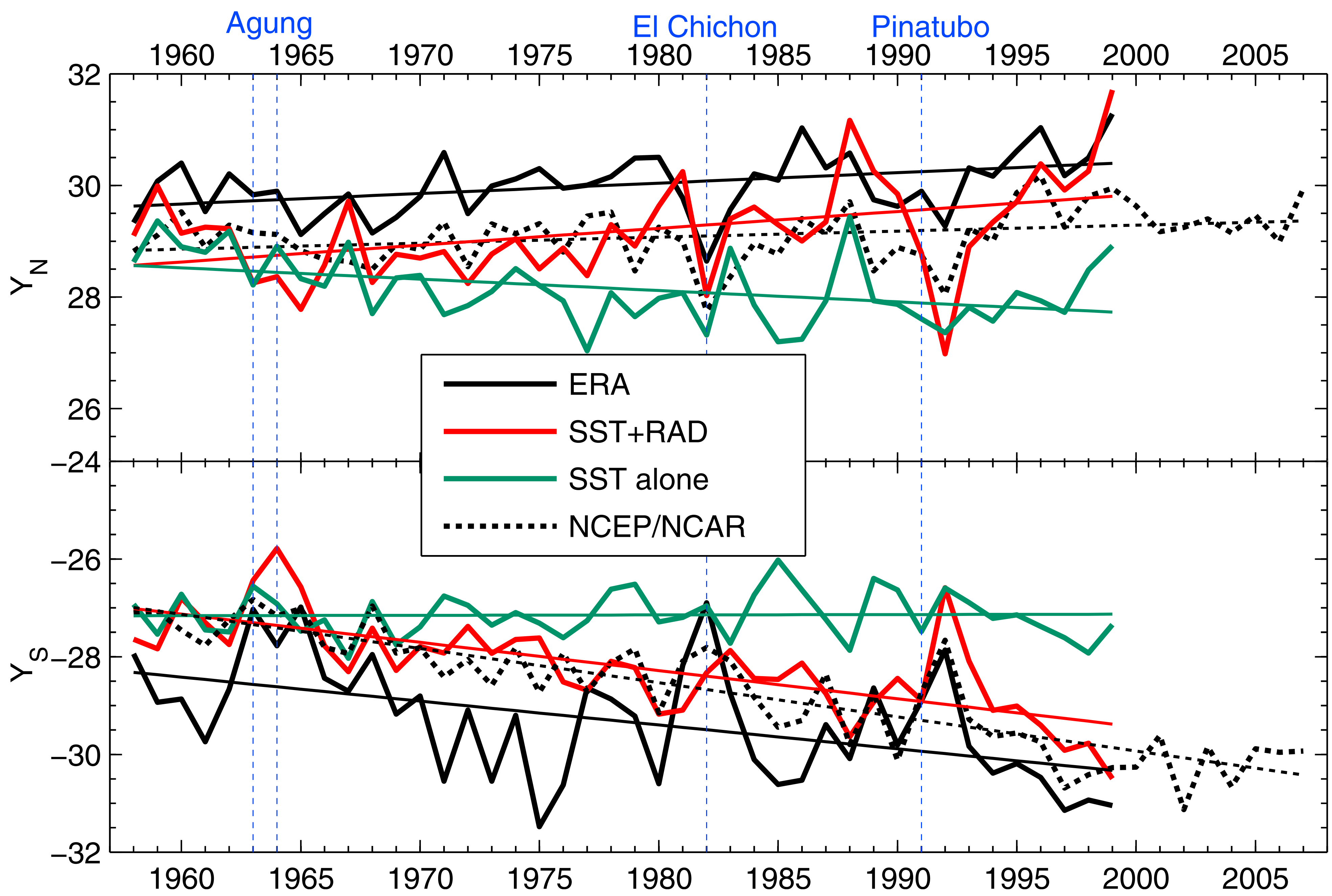


Vary depending on time period - because of sampling of decadal variability

1979-2007



NCEP-NCAR and ERA-40 agree that southern tropics have expanded - based on tropopause height definition. Only reproduced in GCM with change in radiative forcing



Deser et al. (2010)

c.f. Polvani et al. (2011) - it's the ozone

How can we tease out any emerging anthropogenic signal from the tremendous natural variability?

Aim to move beyond analysis of single variables (e.g. *P*, *T*, *u*, *v*) with little attention to mechanisms ....

Idea: a more comprehensive approach is based on a mechanisms analysis of the (multivariate) moisture budget examining both change and variability

Data:

- 15 IPCC AR4 models make all the needed data available.
- Climate change is 2045-2065 minus 1961-2000.
- For internal variability, compute first EOF of annual mean P-E - it is always ENSO - and composite La Ninas minus El Ninos.

NCEP, ERA and MERRA Reanalyses contain spurious trends to changing satellite observing systems so instead we use as the stand-in for the real atmosphere:

(***shock! horror!***) Ground truth is the Compo et al. (2011) 20th C Reanalysis (20CR) - SST-forced, surface pressure assimilating, free of spurious trends. Also an SST forced 16 member CCM3 ensemble.

Breakdown anomalies in the moisture budget into mean circulation dynamics (*MCD*), thermodynamic (*TH*) and transient eddy (*TE*) contributions:

$$\rho_w g \delta(P - E) \approx \delta TH + \delta MCD + \delta TE - \delta S,$$

$$\delta TH = -\int_0^{p_s} \nabla \cdot \left(\bar{\mathbf{u}}_{20} \left[\delta \bar{q}\right]\right) dp,$$

$$\delta MCD = -\int_0^{p_s} \nabla \cdot \left(\left[\delta \bar{\mathbf{u}}\right] \bar{q}_{20}\right) dp,$$

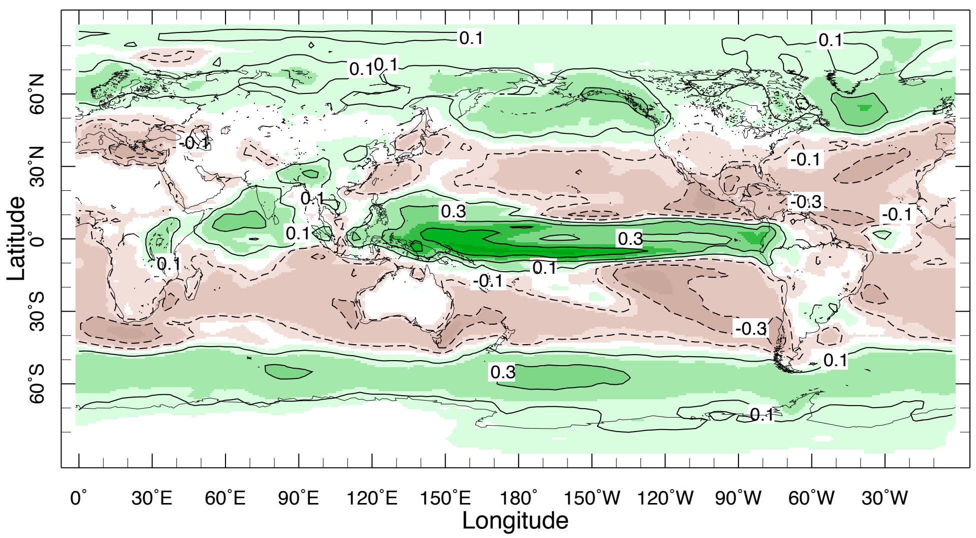
$$\delta TE = -\int_0^{p_s} \nabla \cdot \delta(\overline{\mathbf{u}'\mathbf{q}'}) dp.$$

climate change: $\delta(\cdot) = (\cdot)_{21} - (\cdot)_{20},$

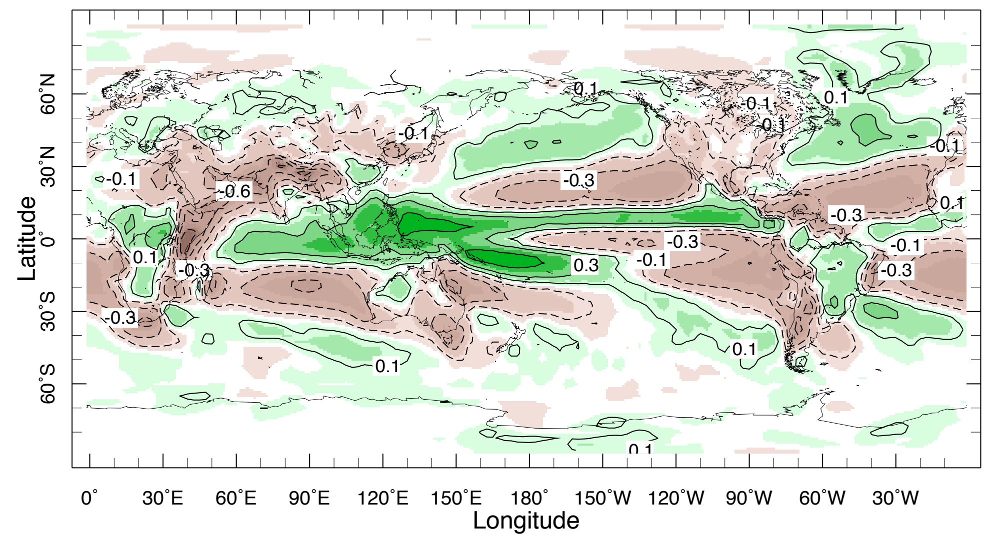
internal variability: $\delta(\cdot) = (\cdot)_{LN} - (\cdot)_{EN},$

MMM - Climate Change

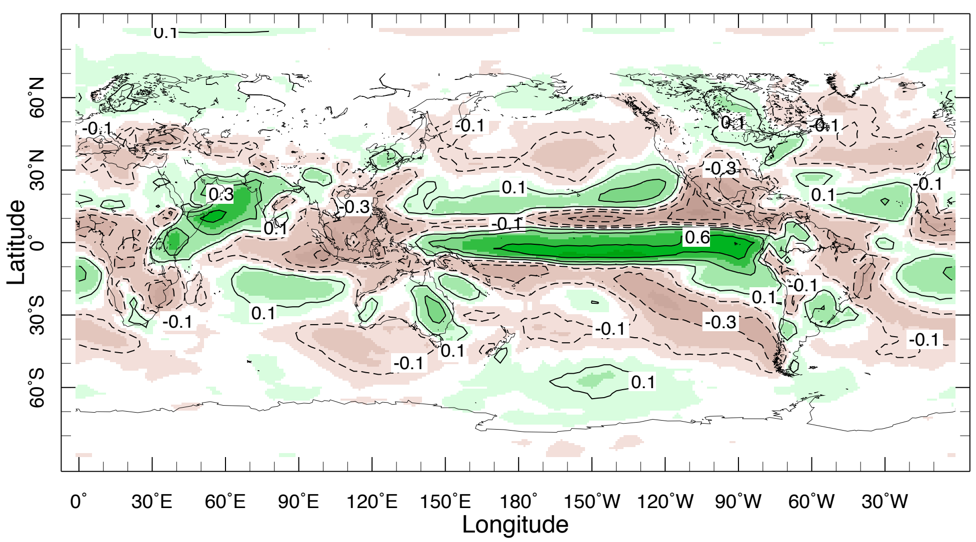
$\delta(P - E)$



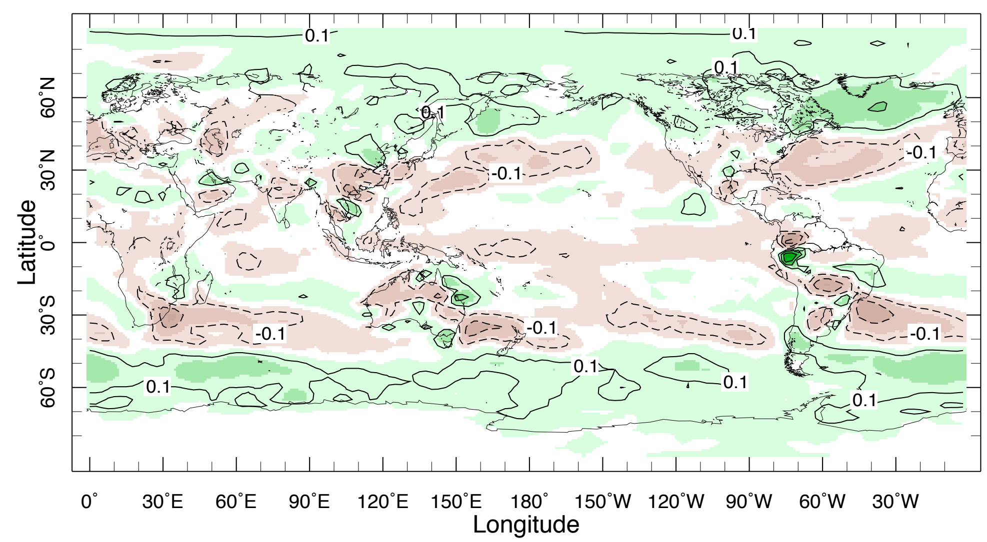
δTH



δMCD

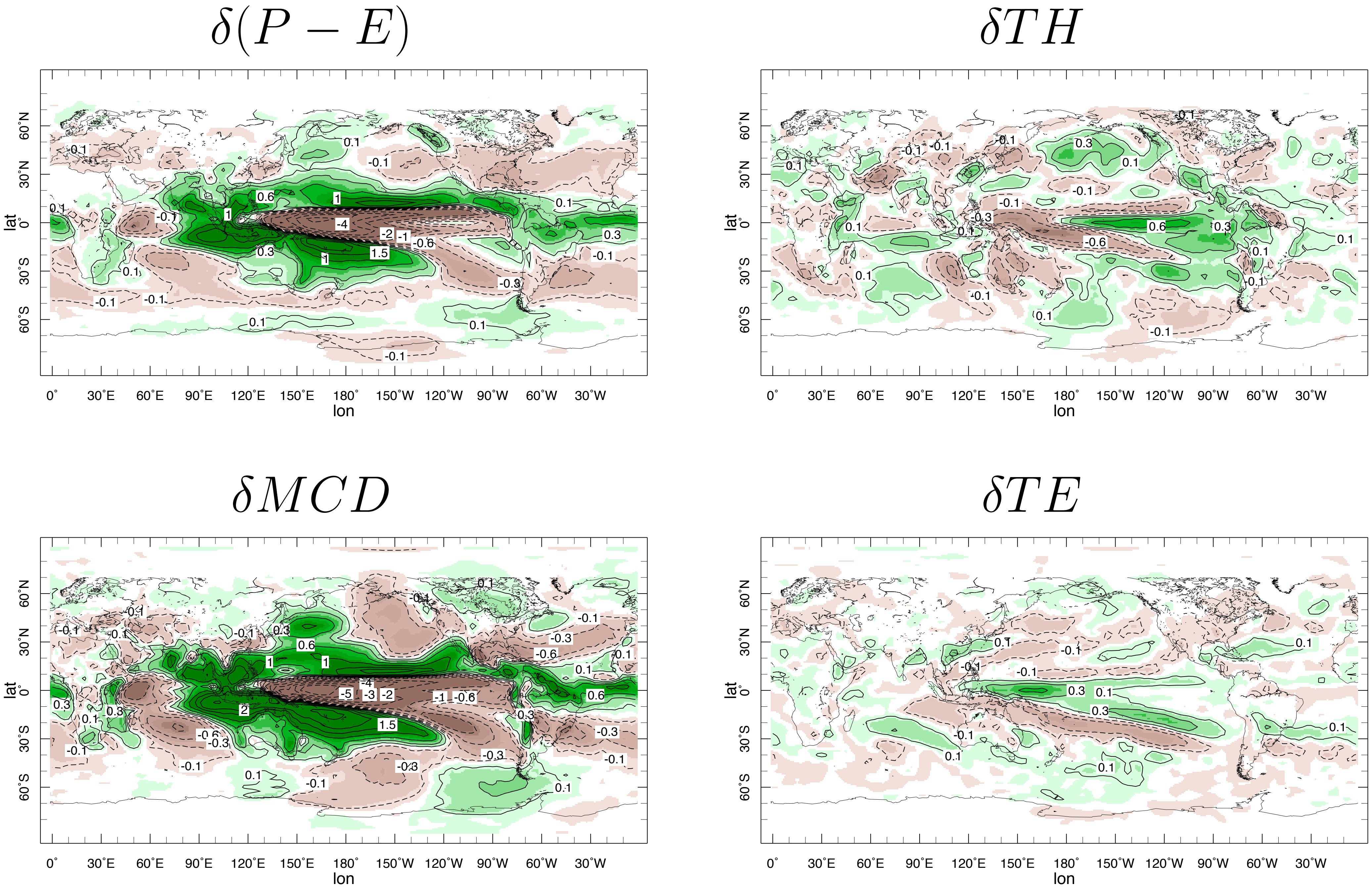


δTE



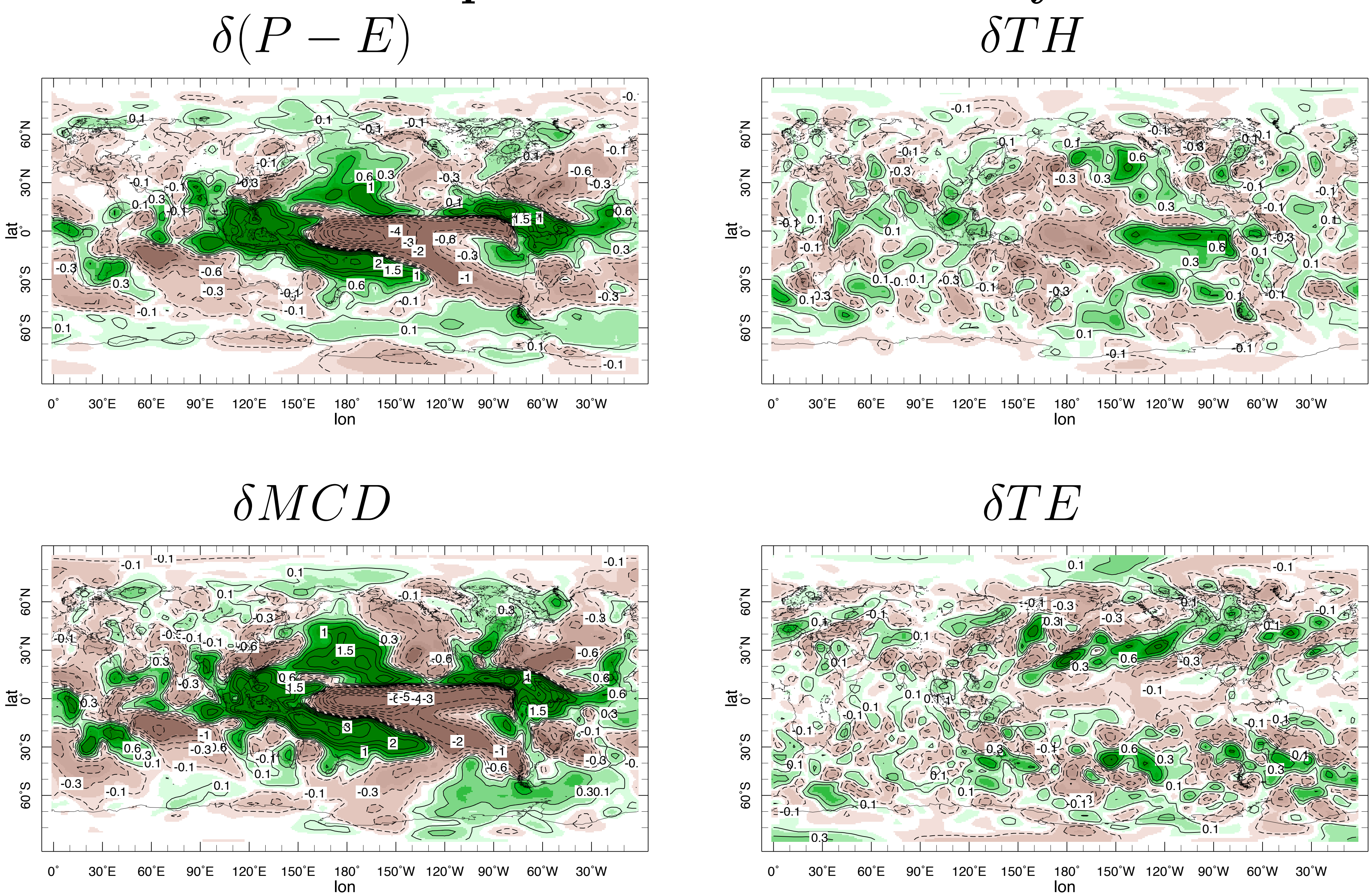
Tropical wetting, subtropical drying strongly influenced by rising *q* and intensified moisture convergence and divergence. Mean circulation change - weaker tropical circulation, Hadley Cell expansion - also important as well as TE intensification and poleward shift. ***'Thermodynamics mediated.'***

MMM - Natural Variability



For internal variability - mostly ENSO - thermodynamic contribution is weak and *P-E* is ***'Dynamics dominated'***.

Compo - Natural Variability



IPCC AR4 mechanisms of internal P-E variability are remarkably similar to observed.

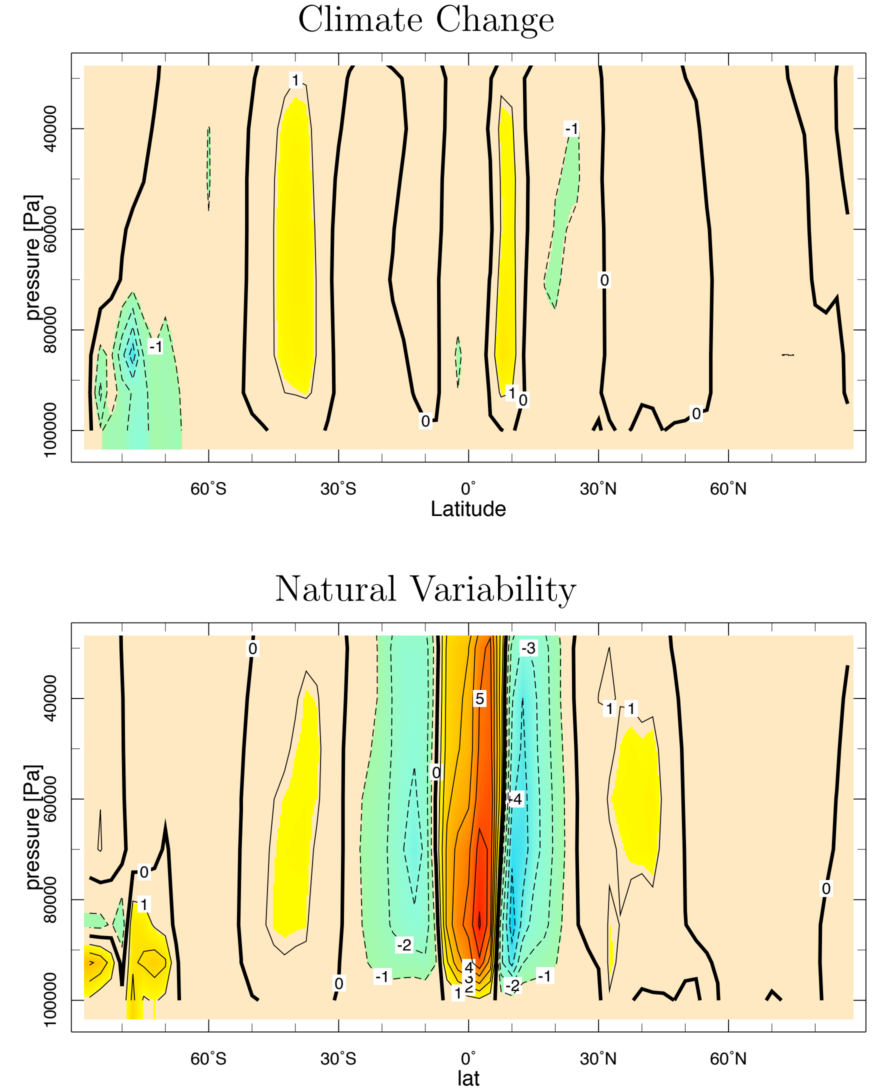
Both climate change and La Nina have similar subtropical-to-midlatitude circulation features (poleward shifted easterlies and descent). Tropical changes are almost opposite

climate change in vertical velocity

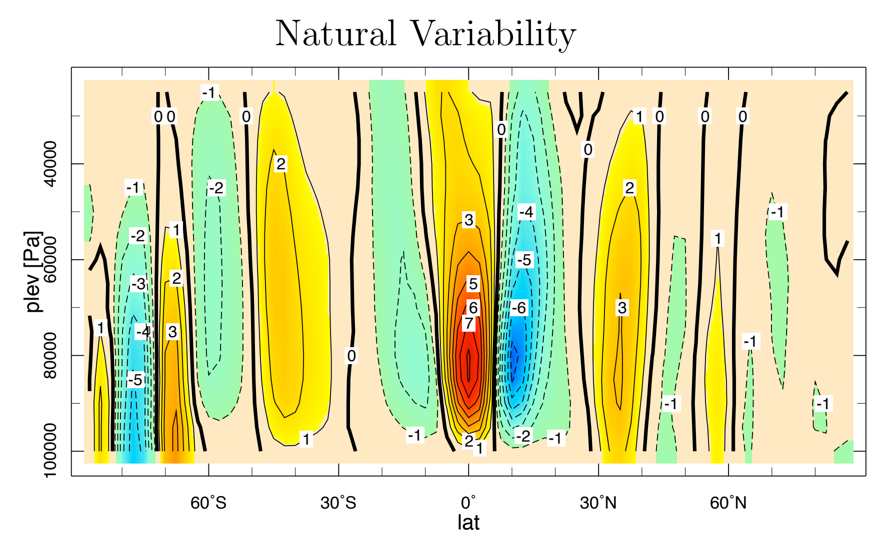
AR4 variability

20CR variability

MMM omega $(= dp/dt)$



Compo omega $(= dp/dt)$



So, despite similarity of extratropical *P-E* patterns, climate change and La Nina-induced subtropical-to-midlatitude drying:

1. have a different mix of dynamic and thermodynamic mechanisms
2. have different signatures in tropical circulation and thermal structure

Use this distinction to attribute post-1979 *P-E* change

Post-1979 P-E change in 20CR

Post-1979 because this is the satellite period used by others.

Divide P-E into that part explained by the first two EOFs (both ENSO) and a residual.

$$P - E = \sum_{n=1}^{2} a_n(t) p_n(x, y) + (P - E)_R,$$

Regress the contributions onto the PCs to get contributions to the residual:

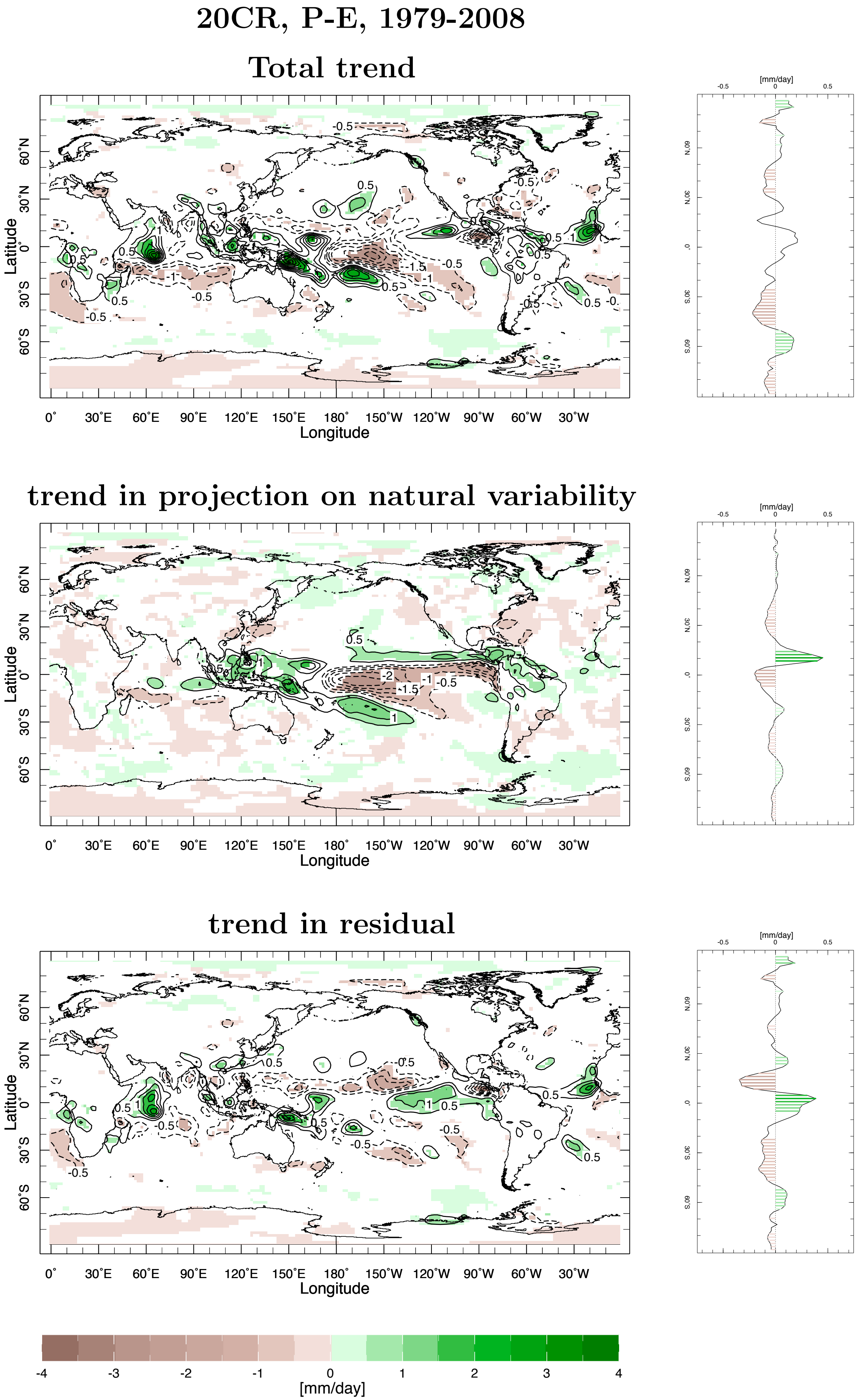
$$P - E = \sum_{n=1}^{2} a_n(t) \left(TH_n + MCD_n + TE_n \right) + TH_R + MCD_R + TE_R,$$

Compute trends in total, internal variability and residual.

The actual P-E trend does have widespread subtropical drying but also equatorial drying.

The part of this trend due to ENSO-variability largely explains the equatorial drying and some of the subtropical-to-midlatitude drying

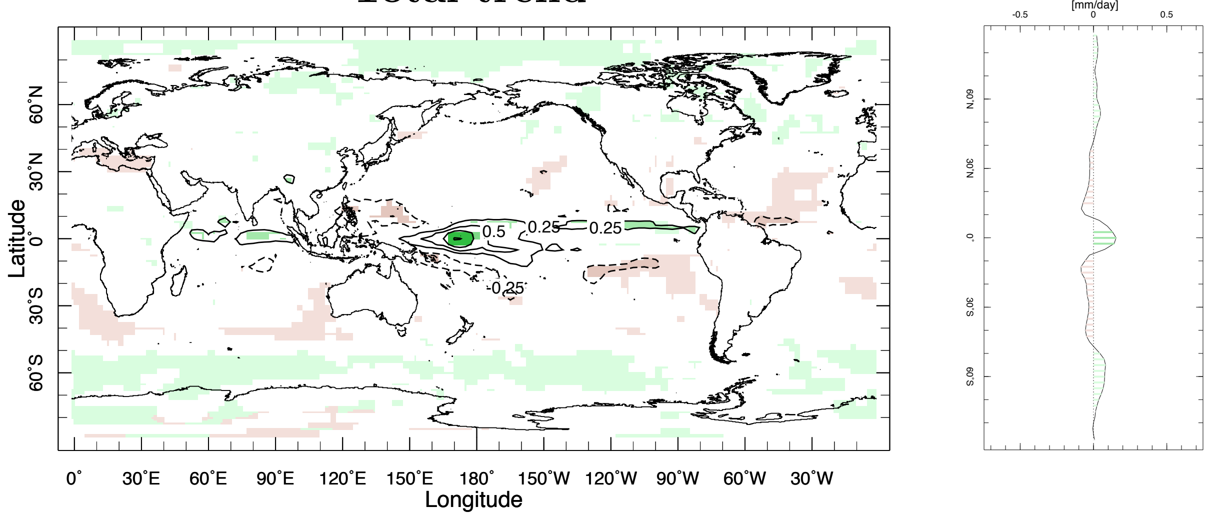
The residual trend, with equatorial wetting, and subtropical-to-midlatitude drying has some GHG-driven character



Very similar results as from 20CR appear in the purely SST-forced GCM ensemble mean - residual trends akin to AR4 post-1979 trends

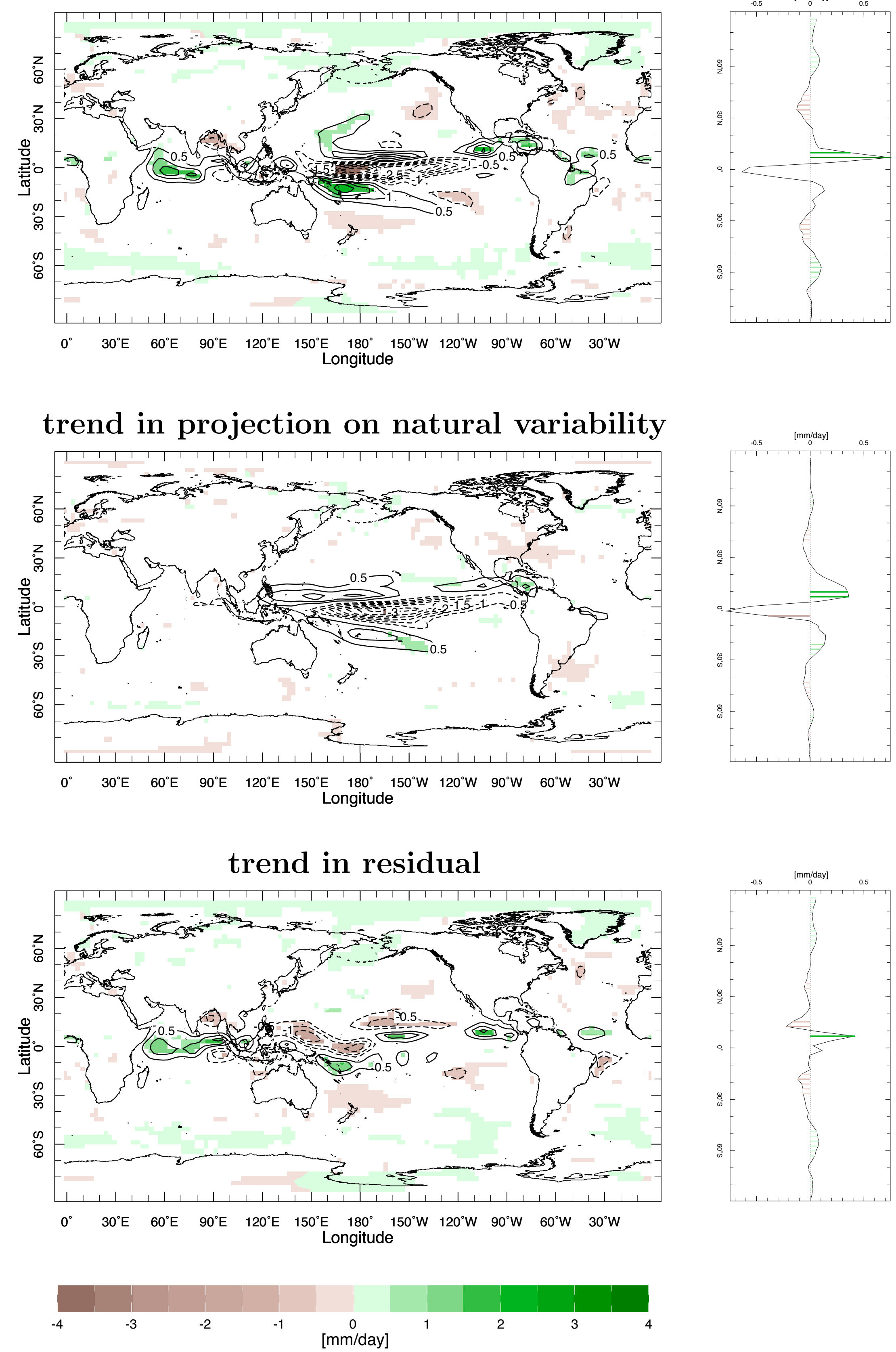
MMM, P-E, 1979-2008

Total trend



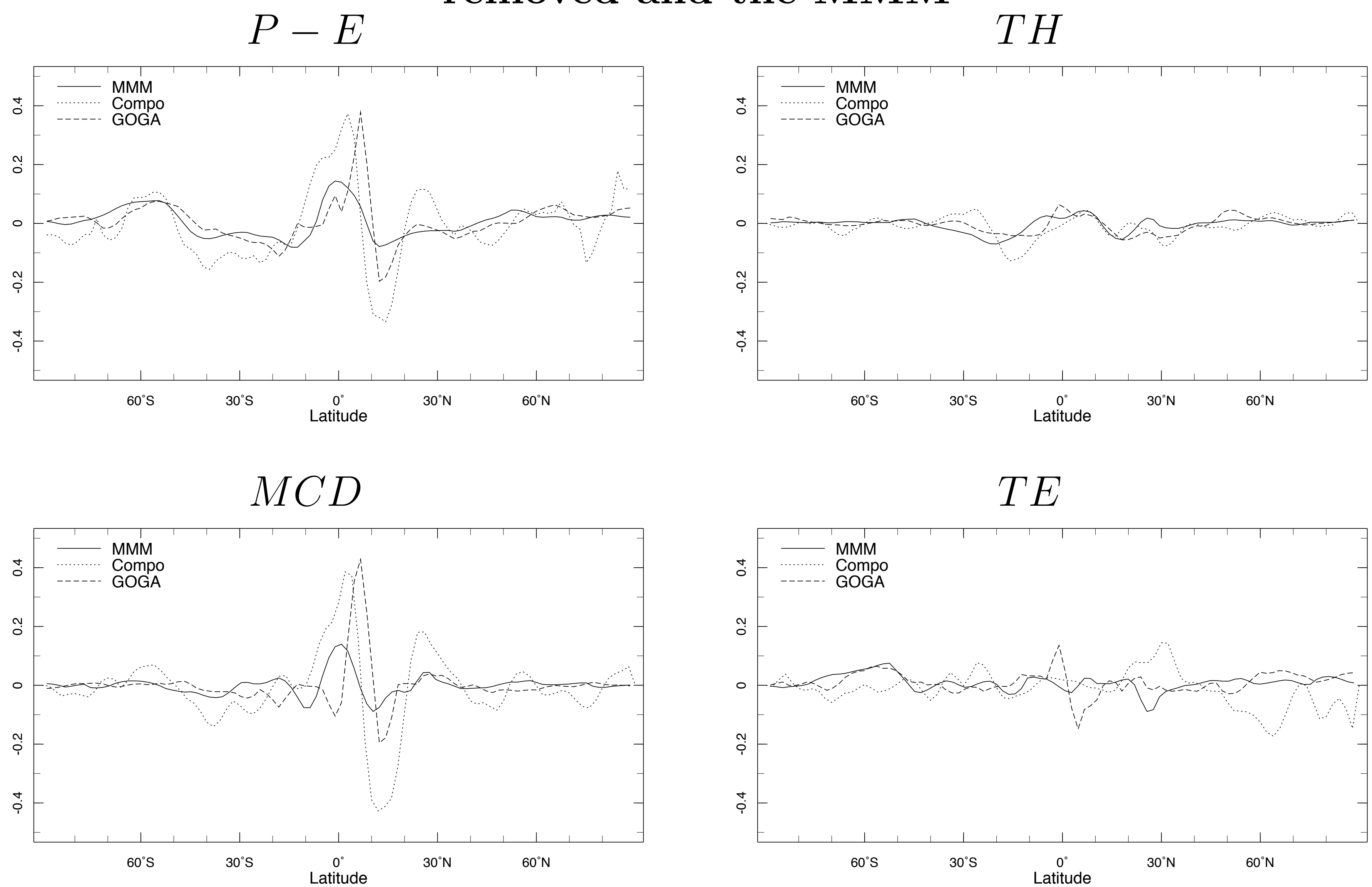
GOGA, P-E, 1979-2008

Total trend



How do mechanisms of AR4 and residual trend compare?

Zonal mean trends for GOGA and Compo, ENSO removed and the MMM



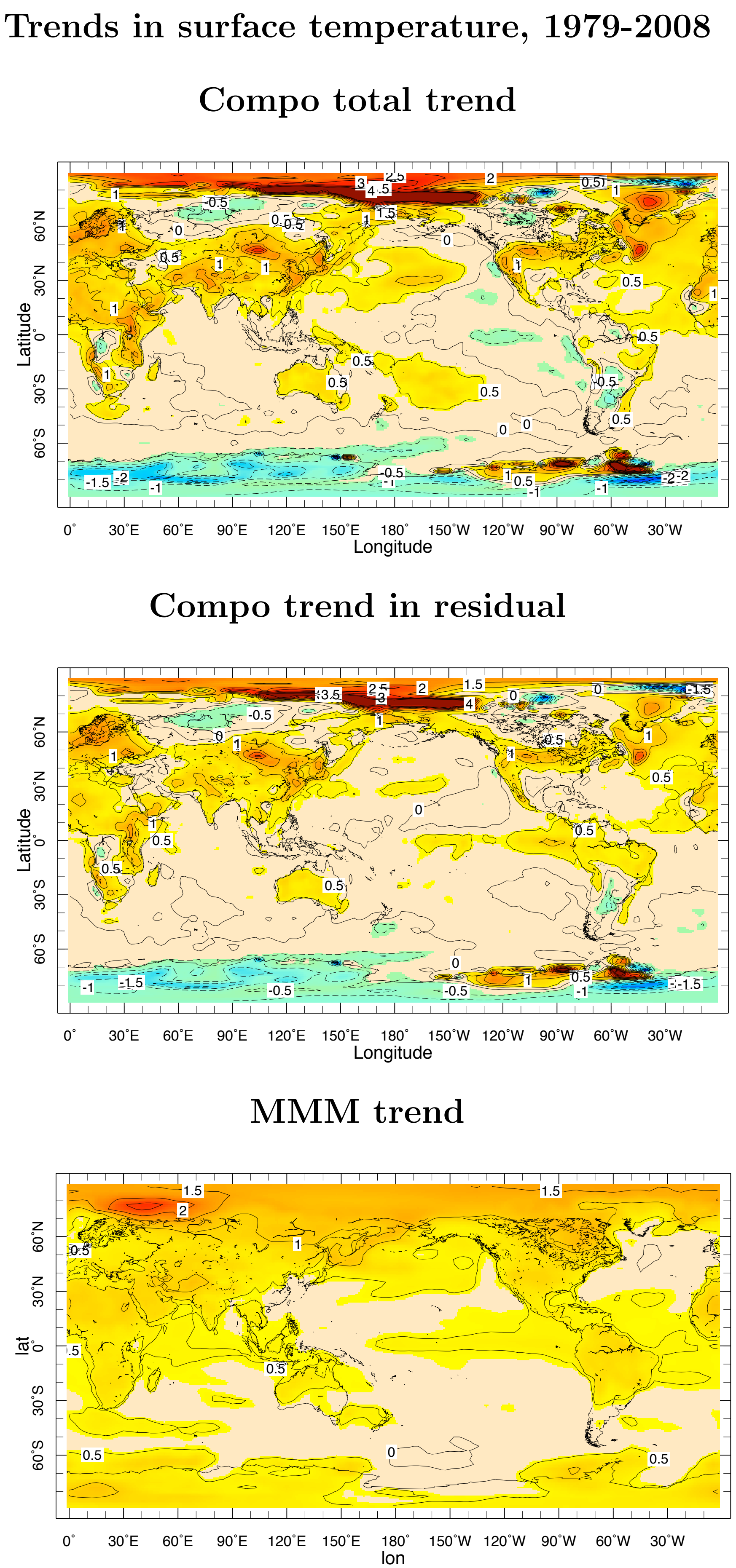
P-E trends largely agree in structure and amplitude, agreement on MCD importance in tropics, TH contribution to wet-get-wetter, dry-get-drier. All modest for 1979 to now, as expected.

For the SSTs, separation into ENSO trends and residual trends converts tropical east Pacific cooling into equatorial warming akin to AR4.

actual trend

residual trend

AR4 trend



Conclusions

Clear distinction in the mechanisms of natural subtropical-to-midlatitude drought ('dynamics dominated') and anthropogenic subtropical drying ('thermodynamics mediated').

Allows mechanisms-based separation of post-1979 P-E change into that due to internal variability and a residual (which contains forced change) with equatorial-wetting and subtropical-to-midlatitude drying, as for AR4.

The mechanisms of residual P-E change, and associated circulation change, also consistent with AR4.

I.e. evidence, based on the inherently multivariate, moisture budget that hydroclimate change is occurring with amplitude and pattern consistent with AR4. But currently relatively small c.f. internal variability on interannual to decadal timescales.