A mechanisms-based approach for distinguishing between natural variability of, and radiatively-forced change in, hydroclimate

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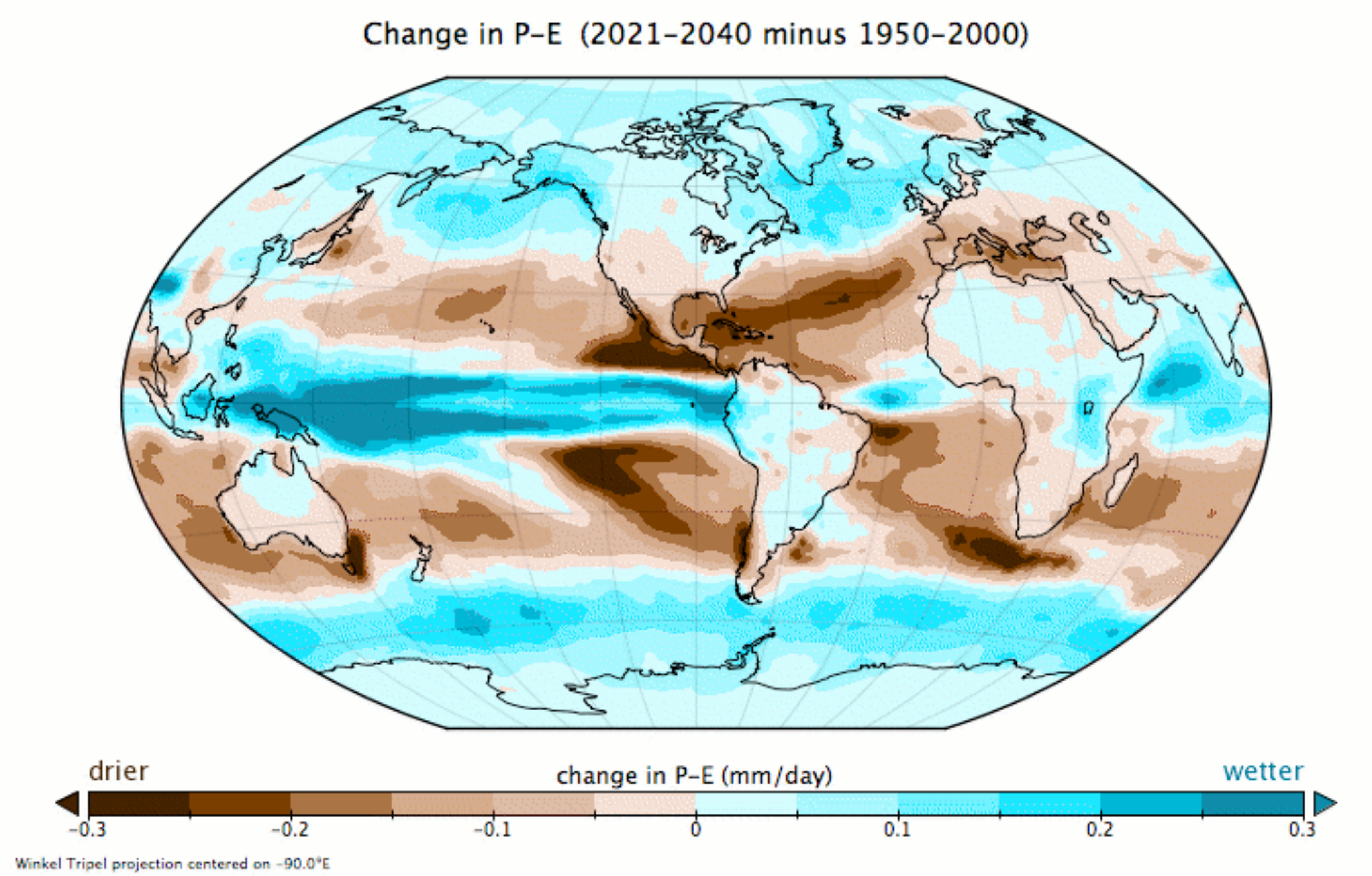
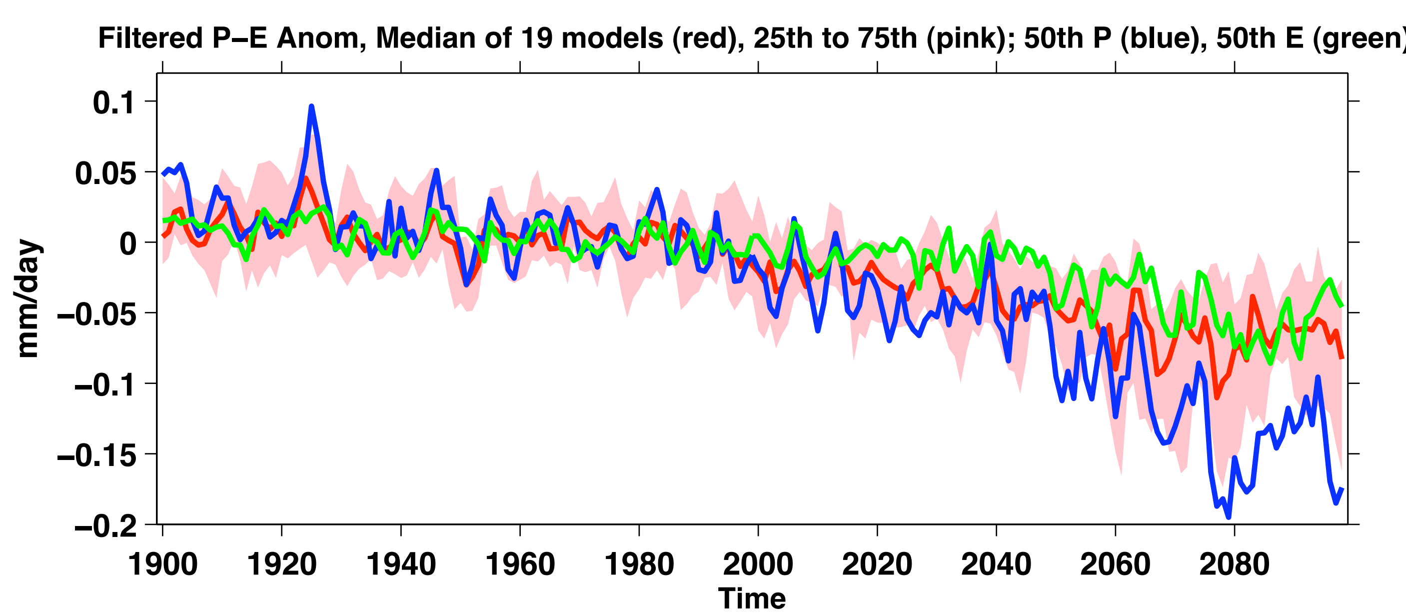
IPCC AR4 models project - a robust, potent, imminent, drying of the global subtropics and latitudinal expansion of subtropical dry zones

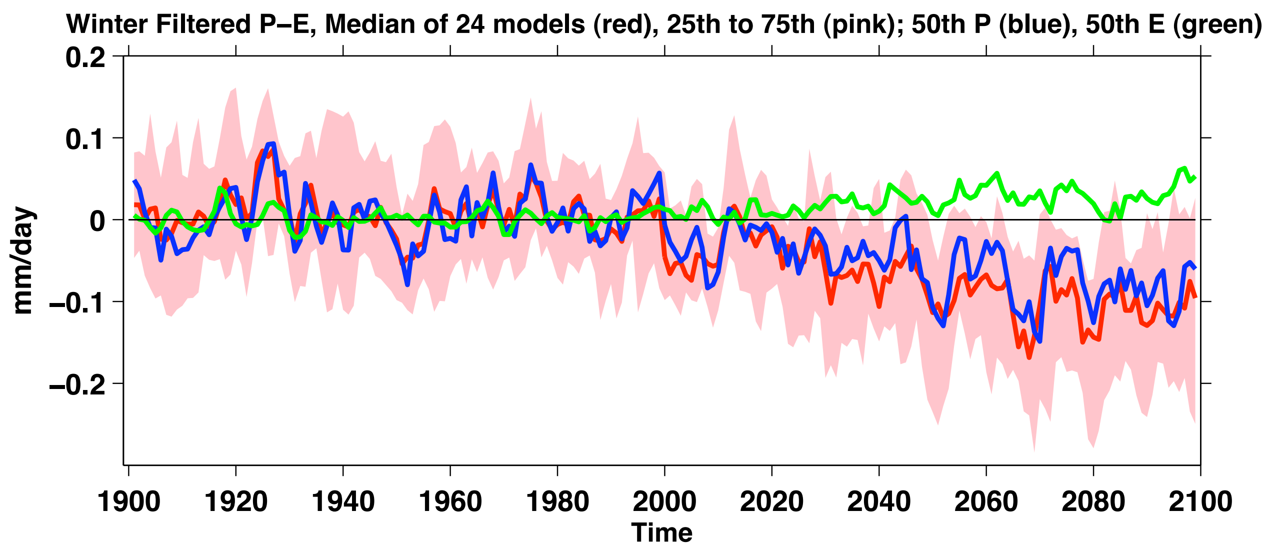


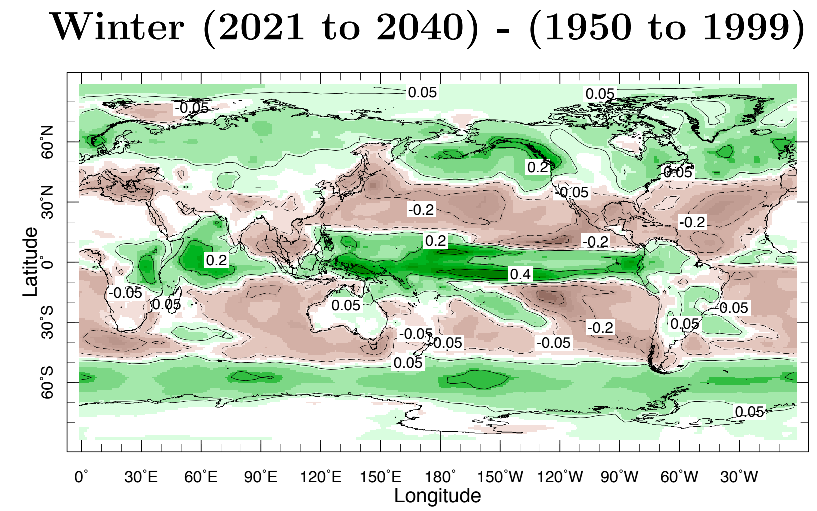
That will impact southwest North America



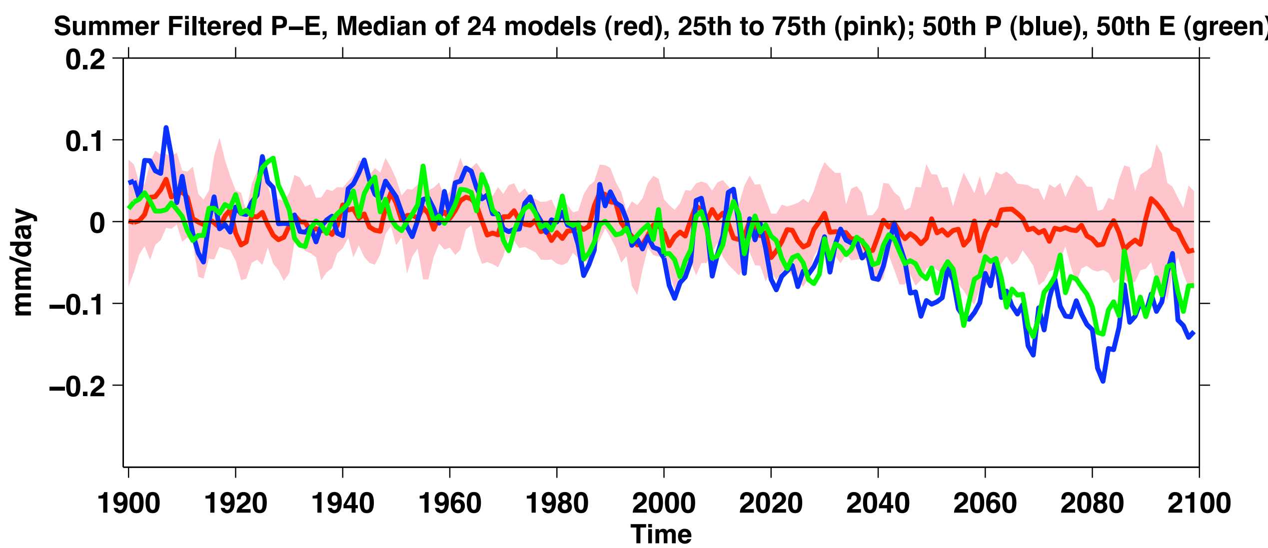
IPCC Precipitation - Evaporation

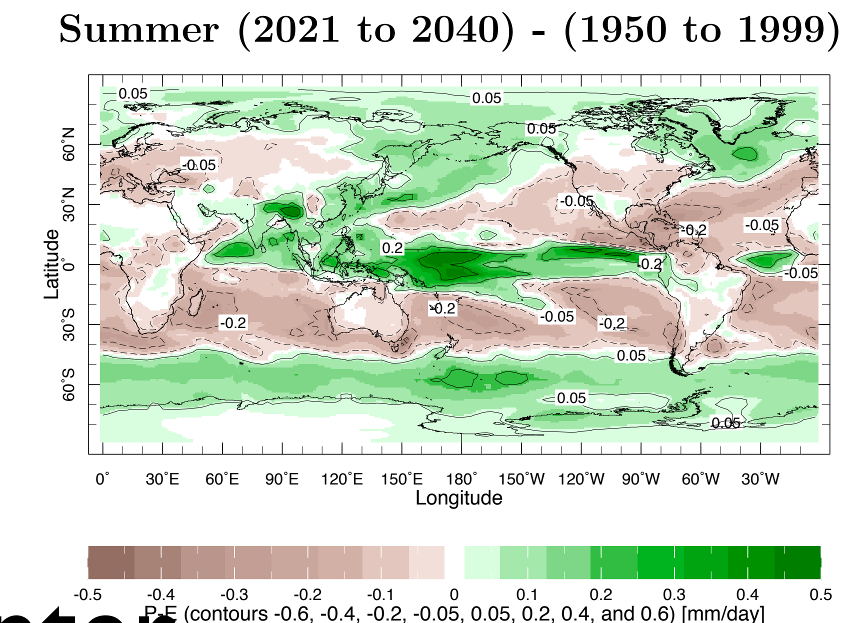
Oct-
Mar





Apr-
Sep





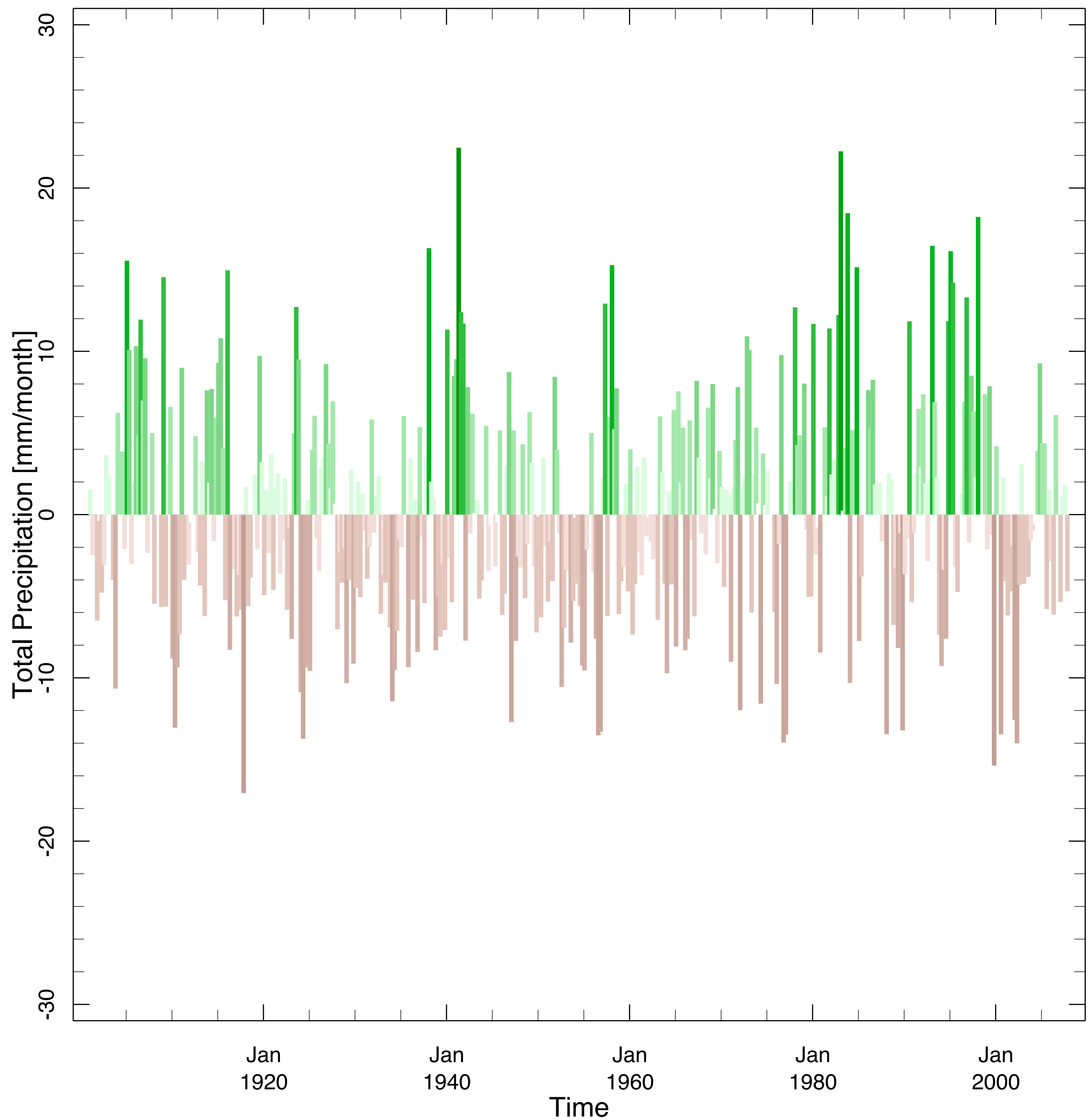
SWNA drying driven by drop in winter *P*, with *E* falling as a consequence.

Should already be happenning.

Drying of SW N. America from the early 1980s to now but no clear evidence of a longer timescale shift.

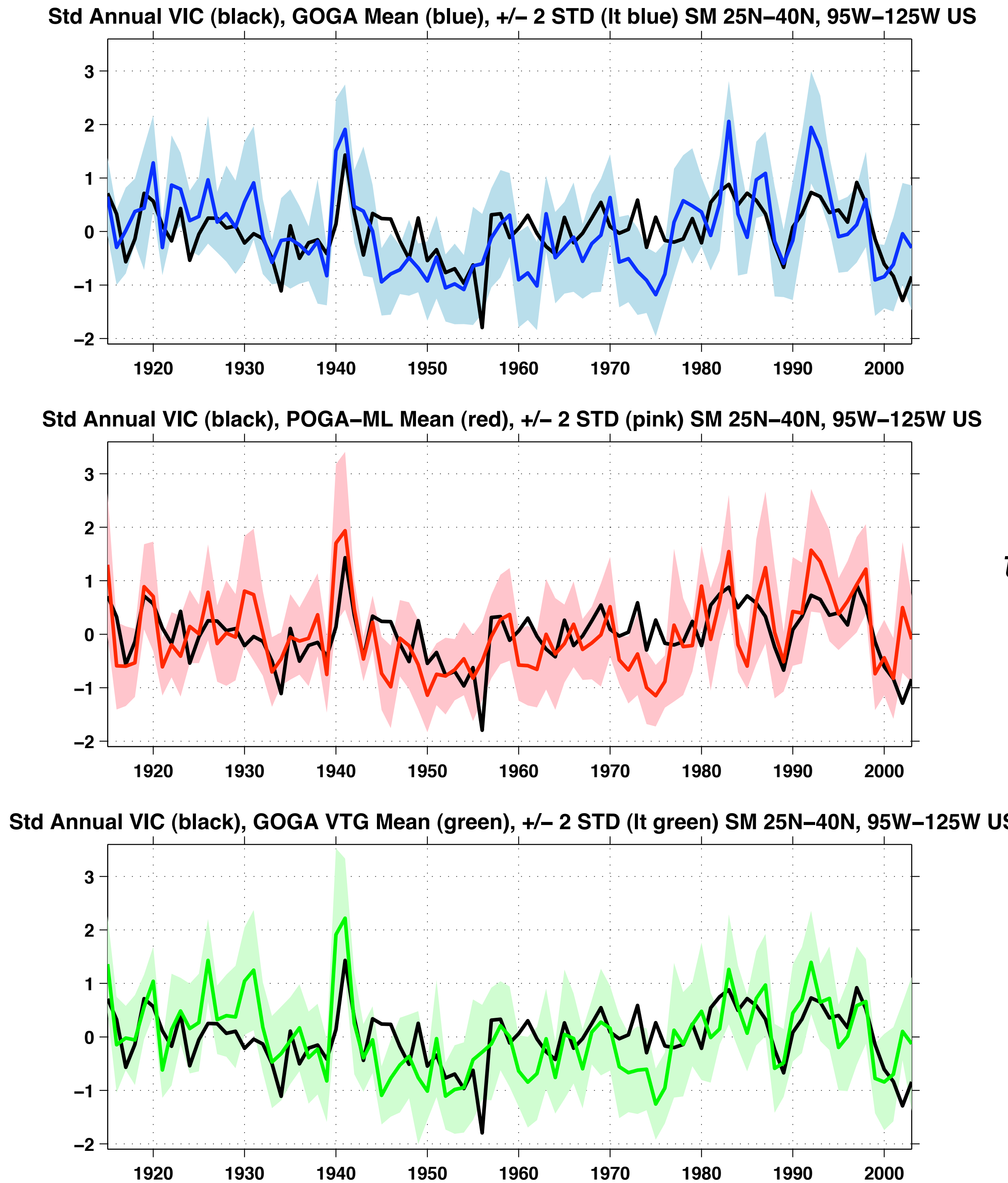
What are the relative roles of natural decadal variability and radiatively-forced change?

seasonal mean precipitation anomalies for *25-40N, 125-95W*, from GPCC rain gauge data



VIC and CCM3 simulations of soil moisture

Last century of soil moisture in SWNA dominated by tropical Pacific SST forcing. No immediately clear additional influence of rising GHGs.



global SST forcing

tropical Pacific SST forcing

global SST forcing plus variable trace gases

Try to distinguish between internal variability and forced change based on mechanisms. Begin with the atmospheric moisture budget equation:

$$\rho_w g(P - E) = -\int_0^{p_s} \left(\nabla \cdot (\bar{\mathbf{u}}\bar{q}) + \nabla \cdot (\overline{\mathbf{u}'\mathbf{q}'})\right) dp - q_s \mathbf{u_s} \cdot \nabla \mathbf{p_s}.$$

overbars indicate monthly means
primes departures from monthly means

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

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

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

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

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

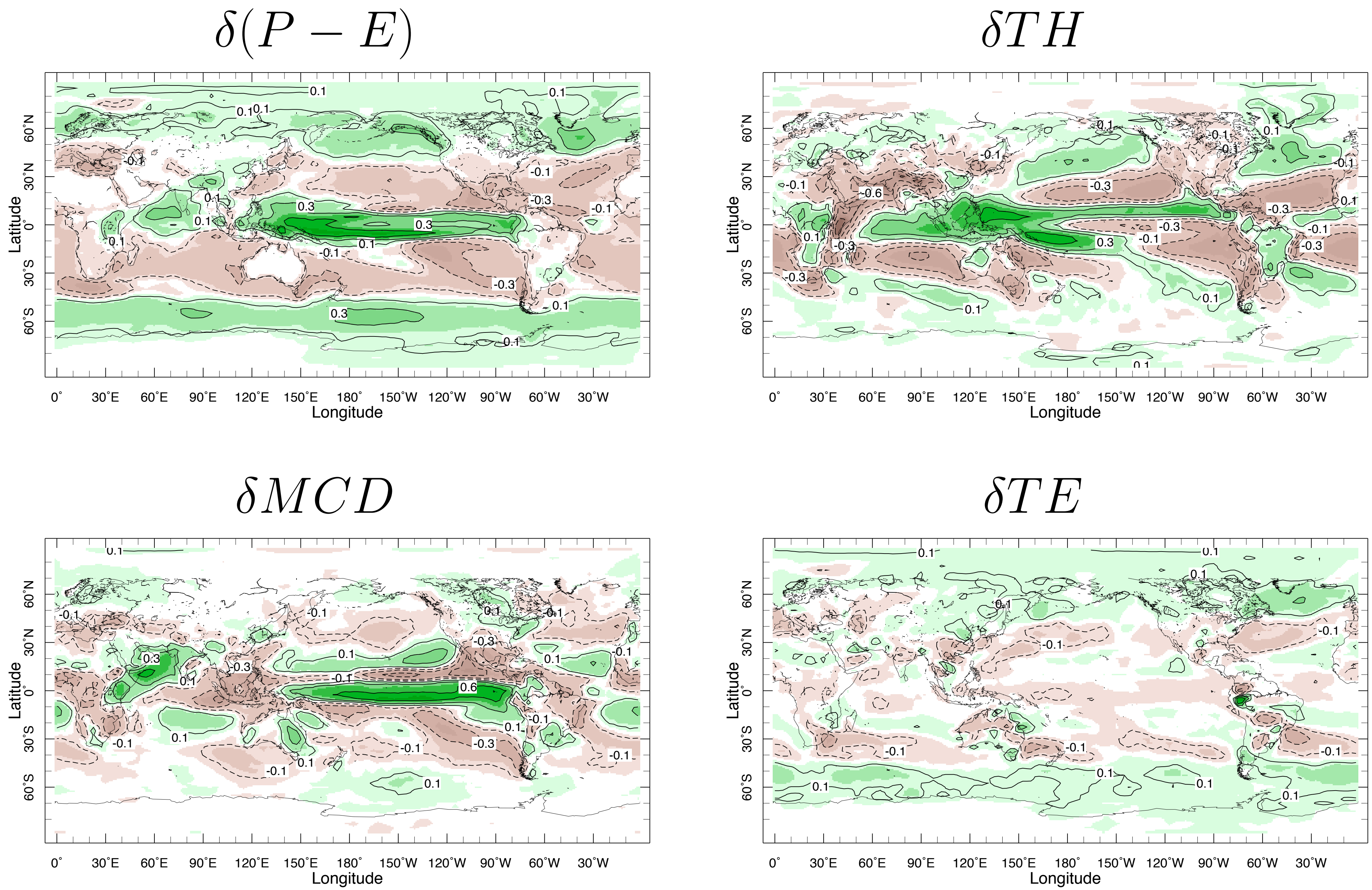
climate change: $\delta(\cdot) = (\cdot)_{21} - (\cdot)_{20},$

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

- 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.

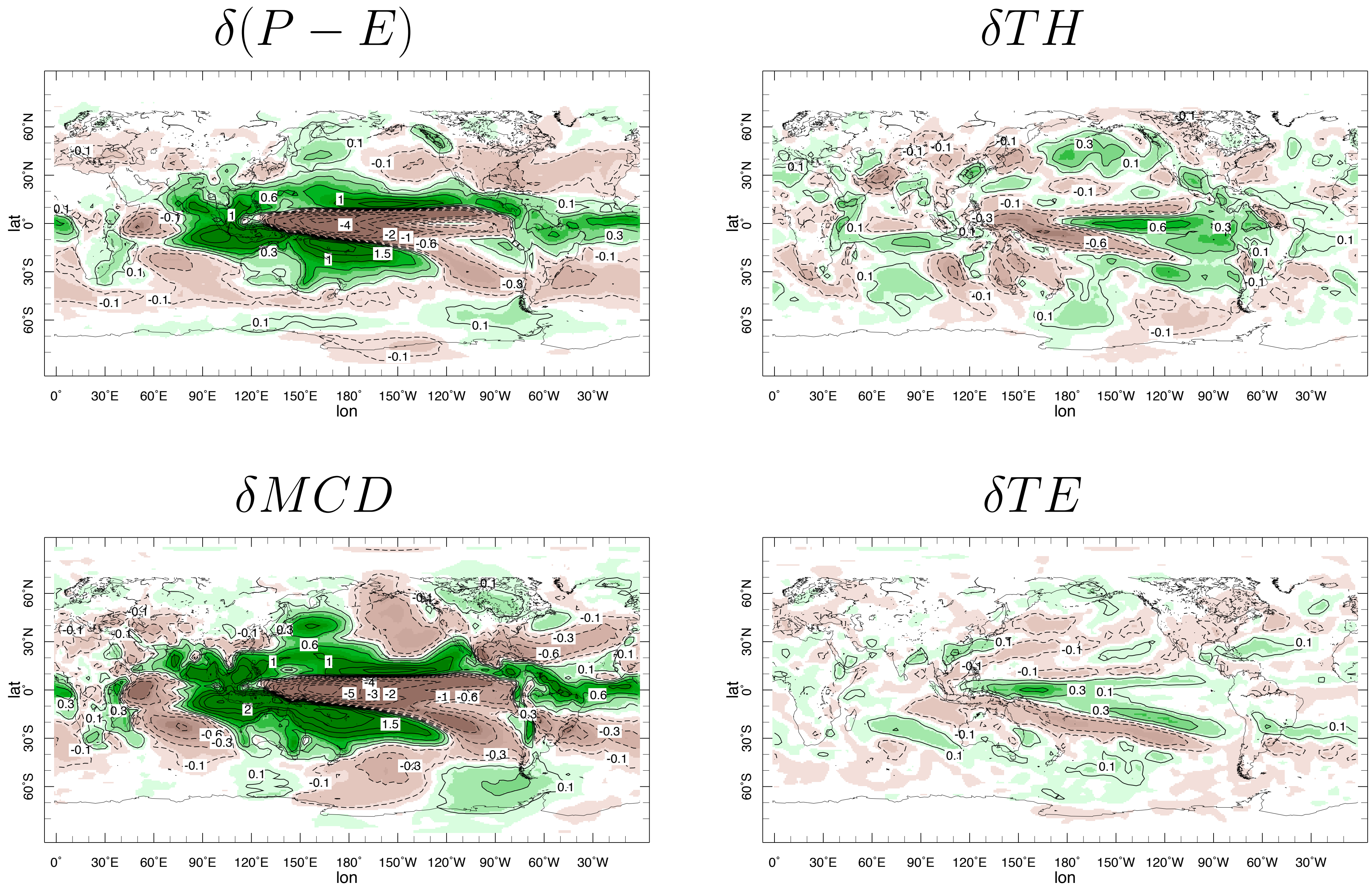
Ground truth is the Compo et al. (2010) 20th C Reanalysis (20CR) - SST-forced, surface pressure assimilating, free of spurious trends. Also an SST forced 16 member CCM3 ensemble.

MMM - Climate Change



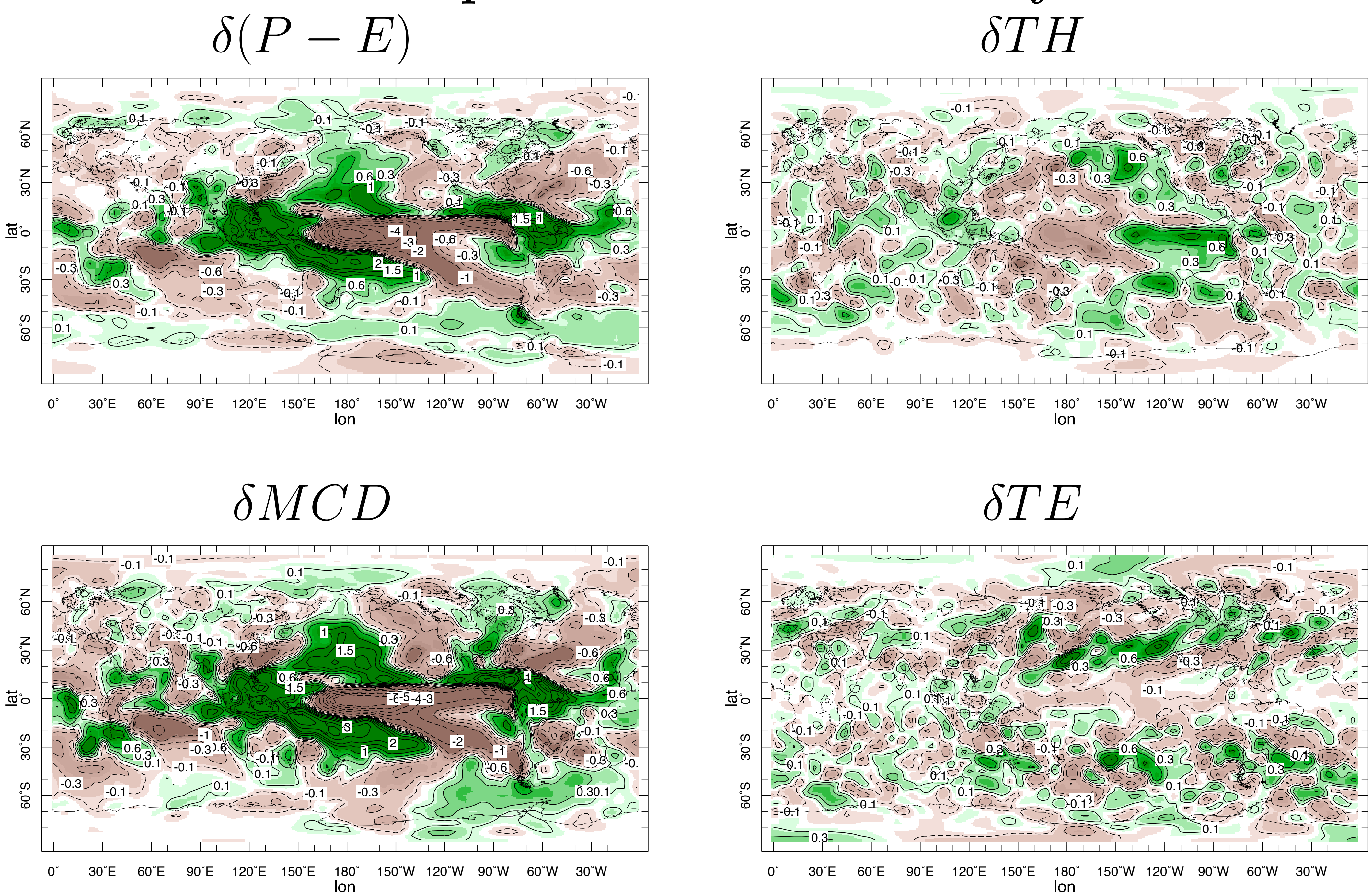
Tropical wetting, subtropical drying strongly influenced by rising *q* and intensified moisture convergence and divergence. Mean circulation change - weaker tropical circulation, Hadley Cell expansion - also important as well as TE intensification and poleward shift. ***'Thermodynamics mediated.'***

MMM - Natural Variability



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

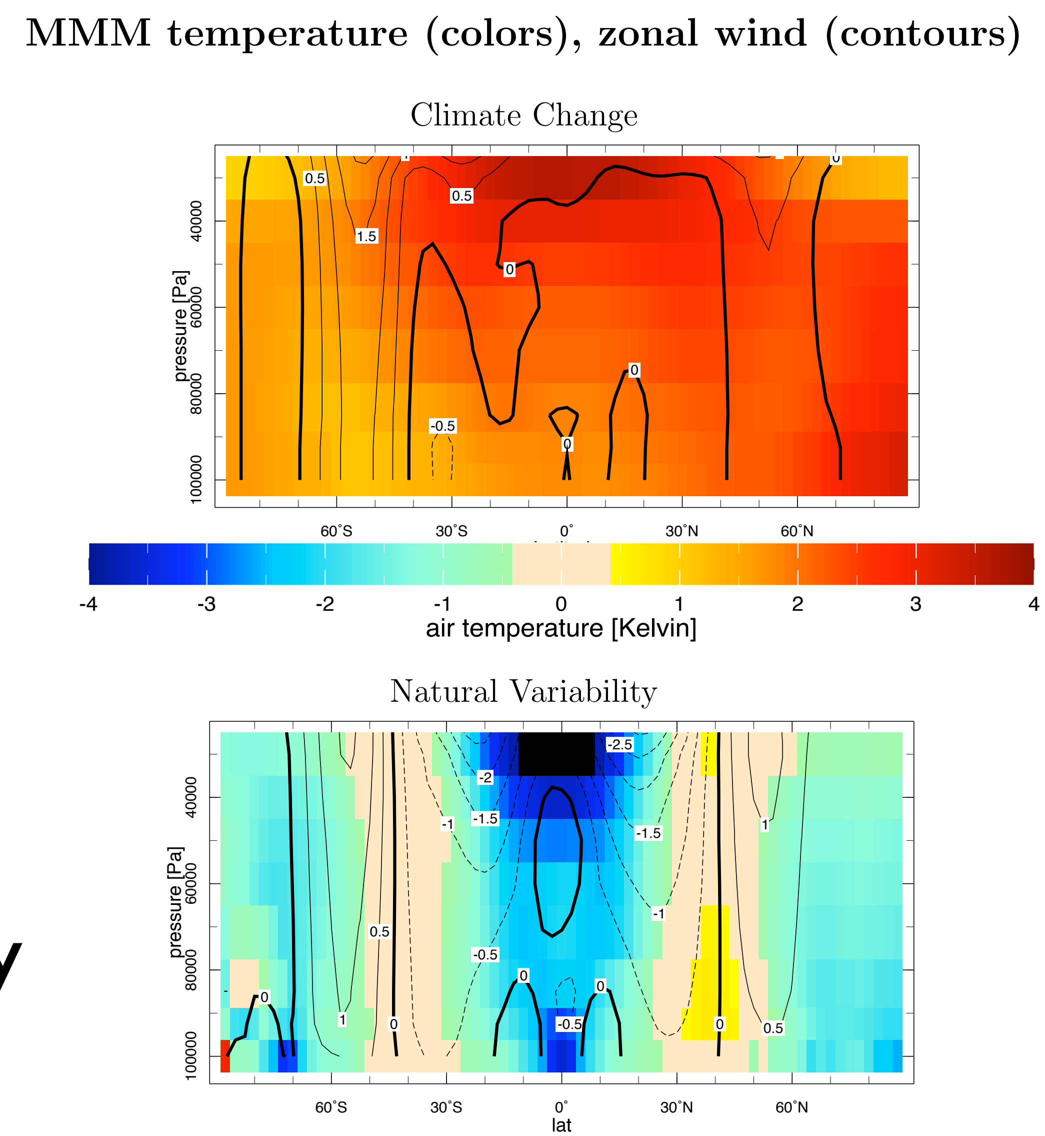
Compo - Natural Variability



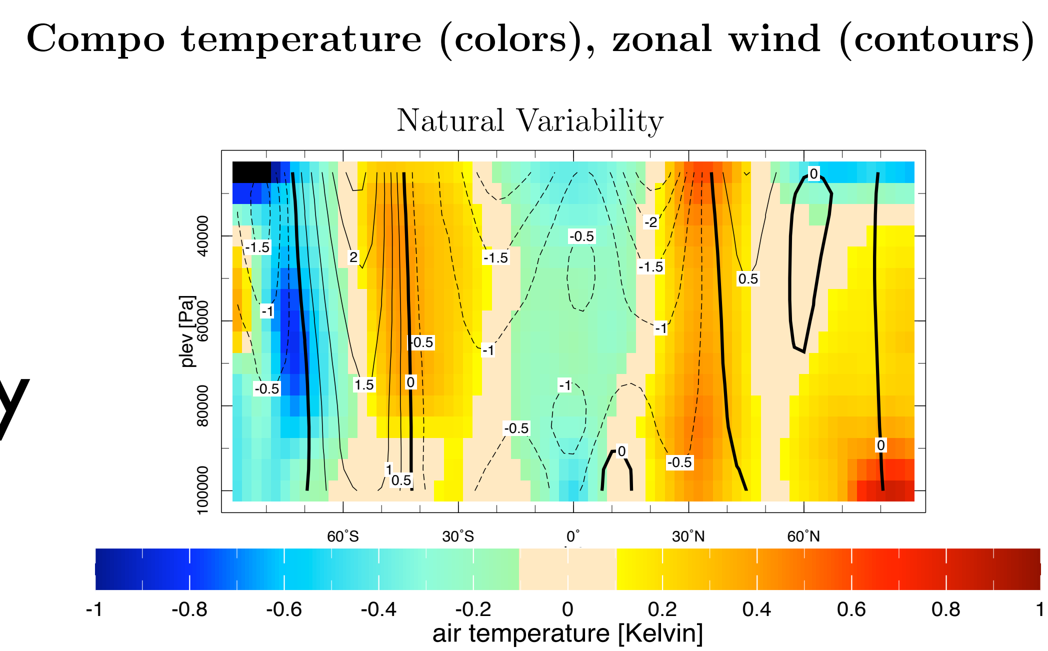
IPCC AR4 mechanisms of internal P-E variability are remarkably similar to observed.

Both climate change and La Nina have poleward shifted jets but distinctly different in the tropics with subtropical easterly anomalies for La Nina,

AR4 variability



20CR variability

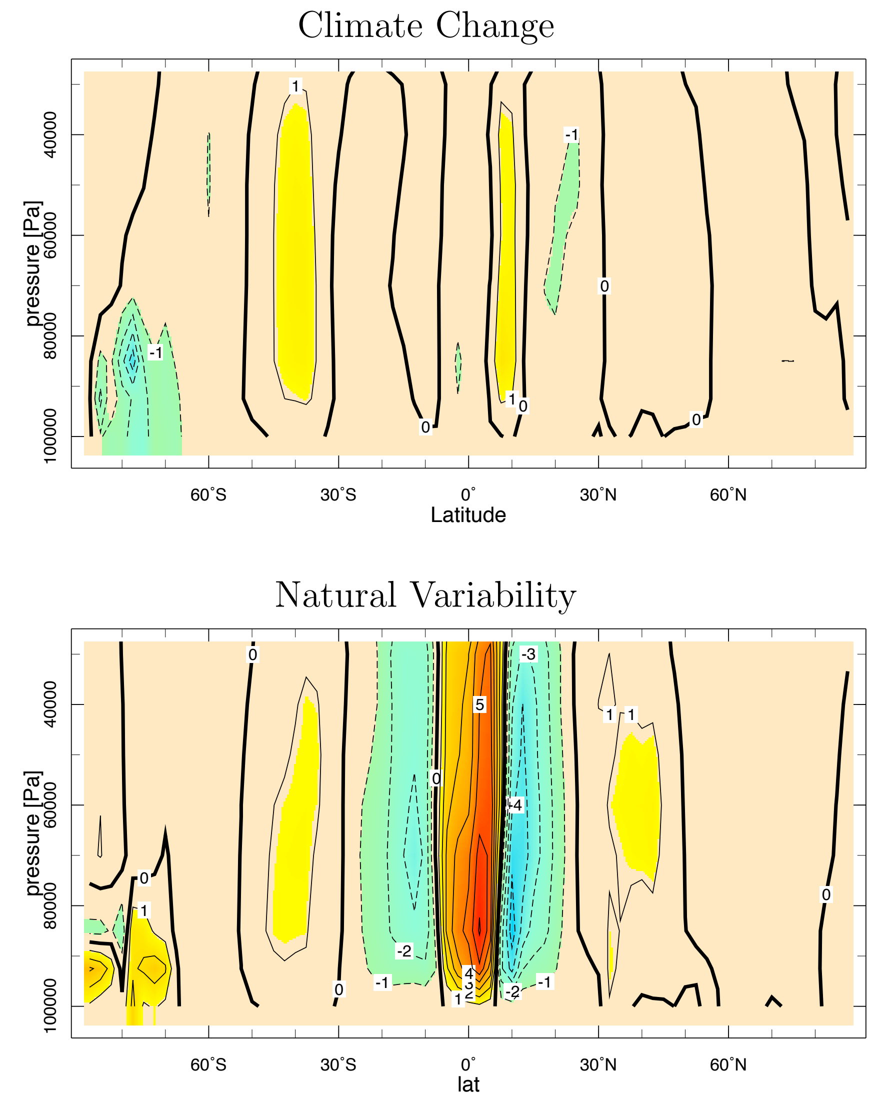


Similarly, both climate change and La Nina have subtropical-to-midlatitude descent (drying) but tropical changes are almost opposite

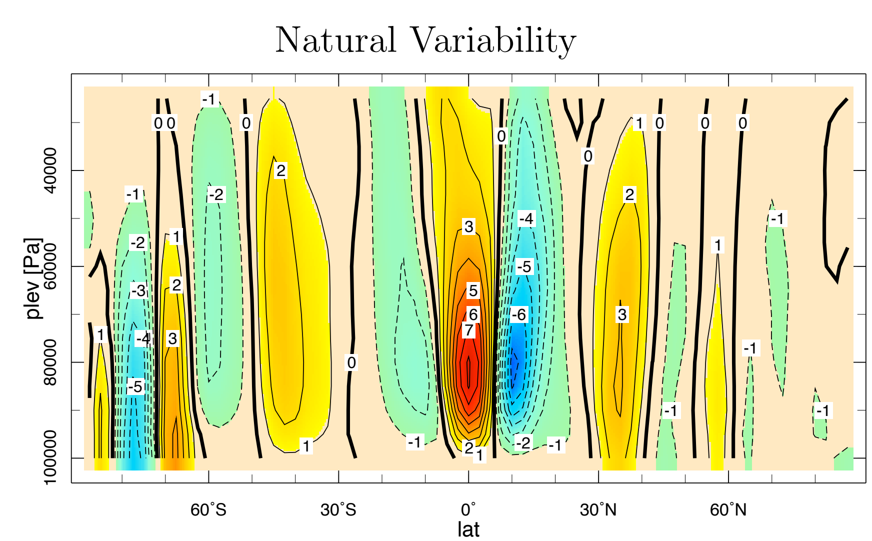
AR4 variability

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:

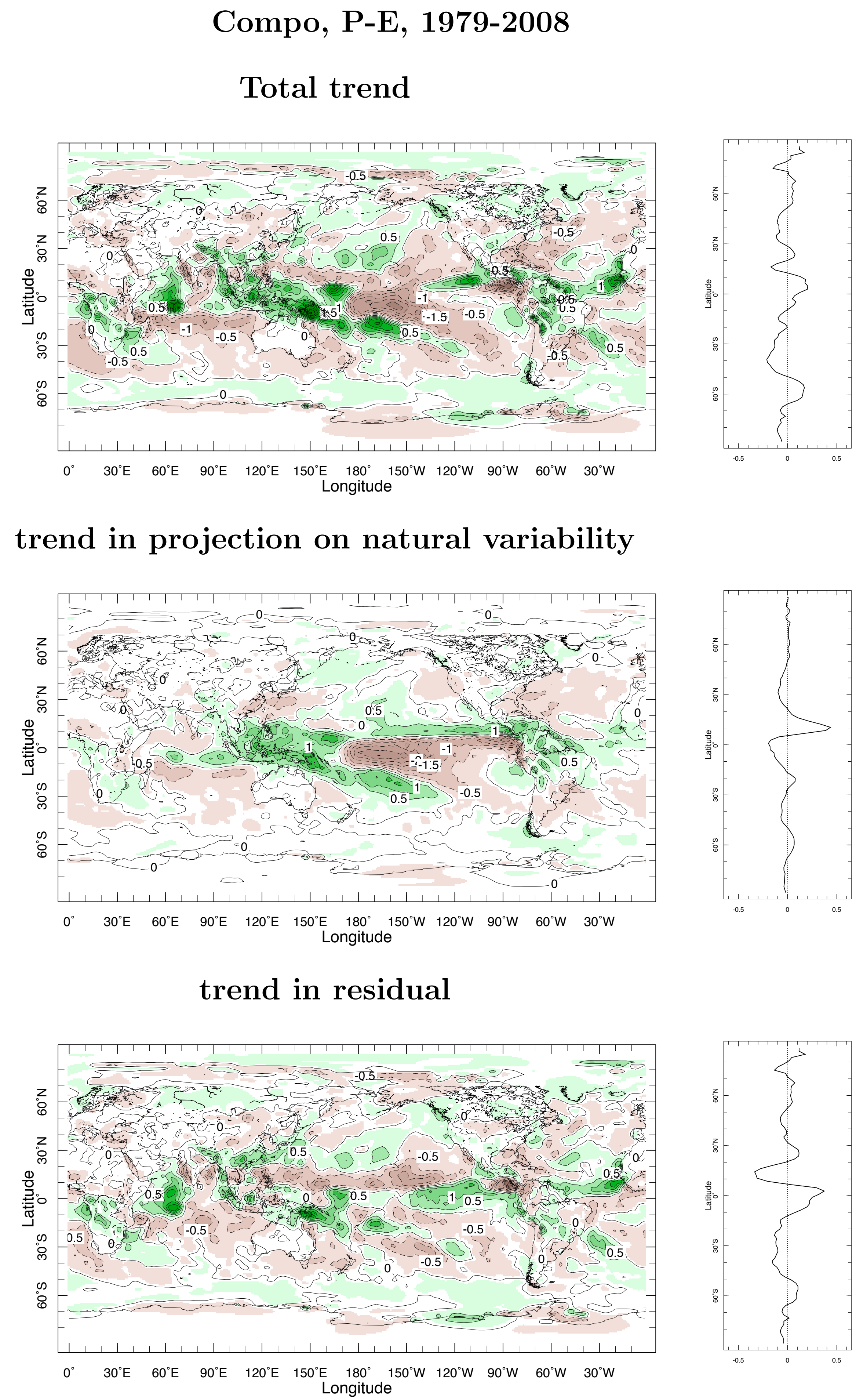
$$P - E = \sum_{n=1}^{2} a_n(t) \left(TH_n + MCD_n + TE_n \right) + TH_R + MCD_R + TE_R,$$

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

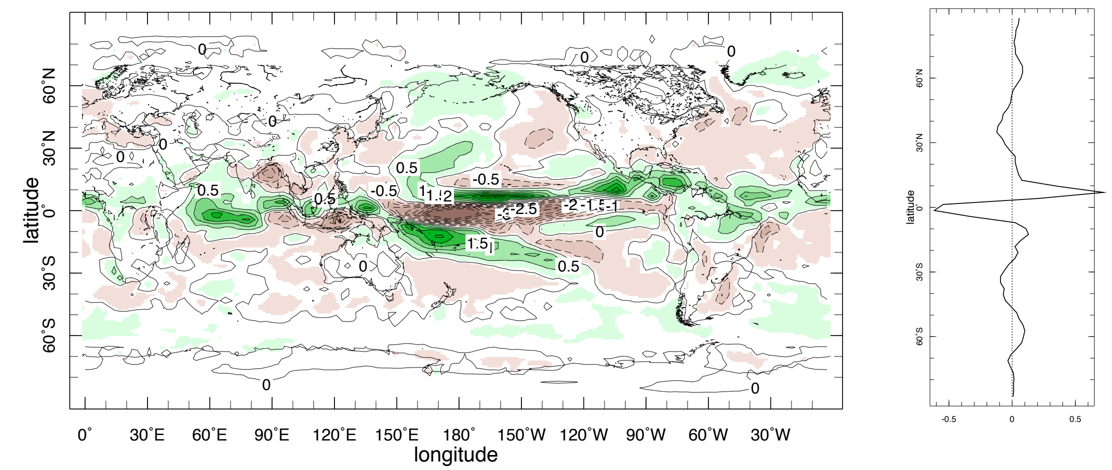
The residual trend, with equatorial wetting, and subtropical-to-midlatitude drying has some GHG-driven character



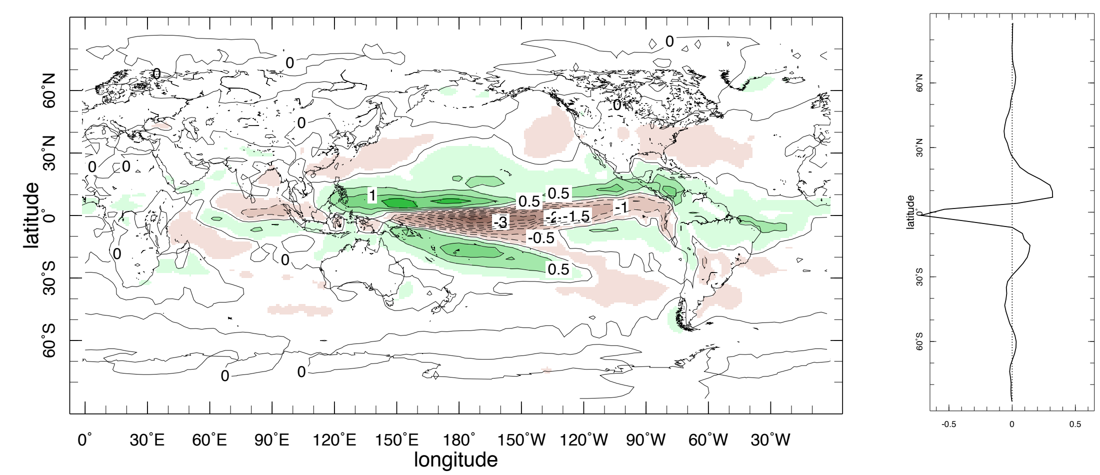
Very similar results as from 20CR appear in the purely SST-forced GCM ensemble mean - residual trends akin to AR4 post-1979 trends

GOGA, P-E

Total trend

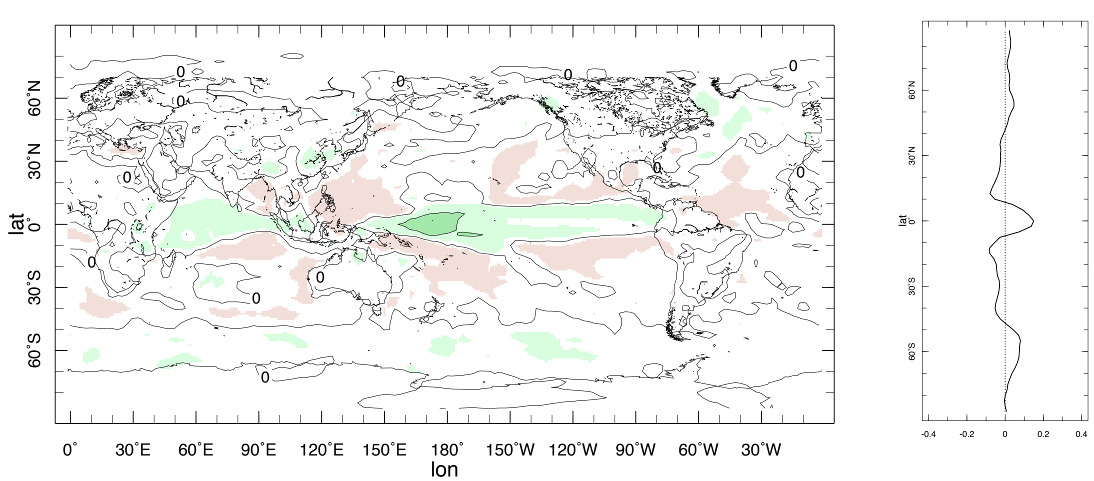


trend in projection on natural variability

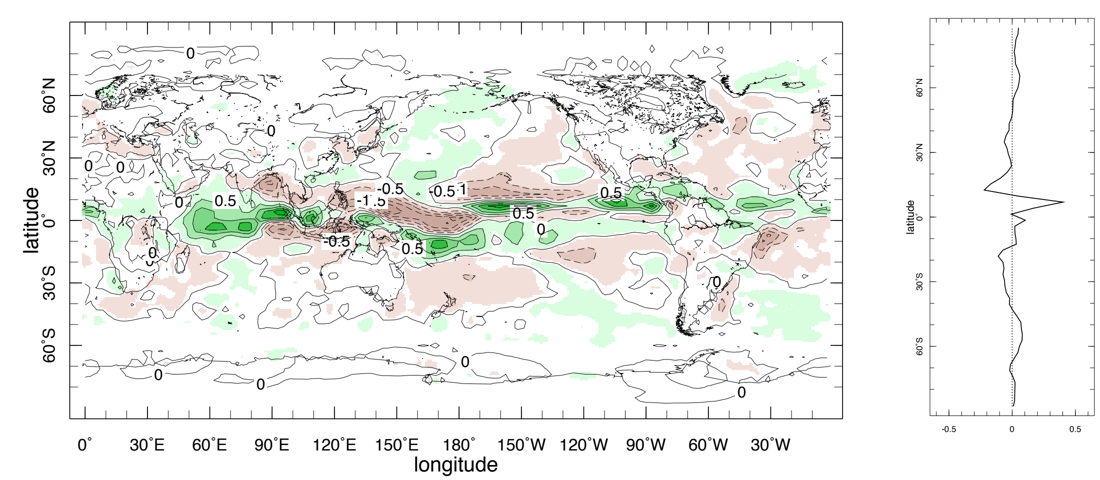


MMM, P-E

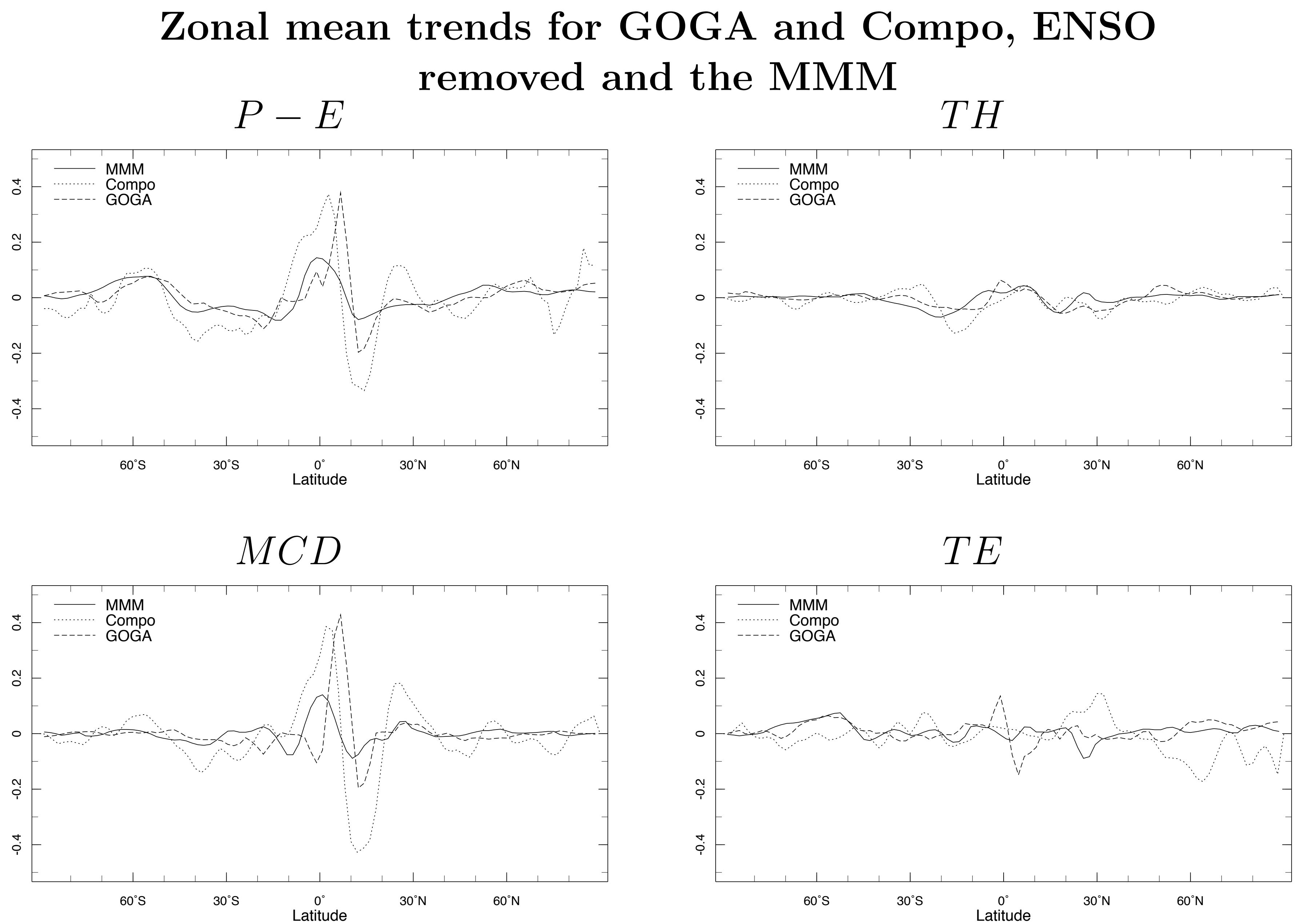
Total trend



trend in residual



How do mechanisms of AR4 and residual trend compare?



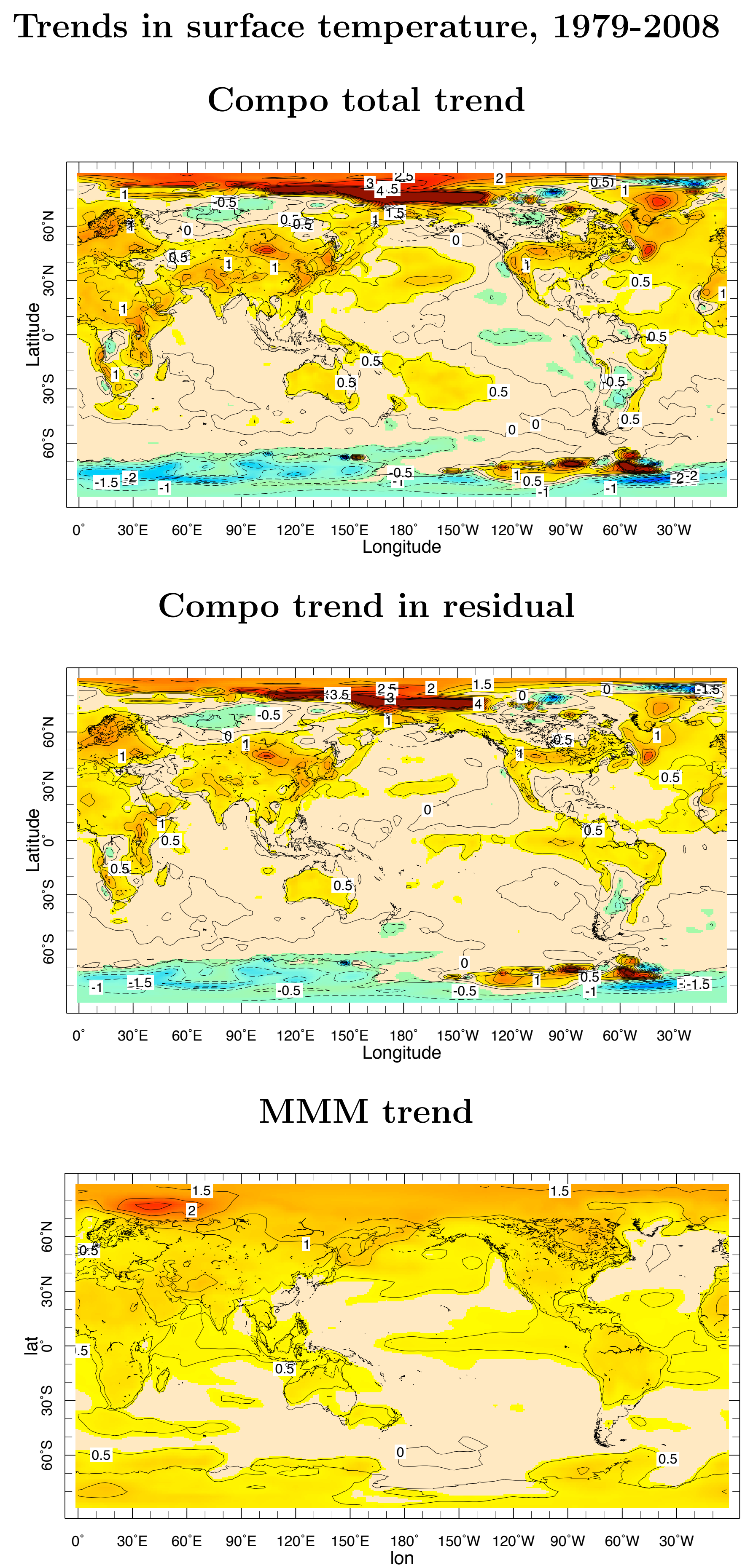
P-E trends largely agree in structure and amplitude, agreement on MCD importance in tropics, TH contribution to wet-get-wetter, dry-get-drier. All modest for 1979 to now, as expected.

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

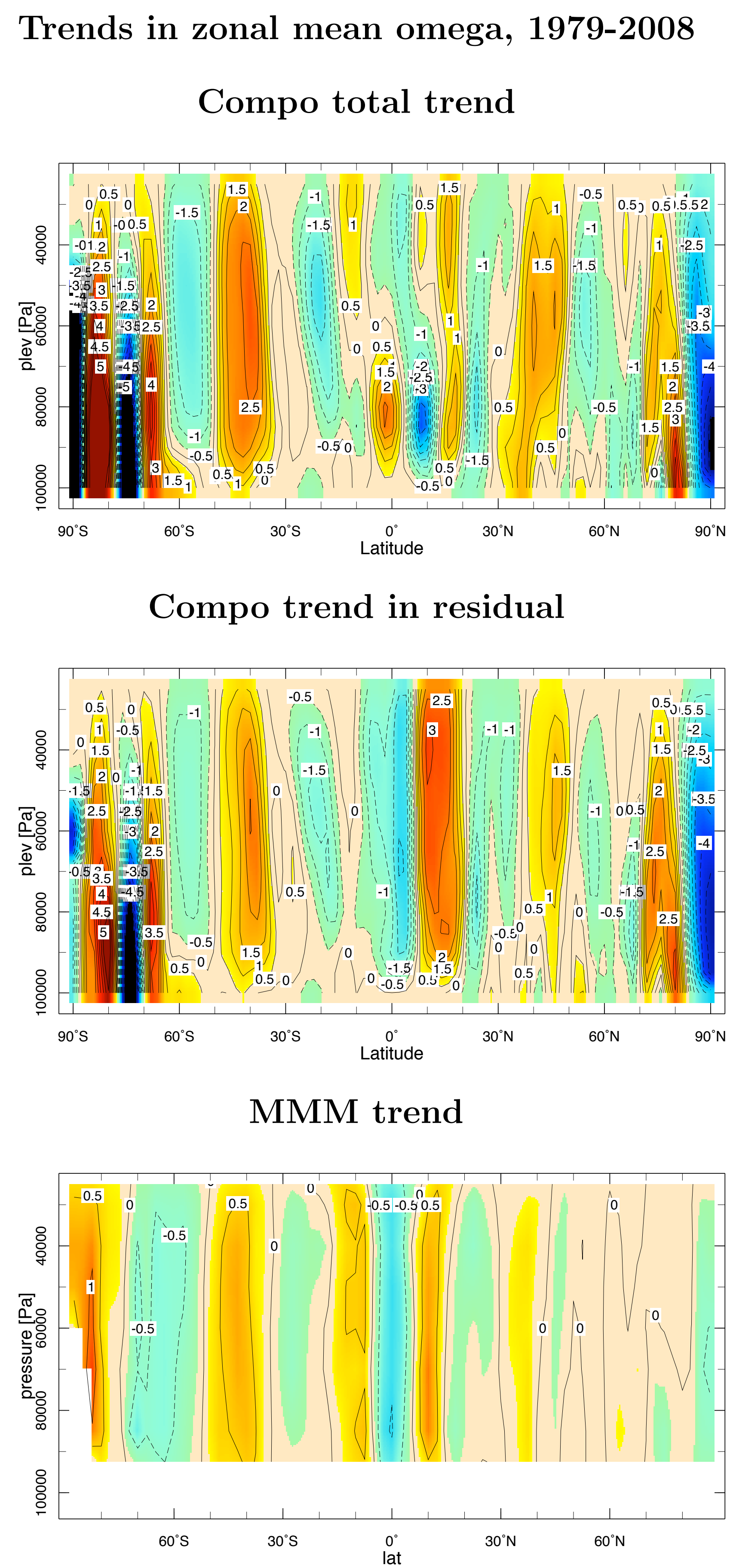
actual trend

residual trend

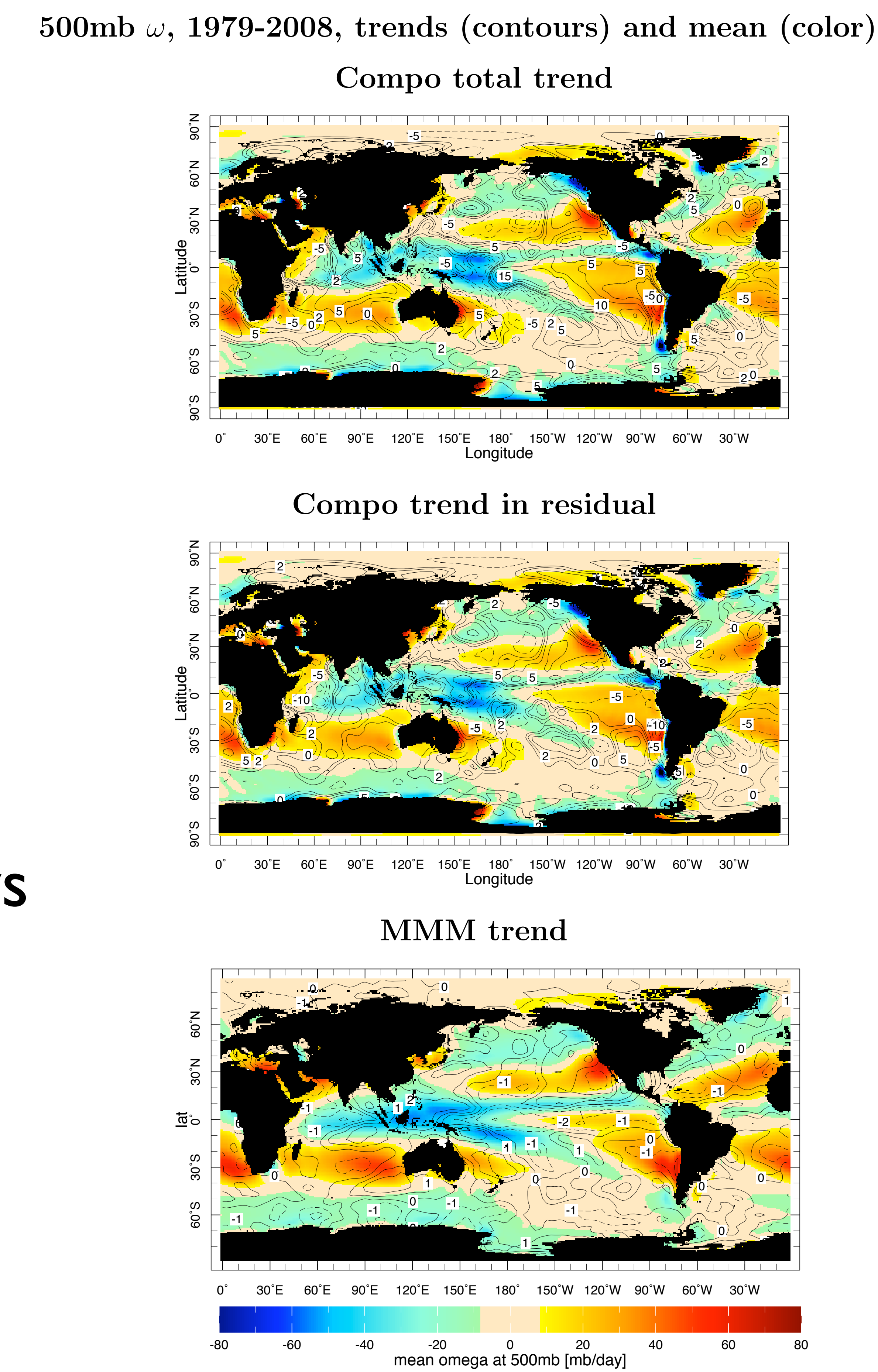
AR4 trend



For vertical velocity the residual shows weakening tropical circulation and SH subtropical-midlatitude descent, not so clear in NH, all much like AR4.

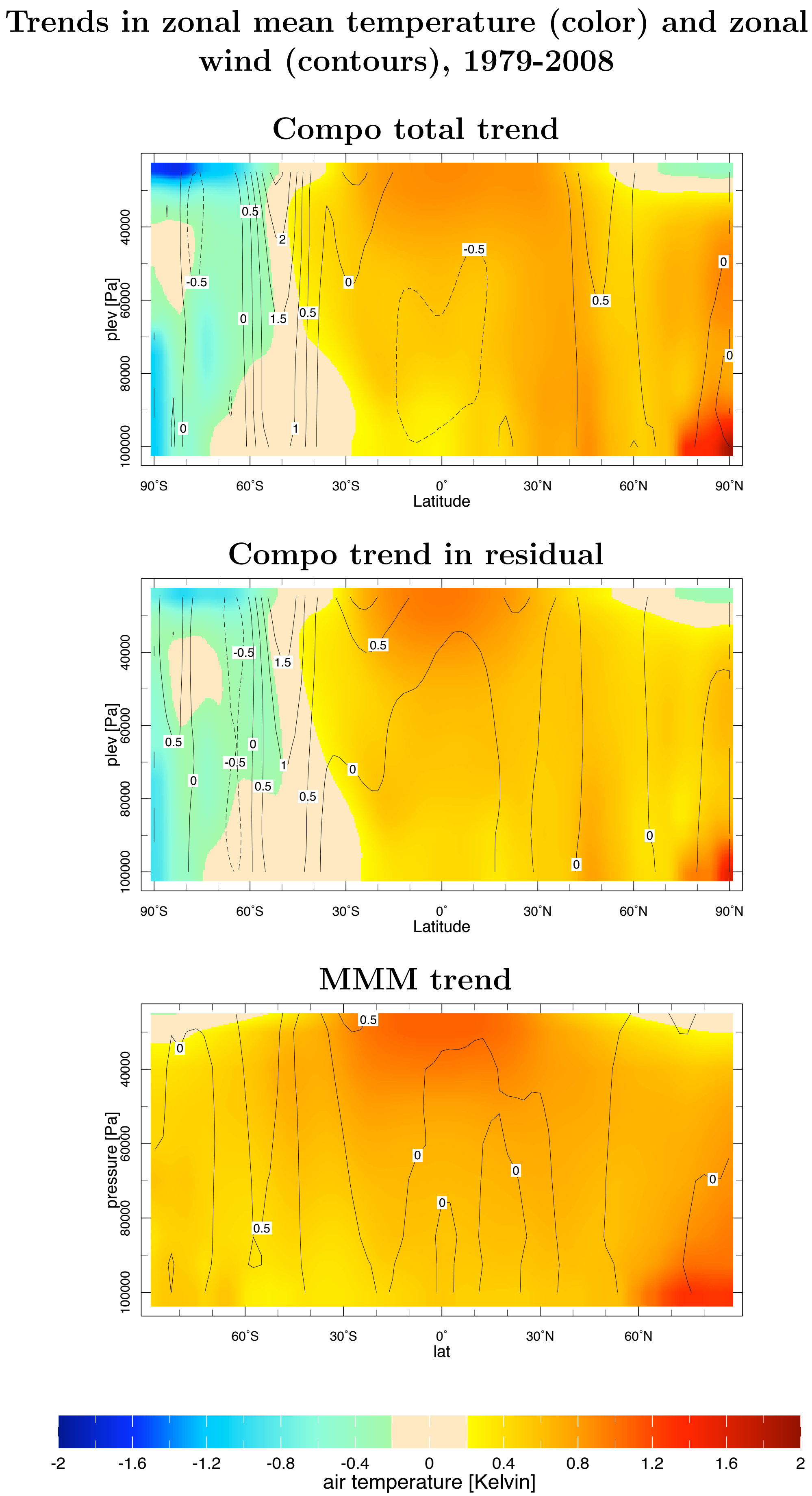


Actual 500mb omega trend is La Nina-like - ascent over warm pool, descent over eastern tropical Pacific.



But, the residual trend shows weakening of the tropical circulation, as in AR4

Same game applied to zonal mean u and T shows much of poleward jet strengthening is natural variability but residual trend broadly consistent with AR4. (Antarctica region?)



Conclusions

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

This distinction can be used to develop 'dynamical early warning systems' for anthropogenic change.

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.

Amounts to 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.