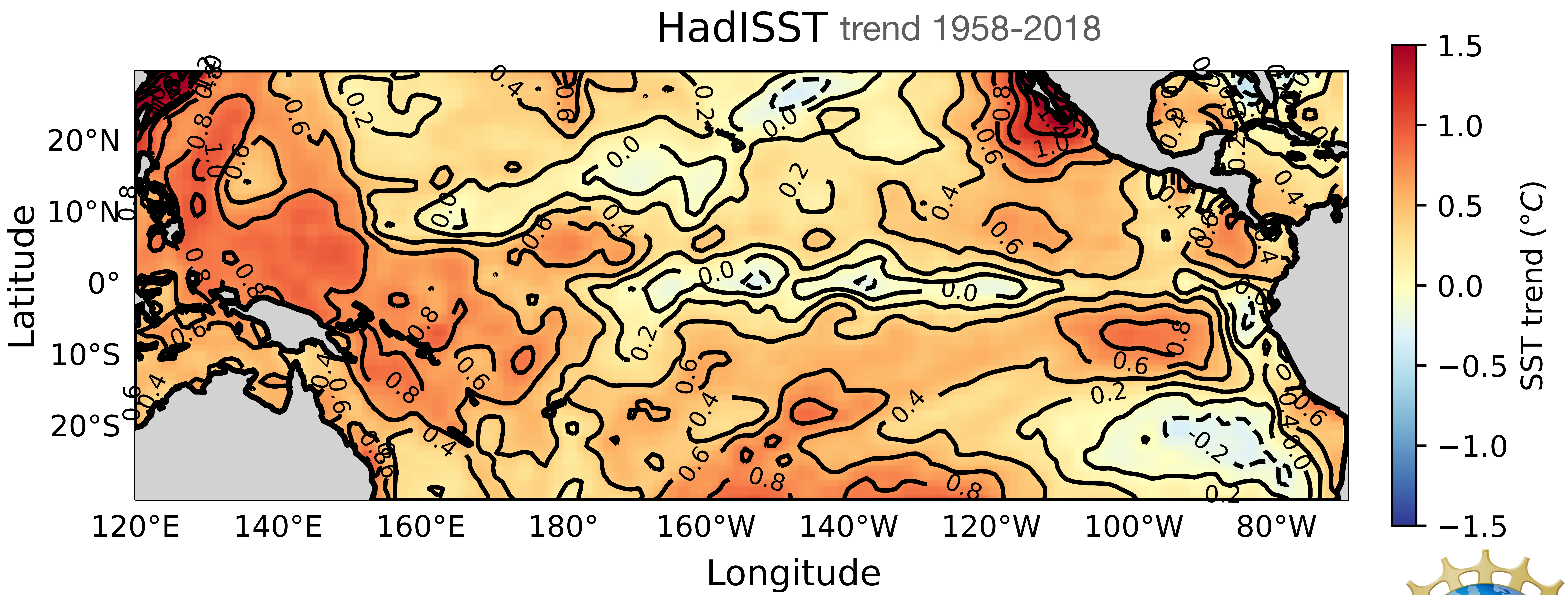
Tropical Pacific zonal SST gradient trends: biases and mechanisms



Richard Seager, Naomi Henderson and Mark Cane
Lamont Doherty Earth Observatory of Columbia University, Palisades, NY

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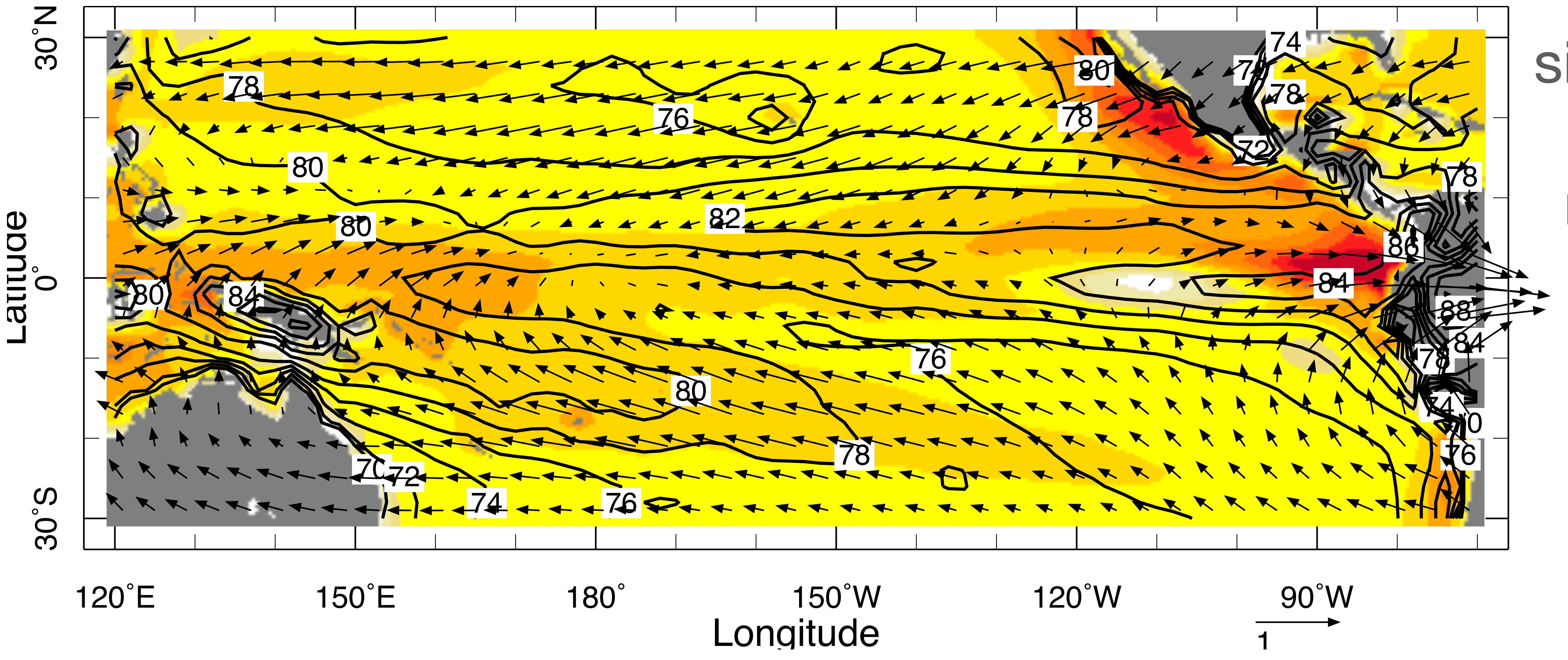
Seager et al. (2019) argued the observed trend was the forced response to rising GHGs and CMIP5 models get this wrong due to tropical Pacific mean state biases

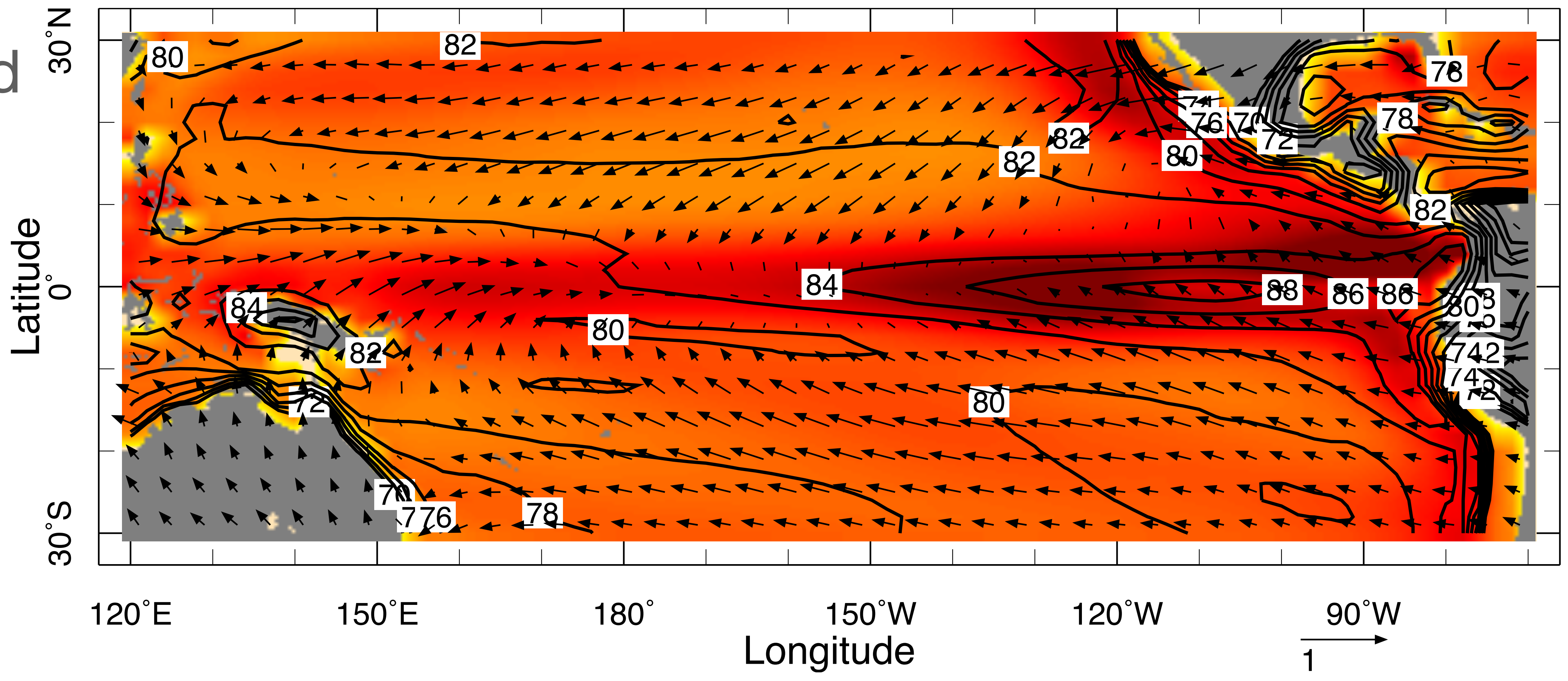
SST trend(colors), 10m wind trend(vectors) and climatological relative humidity(contours)

a) CM-ECMWF world

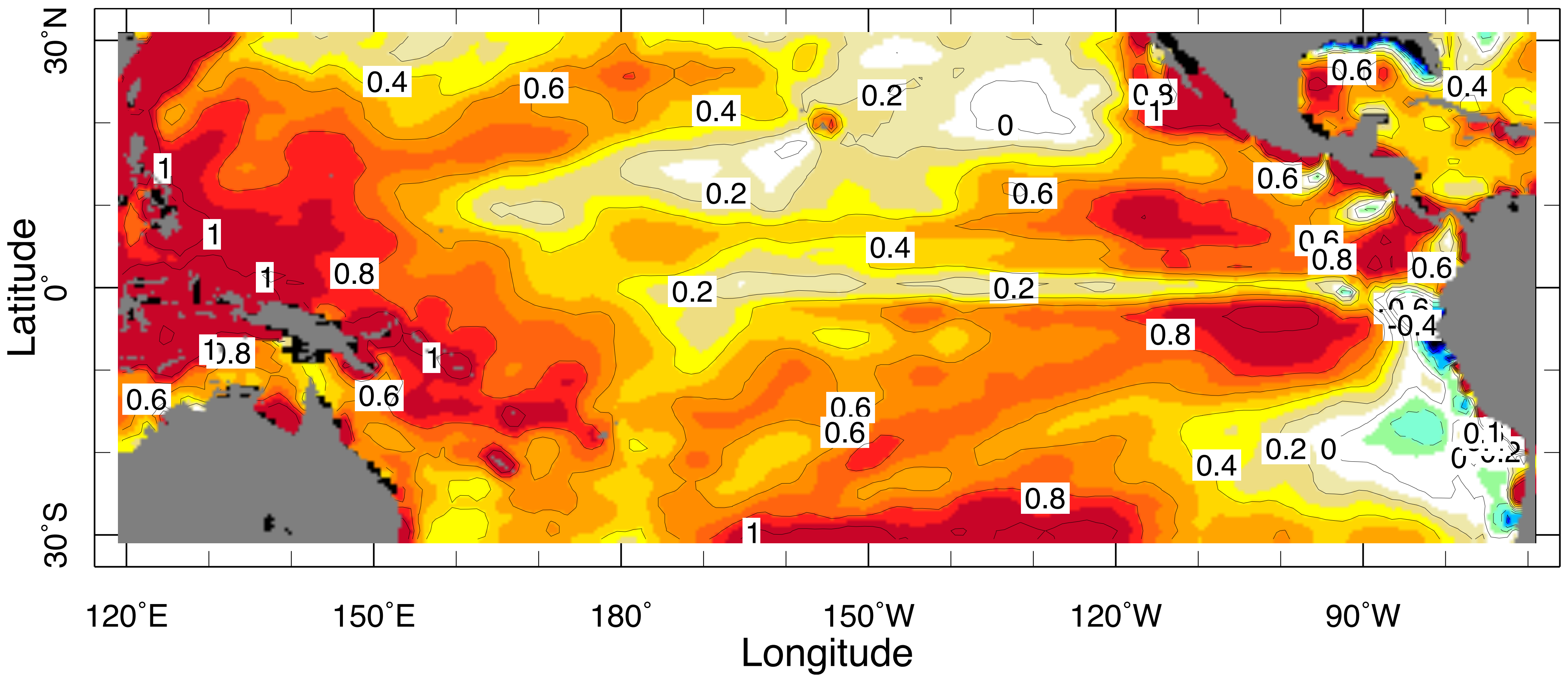


simple coupled model responses to rising GHGs

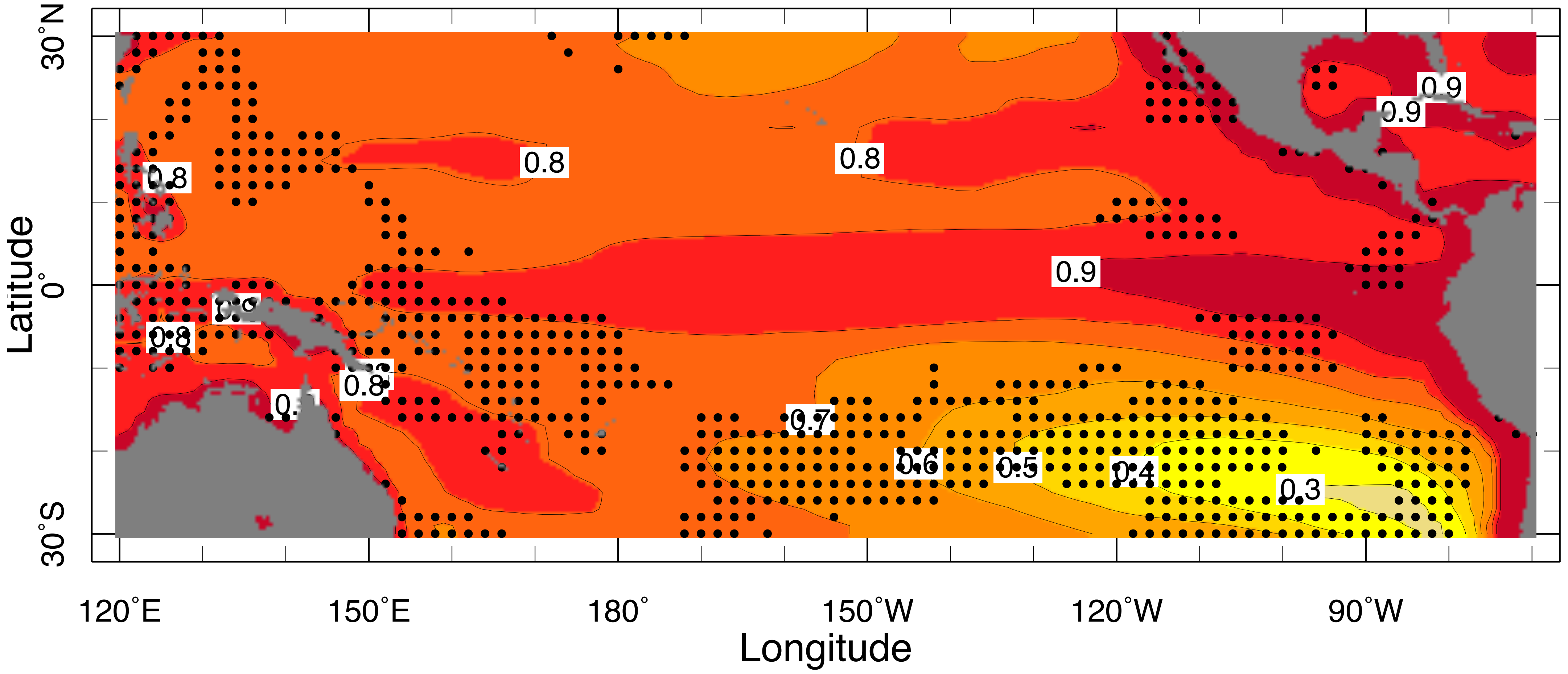
d) CM-CMIP5 world



a) ECMWF/ORAs4

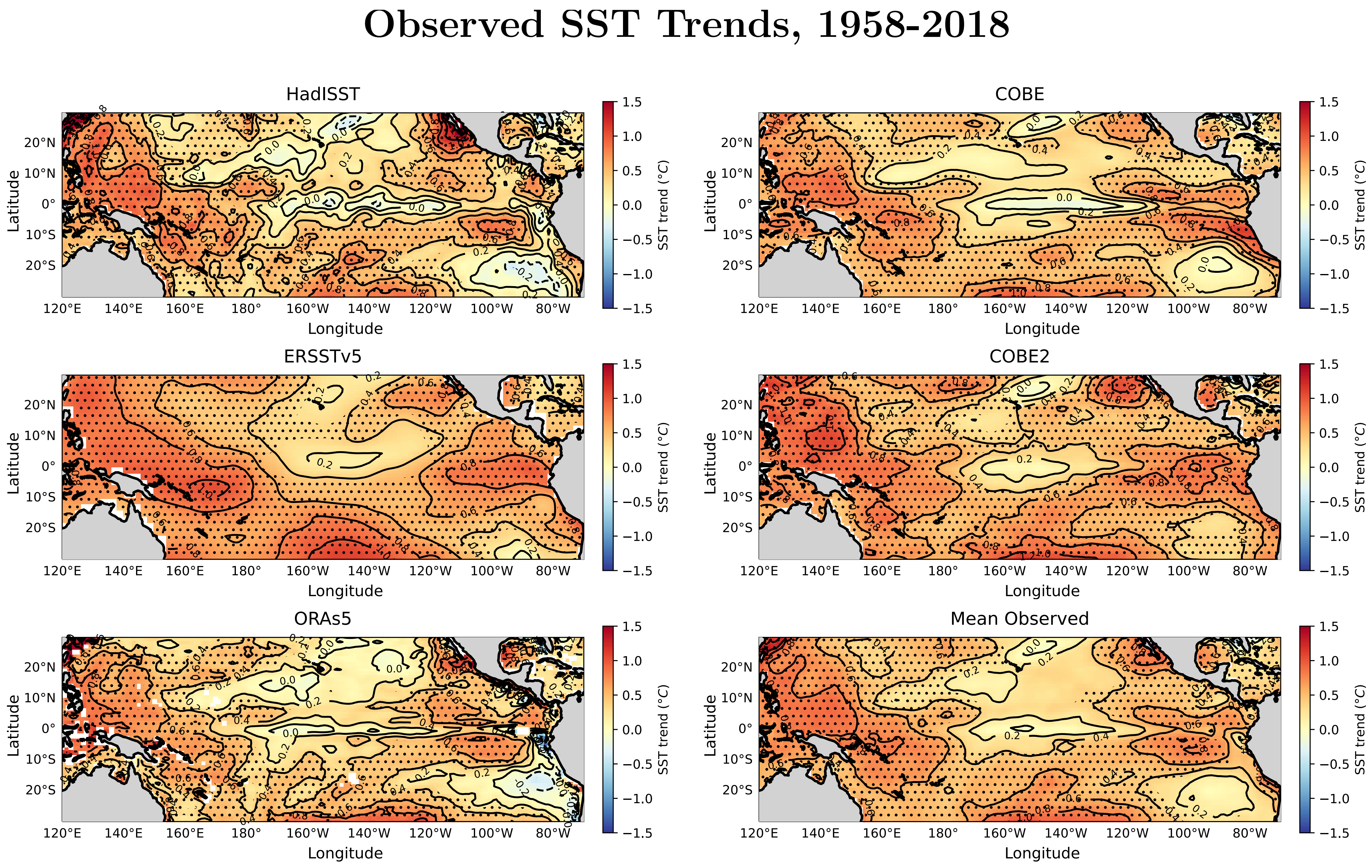


c) CMIP5: historical + RCP8.5

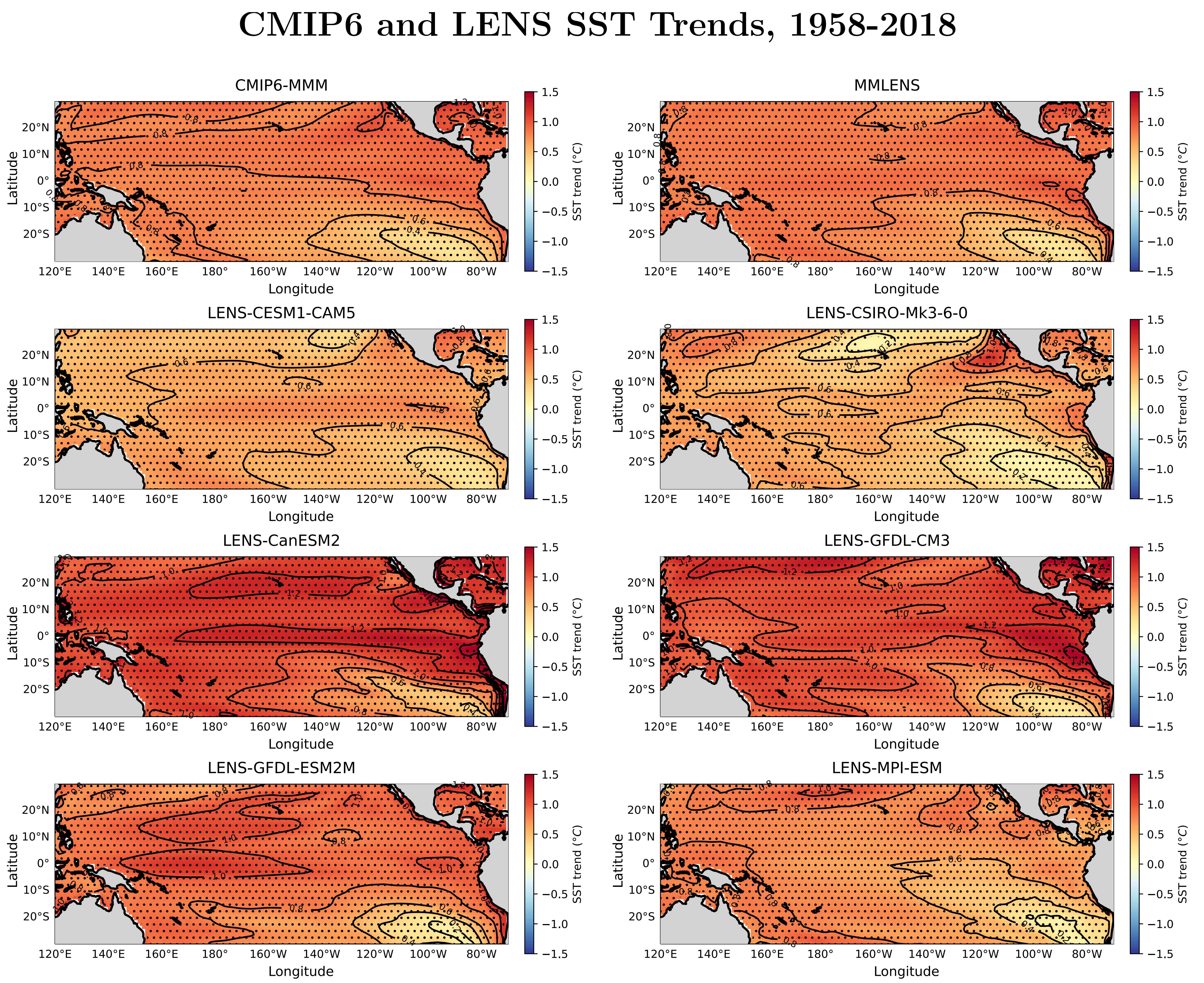


Watanabe et al. (2020) and Olonscheck et al. (2020) argued instead that the observed trend is unlikely but due to natural variability

Observed and CMIP6 and Large Ensemble SST trends over past 60 years



In 5 SST datasets and their average there is a lack of cold tongue warming. This has been seen back to Cane et al. (1997) for the 1900-1993 period.



In contrast, CMIP6 and Large Ensembles have cold tongue warming

Observed, CMIP6 and LENS SST Trend Indices, 1958-2018

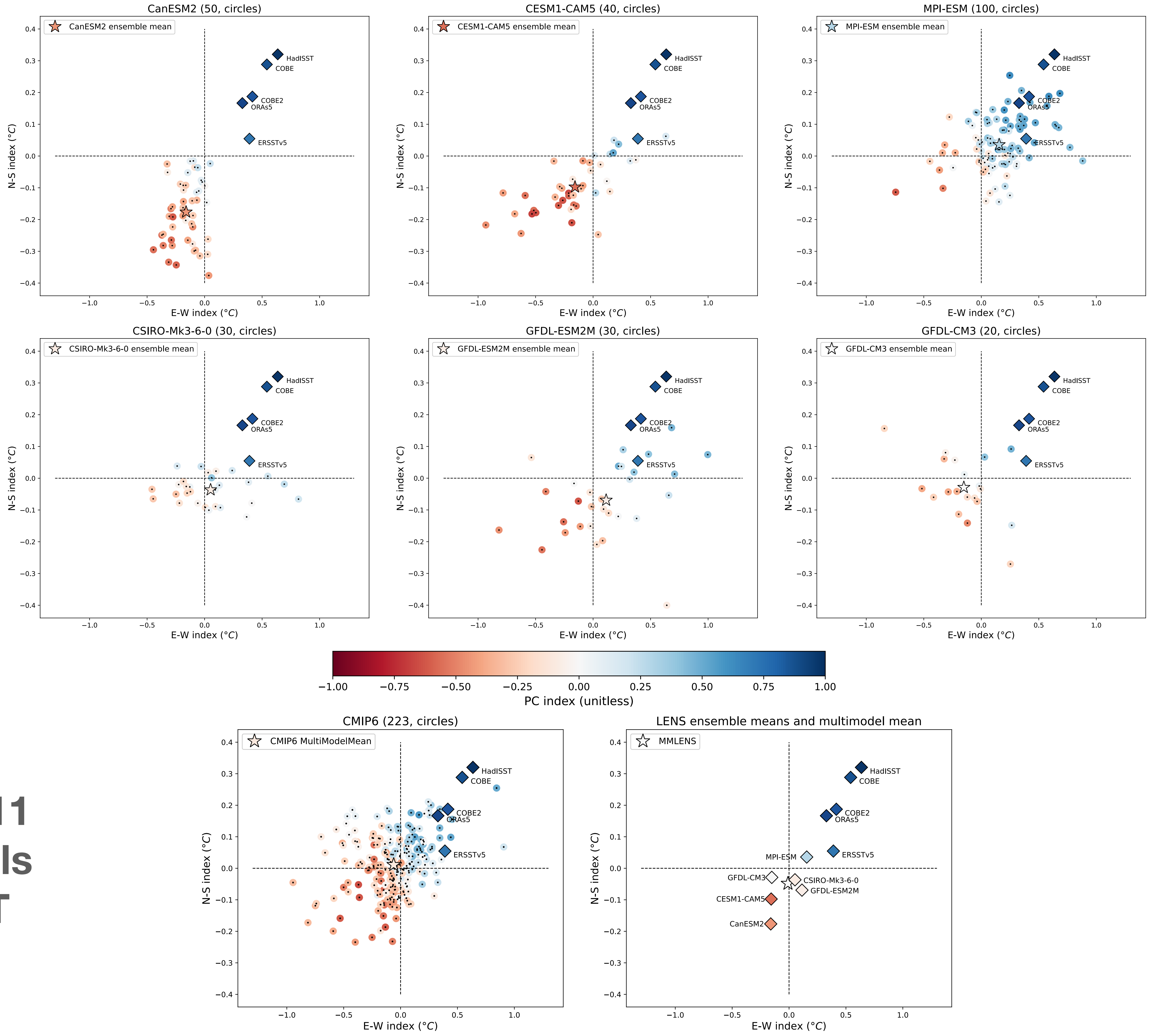
The observed SST trend is characterized by:

An enhanced west-east SST gradient (x-axis)

An enhanced cooling of the cold tongue w.r.t. waters immediately to the north and south (y-axis)

Also measure model trends with a pattern correlation to HadISST observed (color)

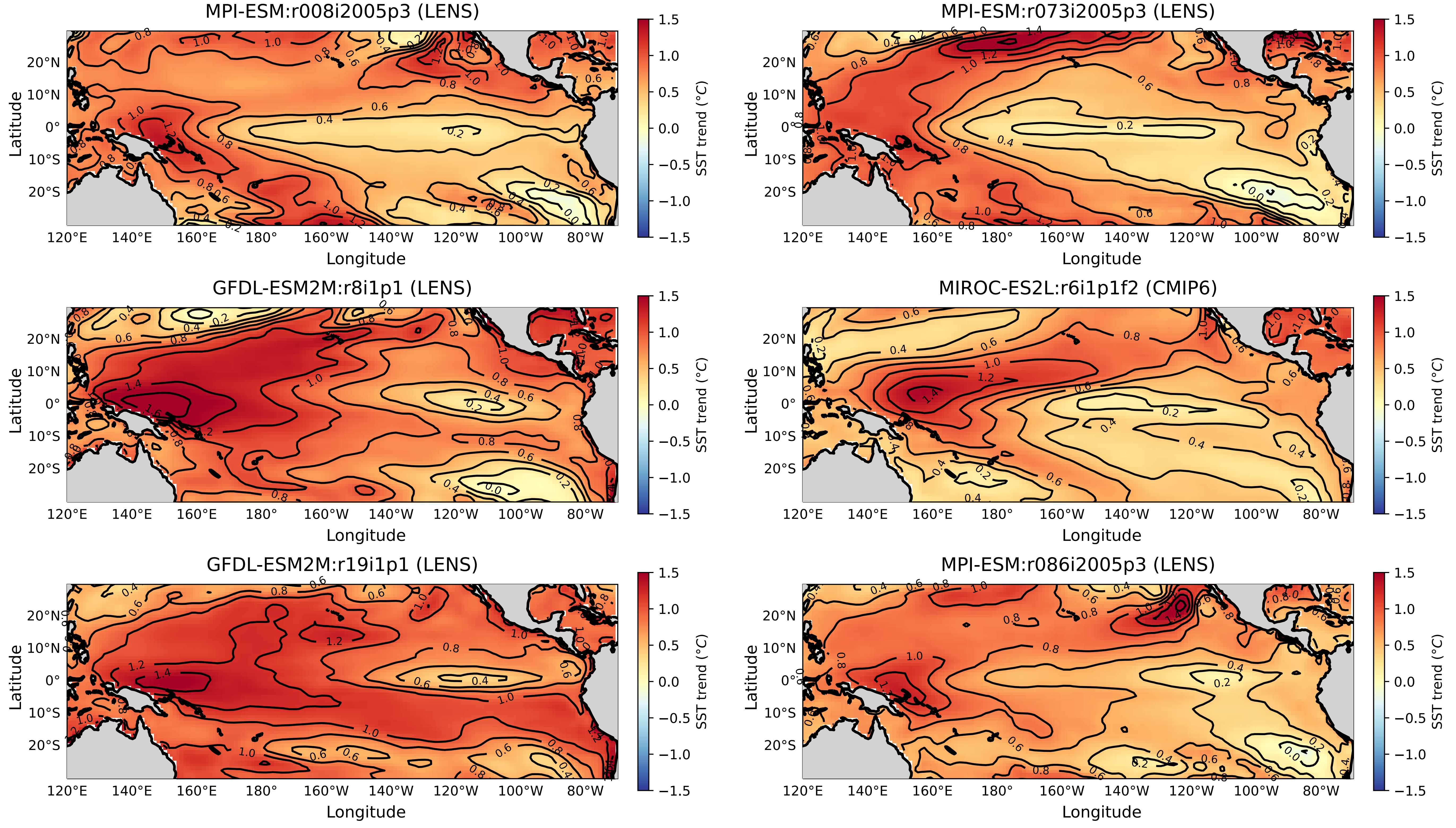
There is almost no overlap between 511 runs from 45 CMIP6 and 6 LENS models and the observed tropical Pacific SST trends



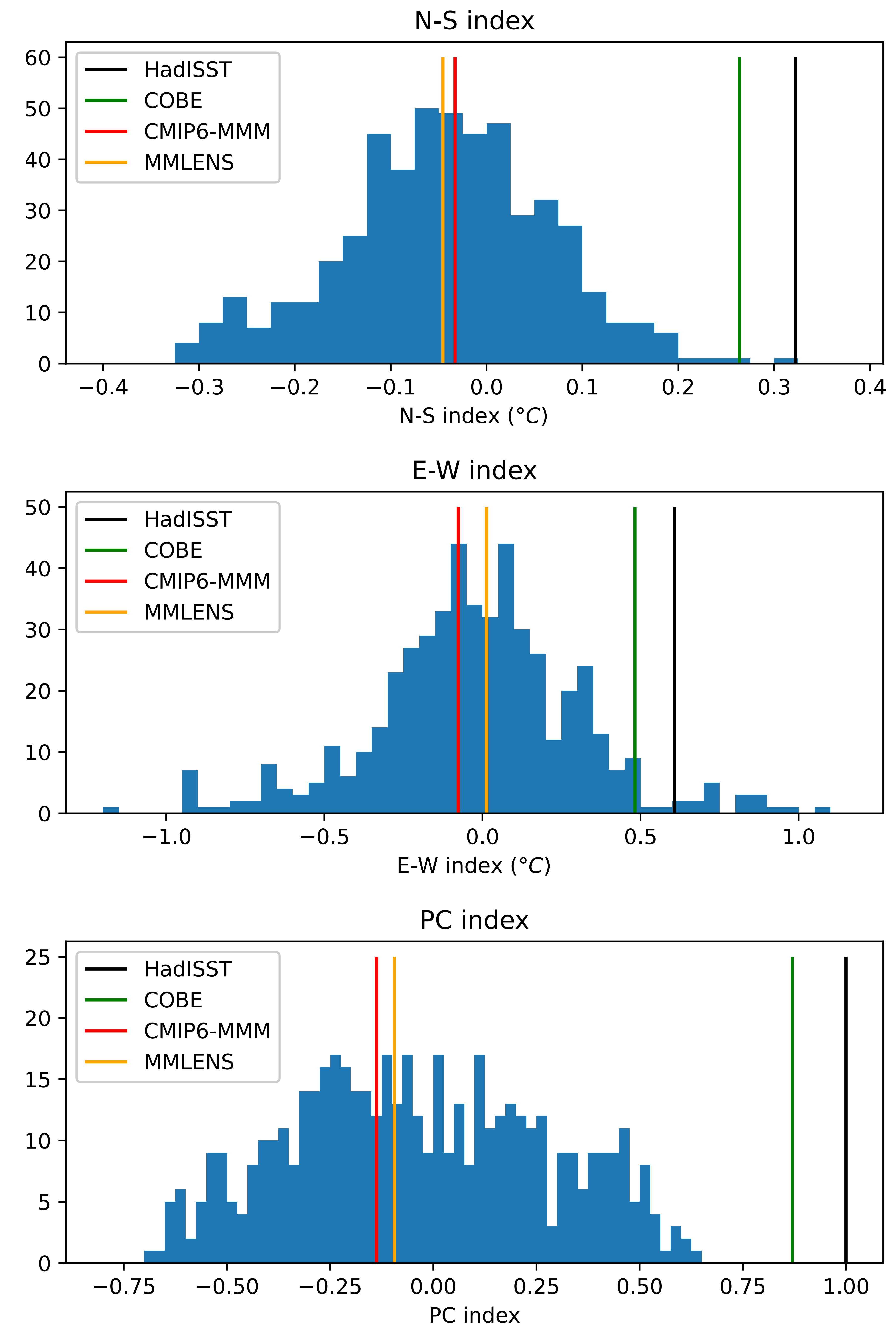
Could the observed trend be explained by natural variability?

Only a handful of 511 CMIP6+LENS model runs come even close to matching observations

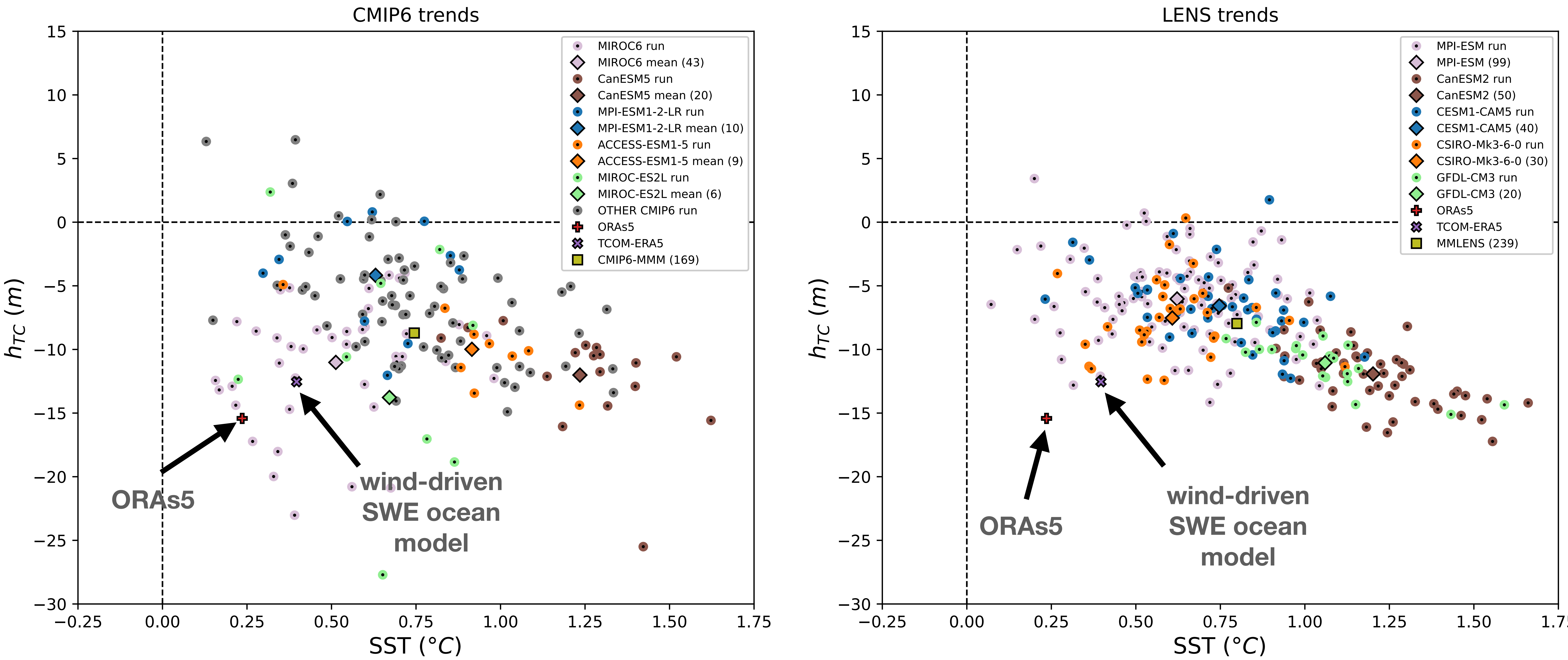
CMIP6 and LENS Trends Closest to Observations



Observed and Histograms of CMIP6 and LENS SST Trend Indices



SST and Thermocline Depth Trends in NINO3.4 region

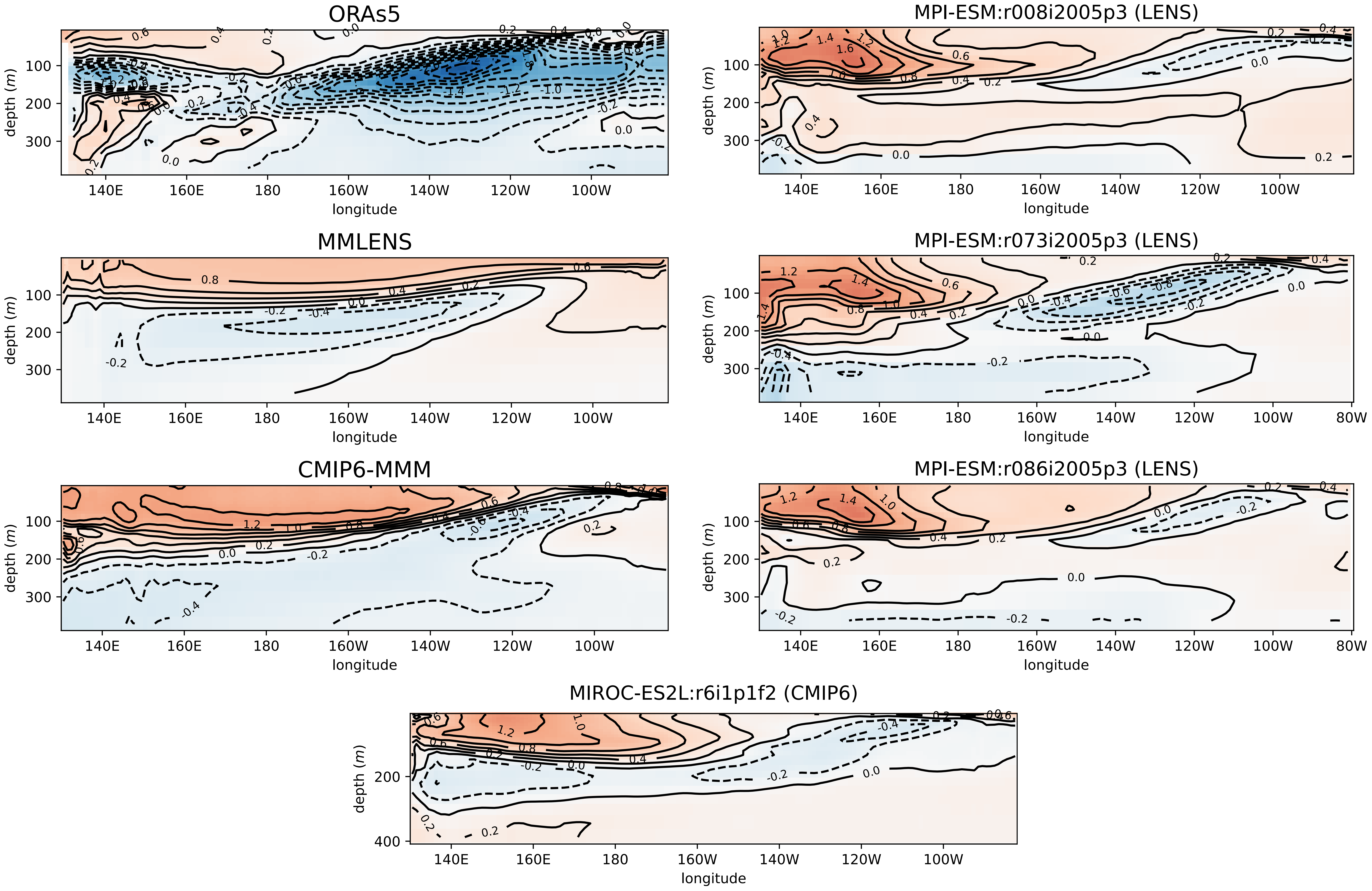


"observed" combination of weak warming and thermocline shoaling in the NINO3.4 region exceedingly rare in CMIP6+LENS models

Strong dynamical shoaling of the equatorial thermocline seen in ocean reanalysis (and data).

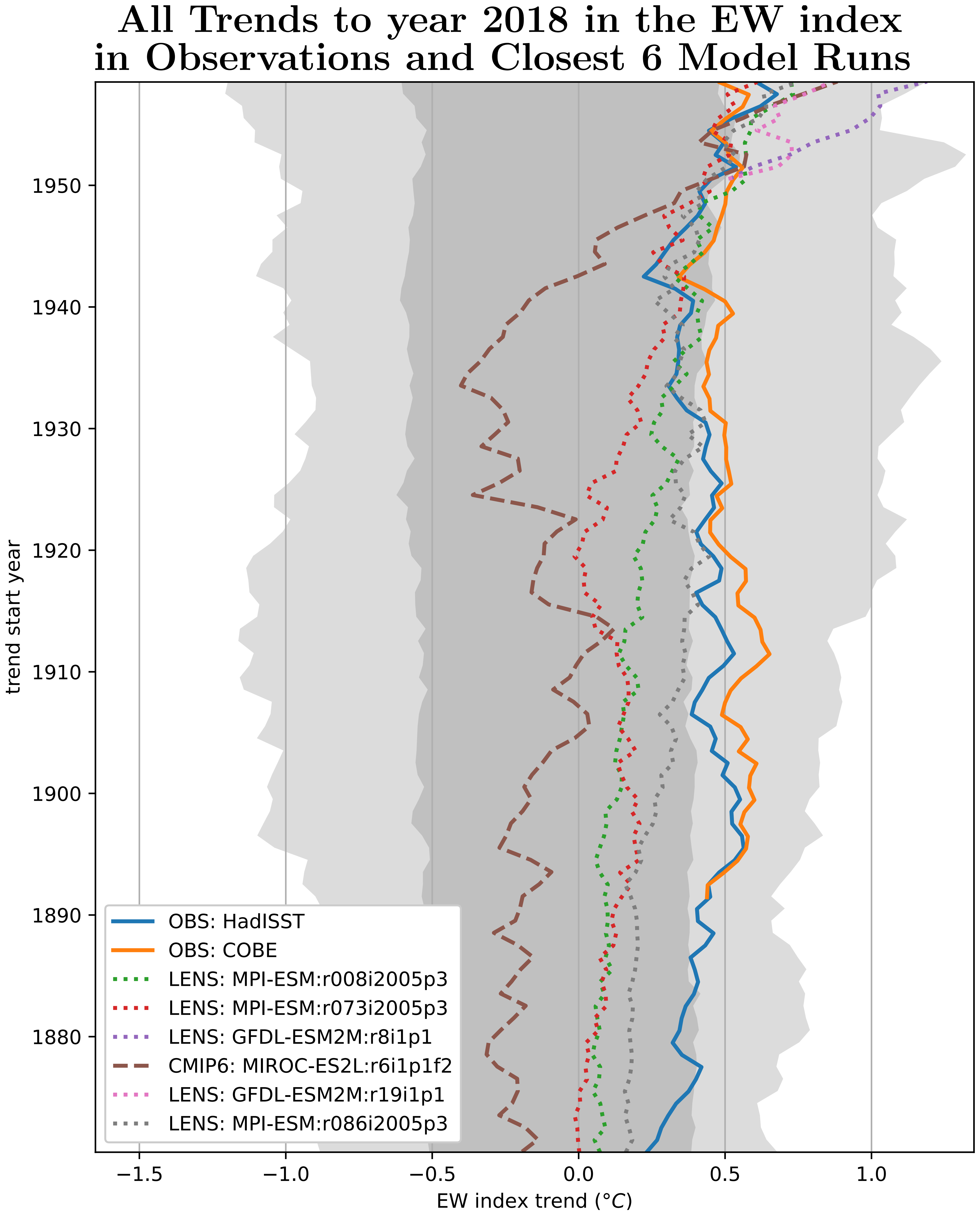
Missing in CMIP6 and LENS models, other than a handful of runs that weakly mimic

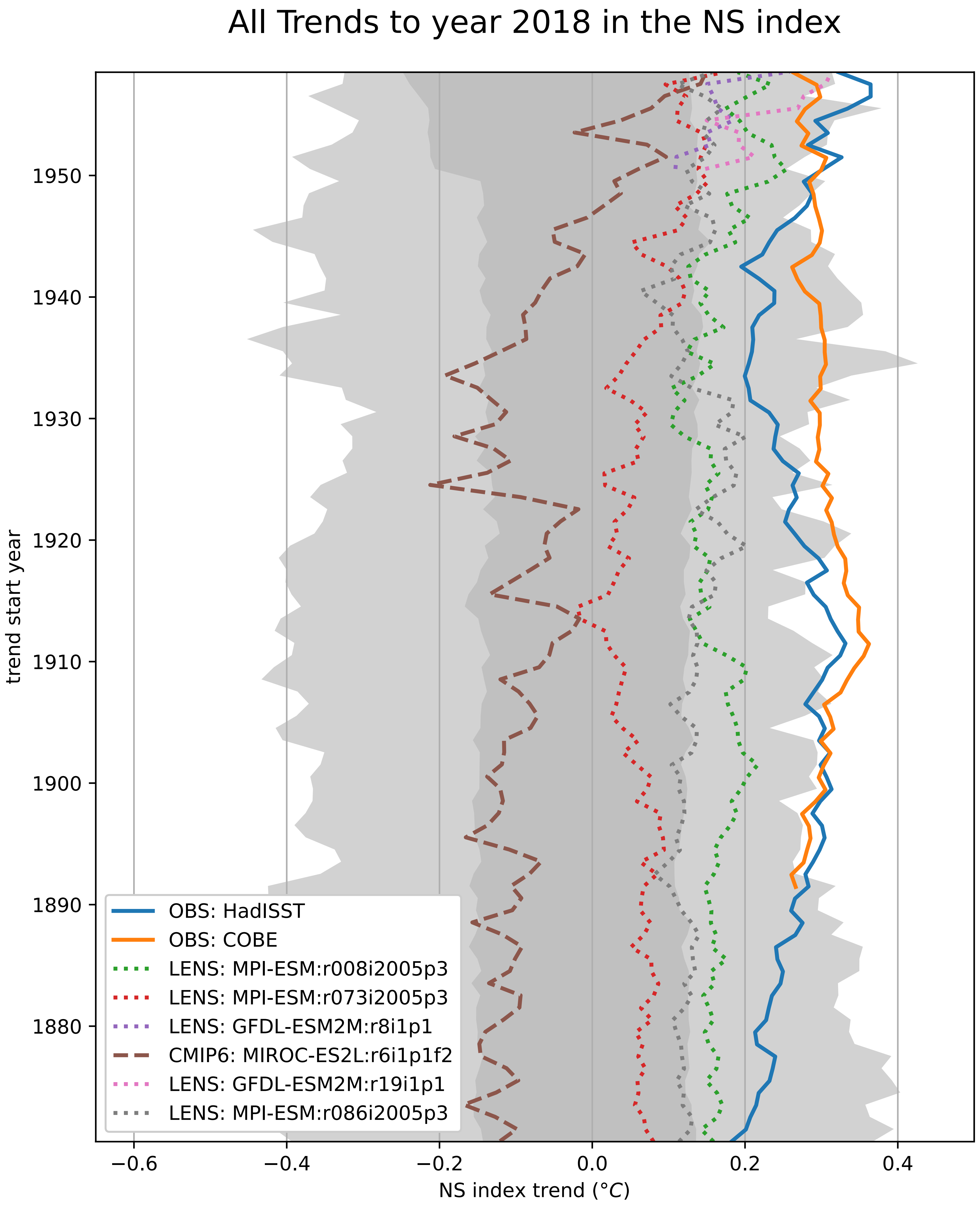
Upper Equatorial Ocean Temperature Trends, 1958-2018



Observed E-W and N-S gradient trends have been very persistent over time - suggestive of a forced response

No model runs capture this with possible exception of two MPI runs





SST gradient trends over all start and end dates for periods 30 years and longer

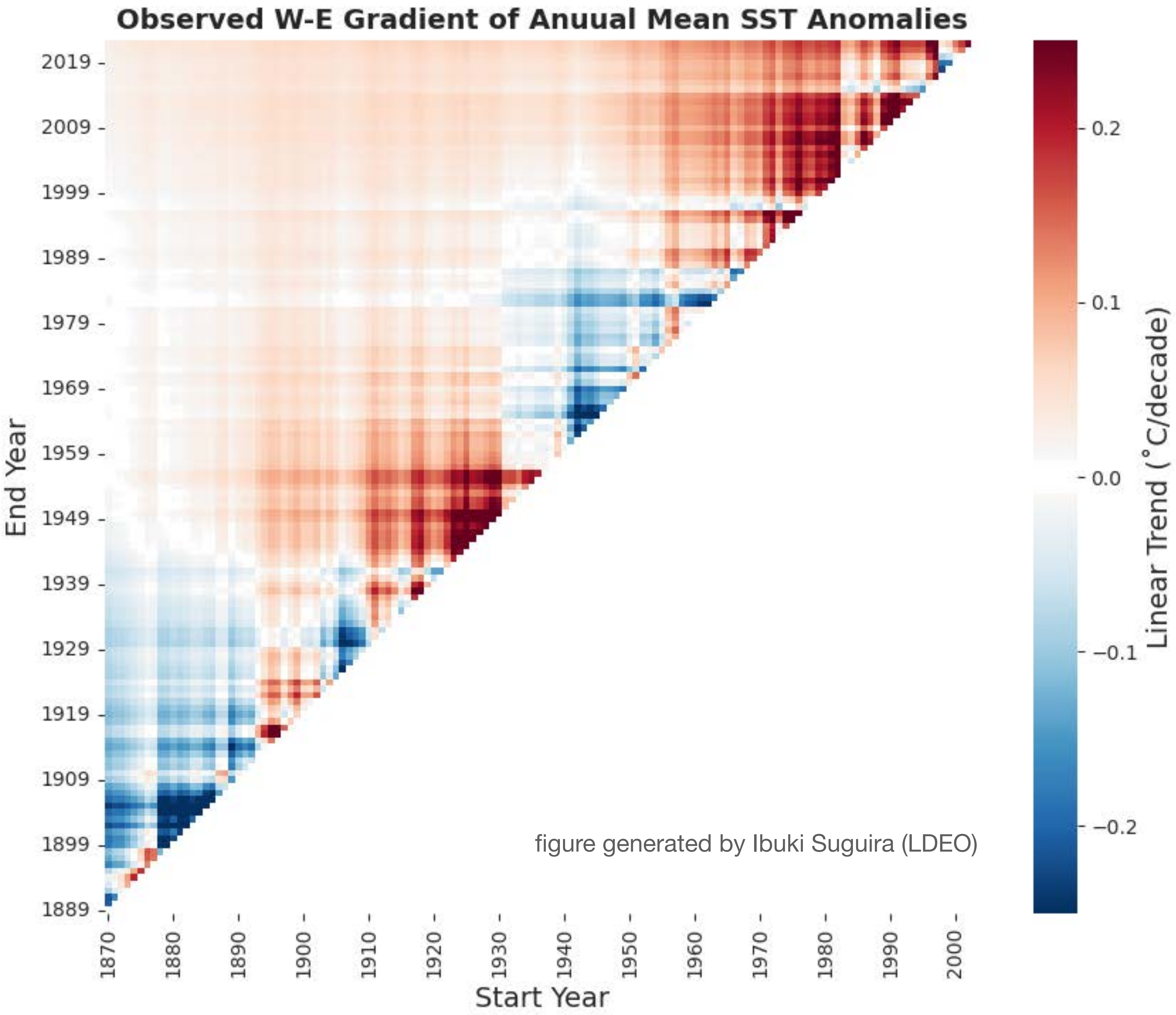
The longer the period, the weaker the trend

The later the end date, the more likely the trend is positive

The longest trends are weakly positive

Given that (1) longer the period the more able to identify a forced signal from the variability, (2) the recent strength of the forcing …. is this consistent with a forced strengthening gradient trend?

see also Rugenstein et al. (2023, submitted)



(A) processes that can cause a reduced zonal gradient

Enhanced thermal stratification in atmosphere causes a weaker Walker circulation

Cooler SST must warm more for same LH’ to balanced enhanced GHG forcing

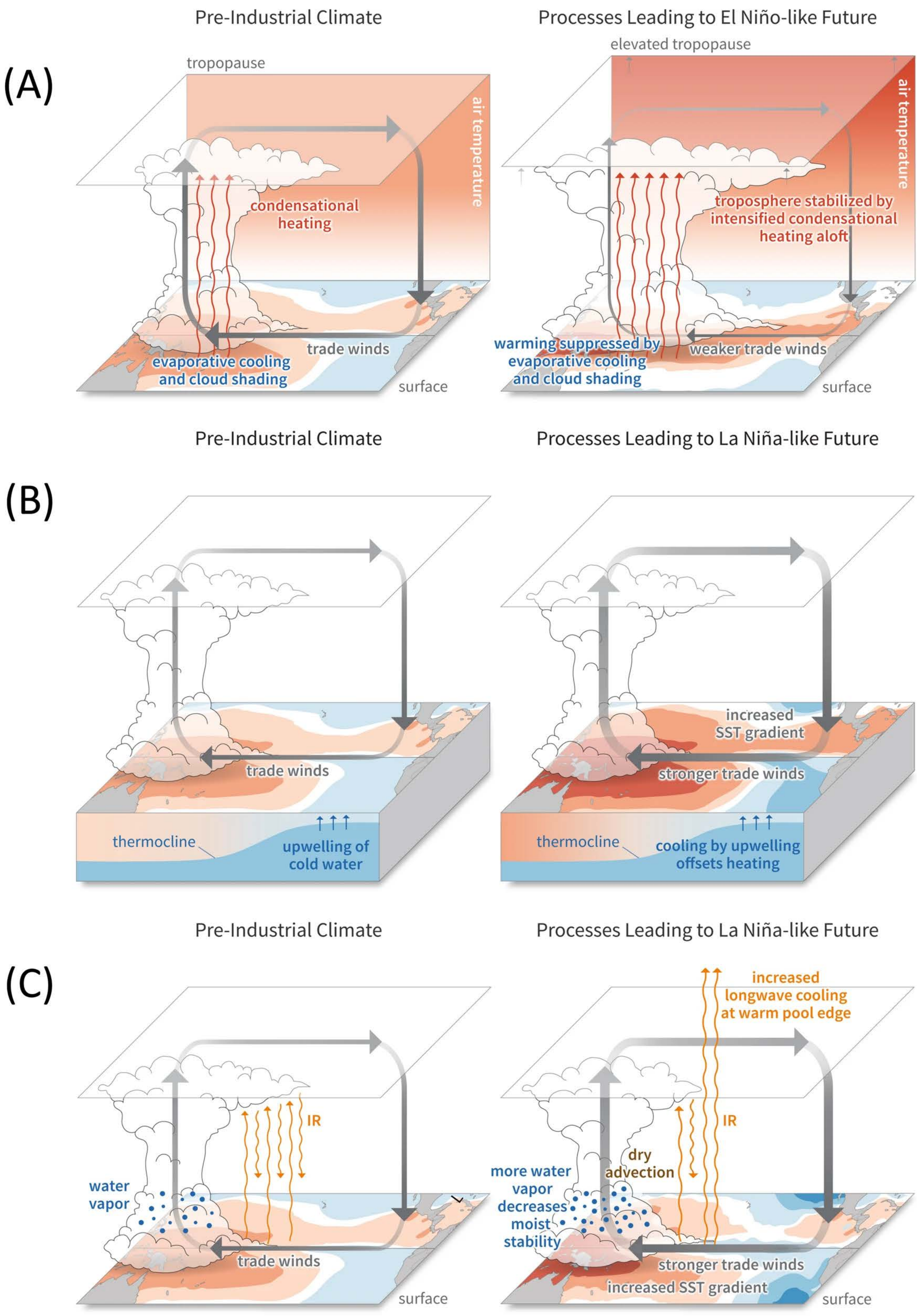
(B) coupled processes that cause an enhanced zonal gradient

GHG induced warming in east is offset by enhanced cooling due to vertical advection, Walker circulation strengthens, thermocline shoals in east cooling SST

(C) enhanced gradient from atmospheric processes

More moisture causes reduced Gross Moist Stability and a stronger Walker circulation.
Dry zonal advection narrows warm pool convection and cools central Pacific

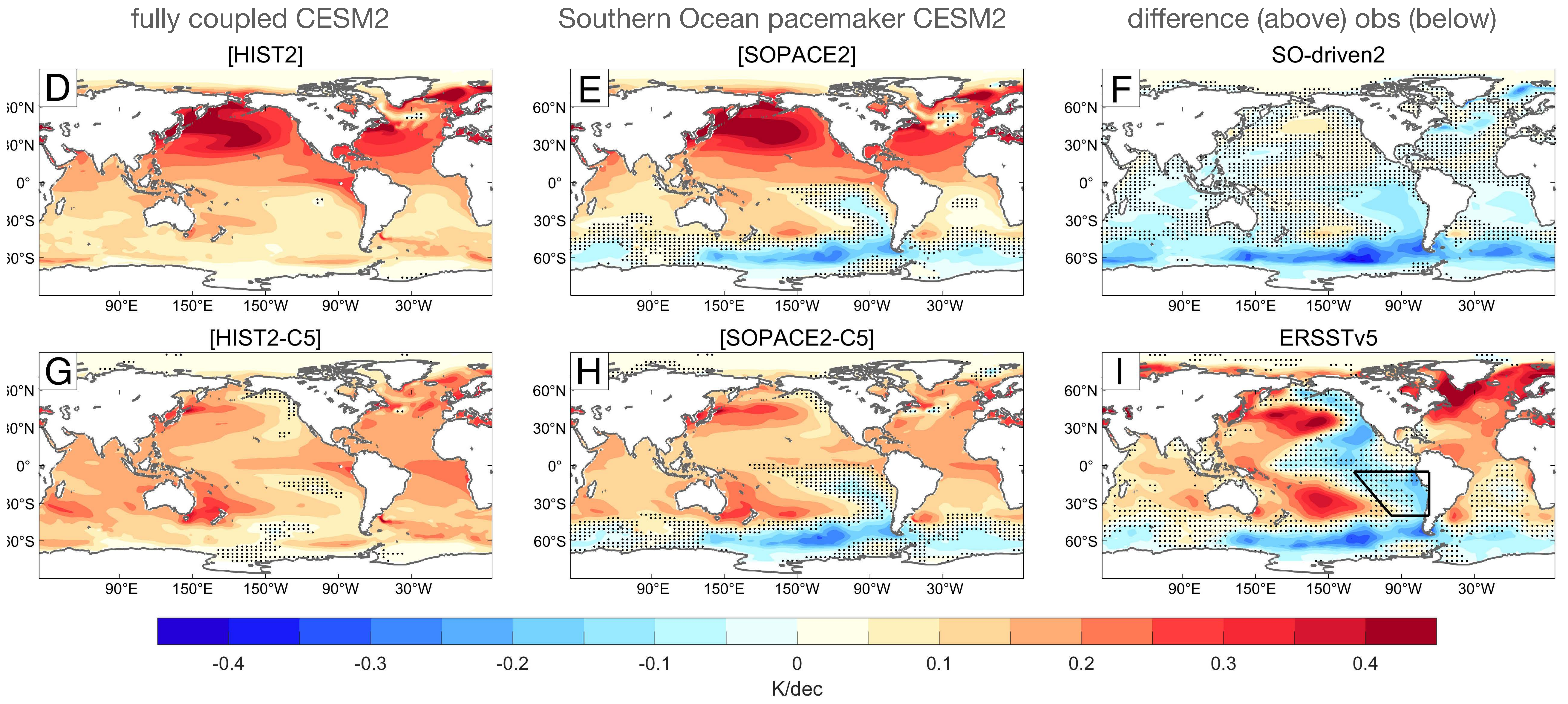
Lee et al. (2022)



Another hypothesis … the equatorial Pacific cooling is a response to Southern Ocean cooling

SST trends 1979 to 2013

Kang et al. (2023 PNAS)



SO cooling ➡ stronger SE Pacific trades ➡ cooler SSTs ➡ more low level clouds ➡ cooler SSTs

Conclusions

Observations are consistent in indicating an enhancing east-west SST gradient across the equatorial Pacific over the past decades and century

Climate models from CMIP3,5,6 indicate that radiative forcing either has, or soon will, reduce this gradient

Some individual runs of some CMIP6 climate models do strengthen the gradient and consistently over past century but almost none with a pattern like that observed

Perhaps, the observed record is dominated by internal variability - an about one in a hundred chance according to models

Or - more likely in our view - the observed record is the forced response and CMIP models get this wrong due to chronic tropical Pacific mean state biases (or remote influences)

Either way, the difference between observed and CMIP modeled SST trends matters for regional hydroclimate, tropical cyclones, drought risk and more (but that's another talk)