A Tropical Source of Error in Multi-Decadal Climate Predictions

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Main Points

1. **Even in a radiatively warming world, to get climate change right**

   we have to get the tropical SST changes right.

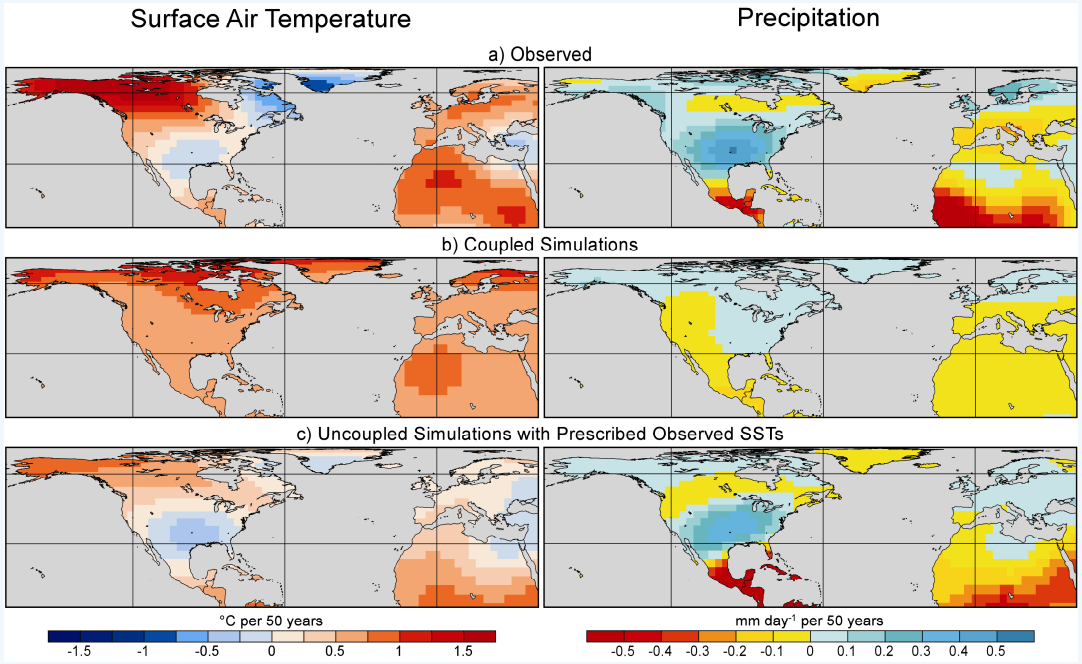
2. ***Climate models are not getting the tropical SST changes right.***

Two relevant papers :

Shin and Sardeshmukh *Climate Dynamics* 2011

Shin, Sardeshmukh, and Pegion *JGR-Atmospheres* 2010

Trends of annual-mean Surface Air Temperatures and Precipitation over 1951-1999



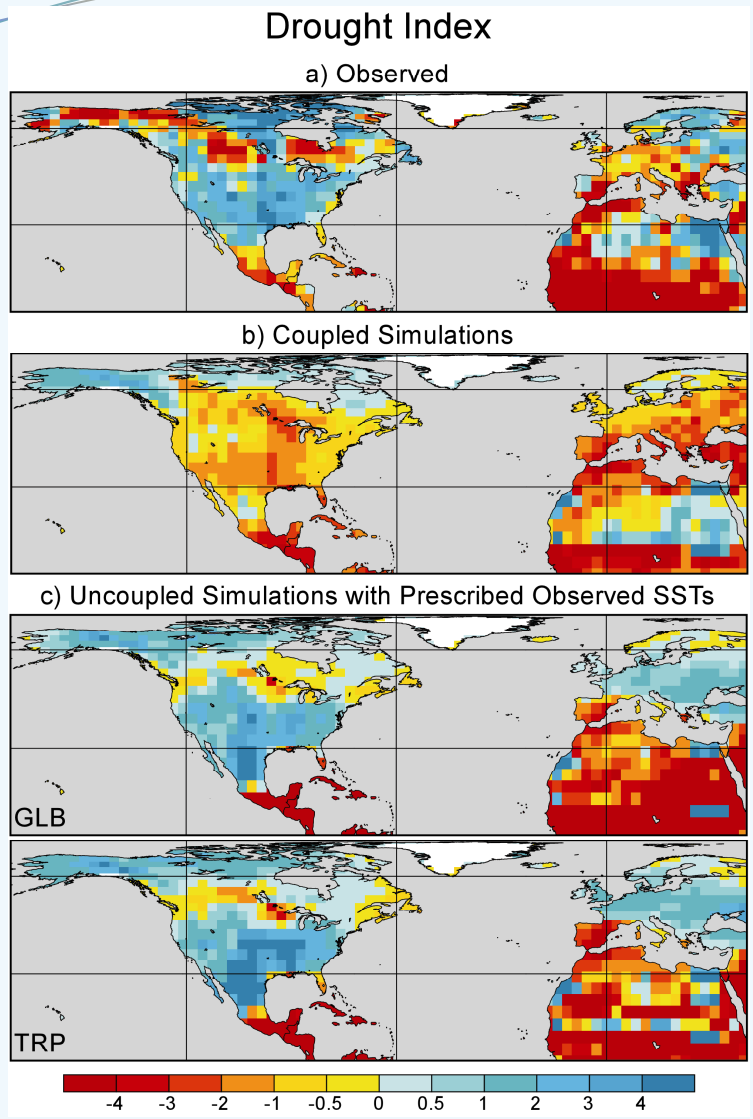
Observed Trends

Multi-model ensemble-mean trends in 76 **COUPLED** climate model simulations with prescribed observed radiative forcings

Multi-model ensemble-mean trends in 87 **UNCOUPLED** atmospheric GCM simulations with prescribed observed global or tropical SSTs, but no explicitly specified radiative forcings.

From Shin and Sardeshmukh Climate Dynamics 2011

Trends of annual Palmer Drought Severity Index (PDSI) over 1951-1999



Observed trends

Simulated in 76 **COUPLED** IPCC/AR4 model simulations with prescribed observed radiative forcings

Simulated in 66 **UNCOUPLED** atmospheric GCM simulations with prescribed observed GLOBAL SSTs, but no explicitly specified radiative forcings (GOGA runs)

Simulated in 21 **UNCOUPLED** atmospheric GCM simulations with prescribed observed TROPICAL SSTs, but no explicitly specified radiative forcings (TOGA runs)

These results show that it is important to get the tropical SST changes right

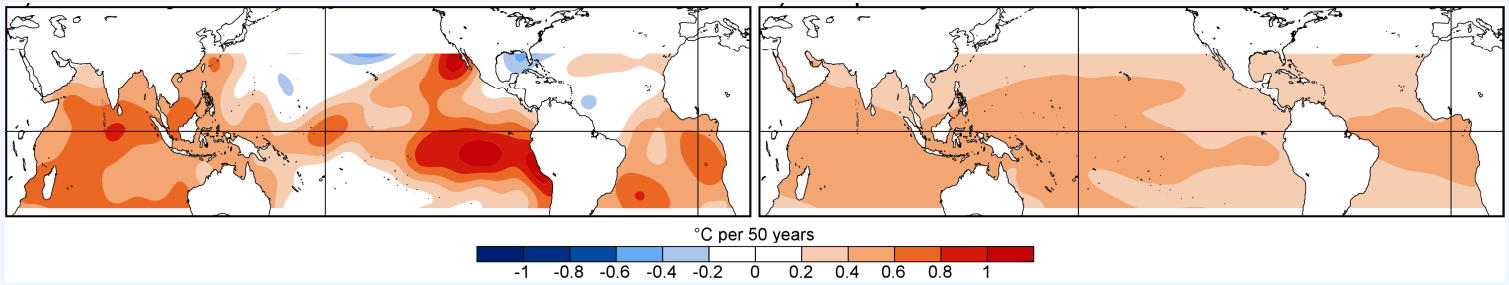
Trend of annual-mean Tropical Ocean Temperatures over 1951-1999

OBSERVED TREND

(average of 3 datasets)

SIMULATED TREND

(average of 76 coupled IPCC/AR4 simulations)



These results show that the IPCC/AR4 models misrepresented the spatially varying tropical SST trends

Trend of annual-mean Tropical Ocean Temperatures over 1951-1999

The lower right panel shows that the IPCC models did not capture the spatial variation of the observed trend field

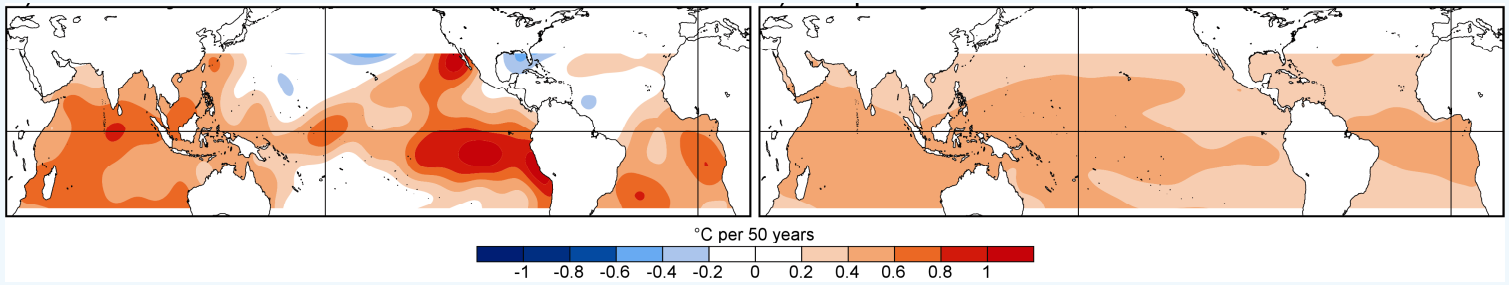
The fact that all the 76 red dots fall outside the grey shaded wedges indicate model error, not just climate noise

OBSERVED TREND

(average of 3 datasets)

SIMULATED TREND

(average of 76 coupled IPCC/AR4 simulations)



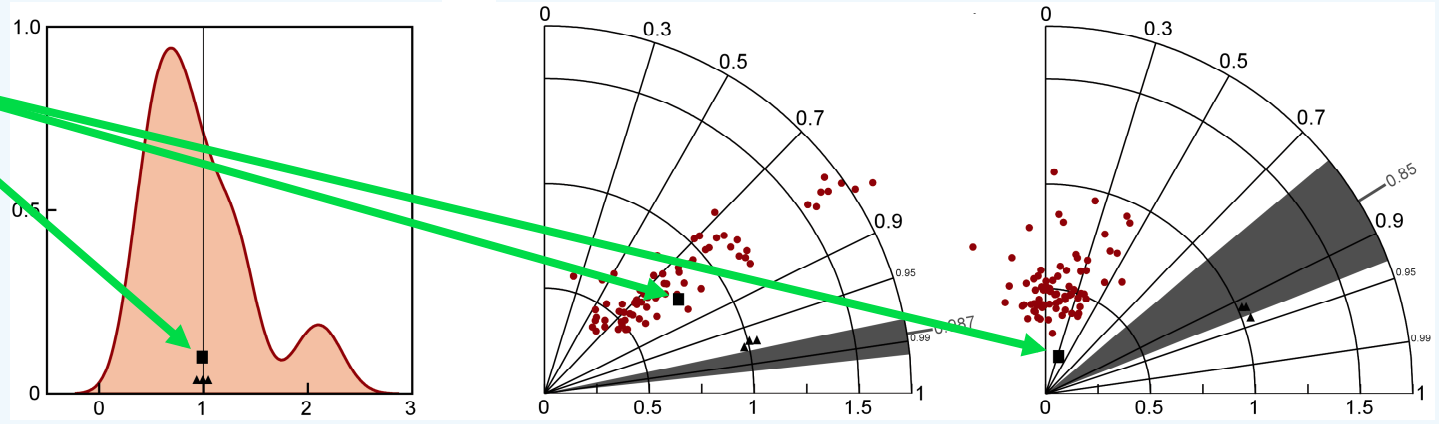
Multi-model Ensemble Mean

Fidelity of all 76 simulated SST trend fields

p.d.f. of area-mean trends

Including area-mean trends

Excluding area-mean trends



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How well do coupled models represent the SST interactions between different tropical regions ?

We have estimated the ***LOCAL AND REMOTE FEEDBACKs*** *on SSTs in 8 tropical regions, using detrended monthly SSTs in* ***3 observational*** *and 76 AR4 simulation datasets of the 20th century*

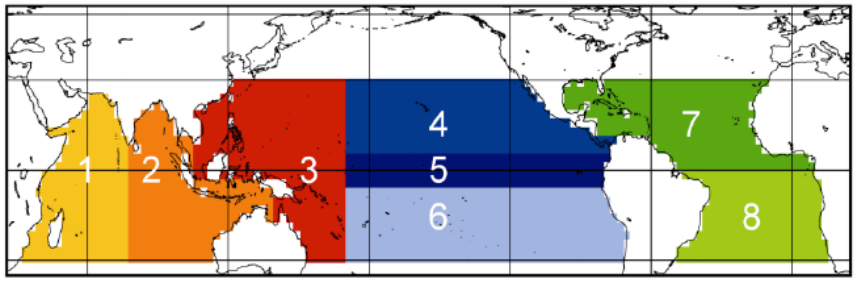
These feedbacks were identified with the elements of the 8x8 matrix $\boldsymbol{L}$ *in the following approximate short-term evolution equation for the monthly SST anomaly vector* $\boldsymbol{x}(t)$ *(whose 8 components are the SSTs in the 8 regions) :*

$$\boldsymbol{dx / dt} \quad = \quad \boldsymbol{L\,x} \quad + \quad \textbf{stochastic noise}$$

$\boldsymbol{L}$ *was estimated via Linear Inverse Modeling (Penland and Sardeshmukh 1995) as*

$$L = \frac{1}{\tau} \ln \left[C(\tau)\, C(0)^{-1} \right]$$

where $C_{ij}(\tau) = \langle x_i(t+\tau)\, x_j(t) \rangle$ *is the SST lag-covariance matrix for lag* τ

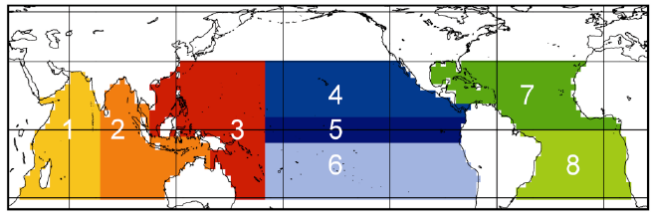


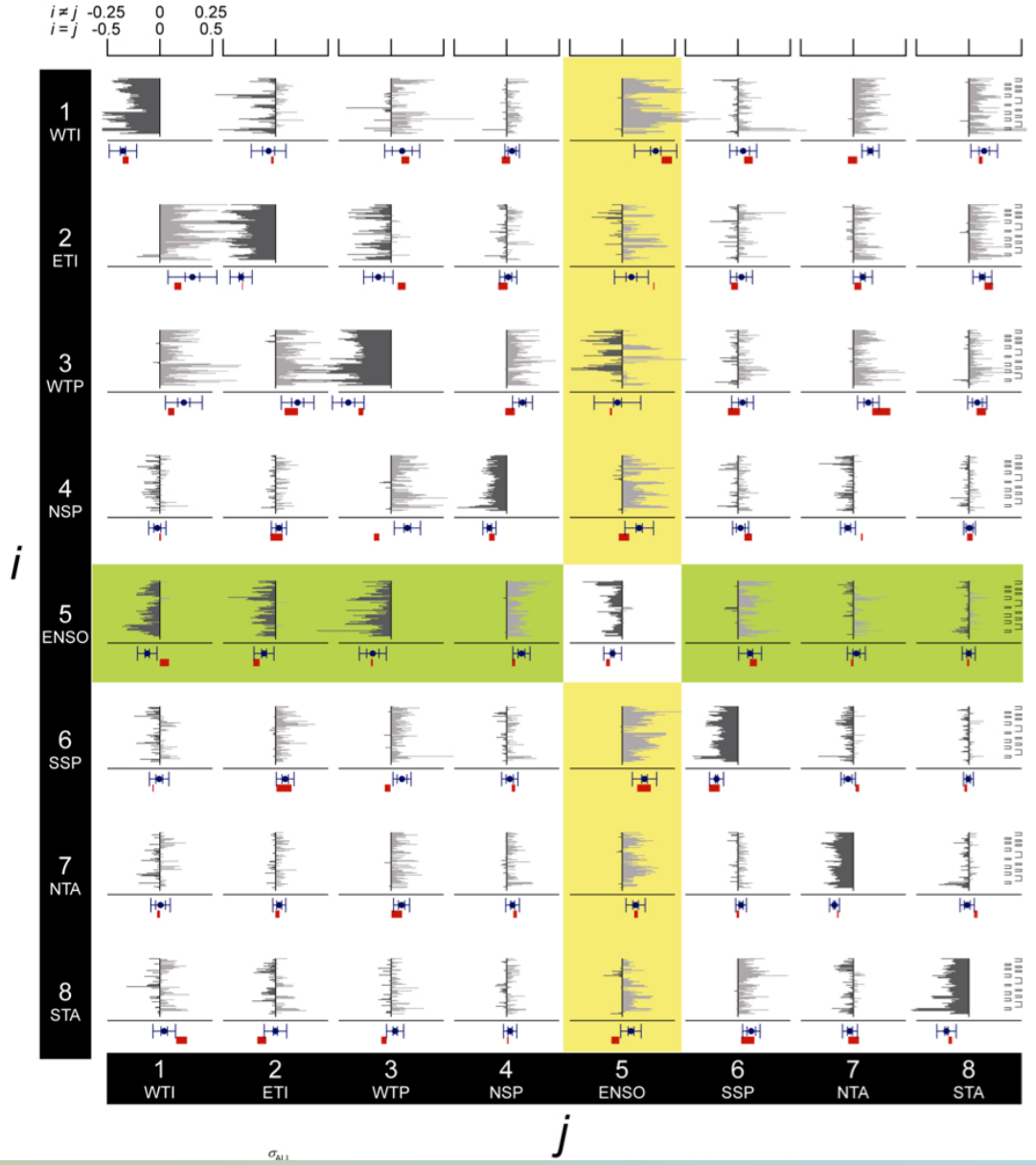
From

Shin, Sardeshmukh, and Pegion

JGR-Atmospheres December 2010

The 8 x 8 Tropical SST Feedback Matrix L





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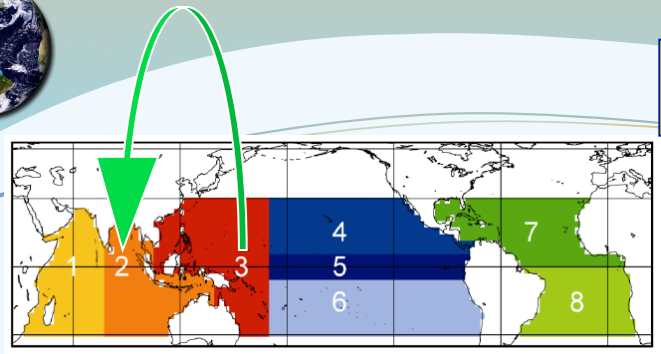
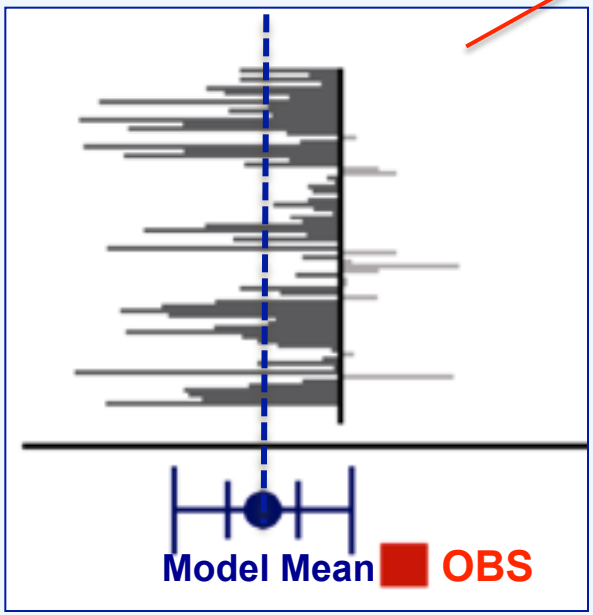
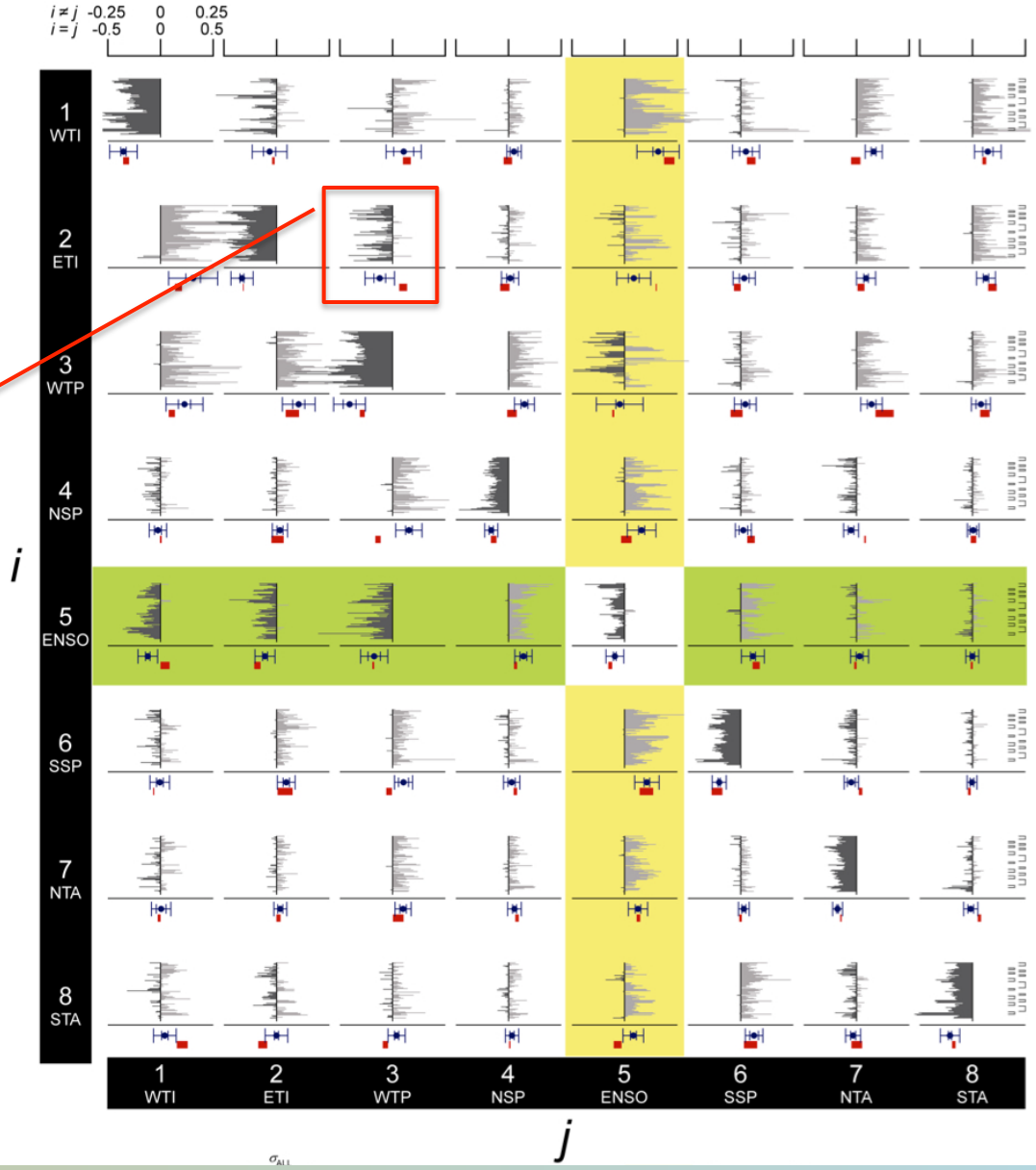


L_{23} = Effect of Region 3 on Region 2





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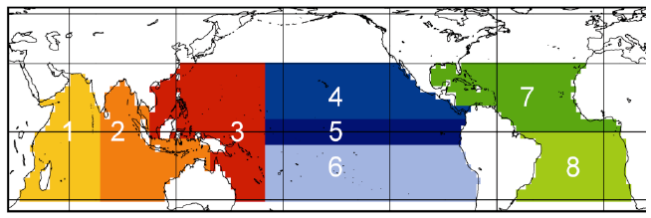
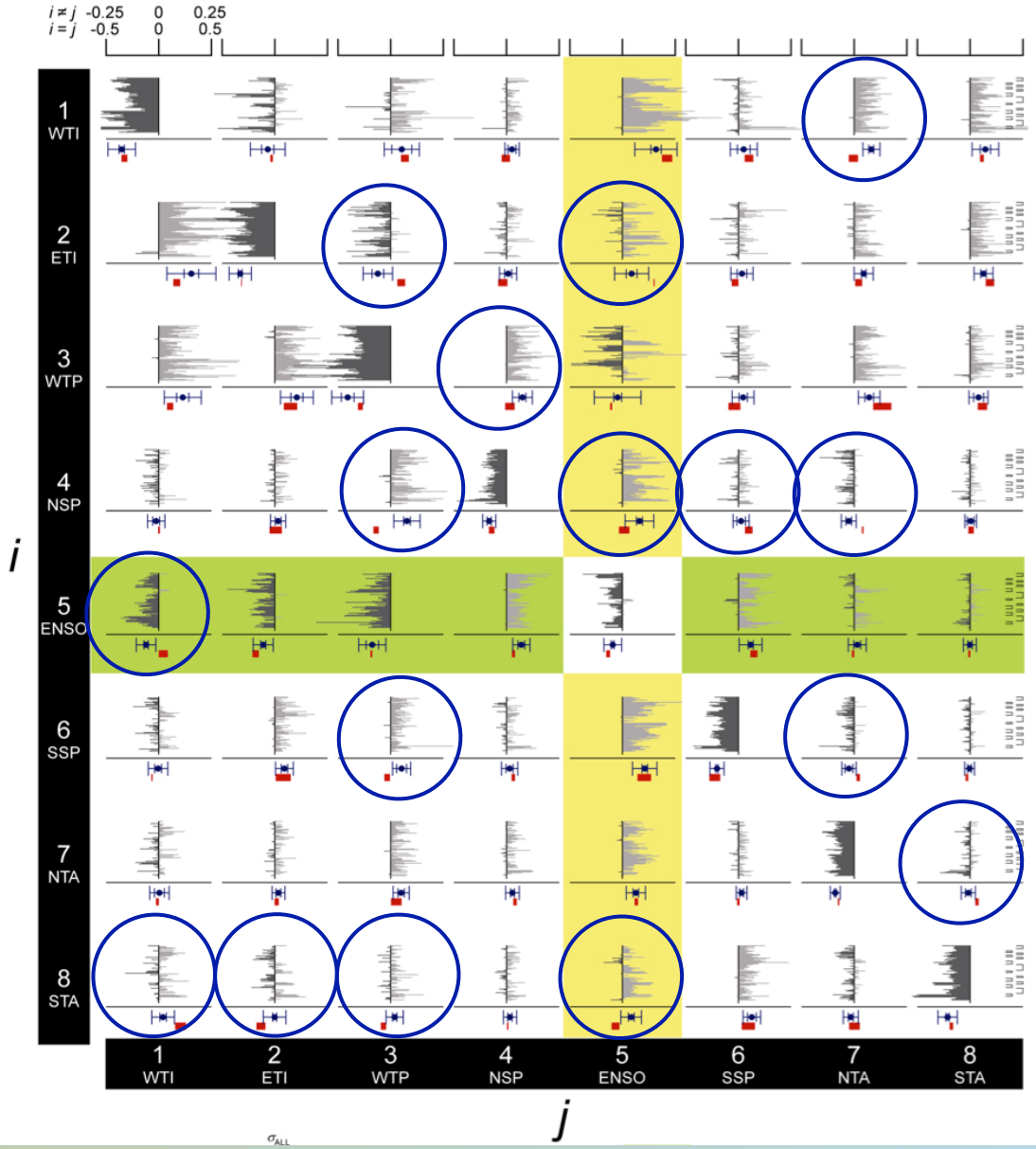


BLUE CIRCLES
highlight those model feedbacks that are ***CLEARLY*** inconsistent with the observed feedbacks



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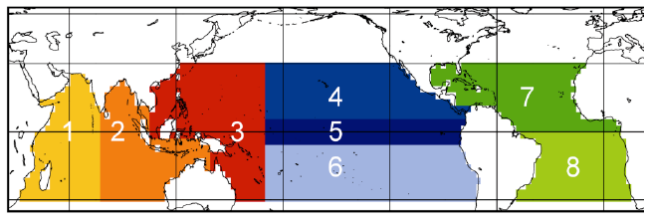
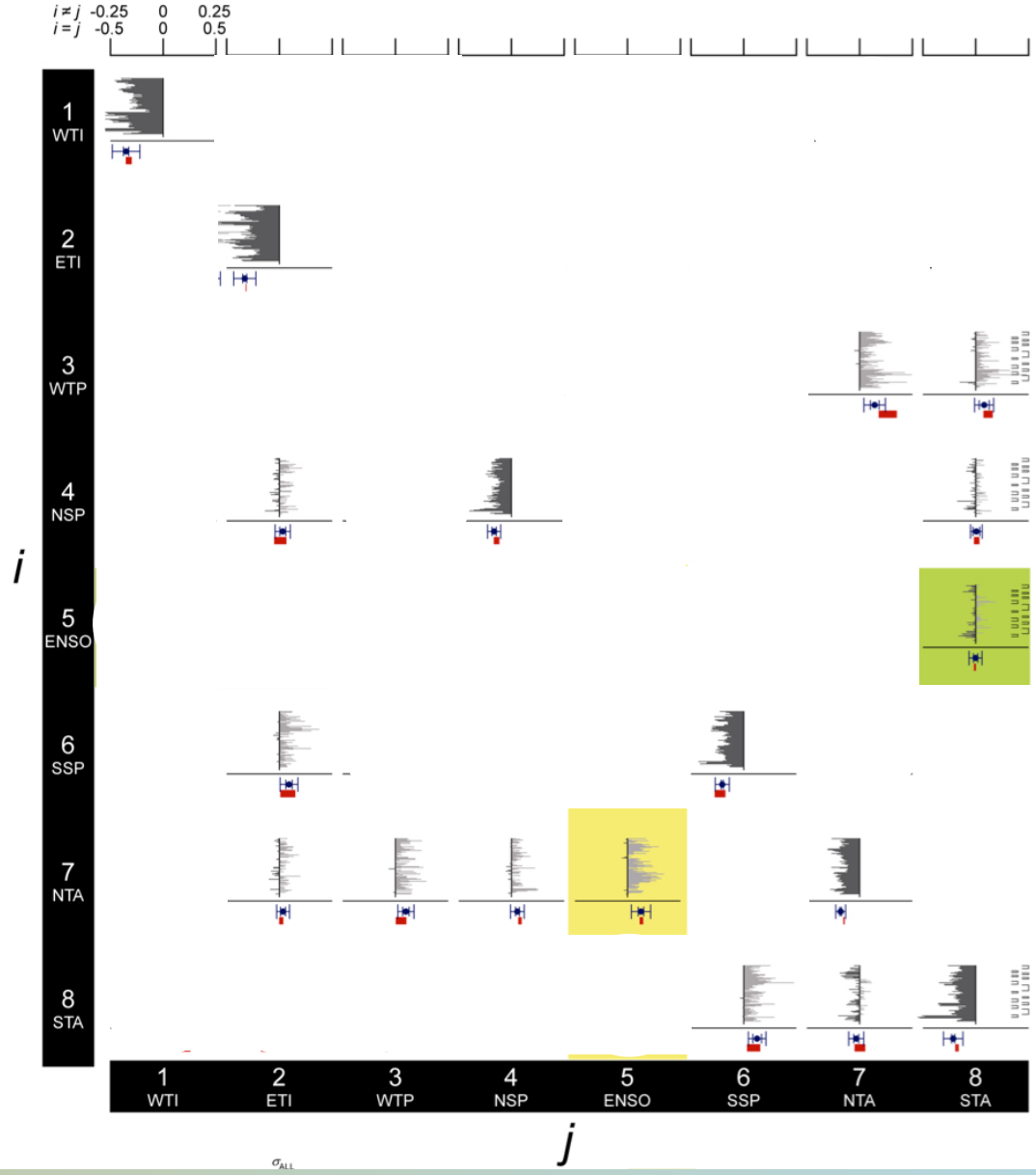


IN GENERAL :

the *local damping feedbacks* are reasonably consistent among the observations and models

but the *non-local feedbacks* are generally not consistent



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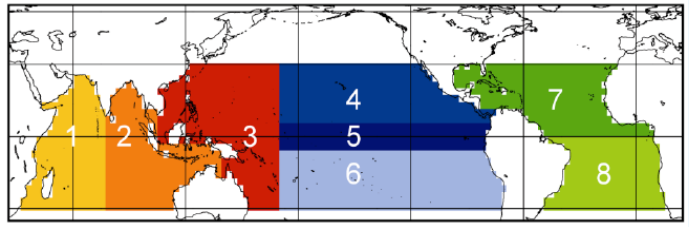
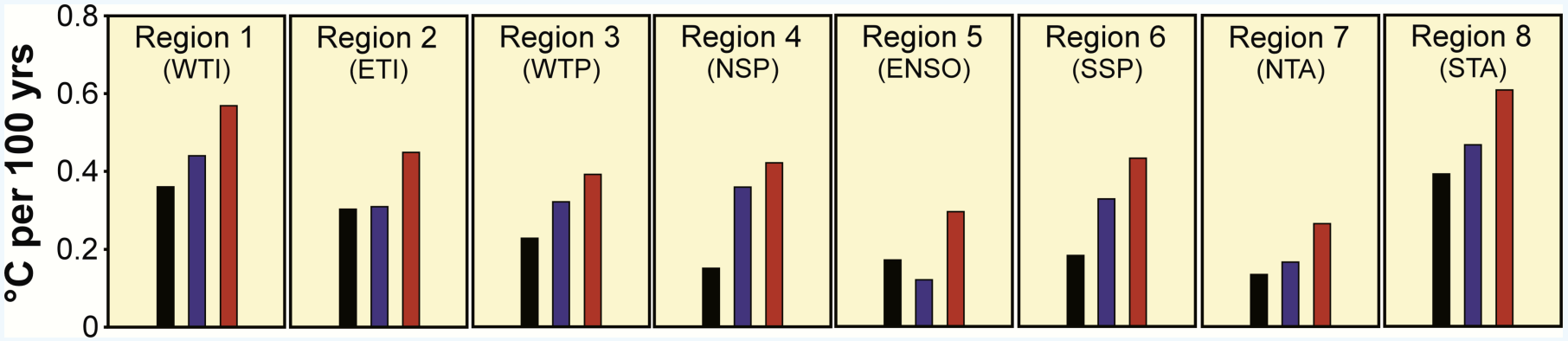
Do the errors in the SST feedback matrix L matter ?

YES **!**

Consider the 20th century SST response to the ***same*** trend forcing $\boldsymbol{F}_{obs}$ using the observational vs model $\boldsymbol{L}$ operators





$\Delta T_{obs} = -L_{obs}^{-1} F_{obs}$ Observed (Use this equation to determine F_{obs})

$\Delta T_{Multi-Model-mean} = -\overline{L_m^{-1}} F_{obs}$ Multi-Model ensemble mean response → Larger than ΔT_{obs}

$\Delta T_{Mean-Model} = -\overline{L_m}^{-1} F_{obs}$ Response of mean model → Also larger than ΔT_{obs}

These results imply that the models are *OVERSENSITIVE* to the trend forcing

Summary

1. **Climate models will continue to have difficulty in capturing regional climate trends around the globe unless they are able to capture the spatial variation of tropical SST trends.**

2. **The large discrepancy of observed and simulated recent 50-yr trends is not just due to natural variability or climate noise, but is also very substantially due to model errors.**

4. To help isolate these model errors, we estimated **the local and nonlocal feedbacks** on monthly SSTs in 8 tropical regions in observations and the IPCC/AR4 models .

5. We found that the models reasonably capture the ***local*** feedbacks (except in the ENSO and western Pacific Warm Pool regions), but not the ***non-local*** feedbacks.

6. **Errors in the tropical SST feedback matrices *L* not only distort the spatial patterns of the simulated tropical SST trends but also tend to generate a positive bias in the multi-model ensemble mean warming trends in the IPCC/AR4 simulations in response to external forcing**.

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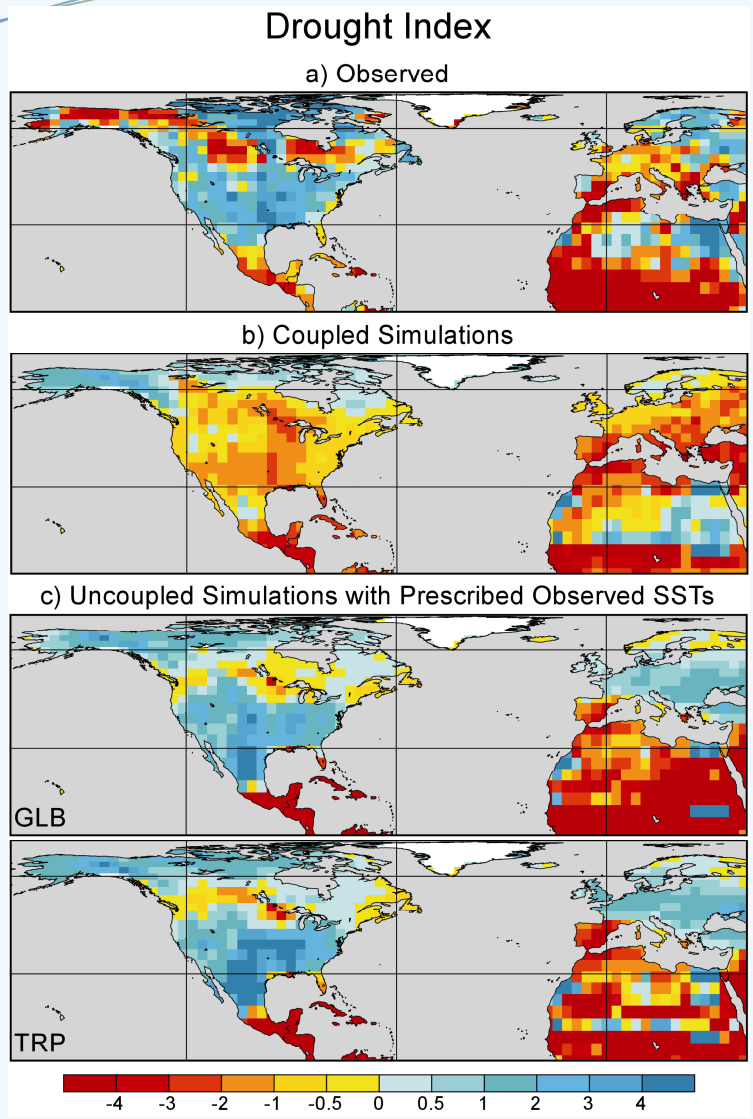

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