Rethinking the Ocean’s Role in Tropical Pacific Climate Variability

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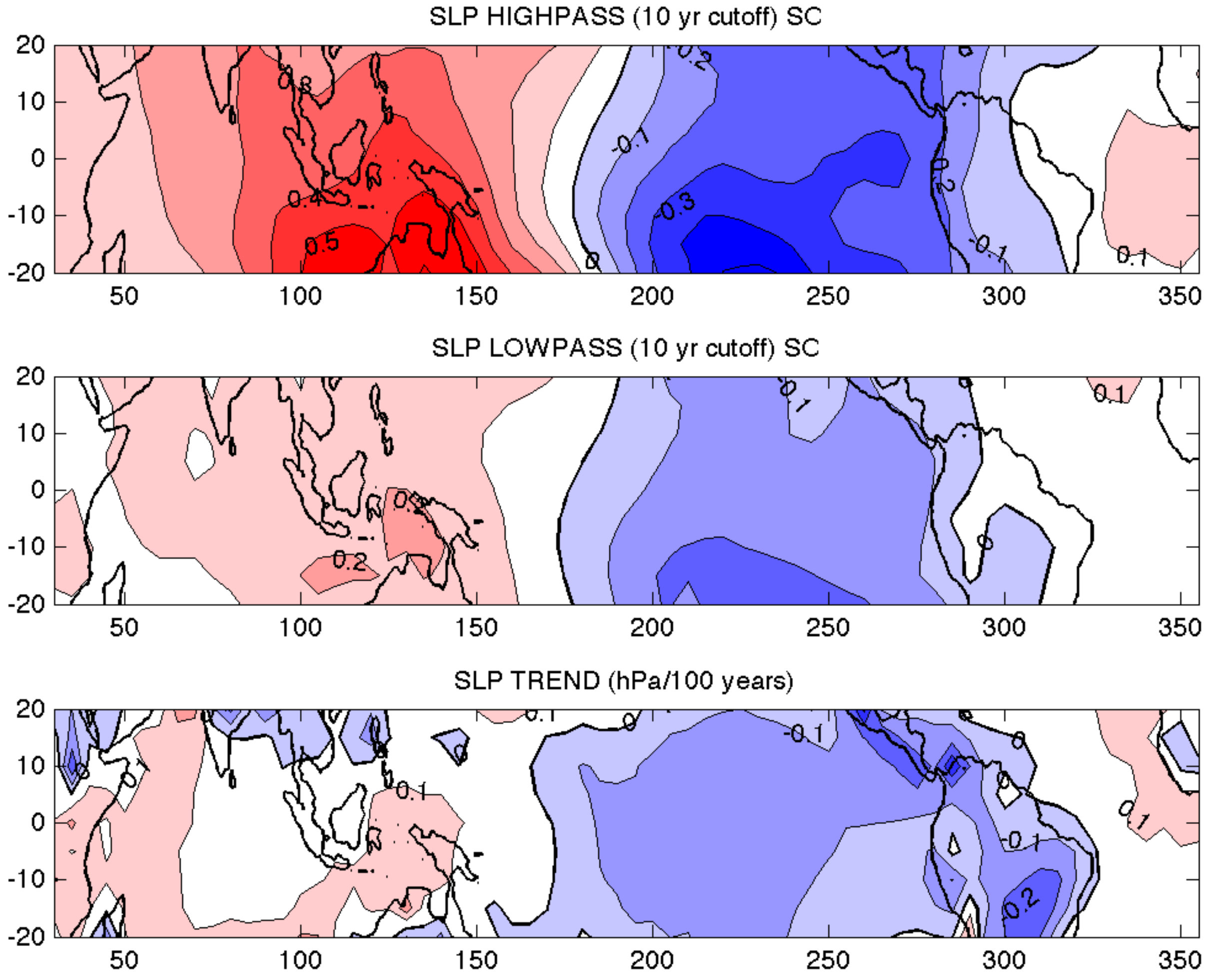
Patterns of Pacific Sea Level Pressure (SLP) variability on different timescales



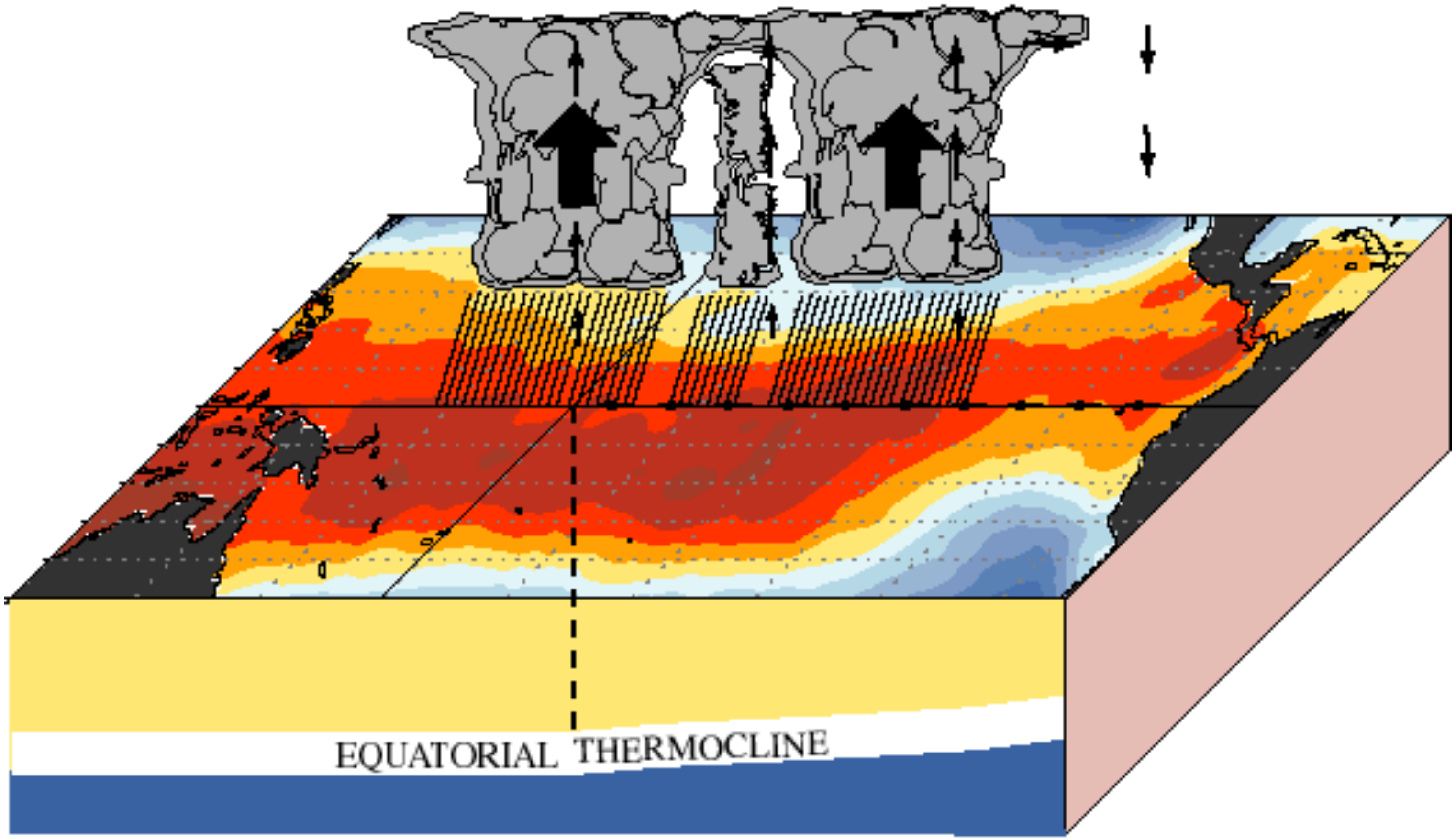
Regression of SLP on normalized SOI – ***interannual timescale***

… ***decadal timescale (10 yr low pass filter)***

20th century trend of SLP (Vecchi et al. 2006, Deser et al 2010)

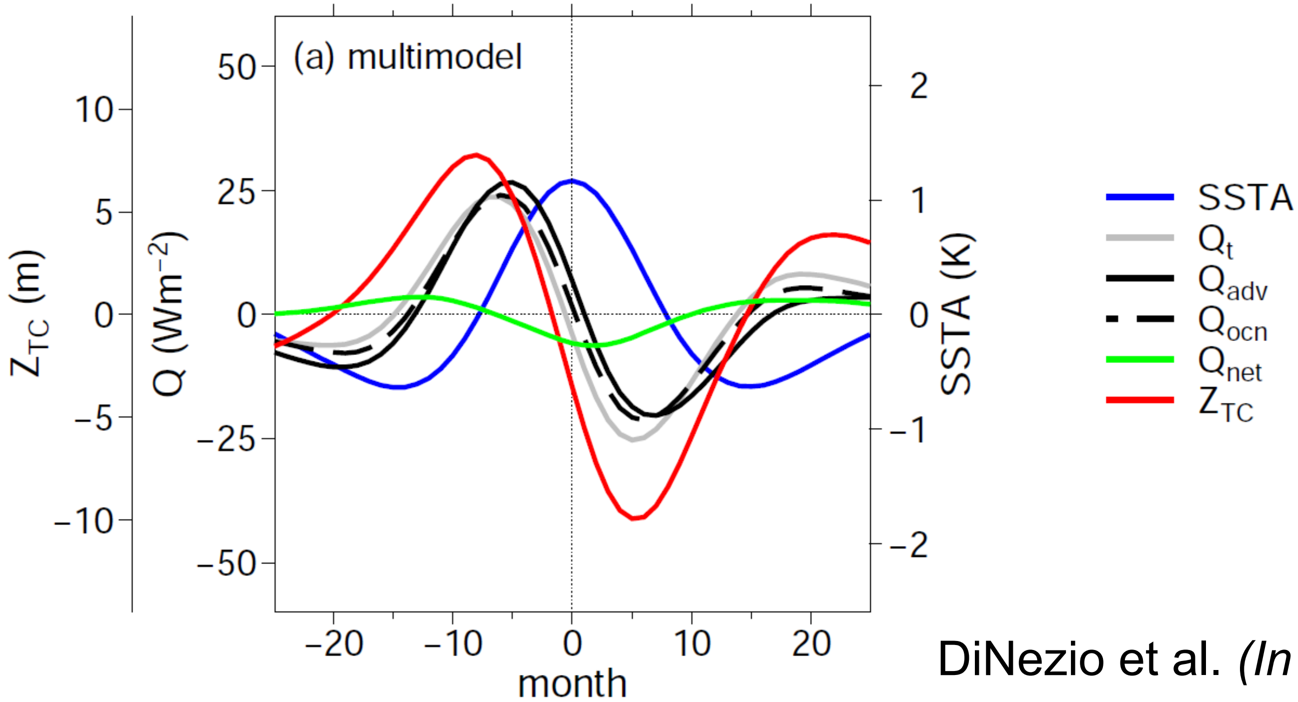
Are the mechanisms analogous on all timescales?

Internal variability: ENSO



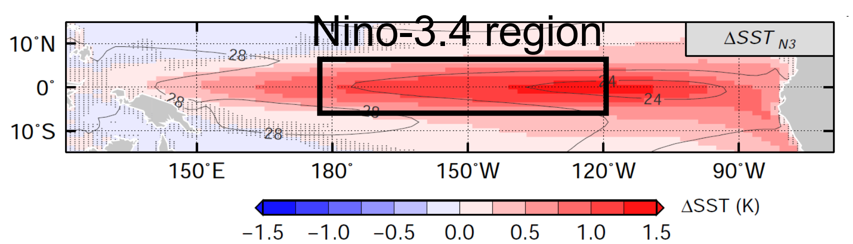
Equatorial thermocline amplifies on a seasonal timescale- i.e. the Bjerknes feedback

ENSO mechanism (coupled climate models)



DiNezio et al. *(In prep)*

ENSO events grow and decay driven by thermocline anomalies



Are coupled ocean dynamics fundamental to the Southern Oscillation on all timescales (as for interannual)?

Clement et al. (2011), *J. Climate*

Methodology

- Climate models with different degrees of coupling with the ocean

    1. Forced with climatological SST

       Uncoupled

    2. Coupled to a SLAB ocean mixed layer (50 m)

       Thermodynamical coupling but
       No interactive ocean dynamics

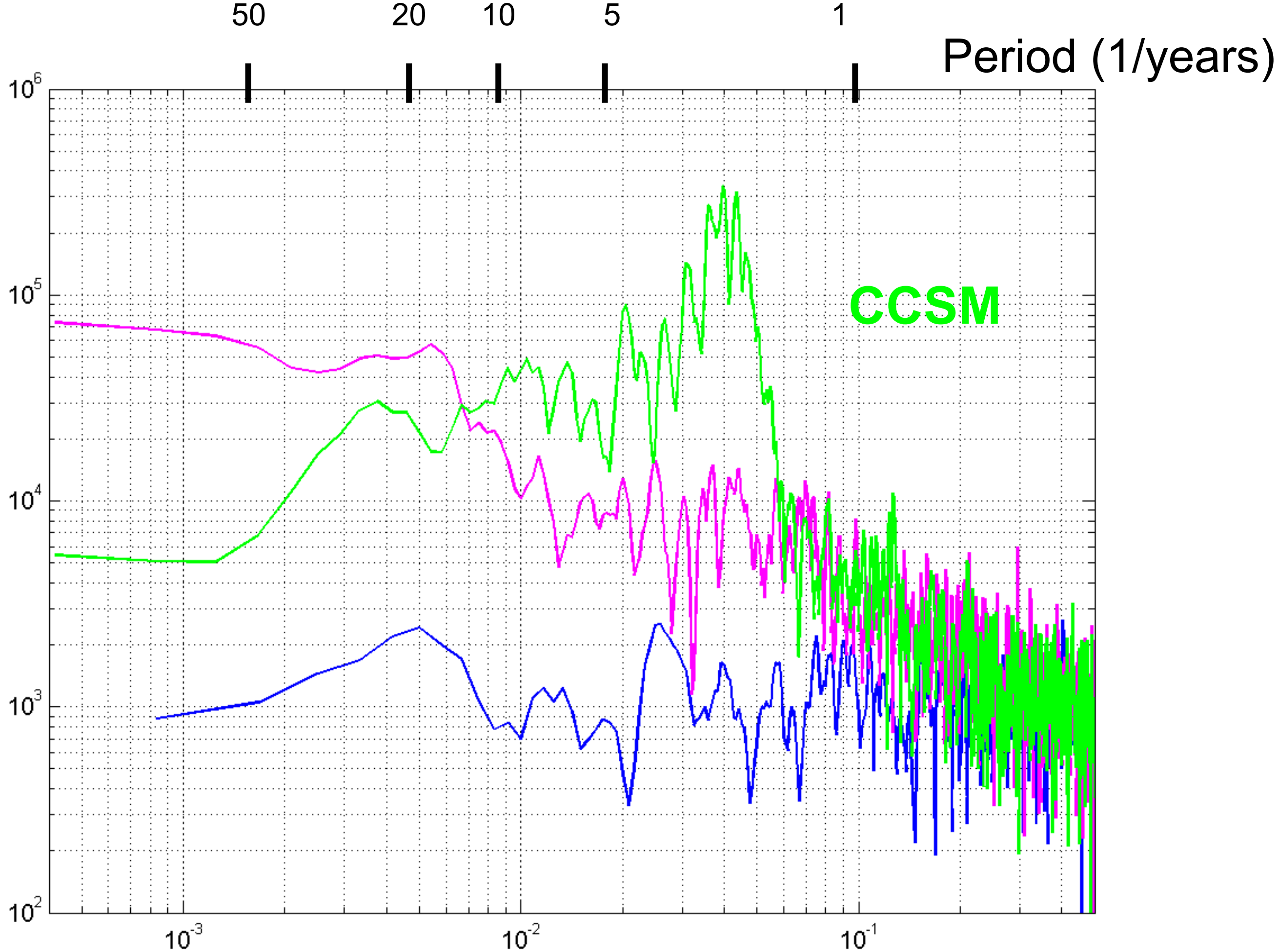
    3. Coupled to a full ocean GCM

       Fully coupled

- Control experiments + 21st century simulations

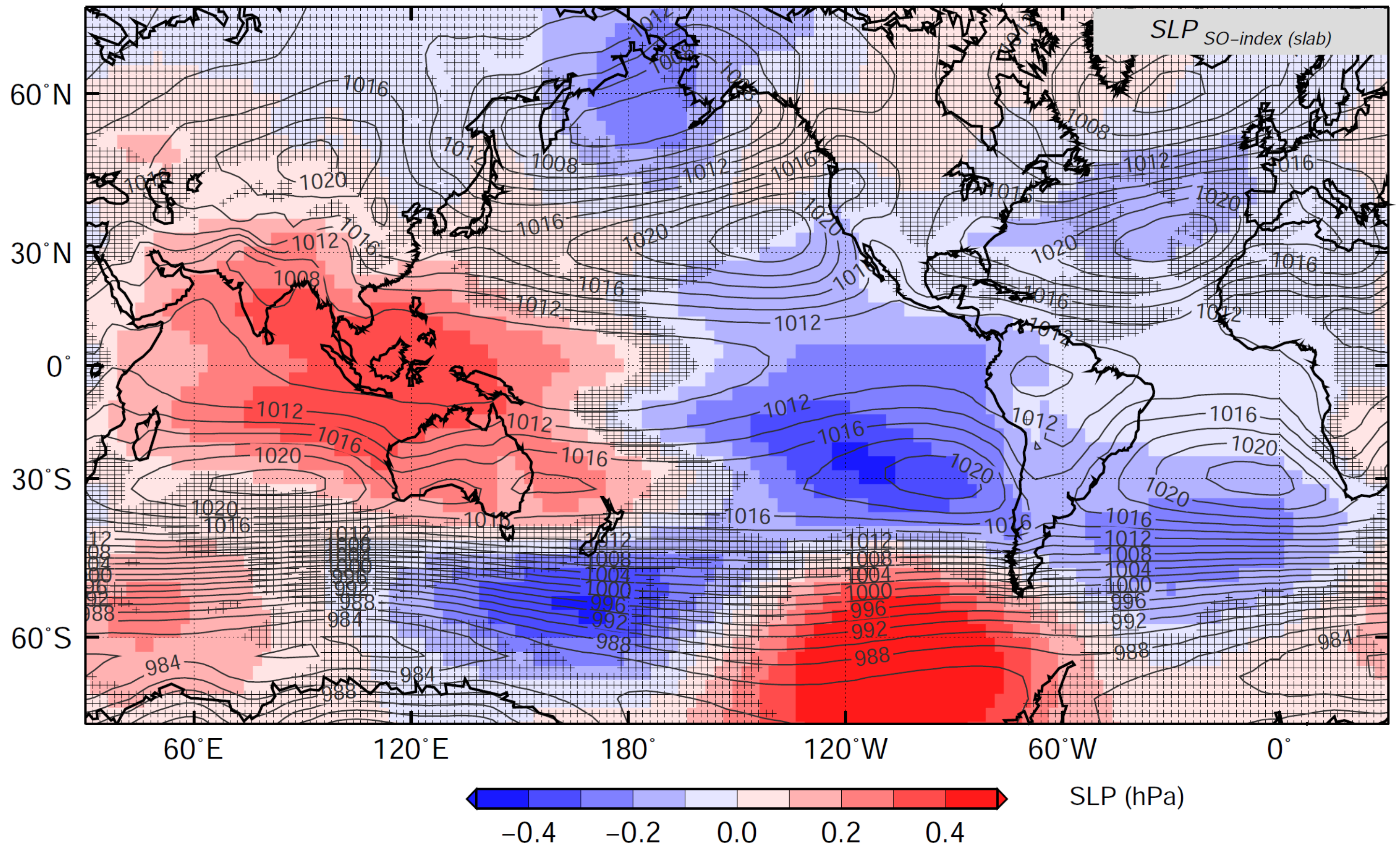
- 13 different AGCMs- multi-model mean fields show structures that are not sensitive to the details of parameterizations

CCSM Spectra of SO with different coupling to ocean



Frequency (1/months)

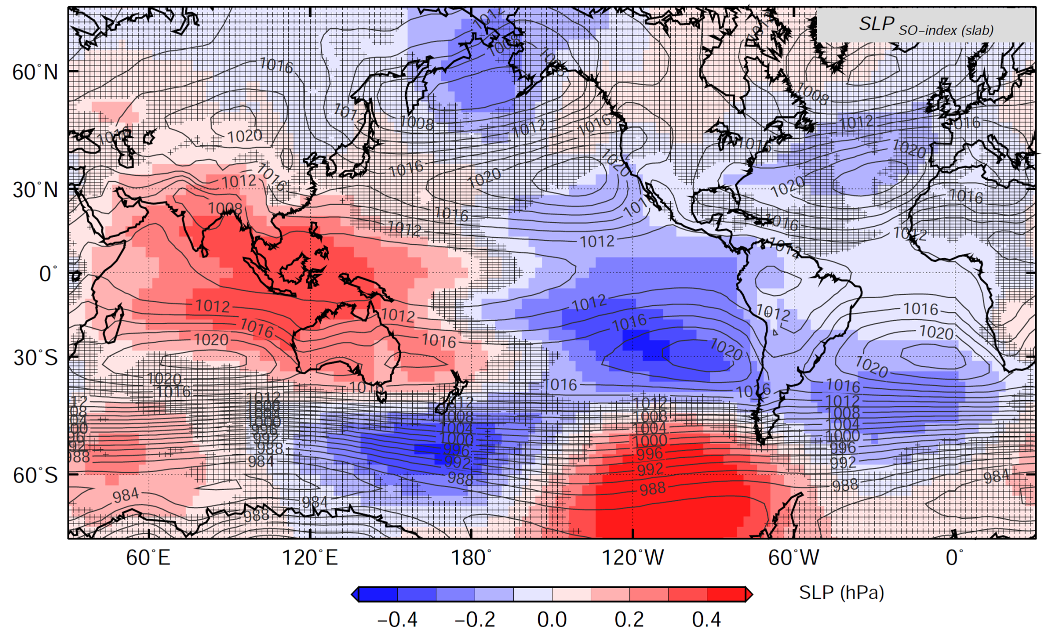
AGCM-slab multi-model mean (13 models) regression on SO Index**



* This pattern is the dominant EOF of tropical Pacific SLP variability in SLAB models
* This pattern does NOT emerge from AGCM forced by climatological SST

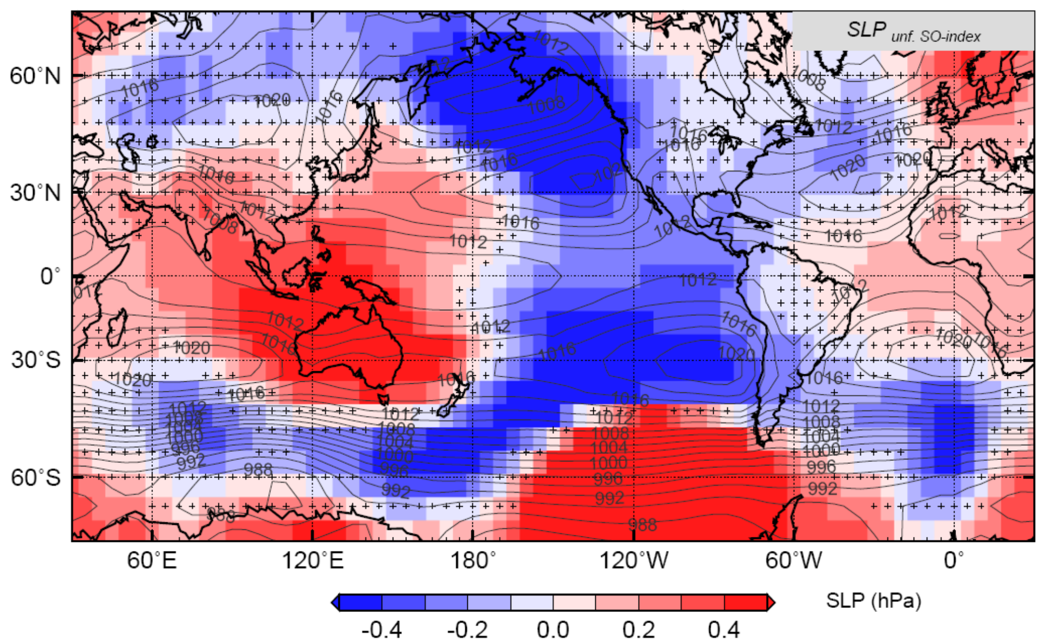
**stippling shows areas where < 10 out of 13 models agree in sign- i.e not robust

AGCM-slab multi-model mean (13 models) regression of SLP on SO index

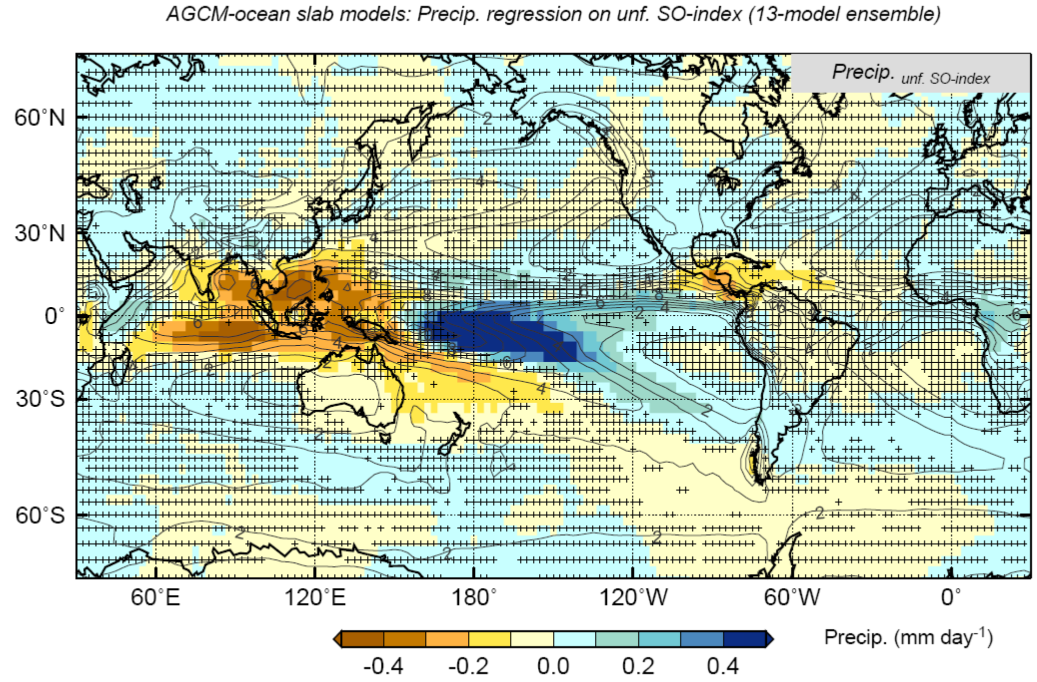


Observed regression of SLP on normalized SO index

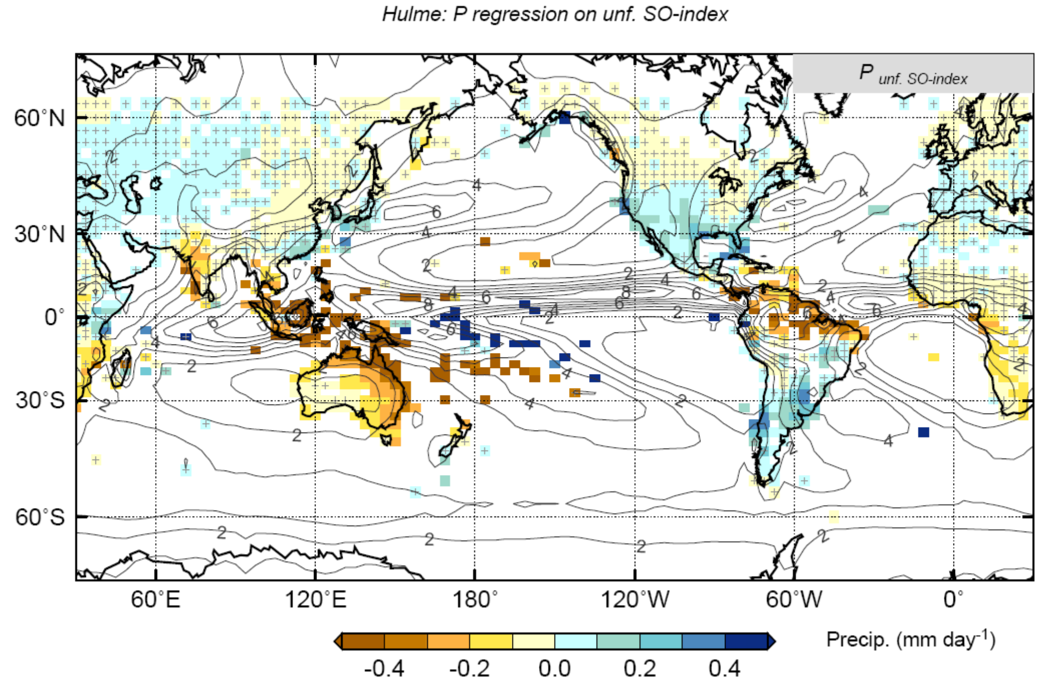
HadSLP: SLP regression on unf. SO-index



AGCM-slab multi-model mean (13 models) regression of precip on normalized SO index

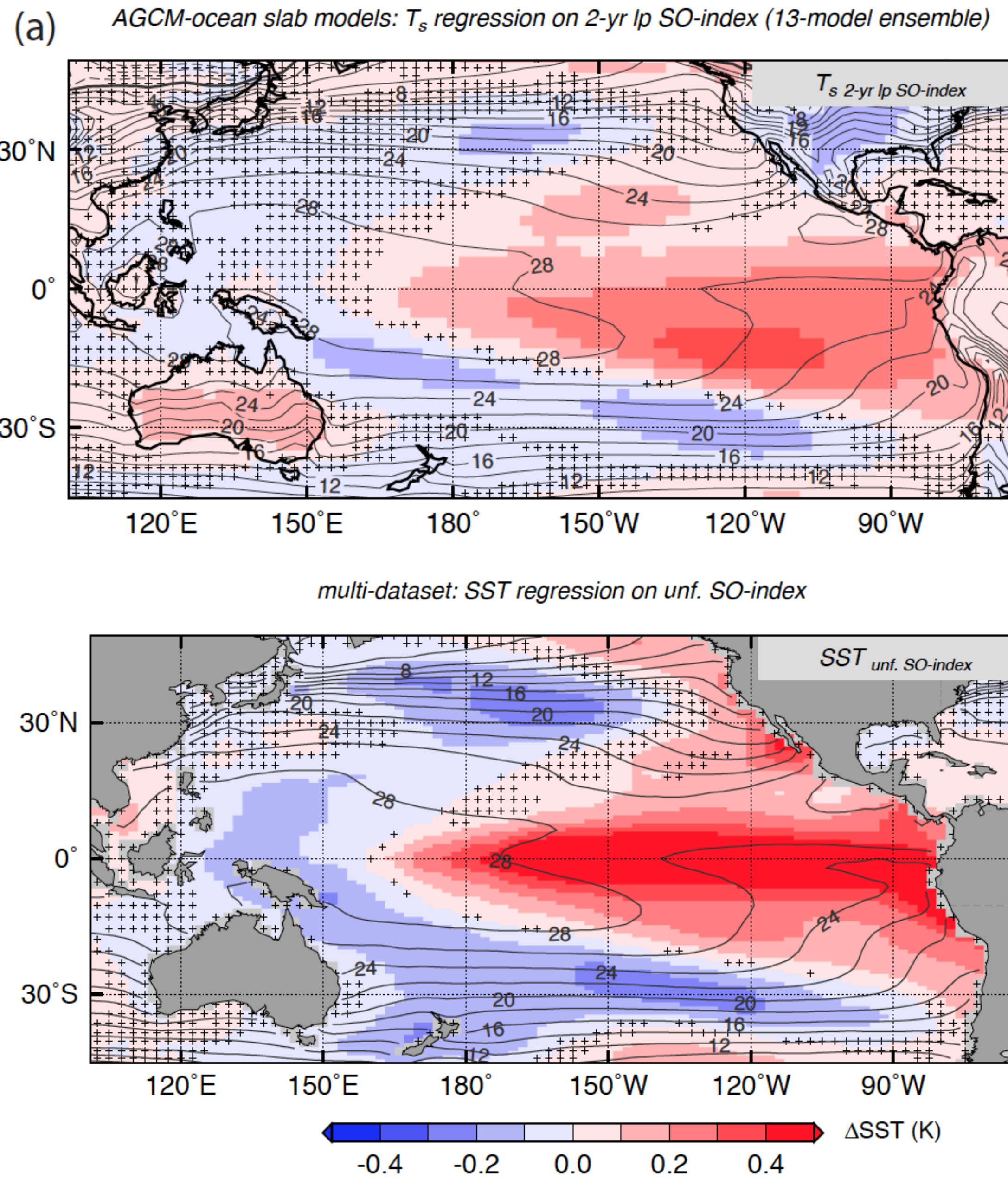


Observed regression of GPCP precip (Adler et al. 2003)

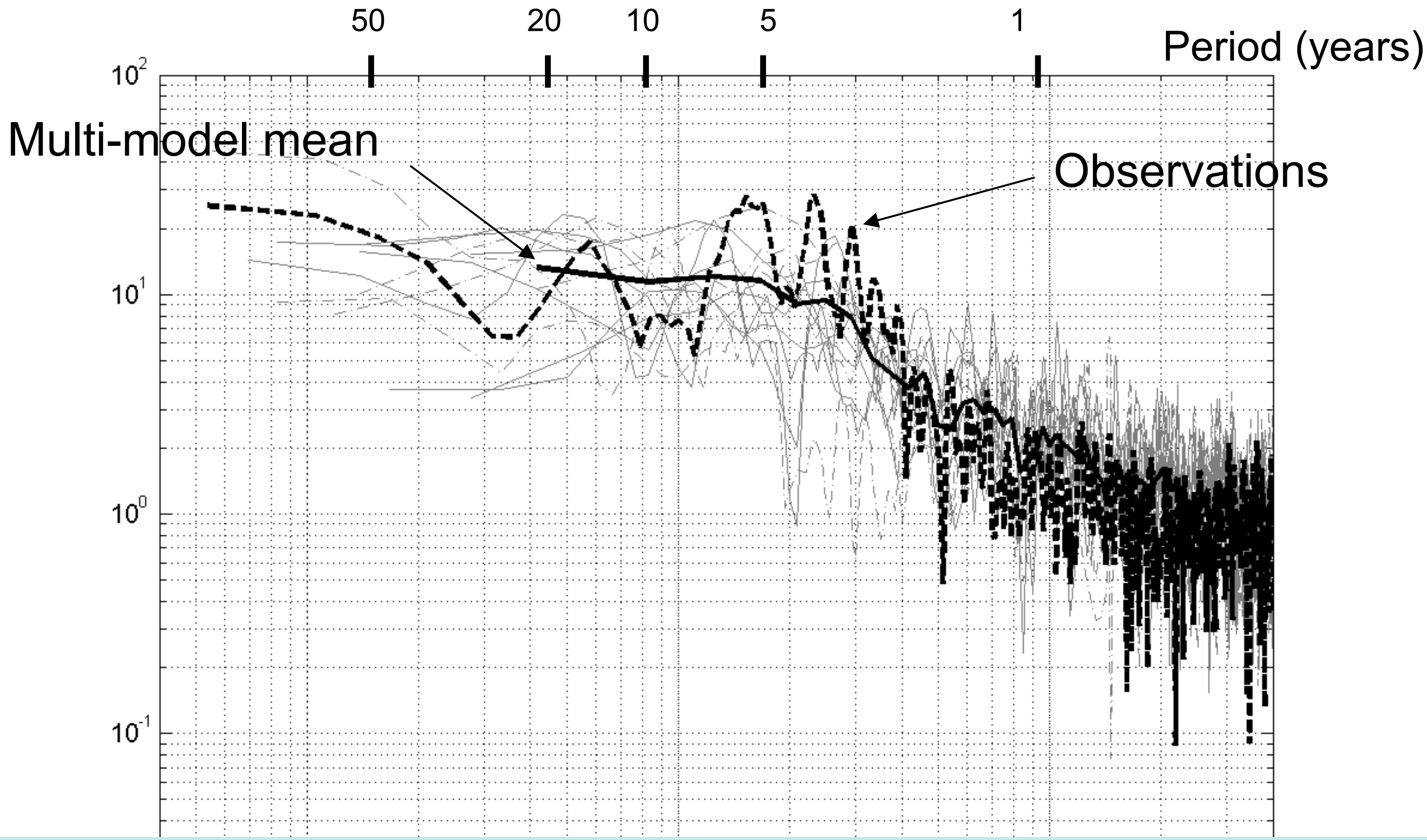


AGCM-slab multi-model mean (13 models) regression of SST on SO index

Observed regression of SST on normalized SO index



SO spectra from 13 AGCM-slab models



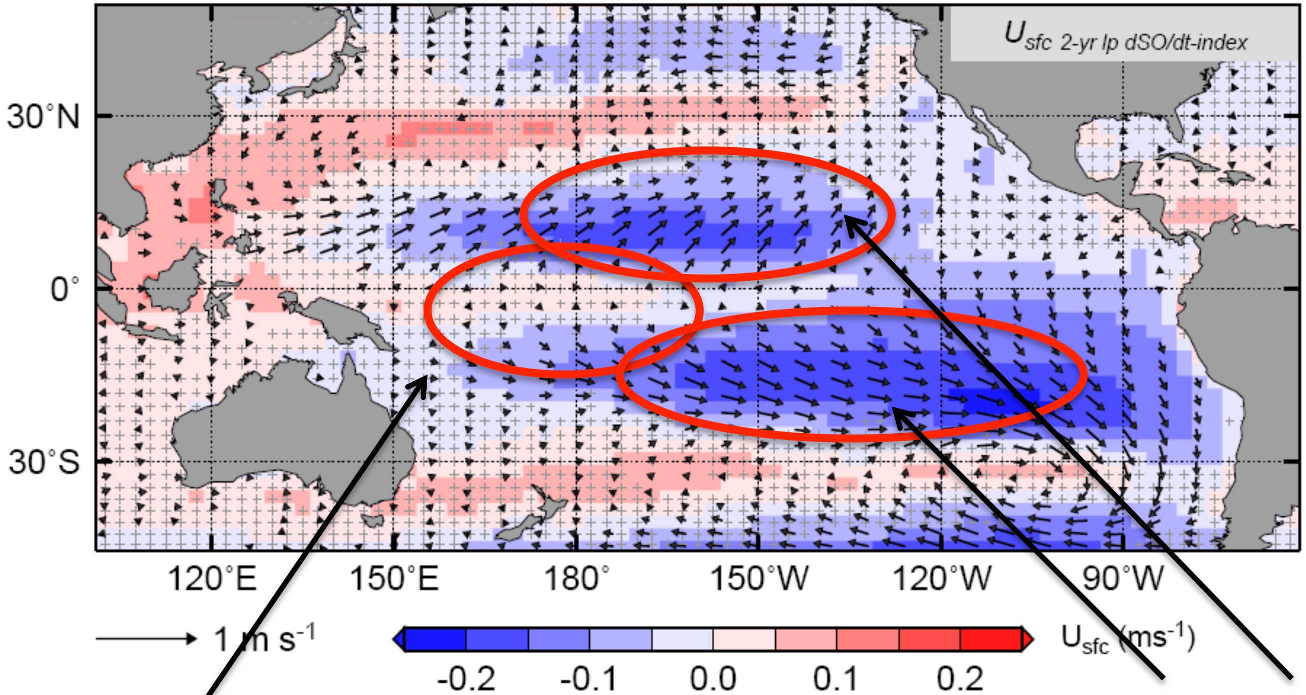
NOTE: Decorrelation timescale varies by almost an order of magnitude among models. Models with the longest timescale (MRI, HadGEM) have a strong positive low-level cloud feedback

Observed std deviation of SO index = 80 hPa

Multi-model mean std deviation = 50 hPa

Mechanism: Stochastic forcing by trade winds 'filtered' through the heat capacity of the ocean

Surface wind speed (colors) and vector



Weaker mass flux convergence→ reduce cloud cover → warming

Reduced surface latent heat flux→ warming

<u>Mechanism:</u> Stochastic forcing by trade winds 'filtered' through the heat capacity of the ocean

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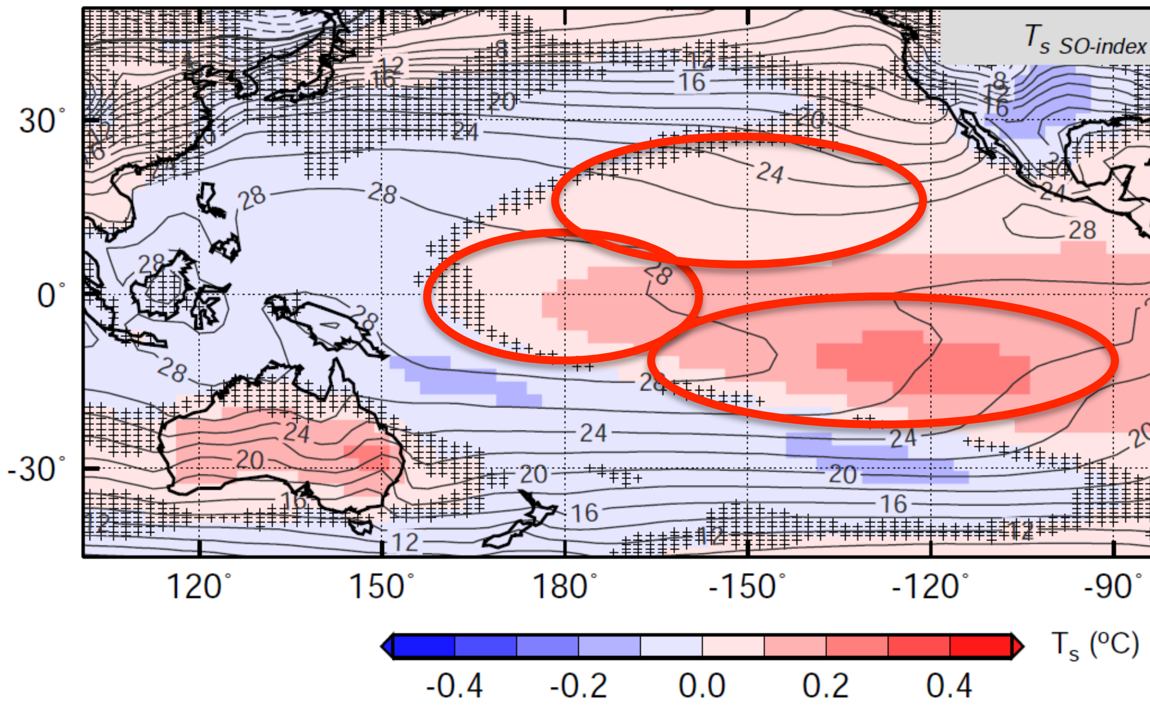


Weaker mass flux convergence→ reduce cloud cover → warming

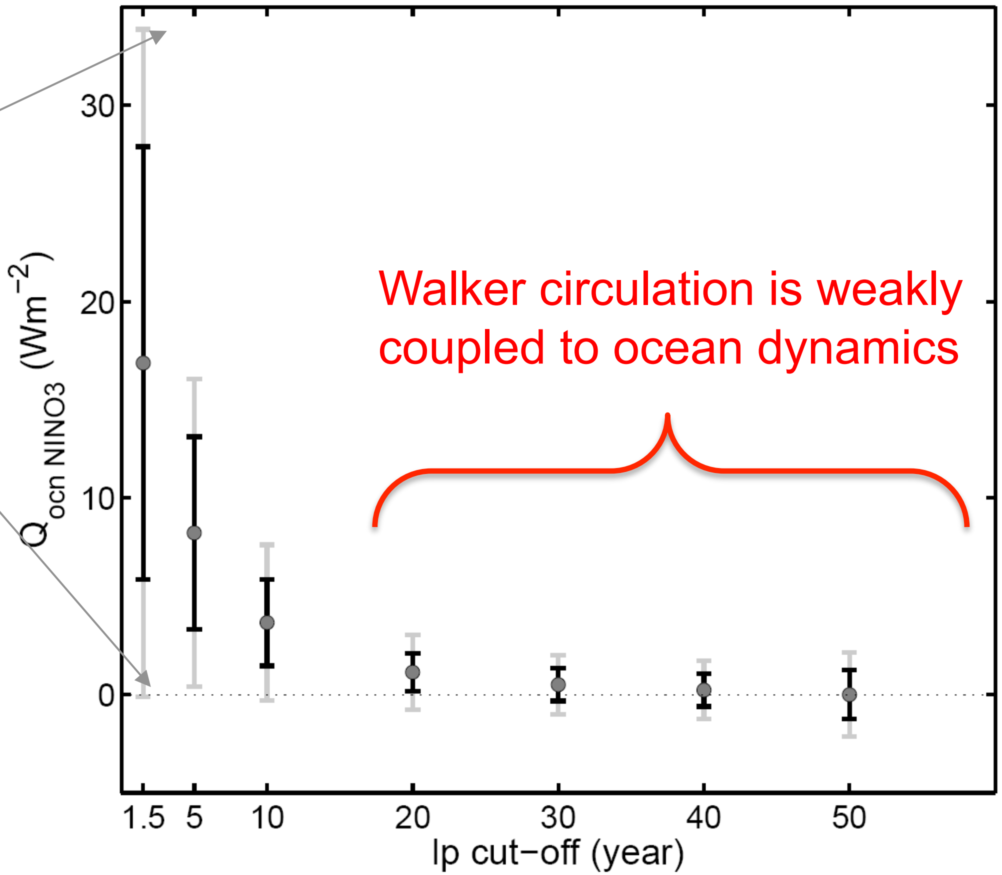
Reduced surface latent heat flux→ warming

Summary point #1:

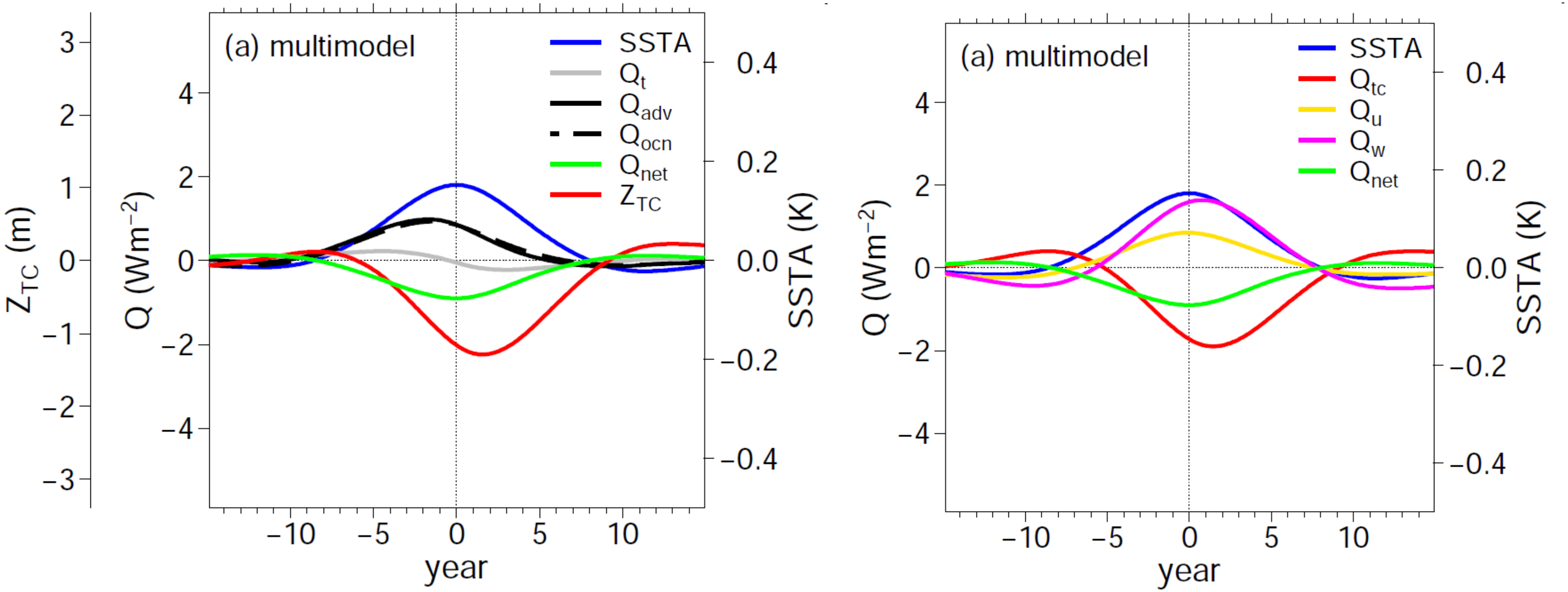
Realistic ENSO-like variability can arise on interannual to decadal timescales without coupled ocean dynamics.

Contribution in models of ocean advection to NINO3 growth on different timescales: coupled GCMS

Min/max of all 13 models



Composites of NINO3.4 evolution in coupled climate models

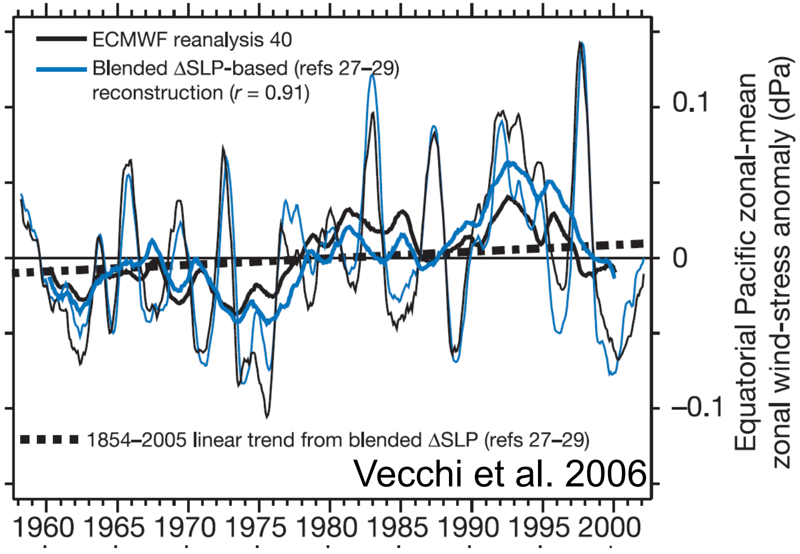


- Zonal advection and upwelling contribute to growth on decadal timescales.
- Thermocline is damps on decadal timescales.

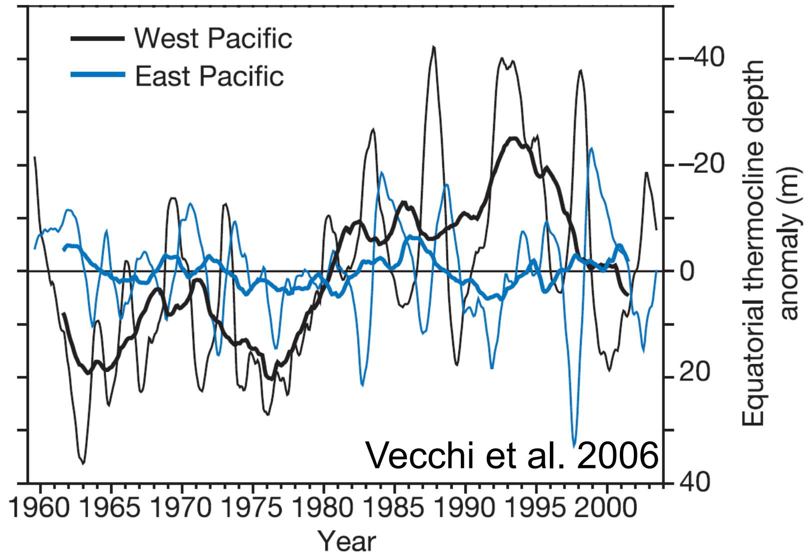
DiNezio et al. *In prep*

Support from ocean reanalysis

τ_x

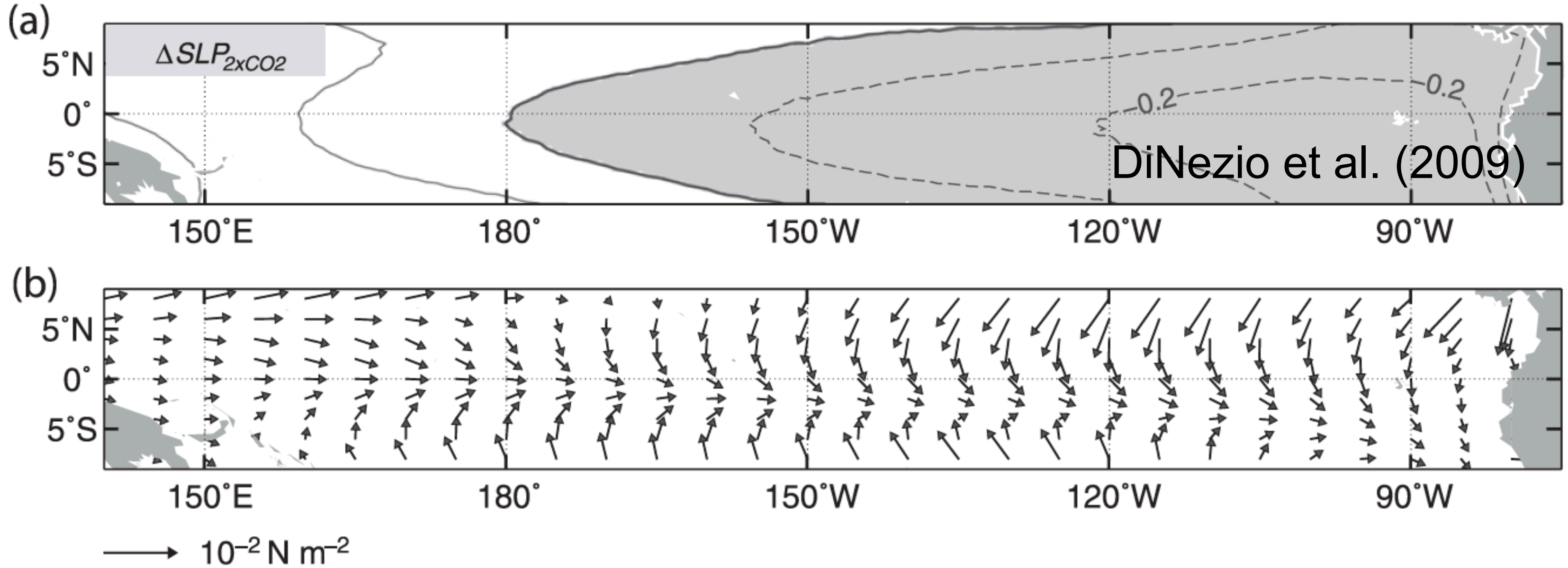


Thermocline depth in the east (blue) and west (black)



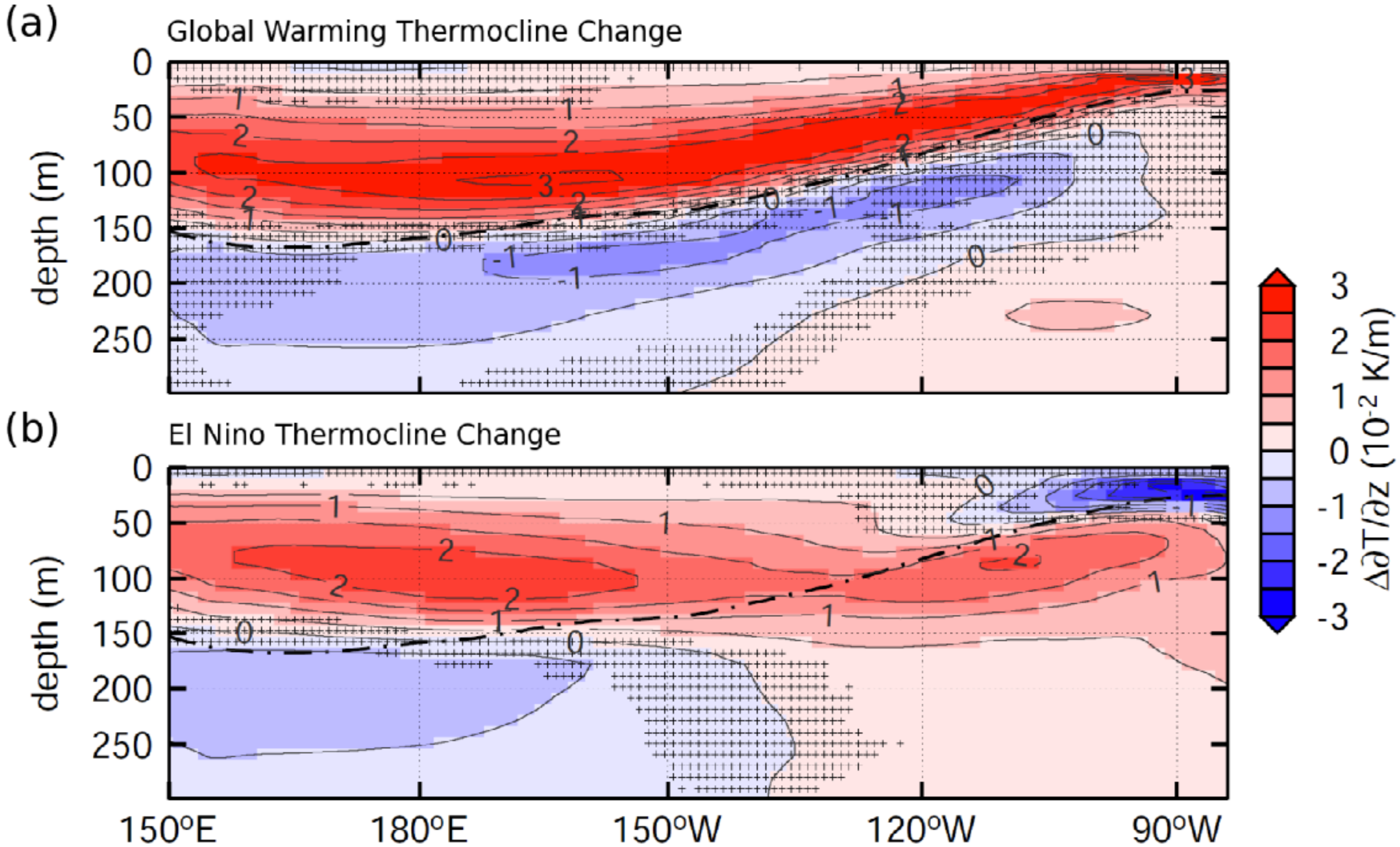
On a decadal timescale, thermocline fluctuations are small in east because of cancellation between tilt and recharge modes (Clarke 2010). In the west and central-west (Nino3.4), they are additive and signals are large.

Anthropogenic forcing



Walker circulation weakens because precipitation does not increase as quickly as evaporation in a warming world (Held and Soden 2006)

Thermocline response is not El Nino-like

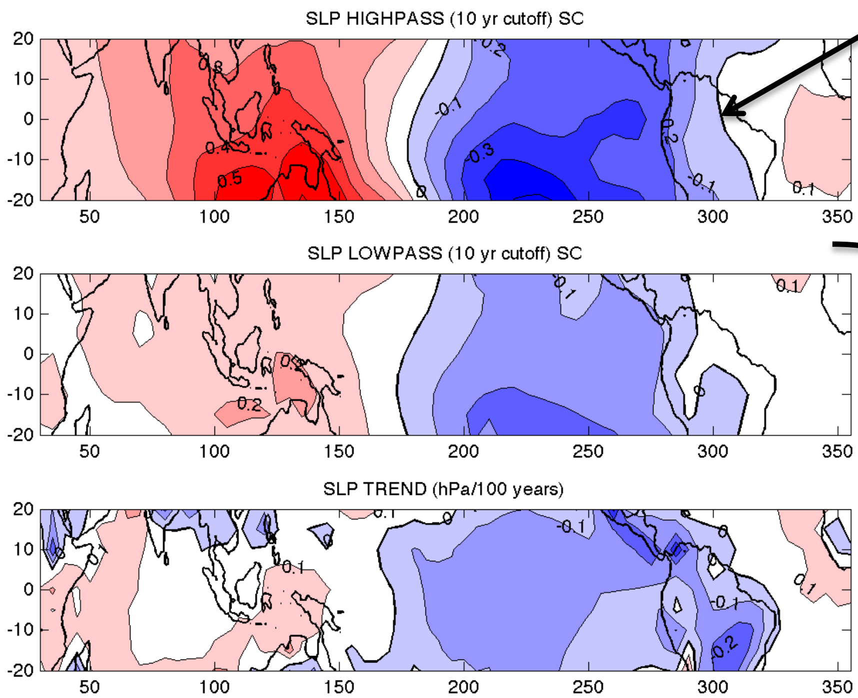


Shoaling and sharpening of the thermocline cools east Pacific:
WEAKLY COUPLED WALKER CIRCULATION

DiNezio et al. (2010)

Conclusions

Are the mechanisms analogous on all timescales?



This pattern emerges on interannual/ decadal timescales without coupled dynamics.

<u>Weakly Coupled Walker Circulation:</u>

Decadal timescale: The thermocline damps variability in the central Pacific with little change in the east limiting the coupled feedback

Anthropogenic forcing: The thermocline sharpens which limits warming in the east/central Pacific

- SO as a preferred pattern (mode) of Pacific variability
- Timescale of SO is unconstrained by current models- role of clouds??

→ Implications for detection/attribution

The answer from paleoclimate records is not very encouraging

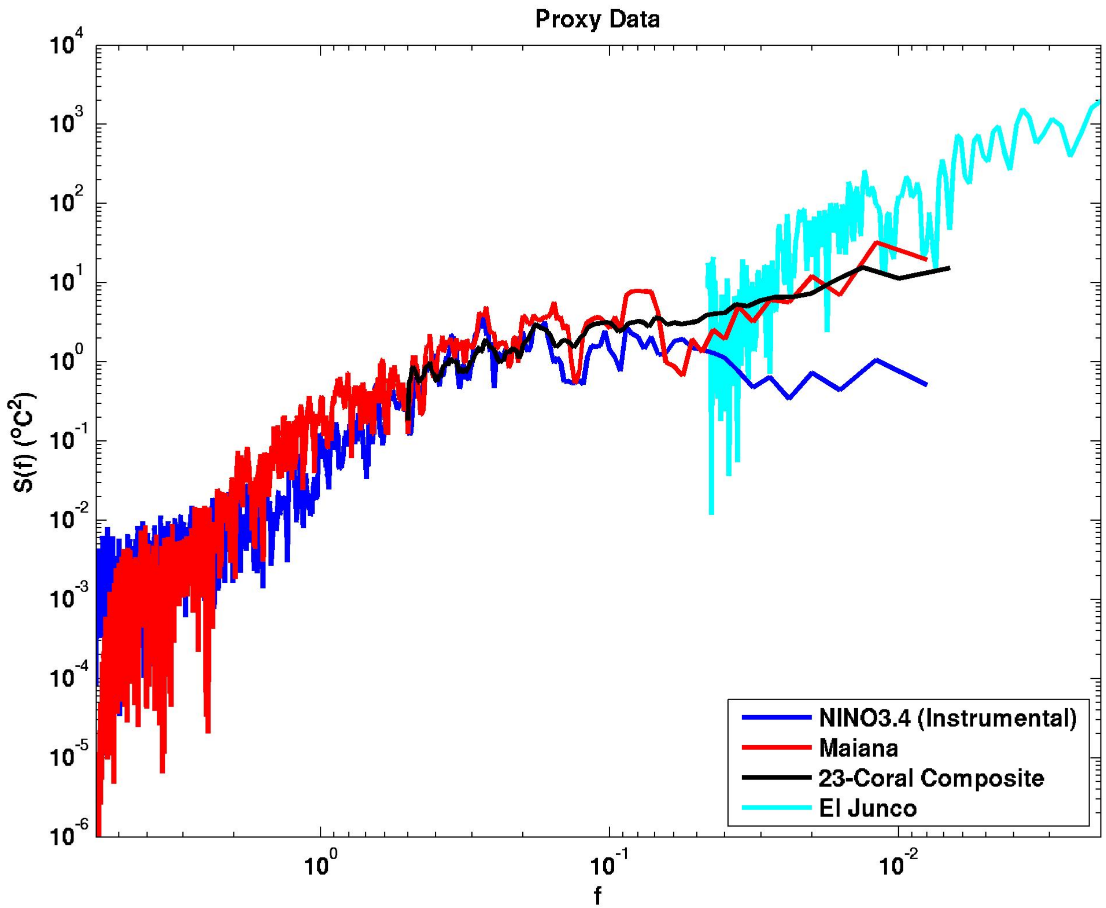
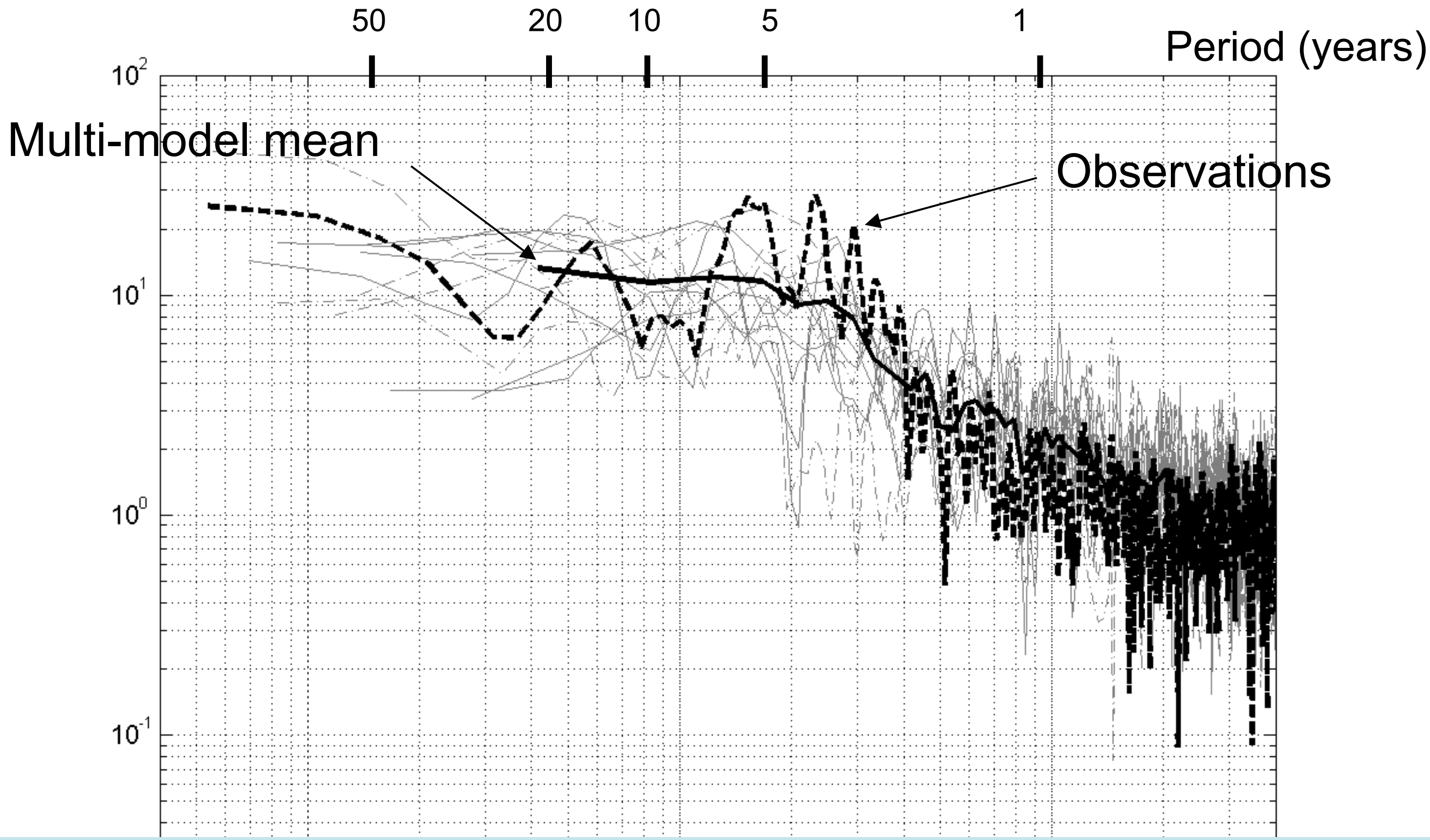


Figure courtesy of Toby Ault (U of Az)

SO spectra from 13 AGCM-slab models



NOTE: Decorrelation timescale varies by almost an order of magnitude among models. Models with the longest timescale (MRI, HadGEM) have a strong positive low-level cloud feedback

Observed std deviation of SO index = 80 hPa

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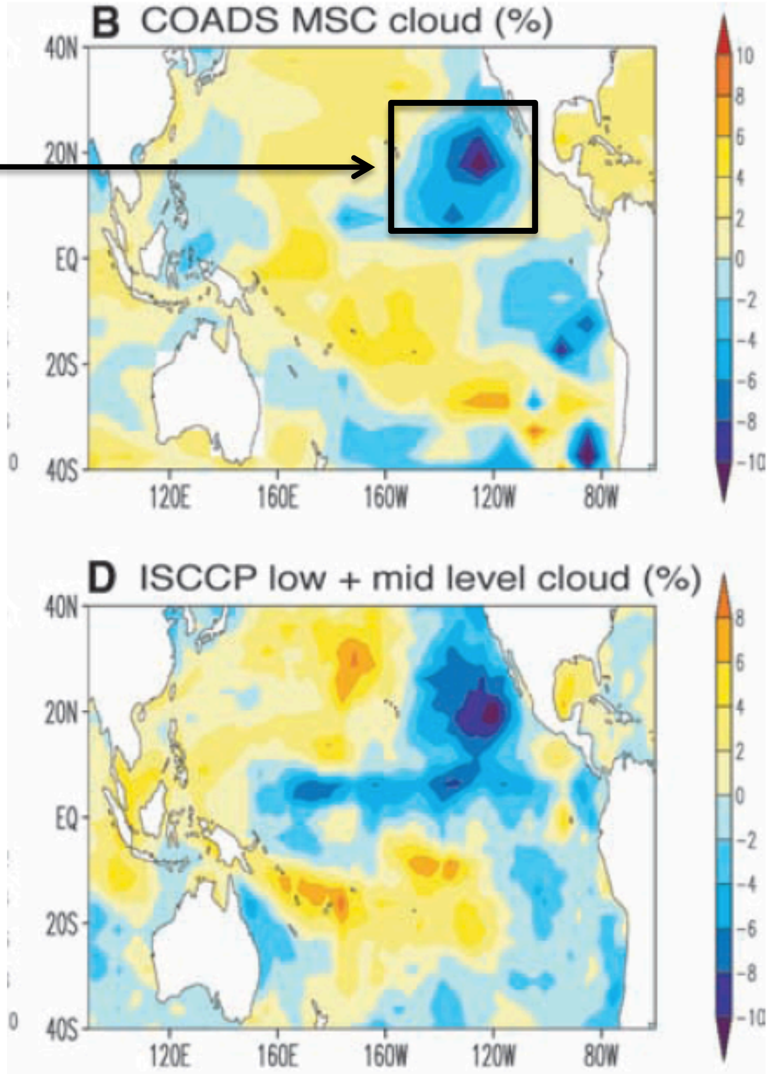
Weaker Walker pattern in low-level clouds from surface-based and satellite observations

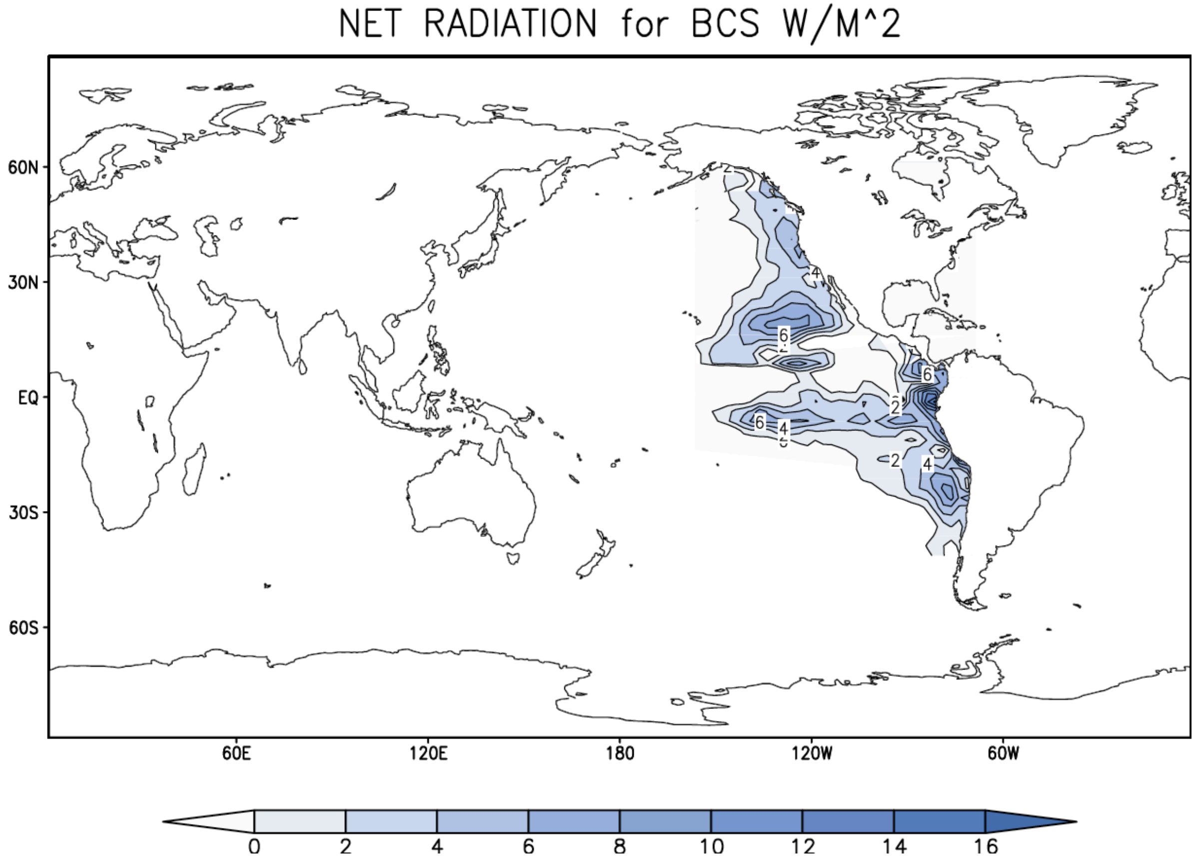
The cloud radiative forcing associated with this change in cloud cover can explain 1K warming in the region



Only one climate model (HADGEM1) simulates this observed low-level cloud cover variability

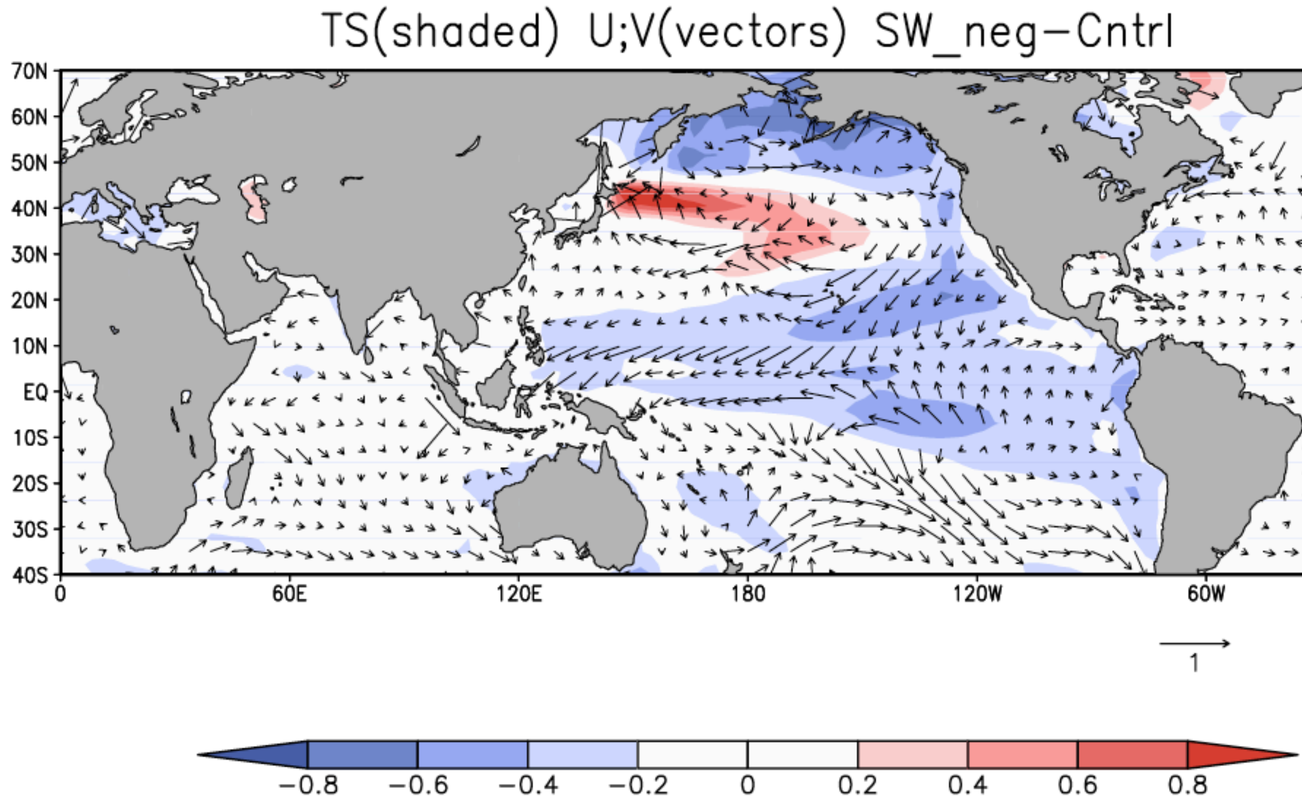
Clement, Burgman and Norris (2009)

Cloud radiative forcing associated with a *stronger* Walker circulation imposed on a coupled GCM



Burgman et al. *In prep.*

Cloud forcing produces a stronger Walker circulation – positive feedback!



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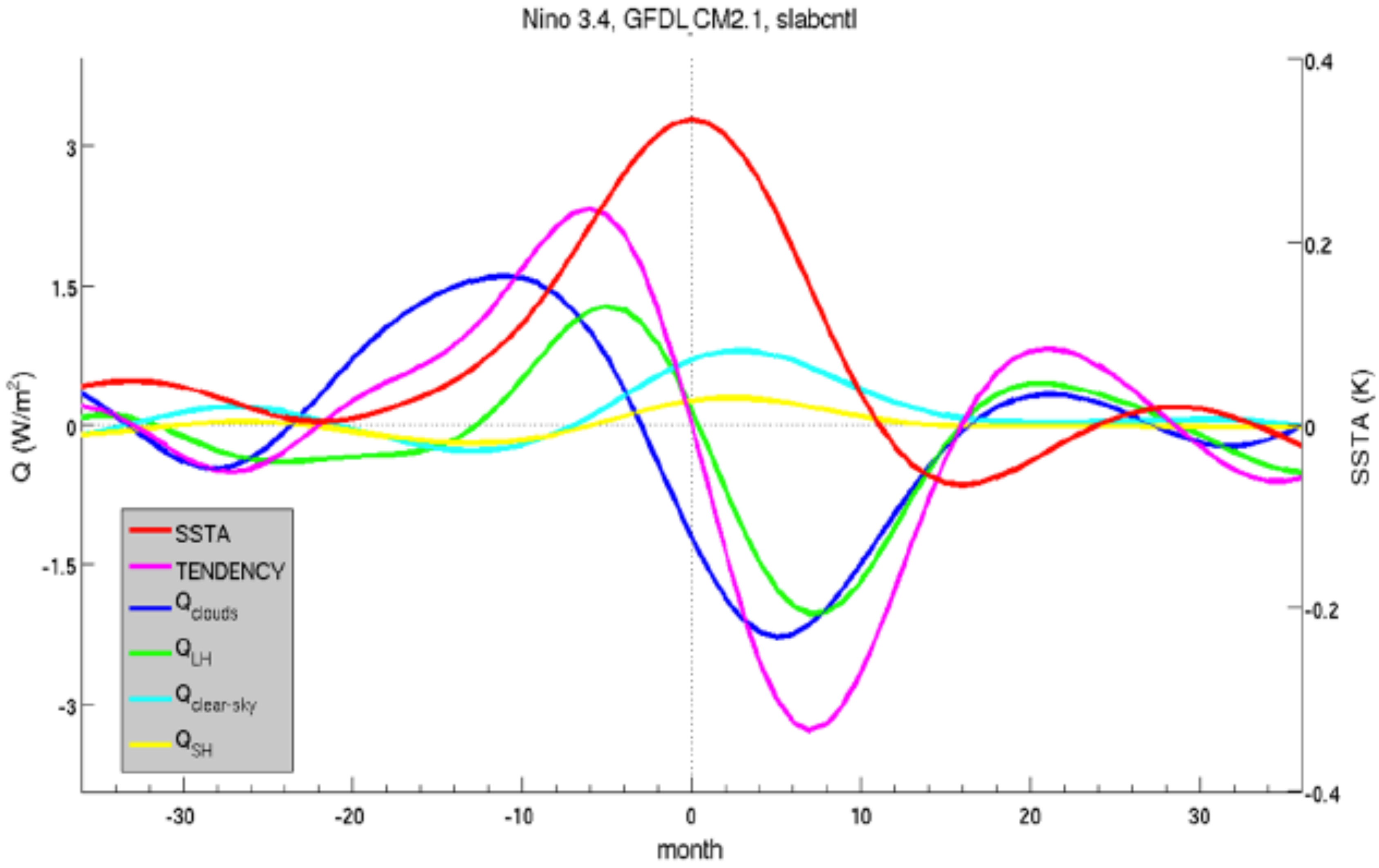
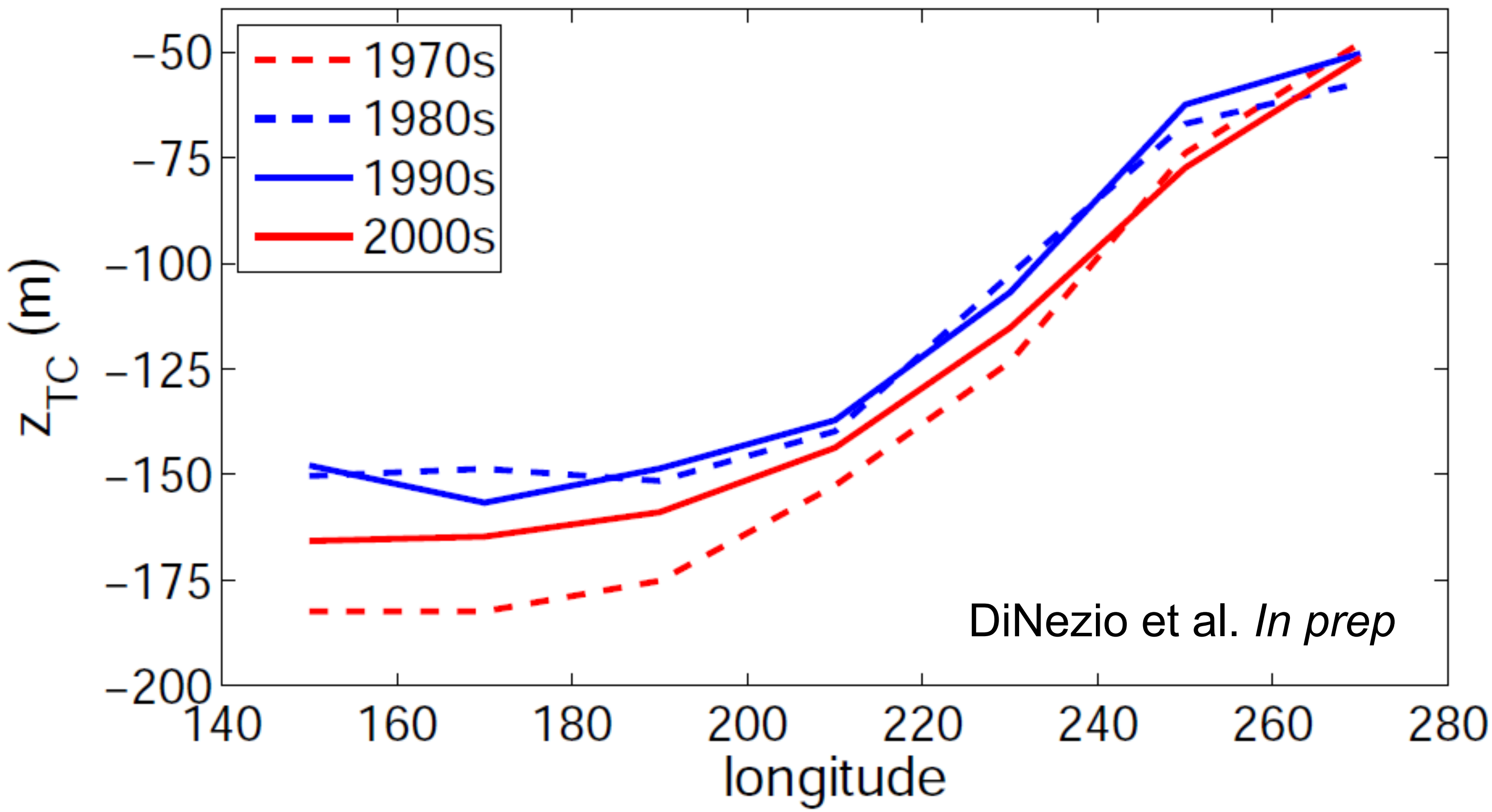


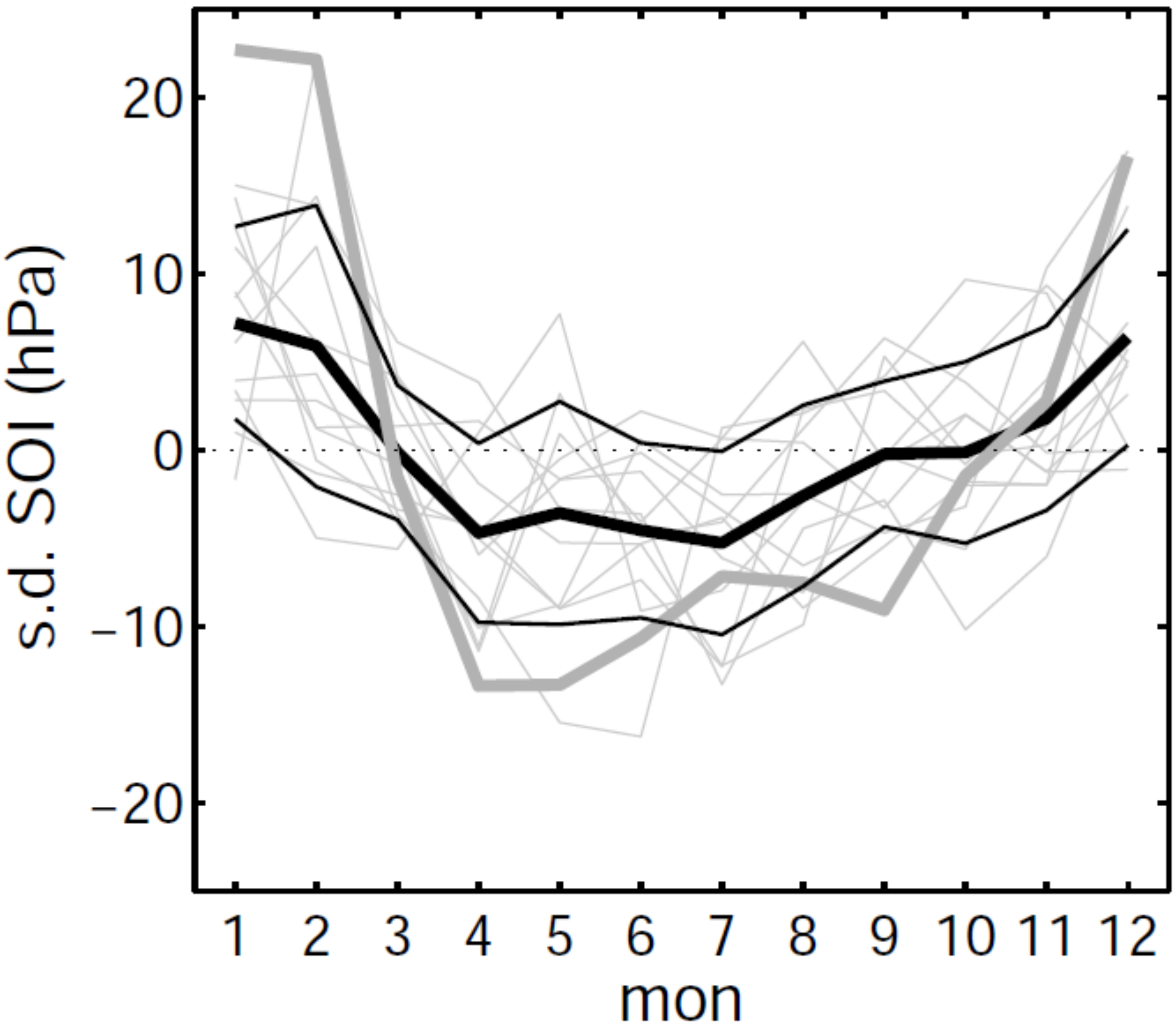
Nino 3.4, GFDL_CM2.1, slabcntl
Q (W/m²)
SSTA (K)
month
3
1.5
0
-1.5
-3
0.4
0.2
0
-0.2
-0.4
-30
-20
-10
0
10
20
30
SSTA
TENDENCY
Q_clouds
Q_LH
Q_clear-sky
Q_SH

Nino

Decadal variability of thermocline



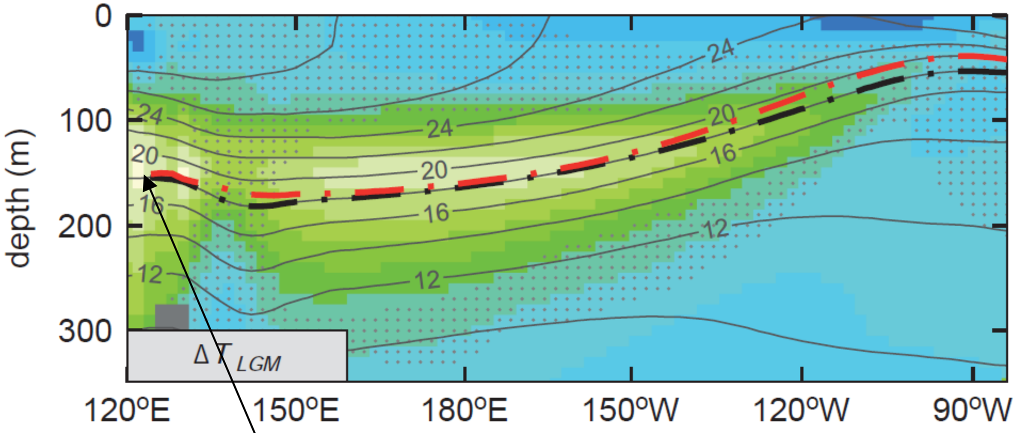
- deep thermocline during decades with stronger winds.
- shallow thermocline during decades with weaker winds.



20
10
0
−10
−20
s.d. SOI (hPa)
1
2
3
4
5
6
7
8
9
10
11
12
mon

Constraining the sensitivity of the Walker circulation using LGM proxies

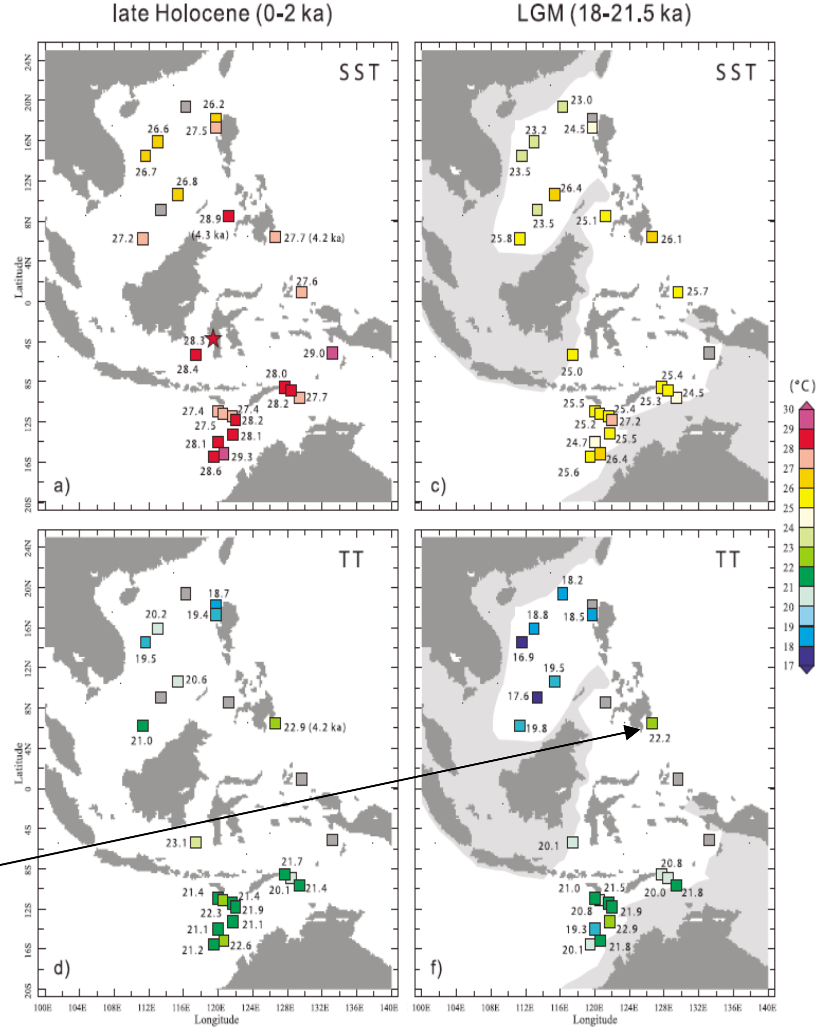
Subsurface temperature changes in models with a stronger LGM Walker circulation



DiNezio et al. 2011

No cooling below the surface due to wind-driven thermocline deepening

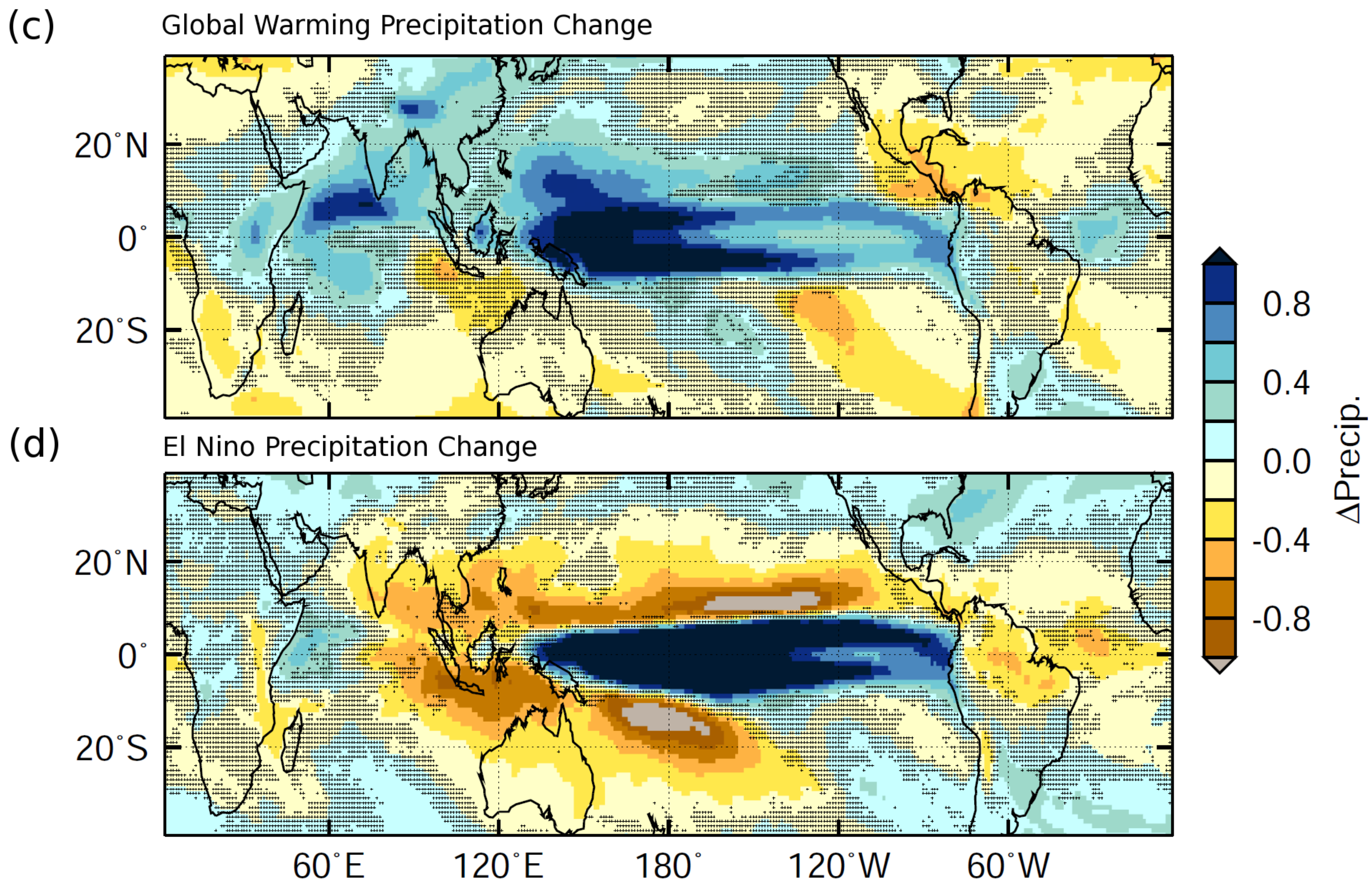
?



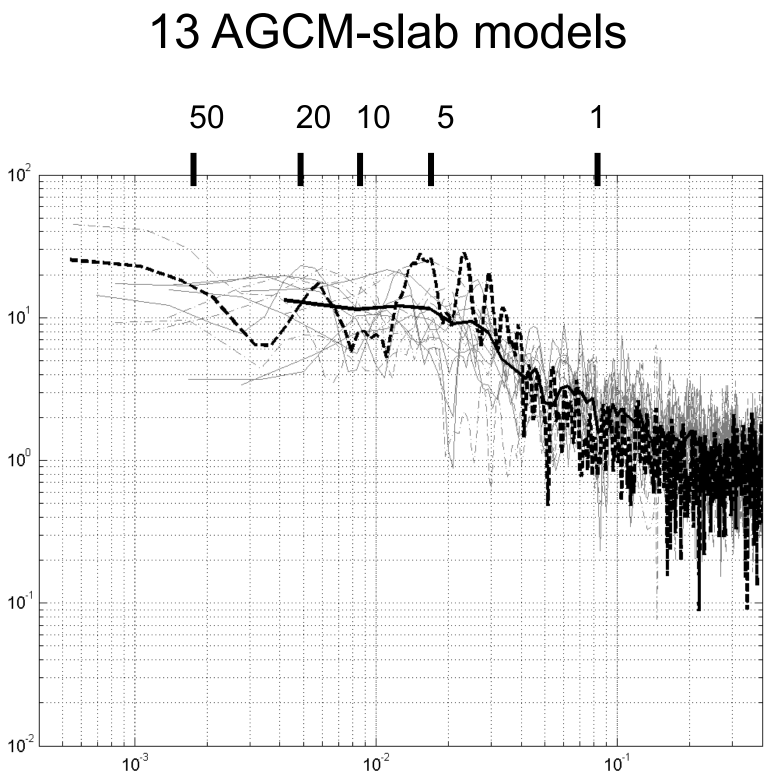
Surface and thermocline temperatures (°C) during late Holocene (0–2 ka), and LGM (18–21.5 ka).

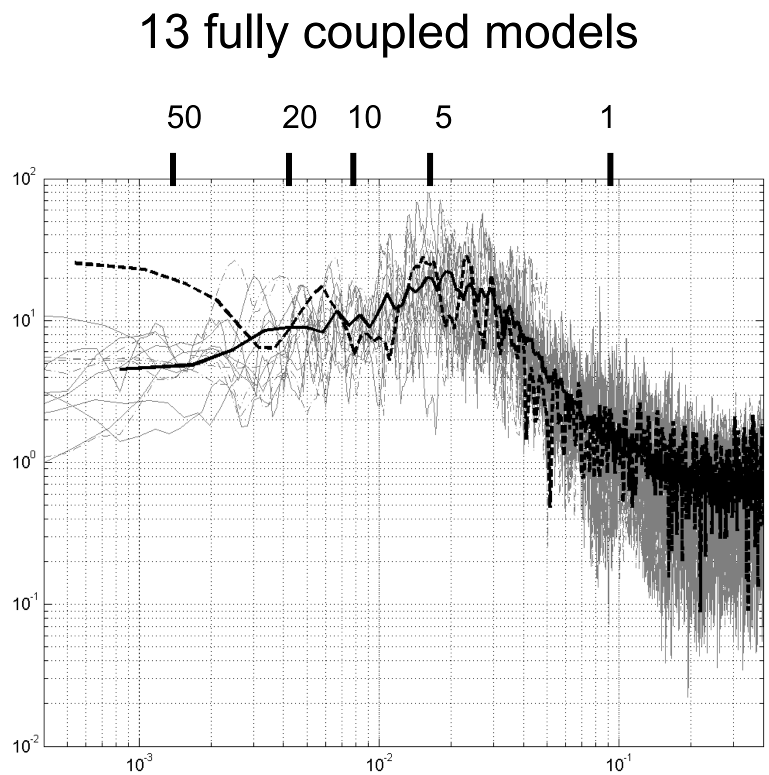
Yu et al. 2010

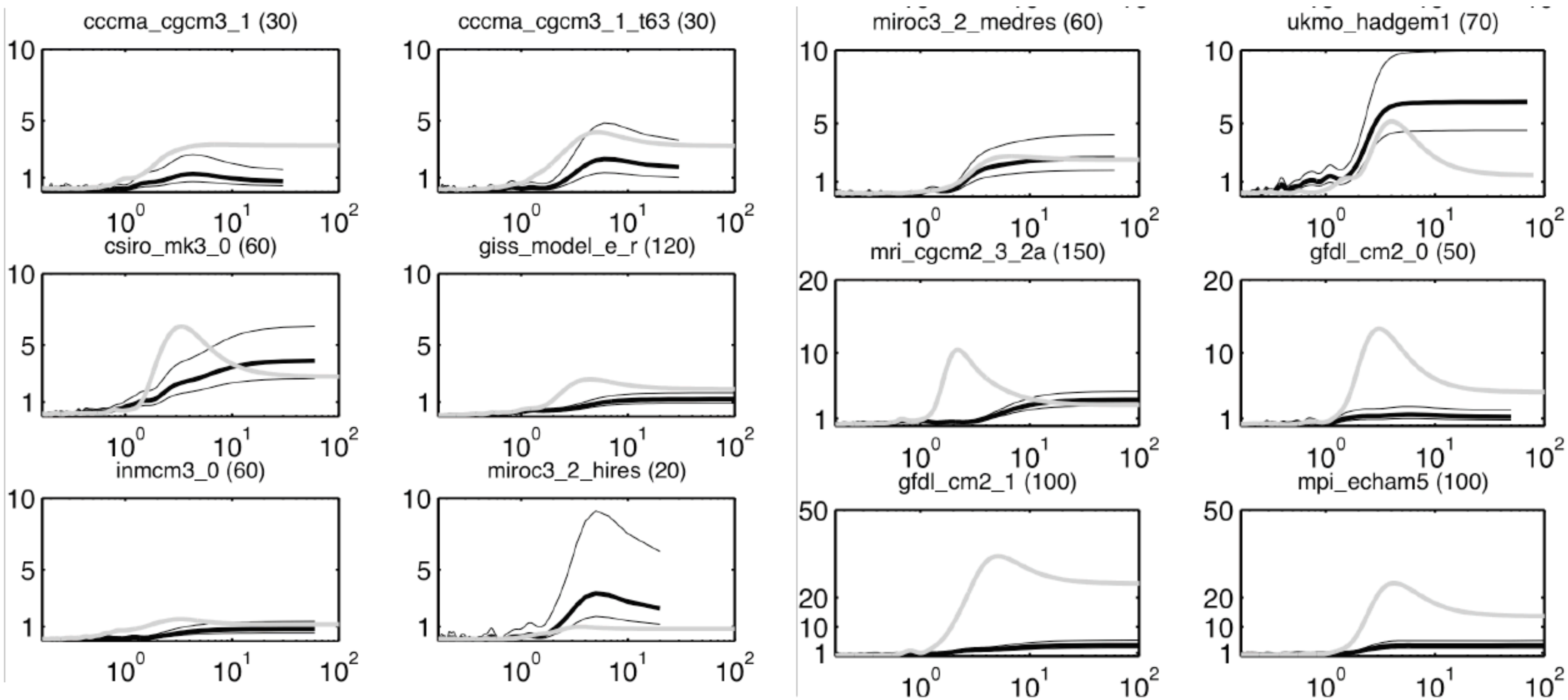
Impacts are not El Nino-like either



The simulated role of the ocean

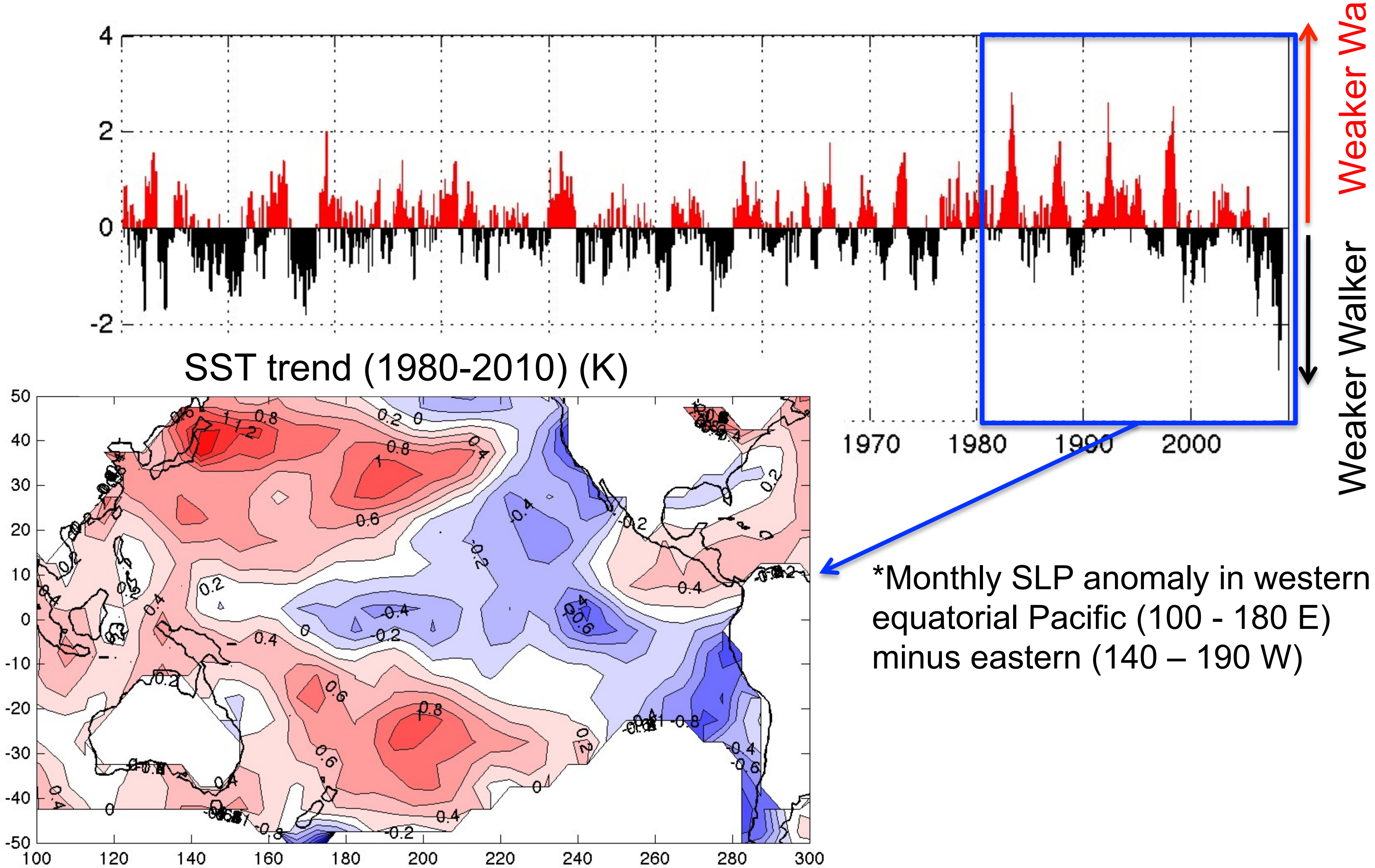






cccma_cgcm3_1 (30)
cccma_cgcm3_1_t63 (30)
miroc3_2_medres (60)
ukmo_hadgem1 (70)
csiro_mk3_0 (60)
giss_model_e_r (120)
mri_cgcm2_3_2a (150)
gfdl_cm2_0 (50)
inmcm3_0 (60)
miroc3_2_hires (20)
gfdl_cm2_1 (100)
mpi_echam5 (100)
10^0
10^1
10^2

Walker Circulation Strength Index*



*Monthly SLP anomaly in western equatorial Pacific (100 - 180 E) minus eastern (140 – 190 W)