Understanding the impacts of mean state biases on the ENSO amplitude

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OUTLINE

1. Background and Motivations
2. Model Development
3. What are the impacts of mean state biases on ENSO amplitude?
4. Summary

Background and motivations

Challenges: amplitude, periodicity, irregularity, skewness, phase locking, and spatial patterns (e.g., Guilyardi et al. 2009).

The poor simulations of ENSO seriously affect

1) the skill of predictability on seasonal to interannual time scales (e.g., Vitart et al. 2003).

2) ability to correctly reproduce some of the most prominent teleconnection patterns (e.g., Cai et al. 2009).

3) the confidence how ENSO will change under anthropogenic forcing (e.g., Latif and Keenlyside, 2009).

The sensitivity of ENSO to mean state has been extensively explored in many previous studies (e.g., Battisti and Hirst 1989; Codron et al. 2001; Guilyardi 2006; Spencer et al. 2007; Manganello and Huang 2009).

However, it is still not fully understood!

Jin et al. (2006) proposed five different feedbacks:

- **Positive**: 1) the zonal advection feedback, 2) the Ekman pumping feedback, 3) the thermocline feedback.
- **Negative**: 1) Mean advection and upwelling feedback, 2) the thermal damping
- Air-sea coupling strength, which measures the wind response to SST anomalies, is a main contributor to the three positive feedbacks.

$$\frac{\partial T}{\partial t} = -\left(\bar{u}\frac{\partial T}{\partial x} + \bar{v}\frac{\partial T}{\partial y} + u\frac{\partial \bar{T}}{\partial x} + v\frac{\partial \bar{T}}{\partial y} + \bar{w}\frac{\partial T}{\partial z} + w\frac{\partial \bar{T}}{\partial z}\right) + Q,$$

Thermal damping

$$\mu_a^* \beta_h \left\langle \frac{H(\bar{w})\bar{w}}{H_m} a \right\rangle$$

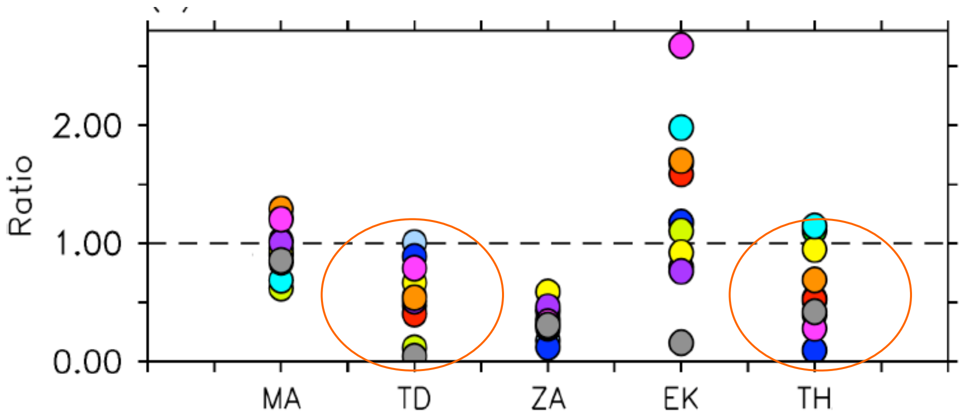
Thermocline feedback

$$\langle h \rangle = \langle T_{sub} \rangle / a.$$

$$\langle h \rangle - [h] = \beta_h [\tau_x].$$

$$[\tau_x] = \mu_a^* \langle T \rangle$$

Jin et al. 2006



TH: thermocline feedback

EK: Ekman feedback

ZA: Zonal advection

TD: thermodynamical damping

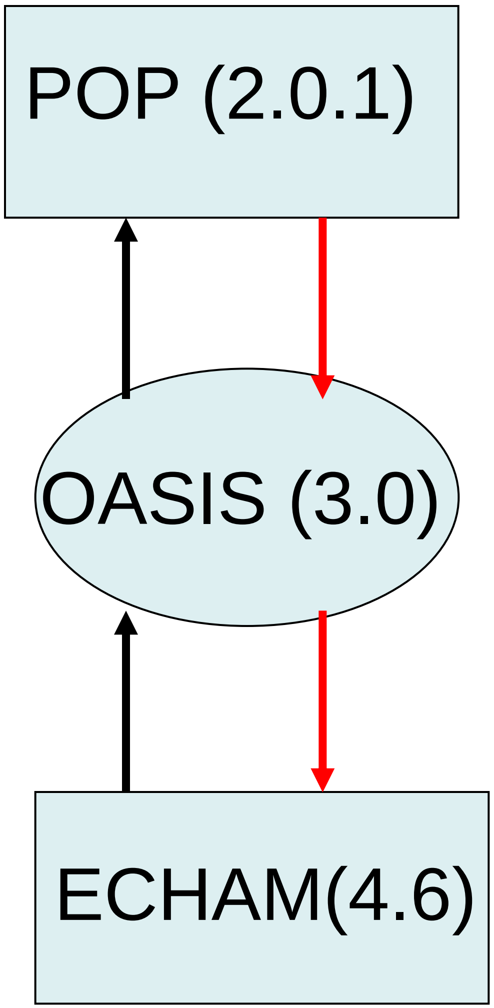
MA: dynamical damping by mean advection and upwelling

cgcm3_1_t47 csiro_mk3_5 iap_fgoals1_0g mpi_echam5
cgcm3_1_t63 gfdl_cm2_0 ipsl_cm4 mri_cgcm2_3a
cnrm_cm3 gfdl_cm2_1 miroc3_2_med ncar_ccsm3_0

Kim and Jin, submitted

Model Development

POEM (POP-OASIS-ECHAM Model)



Los Alamos National Laboratory

CERFACS,

France

MPI

Coupling between 60S-60N (no ice model).

POP model (Horizontal: 100×116 Vertical: 25 levels)

1) Horizontal tracer diffusion: Gent-McWilliams (1990)

2) Vertical Mixing: KPP boundary-layer parameterization

3) Considering the surface ocean currents when calculating wind stress

ECHAM4.6 (T42)

1) Turbulent surface fluxes: Monin-Obukhov similarity theory (Louis, 1979).

2) Cumulus convection is based on the bulk mass flux concept of Tiedtke (1989).

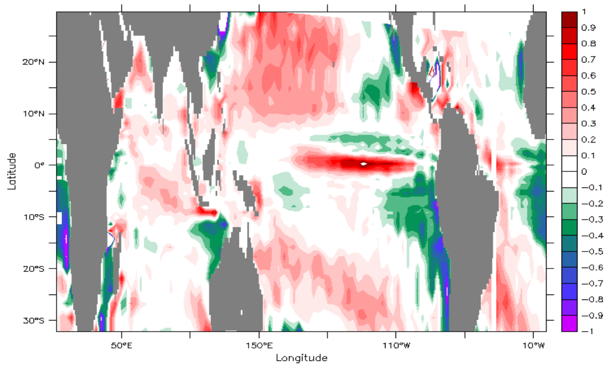
3) Closure/trigger: CAPE/moisture convergence (Kuo-type).

How the mean state biases influence the ENSO simulations?

Experiment Designs

1) POEM: Fully coupled (80 yr after a 300 yr spinup)

2) AMSC: coupled run with annual mean SST correction (Li and Hogan, 1999)



3) OCN run: with daily wind stress from coupled model output and observational heat flux forcings

4) AMIP run

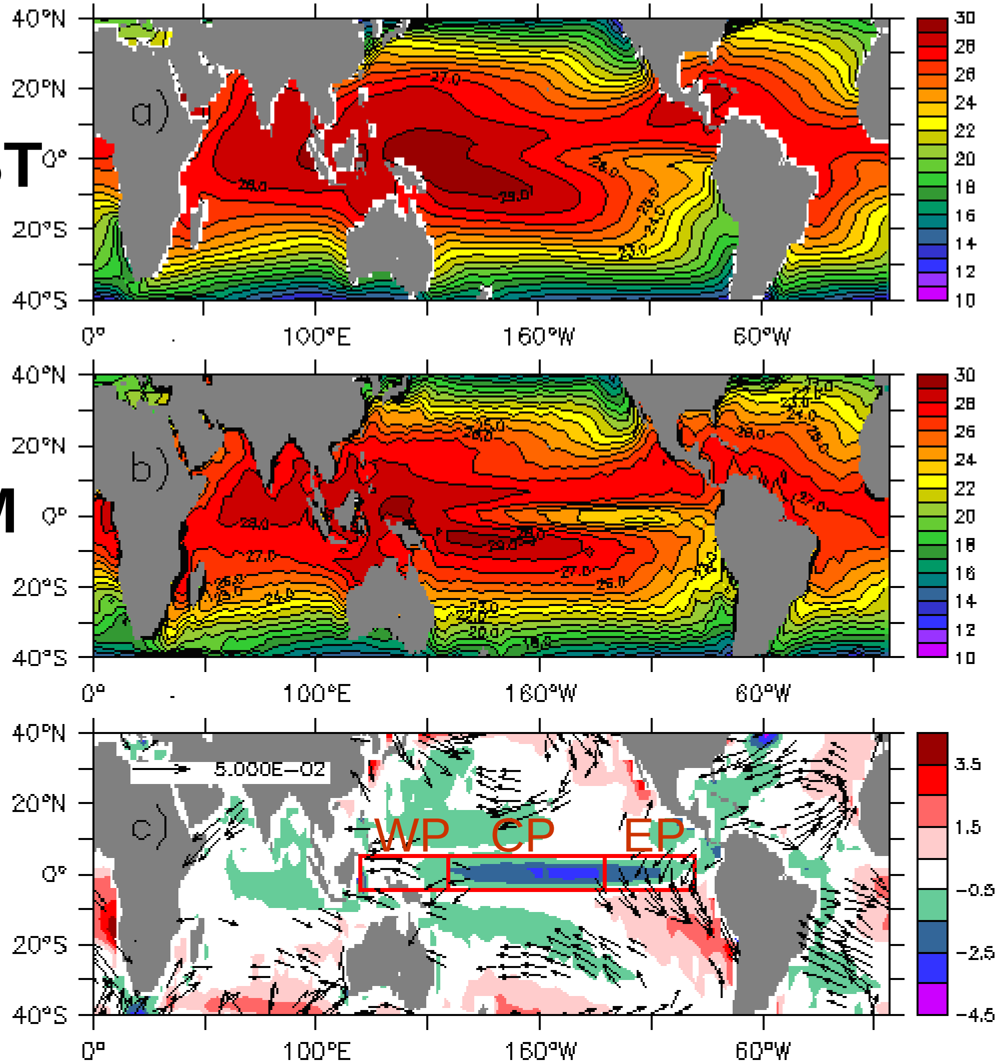
Climatological SST

(1958-2009)

ERSST

POEM

Bias



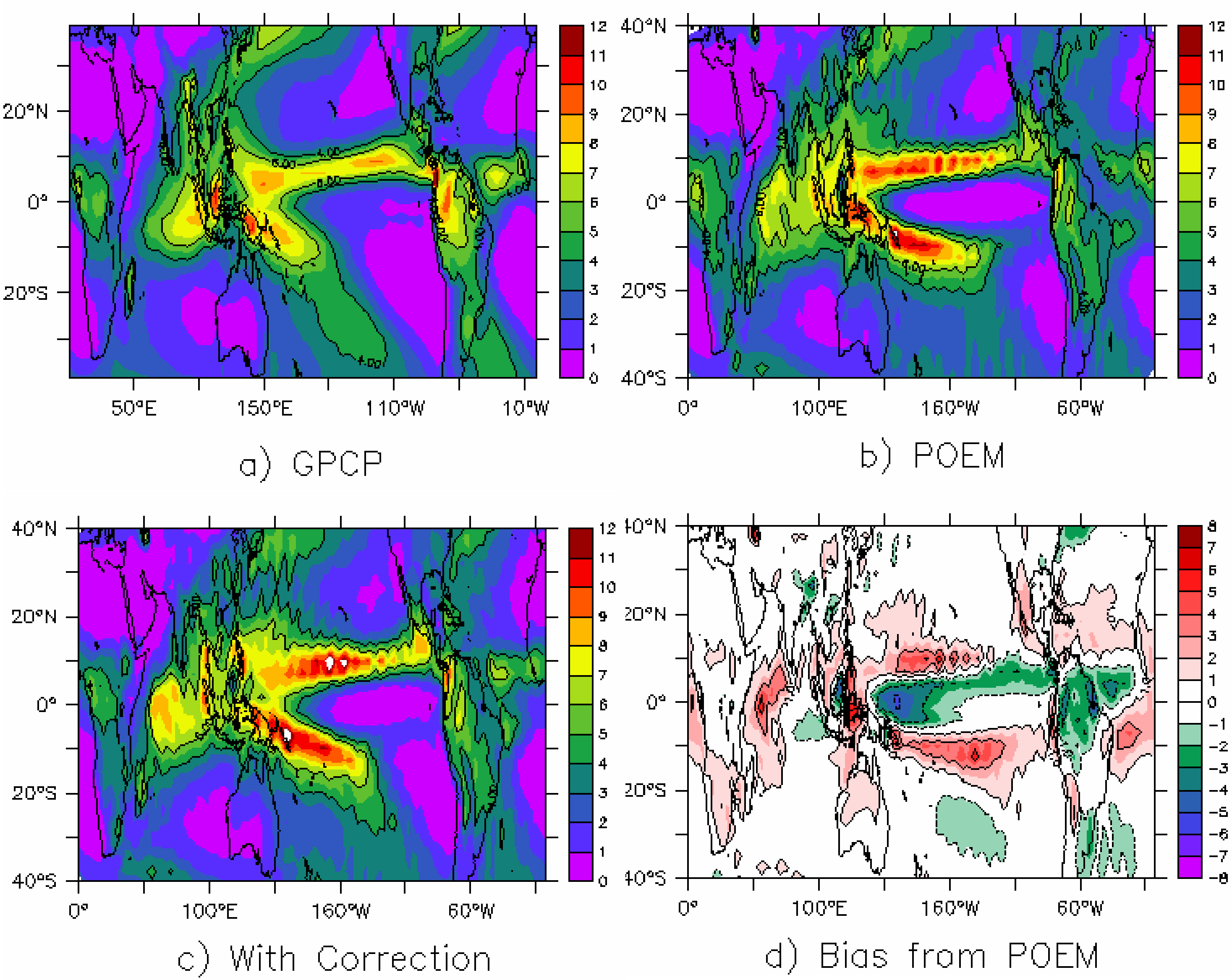
WP: 120-160E

CP: 160E-130W

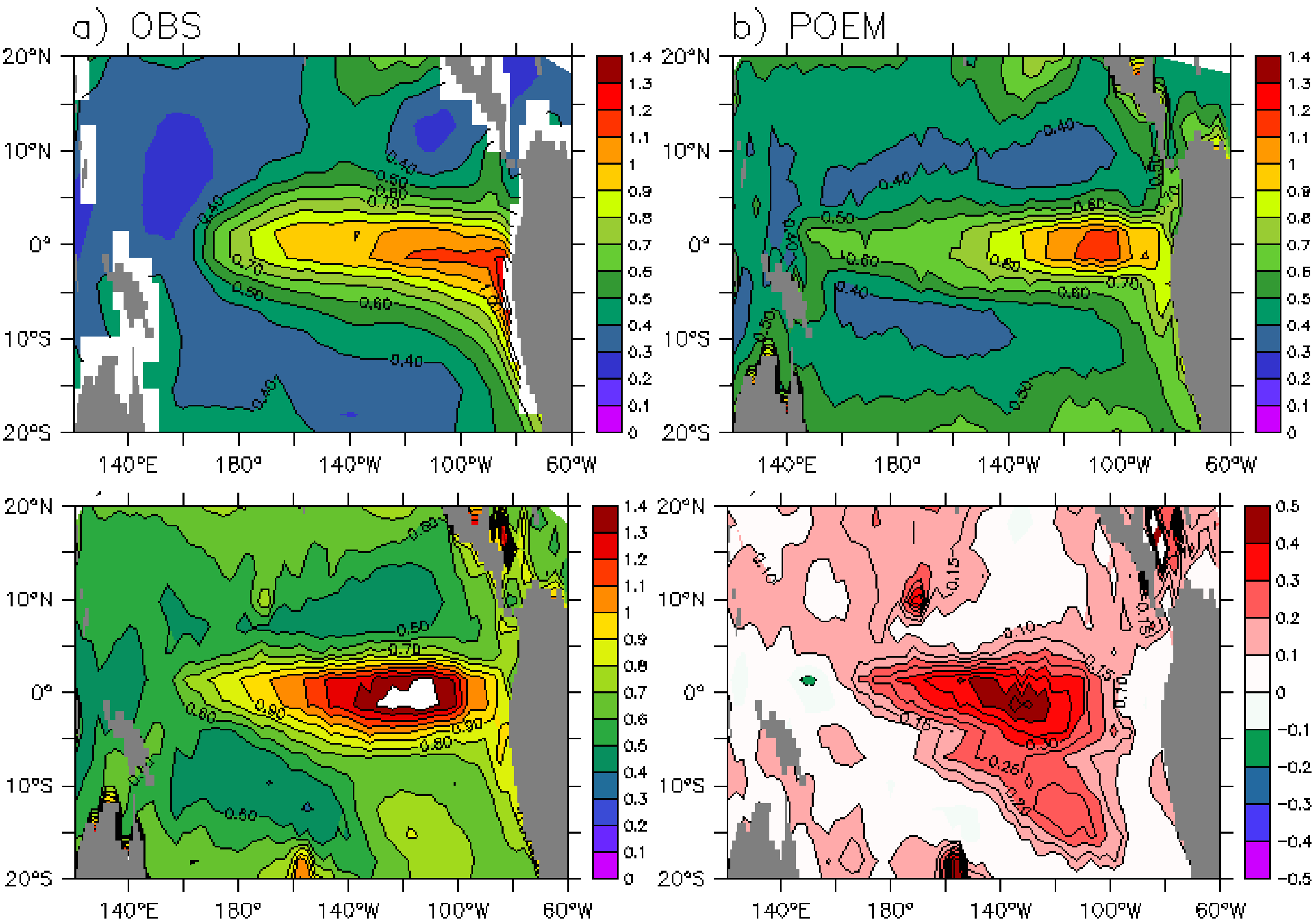
EP: 130W-90W

Vectors in c) represents the surface wind stress bias compared to ERA40 climatology. Units for wind stress is N/ m^2 (values less than 0.015 N/ m^2 not shown).

Climatological Precipitation

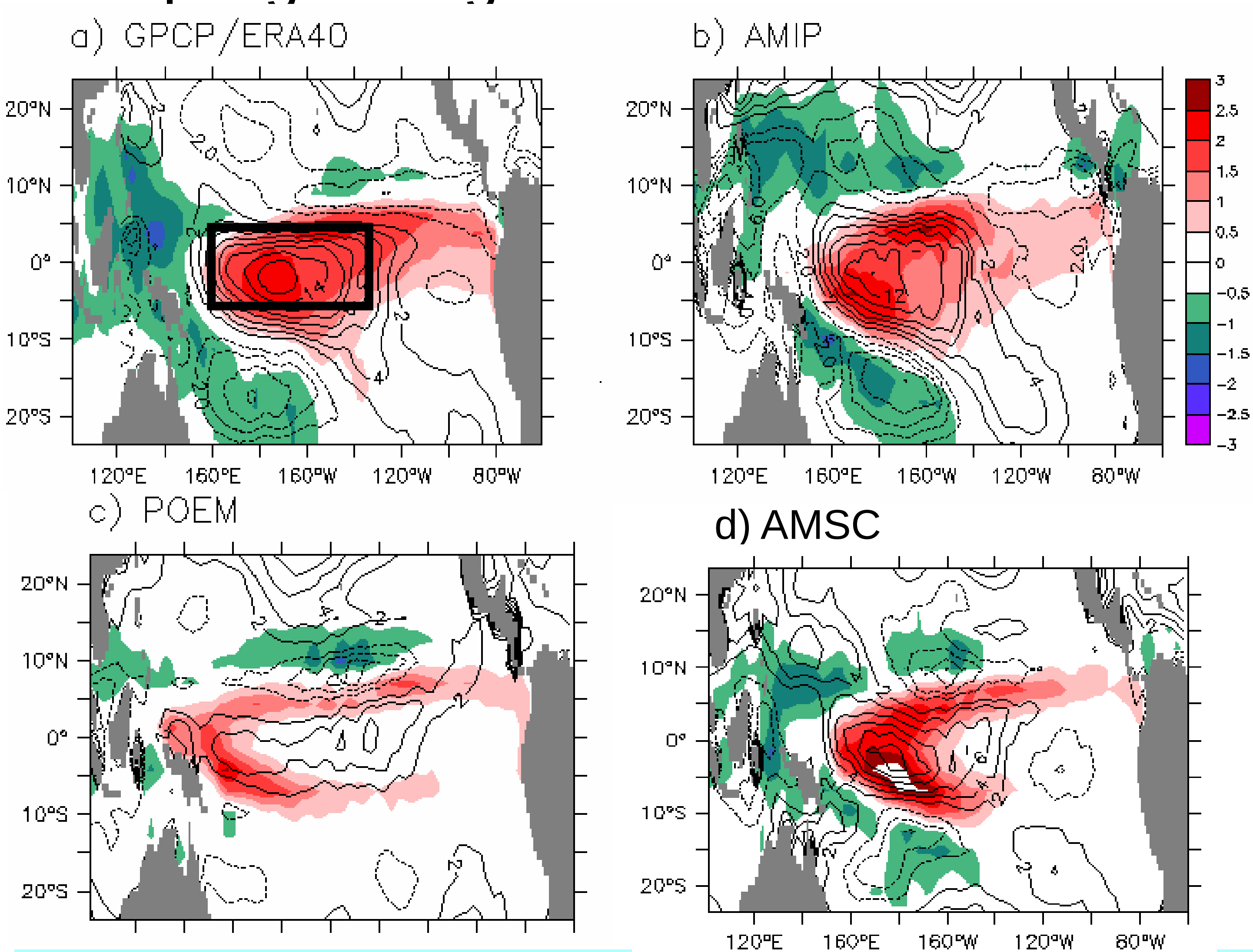


Standard deviations of SSTA



AMSC

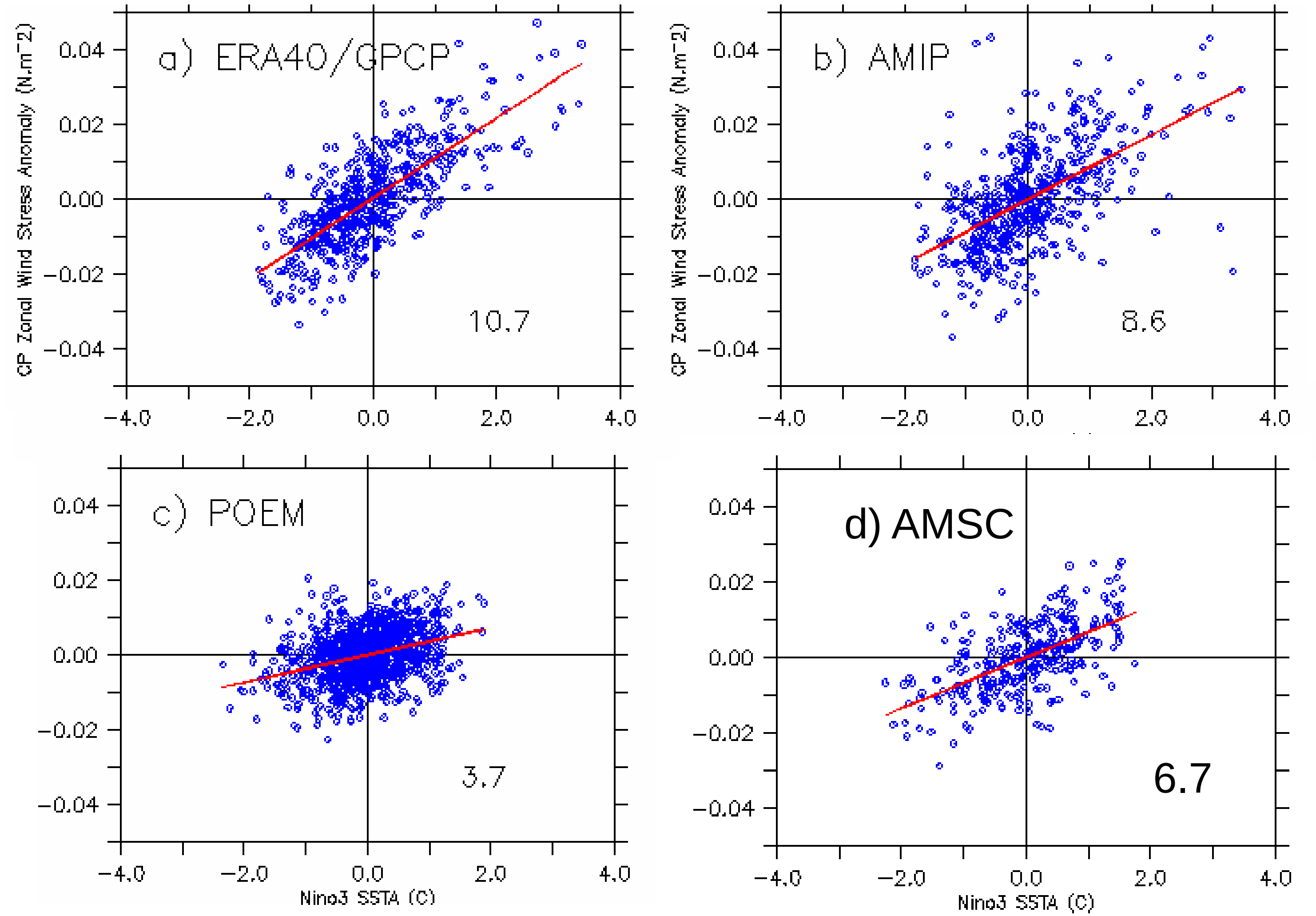
1. Coupling strength



Coupling strength = CP (160E-130W,5S-5N) wind stress anomaly / Nino3 SSTA

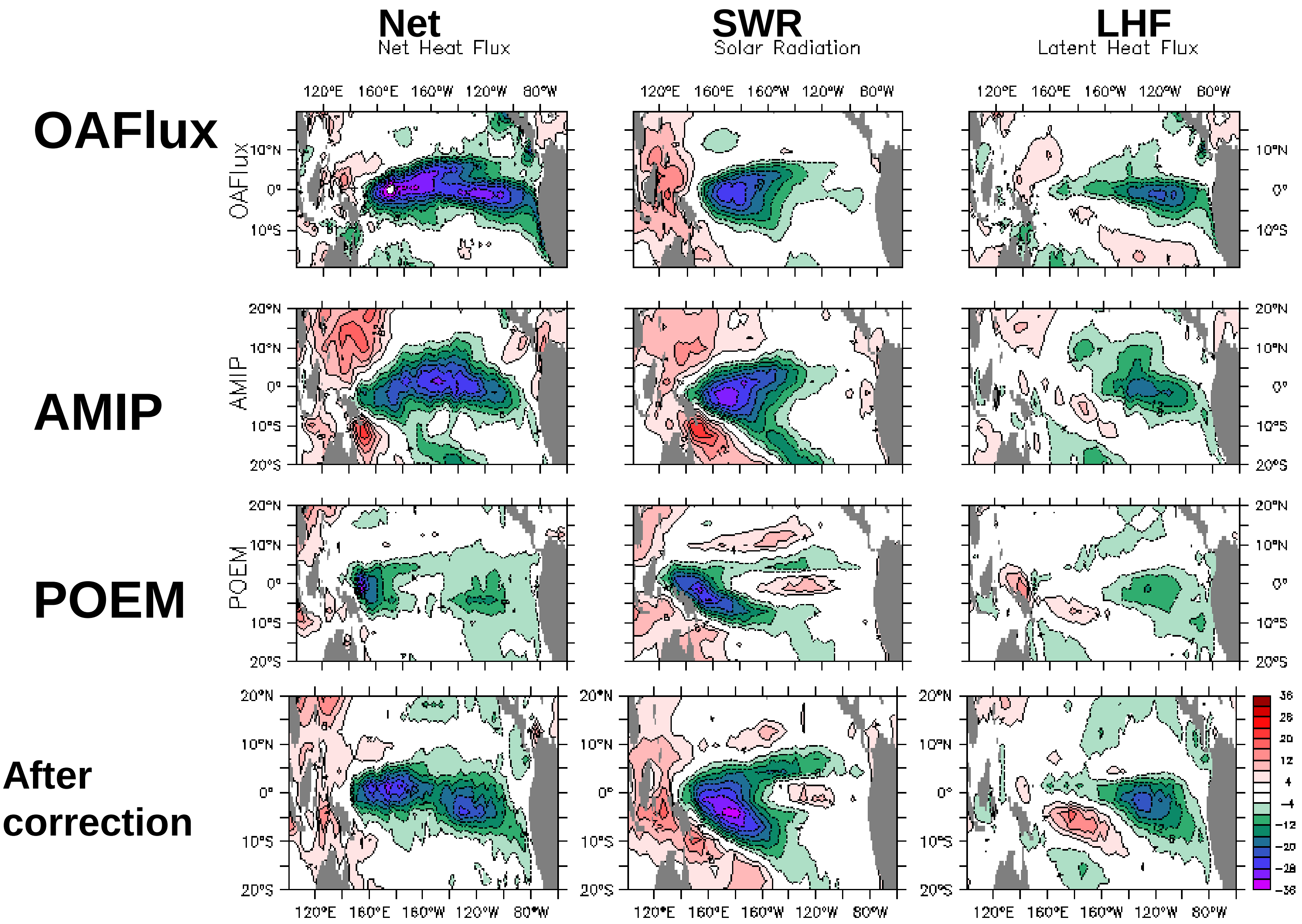
Linear regression of precipitation anomaly (shading) and zonal wind stress anomaly (contours) onto Nino3 index

Scatterplot of monthly CP wind stress anomaly as a function of monthly Nino-3 SSTA.



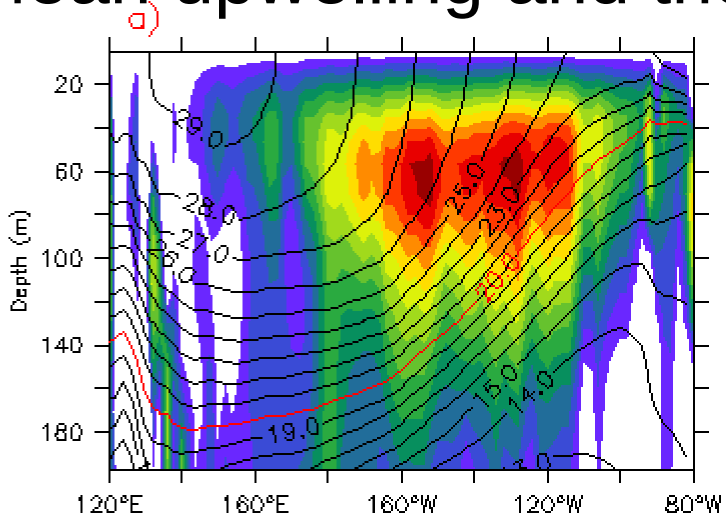
Units: 10^-3N/m2/C

2. Thermal damping

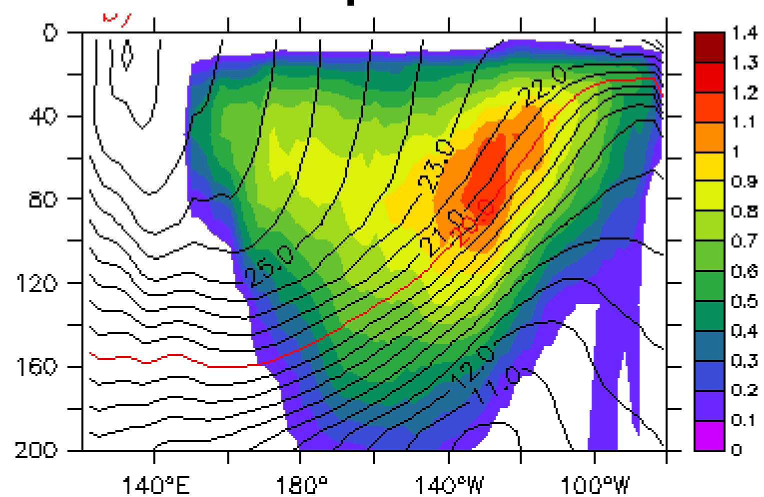


Linear regression of heat flux anomaly onto CP(160E-130W) SSTA.

3. Mean upwelling and thermocline depth

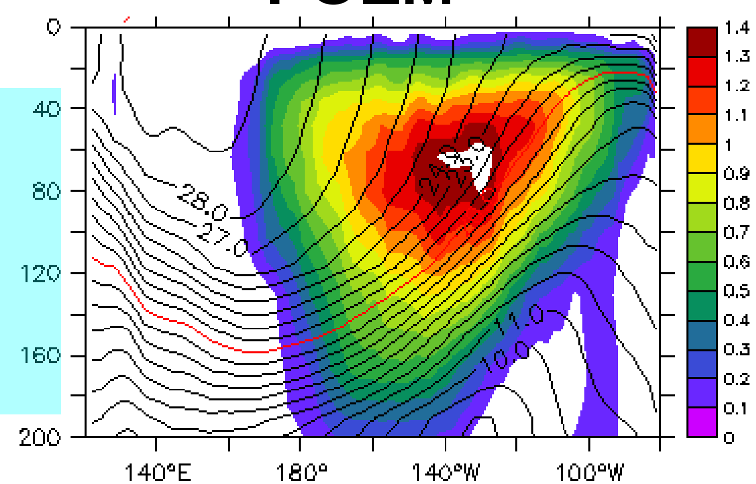


SODA



POEM

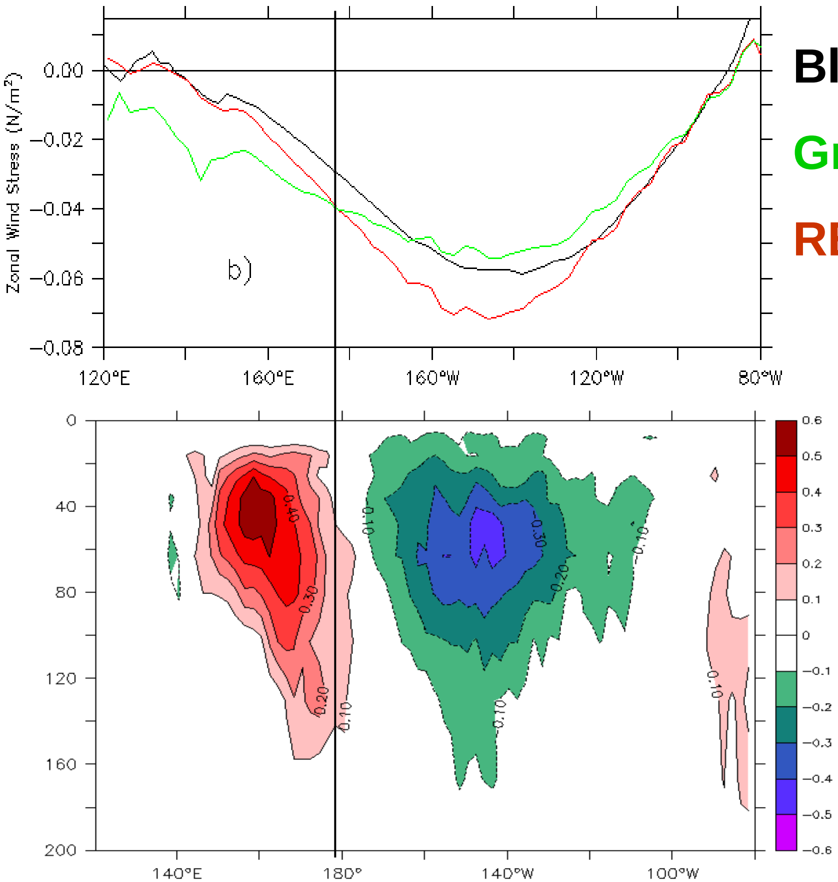
Depth-Longitude diagram of equatorial (2S-2N) upwelling velocity (shading) and temperature (contours)



AMSC

Unit: m/day

Surface wind stress and vertical velocity difference



Black: ERA40

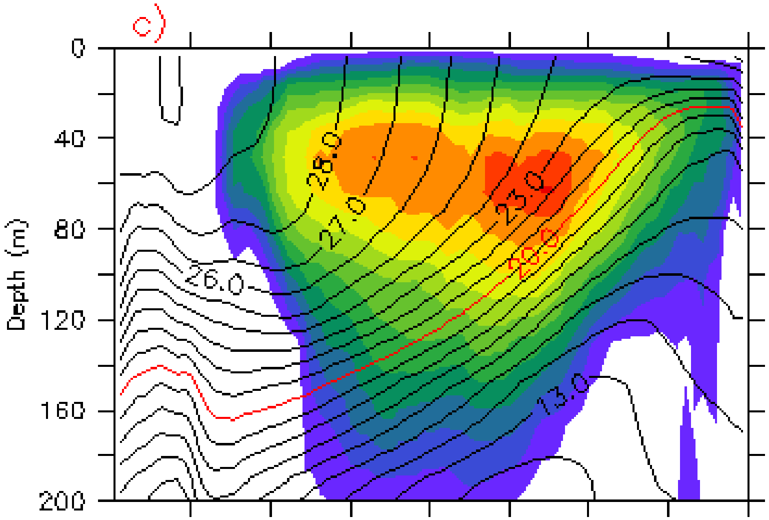
Green: POEM

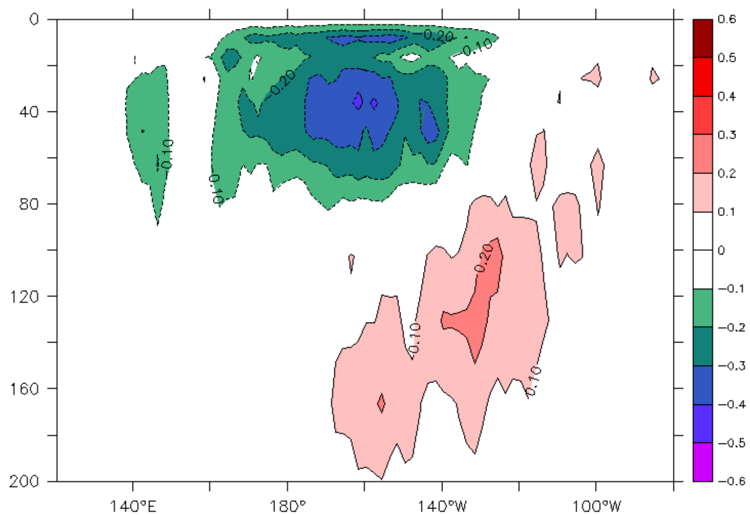
RED: AMSC

POEM - AMSC

The upwelling velocity is controlled by surface wind stress forcing, but it is also strongly influenced by the stratification especially in the near-surface region.

OCN run

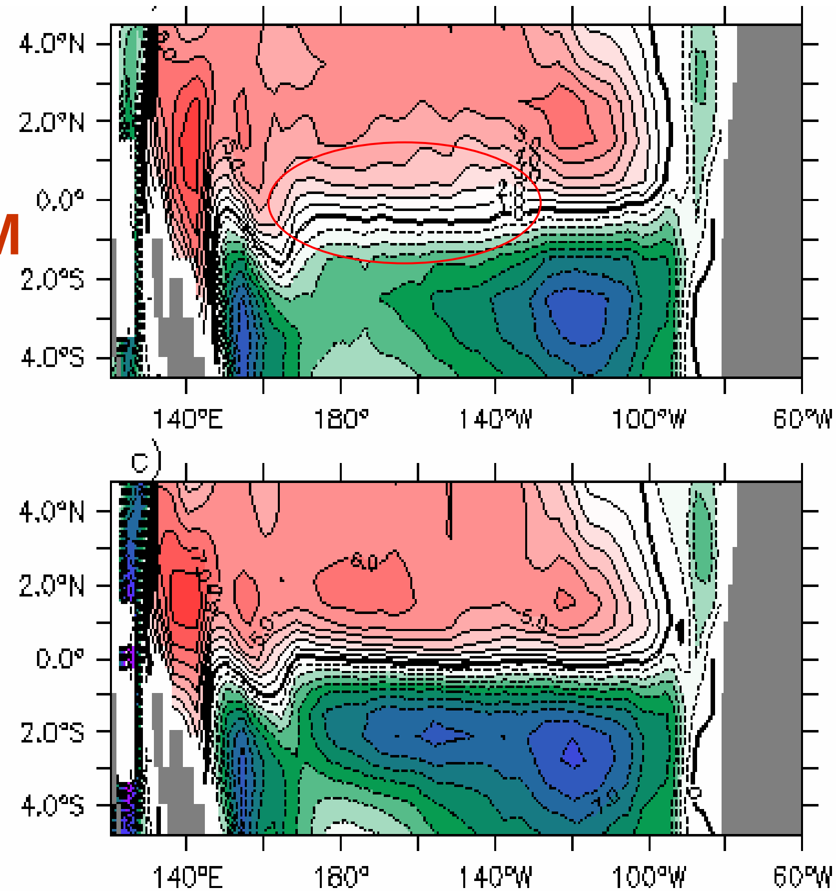




POEM - OCN

POEM

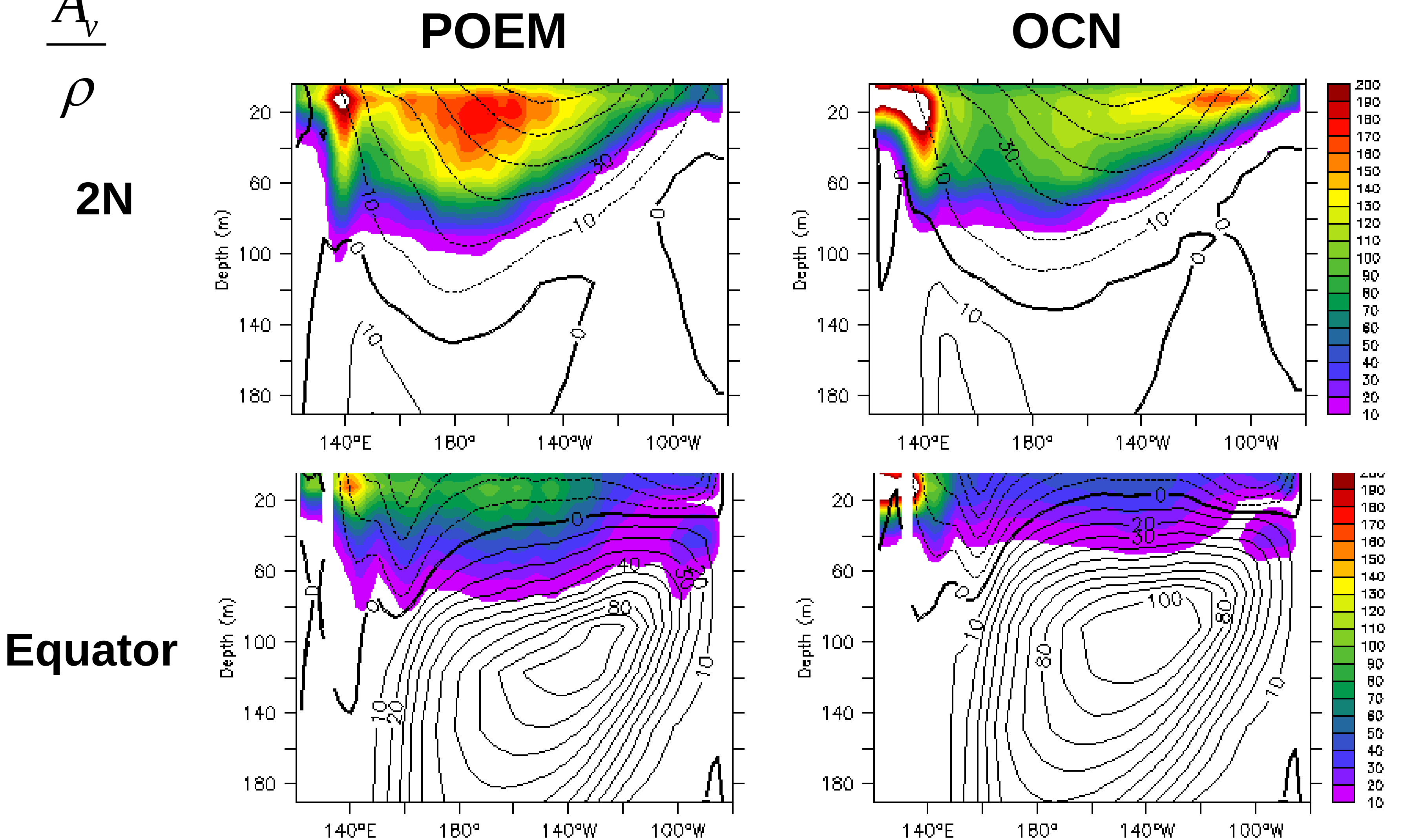
OCN



Climatological meridional currents (Units: cm/s) averaged in the upper ocean (0-30 m)

$$-fv_{ek} = -\frac{1}{\rho}\frac{\partial \tau_x}{\partial z} = -\frac{A_v}{\rho}\frac{\partial^2 u}{\partial z^2}$$

$$\frac{A_v}{\rho}$$

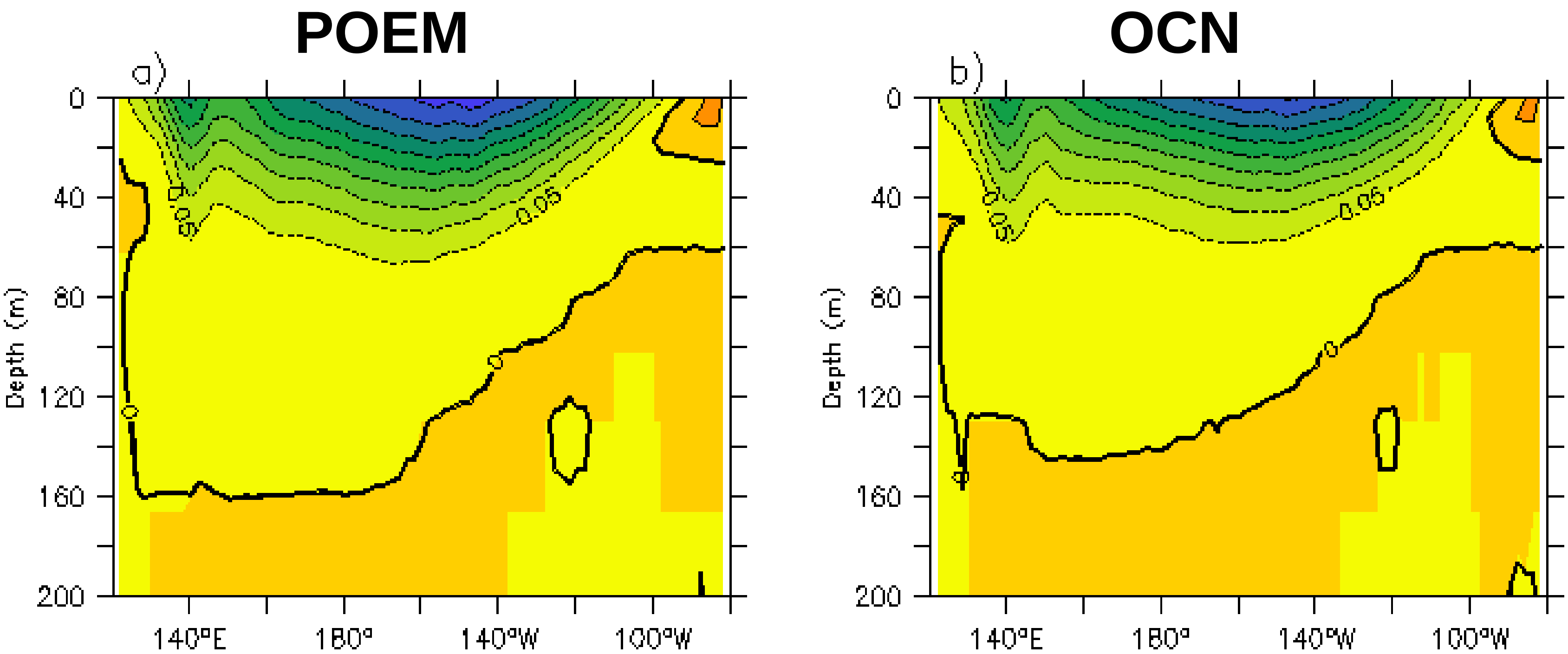


Momentum viscosity (shading, cm2/s) and zonal current (contours, cm/s)

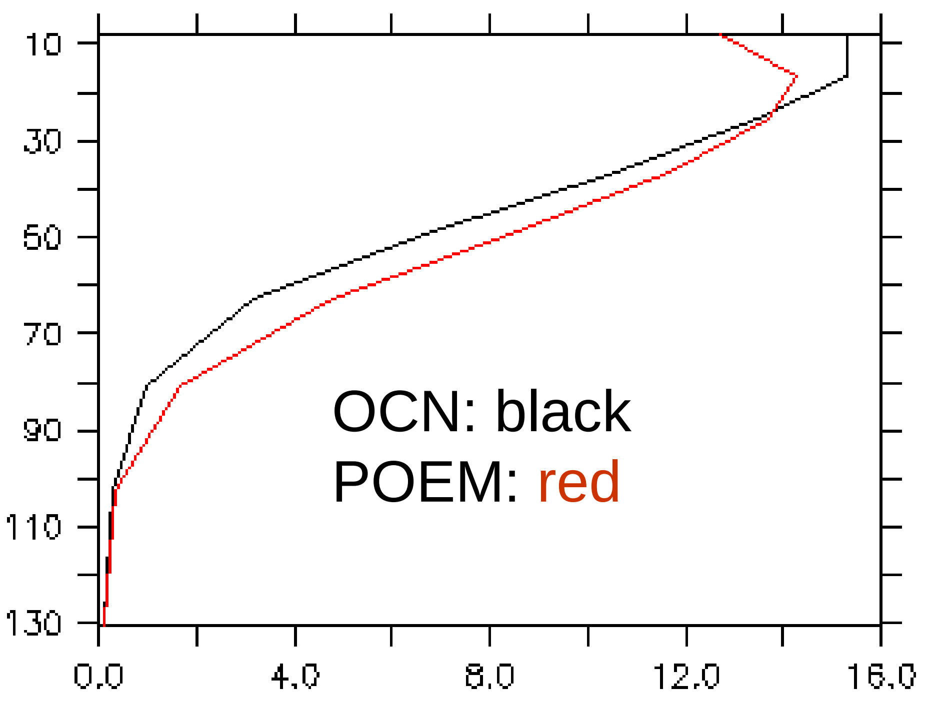
Horizontal viscous stress shear

$$\frac{\tau_x}{\rho}$$

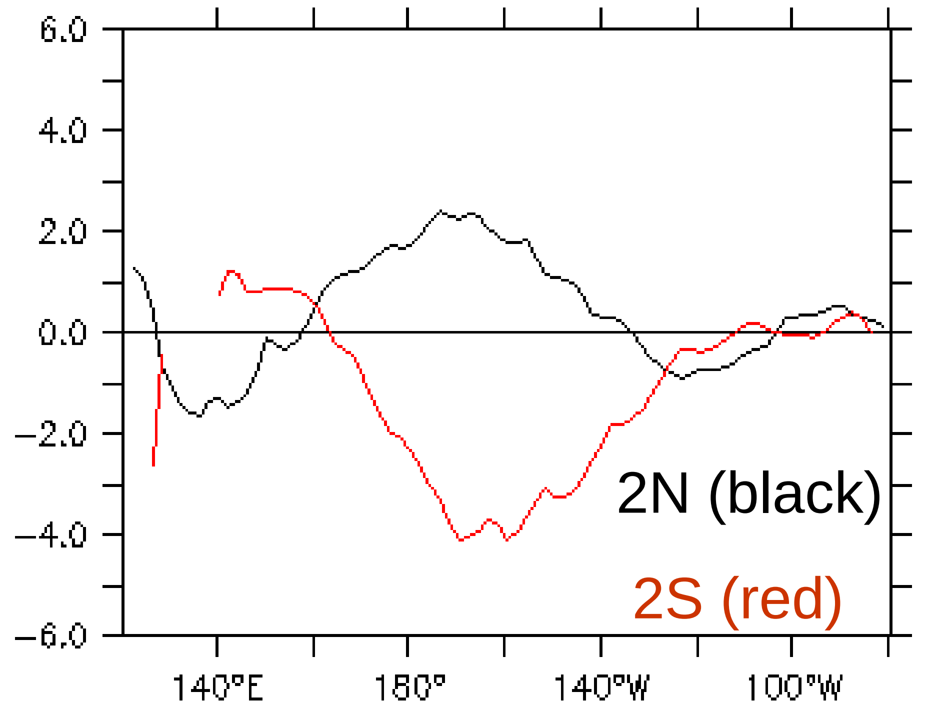
2N



(Unit: cm/s2).



Meridional Ekman velocity averaged over (160E-130W, 2N)



Meridional Ekman velocity differences (OCN – POEM)

Averaged over upper 30 m

Cold SST-induced increased vertical mixing makes the upper ocean more barotropical with considerably reduced vertical shear of zonal current, leading to a weakened upwelling velocity.

Summary

1) Underestimated and westward shift of convection

→ reduced the air-sea coupling strength

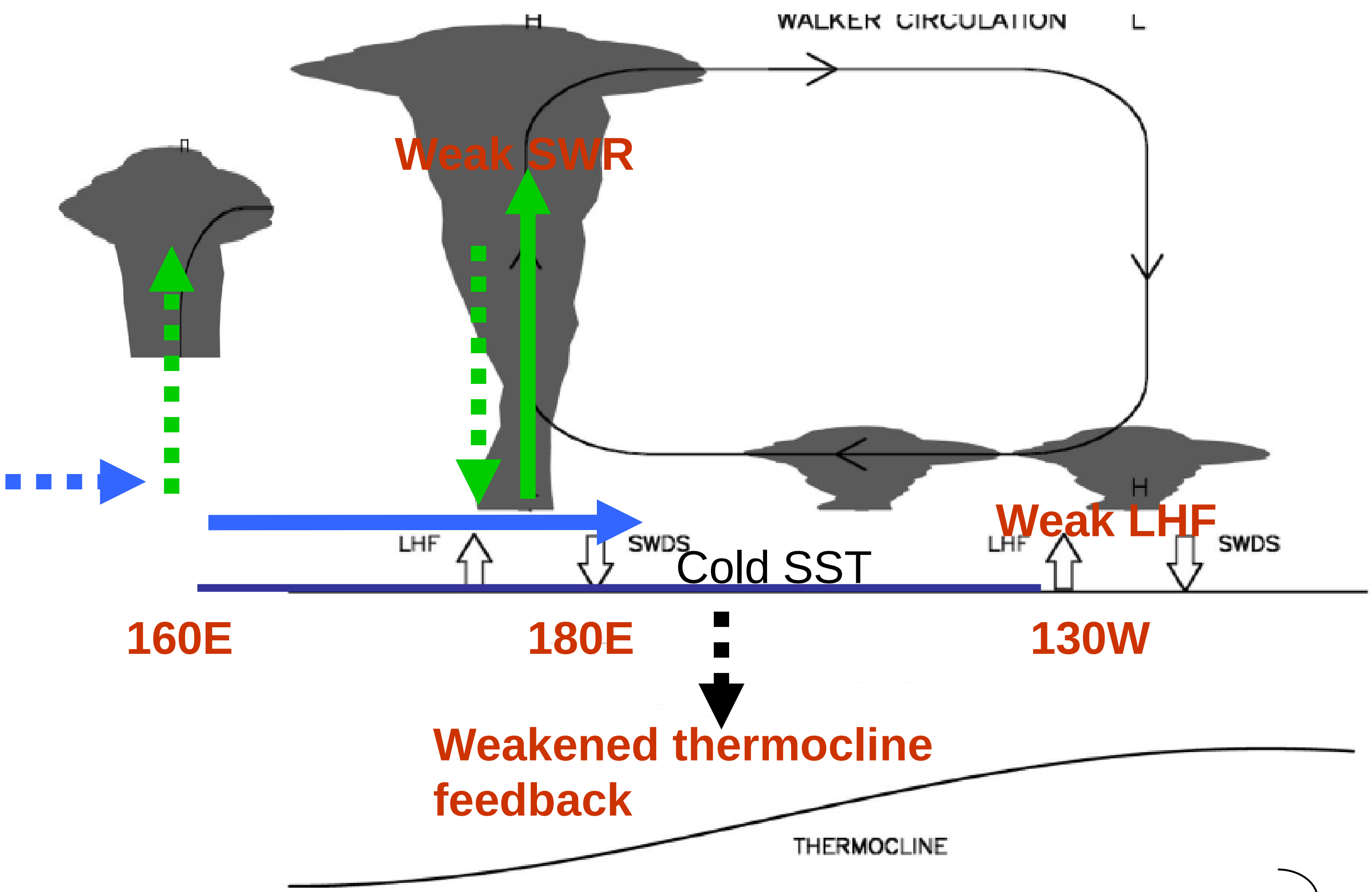
→ reduced thermal damping

2) mean upwelling ↓ → thermocline feedback ↓

zonal SST gradient ↓ → zonal advection feedback ↓

3) The combined effect is to reduce the simulated ENSO amplitude.

Short Summary



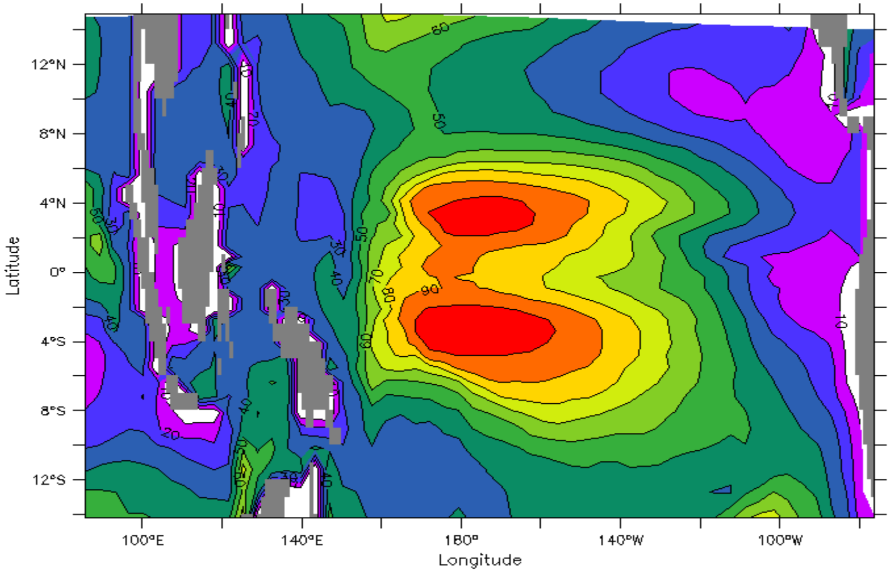
Weak thermal damping

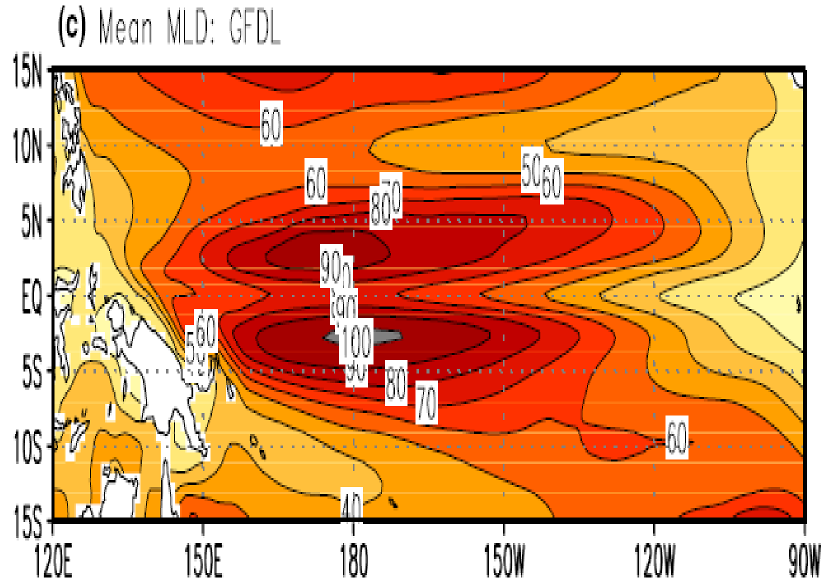
Weak coupling strength

Weak thermocline feedback

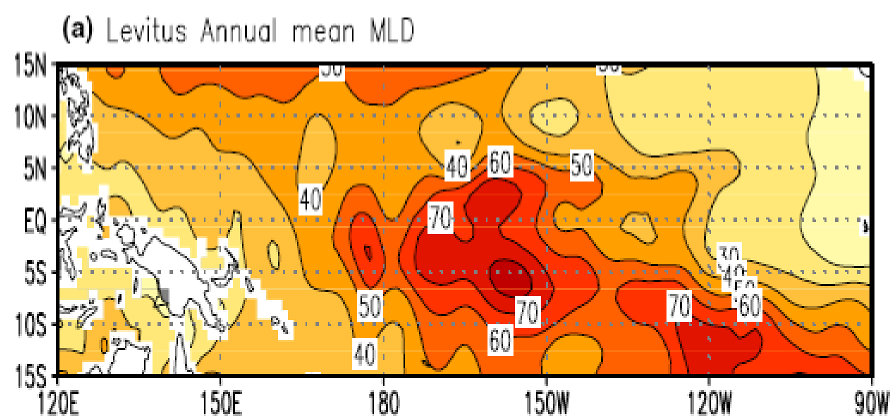
Reduced ENSO amplitude

Thank You





Too closely related to thermocline depth



ERA40 wind forcing and
observed heat flux

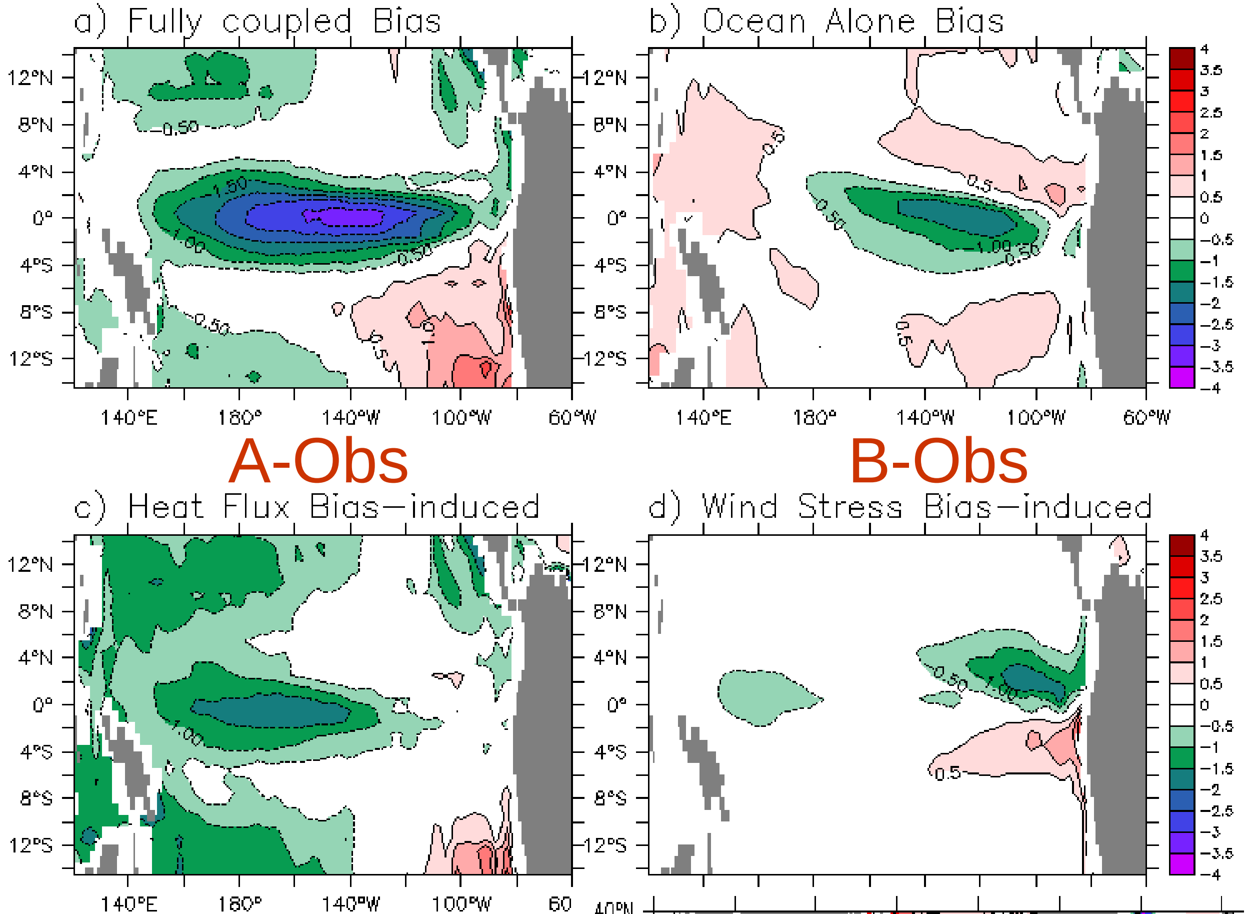
Yeh et al. 2009,
Clim. Dynamics

Question:

What cause the excessive cold tongue extension?

- 1) Ocean model (vertical mixing, solar radiation penetration…)
- 2) Atmosphere model (Convection and Cloud parameterization, Turbulent surface fluxes…)
- 3) Feedback processes

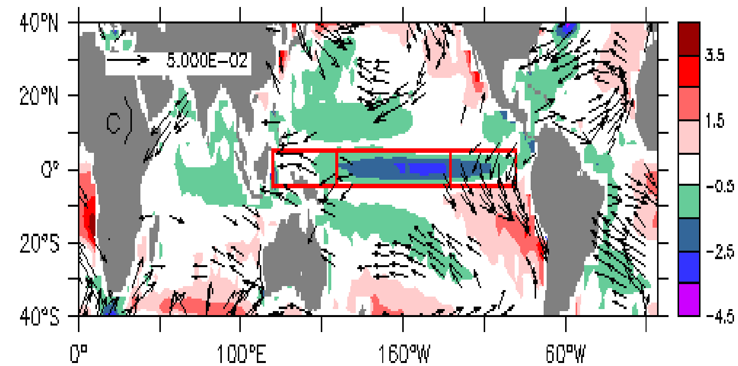
  —-- It can amplify/reduce the internal errors as no model is perfect.



A-Obs

B-Obs

C-A



A: Fully coupled

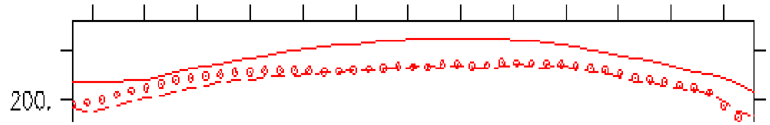
B: Ocean Alone run with ERA40 wind

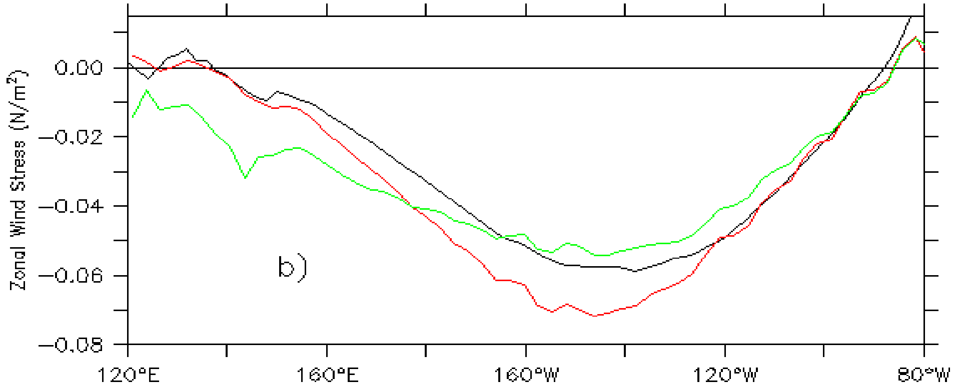
C: Same as B, but with wind stress frc

ux

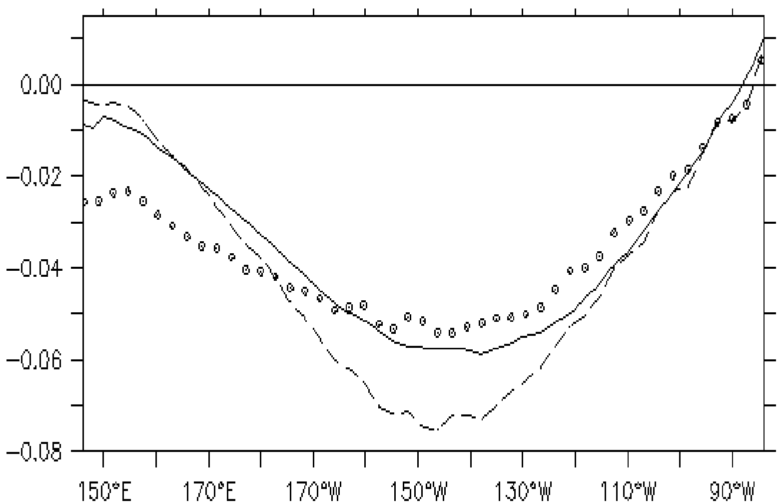
Equatorial (5S-5N) heat flux and zonal wind stress

SWF





Zonal wind stress



Observations (Solid)

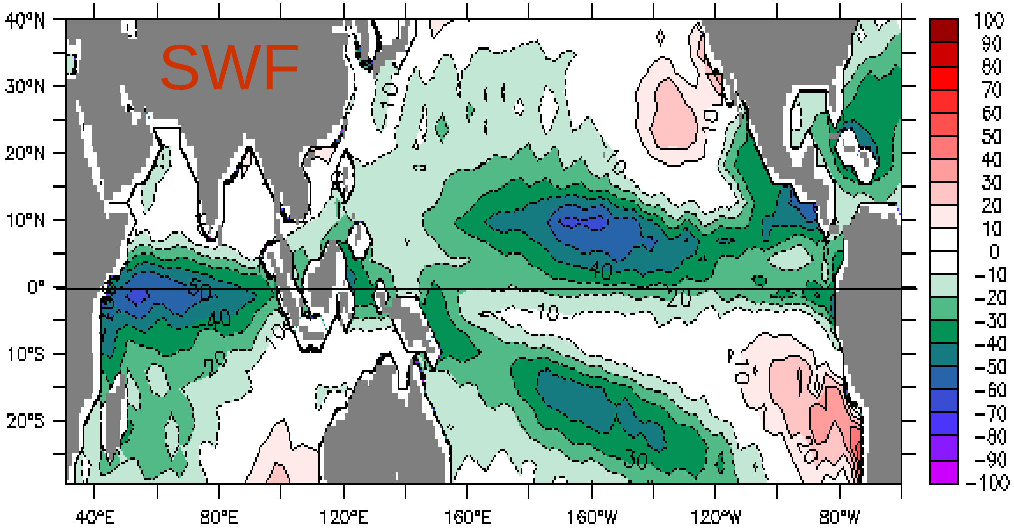
AMIP (dashed)

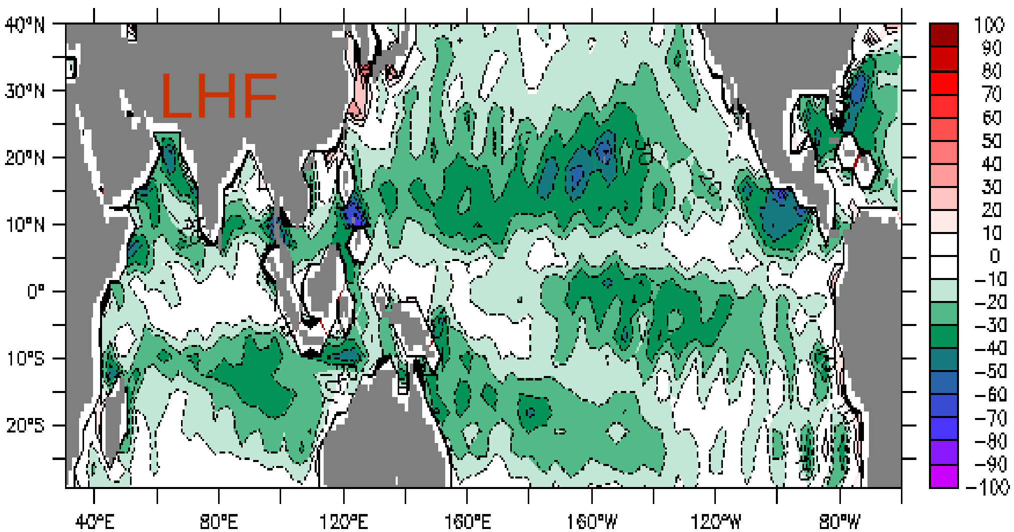
Coupled (circle).

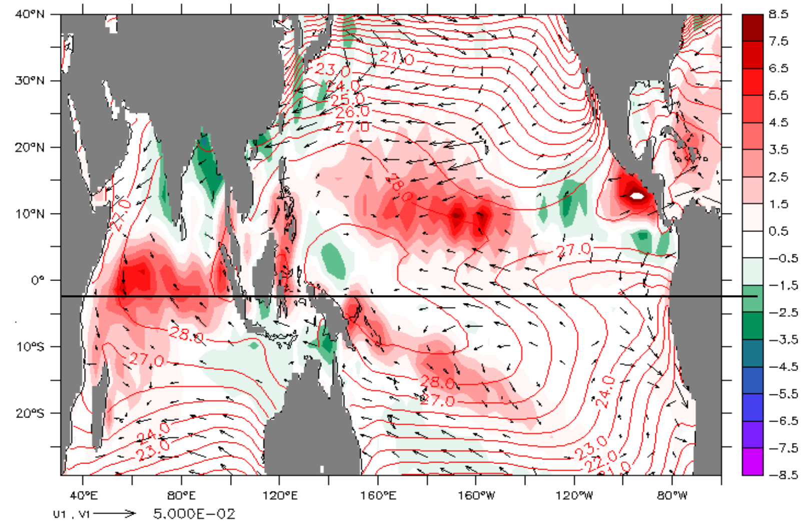
Atmospheric model induced cold bias is constrained in the CP and EP, while air-sea coupling acts as a negative role to reduce it through SST-LHF feedback and SST-upwelling feedback, pushing the most prominent cold SST bias westward

Unit for heat flux: W/m^2, unit for wind stress is N/m^2

Heat flux biases in AMIP run







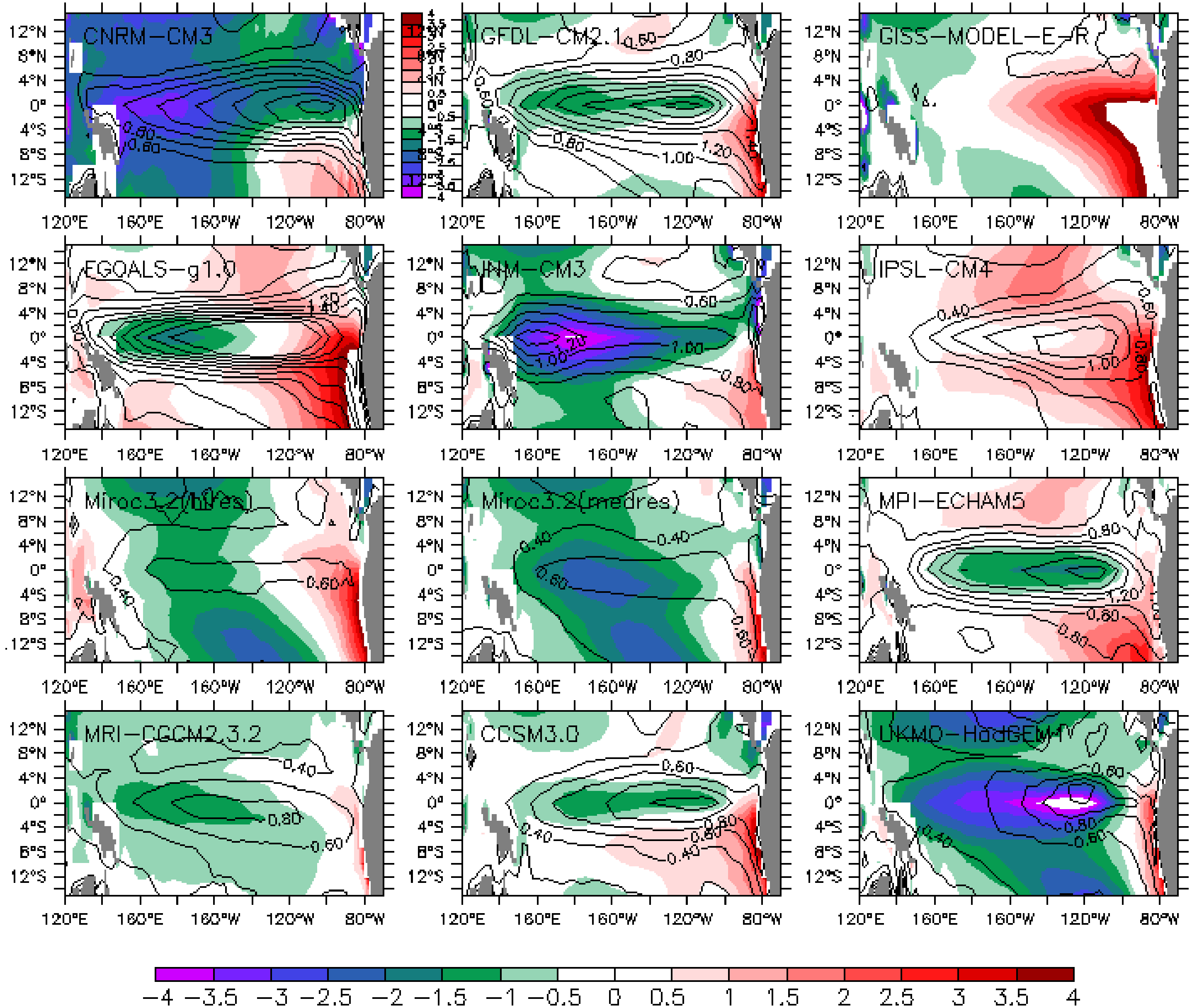
Precipitation bias (shading) and wind stress bias

Possible reasons:

1) Parameterized cumulus precipitation is too closely linked to **moisture convergence.**

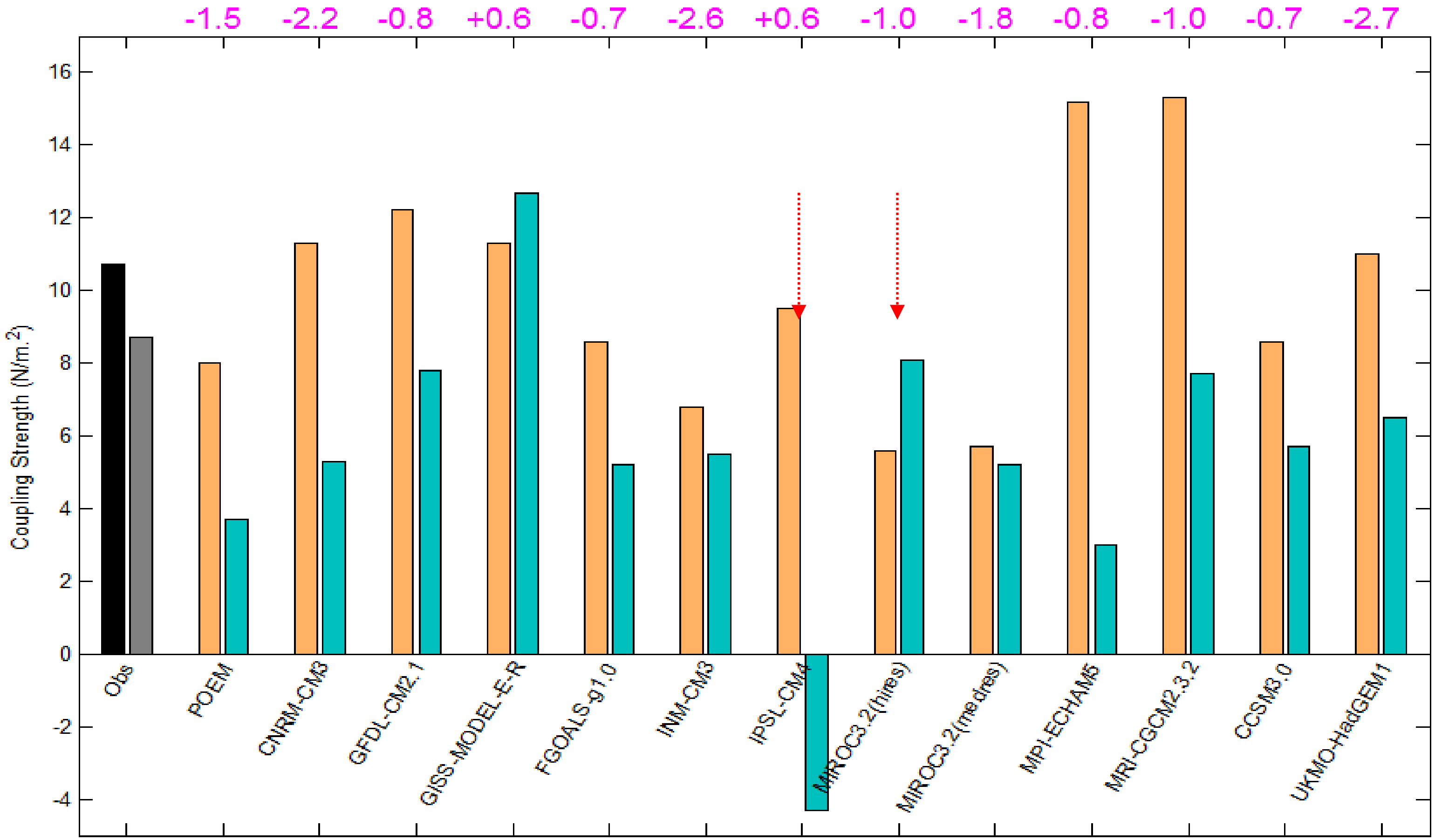
2) The cloud droplet number concentration

3) Liquid water path



CNRM−CM3
GFDL−CM2.1
GISS−MODEL−E−R
FGOALS−g1.0
INM−CM3
IPSL−CM4
Miroc3.2(hires)
Miroc3.2(medres)
MPI−ECHAM5
MRI−CGCM2.3.2
CCSM3.0
UKMO−HadGEM1
12°N
8°N
4°N
0°
4°S
8°S
12°S
120°E
160°E
160°W
120°W
80°W
−4
−3.5
−3
−2.5
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4

Coupling strength from the IPCC AR4 models



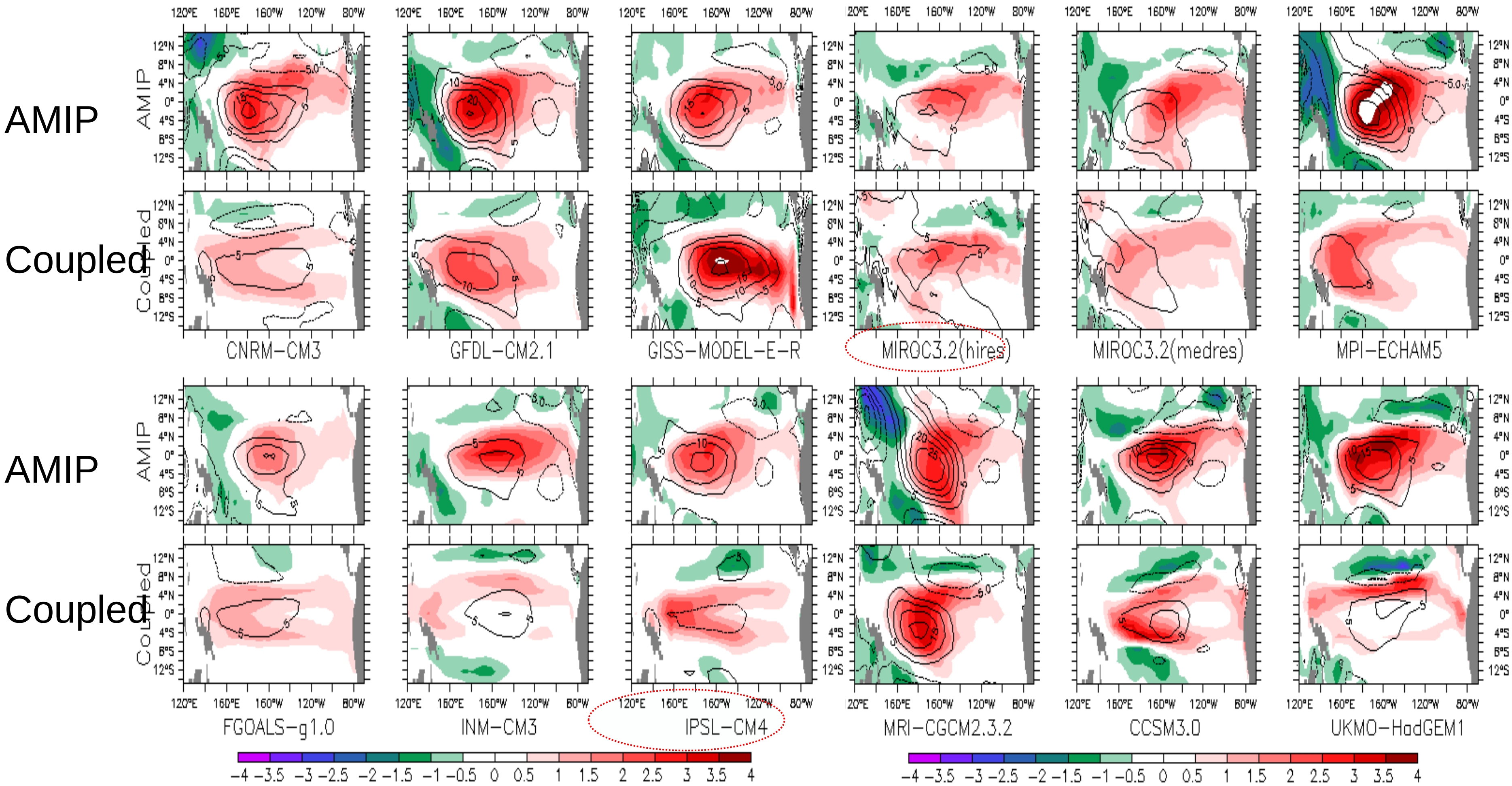
ERA40 (black)

NCEP (grey)

AMIP run (orange)

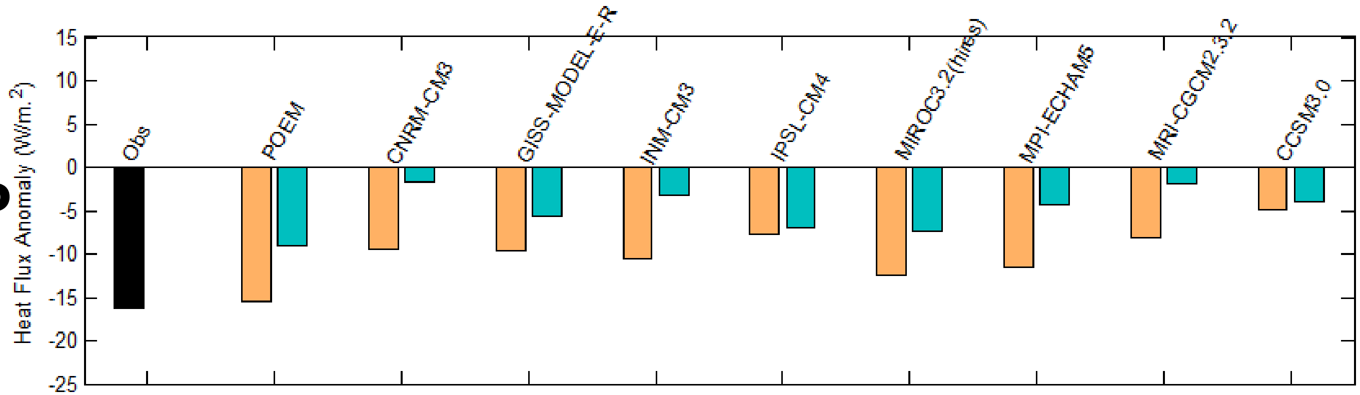
Coupled models (dark cyan)

Linear regression of precipitation anomaly (shading) and zonal wind stress anomaly (contours) onto Nino3 index

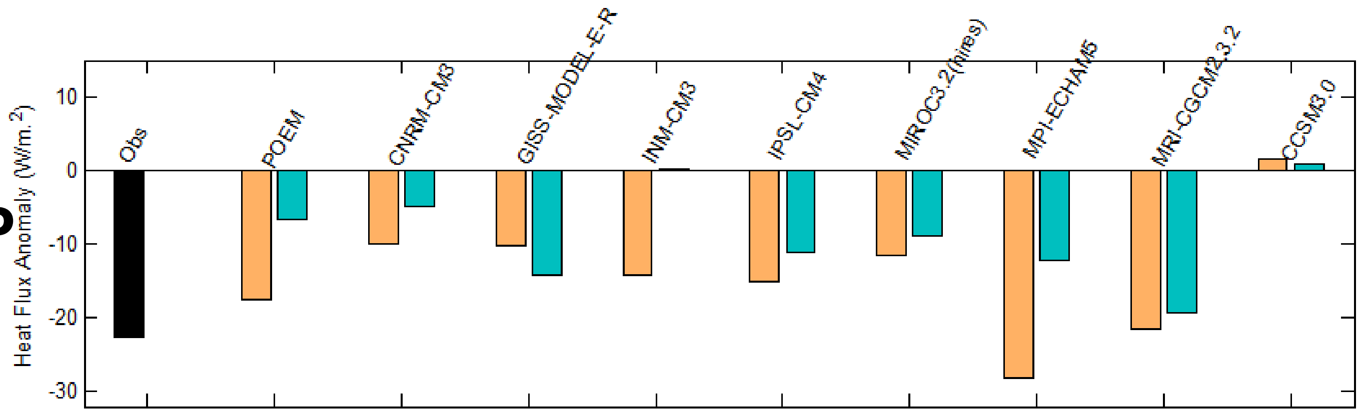


Thermal damping

EP

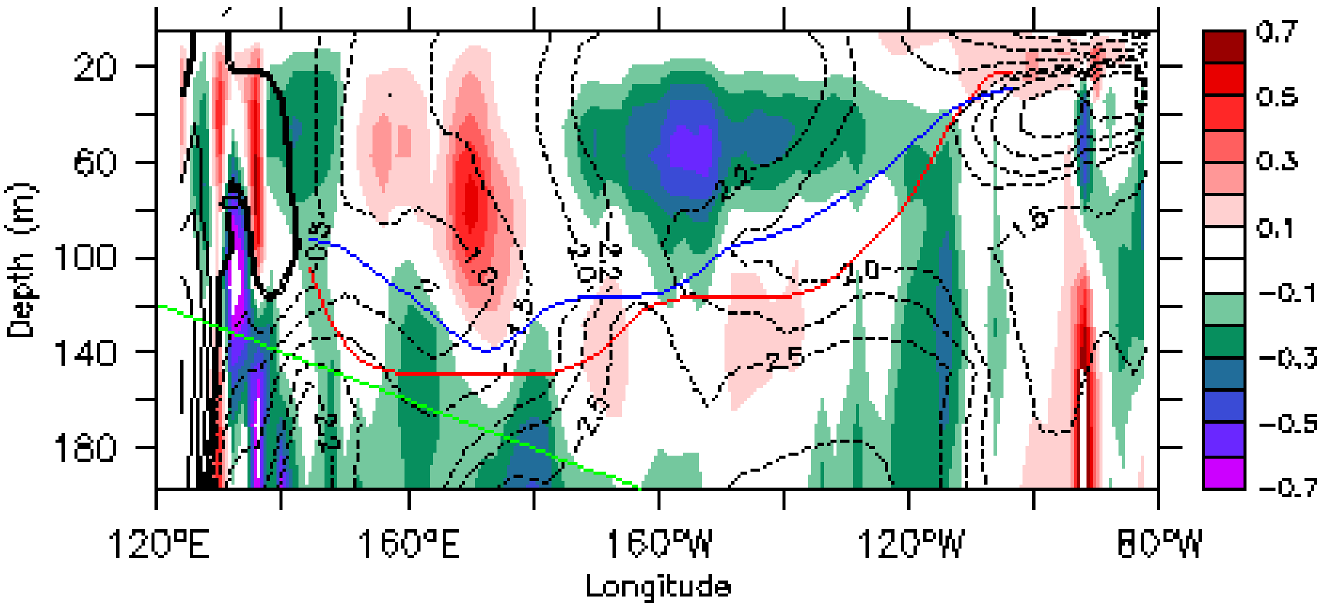


CP

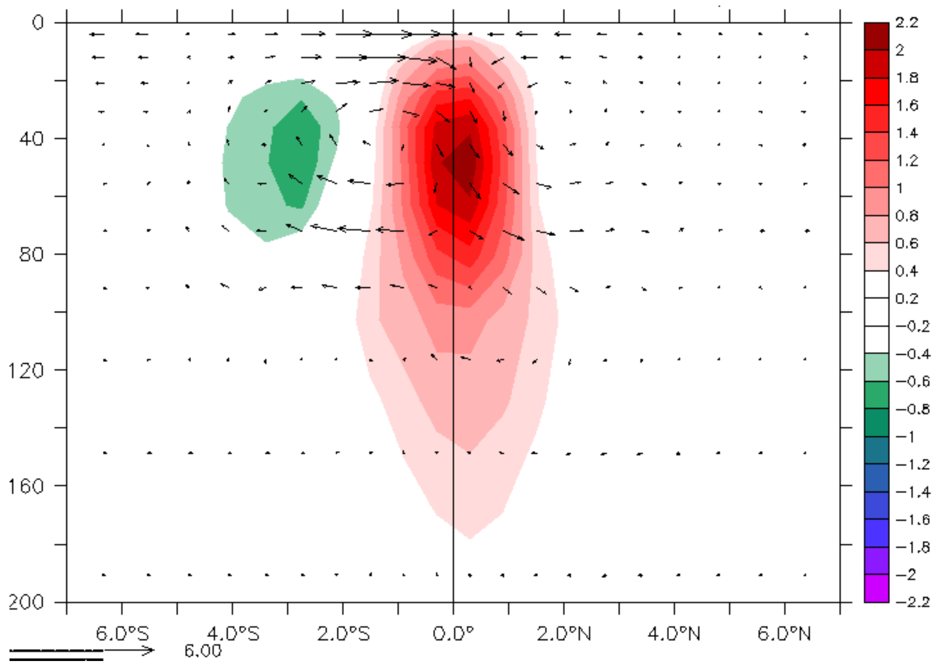


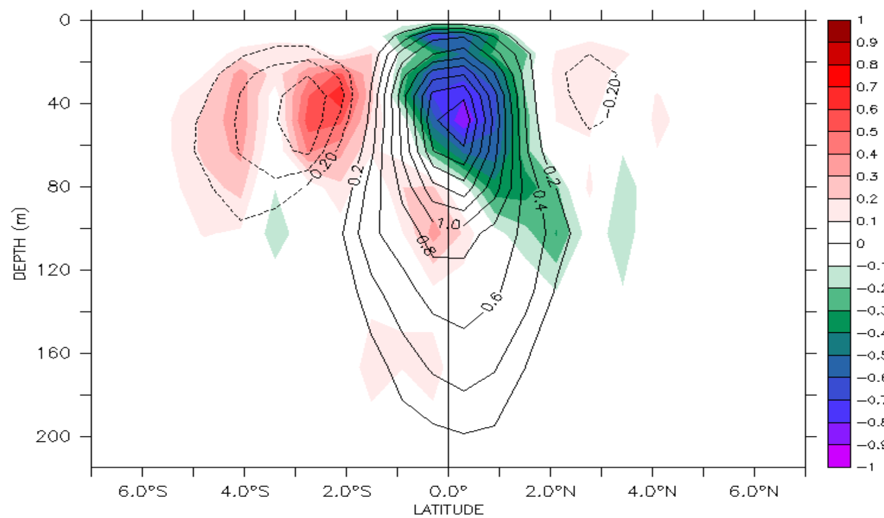
AMIP run (orange)

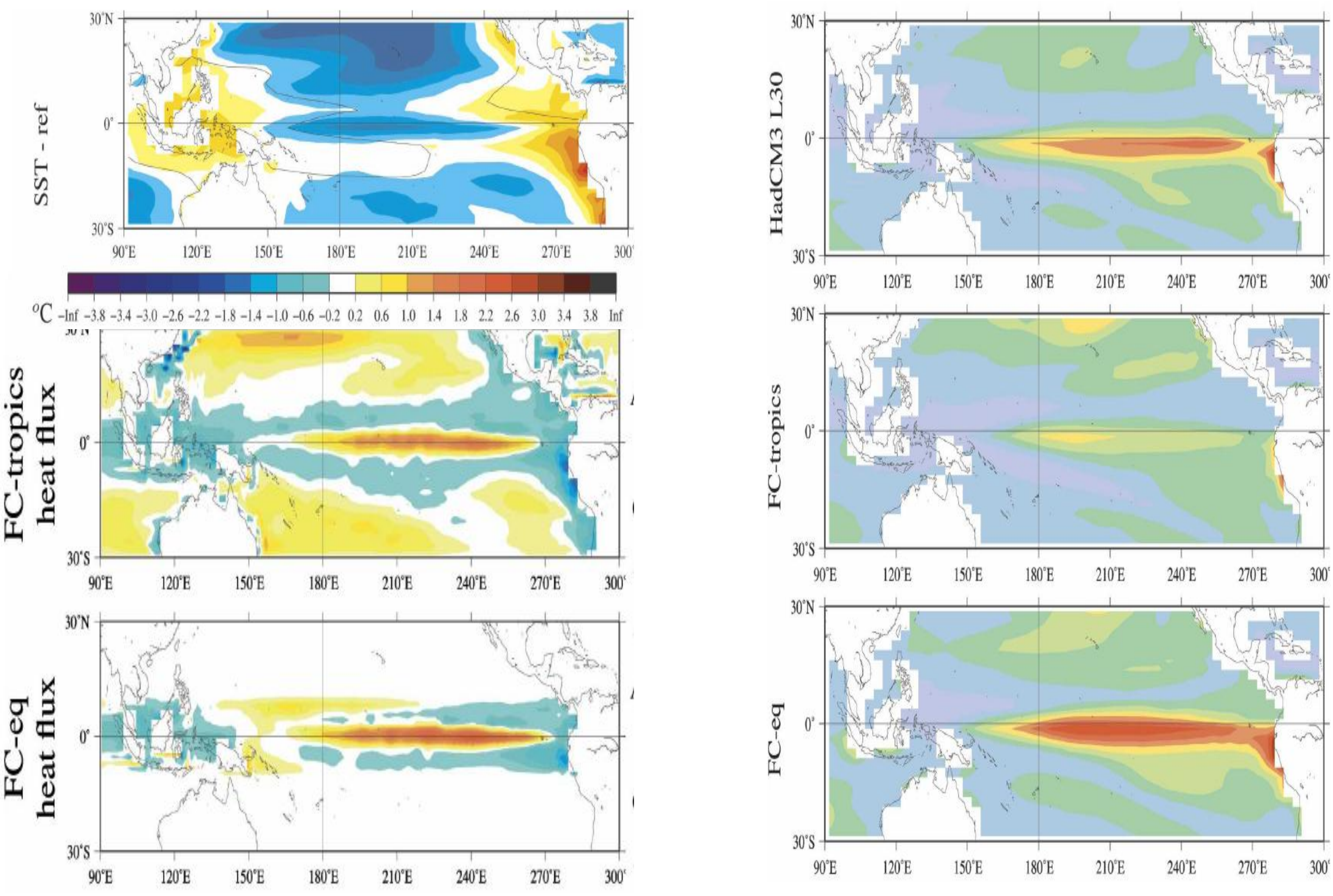
coupled run (dark cyan)



Depth (m)
20
60
100
140
180
120°E
160°E
160°W
120°W
80°W
Longitude
0.7
0.5
0.3
0.1
−0.1
−0.3
−0.5
−0.7


0
40
80
120
160
200
6.0°S
4.0°S
2.0°S
0.0°
2.0°N
4.0°N
6.0°N
6.00
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
−0.2
−0.4
−0.6
−0.8
−1
−1.2
−1.4
−1.6
−1.8
−2
−2.2


DEPTH (m)
0
40
80
120
160
200
6.0°S
4.0°S
2.0°S
0.0°
2.0°N
4.0°N
6.0°N
LATITUDE
0.20
0.2
1.0
0.8
0.6
0.4
−0.20
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
−0.8
−0.9
−1



Spencer et al. 2007