Pacific interdecadal variability driven by tropical-subtropical interactions

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Introduction

1. midlatitude Pacific Decadal Variability (PDV) seems to be a combination of stochastically driven, passive ocean response to the atmosphere and a coupled mode of the ocean-atmosphere system where ocean dynamics plays a critical role (Latif and Barnett, 1996; Barnett et al., 1999a,b).

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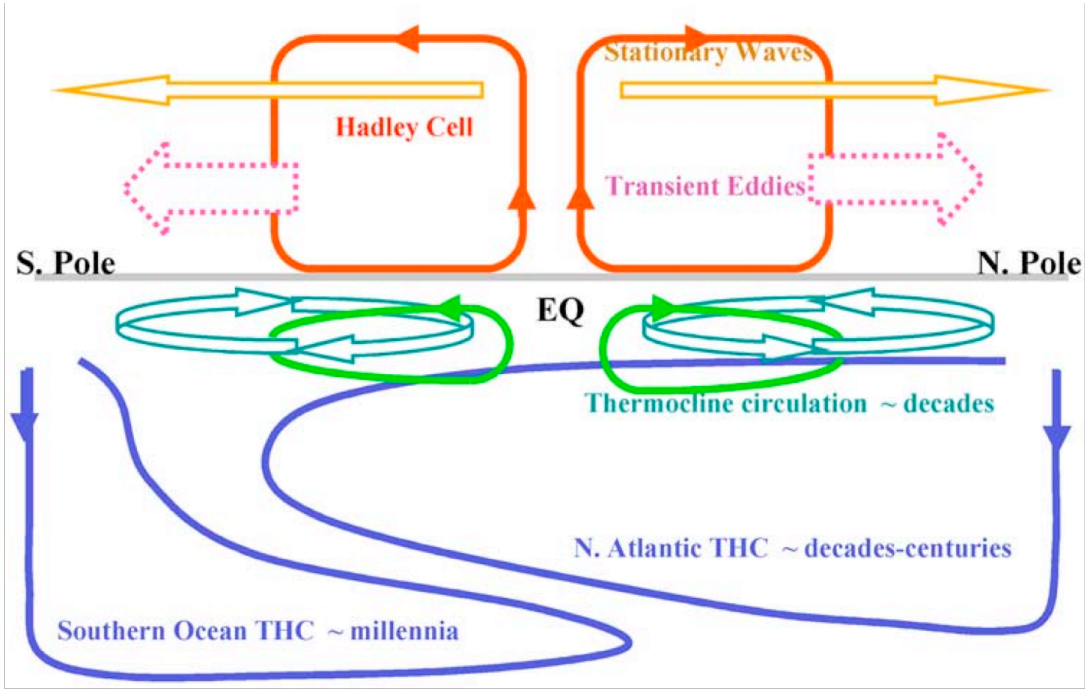
   - Decadal ENSO variability is directly affected by the low-frequency noise over the western part of the tropical Pacific in a linear sense.
   - The impact of extratropical atmospheric noise on the ENSO variability is weaker than the noise in the tropics

Motivation

Tropical$\Longleftrightarrow$extratropical interactions



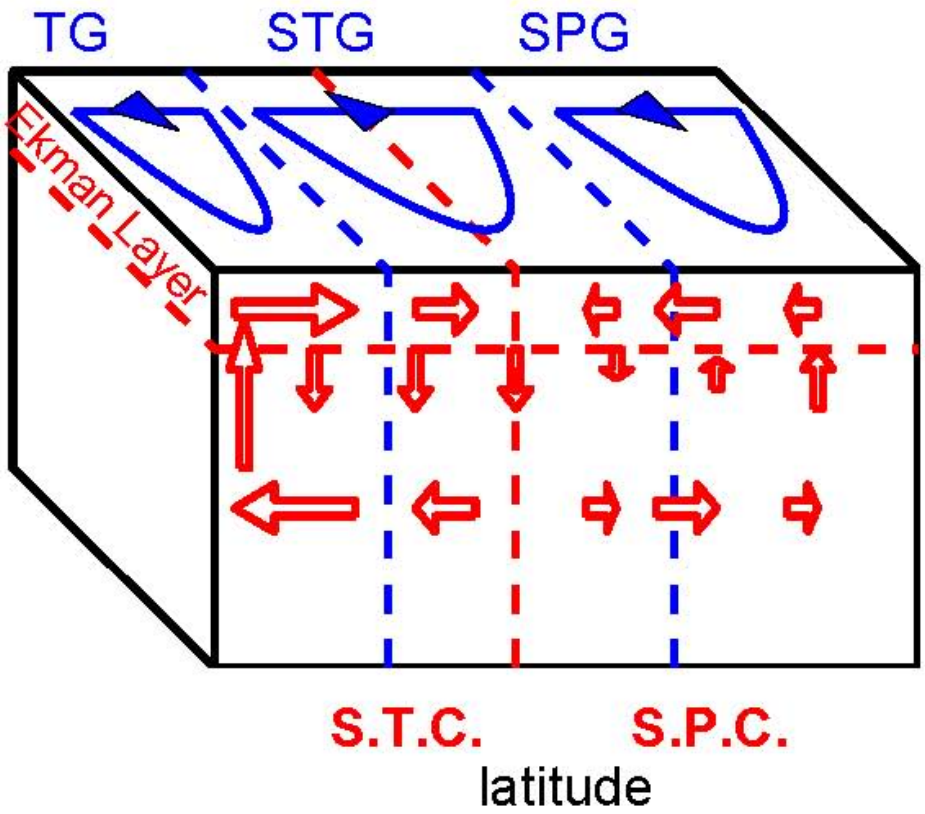
Liu, Z., and M. Alexander (2007), Rev. Geophys

1. PDV has been suggested to force decadal tropical variability (via *atmospheric bridge*) (Barnett et al., 1999a)
2. and there is controversy on *oceanic tunnel* pathway of tropical-subtropical connection in the Pacific (Schneider et al., 1999)

Hypothesis

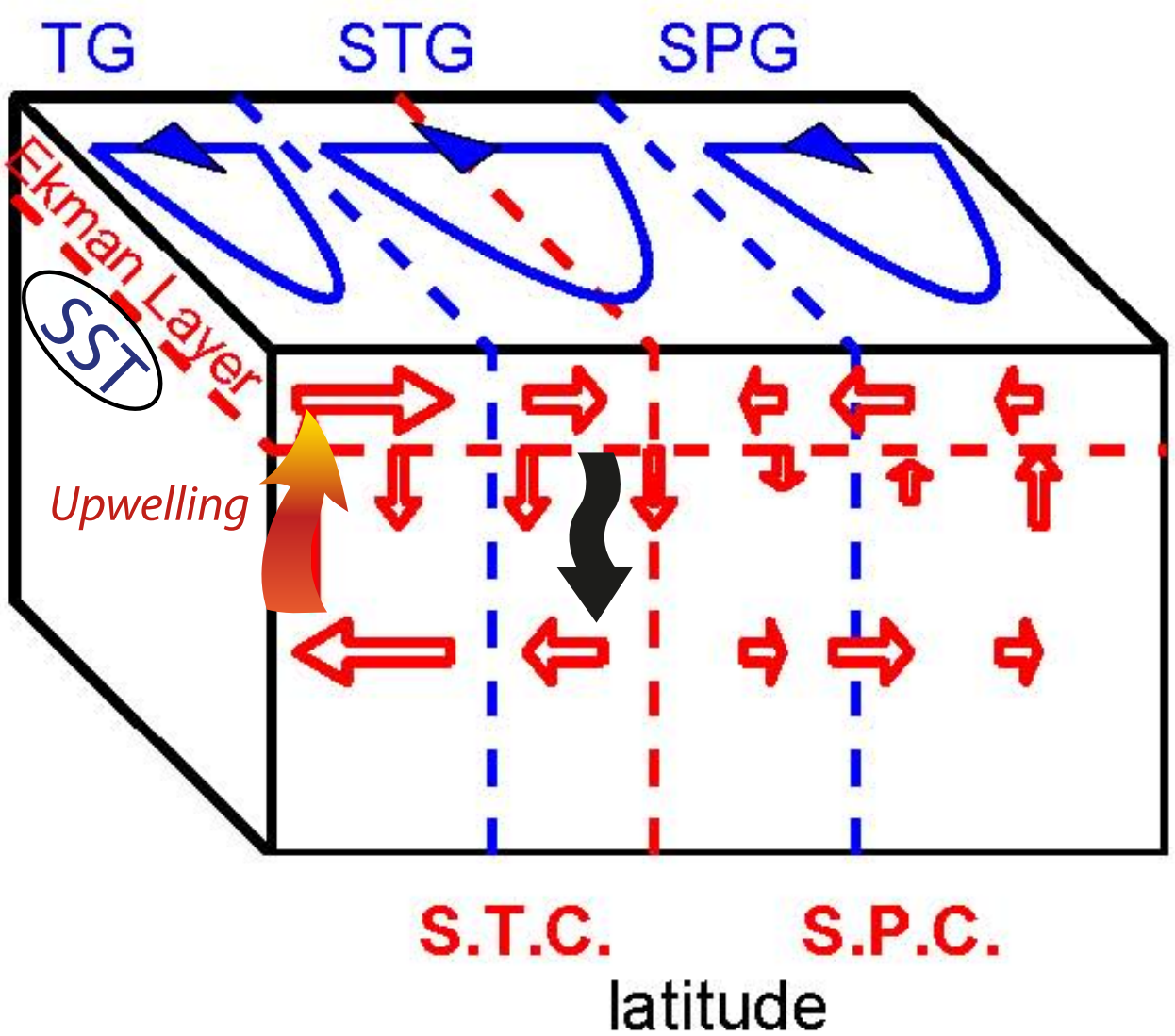
⇒Tropical forcing patterns can force extratropical flow responses (e.g., the Cold Ocean Warm Land Pattern (COWL) reversal observed between 2000/2009 -1990/1999 (Molteni et al. 2010).

⇒Can the atmosphere feed back on the ocean, leading to a time-delayed response of the tropical oceans?



Hypothesis

A possible subtropical-tropical connection



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Ocean model MOM

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6. Initial Conditions: Levitus and Steele

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Atmospheric Model SPEEDY

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3. Horizontal resolution is T30, with 8 levels in the vertical.

Forcing the Ocean Model

1. The Ocean Model is forced with the Coordinated Ocean-ice Reference Experiment (CORE) Normal Year Forcing (NYF) described in Griffies et al. (2009) for 600 years.

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2. Fluxes for the CORE dataset include T, [U,V], Q, SLP, LW and SW, Precip and Runoff. They all derive from a combination of NCEP reanalysis and satellite data.

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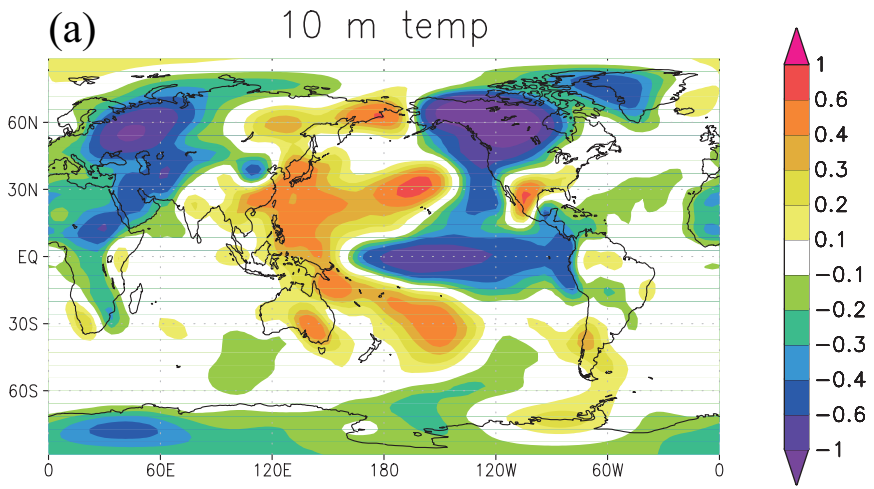
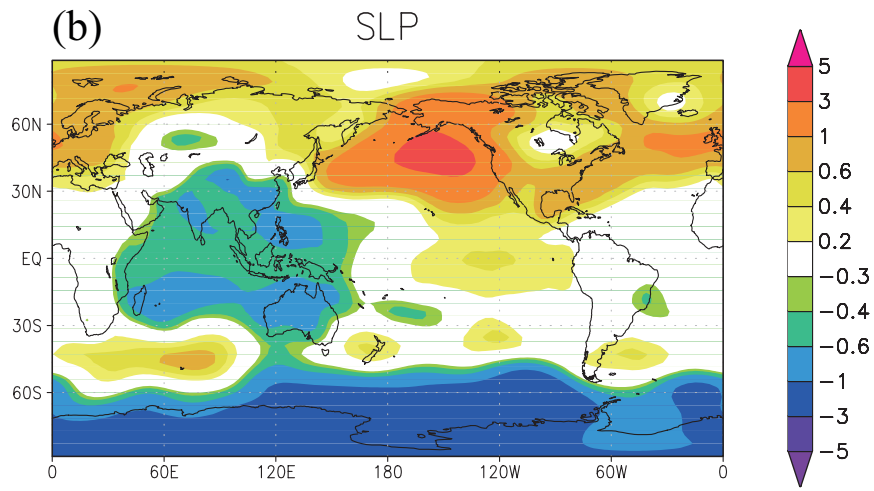
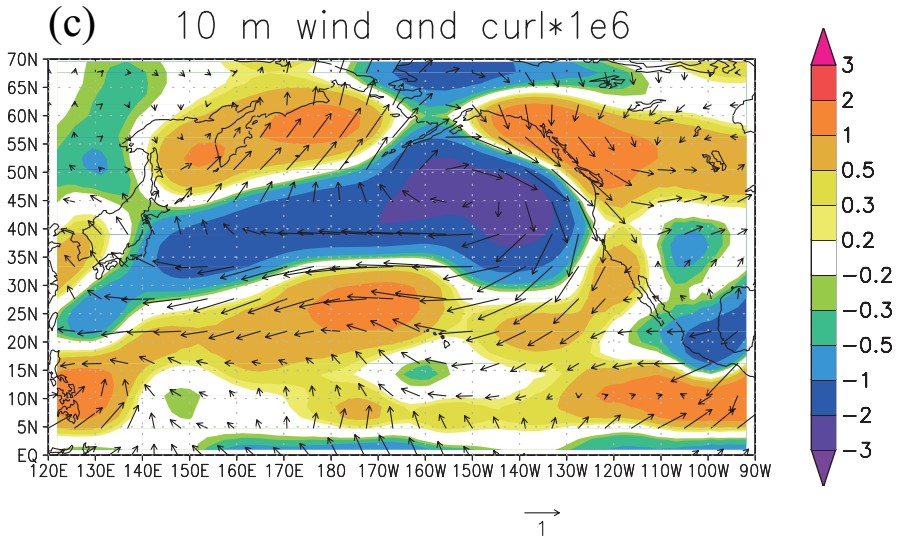
5. The anomalies where then added to each climatological CORE forcing field.

The anomalous forcing







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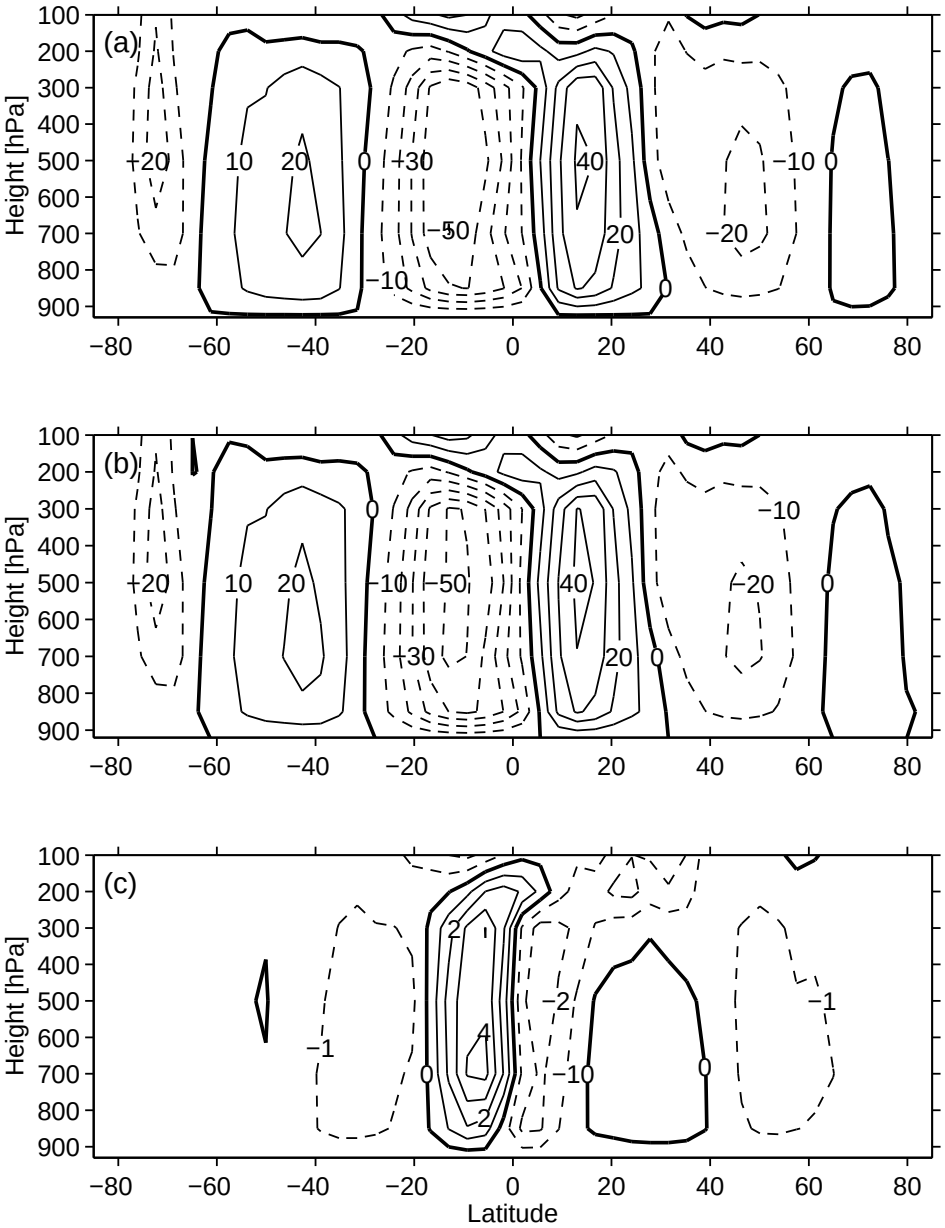
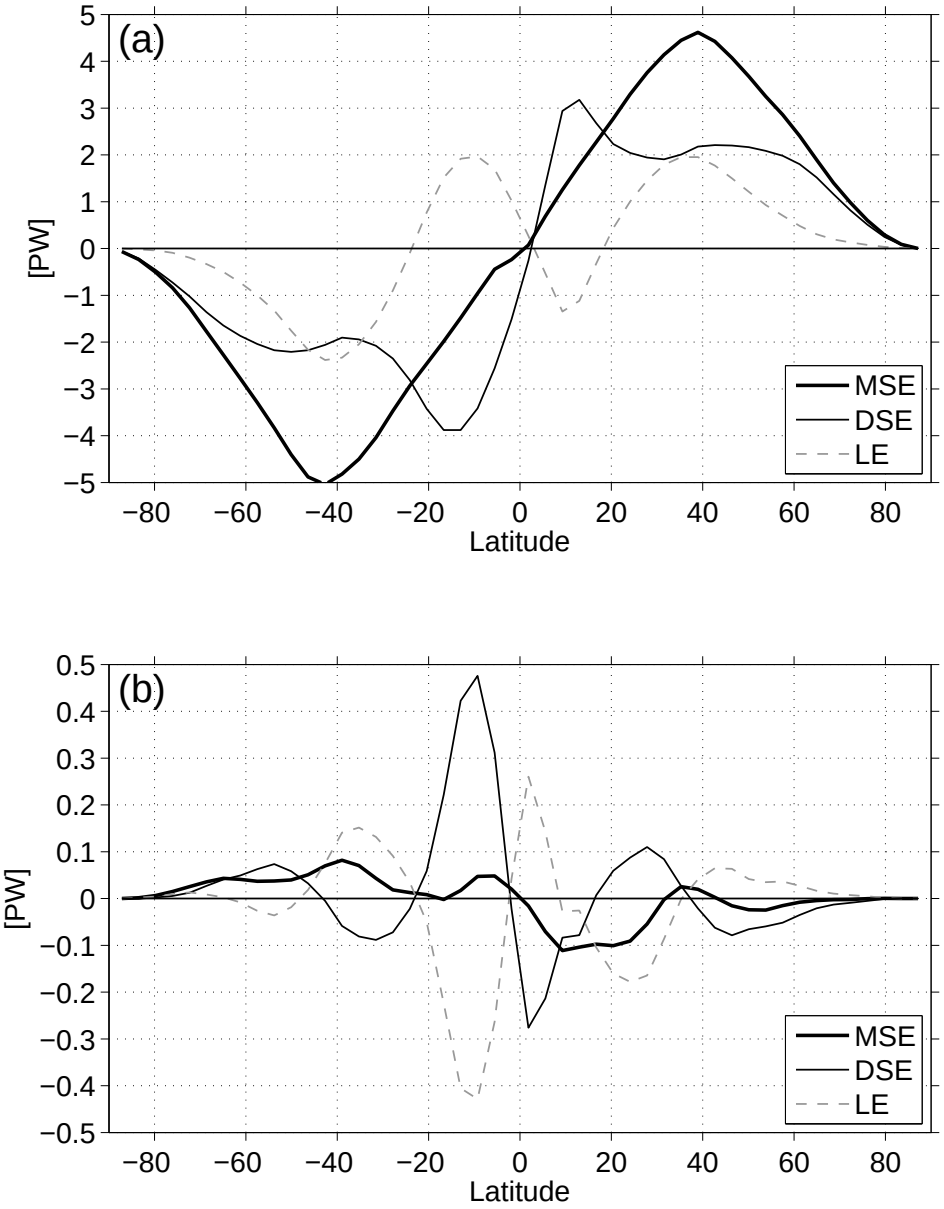
2. A perturbation experiment (SPEEDY), 25 years long, was started at year 350 of the CTL run.
3. Results seem robust and stable already after the first 10-15 years.

Atmospheric response: MOC



Ensemble mean of the meridional mean overturning circulation in the atmosphere for
(a) the decade 2000-2009,
(b) the decade 1990-1999, and
(c) their difference.
Units are Sv (1 Sv $\equiv 10^9$ kg s^{-1}).
[consistent with Hazeleger et al. (2005)]

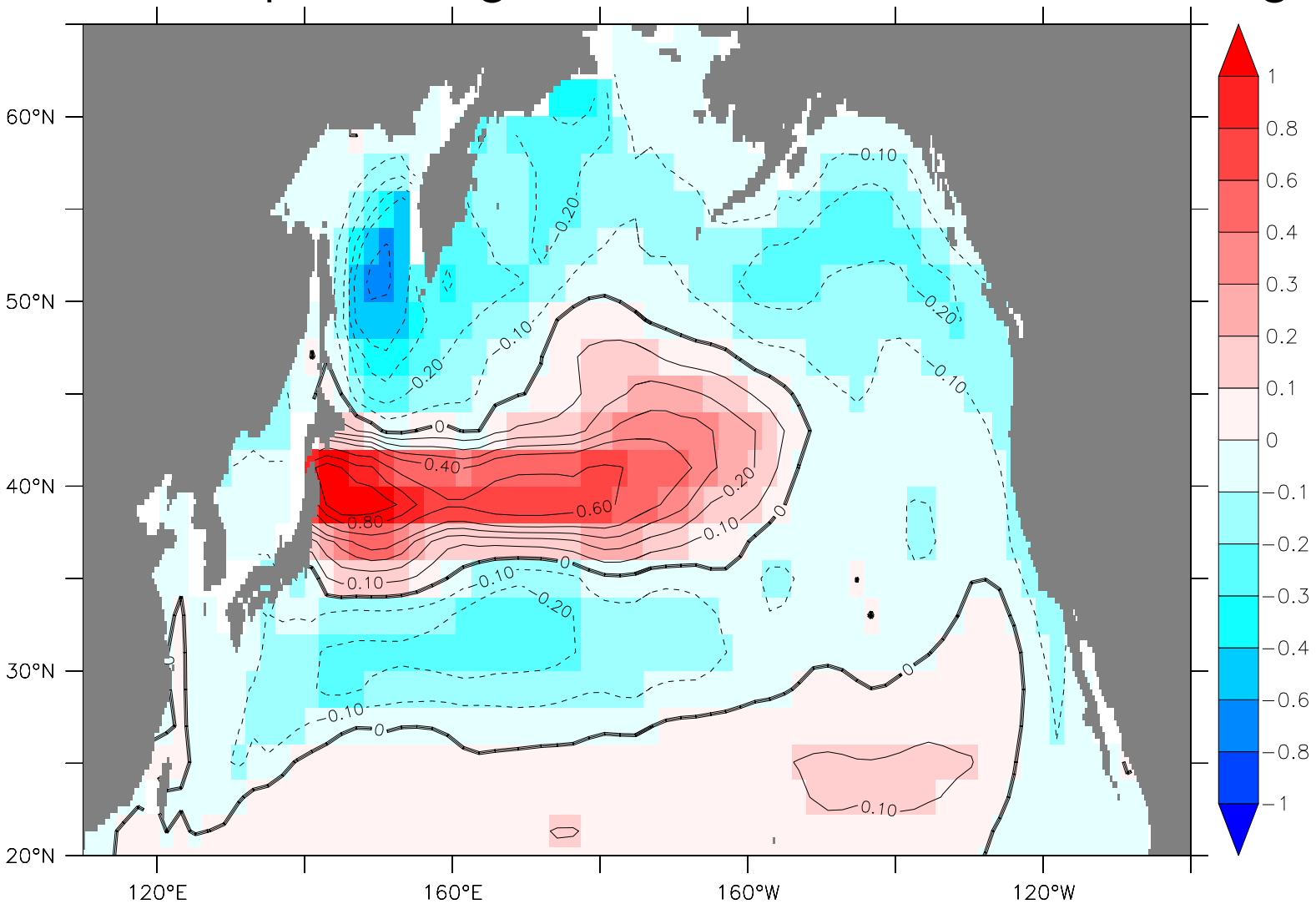
Atmsopheric response: Meridional Energy Fluxes



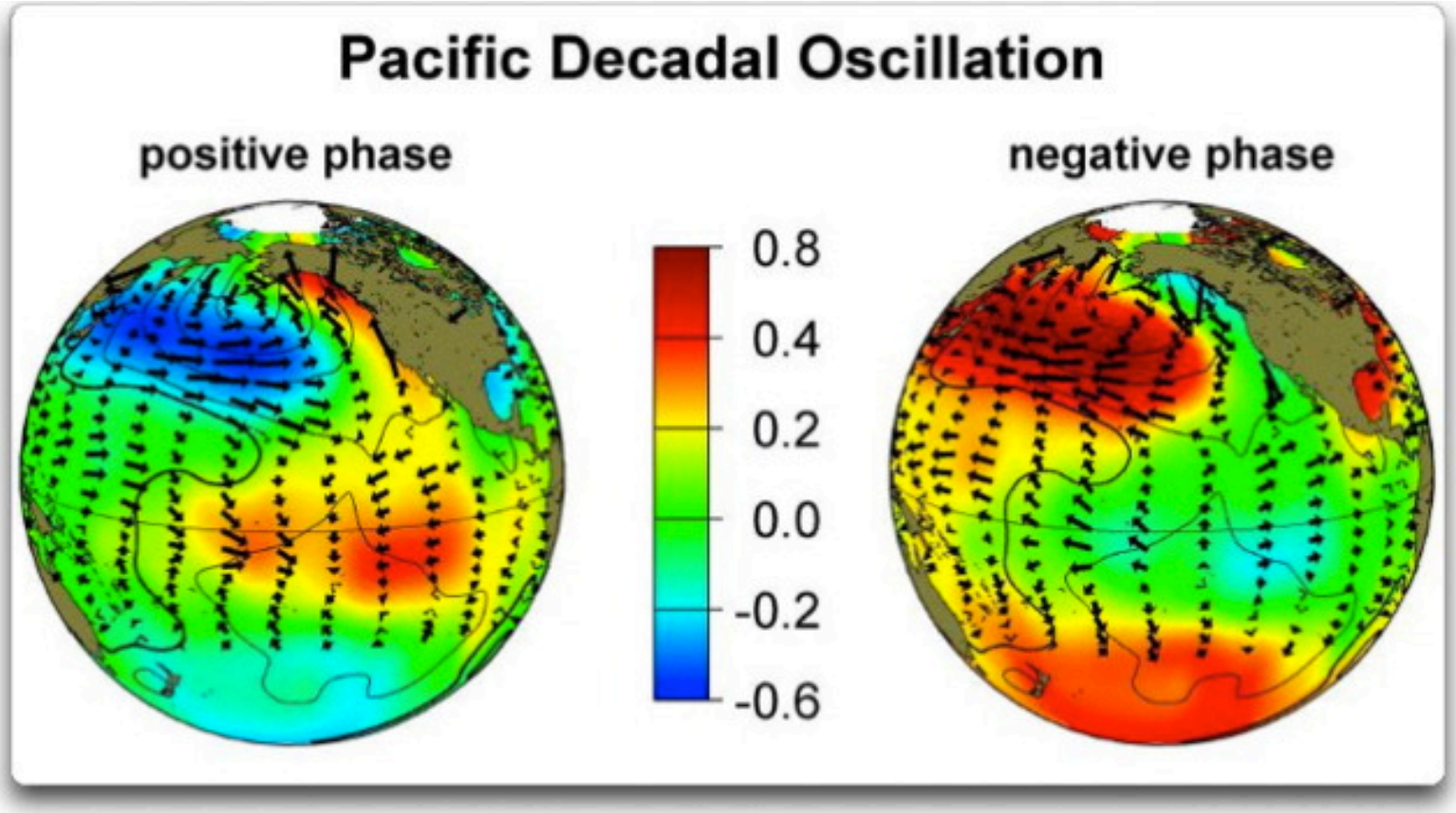
(a) Atmospheric meridional energy fluxes for the decade 1990-1999. The total transport, or moist static energy (MSE; bold solid line), dry static energy (DSE; thin solid line) and latent energy (LE; dashed grey line) are represented.
(b) Anomalies in poleward fluxes, computed as the ensemble mean difference between the 2000-2009 decade and the 1990-1999 decade. Units are PW (1 PW = 10^{15} W).

The Ocean response: SST EOF-1

A PDO-like pattern is generated when the anomalous forcing is added



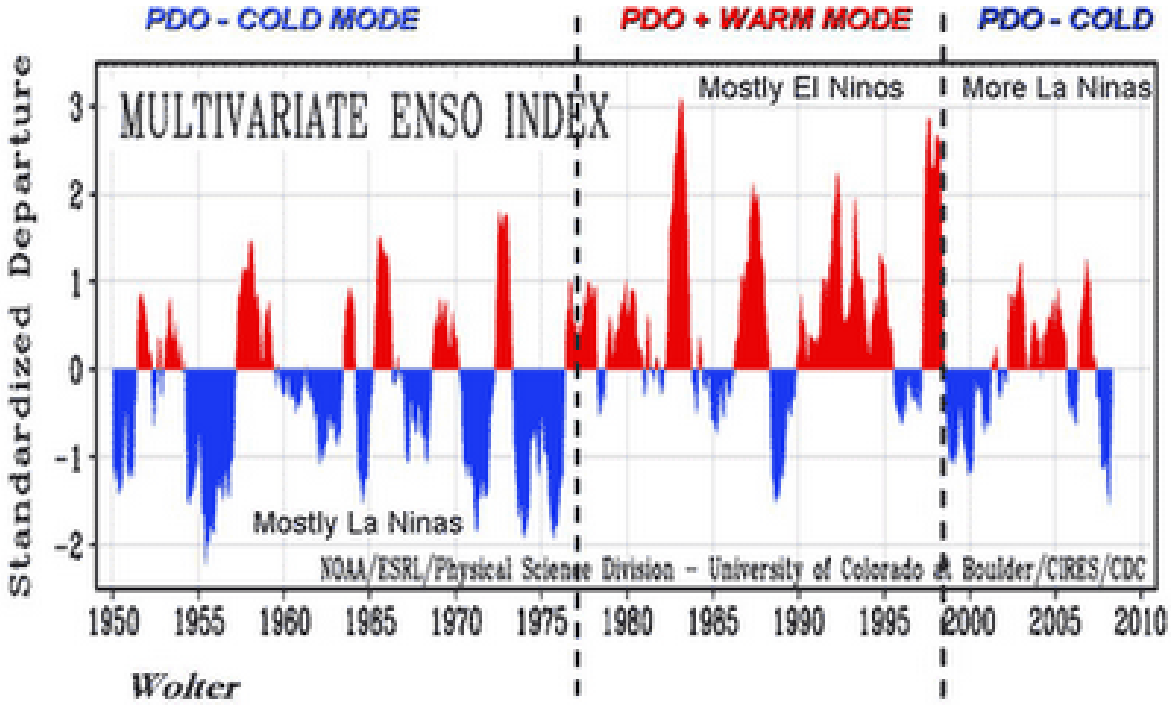
The observed PDO looks like this ...

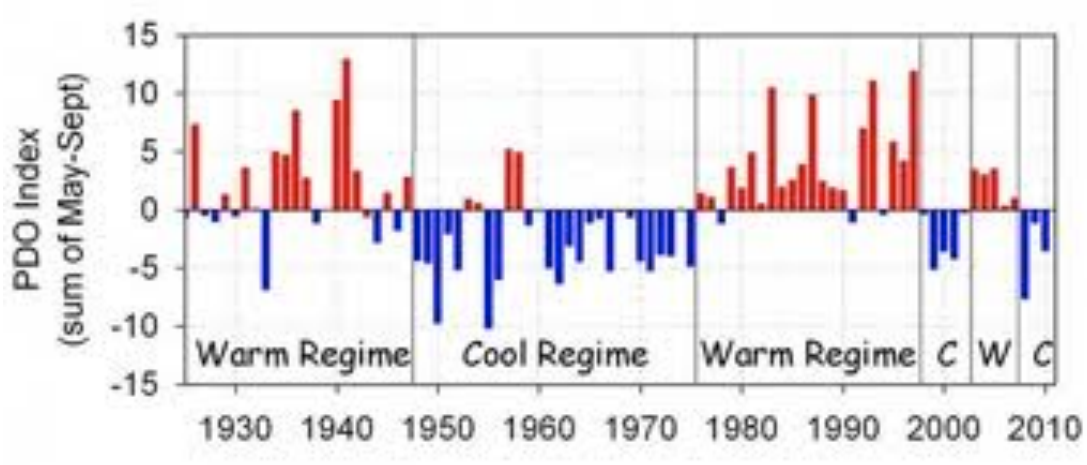


[jisao.washington.edu]

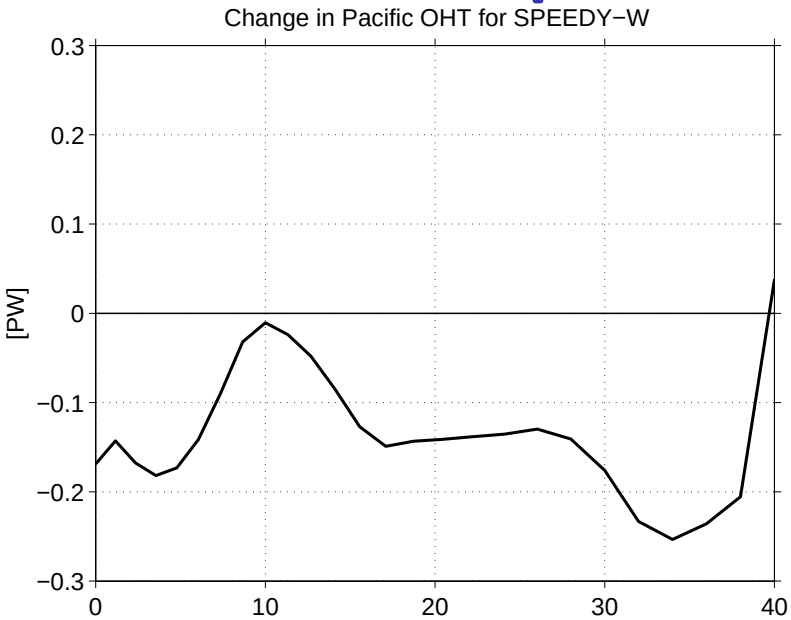
At decadal time scales, about a third of the PDO signal might be remotely-driven, with the remaining variance explained by oceanic zonal advection anomalies and variability of the Aleutian low (Schneider and Cornuelle, 2005).

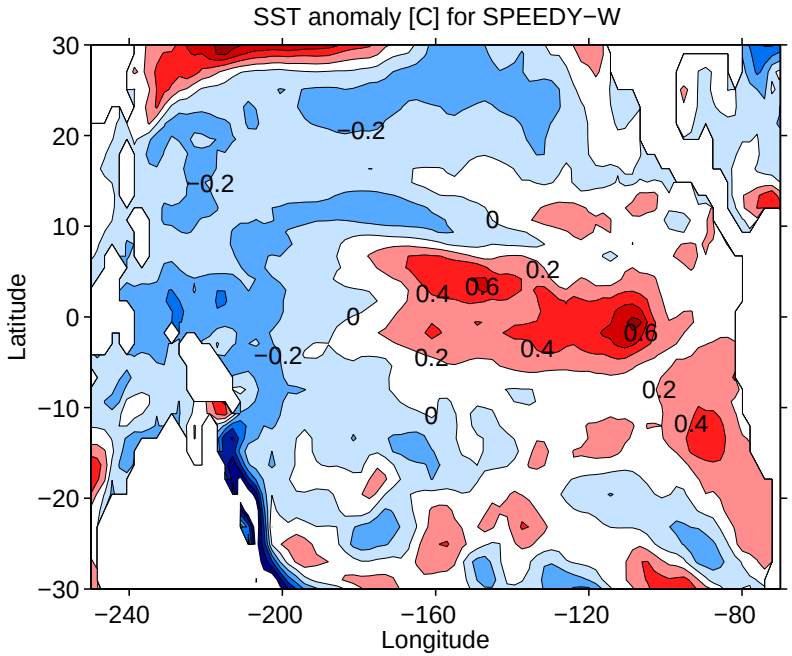
PDO - ENSO indeces

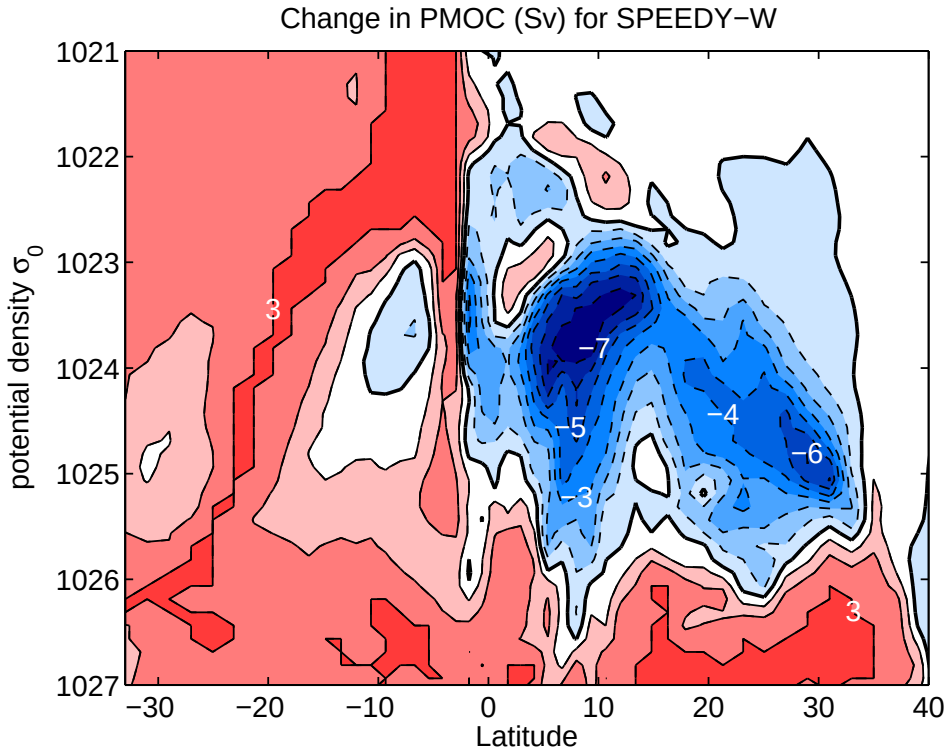




The ocean response



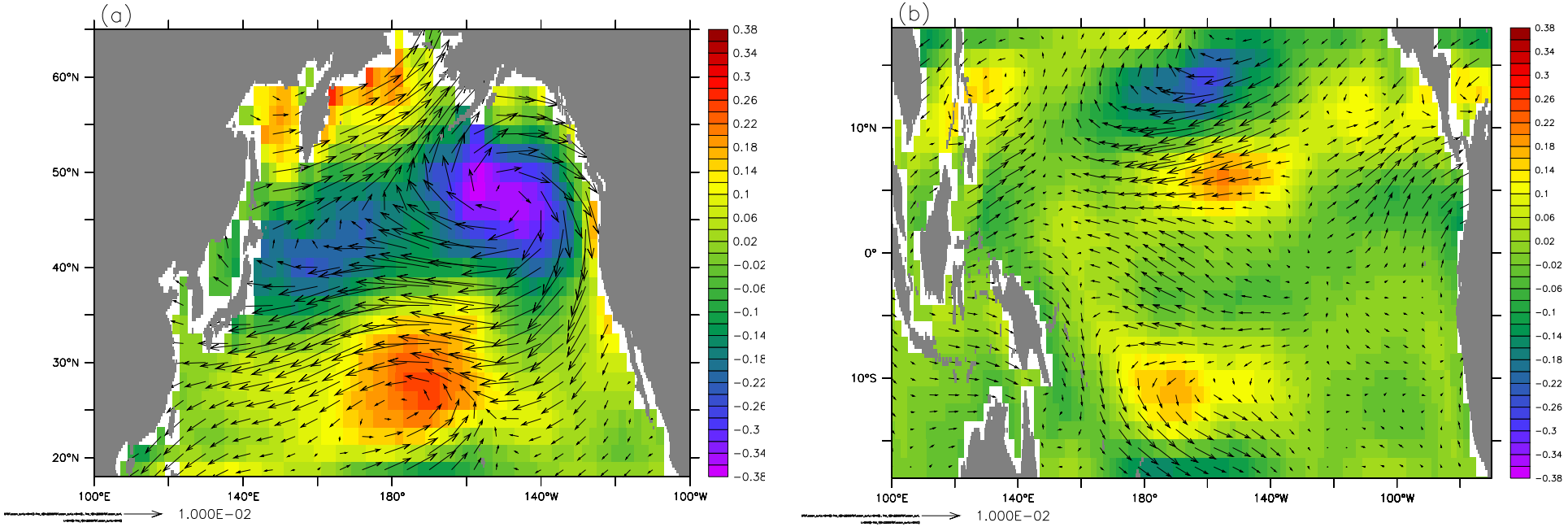




OHT and STC transport are reduced $\Rightarrow$ Equatorial SSTa is positive: The weakening of the OHT in the Equator leads to an anomalous warming there, so damping the original cooling pattern

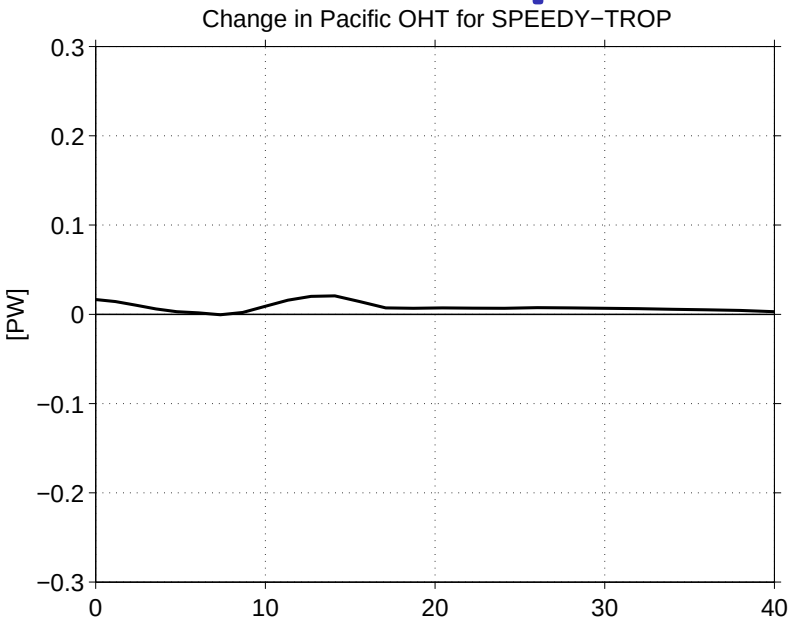
Sensitivity to location of the forcing

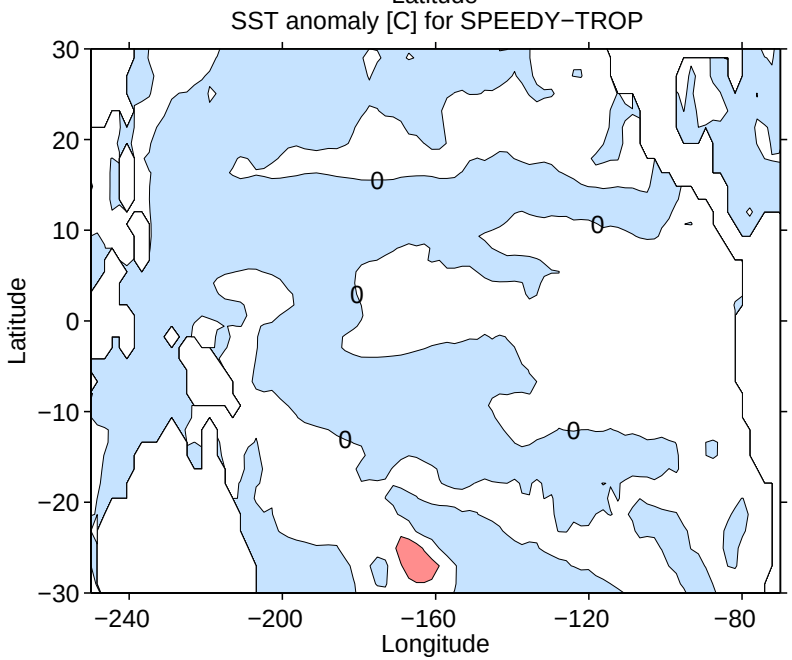
SPEEDY-NOTROP and SPEEDY-TROP experiments.

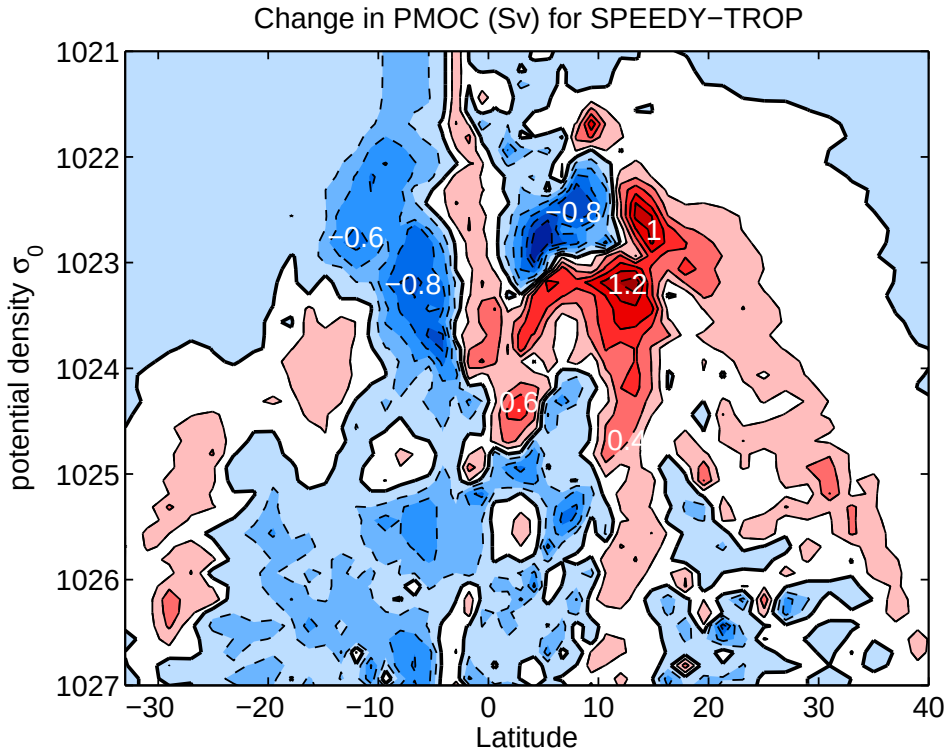


Wind stress (vectors; N m^{-2}) and wind stress curl (shading; $\times 10^{-7}$ N m^{-3}) anomalies computed by the ocean model in the (a) SPEEDY-NOTROP and (b) SPEEDY-TROP experiments.

The ocean response: TROP

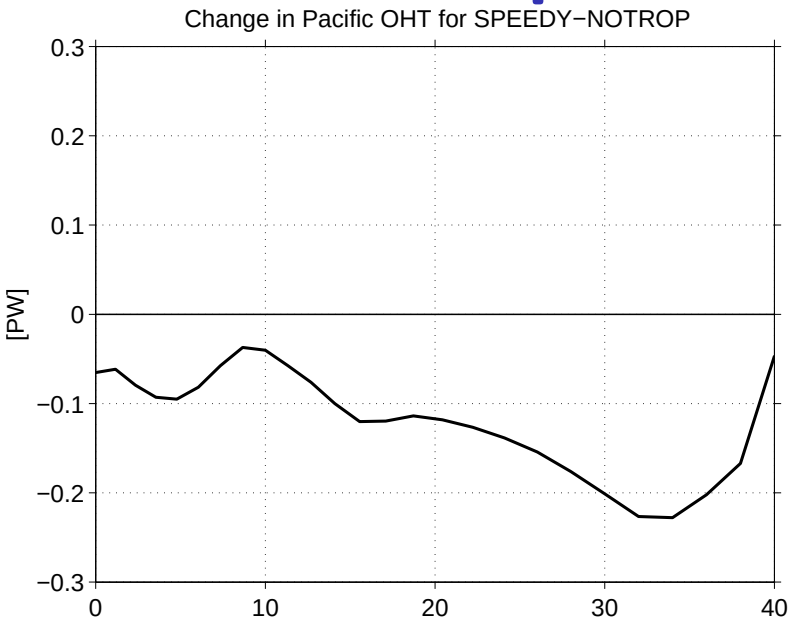


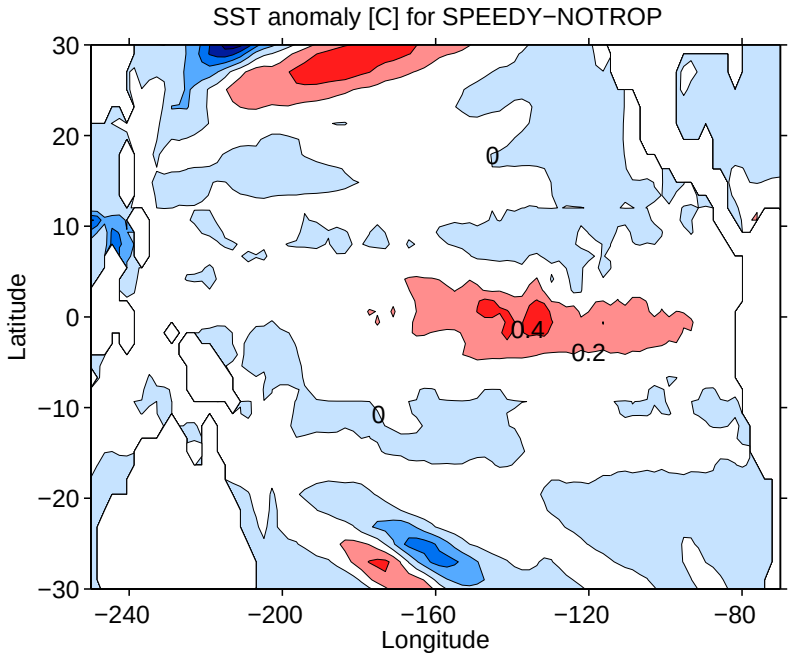


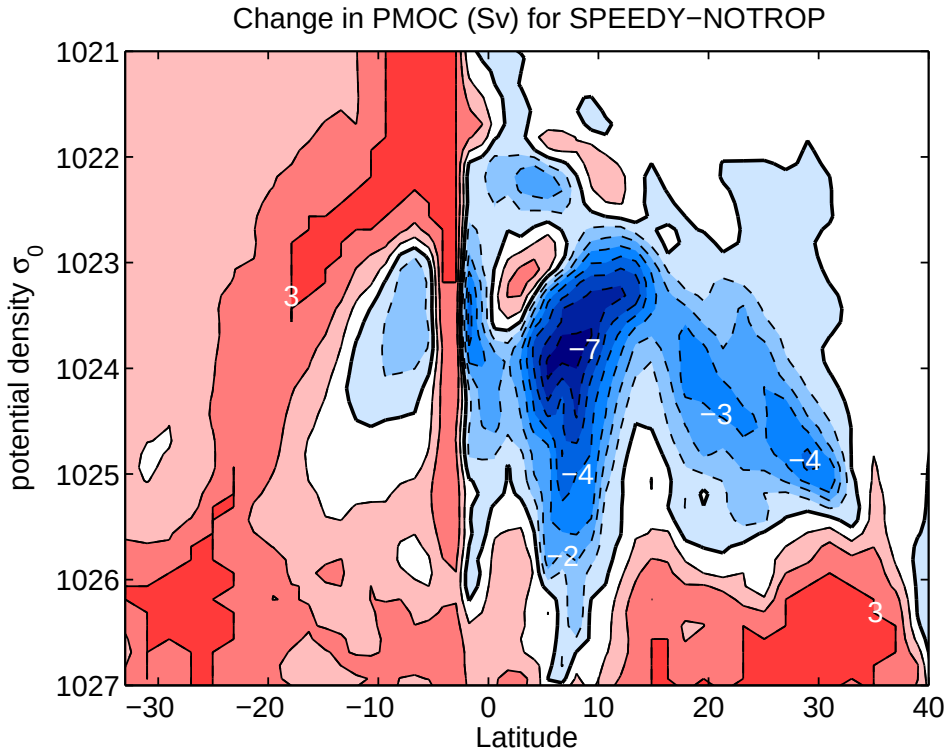


- no significant response (small positive feedback)

The ocean response: NOTROP



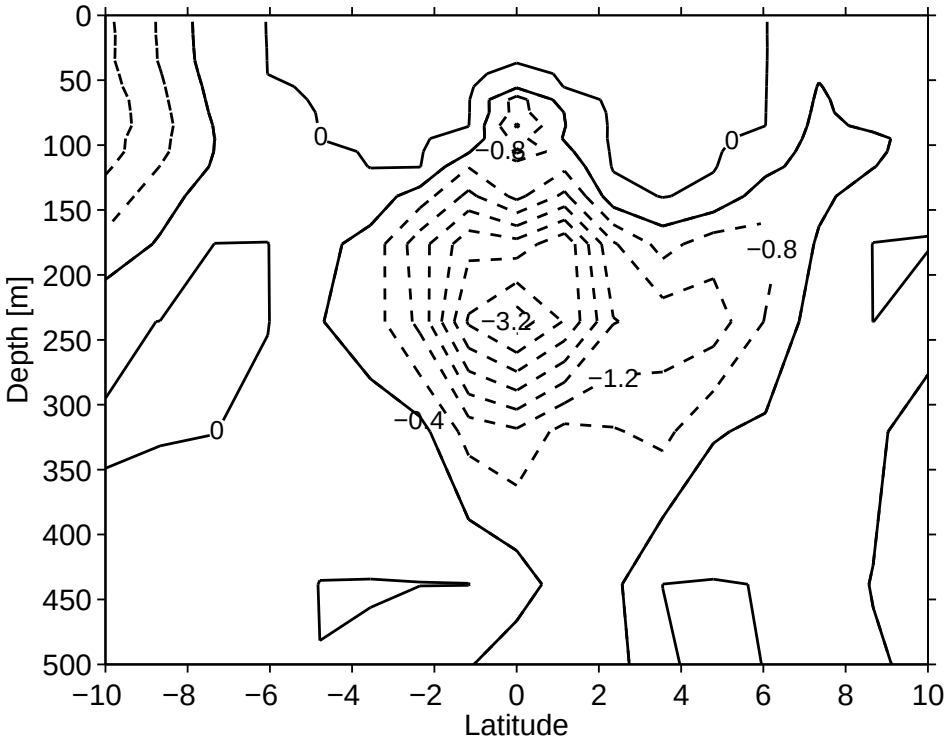




- significant response (similar to the full forcing case)

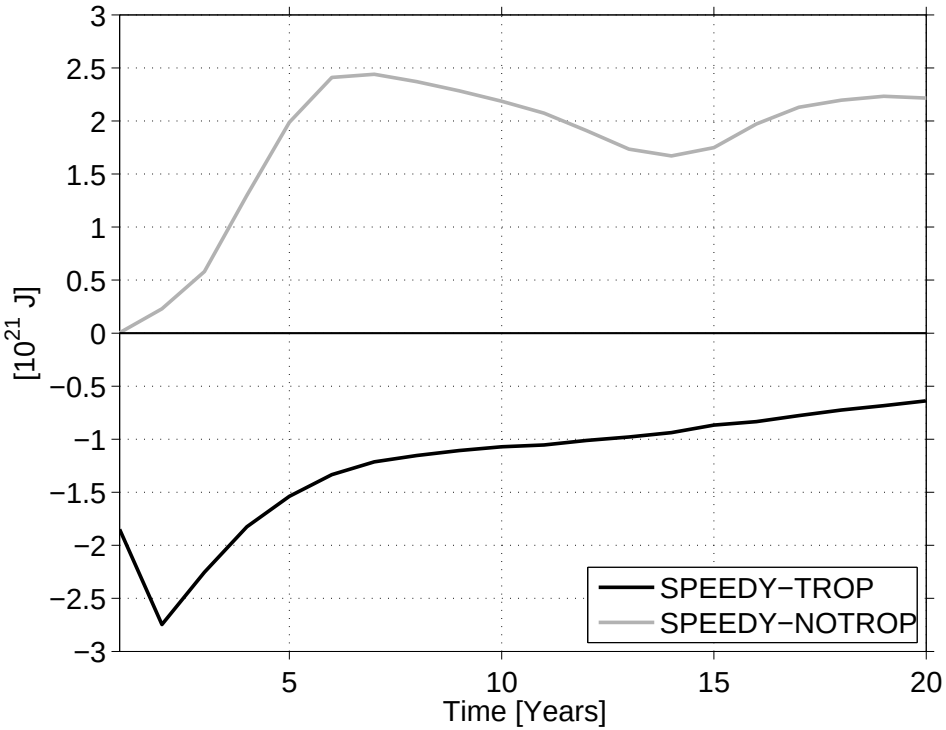
The ocean response: The EUC

Change in the equatorial undercurrent (EUC; in cm s^{-1}) for the SPEEDY-NOTROP experiment.



A weakening of the EUC is consistent with a weaker equatorward transport of subducted subtropical waters (see theory of Pedlosky, 1987).

Heat Content anomalies



Evolution of heat content anomalies relative to the Control for the SPEEDY-TROP (black line) and SPEEDY-NOTROP (gray line). Heat content is computed in the region [160°W - 90°W; 12°S - 12°N] and over the 0-500 m layer.

An idealized model of the interactions between ENSO, the Pacific sub-tropical gyre and the sub-tropical cells

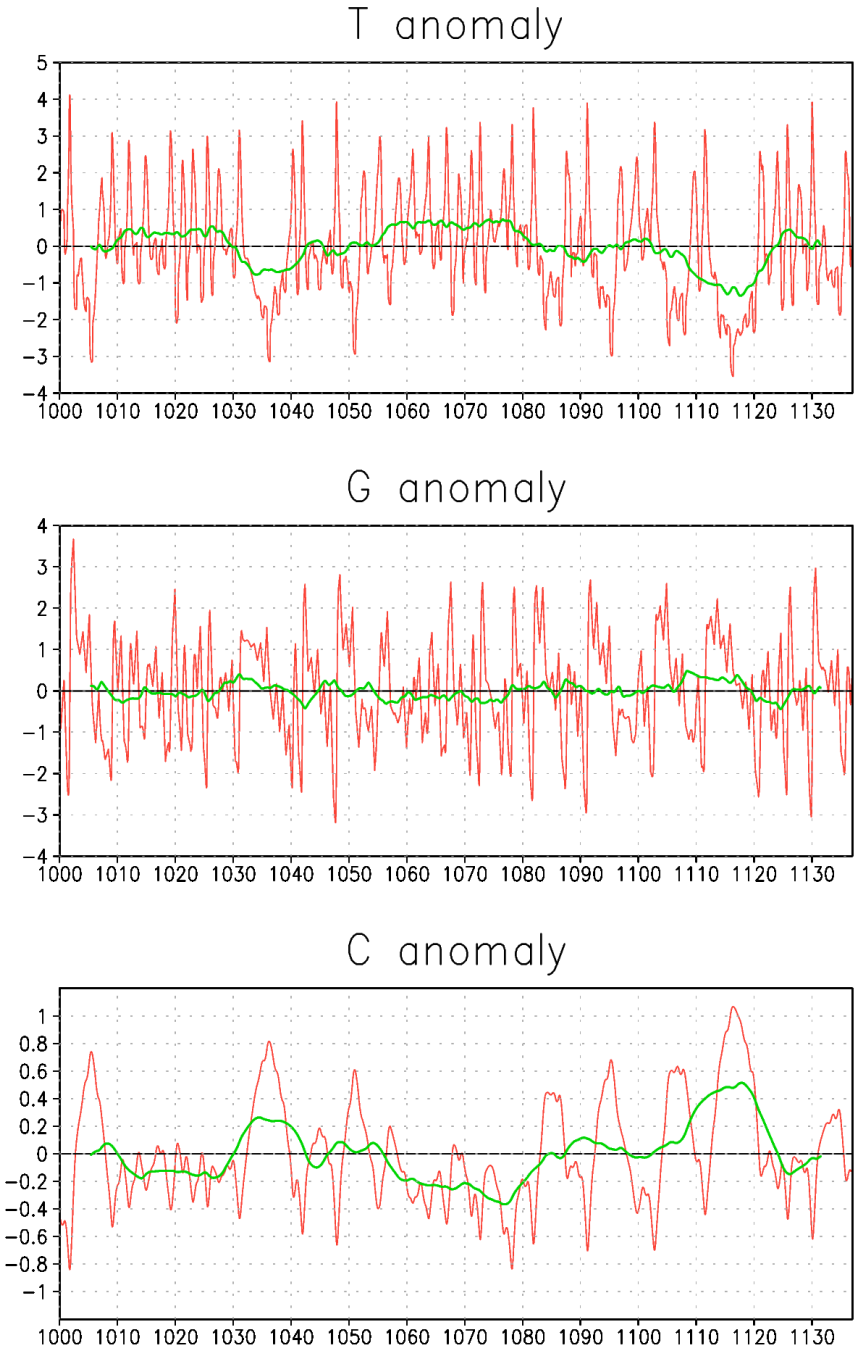
If T represents the SST anomaly in central equatorial Pacific, G and C are indices of the anomalies in the intensity of the Pacific sub-tropical gyre and cells respectively (based on the ENSO delayed oscillator ofSuarez and Schopf (1988)):

$$\frac{\mathrm{d}\,T}{\mathrm{d}\,t} = T - \alpha\, T(t-\delta) - r_1 (T - T_0)^3 - E(G + G_0) \tag{1a}$$

$$\frac{\mathrm{d}\,G}{\mathrm{d}\,t} = -\omega\, C + E\, T + r_2 \tag{1b}$$

$$\frac{\mathrm{d}\,C}{\mathrm{d}\,t} = \omega\, G - k\, C, \tag{1c}$$

where $T_0 = -\beta\, C$.



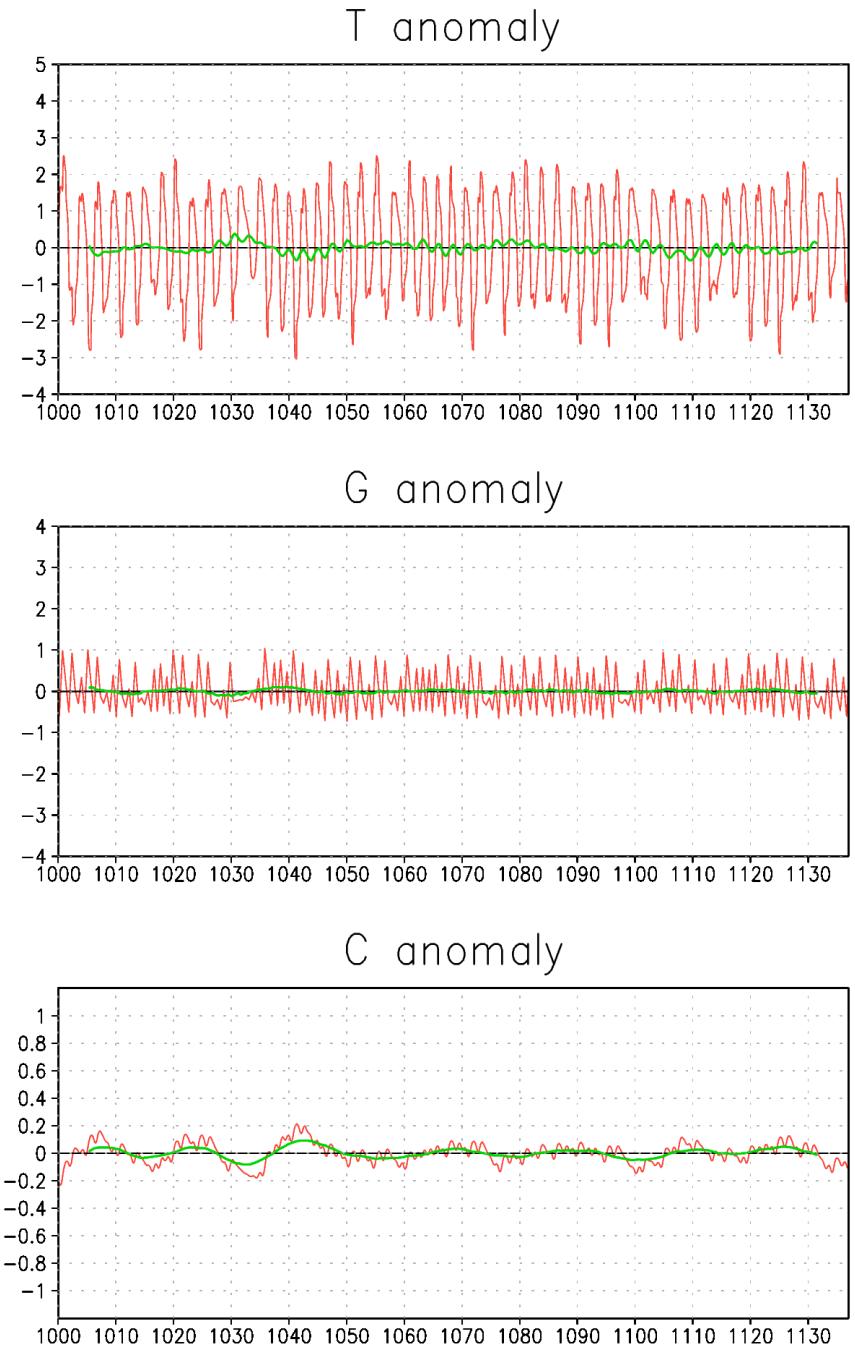
1. Time series for the three variables T (ENSO SST) , G (subtropical gyre) and C (subtropical cells) in the idealized model.
2. Decadal variability in T and C, which are anticorrelated by construction.

If there is no direct interaction between T and G ...

$$\frac{\mathrm{d}\,T}{\mathrm{d}\,t} = T - \alpha\, T(t-\delta) - r_1 (T - T_0)^3 - \cancel{E(G + G_0)} \tag{2a}$$

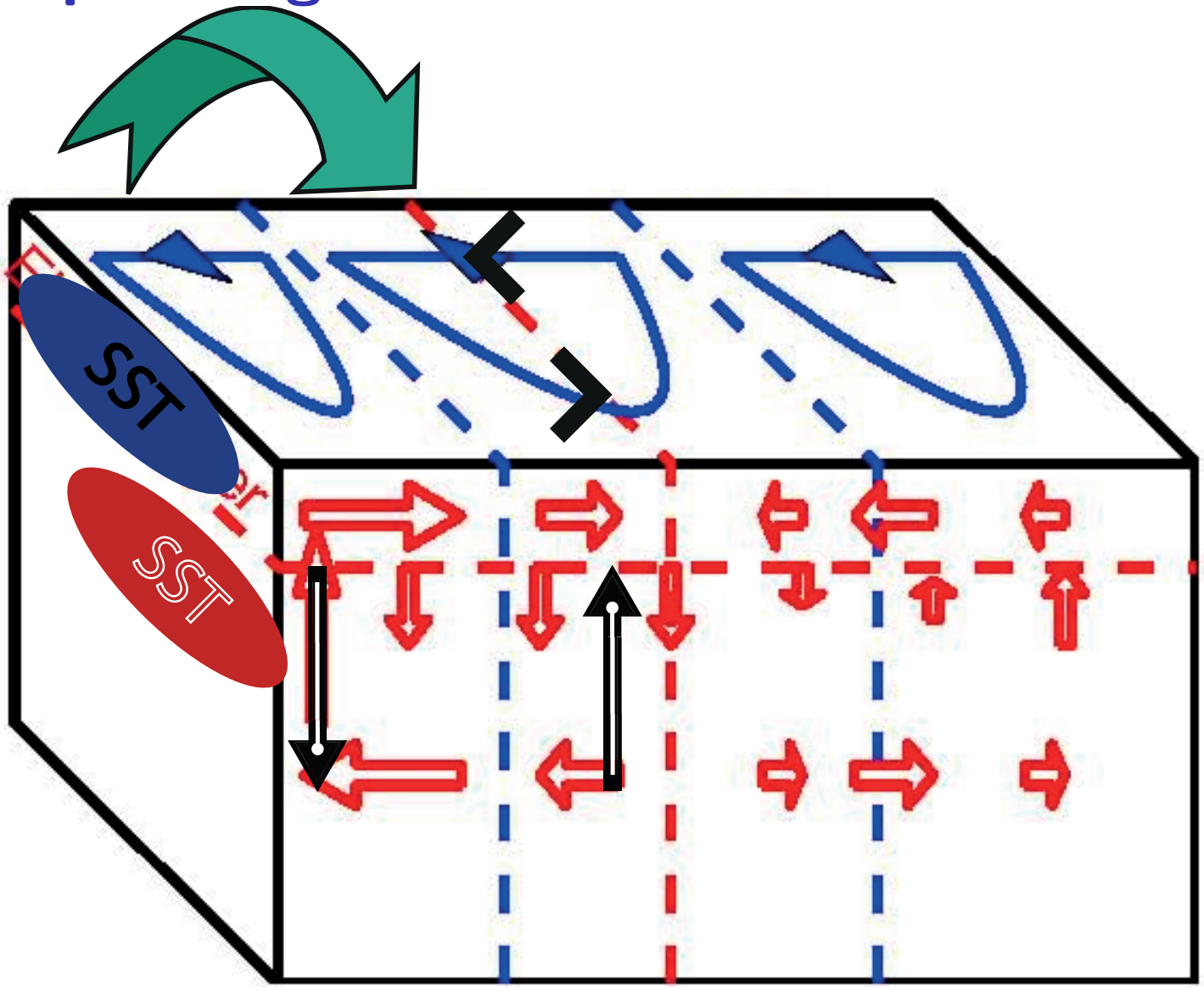
$$\frac{\mathrm{d}\,G}{\mathrm{d}\,t} = -\omega\, C + \cancel{E\, T} + r_2 \tag{2b}$$

$$\frac{\mathrm{d}\,C}{\mathrm{d}\,t} = \omega\, G - k\, C, \tag{2c}$$



1. Much reduced variability in C and regular variations in T

A coupled negative feedback



Conclusions

1. The atmospheric response to tropical forcing has feedbacks on the subtropical ocean, which is forcing an equatorial time-delayed response, generating decadal SST anomalies
2. A possible mechanism for coupled ocean-atmosphere Pacific multidecadal variability and ENSO decadal variability, involving both the *atmospheric bridge* and the *oceanic tunnel*.
3. BUT: our results seem at odds with the theory of McCreary and Lu (1994), where the strength of the STC is not directly related to subtropical subduction.
4. BUT: our results seem at odds with the notion of no interdecadal tropical predictability
5. CAVEATS: uncoupled and coarse model.

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