Pacific interdecadal variability driven by tropical-extratropical interactions

MODEL HIERARCHIES WORKSHOP
PRINCETON UNIVERSITY, USA. 2-4 NOVEMBER 2016

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Thanks to: F. Molteni (ECMWF) & F. Kucharski (ICTP)

World Climate Research Programme

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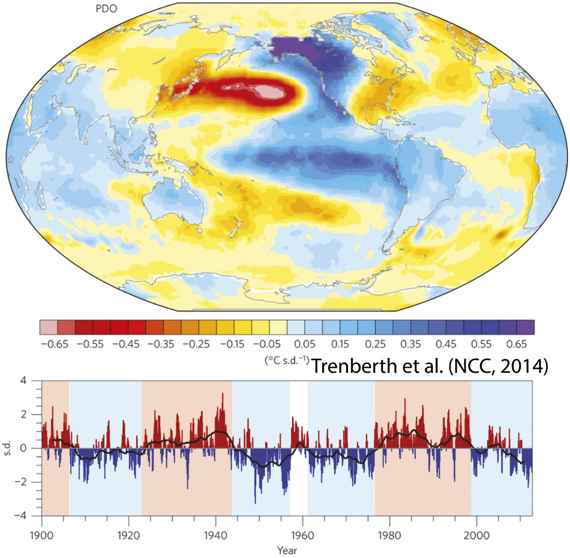
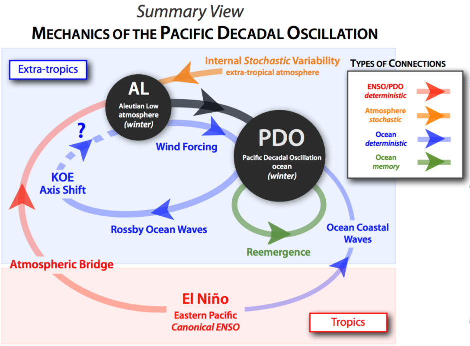
The Pacific Decadal Oscillation



Trenberth et al. (NCC, 2014)

- The PDO is defined by the leading pattern (EOF) of SST anomalies in the North Pacific basin (typically, polewards of 20N).
- At decadal time scales, about a third of the PDO signal might be remotely-driven.

What is the PDO?

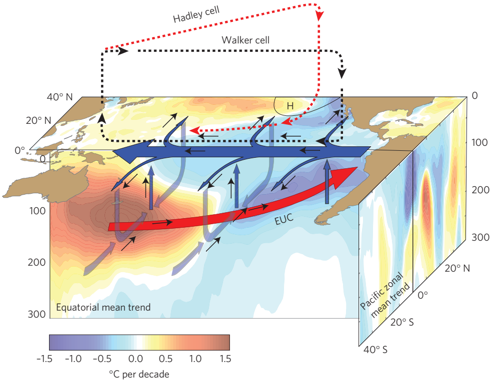


(Newman et al., 2016)

- The PDO is not a physical mode but rather is the sum of several physical processes:
- North Pacific SST integrates **weather noise** (fluctuations in the Aleutian Low)
- SST anomalies provide **reduced damping** of atmospheric signals at low-frequency
- Midlatitude **ocean dynamics** (partly) sets the timescale
- **Teleconnections** from the Tropics

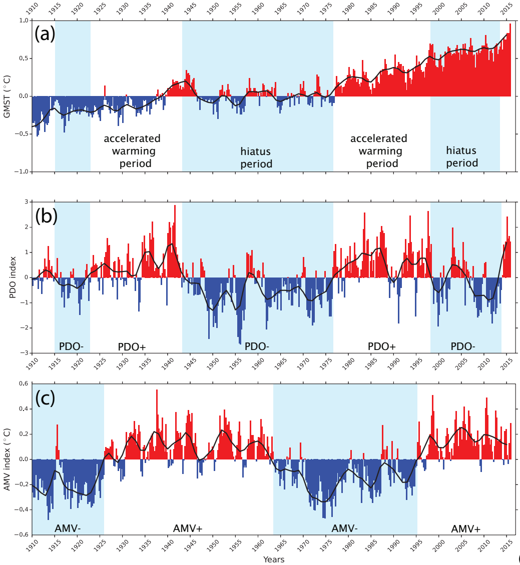
The PDO and the warming hiatus (slowdown)

- Kosaka and Xie (2013), accounting for the recent cooling in the eastern equatorial Pacific reconciled climate simulations and observations.
- England et al. (2014) showed that a pronounced strengthening in Pacific trade winds over the past two decades is sufficient to account for the cooling of the tropical Pacific and the slowdown in surface warming.



England et al. (2014)

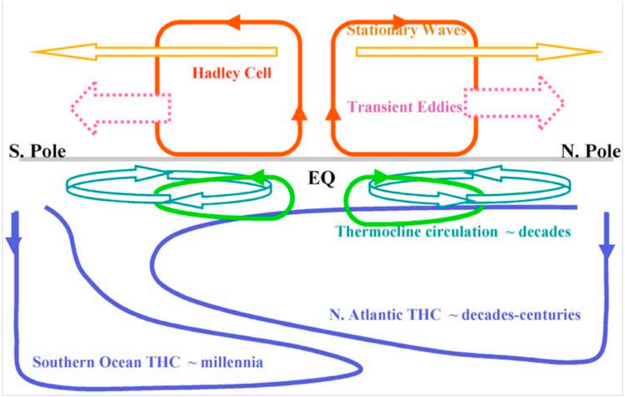
PDO & Global Mean Surface Temperature



(Farneti, 2016)

Hypothesis: tunnels and bridges

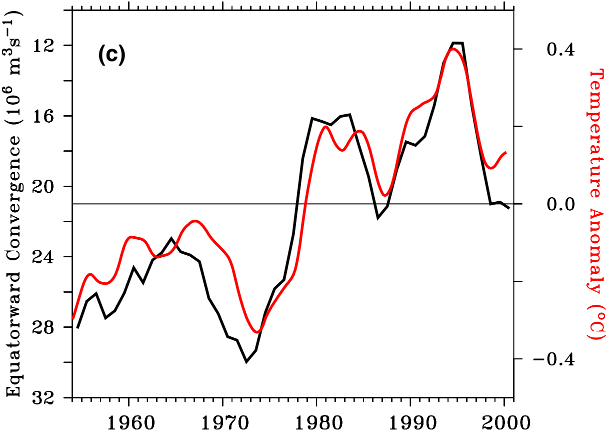
Tropical⟺extratropical interactions



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

- Tropical forcing patterns can force extratropical flow responses
- Can the atmosphere feed back on the ocean, leading to a time-delayed response of the tropical oceans?

The role of Pacific SubTropical Cells



(Zhang and McPhaden, 2006)

Models & Experiments

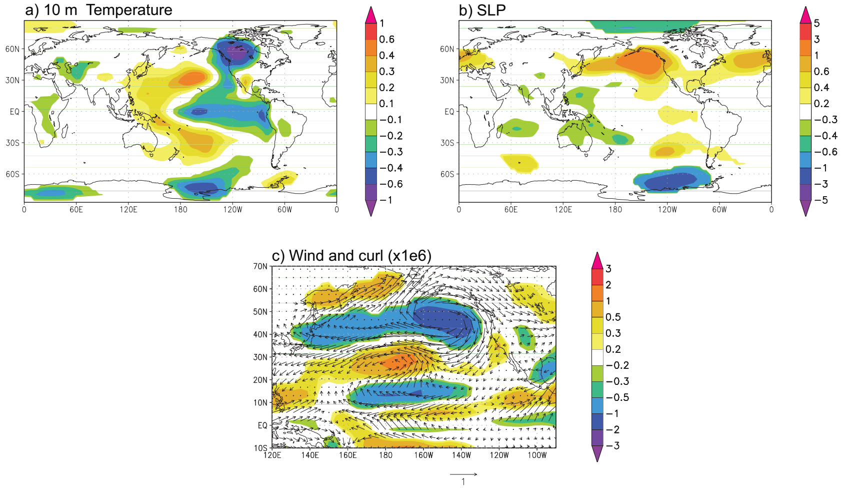
MOM and SPEEDY

1. **OCEAN:** MOM at 2°resolution. NO SST Restoring. Forced with the Coordinated Ocean-ice Reference Experiment (CORE) Normal Year Forcing (NYF) (Griffies et al., 2009) for 600 years.
2. **ATMOSPHERE:** the Intermediate Complexity SPEEDY at T30 resolution, with 8 levels in the vertical.

The experiments

1. 10-member SST-forced SPEEDY ensemble with interannually varying SST, only in the Pacific region, derived from the HadISST dataset.
2. From the ensemble mean, we produced decadal (2000/2009)-(1990/1999) anomalies, which were then added to each climatological CORE field forcing the ocean.

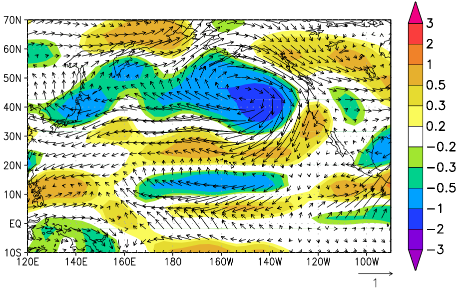
The anomalous forcing



Asymmetric response. Wind stress and wind stress curl anomalies have the opposite

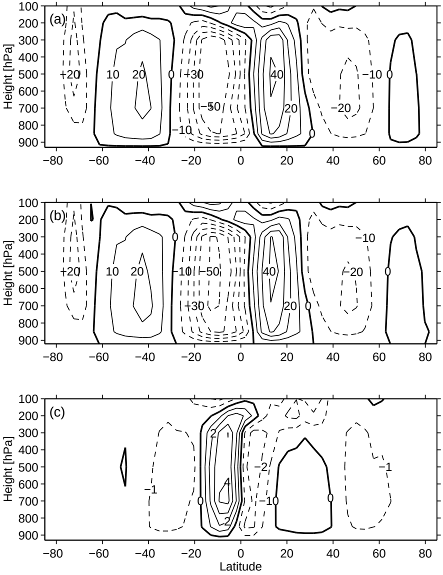
but where is the anomaly coming from?

Most of the anomalies in extratropical winds are generated from tropical forcing, and only a minor fraction comes from local air-sea interactions



Anomalous wind and its curl for an ensemble of tropical (18°S to 18°N) SST forcing only.

Atmospheric response



Ensemble mean of the meridional mean overturning circulation in the atmosphere for

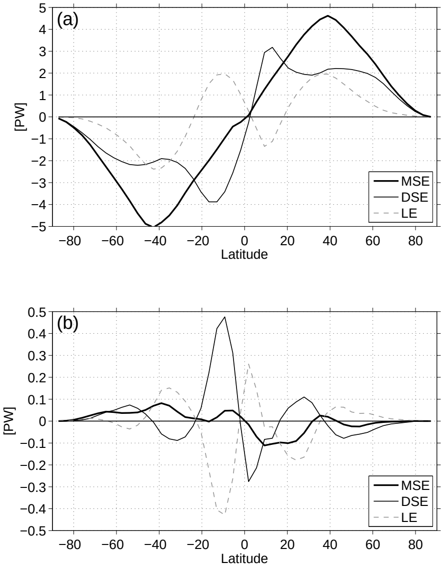
(a) the decade 2000-2009,

(b) the decade 1990-1999

(c) their difference.

Units are Sv (1 Sv $\equiv 10^9$ kg s^{-1}).

Atmospheric response



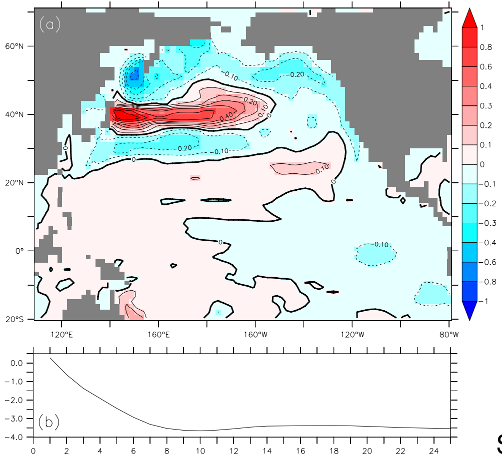
(a) Atmospheric meridional energy fluxes for the decade 1990-1999.

MSE: Total transport, or moist static energy, DSE: dry static energy, and LE: latent energy.

(b) Anomalies in poleward fluxes, computed as the ensemble mean difference between the 2000-2009 and the 1990-1999 decade. Units are PW (1 PW = 10^{15} W).

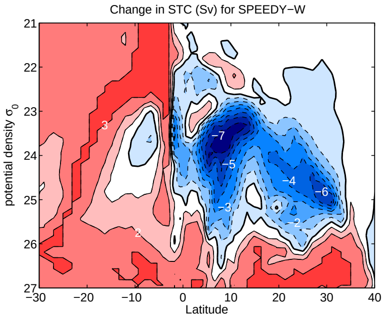
Ocean response

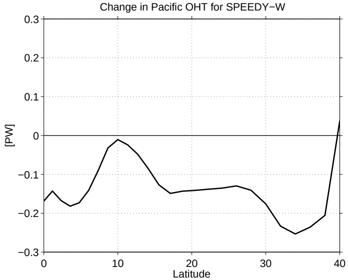
A PDO-like pattern is generated when the anomalous forcing is added

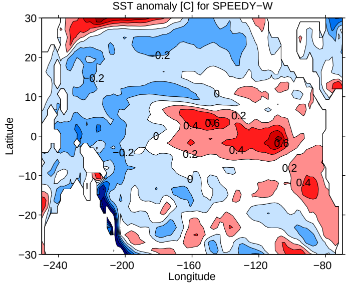


SST EOF-1

Interior Ocean response



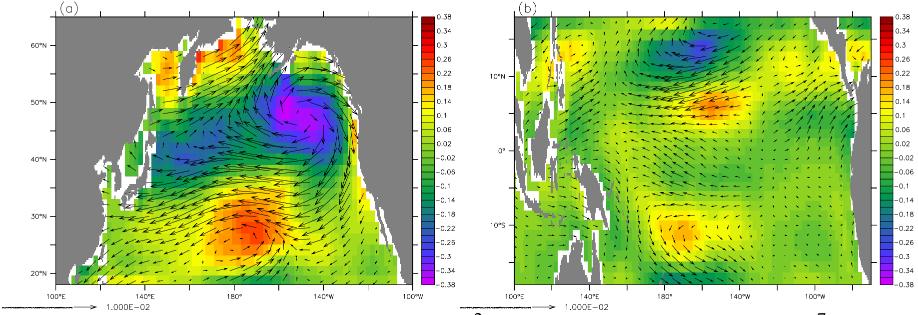




- OHT and STC transport are reduced and SSTa are positive.
- The anomalous warming damps the original cooling pattern.

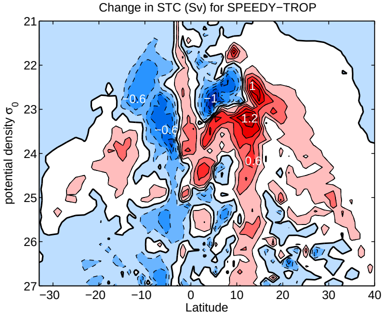
Sensitivity to location of the forcing

SPEEDY-NOTROP and SPEEDY-TROP

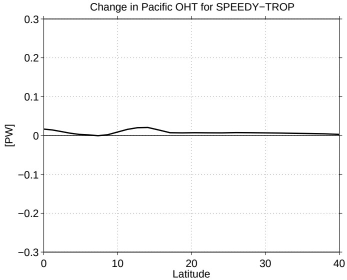


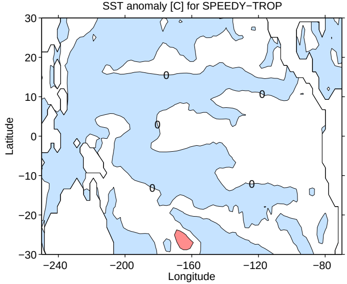
Anomalous wind stress (vectors; Nm^{-2}) and its curl (shading; $\times 10^{-7}$ Nm^{-3}) computed by the ocean model in the sensitivity experiments.

Ocean response: TROP

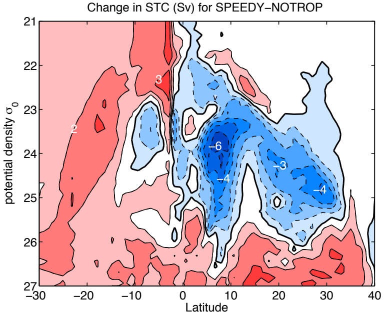


- no significant response for tropical wind anomalies (small positive feedback, if anything)

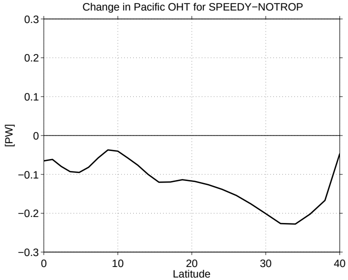


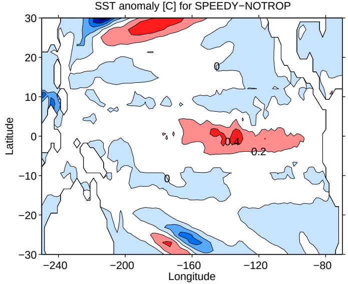


Ocean response: NOTROP



- significant response for extratropical wind anomalies (similar to the full forcing case)





An idealized model for the ENSO-STG-STC interactions

Let **T** be the SST anomaly in central equatorial Pacific, **G** and **C** the indices of the anomalies in the intensity of the Pacific sub-tropical gyre (G) and cells (C) [based on the ENSO delayed oscillator of Suarez and Schopf (1988)]:

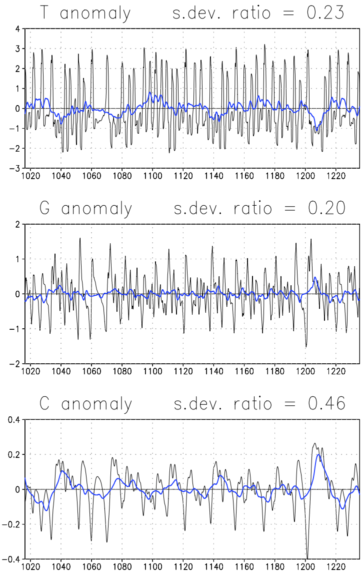
$$\frac{\mathrm{d}\,T}{\mathrm{d}\,t} = T - \alpha\,T(t-\delta) - r_1(T-T_0)^3 - E\,G \qquad (1a)$$

$$\frac{\mathrm{d}\,G}{\mathrm{d}\,t} = E\,T - \kappa\,G + \gamma\,r_2 \qquad (1b)$$

$$\frac{\mathrm{d}\,C}{\mathrm{d}\,t} = -\kappa\,(C-G) \qquad (1c)$$

where $T_0 = -\beta C$, γ = 0.25 and κ = 0.025 (because atmospheric response is 10$\times$faster than the G-C interactions).

An idealized model for the ENSO-STG-STC interactions



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

An idealized model for the ENSO-STG-STC interactions

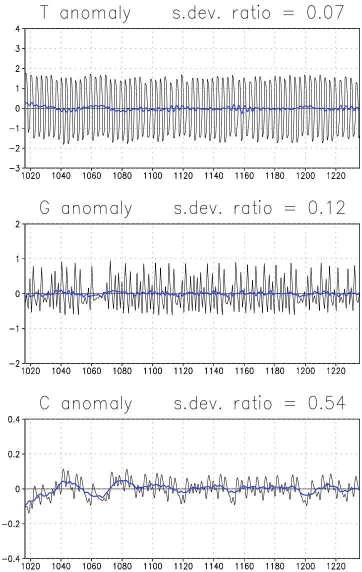
If there is no direct interaction between T and G, i.e. E = 0 & r_1 = const.

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

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

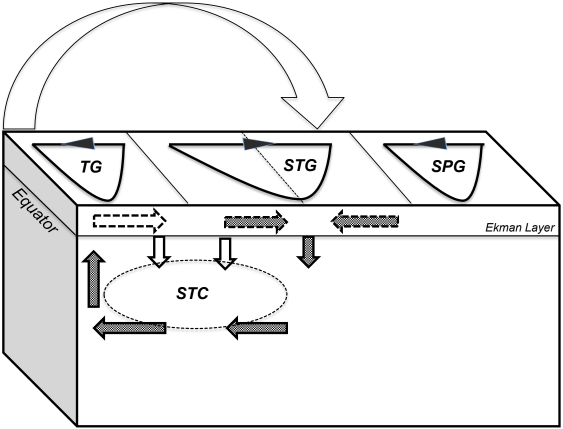
$$\frac{\mathrm{d}\,C}{\mathrm{d}\,t} = -\kappa\,(C-G) \tag{2c}$$

An idealized model for the ENSO-STG-STC interactions



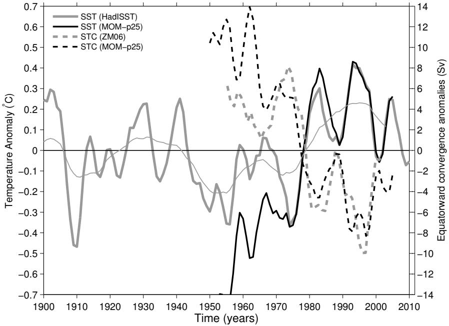
1. Much reduced variability in C and G and regular variations in T.
2. The gyre forcing by chaotically-modulated ENSO response is crucial.

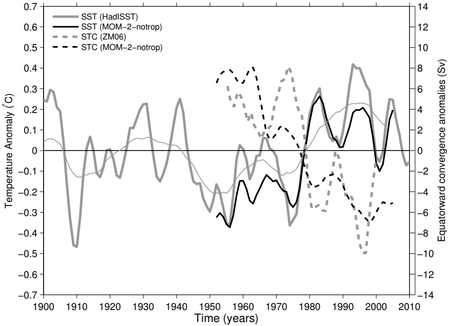
Coupled tropical-extratropical feedbacks and the generation of low-frequency ENSO/PDO variability



(Farneti et al., 2014b)

Evolution of the Pacific STC & SST for the period 1948-2007 in forced ocean models



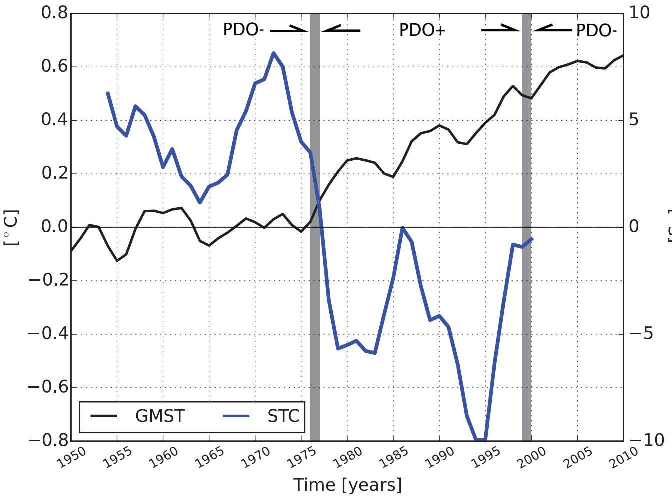


- Model results agree well with observed estimates of STC convergence, and equatorial SSTa (ZM06, Zhang and McPhaden, 2006).

(Farneti et al., 2014a)

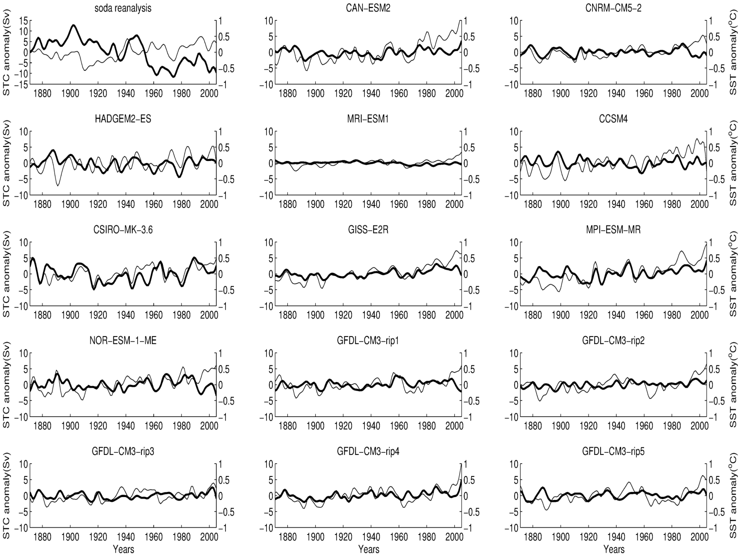
- Subtropically-forced STC variability is identified as a major player in the generation of equatorial Pacific decadal SSTa.

STC - PDO - GMST

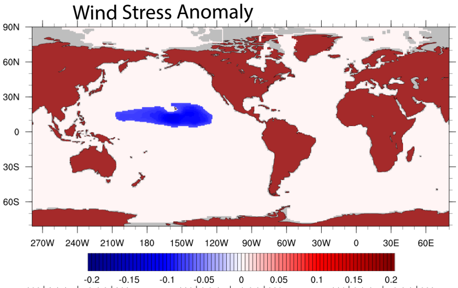


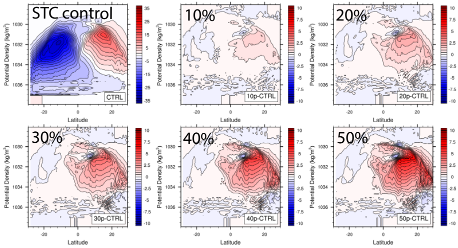
PDO-
PDO+
PDO-
GMST
STC
[° C]
[Sv]
Time [years]
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
10
5
0
−5
−10
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

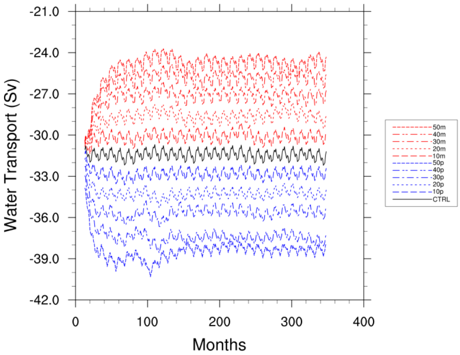
Do CMIP5 models reproduce the observed STC variability? NO



Ocean-only idealized simulations



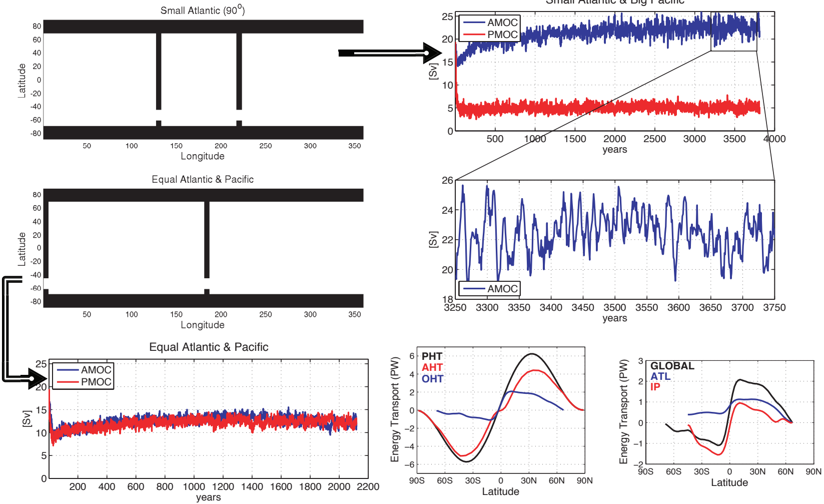




STCs spin up with strengthened subtropical τ^x, strengthening the EUC and generating a negative SSTa at the equator.

Coupled idealized simulations

Intermediate Complexity Coupled Model (ICCM) [Farneti & Vallis, 2011]



Conclusions

1. Trough a hierarchy of models we have (*and will*) studied tropical–extratropical interactions in the Pacific giving rise to low-frequency variability.
2. The system outlines a possible coupled mechanism for Pacific variability, involving both the *'atmospheric bridge'* and the *'oceanic tunnel'*.
3. Subtropically-forced STC variability is major player in the generation of equatorial Pacific decadal SST anomalies, pacing tropical Pacific natural climate variability on decadal time scales, as observed in historical records.

References

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