Pacific interdecadal variability driven by tropical-extratropical interactions (teleconnections)

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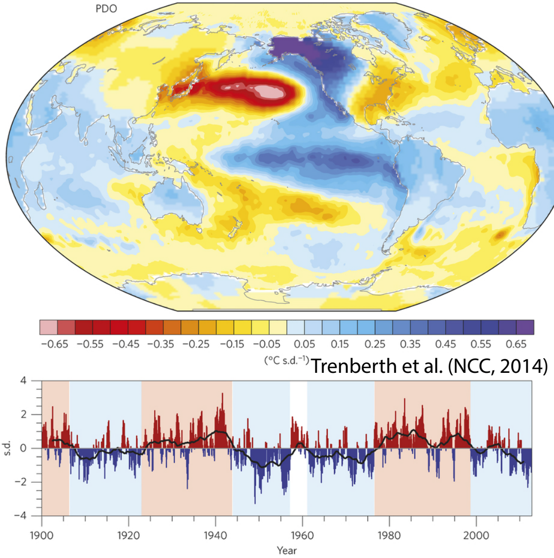
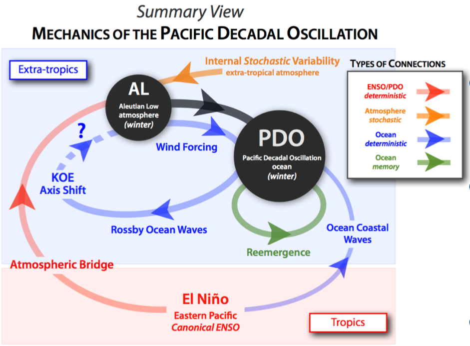
The Pacific Decadal Oscillation



- The Pacific Decadal Oscillation (PDO) is defined by the leading pattern (EOF) of sea surface temperature (SST) anomalies in the North Pacific basin (typically, polewards of 20N).

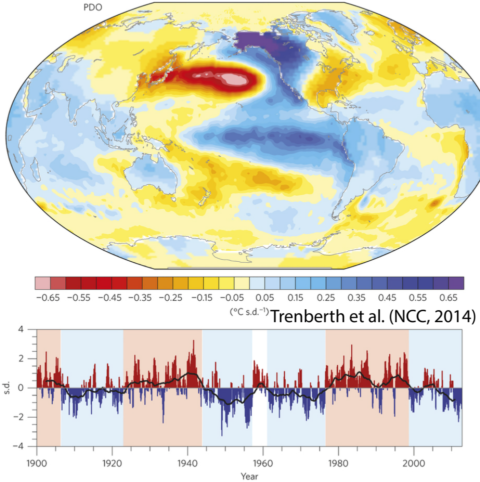
What is the PDO?



(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

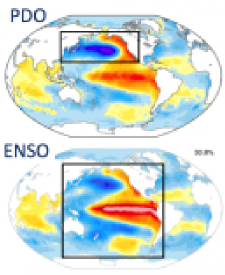
The Pacific Decadal Oscillation



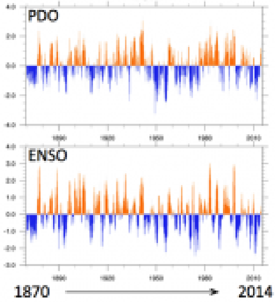
Trenberth et al. (NCC, 2014)

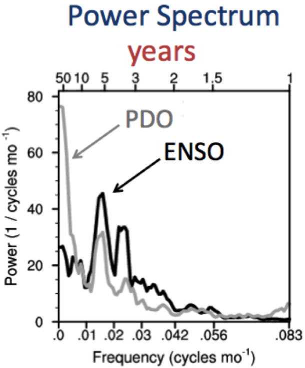
- At decadal time scales, about a third of the PDO signal might be remotely-driven, with the remaining variance explained by oceanic zonal advection anomalies and variability of the Aleutian low (Schneider and Cornuelle, 2005).

The observed PDO & ENSO

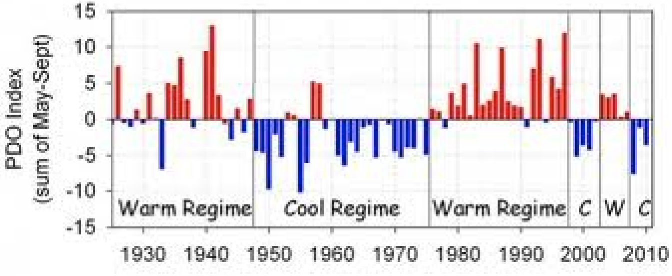


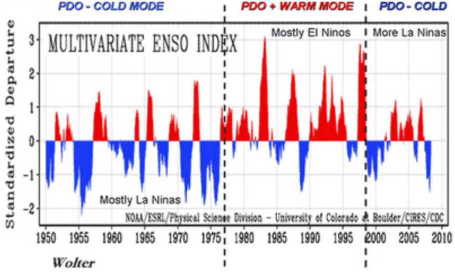
Deser et al. 2010



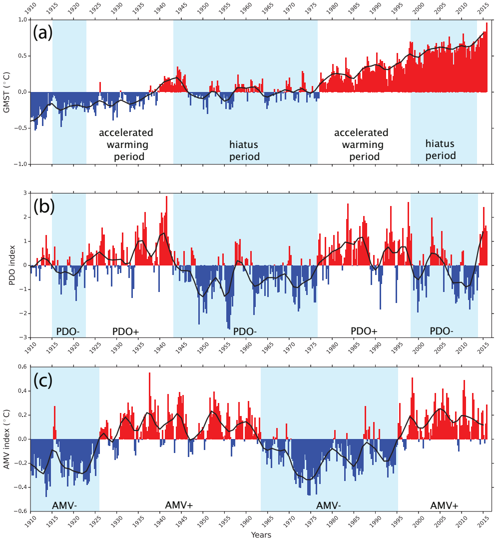


PDO & ENSO indeces





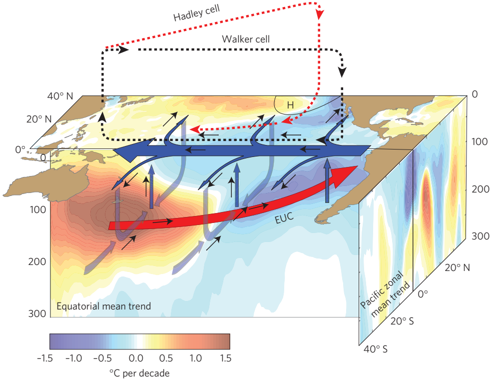
PDO & Global Mean Surface Temperature



(Farneti, 2016)

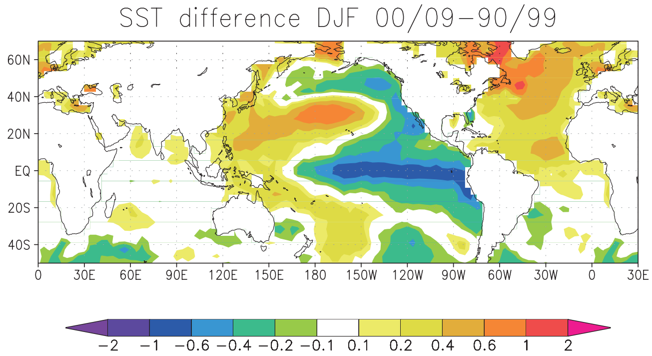
The recent warming hiatus (slowdown)

- Accounting for the recent cooling in the eastern equatorial Pacific reconciled climate simulations and observations *(Kosaka and Xie, 2013)*.
- *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.



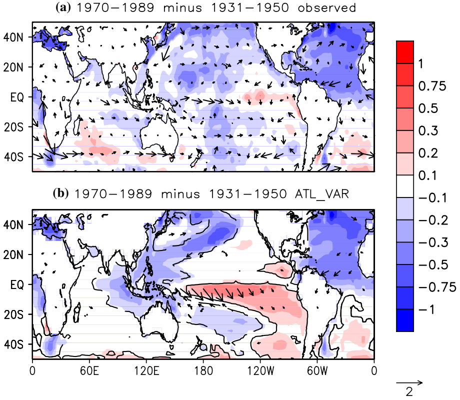
(England et al., 2014)

SST anomalies [2000-2009] - [1990-1999]



Teleconnections are also possible drivers

The Atlantic forcing decadal Pacific variability



Kucharski et al. (2015)

- Atlantic Multidecadal Oscillation (AMO) has had a substantial influence on the equatorial Pacific decadal variability
- Pacemaker experiments confirm the teleconnection (Kucharski et al., 2015); see also McGregor et al. (2014)

1. The Pacific Decadal Oscillation (**PDO**) seems to be partly (i) stochastically driven, (ii) a passive ocean response to the atmosphere and (iii) a coupled mode of the ocean-atmosphere system where ocean dynamics plays a critical role (Latif and Barnett, 1996; Barnett et al., 1999).
2. The **PDO** is believed to be associated with both tropical forcing, through an atmospheric bridge of low-frequency ENSO signal, and local extratropical atmospheric stochastic forcing (Liu and Alexander, 2007).
3. The **PDO** might be a combination of several different processes (Newman et al., 2016).
4. *What is the origin of ENSO Decadal Variability (***EDV***)?* from the Pacific midlatitudes (Barnett et al., 1999b, Yeh and Kirtman, 2005)? is there a role for tropical noise and mean state in low frequency ENSO modulation? a teleconnection from the Atlantic (Kucharski et al., 2015)?
5. Incidentally, what could be (yet another) cause of the recent slowdown in the rate of surface warming (the so-called *warming hiatus/slowdown*)?

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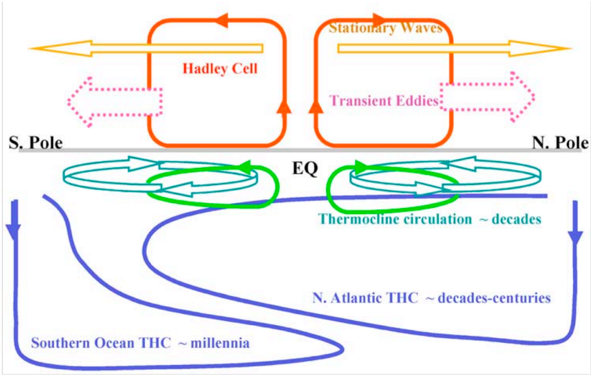
Hypothesis: tunnels and bridges

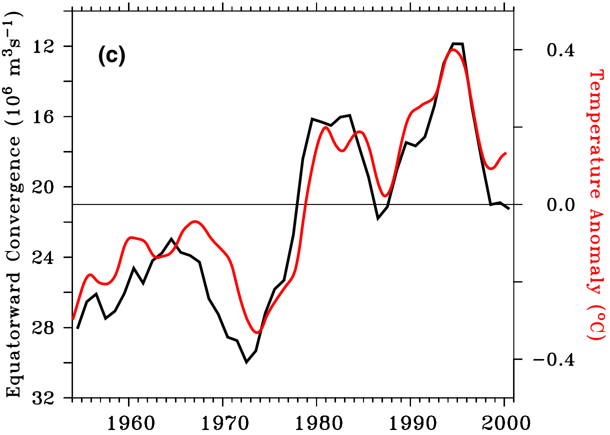
Tropical⟺extratropical interactions



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 SubTropical Cells



(Zhang and McPhaden, 2006)

The Models

Ocean model: MOM

1. 2°resolution (∼1° at Equator), 30 levels, z^* coordinate
2. **NO SST RESTORING**
3. Forced with the Coordinated Ocean-ice Reference Experiment (CORE) Normal Year Forcing (NYF) described in Griffies et al. (2009) for 600 years.
4. 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.

Atmospheric Model: SPEEDY

1. the ICTPAGCM SPEEDY (Molteni, 2003)
2. Spectral dynamical core, hydrostatic, σ-coordinate.
3. Horizontal resolution is T30, with 8 levels in the vertical.

The anomalous forcing

1. We ran a 10-member SST-forced SPEEDY ensemble with interannually varying SST, derived from the HadISST dataset.
2. The forcing was applied only to the Pacific region; elsewhere, climatological, monthly varying SSTs are used.
3. From the ensemble mean, we calculated the difference between decades 2000/2009 and 1990/1999, for all CORE forcing fields,.
4. The anomalies were then added to each climatological CORE forcing field driving the ocean.

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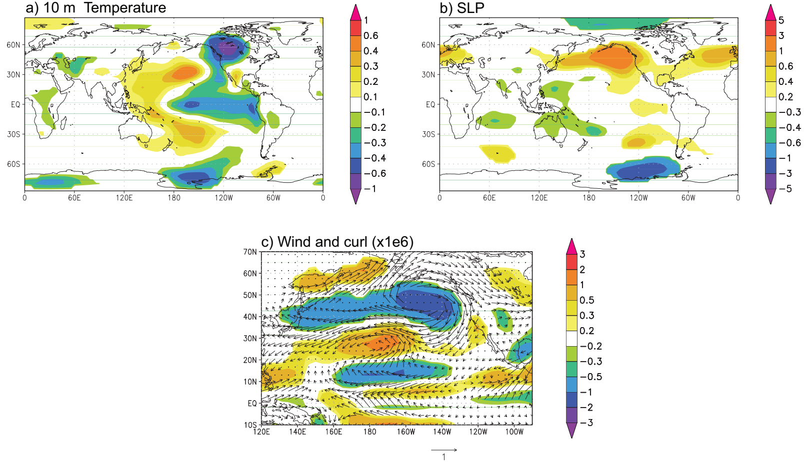
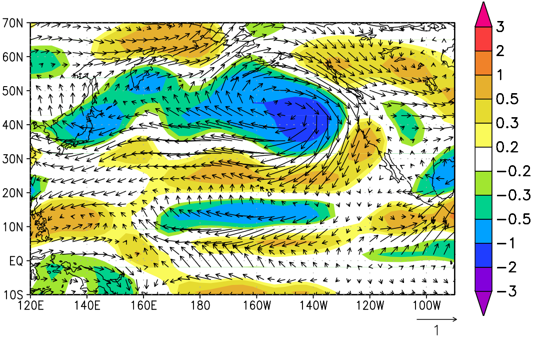


1. Asymmetric response
2. wins stress and wind stress curl anomalies have the opposite sign from the climatological mean.

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

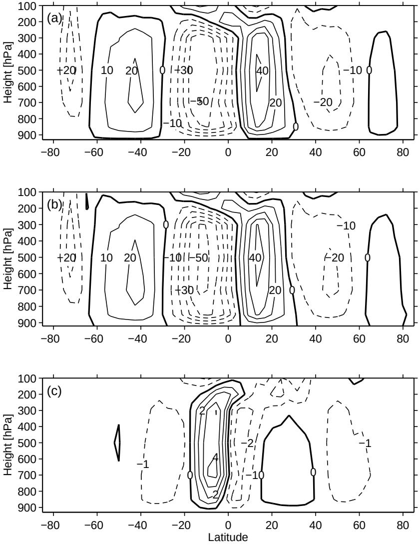


Anomalous wind and its curl for an ensemble of tropical (18°S to 18°N) SST forcing only.

CTL and SPEEDY experiments

1. The Control (**CTL**) experiment is 600 years long.
2. A perturbation experiment (**SPEEDY-ALL**), 25 years long, was started at year 350 of the CTL run.
3. **SPEEDY-TPW**: as **SPEEDY-ALL**, but only temp, SLP and wind anomalies.
4. **SPEEDY-W**: as **SPEEDY-ALL**, but only wind anomalies.
5. Results seem robust and stable after the first 10-15 years.

Atmospheric response



A weakening of the thermally-direct Hadley Cell

Ensemble mean of the meridional overturning circulation in the atmosphere for

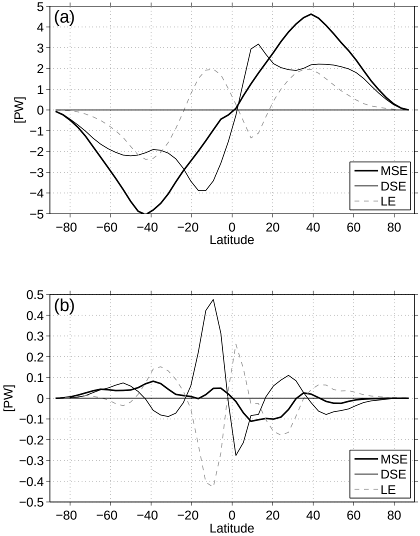
(a) the decade 2000-2009,

(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)

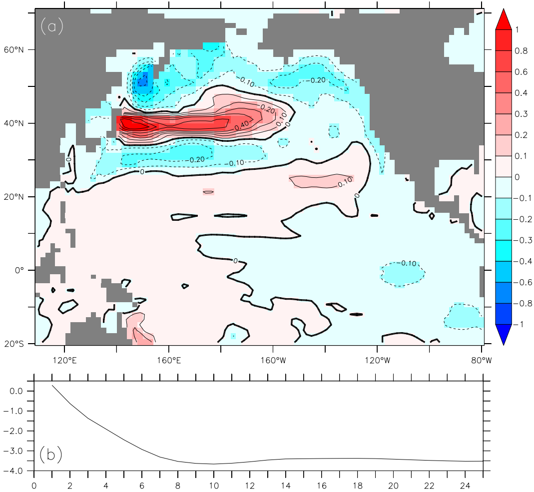
Atmospheric response



(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 decade and the 1990-1999 decade. Units are PW (1 PW = 10^{15} W).

Ocean response

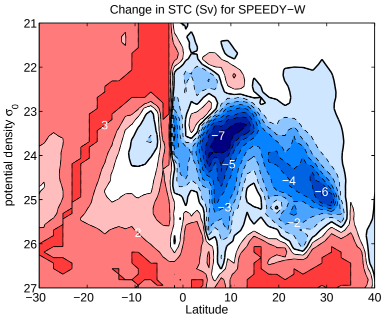


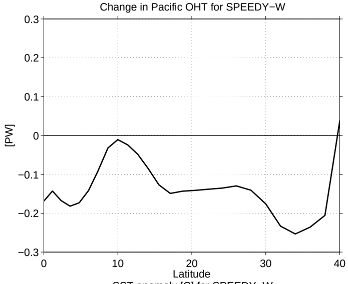
A PDO-like pattern is generated when the anomalous forcing is added

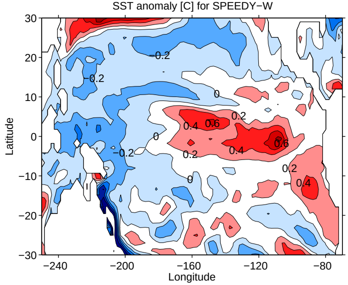
SST EOF-1

SST PC-1

Ocean response



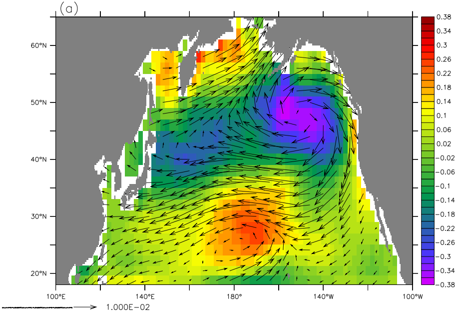


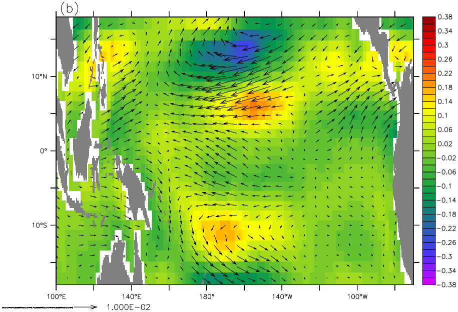


- OHT and STC transport are reduced and SSTa are positive.
- The anomalous warming damps the original cooling pattern.

Sensitivity to location of the forcing

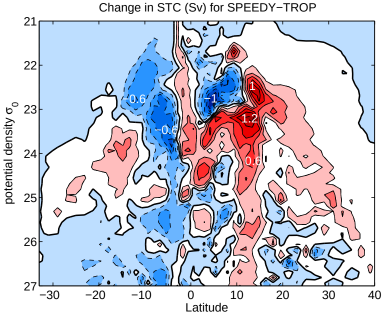
SPEEDY-NOTROP and SPEEDY-TROP



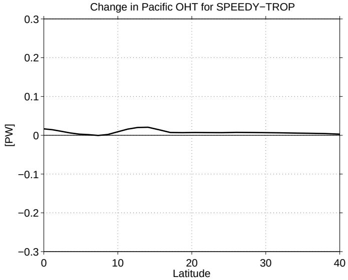


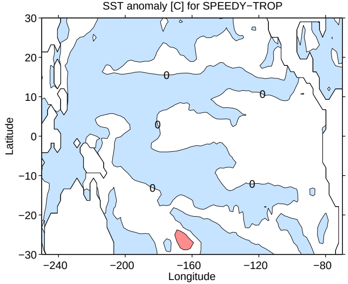
Anomalous wind stress (vectors; Nm^{-2}) and its curl (shading; $\times 10^{-7}$ Nm^{-3}) computed by the ocean model in the sensitivity experiments.

Ocean response: TROP

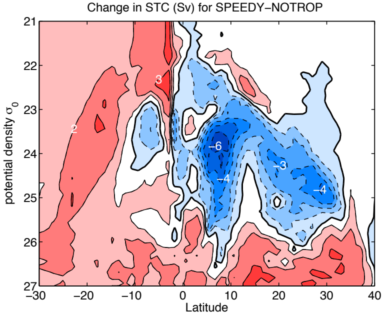


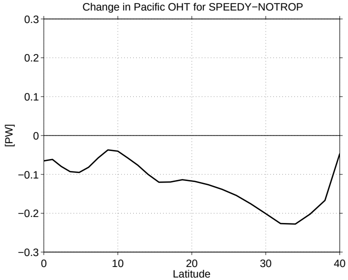
- no significant response for tropical wind anomalies (small positive feedback, if anything)

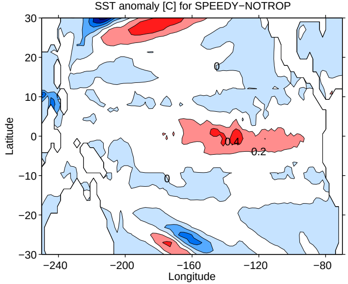




Ocean response: NOTROP



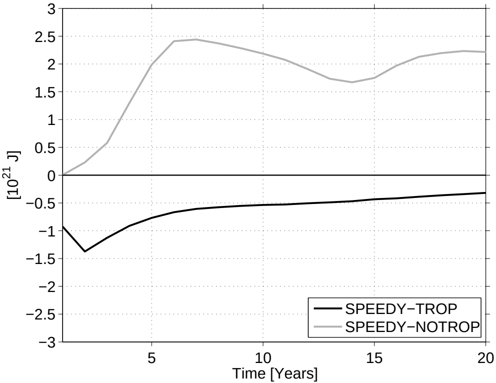




- significant response for extratropical wind anomalies (similar to the full forcing case)

Heat Content anomalies

Evolution of heat content anomalies relative to the Control



- 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 for the ENSO-STG-STC interactions

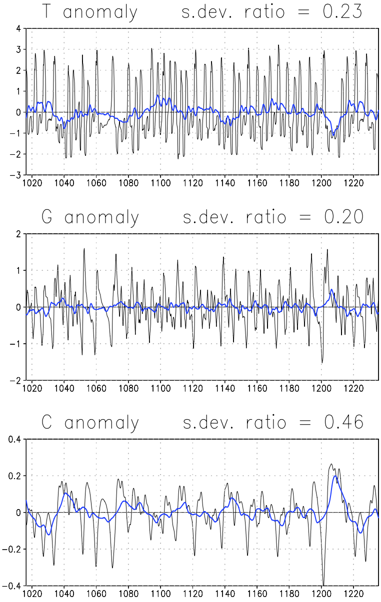
Let **T** be the SST anomaly in central equatorial Pacific, **G** and **C** the indices of the anomalies in the intensity of the Pacific sub-tropical gyre and cells [based on the ENSO delayed oscillator of Suarez and Schopf (1988)]:

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

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

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

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



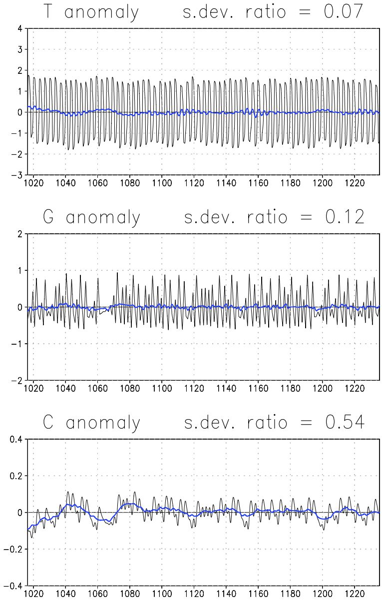
- Time series for the three variables
  T (ENSO SST)
  G (subtropical gyre)
  C (subtropical cells)
  in the idealized model.
- Decadal variability appears in **T** and **C**, which are anticorrelated by construction.

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

$$\frac{dT}{dt} = T - \alpha T(t-\delta) - r_1 (T - T_0)^3 - \cancel{EG} \tag{2a}$$

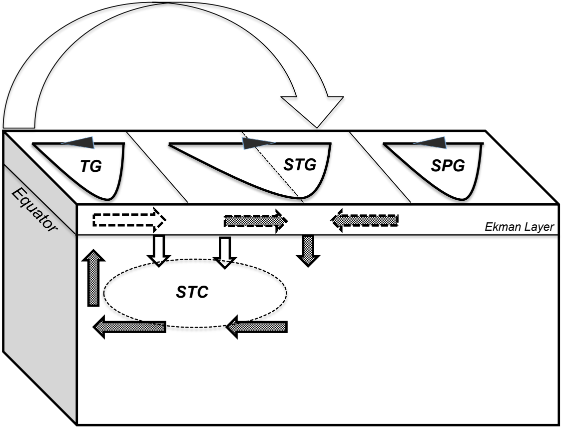
$$\frac{dG}{dt} = \cancel{ET} - \kappa G + \gamma r_2 \tag{2b}$$

$$\frac{dC}{dt} = -\kappa (C - G) \tag{2c}$$



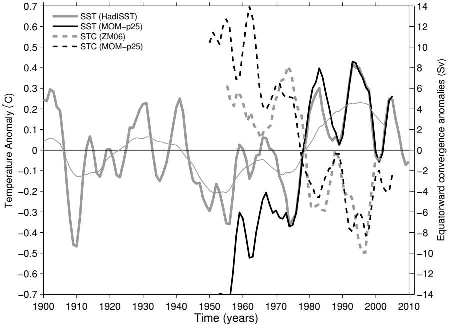
- Much reduced variability in **C** and **G** and regular variations in **T**.
- In this model, the **G**yre forcing by chaotically-modulated ENSO response is crucial.

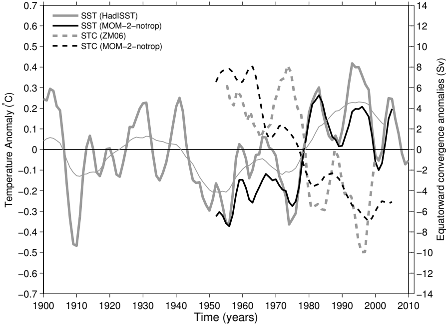
Coupled tropical-extratropical feedbacks and the generation of low-frequency ENSO variability



(Farneti et al., 2014b) and based on theories and simulations by McCreary and Lu (1994); Kleeman et al. (1999); Klinger et al. (2002)

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



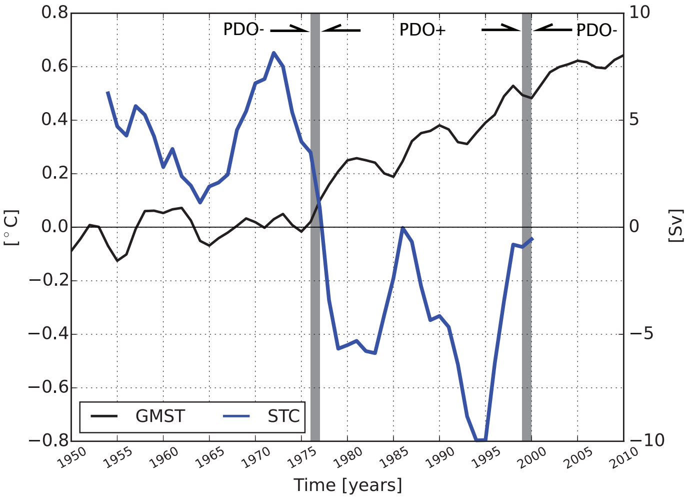


- Model results agree well with observed estimates of STC transport, convergence, and equatorial SSTa (ZM06, Zhang and McPhaden, 2006).

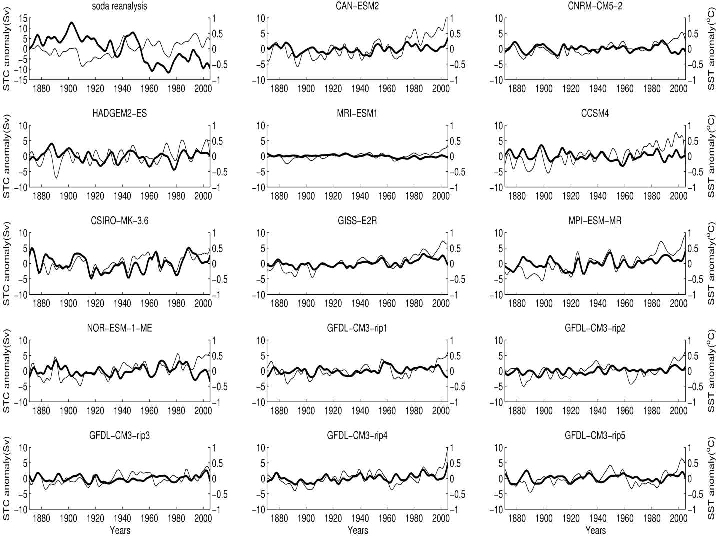
(Farneti et al., 2014a)

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

STC - PDO - GMST


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

Do CMIP5 models reproduce the observed STC variability? NO



Conclusions

1. The atmospheric response to tropical forcing has feedbacks on the subtropical ocean, which is in turn forcing an equatorial time-delayed response, generating decadal SST anomalies.
2. The system outlines a possible coupled mechanism for ENSO decadal variability, involving both the *'atmospheric bridge'* and the *'oceanic tunnel'*.
3. Subtropically-forced STC variability is identified as a key player in the generation of equatorial Pacific decadal SST anomalies, pacing tropical Pacific natural climate variability on decadal time scales.
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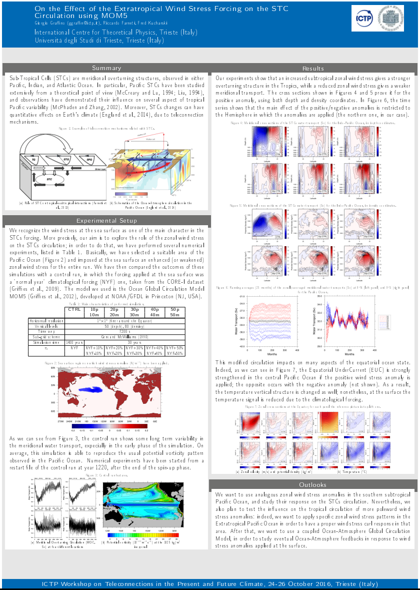
Next: Sensitivity studies on location and intensity of Wind stress



← Giorgio's Poster. Preliminary results on:

- The effect of subtropical winds on STC transport
- and equatorial SST anomalies

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