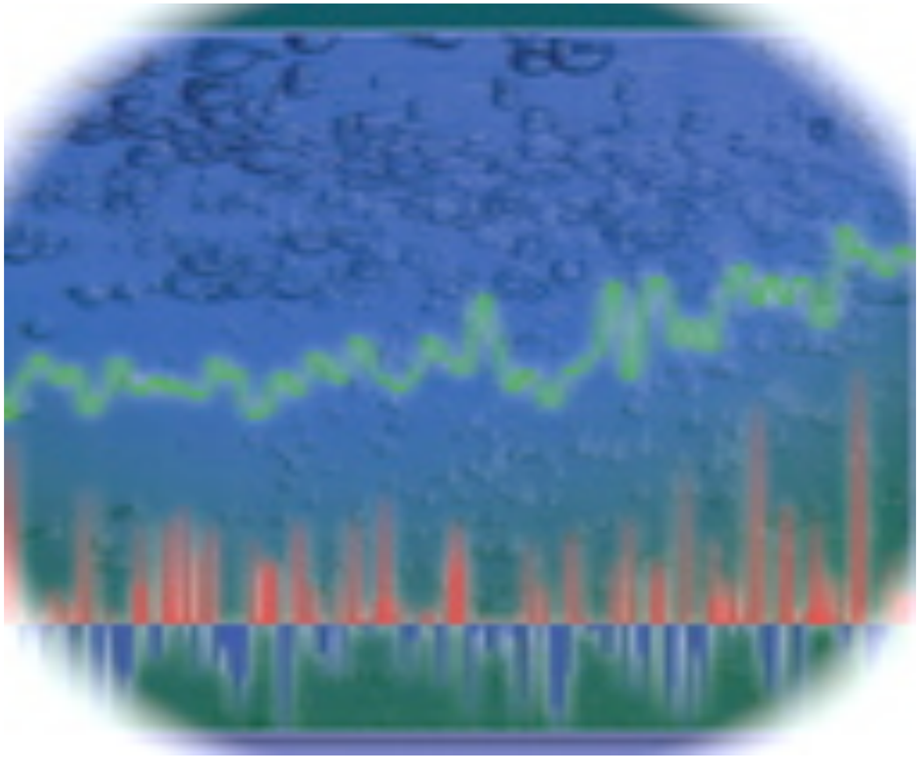
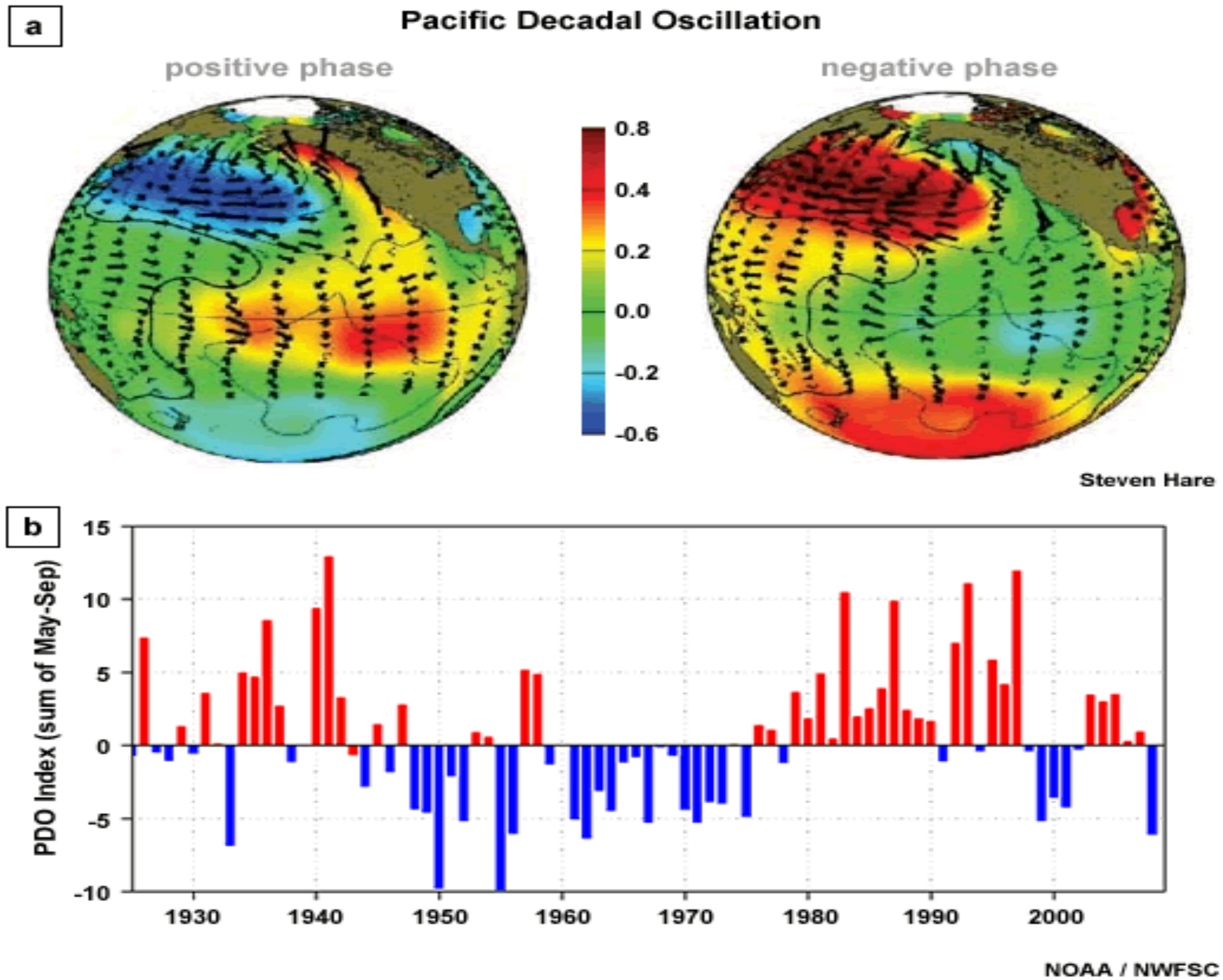
Climate Dynamics: Why Does Climate Vary?



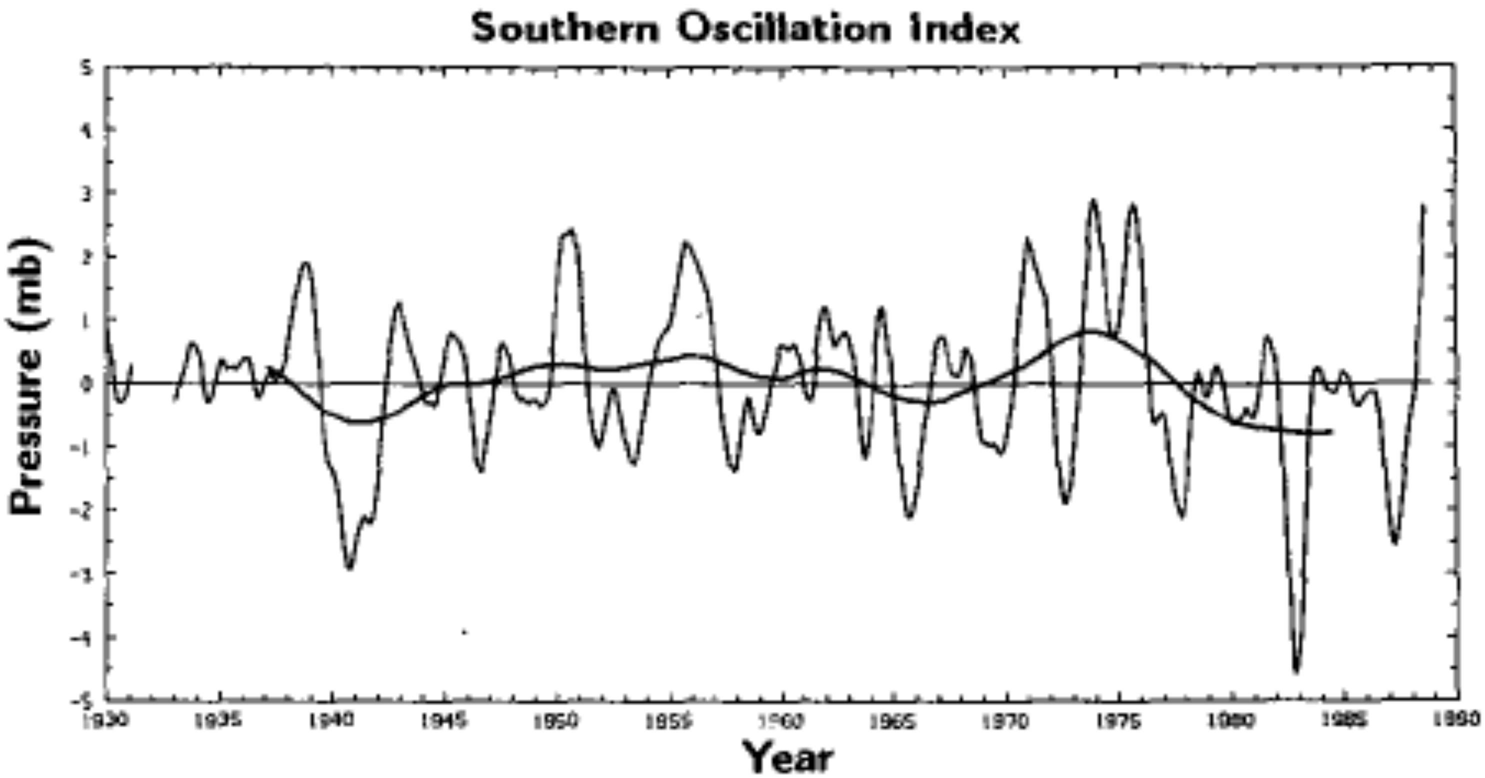
Pacific Decadal Oscillation: Noise Integration, Nonlinear Rectification, and Scale Interaction

http://www.esrl.noaa.gov/psd/people/dezheng.sun/lectures/ATOC7500.html

The Pacific Decadal Oscillation

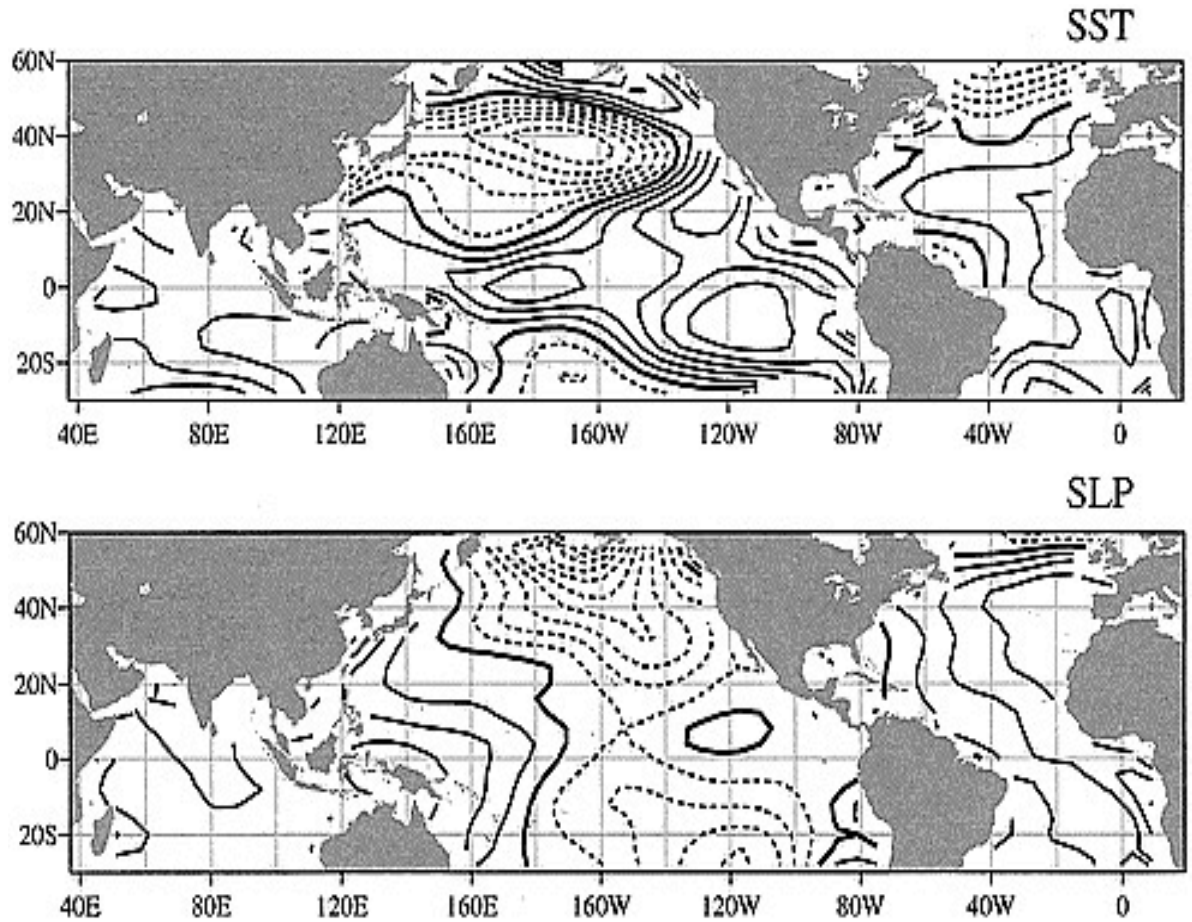


The 1976 Regime Shift

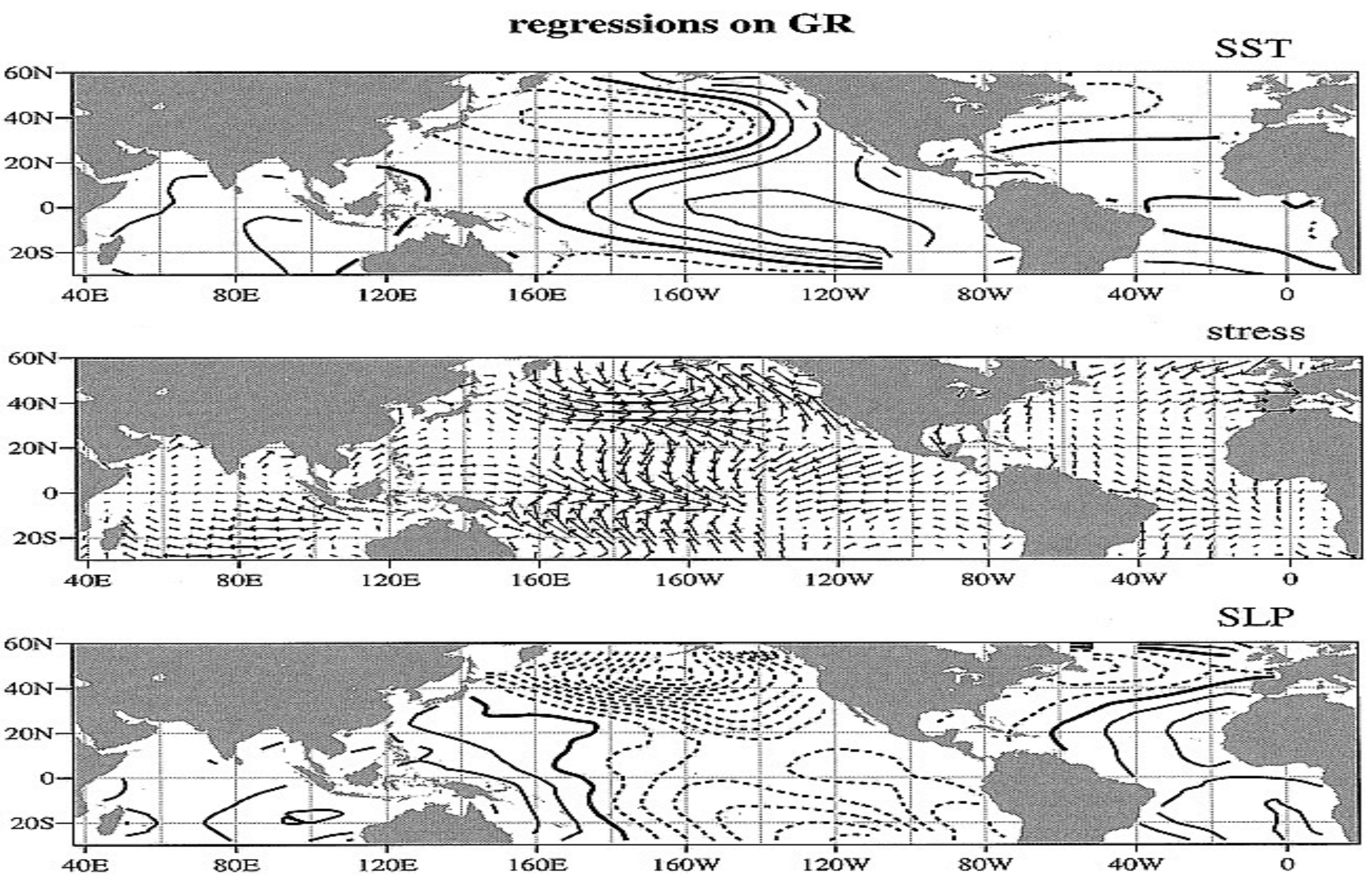


Trenberth (1990)

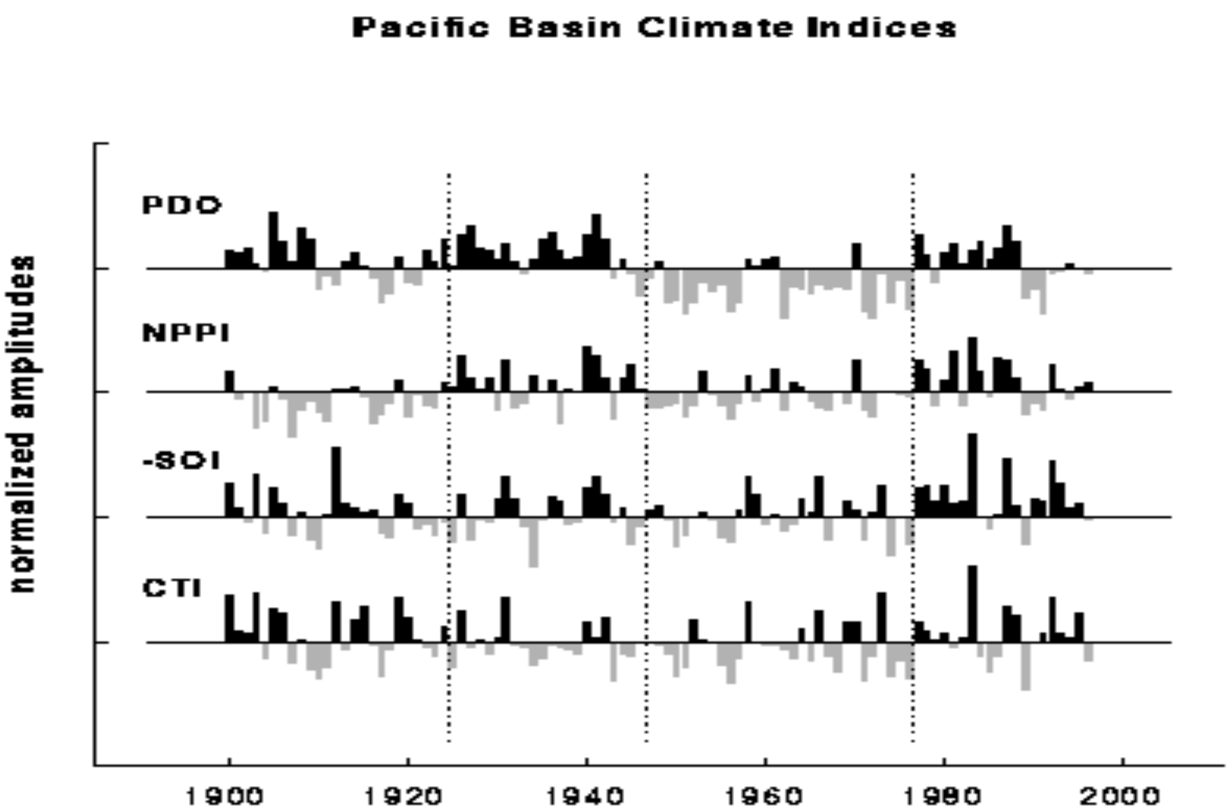
The 1976 Regime Shift
Epoch 1977–93 minus epoch 1950–76



PDO: Spatial Patterns



PDO and Other Pacific Basin Climate Indices



The PDO and Alaskan salmon production

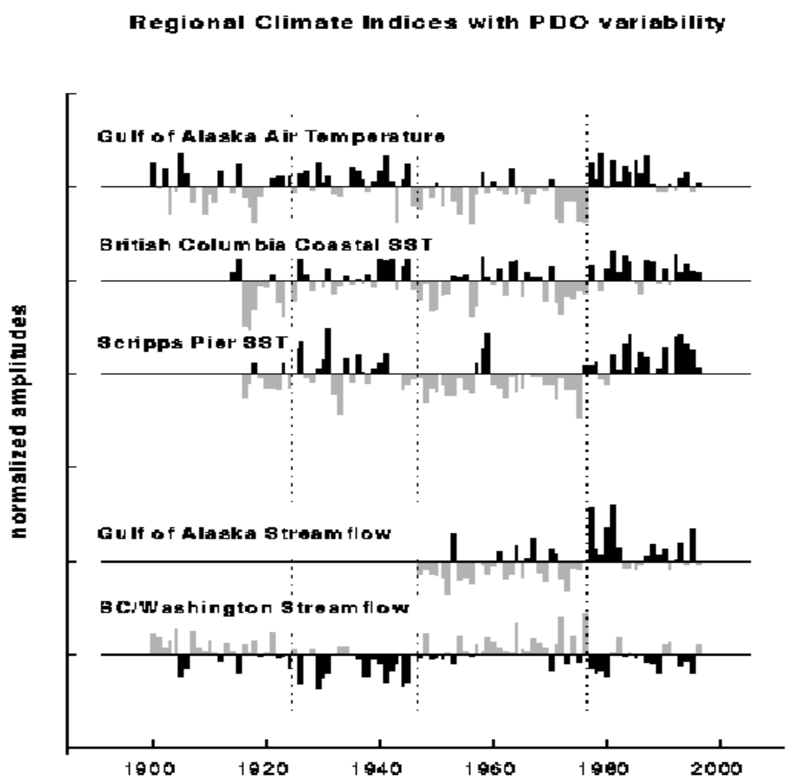


Figure 5

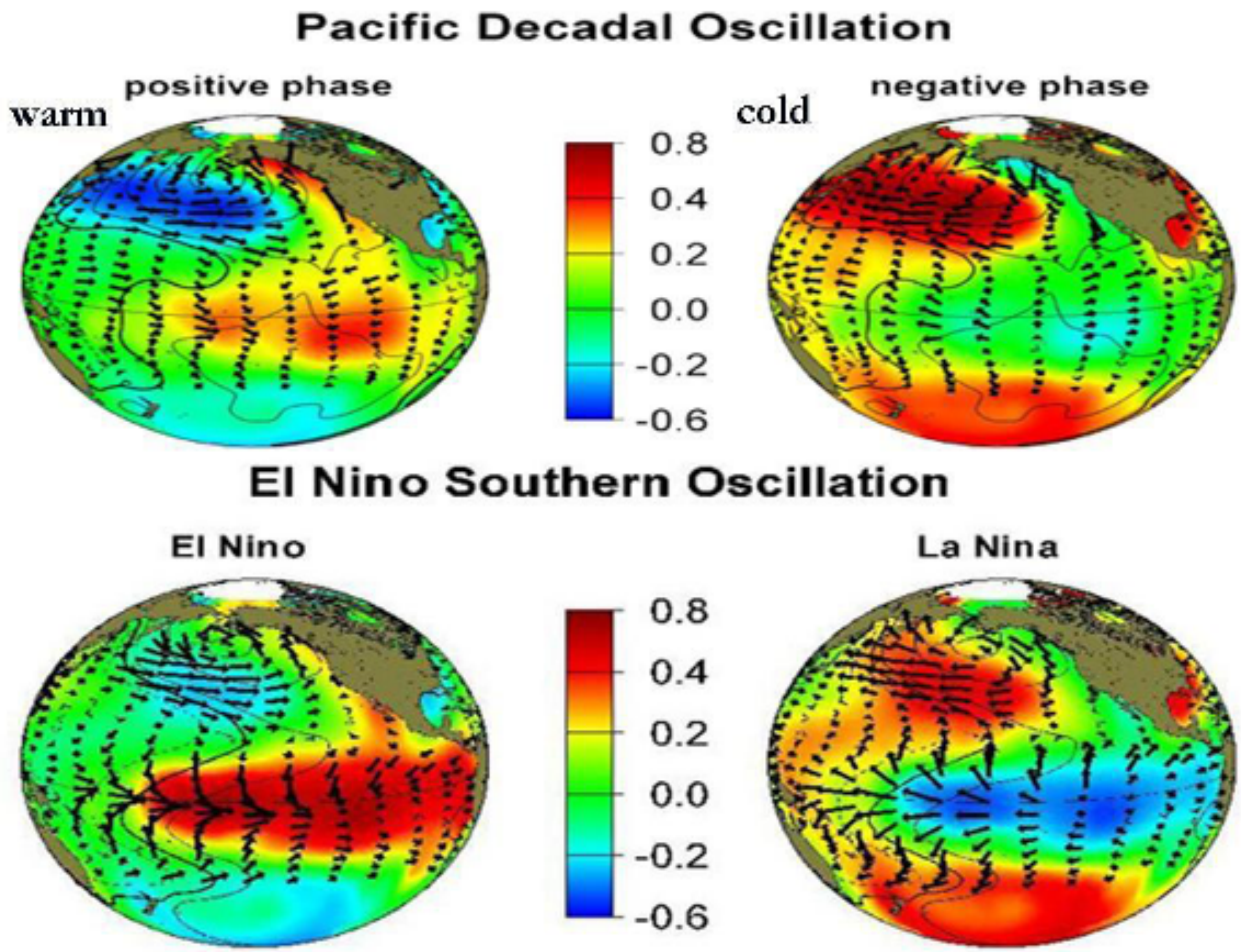
Selected regional climate time series with PDO signatures. Dotted vertical lines are drawn to mark the PDO polarity reversal times in 1925, 1947, and 1977. Bars are shaded as in Figure 1.

TABLE 3: Percent change in mean catches of four Alaskan salmon stocks following major PDO sign changes in 1947 and 1977.

salmon stock	1947 step	1977 step
western Alaska sockeye	-37.2%	+242.2%
central Alaska sockeye	-33.3%	+220.4%
central Alaska pink	-38.3%	+251.9%
southeast Alaska pink	-64.4%	+208.7%

Mantua et al. 1997

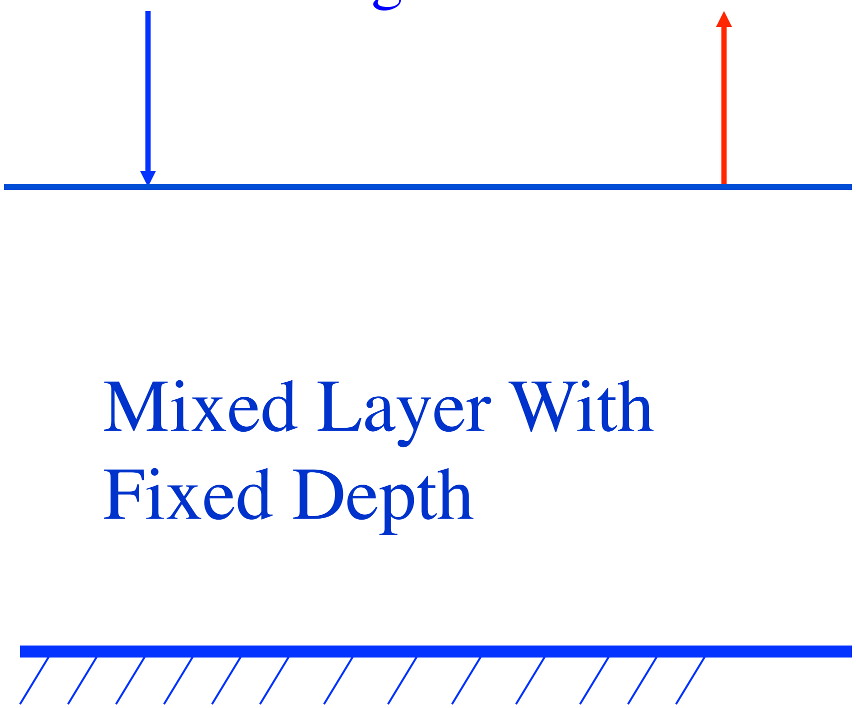
Spatial Patterns of PDO and ENSO: Similarity and Differences



The Hasselmann Mechanism for SST Variability

Heat fluxes associated with weather events, “random forcing”

Ocean response to flux back heat which slowly damps SST anomalies



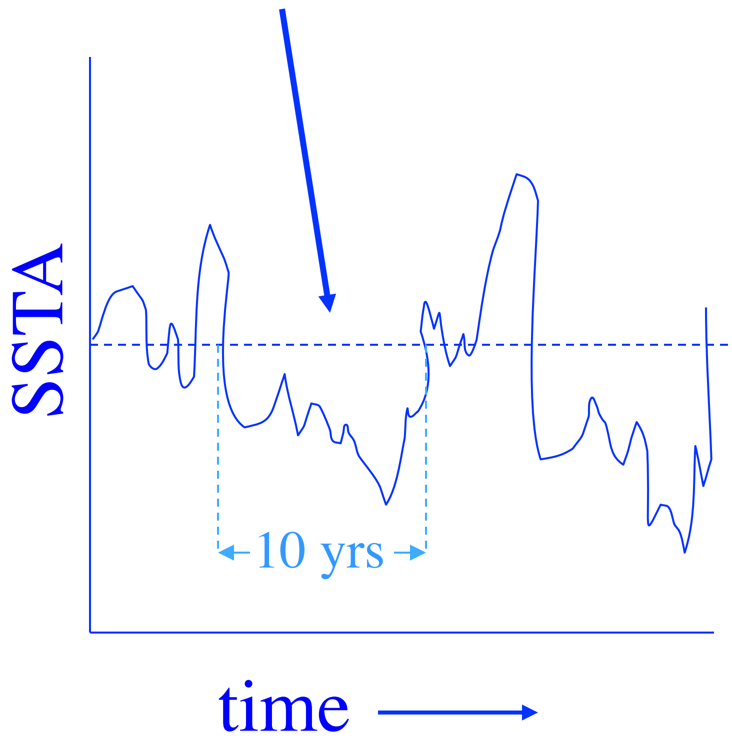
$$\frac{dT'}{dt} = -\lambda T' + Q'$$

$$Q' = \sum A e^{i\omega t}$$

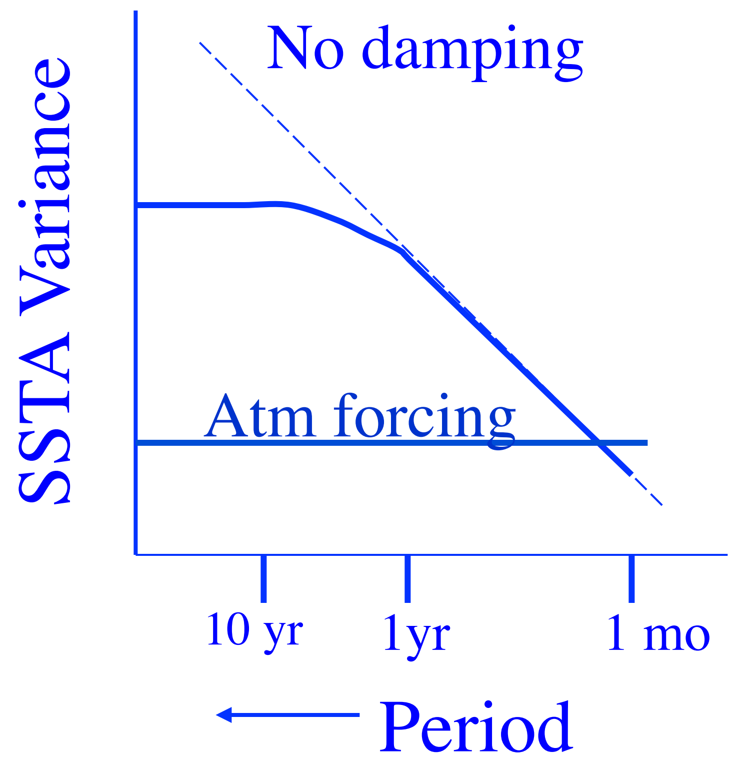
$$\left|T'(\omega)\right|^2 = \frac{|A|^2}{\omega^2 + \lambda^2}$$

The Simple Ocean's SST Anomaly Variability

Complex behavior with decadal anomalies!



Log plot of SSTA Spectra

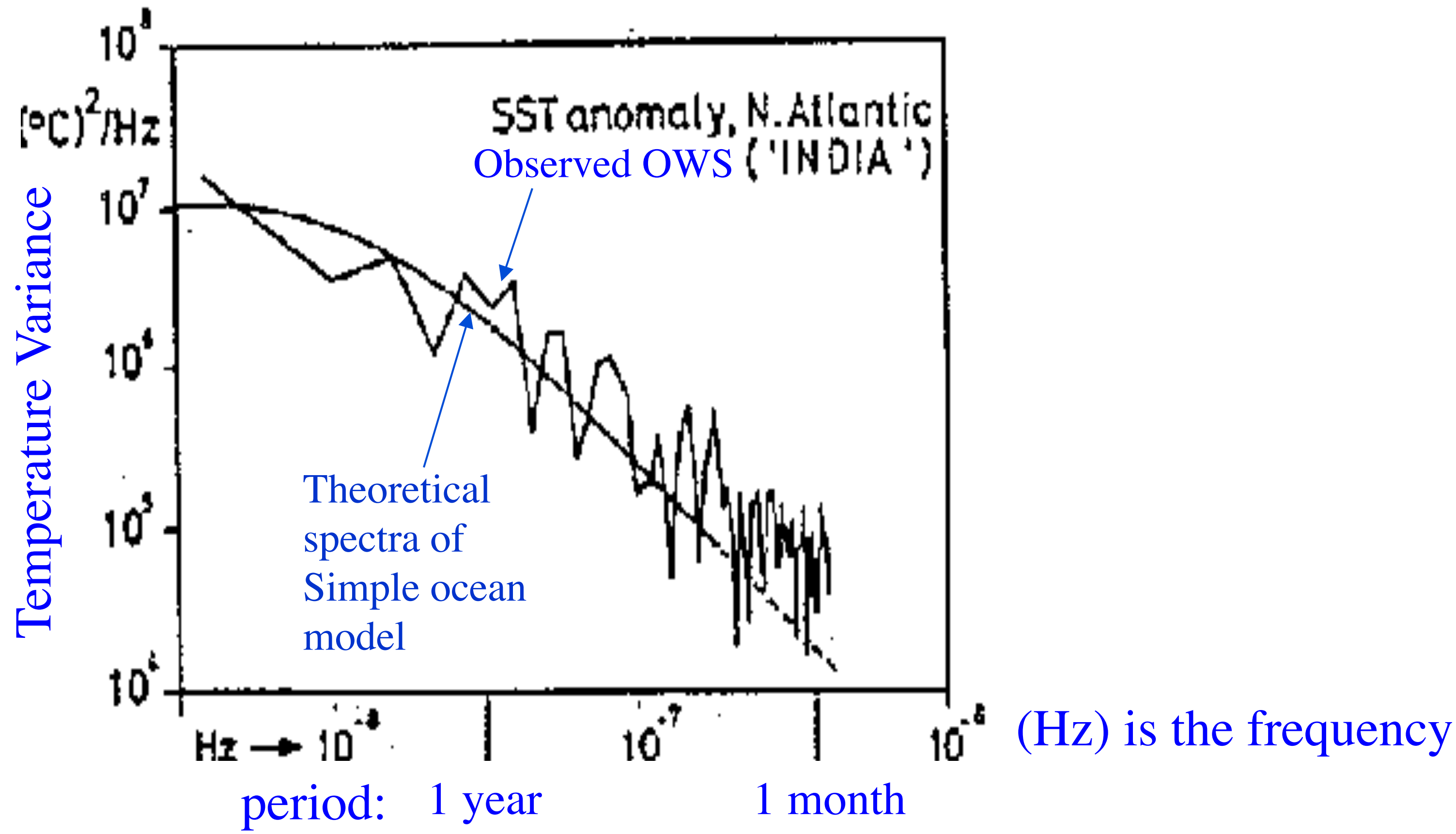


$SST_{n+1} = \lambda * SST_n + \eta$

λ=constant; η = Random number

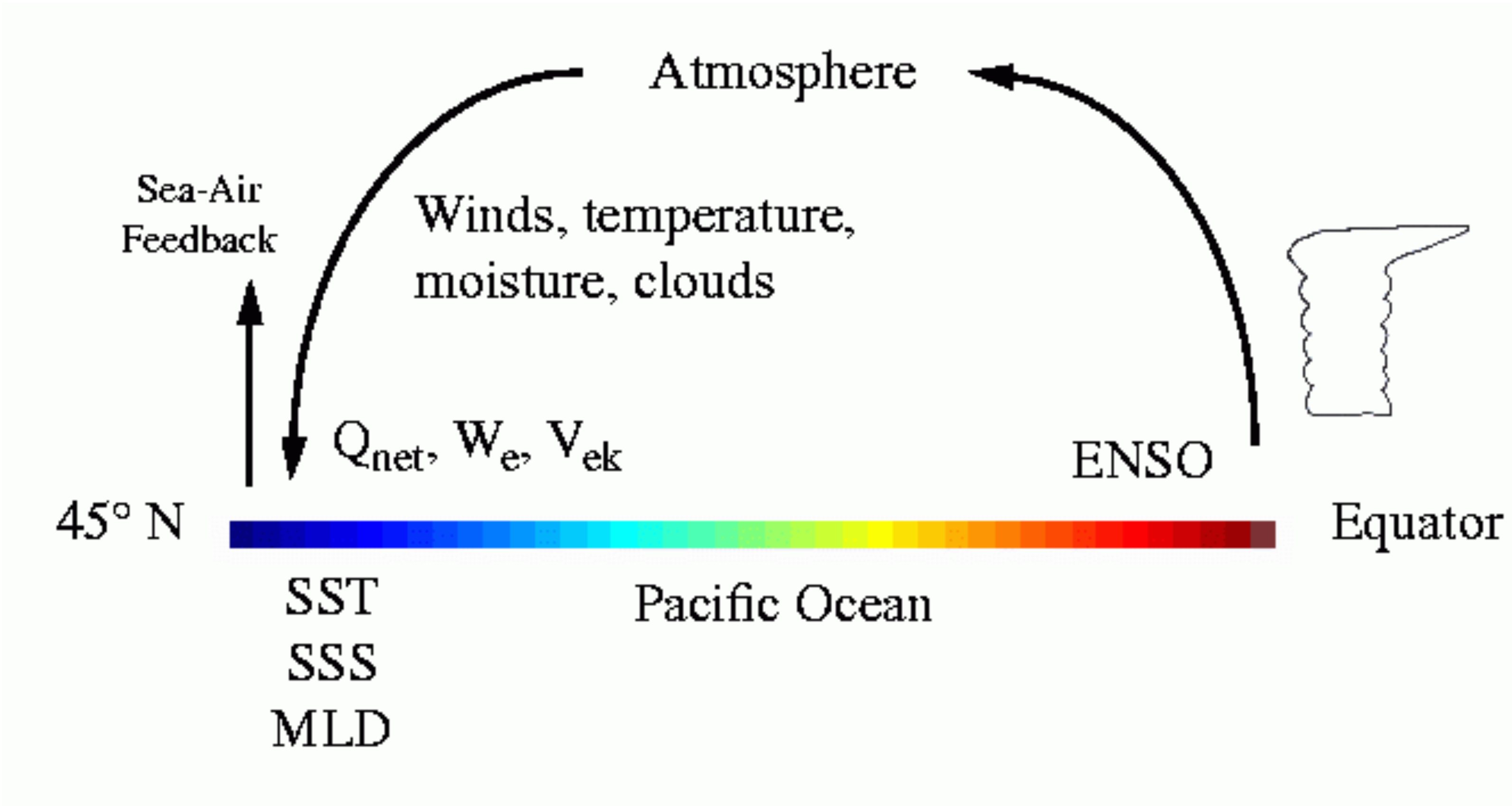
Simple Ocean Model: correspondence to the real world?

Observed and Theoretical Spectra for a location in the North Atlantic Ocean



Atmospheric forcing and ocean feedback estimated from data

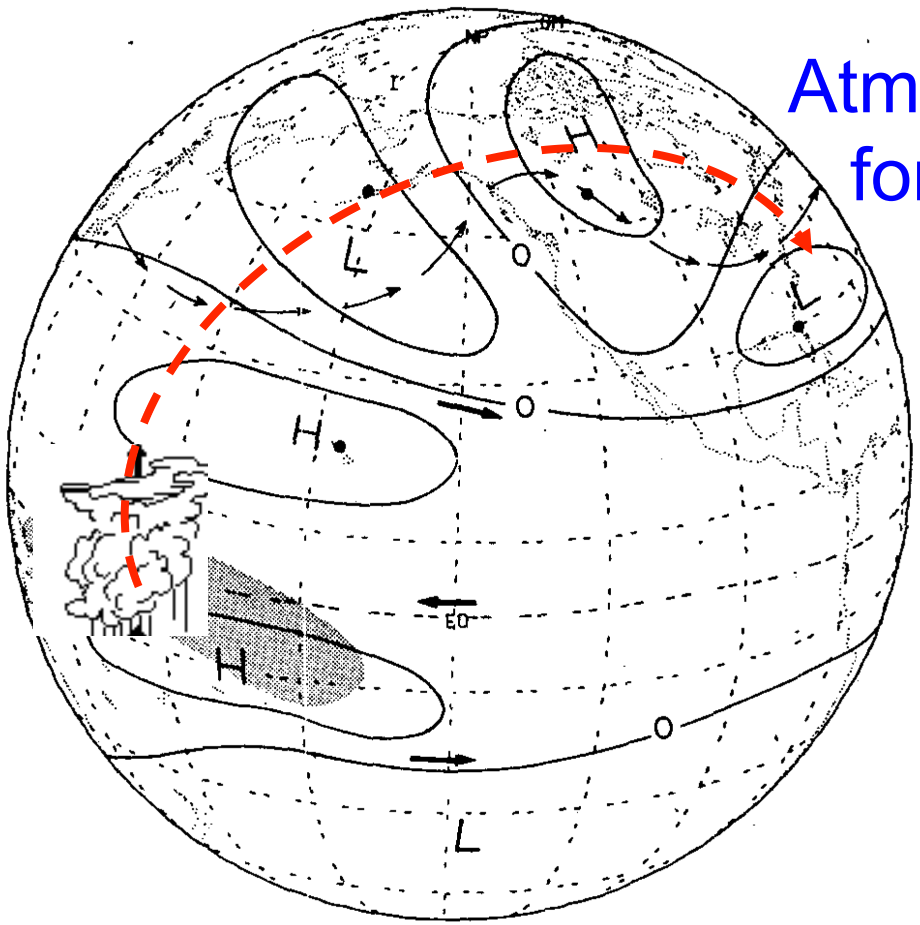
“The Atmospheric Bridge”



Meridional cross section through the central Pacific

(Alexander 1992; Lau and Nath 1996; Alexander et al. 2002 all J. Climate)

Mechanism for Atmospheric Circulation Changes due to El Nino/Southern Oscillation



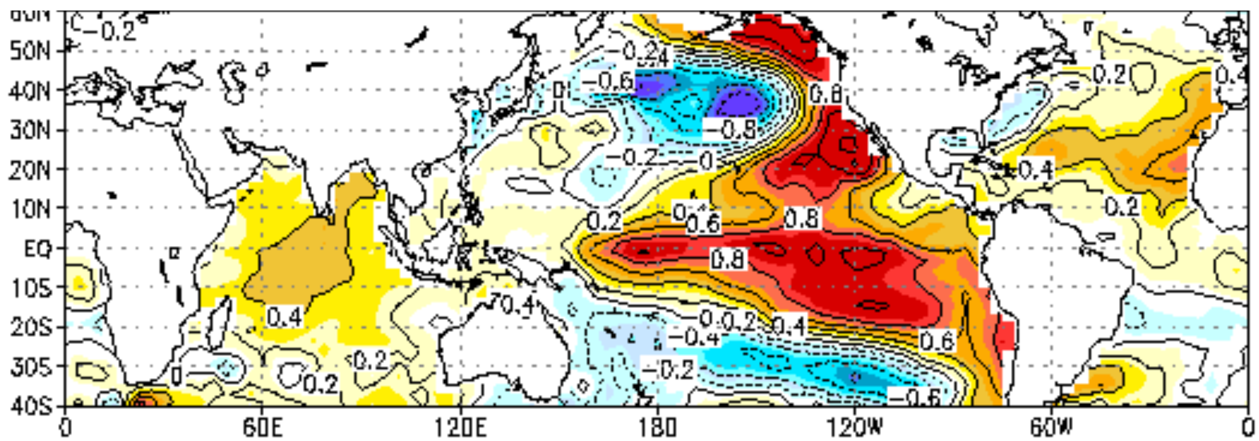
Atmospheric wave forced by tropical heating

Latent heat release in thunderstorms

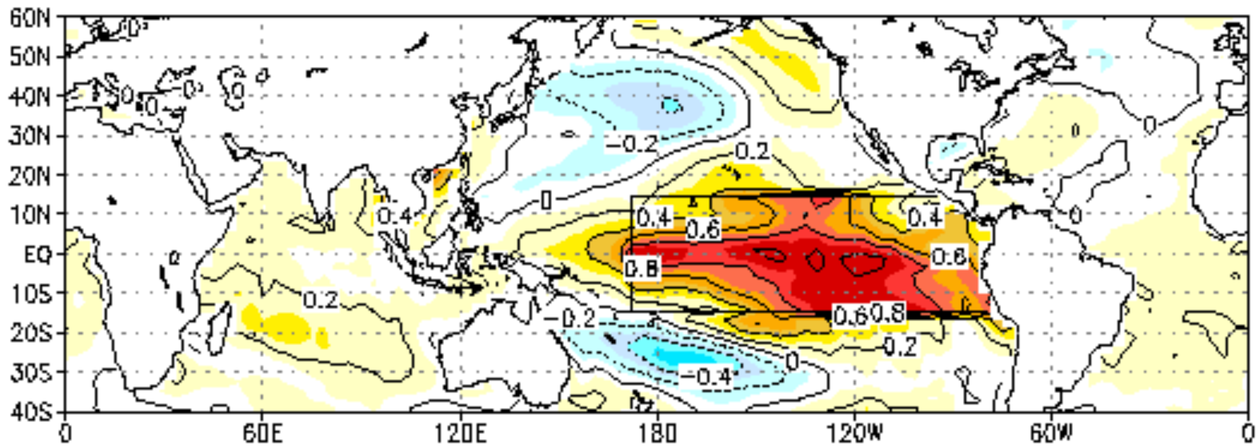
Horel and Wallace, Mon. Wea Rev. 1981

“Decadal” variability in the North Pacific: tropical (ENSO) Connection?

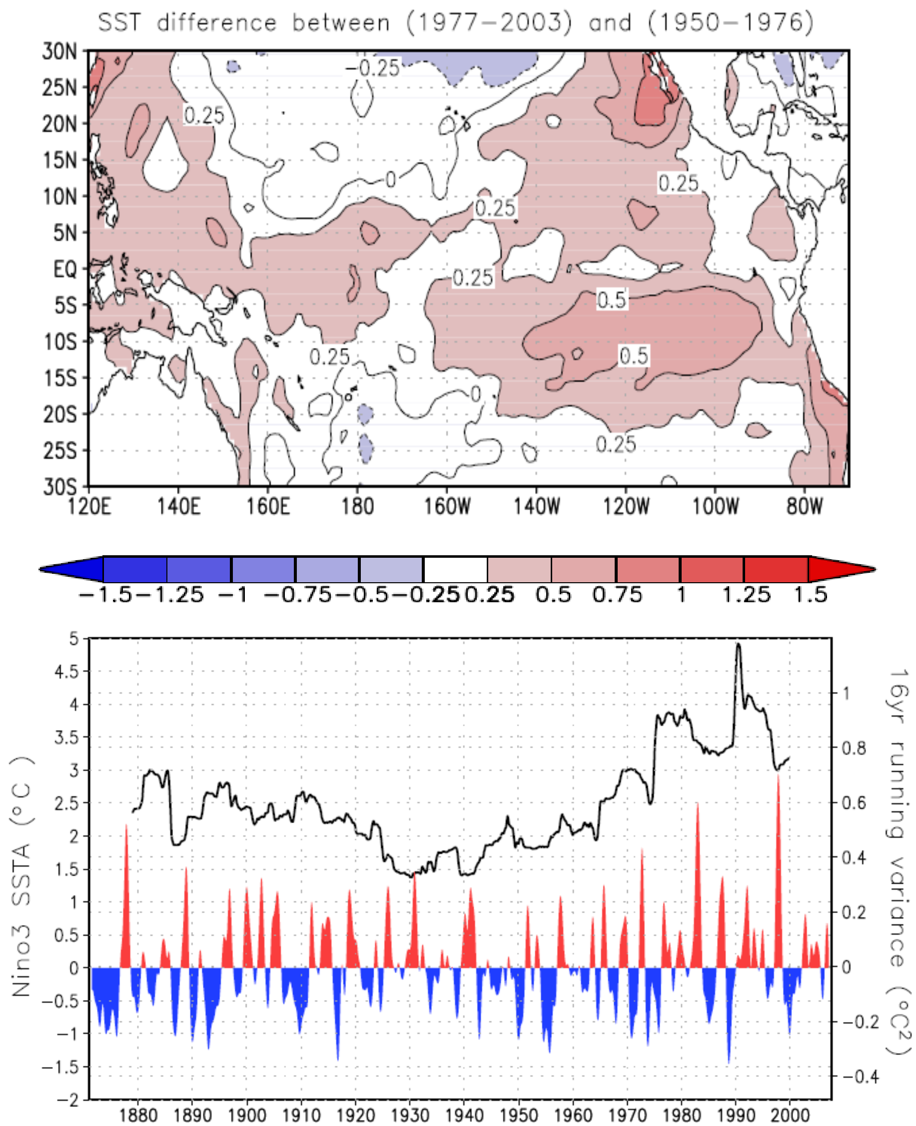
Observed SST Nov-Mar (1977-88) – (1970-76)



MLM SST Nov-Mar (1977-88) – (1970-76)



Tropical Pacific Decadal Variability:
A Consequence of the Rise and Fall of ENSO Activity?



The time-mean effect of ENSO (or the Rectification of ENSO)

While ENSO has two phases, in reference to the long-term mean climate, the integrated effect of ENSO over a decade or longer is not zero, but a significant warming effect on the eastern tropical Pacific, with a spatial a pattern that highly resembles the pattern of tropical Pacific decadal variability.

Methodologies

- Compare *the equilibrium state* of the coupled tropical ocean-atmosphere system with the time-mean state of the system, though the use of a box model whose unstable equilibrium can be analytically obtained.

- Force an Ocean GCM using surface forcing with and without ENSO fluctuations

- Perturbation Experiments with coupled GCMs with and without equatorial coupling between surface winds and SST gradients

Equilibrium State Versus Time-Mean State

The System: $$\frac{dA}{dt} = f(A,\lambda)$$ (1)

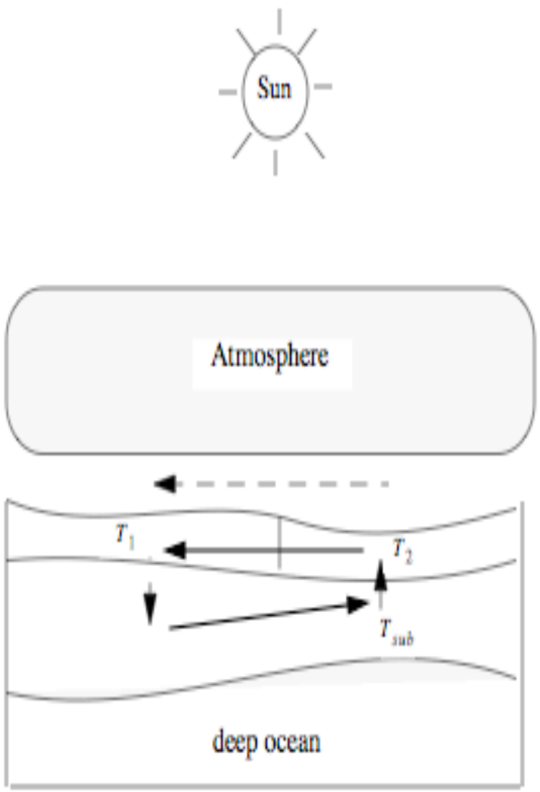
Equilibrium State: $$f(A_0,\lambda) = 0$$ (2)

Time Mean State: $$\overline{f(\overline{A} + A',\lambda)} = 0$$ (3)

$$f(A_0,\lambda) + \tfrac{\partial f}{\partial A}\overline{(\overline{A} + A' - A_0)} + \tfrac{\partial^2 f}{\partial^2 A}\overline{(\overline{A} + A' - A_0)^2} + \ldots = 0$$ (4)

When $f(A,\lambda)$ Is nonlinear $\overline{A} \neq A_0$ (5)

A Box Model for the ENSO System



West East

$$\frac{dT_1}{dt} = c(T_e - T_1) + sq(T_2 - T_1)$$

$$\frac{dT_2}{dt} = c(T_e - T_2) + q(T_{sub} - T_2)$$

$$q = \frac{\alpha}{a}(T_1 - T_2)$$

$$T_{sub} = \Phi(-H_1 + h_2')$$

$$\Phi(z) = T_e - \frac{T_e - T_b}{2}\left(1 - \tanh\left(\frac{z + z_0}{H^*}\right)\right)$$

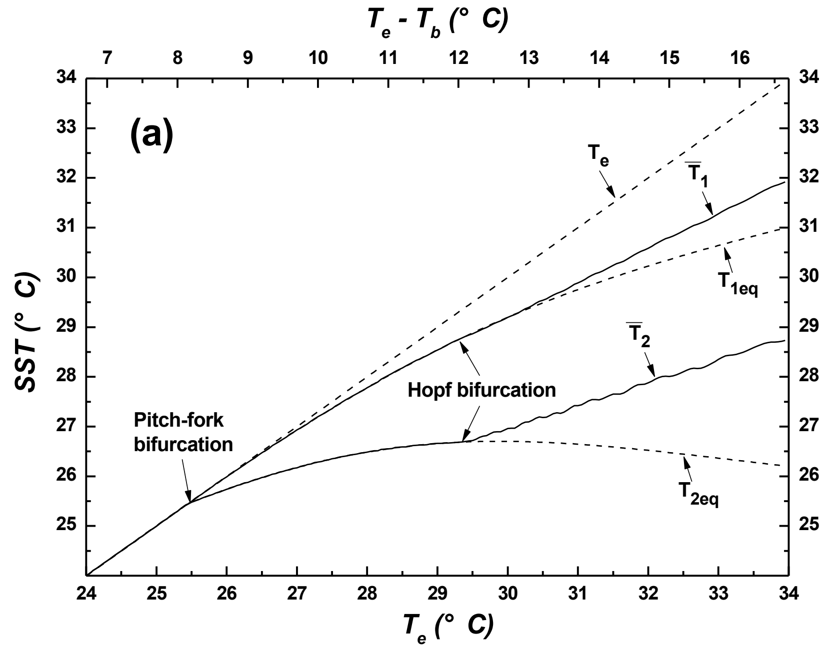
$$h_2' - h_1' = -\frac{H_1}{H_2} H \frac{\alpha}{b^2}(T_1 - T_2)$$

$$\frac{1}{r}\frac{dh_1'}{dt} = -h_1' + \frac{H_1}{2H_2} H \frac{\alpha}{b^2}(T_1 - T_2)$$

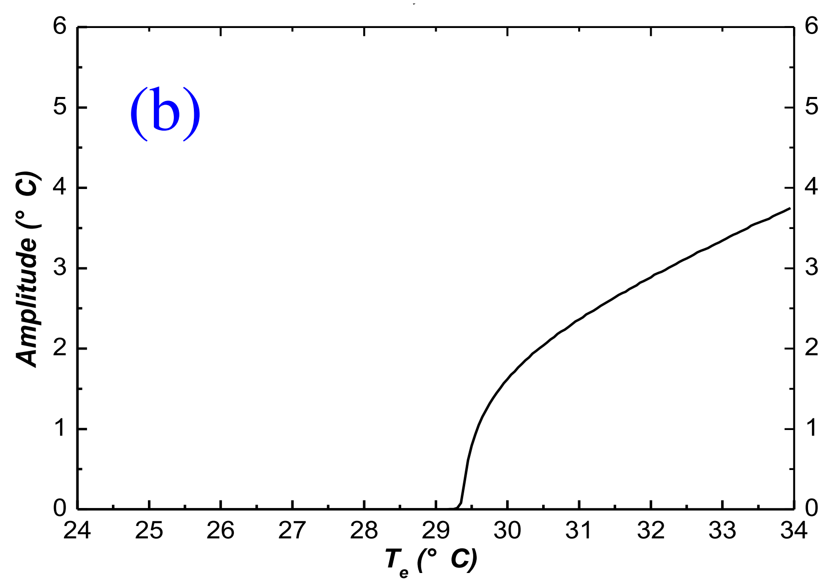
Sun and Liu 1996, Jin 1996, Sun 1997,

Tropical Pacific Climate as a Function of T_e.

Equilibrium and Time-Mean SST

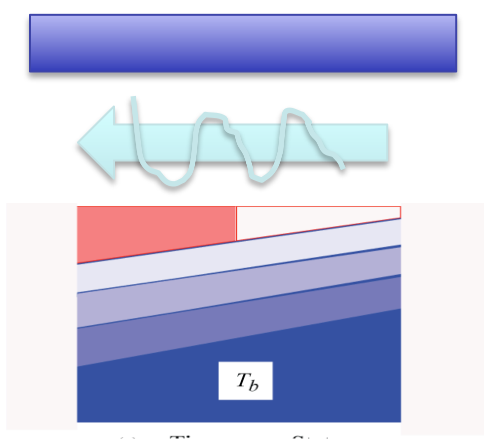


Amplitude of ENSO

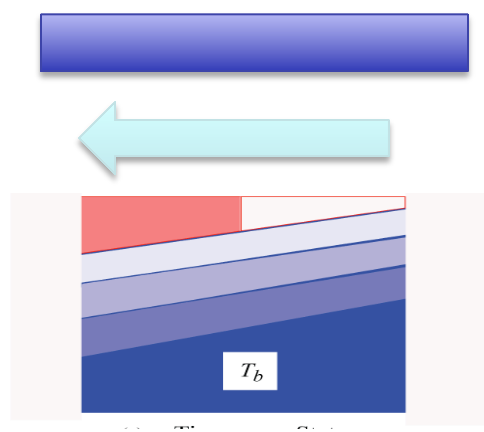


Forced Ocean GCM Experiments
with and without ENSO in the Forcing

A



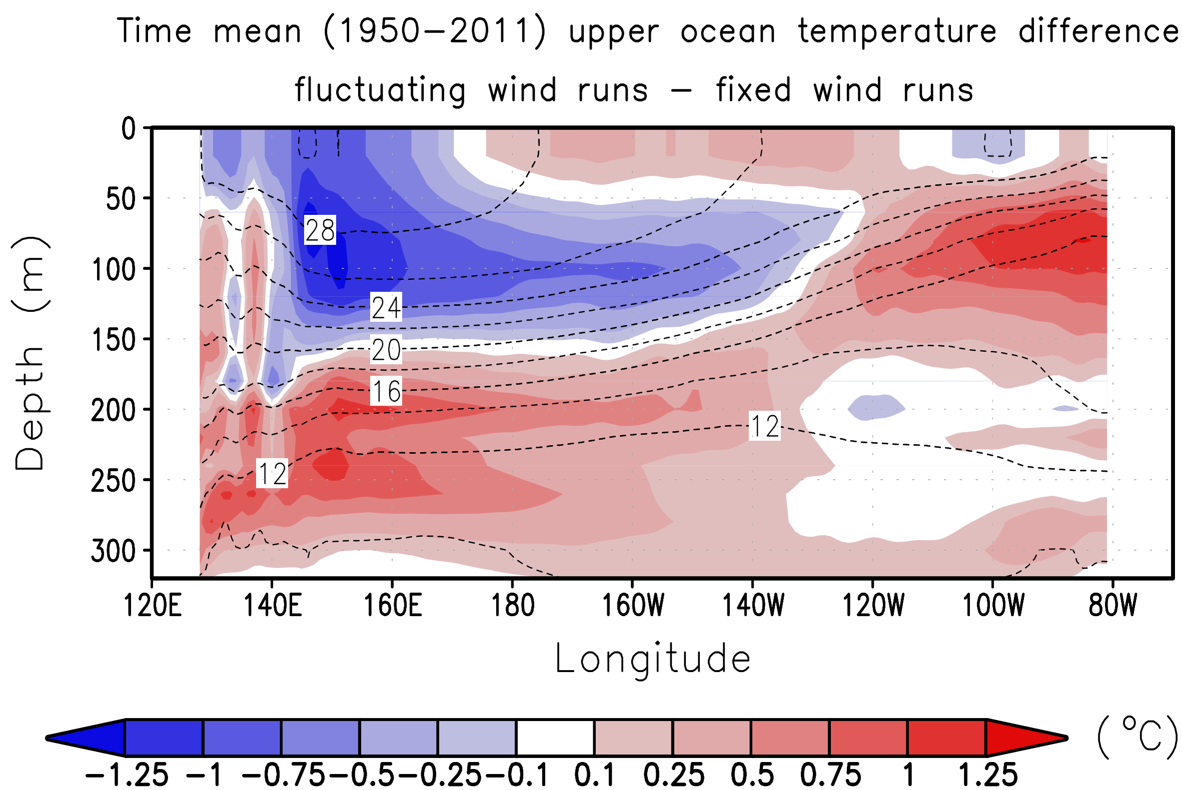
B



- The long-term mean winds are identical for A and B, but A has interannual variations and B does not.

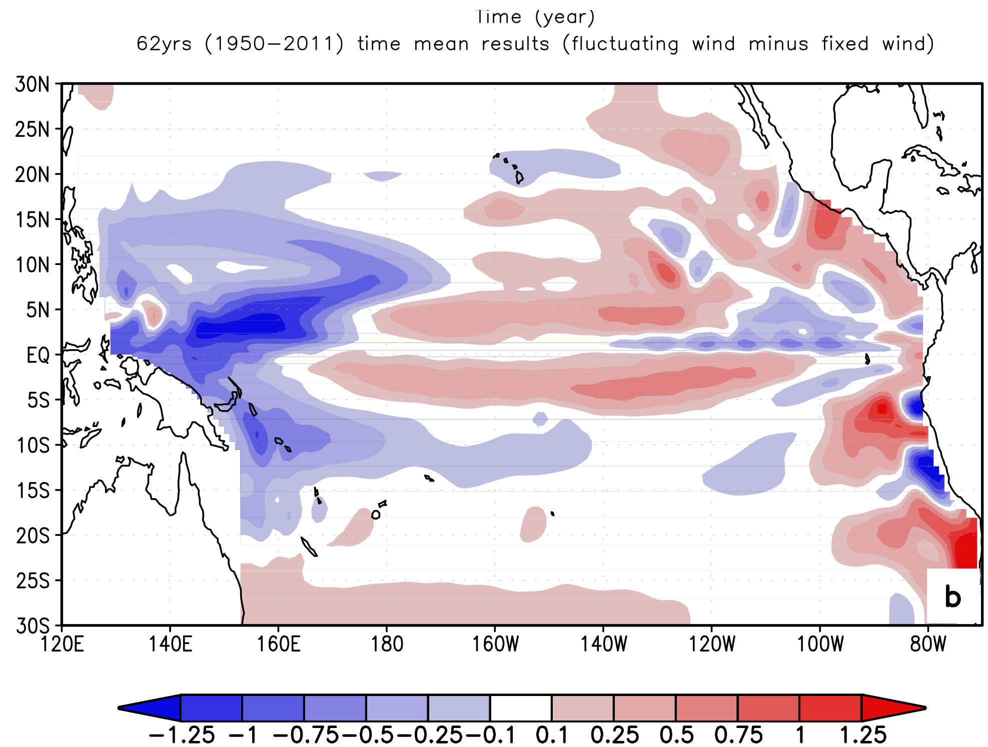
- The thermal BCs for A and B are identical-- both are restored to a prescribed potential SST

Upper T Difference Between Experiments with/without ENSO



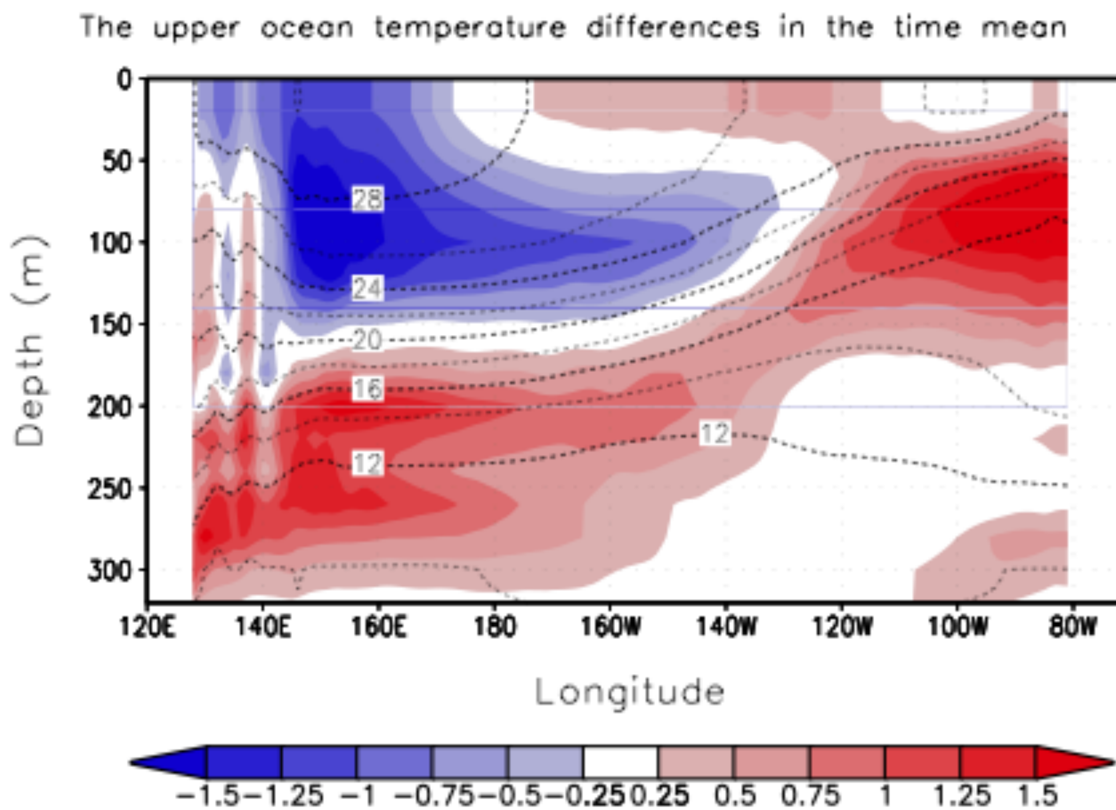
Sun, D.-Z., T. Zhang, Y. Sun, and Y. Yu, 2012: Rectification of El Nino-Southern Oscillation into Climate Anomalies of Decadal and Longer Time-scales. J. Climate, Submitted

SST Difference Between Experiments with/without ENSO



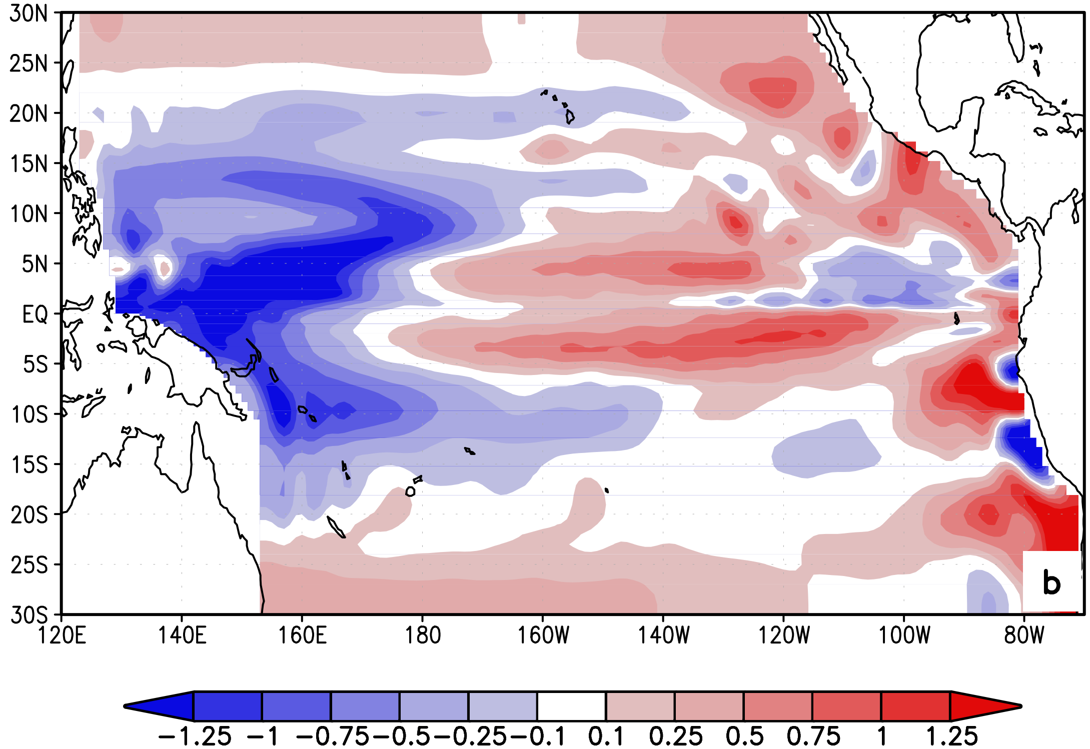
Sun et al. 2012

Upper T Difference Between Experiments with/without ENSO



Sun et al. 2012

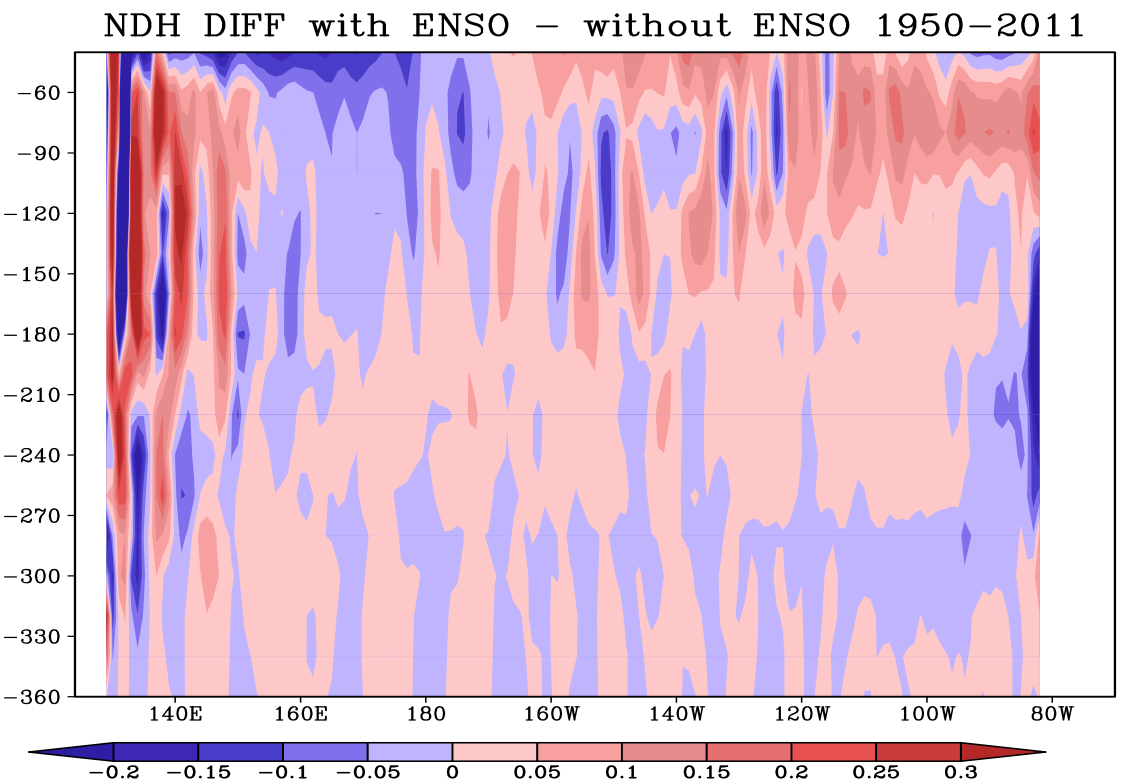
SST Difference Between Experiments with/without ENSO



Sun et al. 2012

Difference in convergence of $\overline{V'T'}$

(with ENSO minus without ENSO)



Sun et al. 2012

Difference in convergence of $\overline{V'T'}$

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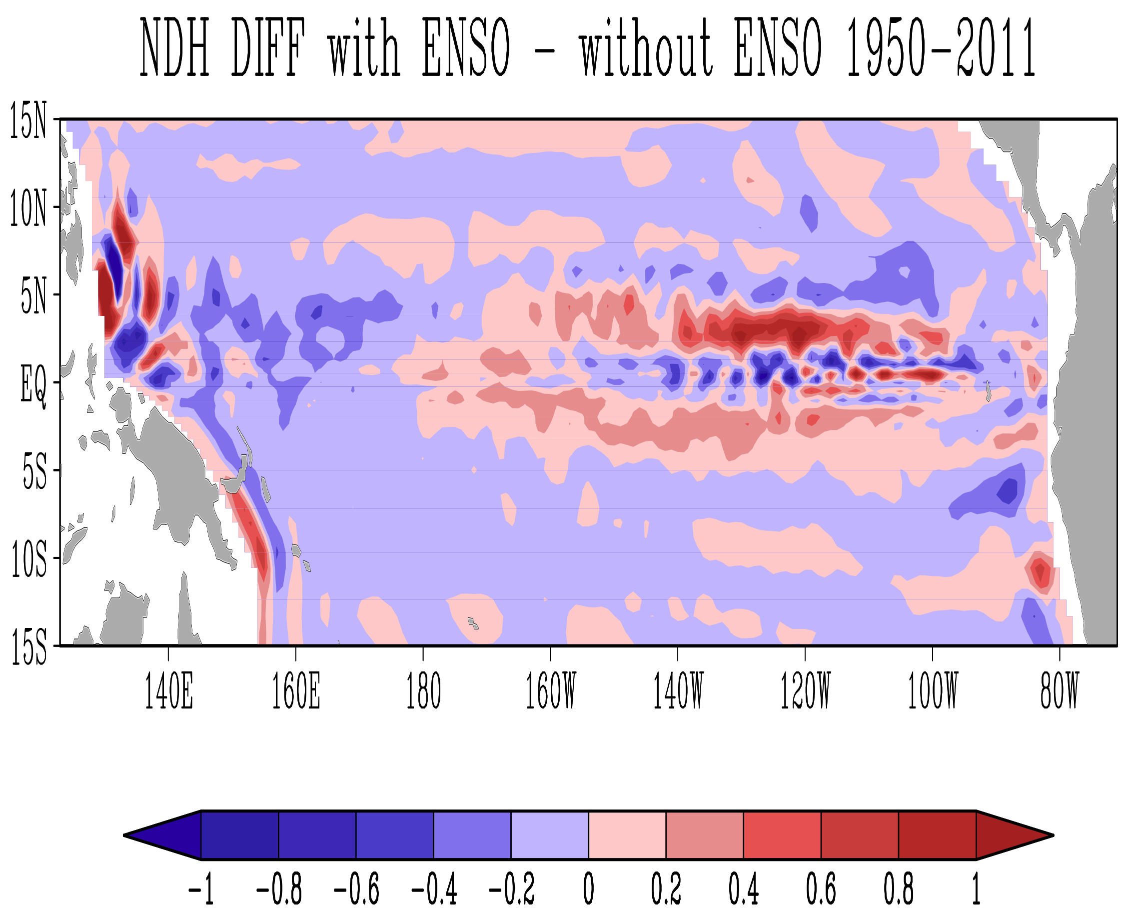


Sun et al. 2012

Two Emerging Scenarios for TPDV

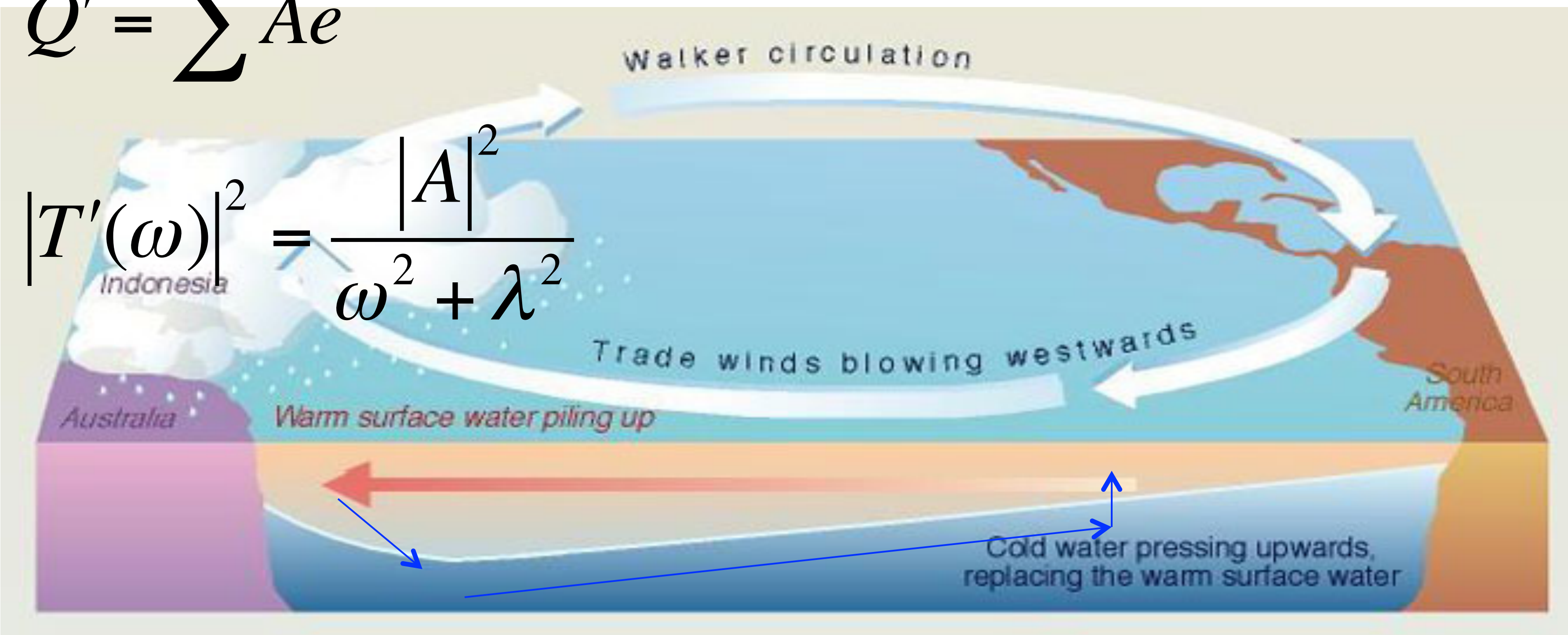
- Stochastic forcing from weather events over the western Pacific warm-pool results in a decadal component in the long-term variability in the level of ENSO activity, which in turn results in TPDV through the nonlinear rectification of ENSO.
- TPDV results from an interaction between the variance of ENSO variability and the decadal background state.

A Mechanism for Decadal Variability in the Level of ENSO Activity: Forcing form Weather Events From the Warm-pool

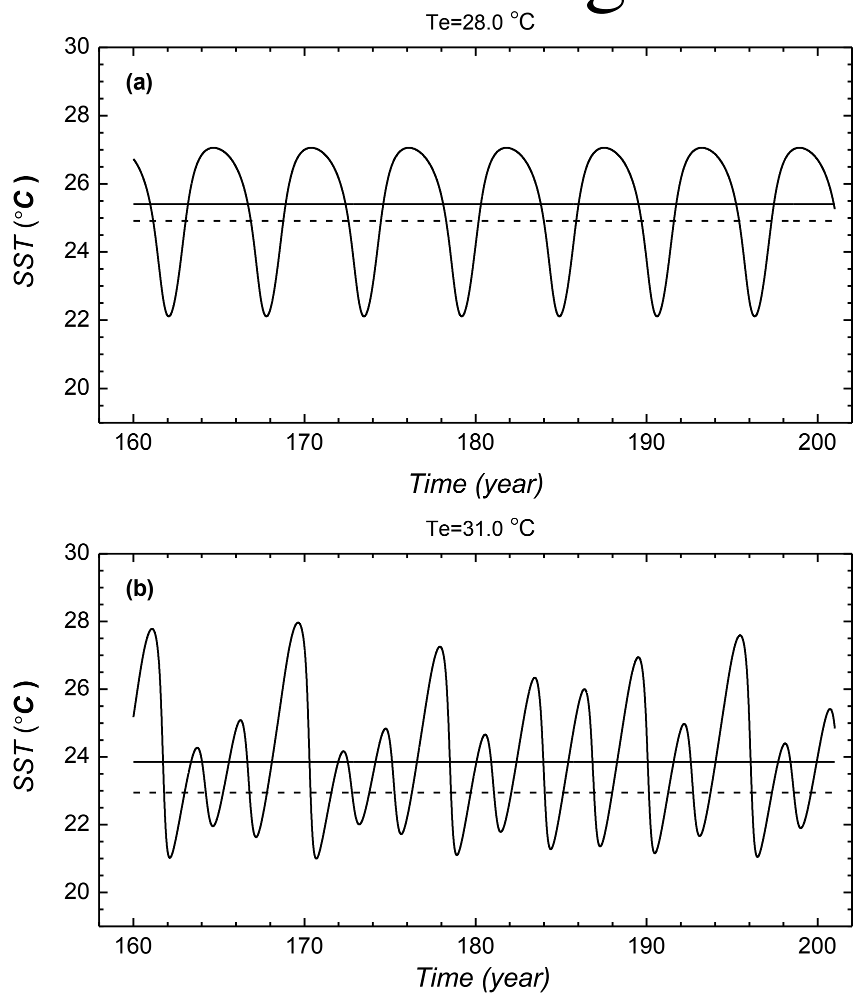
$$\frac{dT'}{dt} = -\lambda T' + Q'$$

$$Q' = \sum A e^{i\omega t}$$

$$\left|T'(\omega)\right|^2 = \frac{|A|^2}{\omega^2 + \lambda^2}$$



Oscillations in the Model different regimes



Liang,J., Xiu-Qun Yang, and De-Zheng Sun, 2011: The effect of ENSO events on the Tropical Pacific Mean Climate: Insights from an Analytical Model. J. Climate, 25, 7590-7606.

Homework

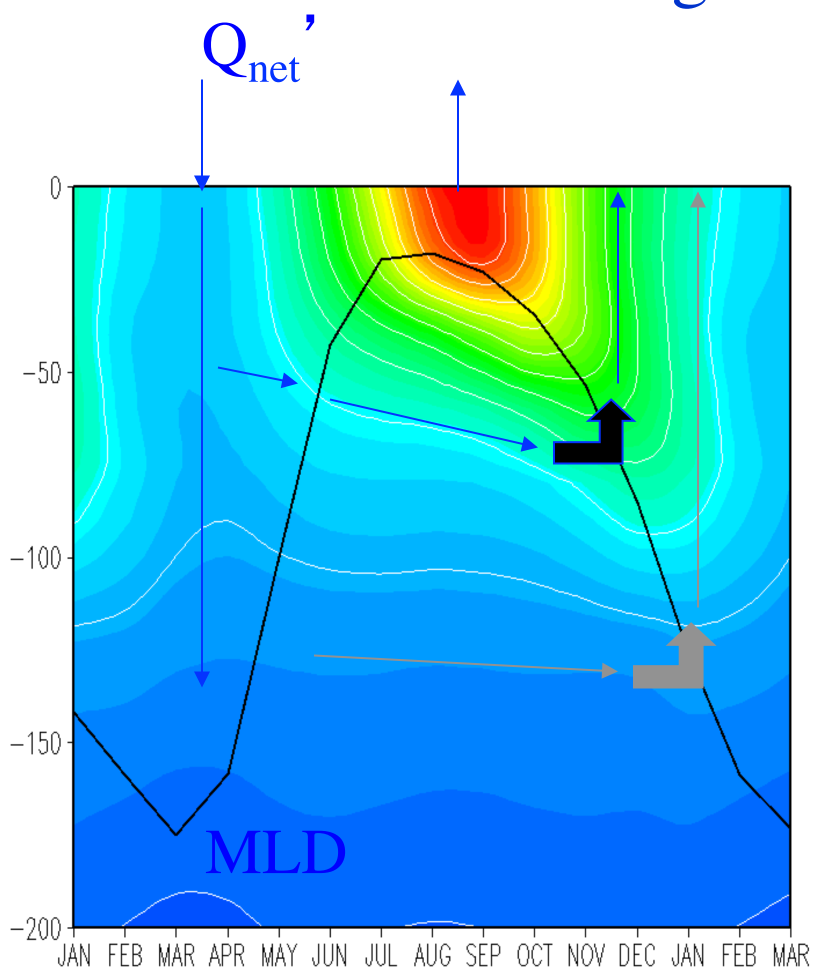
- Through the “atmospheric bridge”, a tropical SST anomaly can exert its impact on the extratropical ocean and cause a SST anomaly there. Based on what you know about the atmosphere and ocean dynamics, can you envision a mechanism that may do the reverse –allowing an extratropical SST anomaly to cause a change in the tropical SST?

- Do you expect to see a counterpart of PDO in the Atlantic sector? Why?

Recommended Reading For the Next Lecture

- Diaz, Henry F., Ricardo Trigo, Malcolm K. Hughes, Michael E. Mann, Elena Xoplaki, David Barriopedro, 2011: Spatial and Temporal Characteristics of Climate in Medieval Times Revisited. *Bull. Amer. Meteor. Soc.*, **92**, 1487–1500.

Seasonal cycle of Temperature & MLD in N. Pacific Reemergence Mechanism



- Winter Surface flux anomalies
- Create SST anomalies which spread over ML
- ML reforms close to surface in spring
- Summer SST anomalies strongly damped by air-sea interaction
- Temperature anomalies persist in summer thermocline
- Re-entrained into the ML in the following fall and winter

Alexander and Deser (1995, JPO), Alexander et al. (1999, J. Climate)