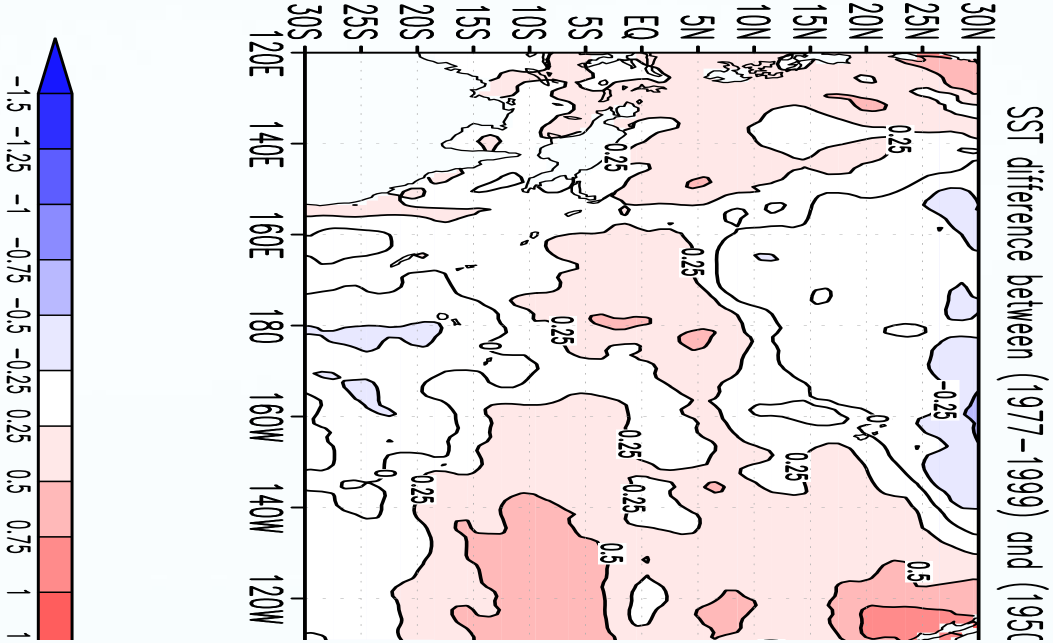
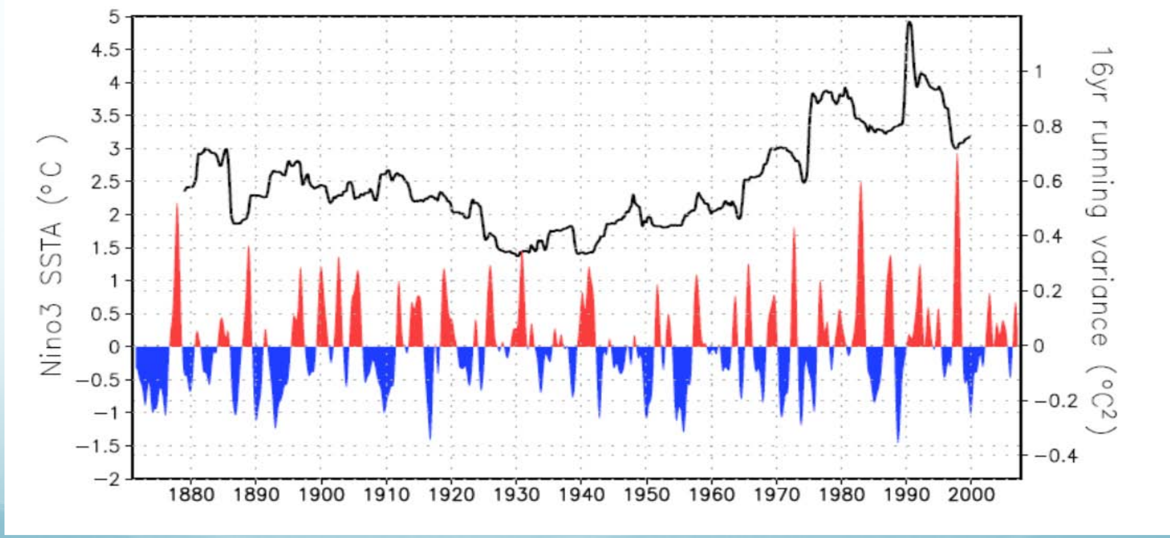
Rectification of El Nino-Southern Oscillation as a possible cause for The Tropical Pacific Decadal Variability

De-Zheng Sun
CIRES, University of Colorado &
Earth System Research Laboratory, NOAA
www.esrl.noaa.gov/psd/people/dezheng.sun/

Collaborators:
Jin Liang, Tomomichi Ogata, Yan Sun, Yongqiang Yu,
Andrew Wittenberg Shang-Ping Xie, Xiu-Qun Yang, Tao Zhang

TPDV and Level of ENSO Activity



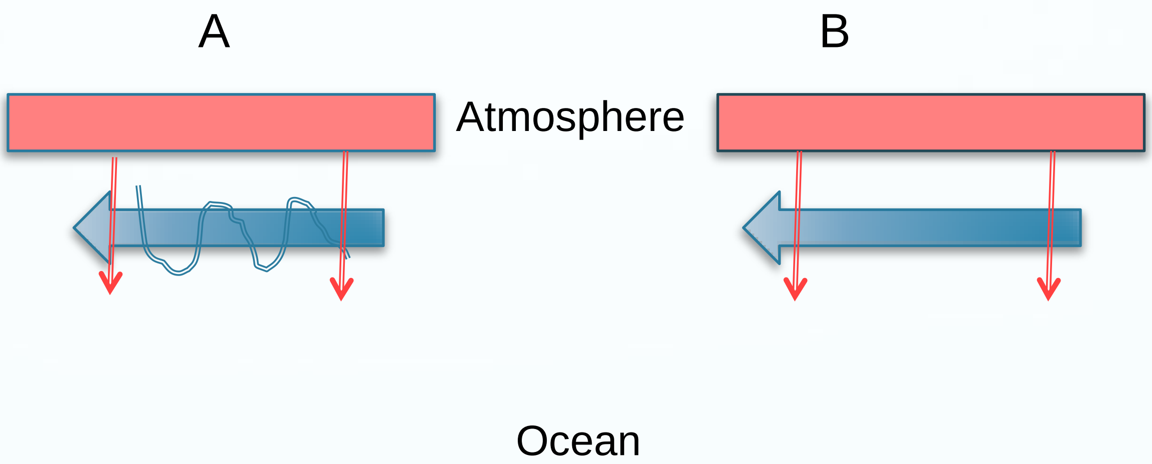


employed to determine

the time-mean (or rectified) effect of ENSO

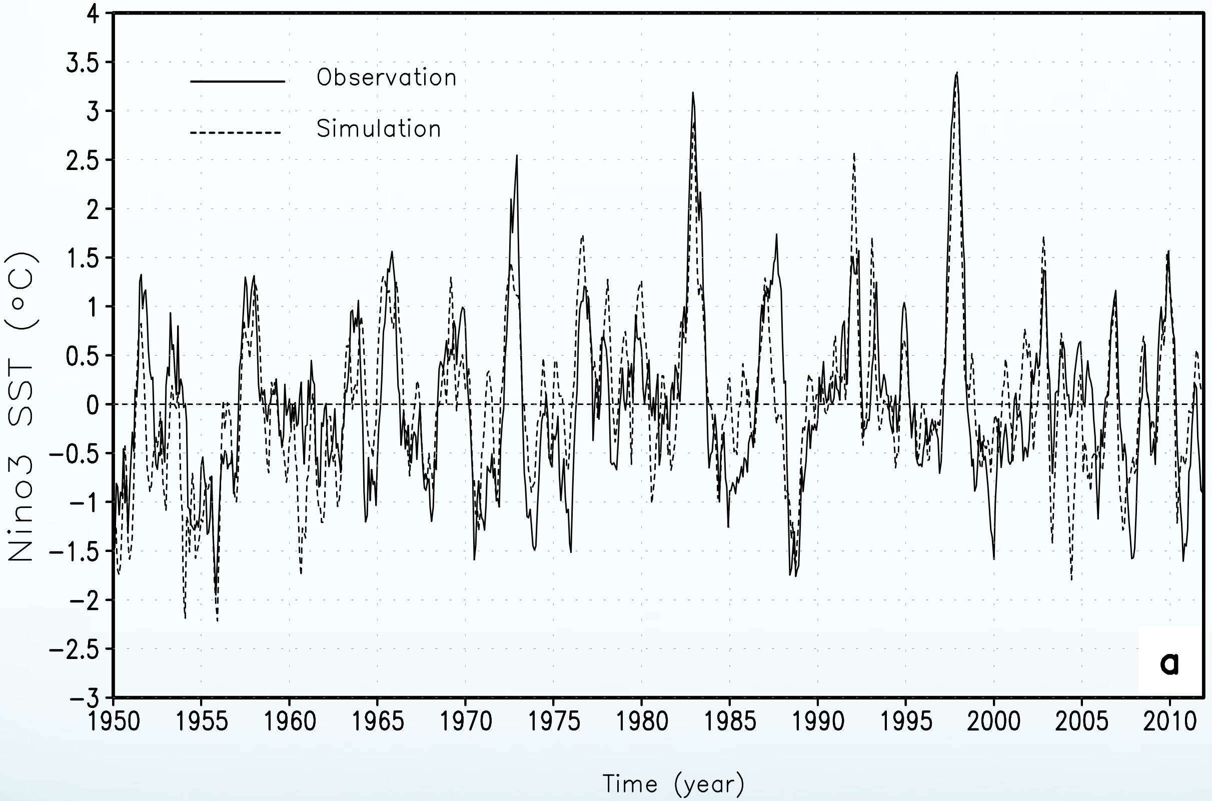
- Compare *the equilibrium state* of the coupled tropical ocean-atmosphere system with the time-mean state of the system, though the use of a box model whose unstable equilibrium state can be analytically obtained (Liang et al. 2012, J. Climate, 25, 7590-7606)
- **Force an Ocean GCM using surface forcing with and without ENSO fluctuations (Sun et al. 2013, J. Climate, Accepted)**
- Analysis of a 2000 yr- long-run by GFDL CM2.1 (Ogata et al. 2013, J. Climate, Accepted).

Forced Ocean GCM Experiments with and without ENSO in the Surface Forcing



- 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

ENSO in the model and observations



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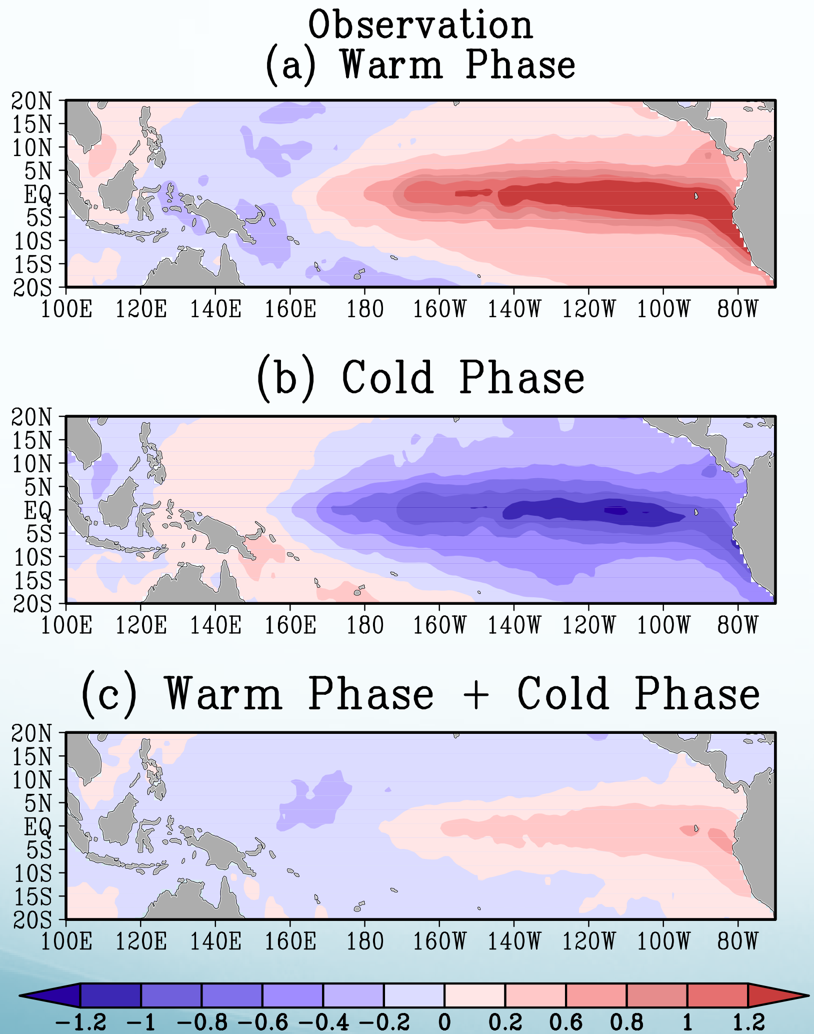
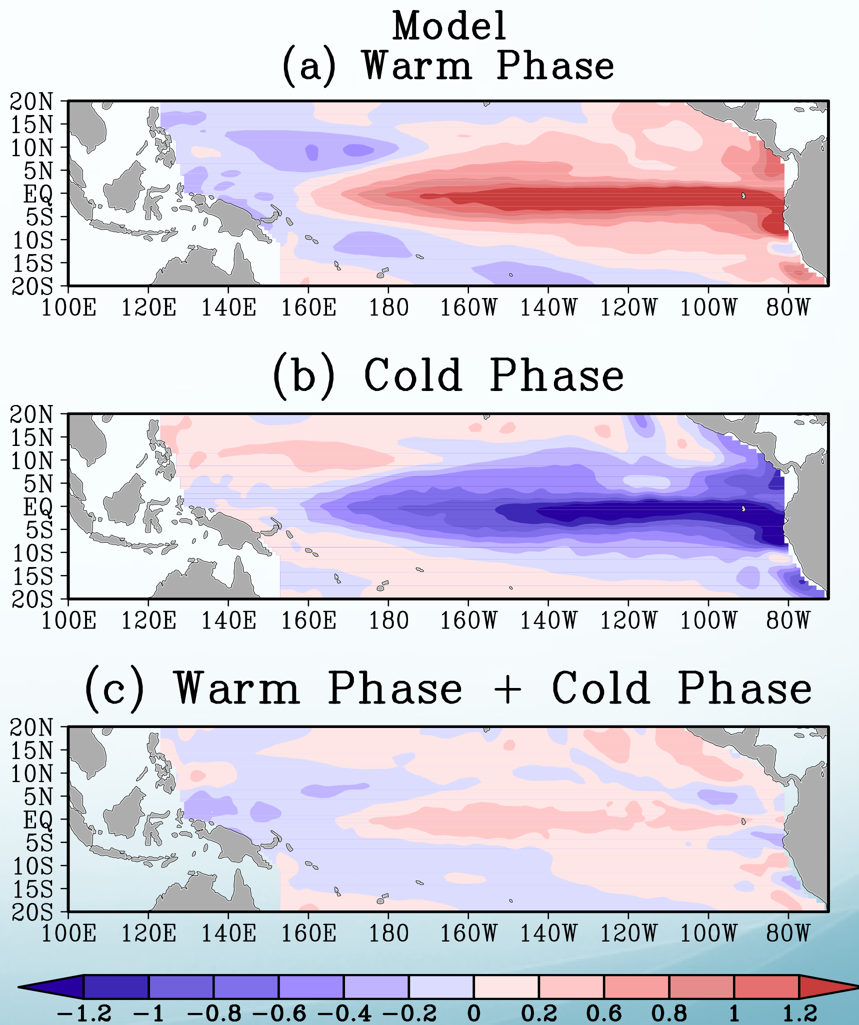
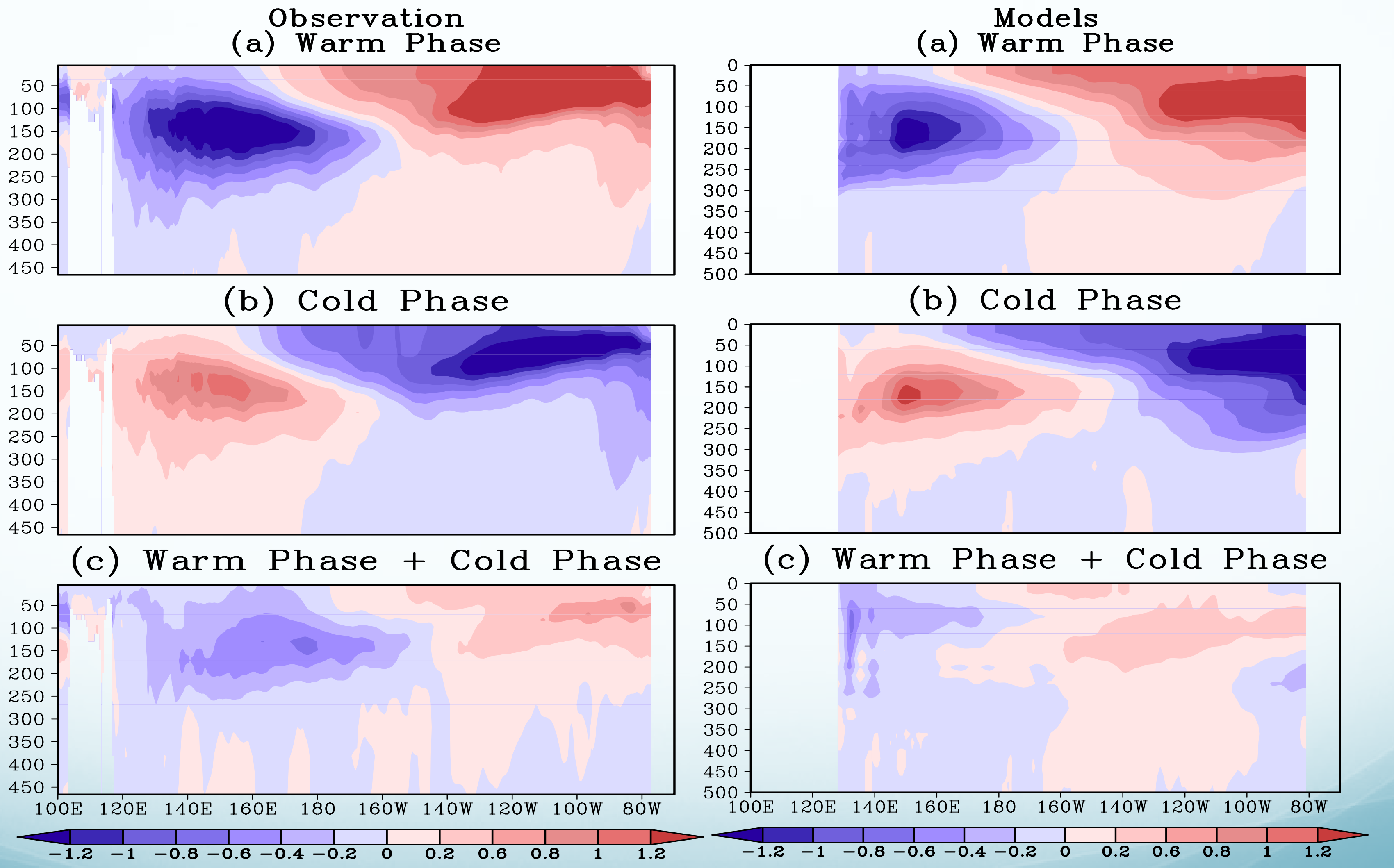
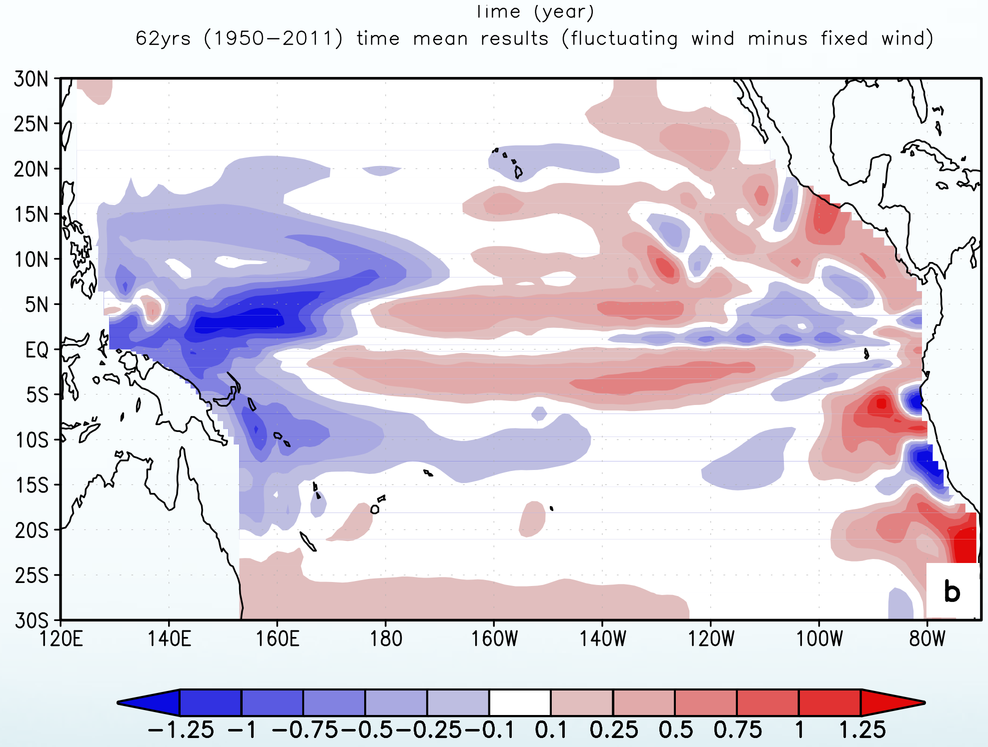




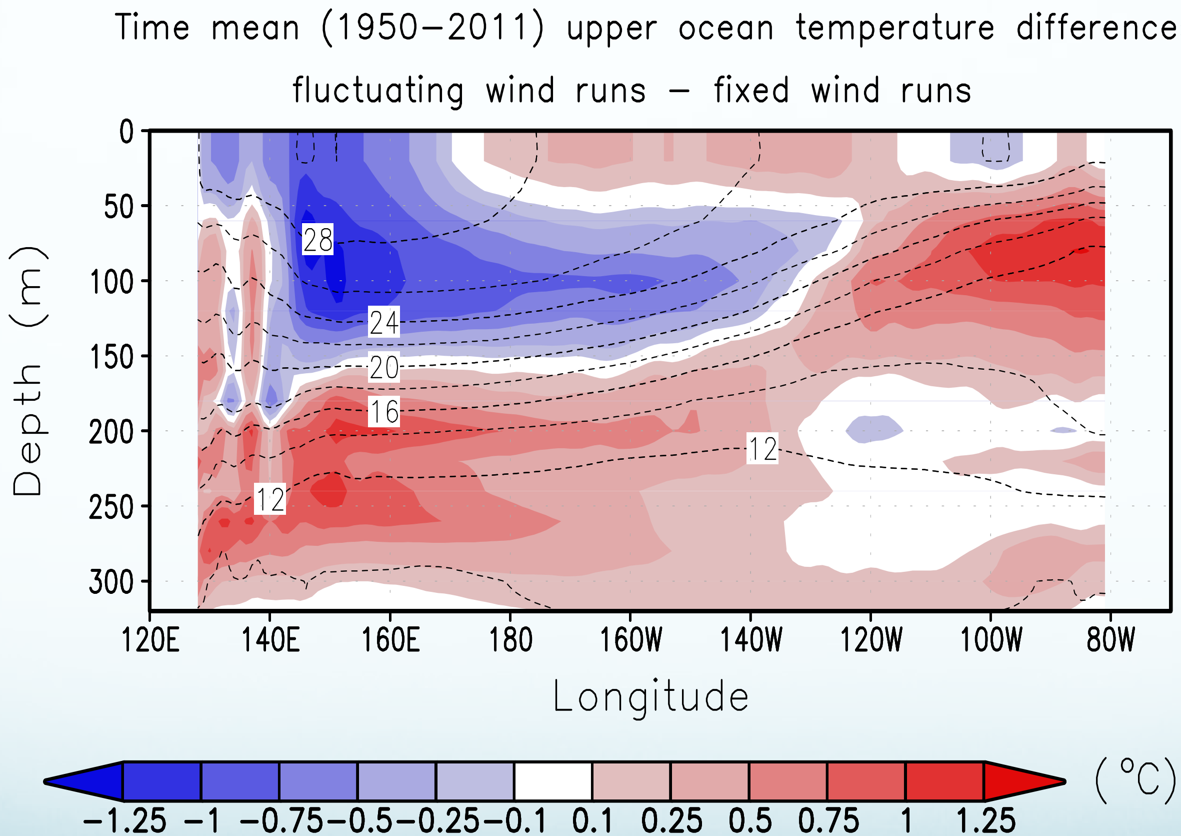
ENSO in the model and observations



SST Difference Between Experiments with/without ENSO



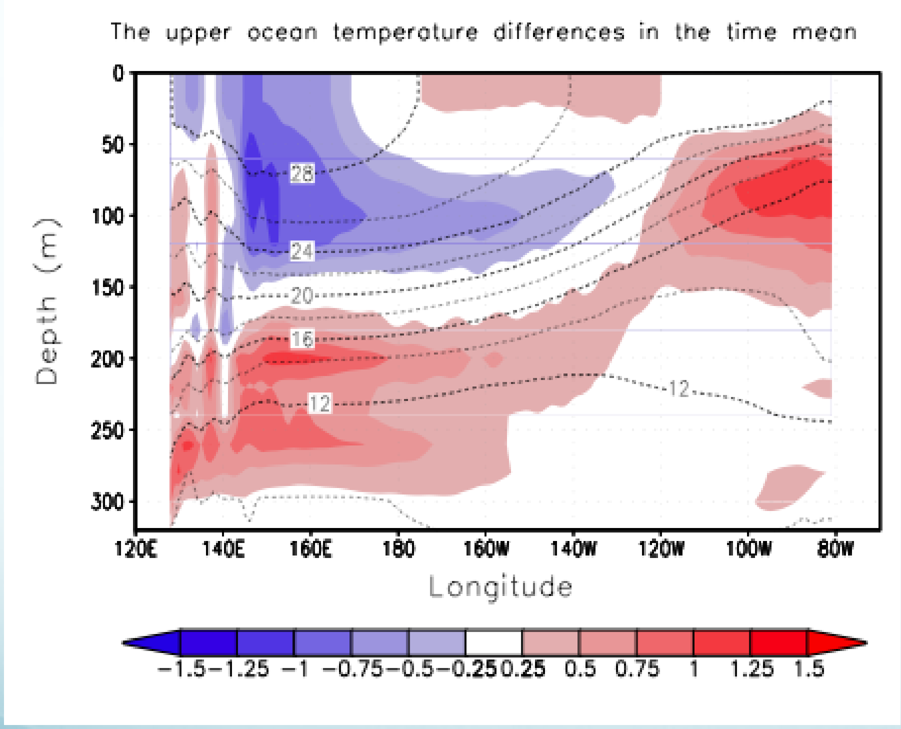
Upper T Difference Between Experiments with/without ENSO

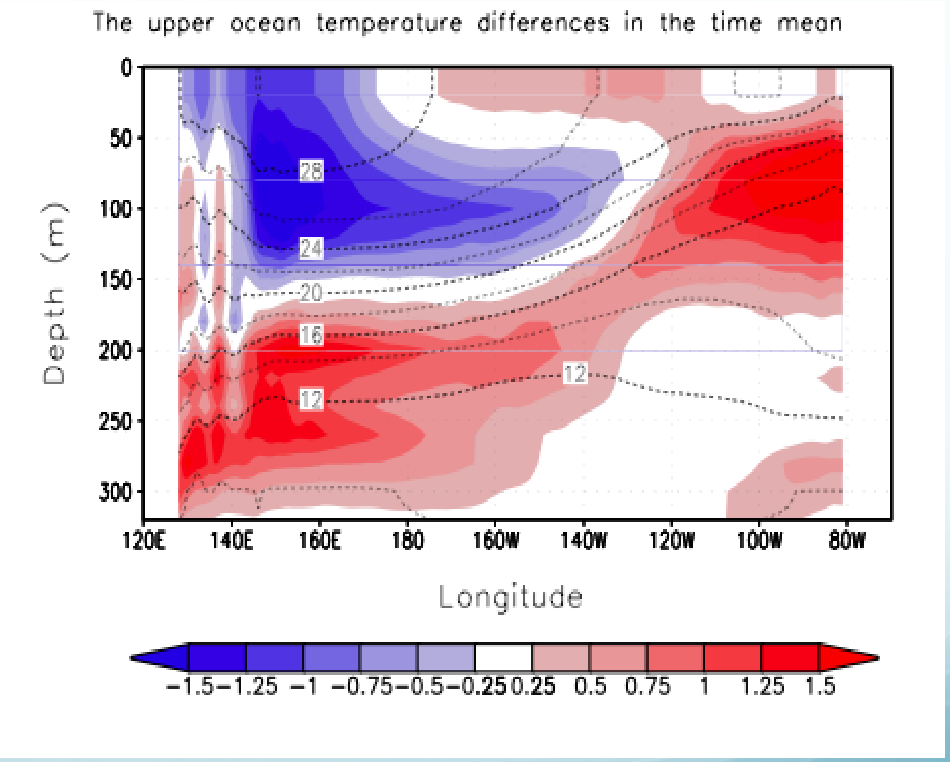


The rectified effect of ENSO in the Upper Ocean T: Sensitivity to the variance of ENSO

τ'

$1.5\tau'$

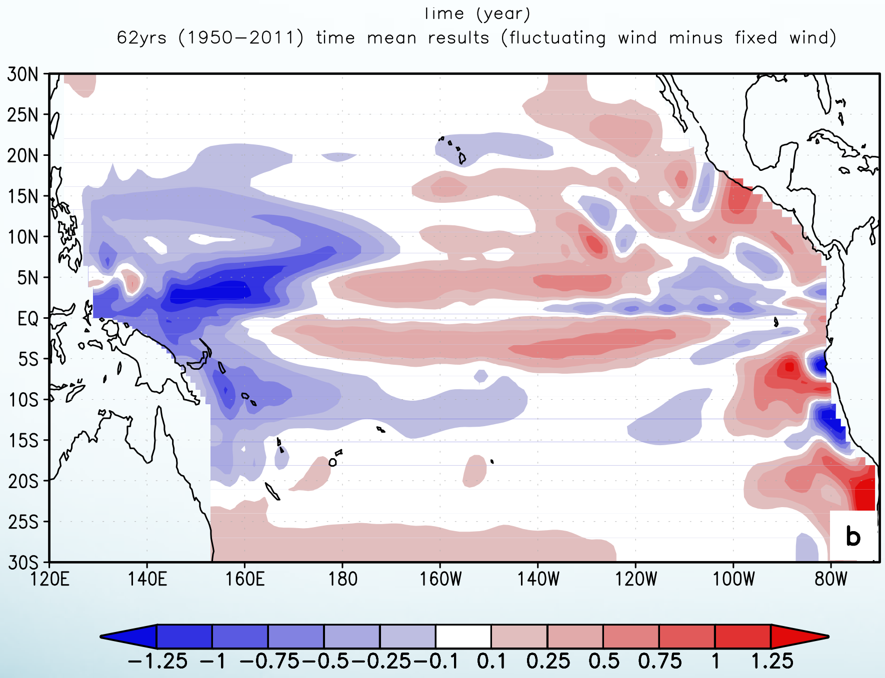


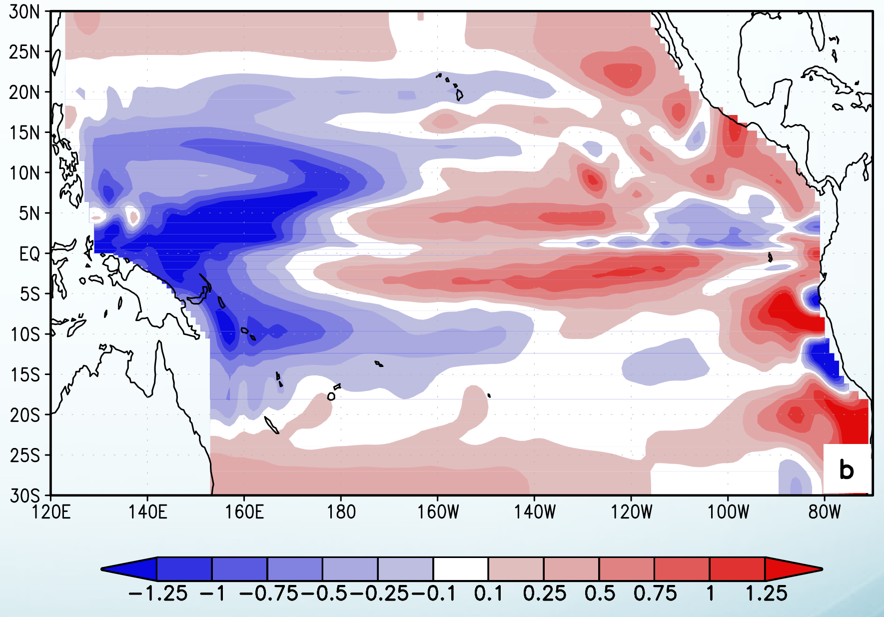


The Rectified Effect of ENSO on the SST: Sensitivity to the variance of ENSO

τ'

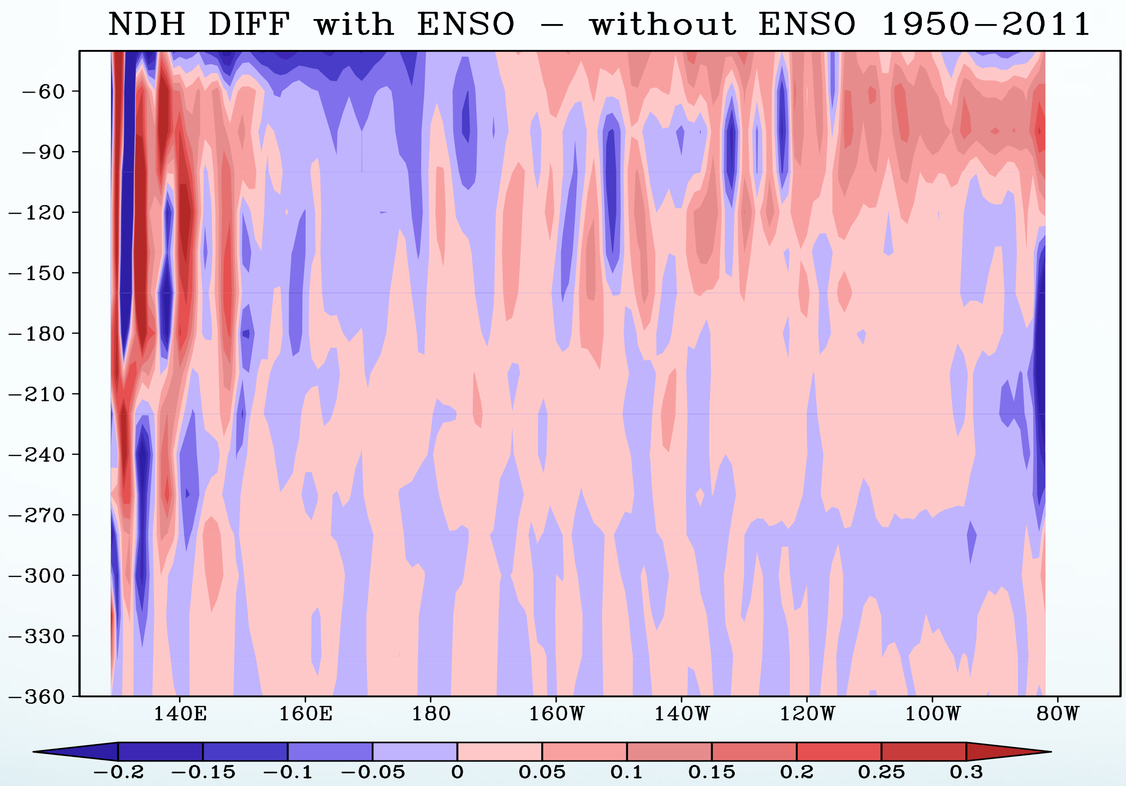
$1.5\tau'$





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

(with ENSO minus without ENSO)



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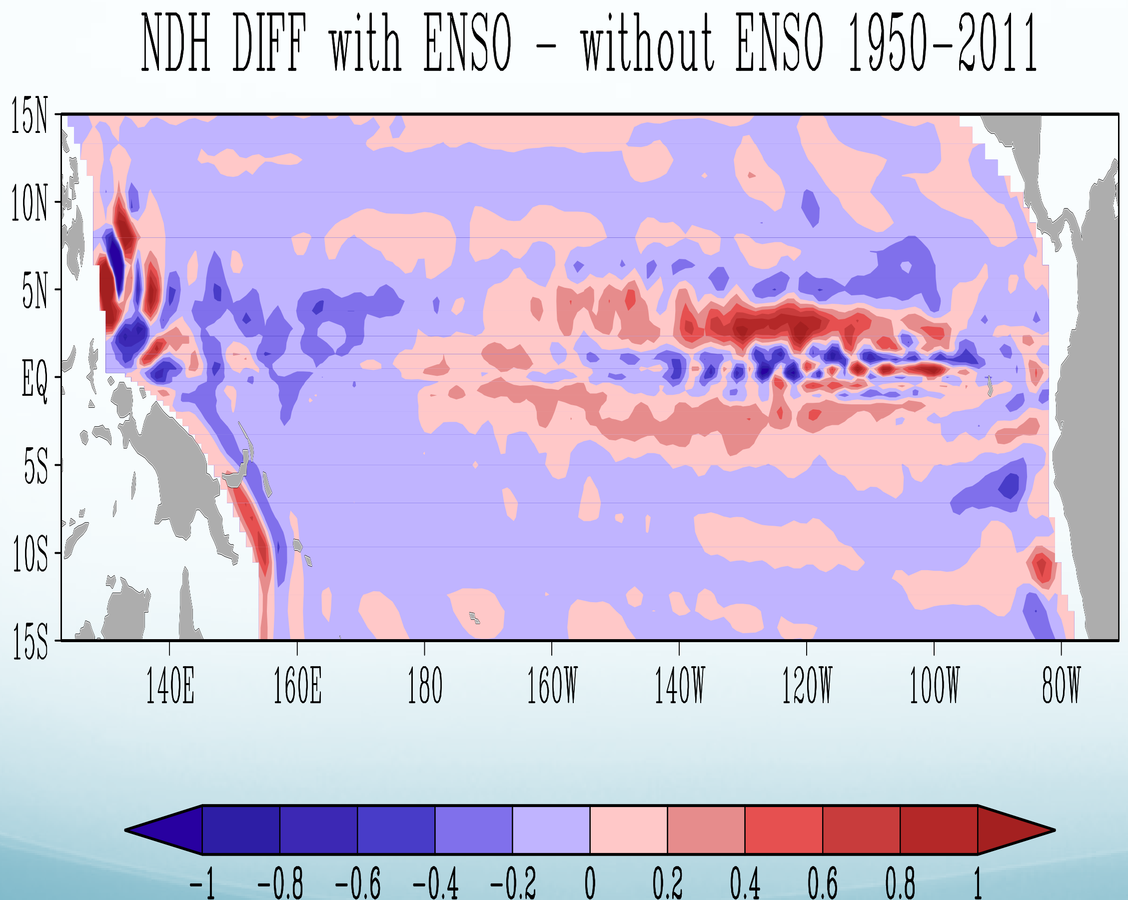


Key Results
From Forced Ocean GCM Experiments

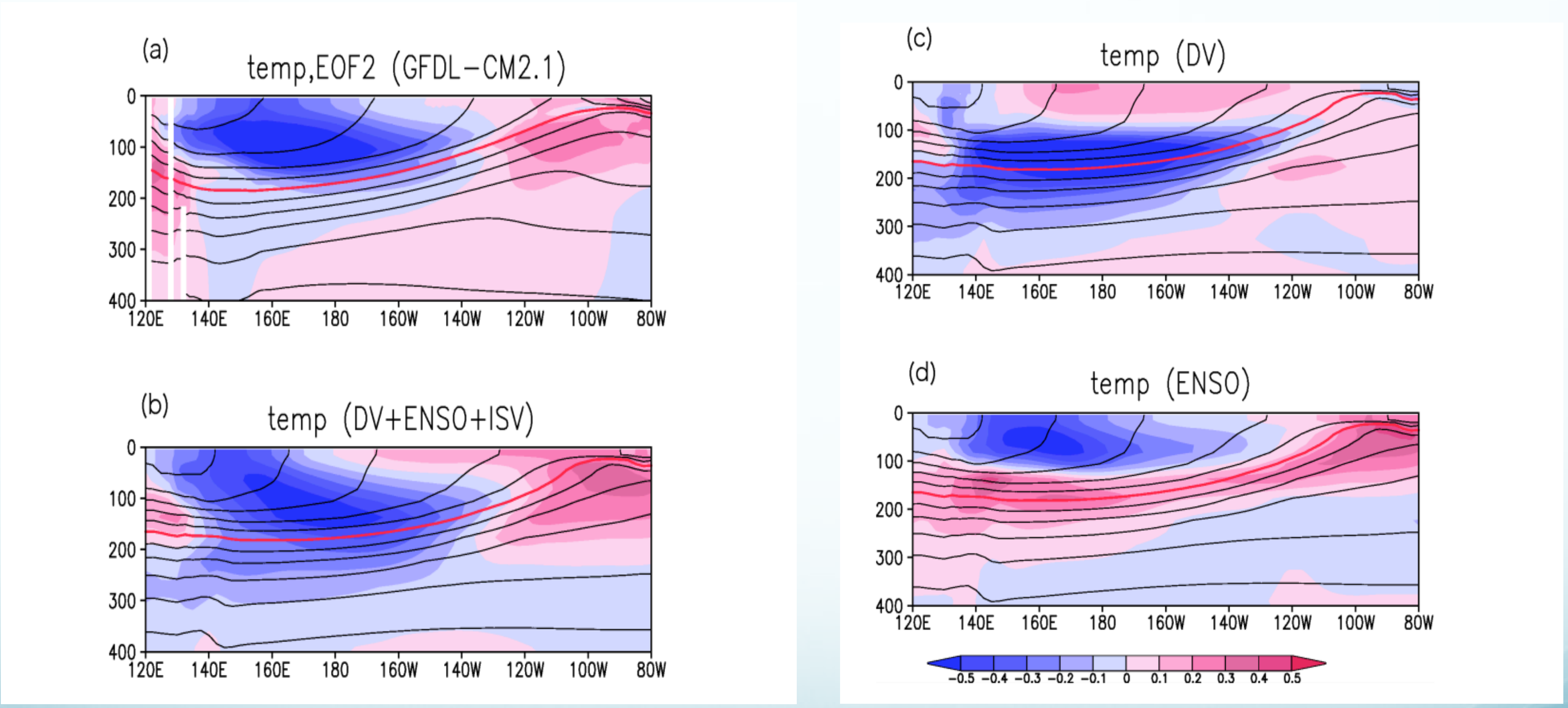
- The rectified effect of ENSO events is to cool the warm-pool water, warm the subsurface equatorial thermocline water, and the surface water in the broad region of eastern Pacific. The overall structure indicates a diffusive effect that stabilizes the coupled system, but the stabilizing effect has regional differences. The reduction of the stratification in the central Pacific is accompanied by an increase in stratification in the central Pacific.

- The spatial pattern of the rectified effect of ENSO events in the eastern Pacific resembles the decadal warming in the tropical Pacific

- The rectified effect of ENSO events increases with increases in the level of ENSO activity.

- The rectified effect of ENSO is linked to nonlinear advection(convergence of $\overline{V'T'}$)

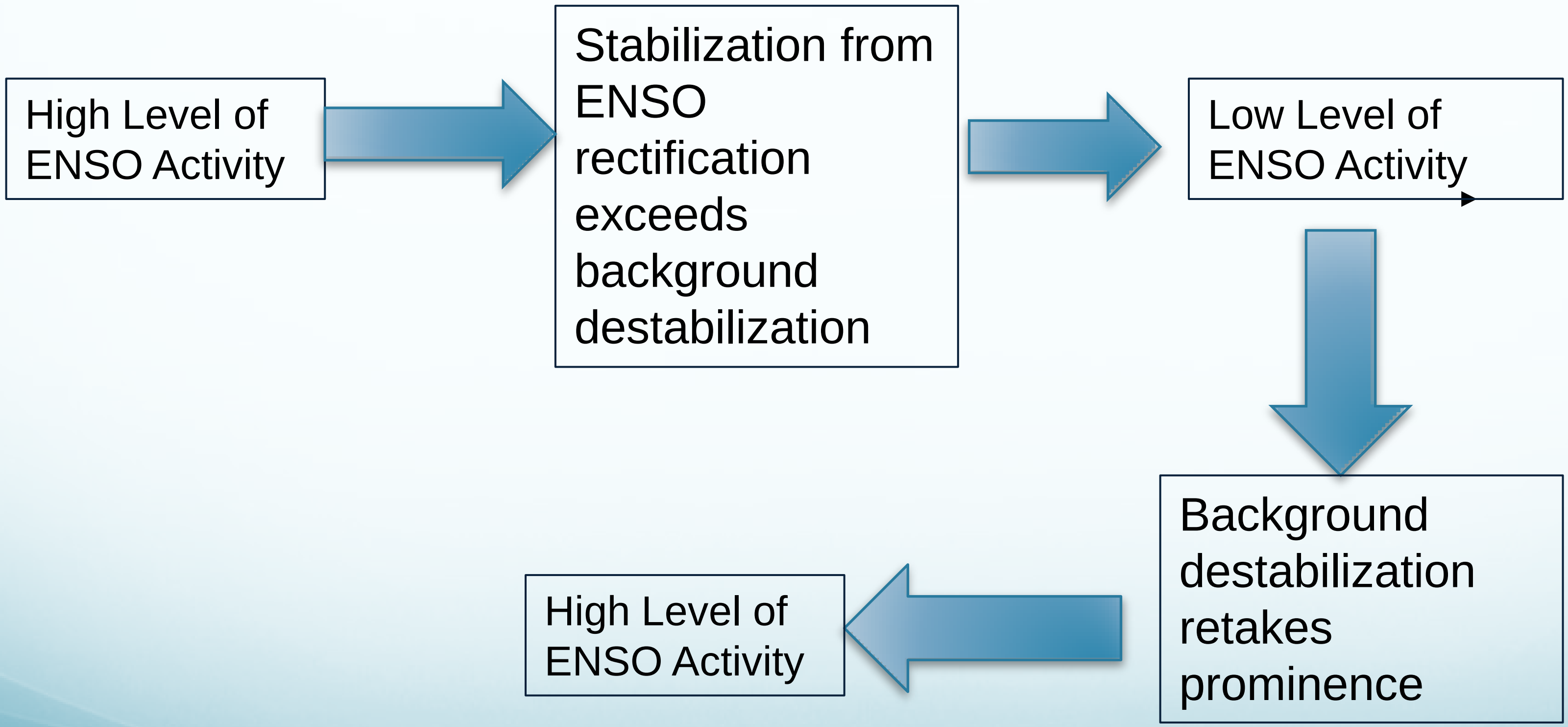
Rectified effect of ENSO
inferred from decadal variability in GFDL CM2.1



Future Work Planned

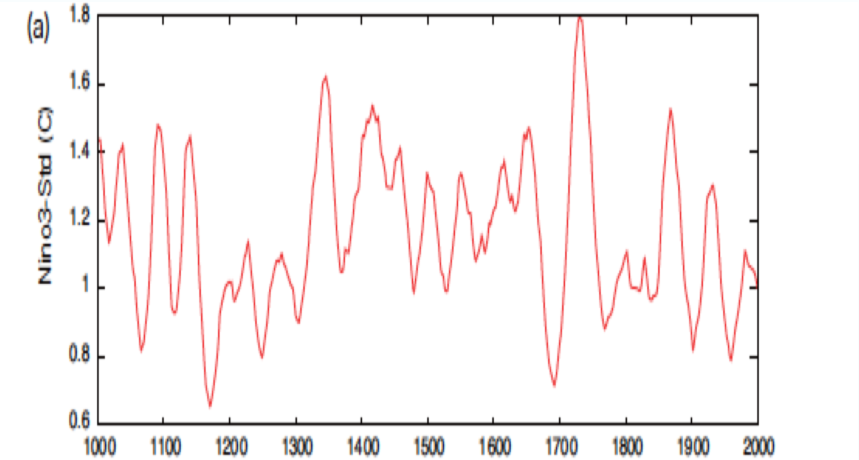
- Examine whether the rectification of ENSO is a significant contributor to the TPDV in CESM
- Examine what are the causes for the decadal variability in the level of ENSO activity, in particular whether a self sustained TPDV and decadal variability in the level of ENSO activity can be maintained through the interaction between the time-mean effect of ENSO and its decadal background state.

A Hypothesis For
TPDV and Decadal Modulation of ENSO

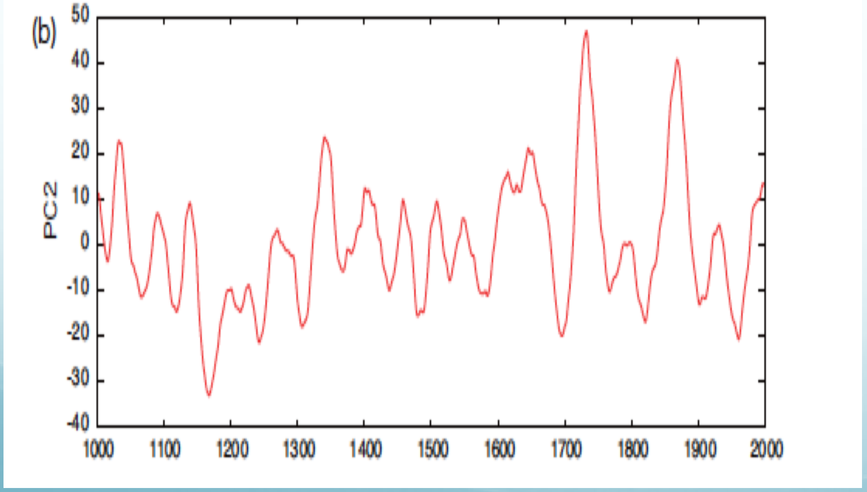


TPDV and Level of ENSO Activity in GFDL CM2.1

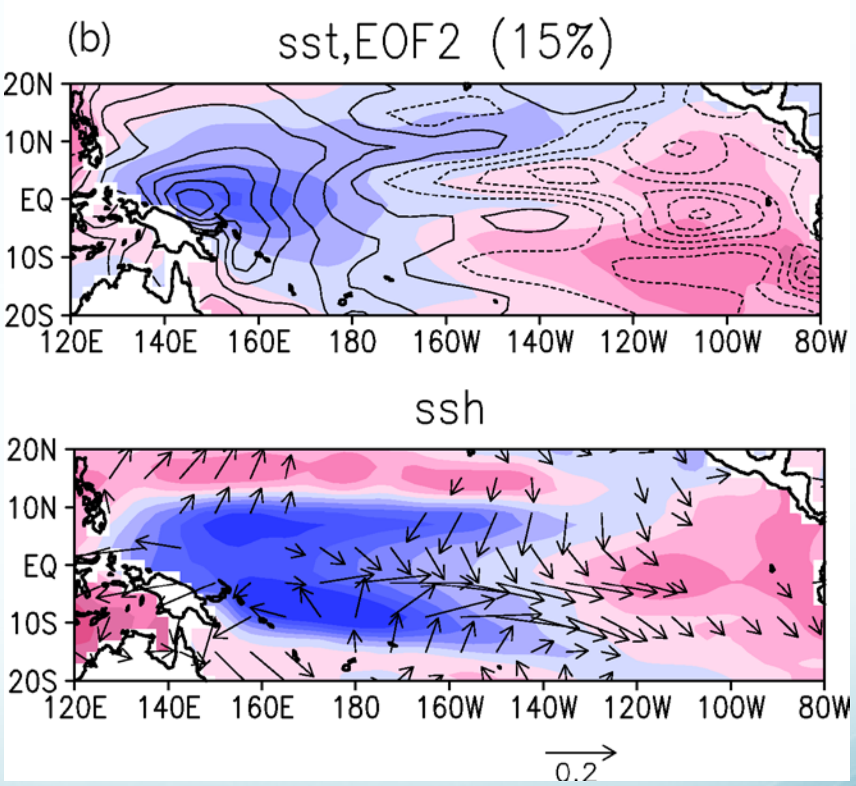
Decadal Variation in the STD of Nino3 SST



Decadal Variation in the Mean State (TPDV)



Spatial Pattern of TPDV in CM2.1



Other terms used for the rectification of El Nino-Southern Oscillation

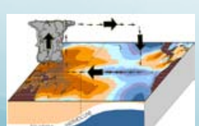
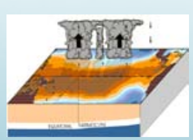
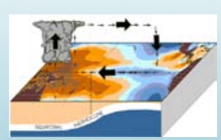
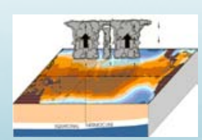
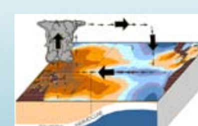
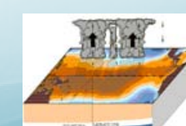
The use of word “rectification” follows the study of Kessler and Kleeman (2000) in which they argued that an ENSO anomaly can be created by an integral effect of MJO.

- Residual effect of El Nino-Southern Oscillation (Rodger et al. 2004, Yeh and Kirtman 2004, Sun and Yu 2009; Yu and Kim 2011, Choi et al. 2011)
- Time-mean effect of El Nino-Southern Oscillation (Sun 2003, Sun and Zhang 2006, Sun et al. 2013)

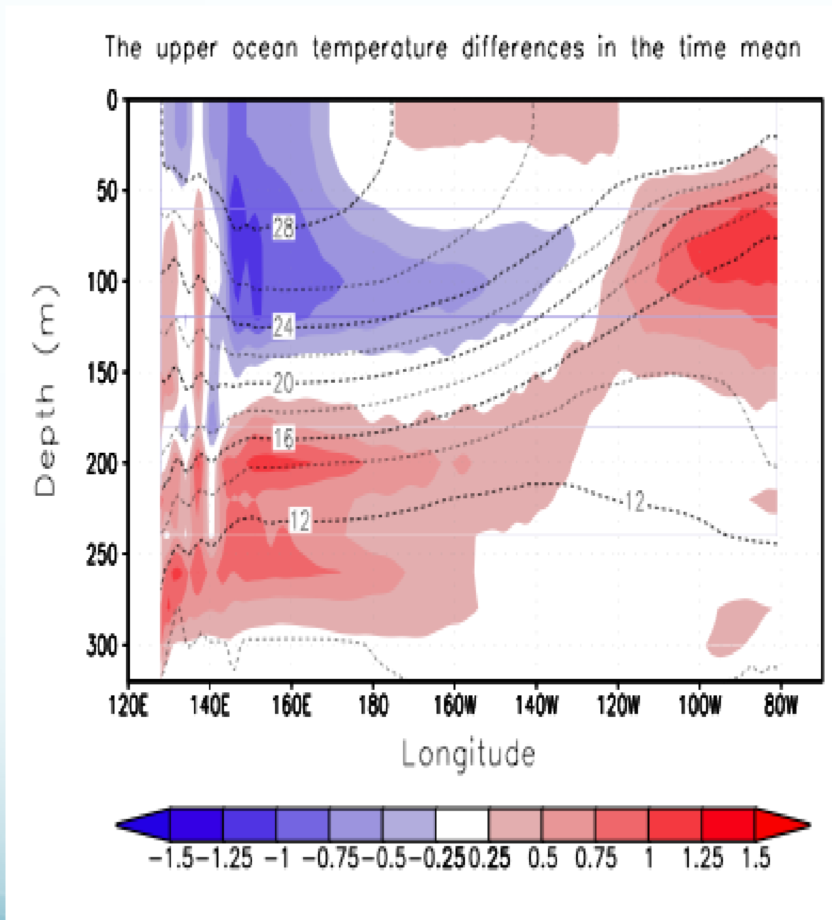
The basic premise: Averaged on the decadal and longer time-scales, the effect of ENSO events does not cancel out, but is finite. Moreover, the greater the level of ENSO activity over the considered period, the greater this effect integrated over this period.

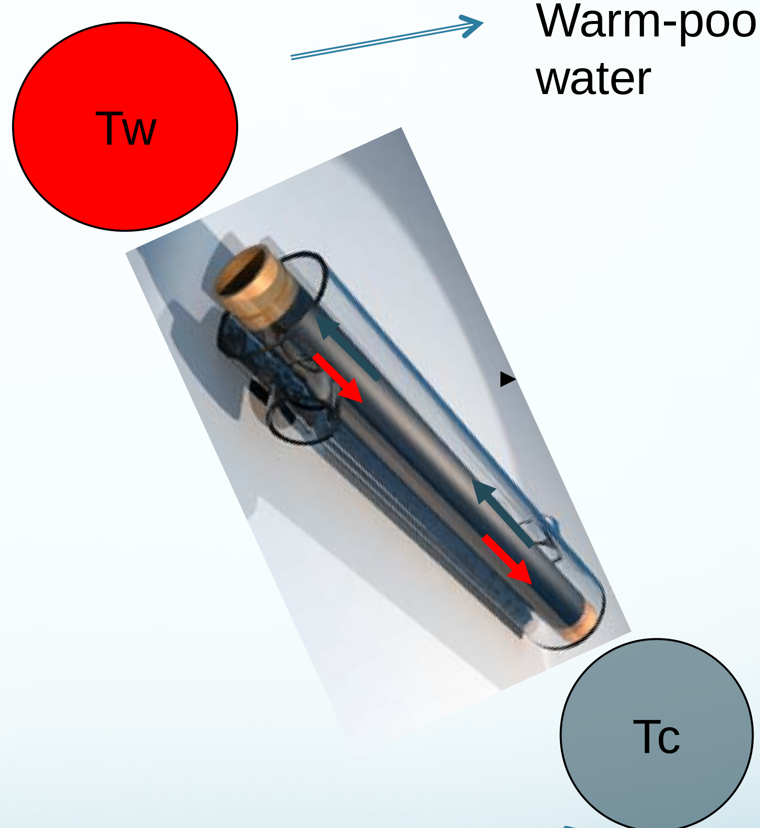
Why are we interested in
the time-mean effect of
El Nino--Southern Oscillation

Viewed on a decadal and longer time-sales, ENSO events are transients just as weather events viewed on the time-scale of a year or longer. We are interested in the time-mean effect of ENSO events for the same reason as we were interested in the time-mean effect of weather events. ***Do ENSO events collectively play a role in maintaining the climatological state of the tropical Pacific, and if so, what is this role?***

A Conceptual Picture for the Time-Mean Effect of ENSO: A Heat Mixer





Warm-pool water

Thermocline water

Equilibrium State, Time-Mean State and the level of transient activities

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

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

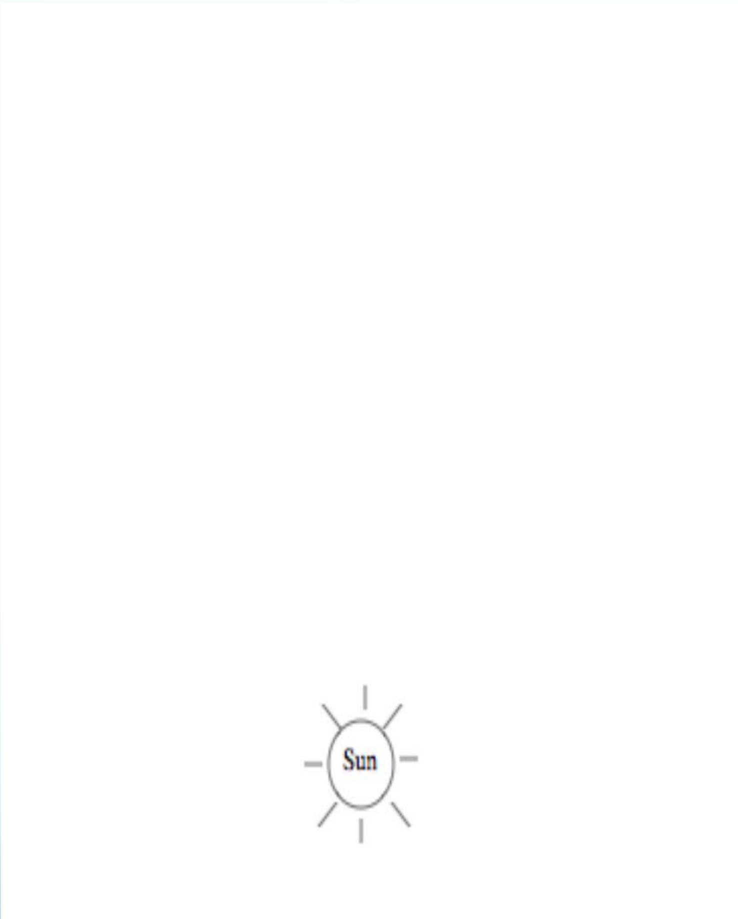
Time Mean State: $$\overline{f(\bar{A} + A', \lambda)} = 0 \quad (3)$$

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

When $f(A, \lambda)$ Is nonlinear and $A'^2 \neq 0, \bar{A} \neq A_0$ (5)

Time-mean effect: $$\bar{A} - A_0 = F\left(\overline{A'^2}\right) \quad (6)$$

A Box Model for the ENSO System



West

East

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

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

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

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

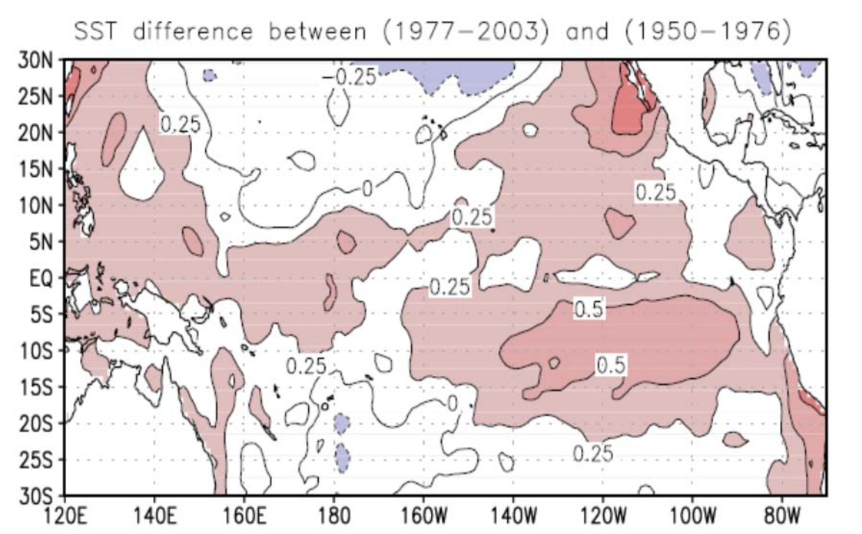
$$\Phi(z) = T_e - \frac{T_e - T_b}{2}\left(1 - \tanh\left(\frac{z + z_0}{H^*}\right)\right)$$

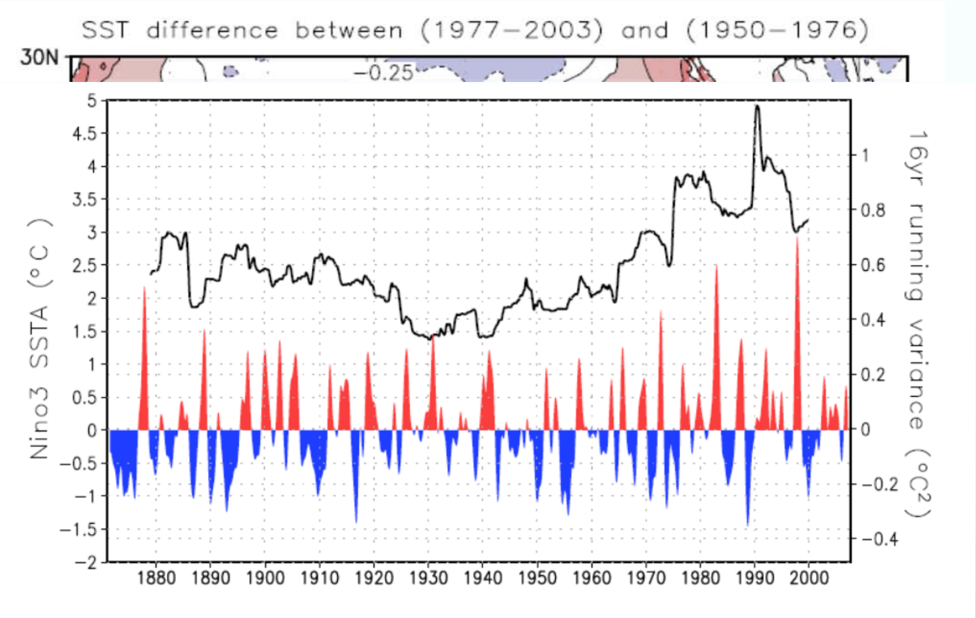
$$h_2' - h_1' = -\frac{H_1}{H_2} H \frac{\alpha}{b^2}(T_1 - T_2)$$

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

Jin 1996, Sun 1997

TPDV and Level of ENSO Activity in observations





TPDV and Level of ENSO Activity
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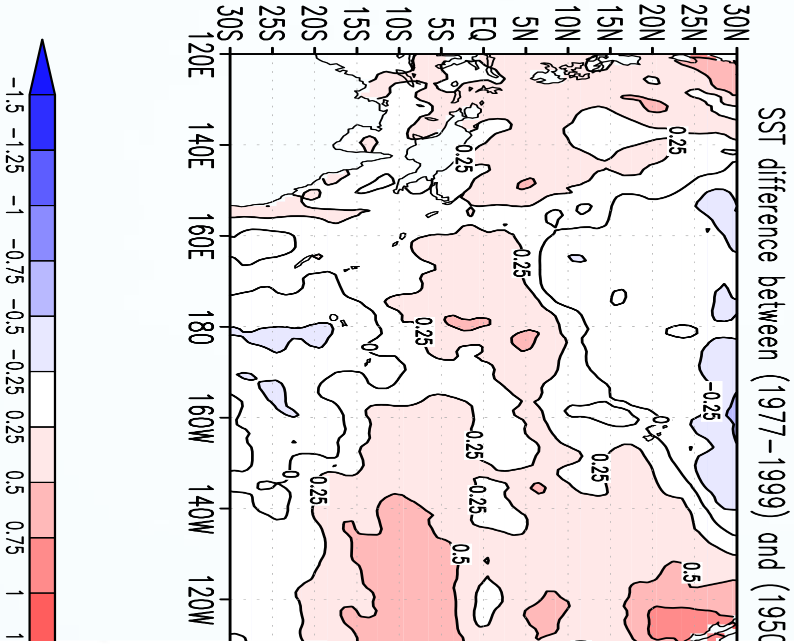
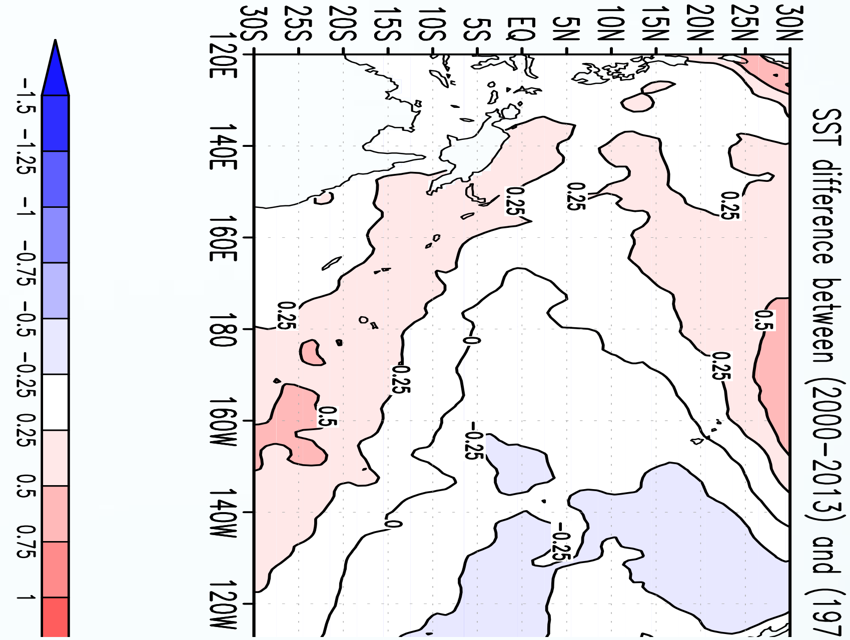
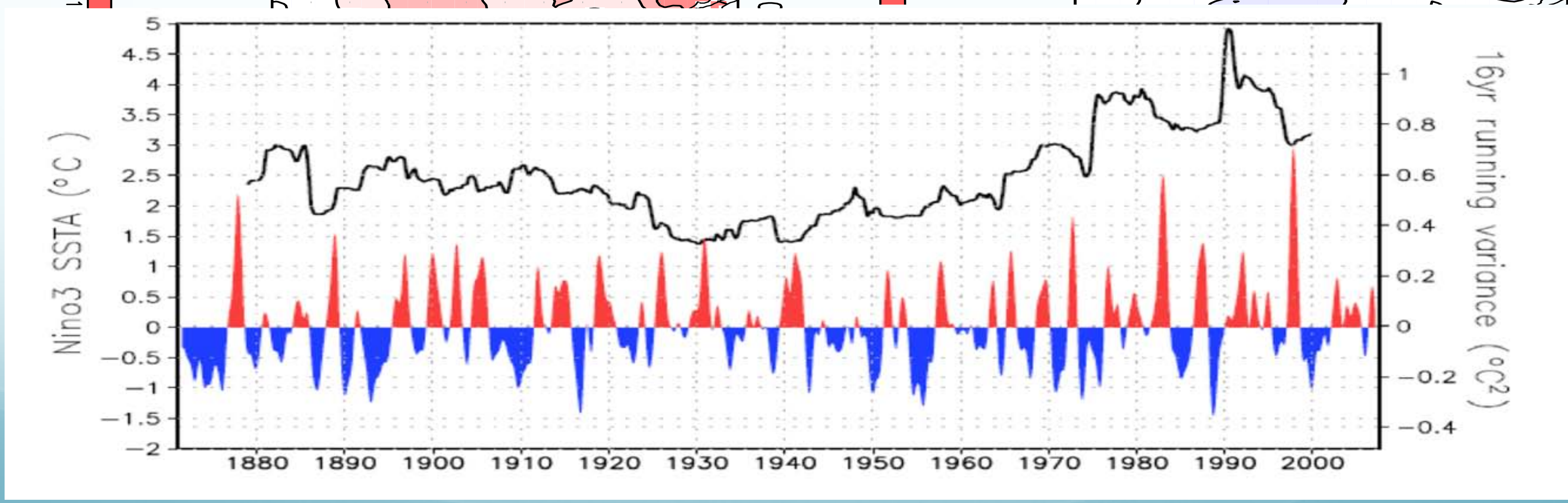
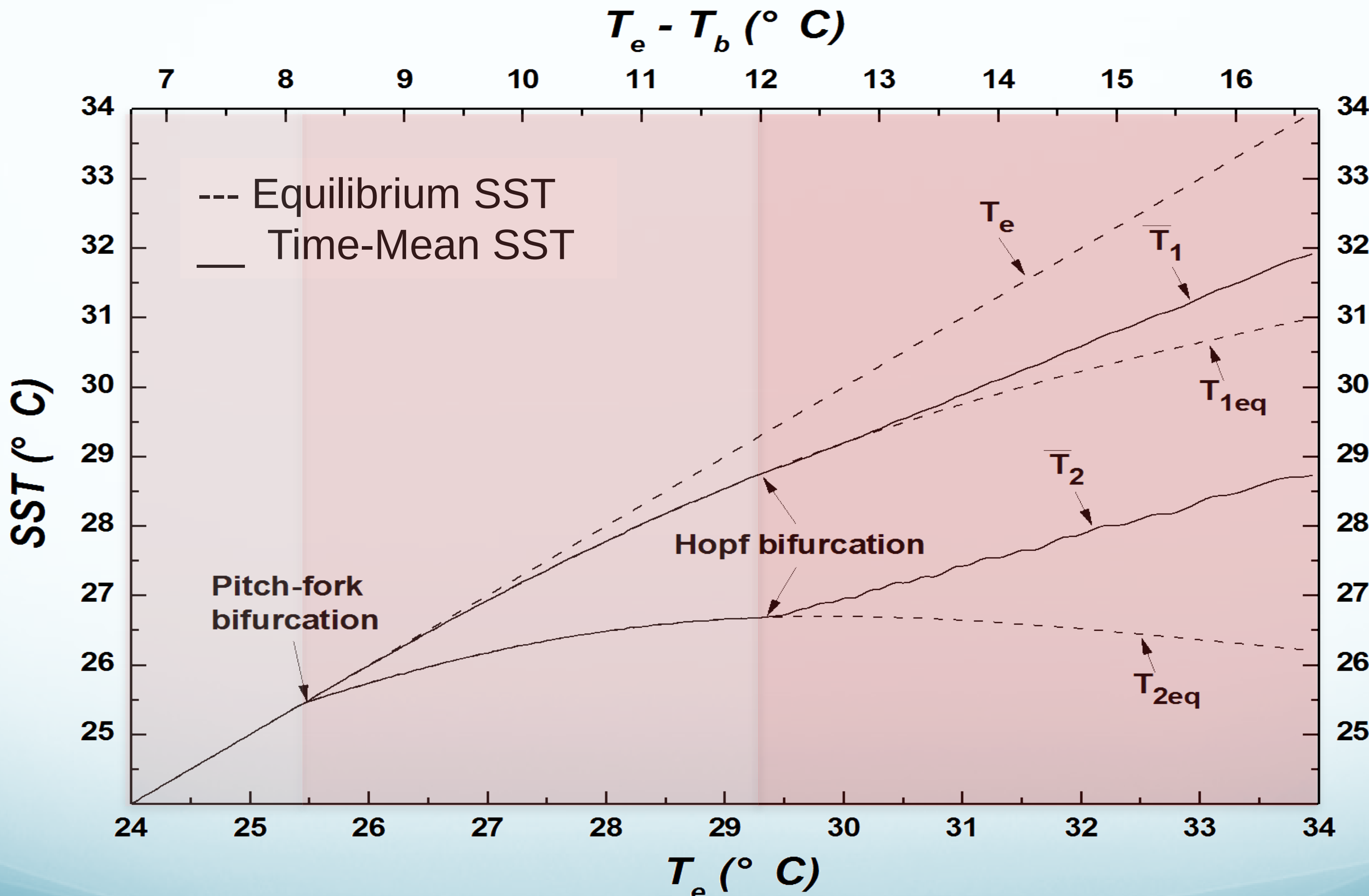


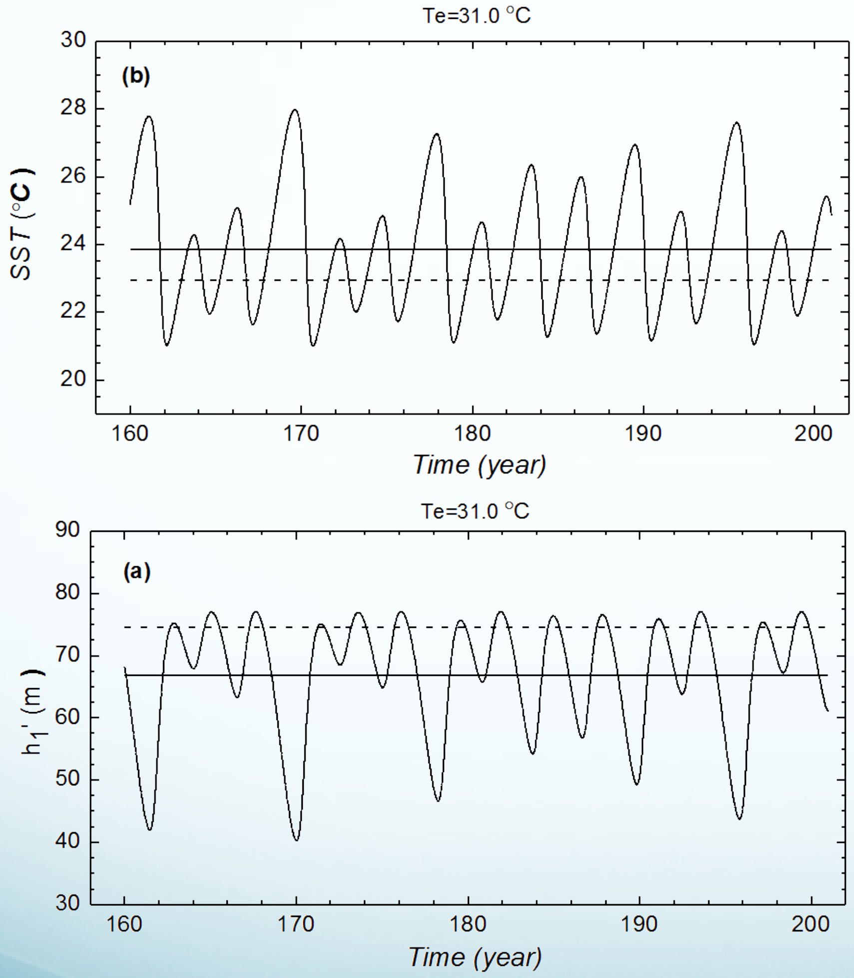


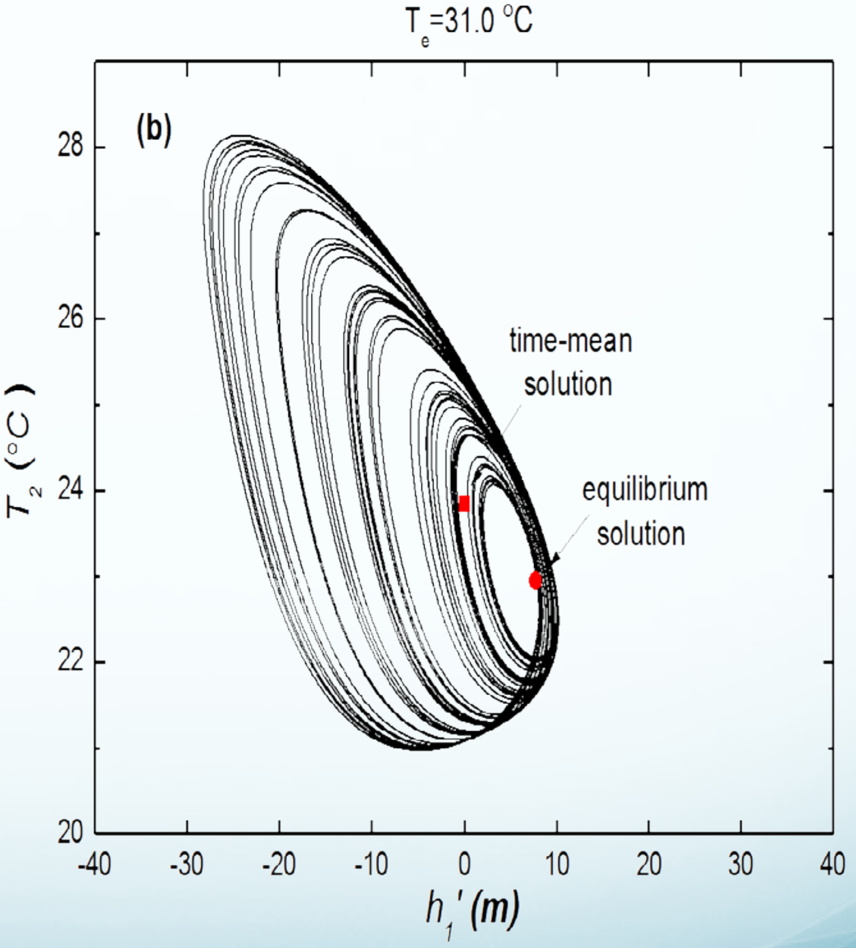


Tropical Pacific SST as a Function of Radiative *Heating*



Asymmetry in the Oscillation

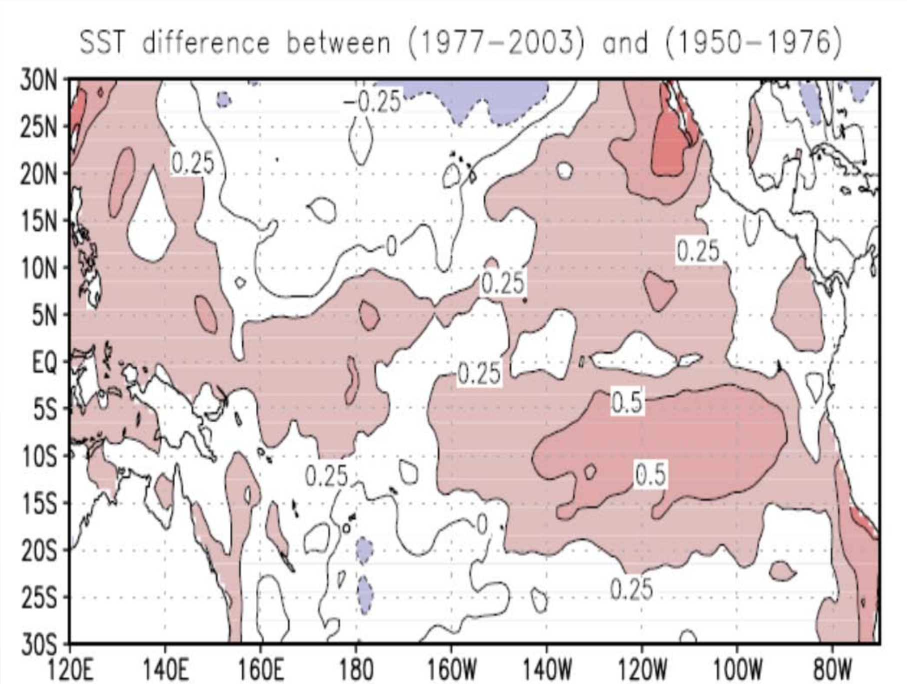


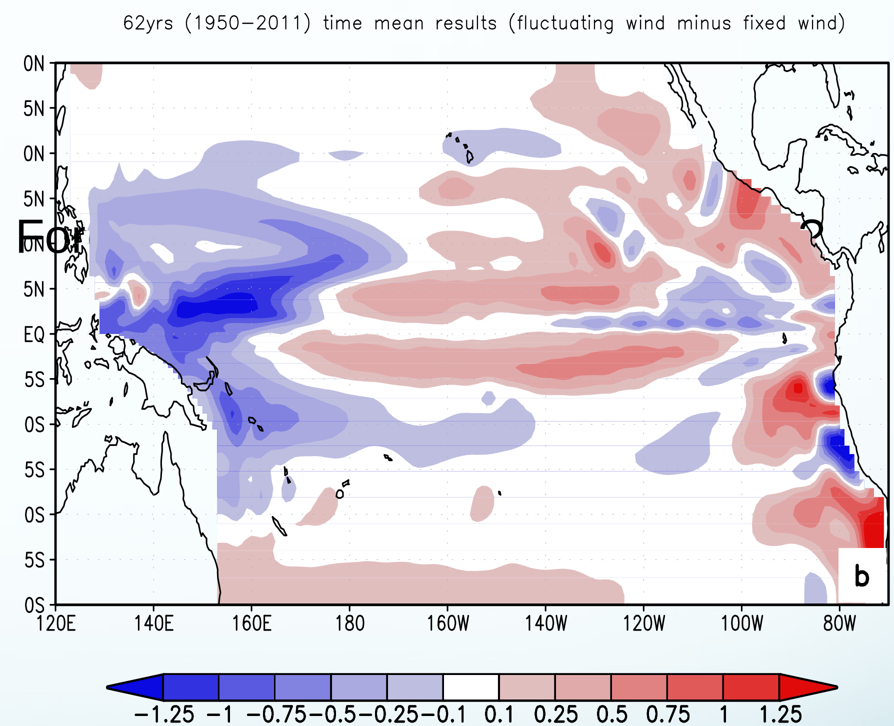


A “Convective” Model for the ENSO System

In the strongly forced regime, El Nino event may be viewed as an episodic “flooding” event of the eastern Pacific region—a region that is otherwise cold (when instability does not take place)—by warm water in the western Pacific. In this conceptual picture of ENSO, La Nina is more an artifact from the way we define what is normal than a real physical phenomenon.

Implication for the causes of the tropical Pacific decadal variability

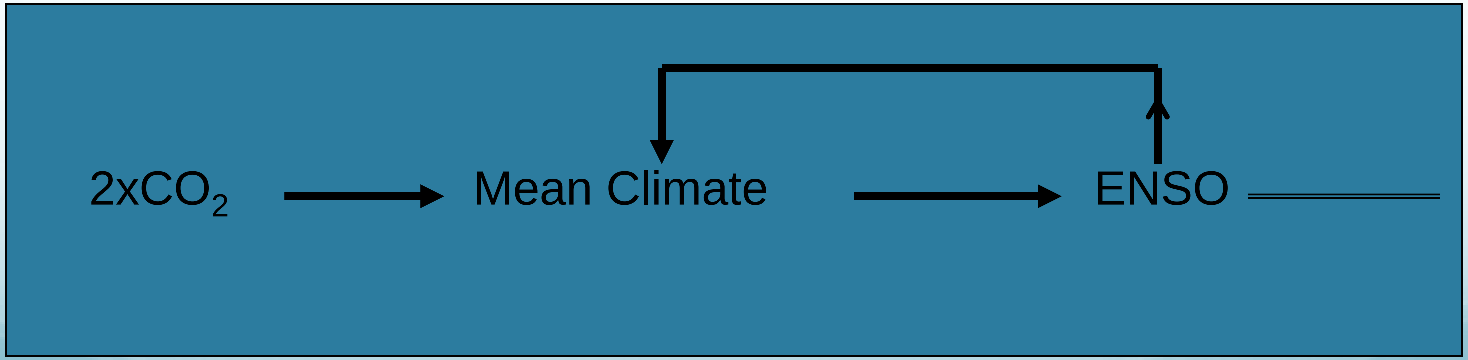




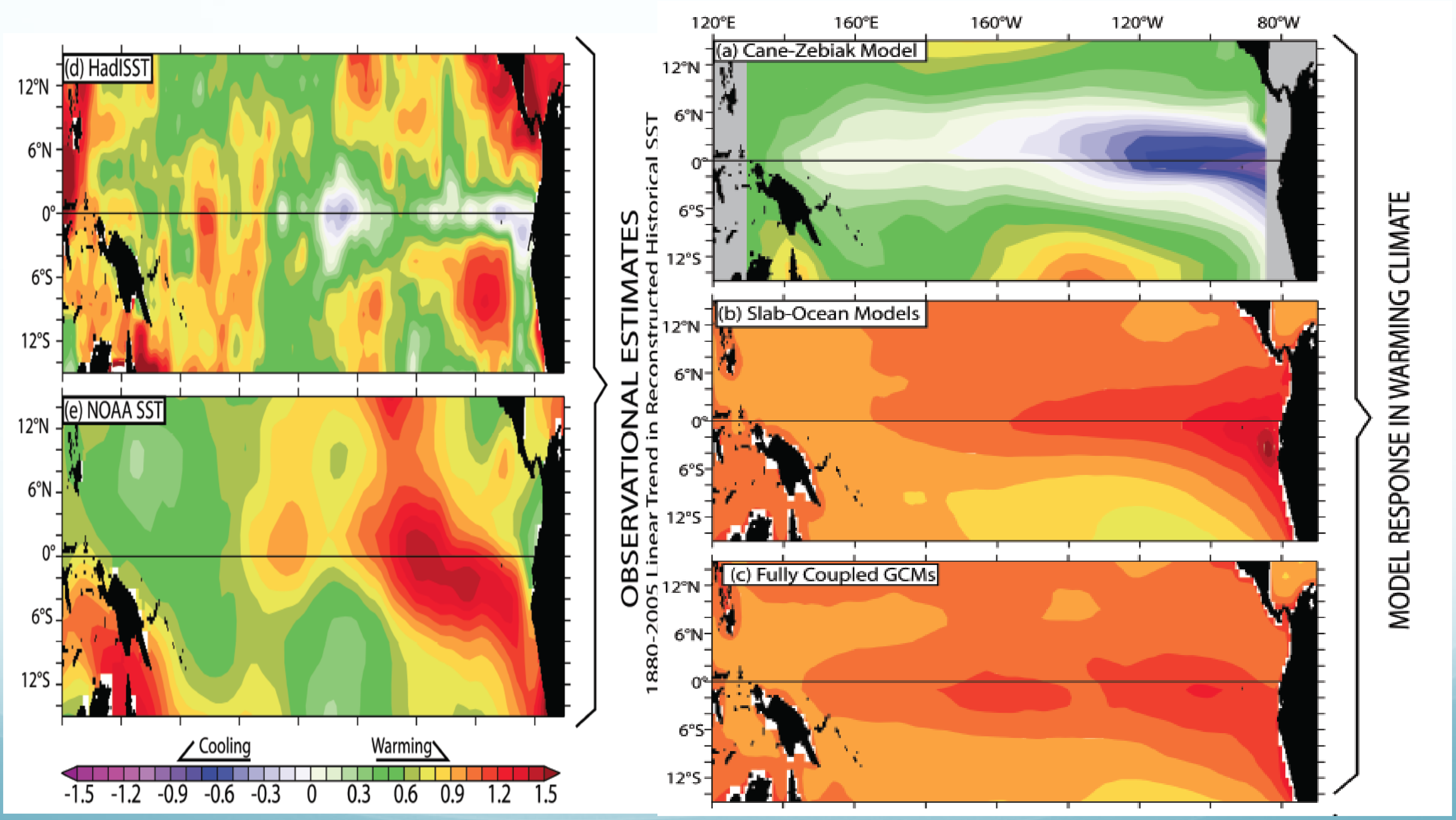
Implication for Understanding Climate Response to The Rise of CO2 Concentration

Existing Paradigm:

A Revised Paradigm:

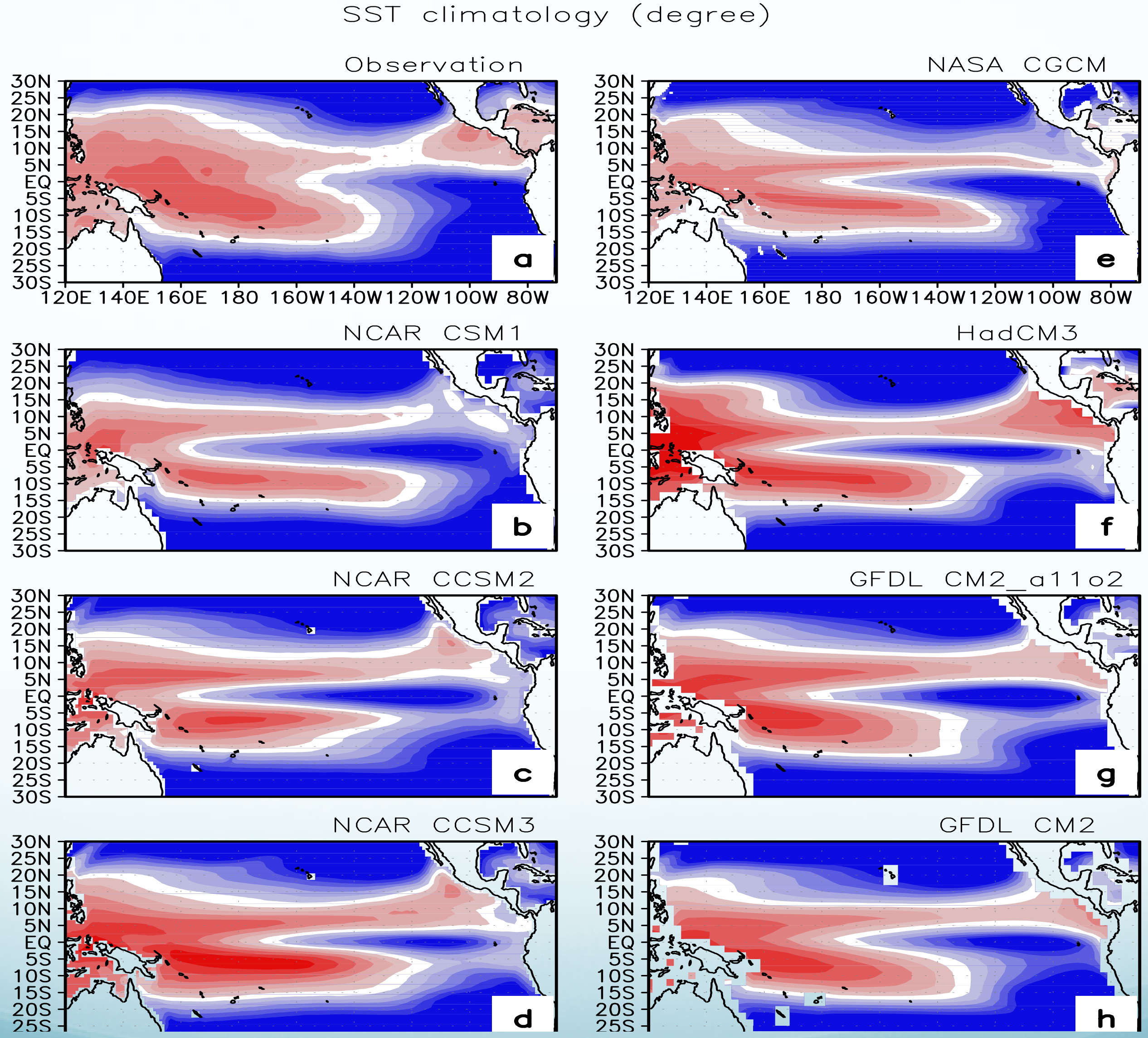


Why no trend has shown up in the zonal SST contrast in the observations?

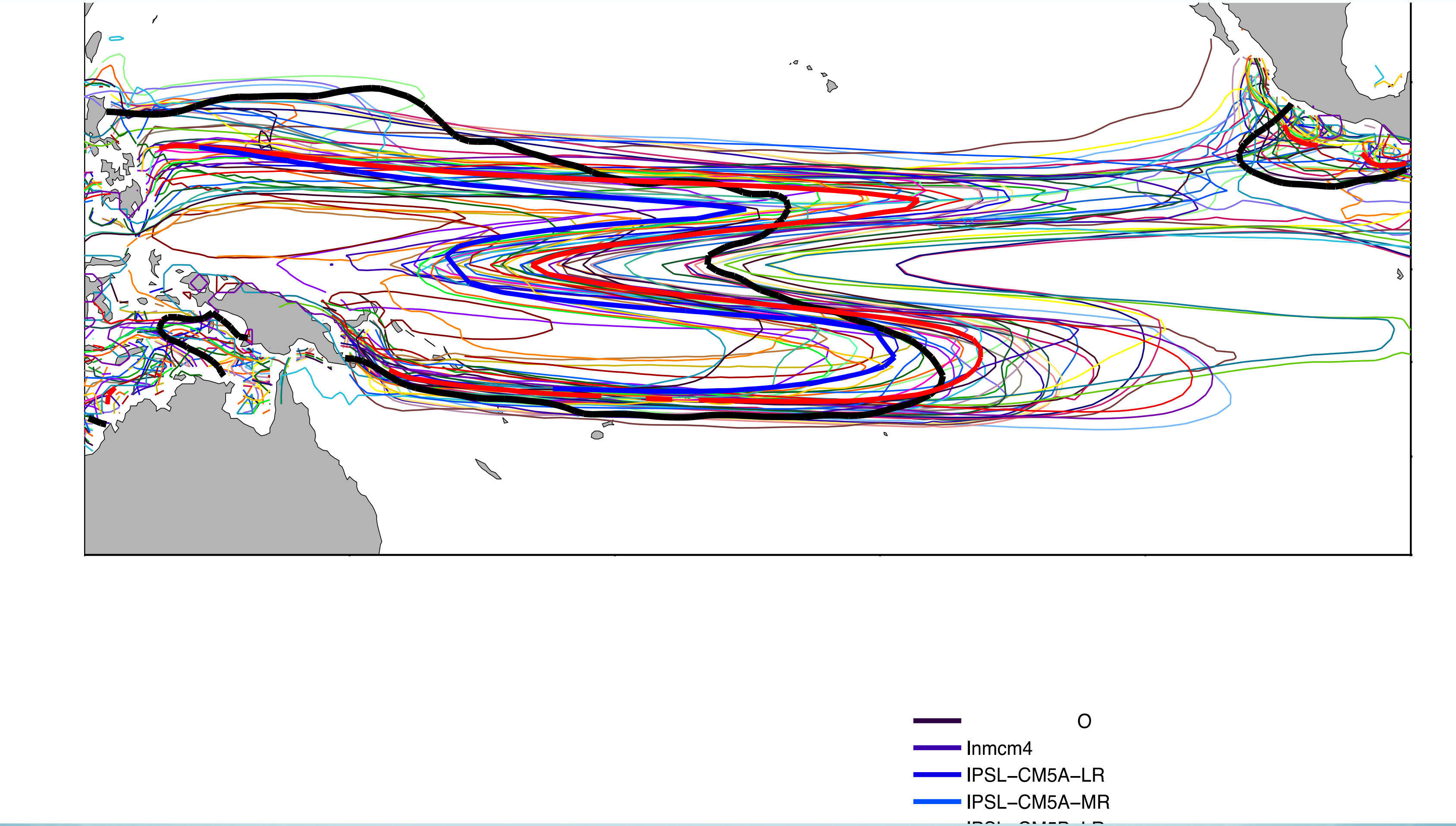


Vecchi et al. 2008

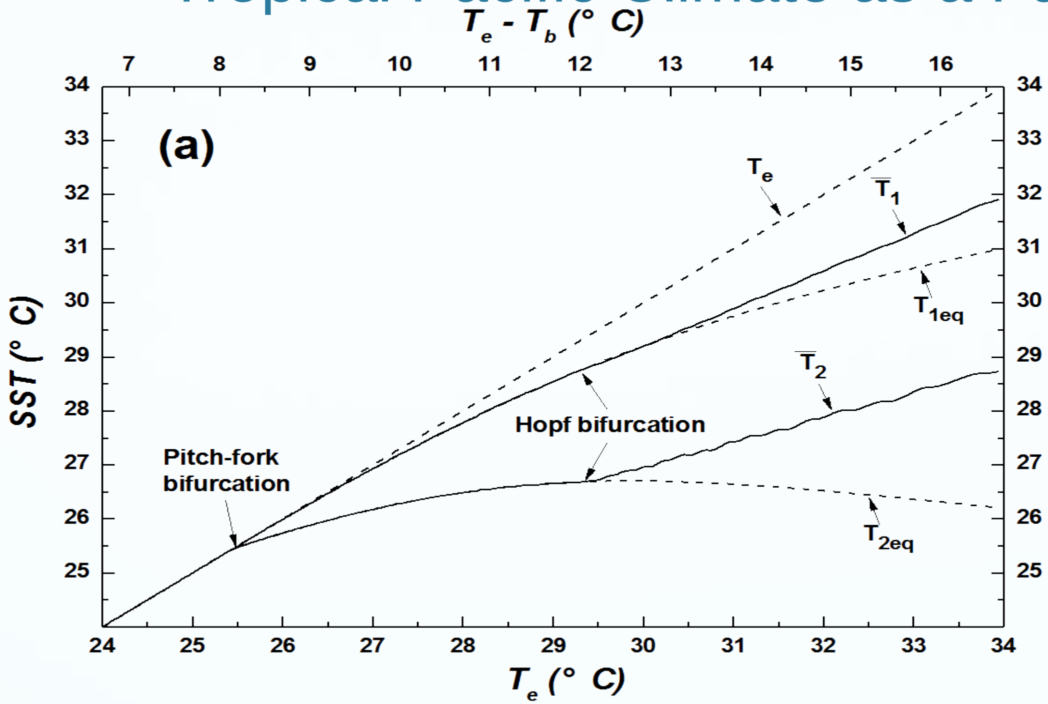
The Excessive Cold-tongue



The Excessive Cold-tongue

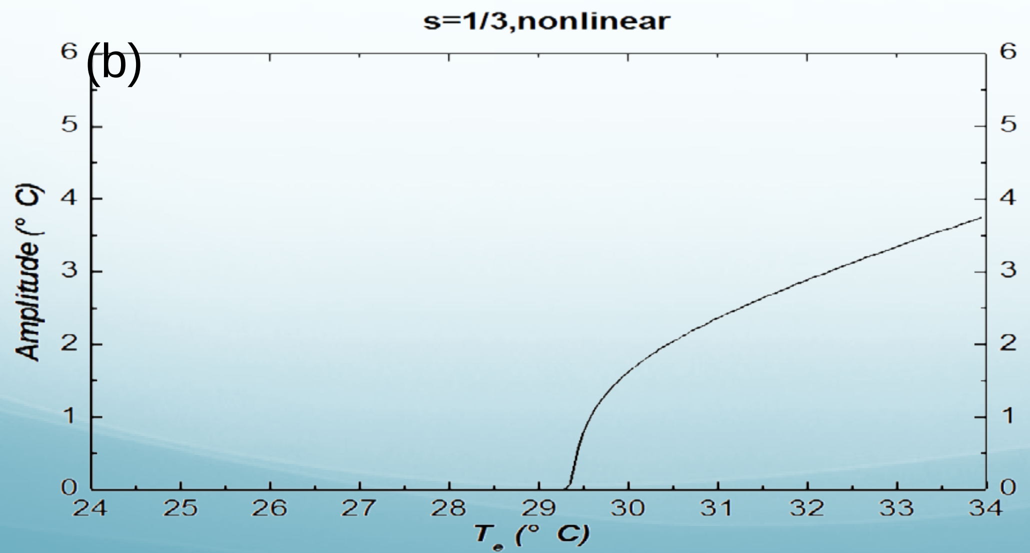


Tropical Pacific Climate as a Function of T_e.



--- Equilibrium SST

__ Time-Mean SST



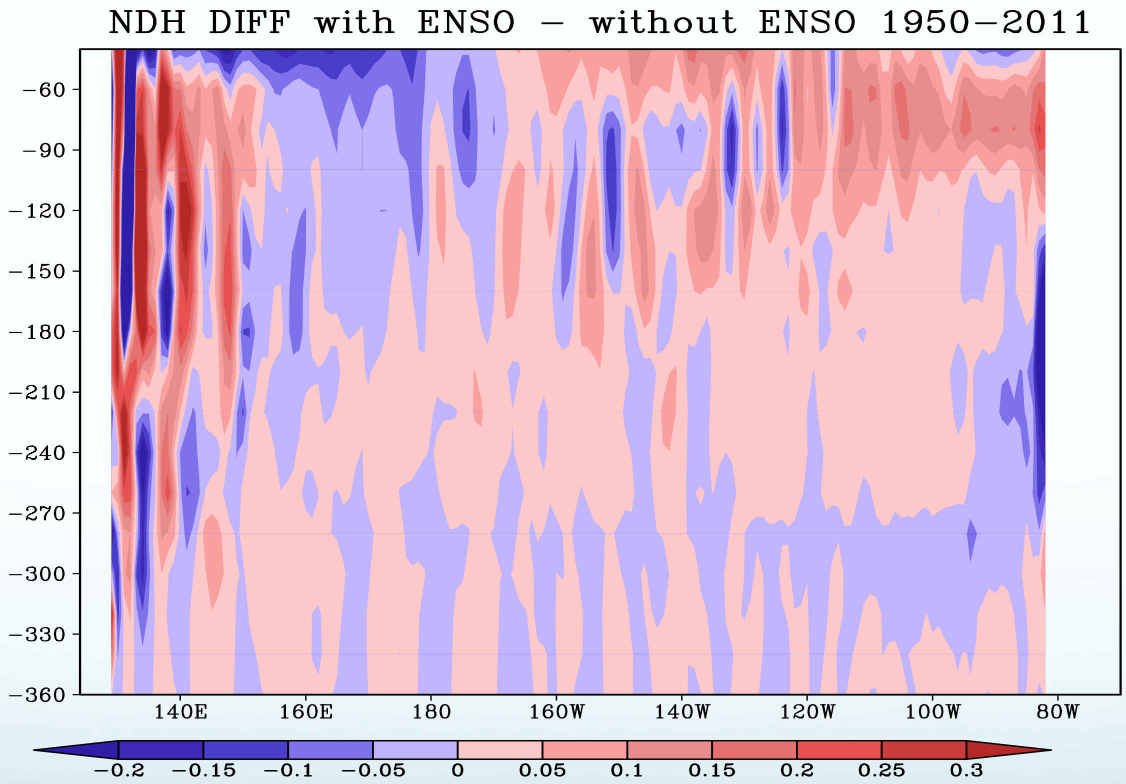
Amplitude of ENSO

Key Results from the Box Model

- The time-mean SST in the eastern equatorial Pacific is found to be significantly different from the corresponding equilibrium SST, with the former being warmer than the latter. The difference is found to be proportional to the amplitude of ENSO.
- The zonal SST contrast of the time-mean state is found to be less sensitive to increases in external forcing than that of the equilibrium state, due to warming effect of ENSO events on the eastern Pacific.
- This rectification effect of ENSO events owns to the nonlinear advection term in the heat budget equation.
- The asymmetry of the oscillation relative to the time-mean state stems fundamentally from the asymmetry of the dynamics relative to the equilibrium state of the system.
- In the strongly forced regime, El Nino event may be viewed as an episodic “flooding” event of the eastern Pacific region—a region that is otherwise cold (when instability does not take place)—by warm water in the western Pacific. In this conceptual picture of ENSO, La Nina is more an artifact than a real physical phenomenon.

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

(with ENSO minus without ENSO)



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

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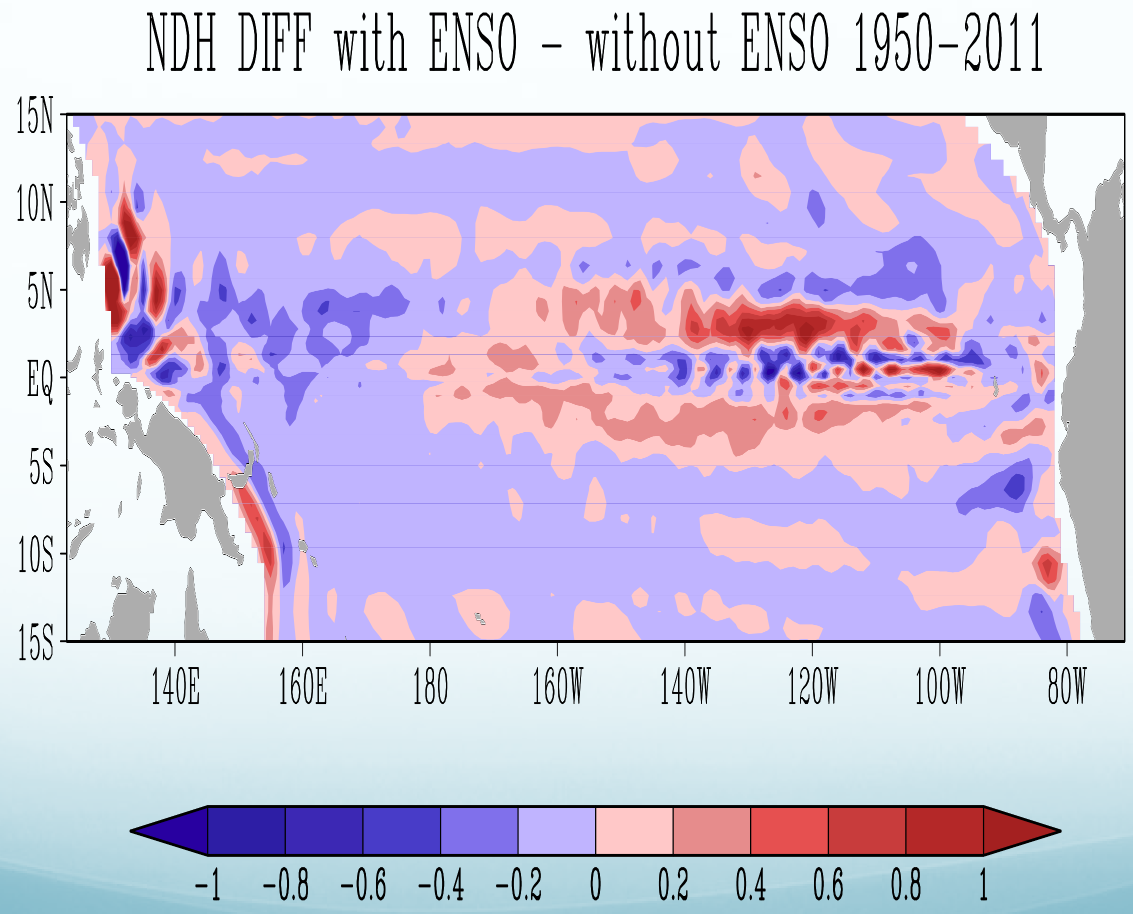
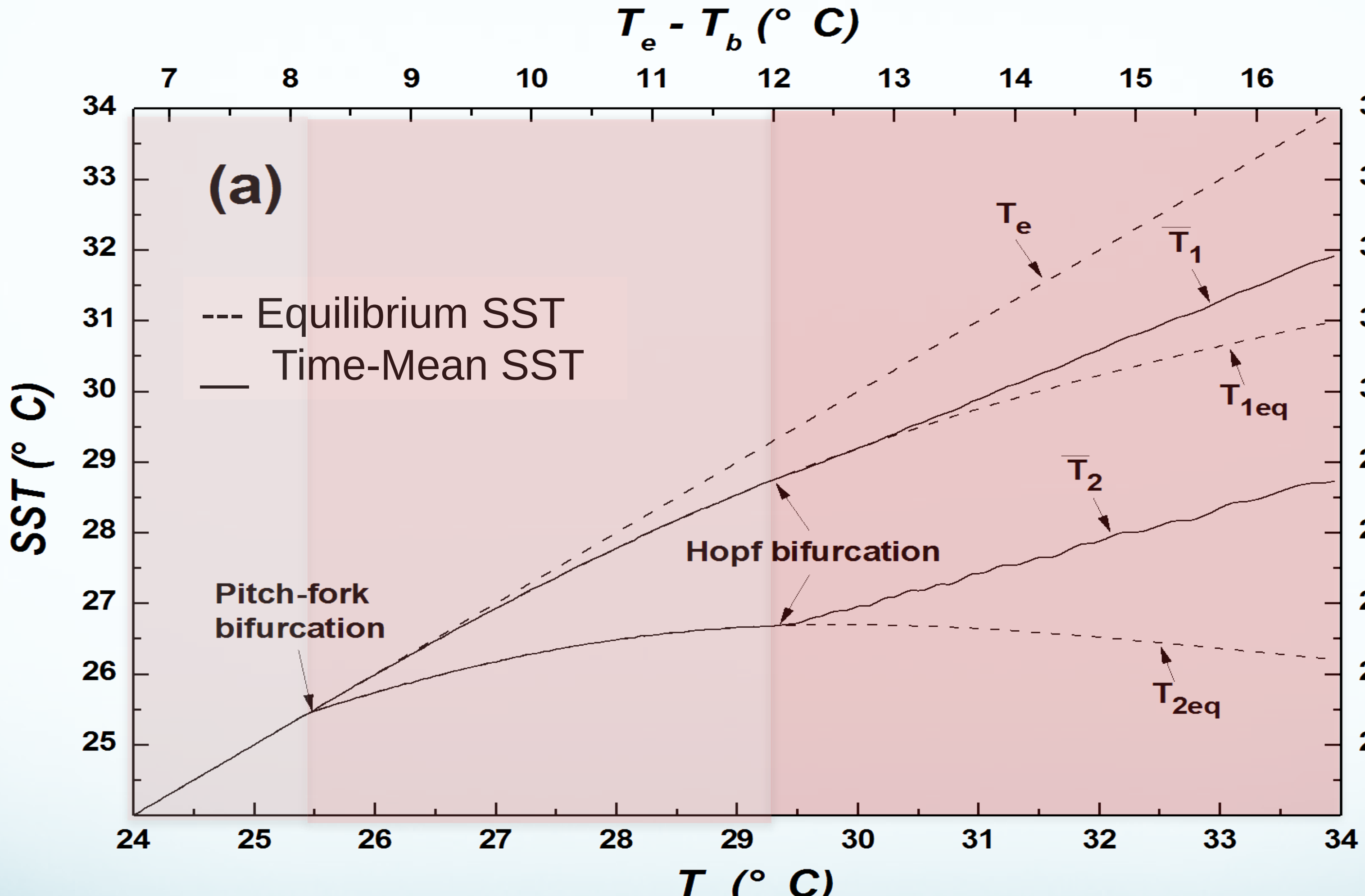
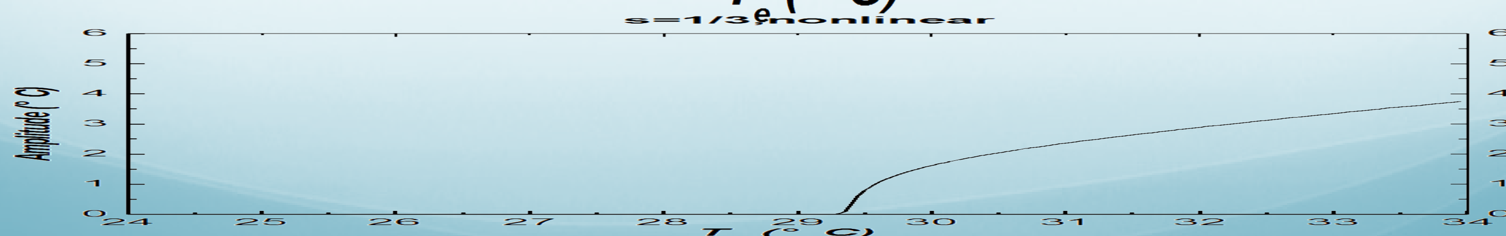


Implications

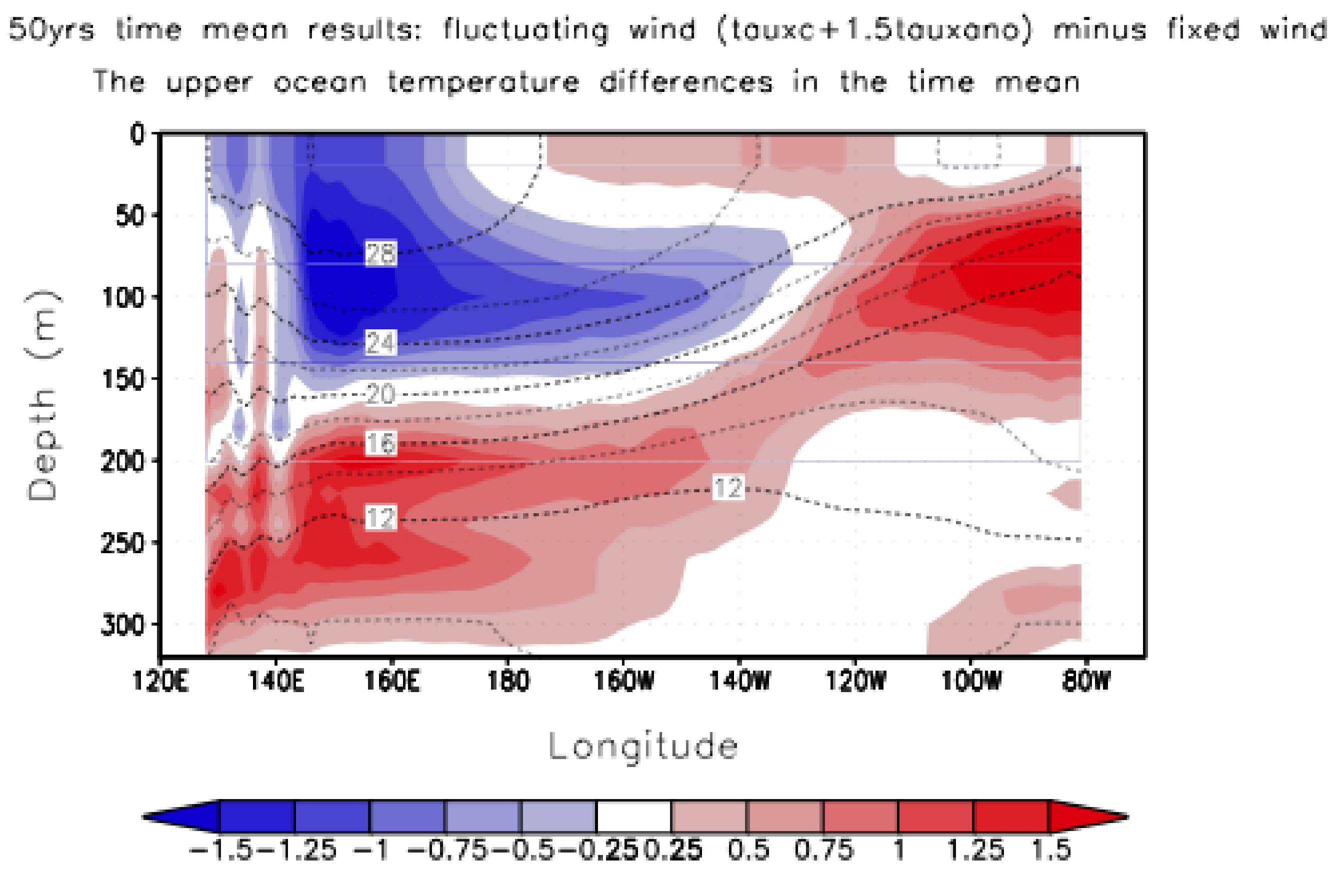
- The decadal warming in the recent decades in the eastern tropical Pacific may be more a consequence than a cause of the elevated ENSO activity during the same period.
- The lack of a significant long-term trend in the zonal SST contrast may be due to the feedback from ENSO events due to the time-mean effect.

Tropical Pacific SST as a Function of Radiative *Heating*

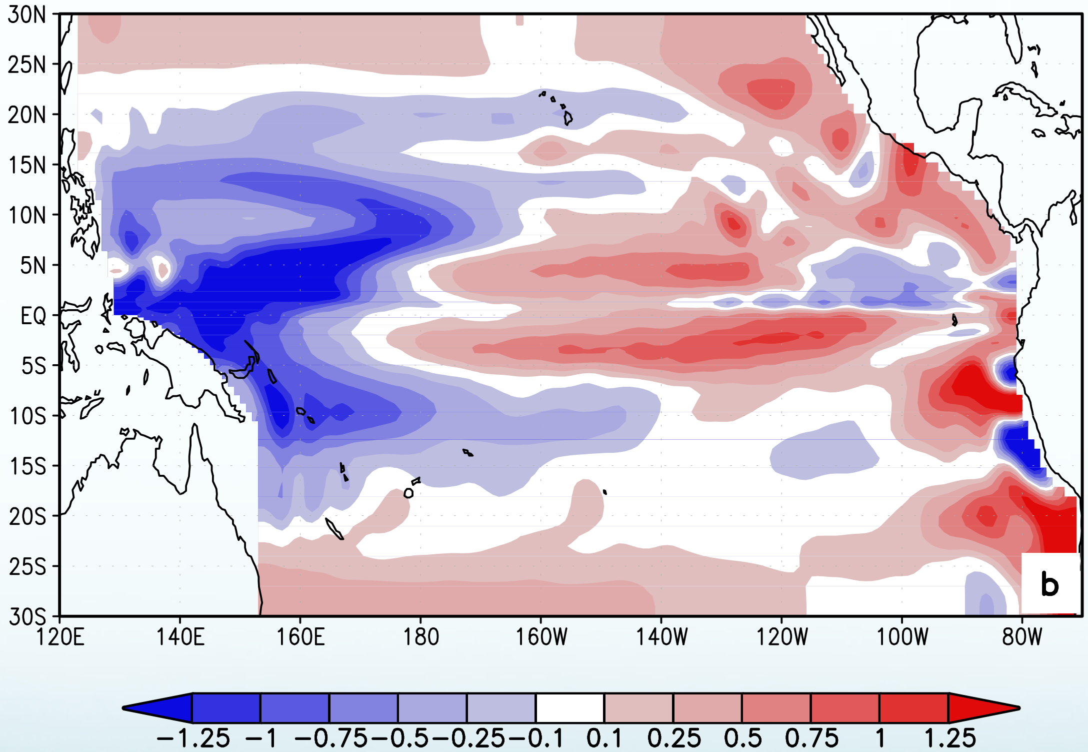




Upper T Difference Between Experiments with/without ENSO



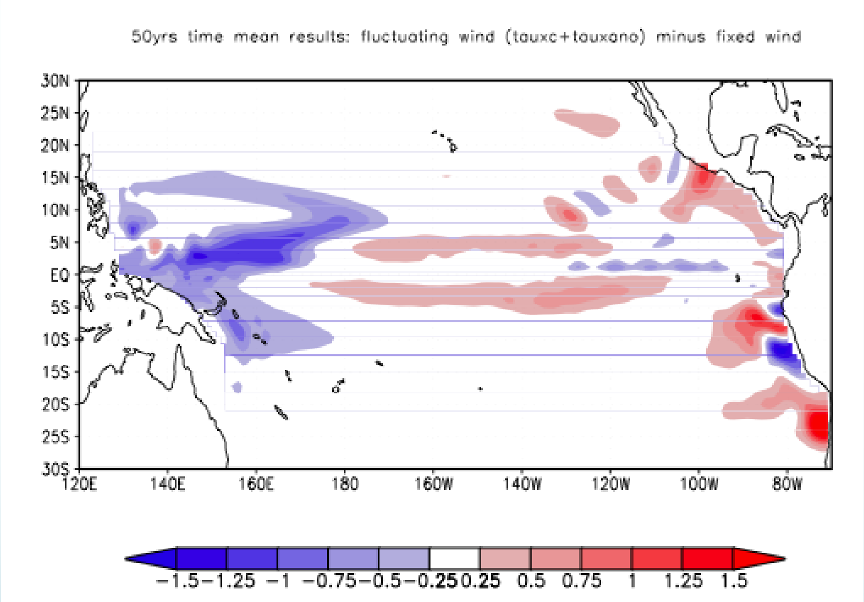
SST Difference Between Experiments with/without ENSO

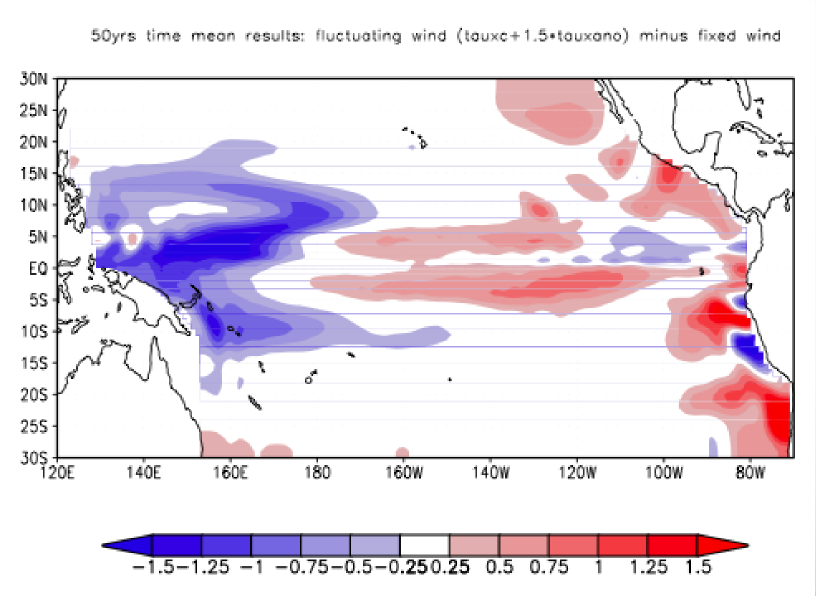


The Effects of ENSO on the SST: Sensitivity to the amplitude of ENSO

τ'

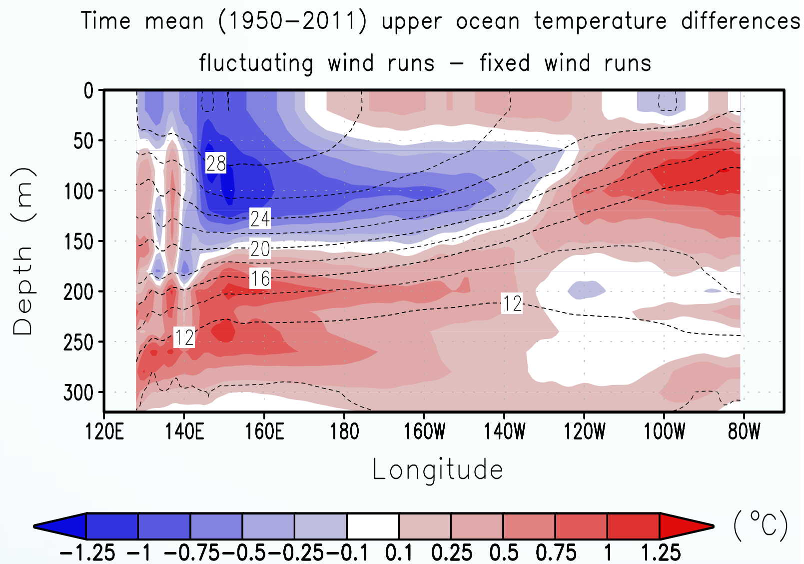
$1.5\,\tau'$



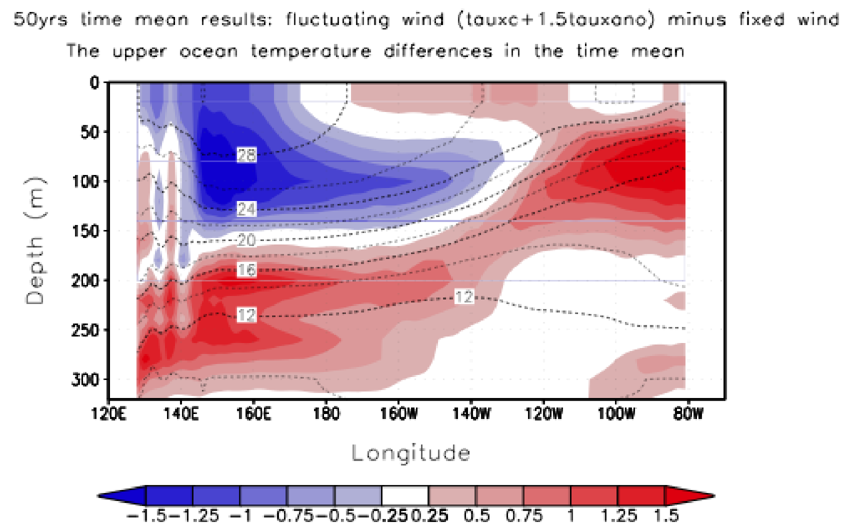


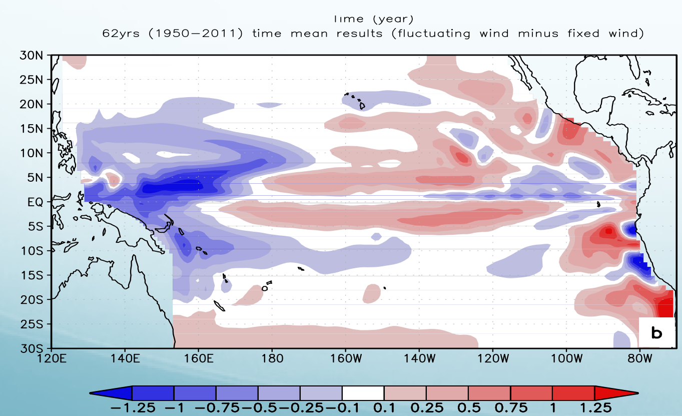
Upper T Difference Between Experiments with/without ENSO

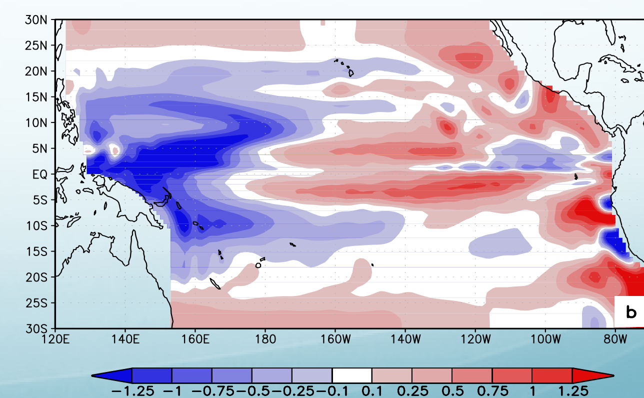
τ'



$1.5\tau'$







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- Liang, J., X.-Q. Yang, and D.-Z. Sun, 2012: The effect of ENSO events on the Tropical Pacific Mean Climate: Insights from an Analytical Model. *J. Climate*, **25**, 7590–7606.

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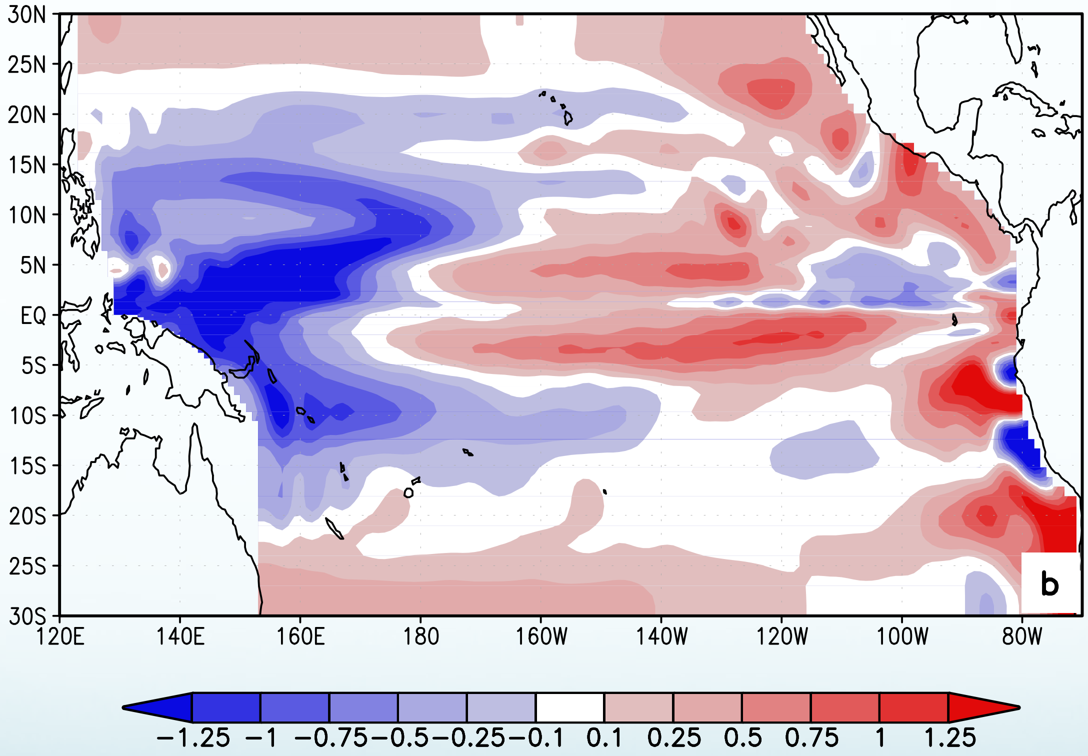
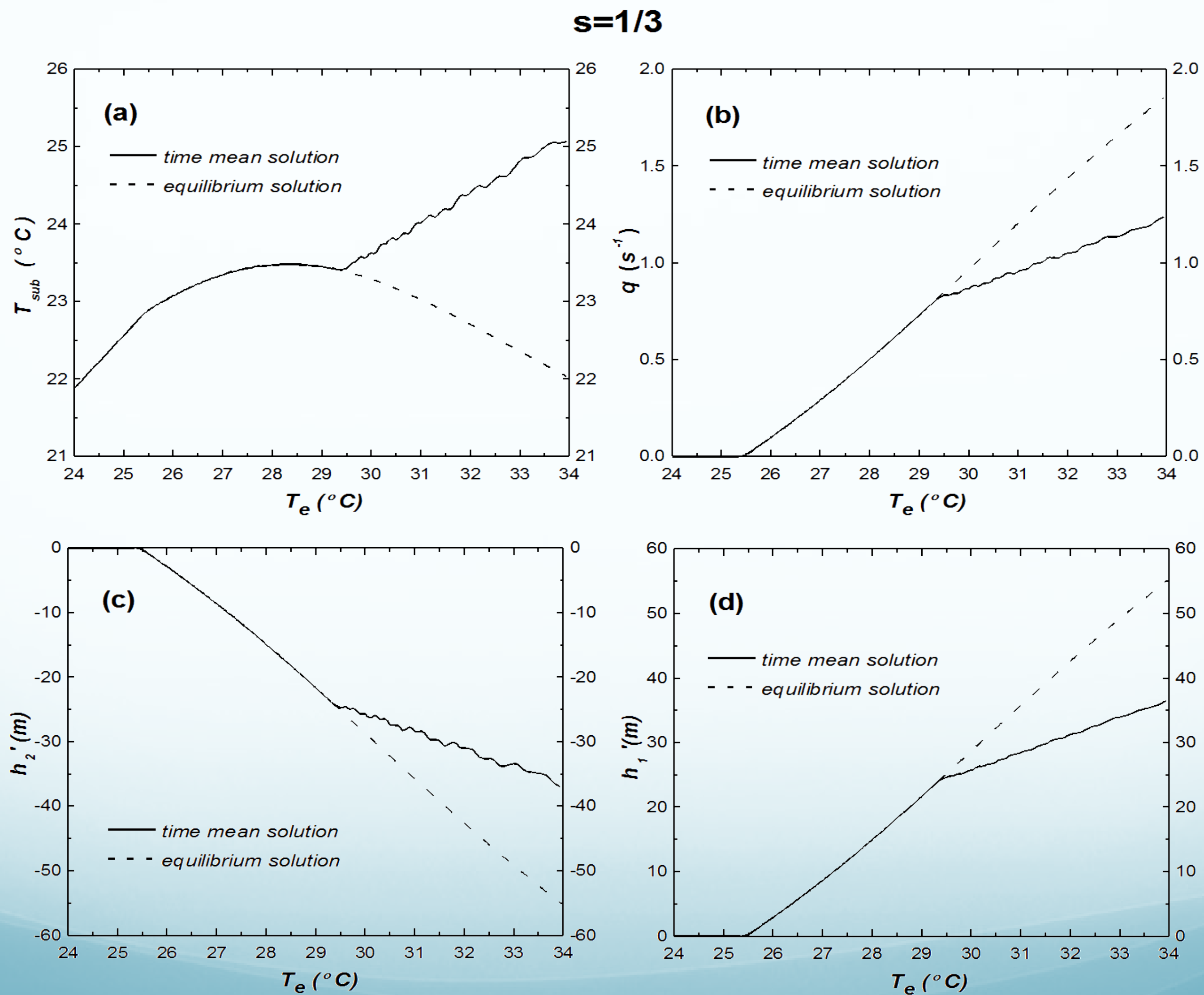
www.esrl.noaa.gov/psd/people/dezheng.sun/

SST Difference Between Experiments with/without ENSO



Tsub, q, h1, and h2 as a function of T_e.



An Increase in Te Leads to Greater Asymmetry in the Oscillation

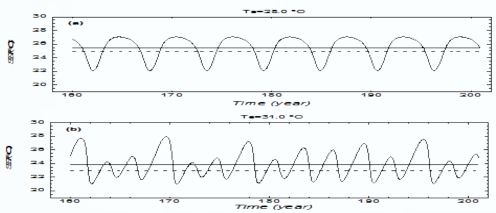
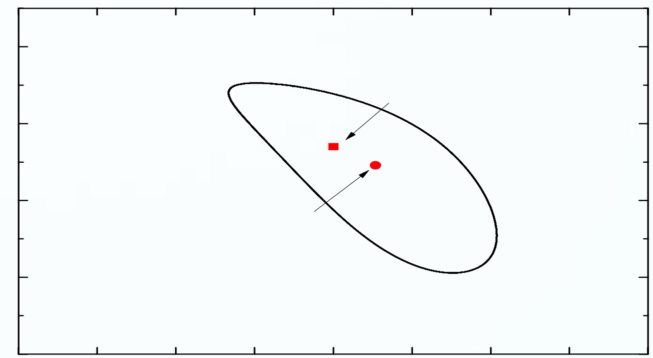
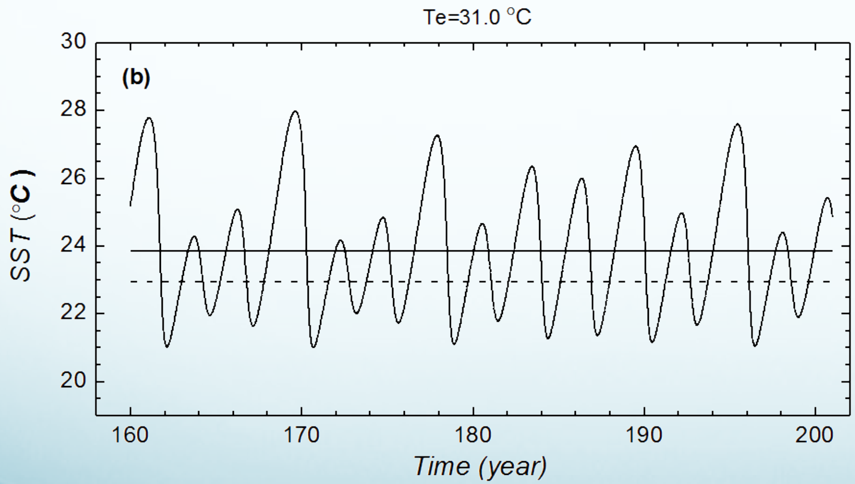
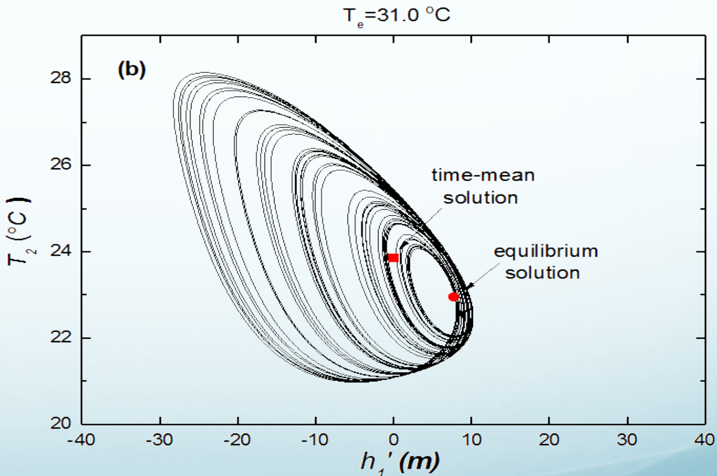


FIG. 5. Time series of T_2 when T_e=28.5°C and T_e=31°C. The time series are taken from the case with s=0.096 (Fig. 4cd). The two horizontal lines in the figure indicate respectively the time-mean value of T_2 (solid line) and its equilibrium value (dashed line).

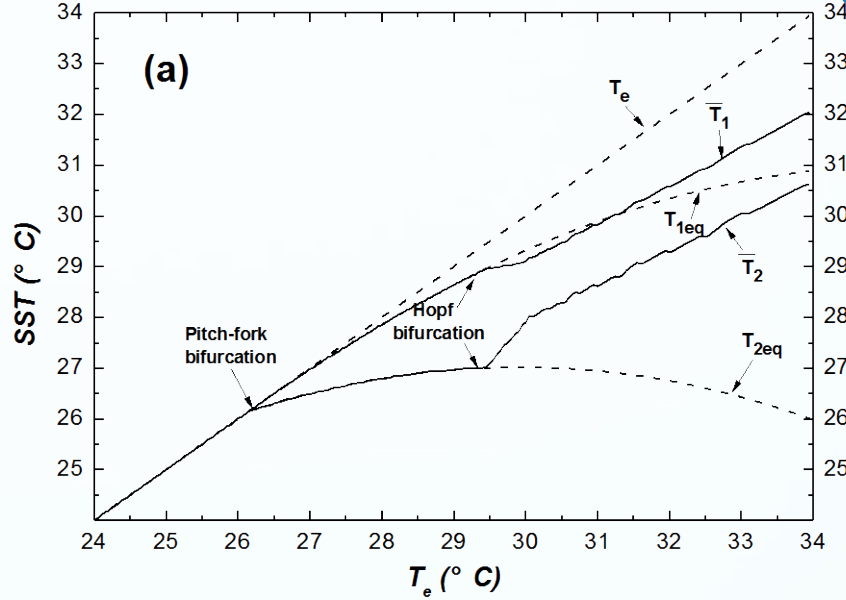






Tropical Pacific Climate as a function of T_e

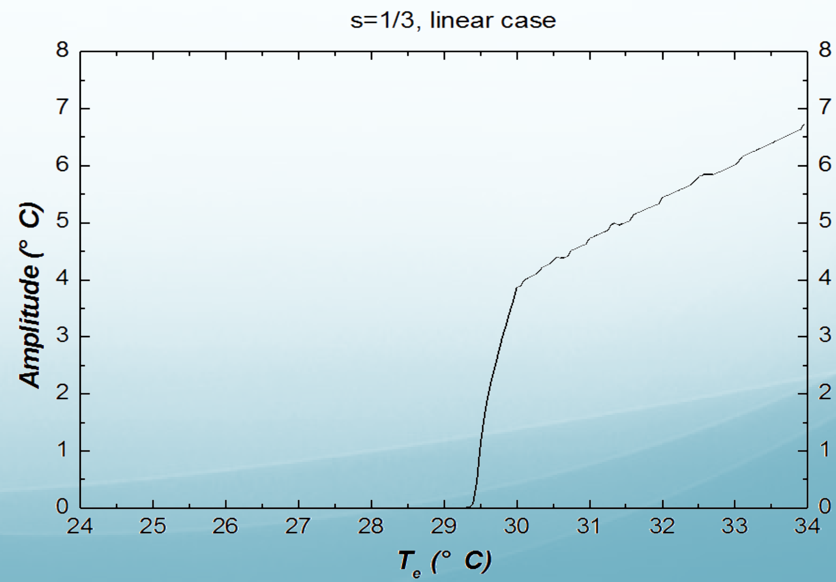
Equilibrium and Time-Mean SST



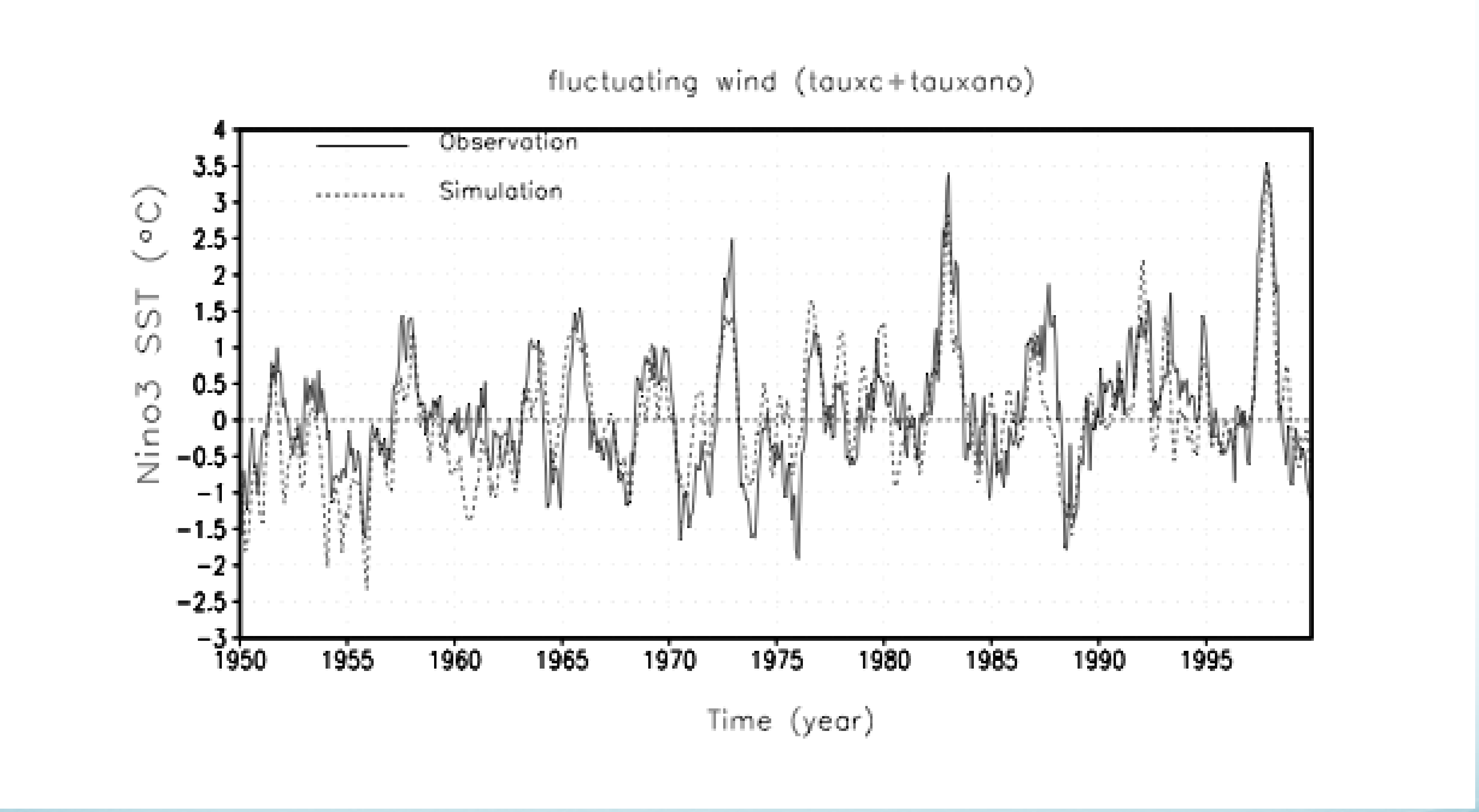
$$\Phi(z) = T_{s0} + \gamma(z + H_1)$$

$$T_{sub} = T_{s0} + \gamma h_2'$$

Amplitude of ENSO



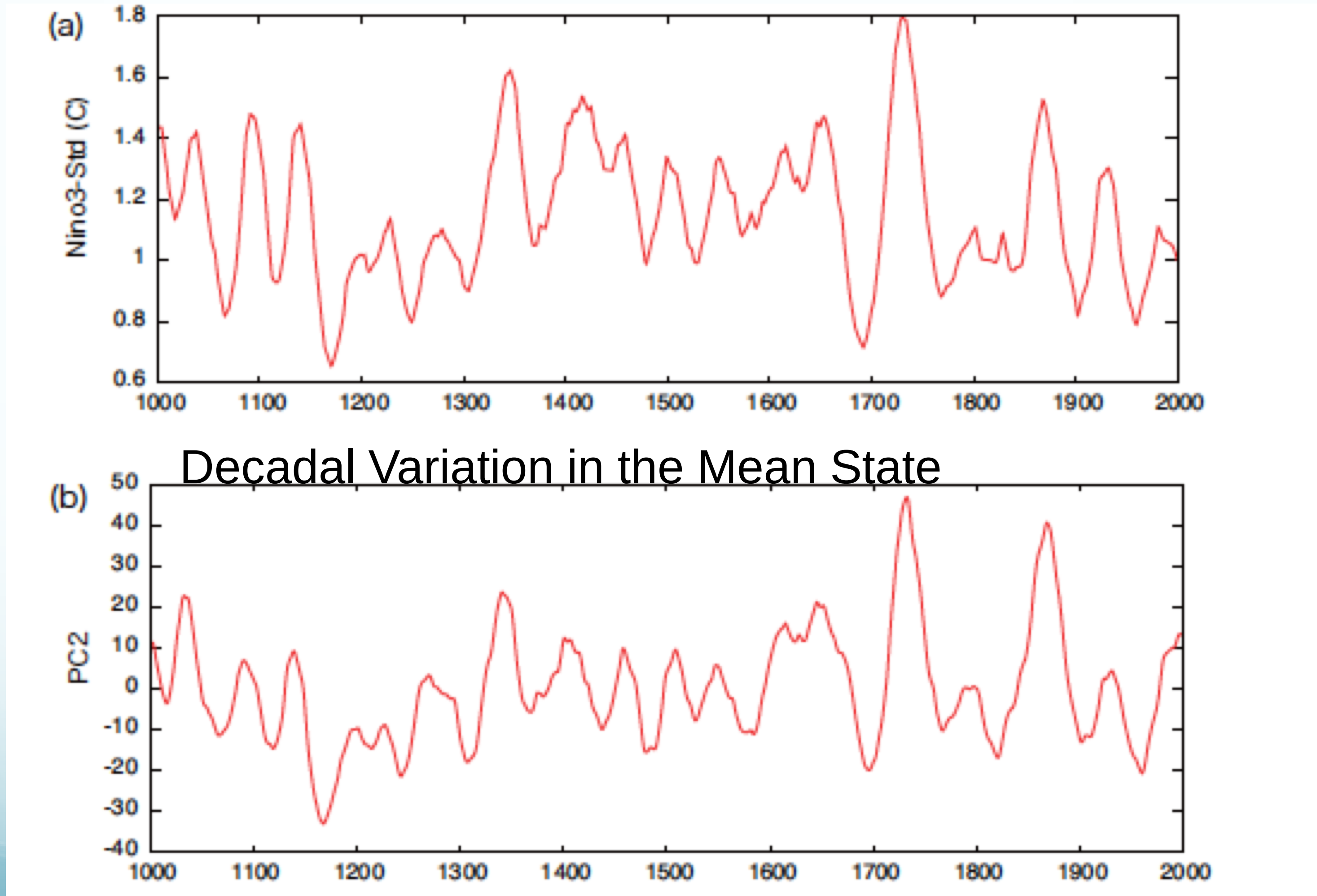
ENSO In the Forced Experiment



Who Drives Who in Decadal Changes in Tropical Pacific in GCMs?

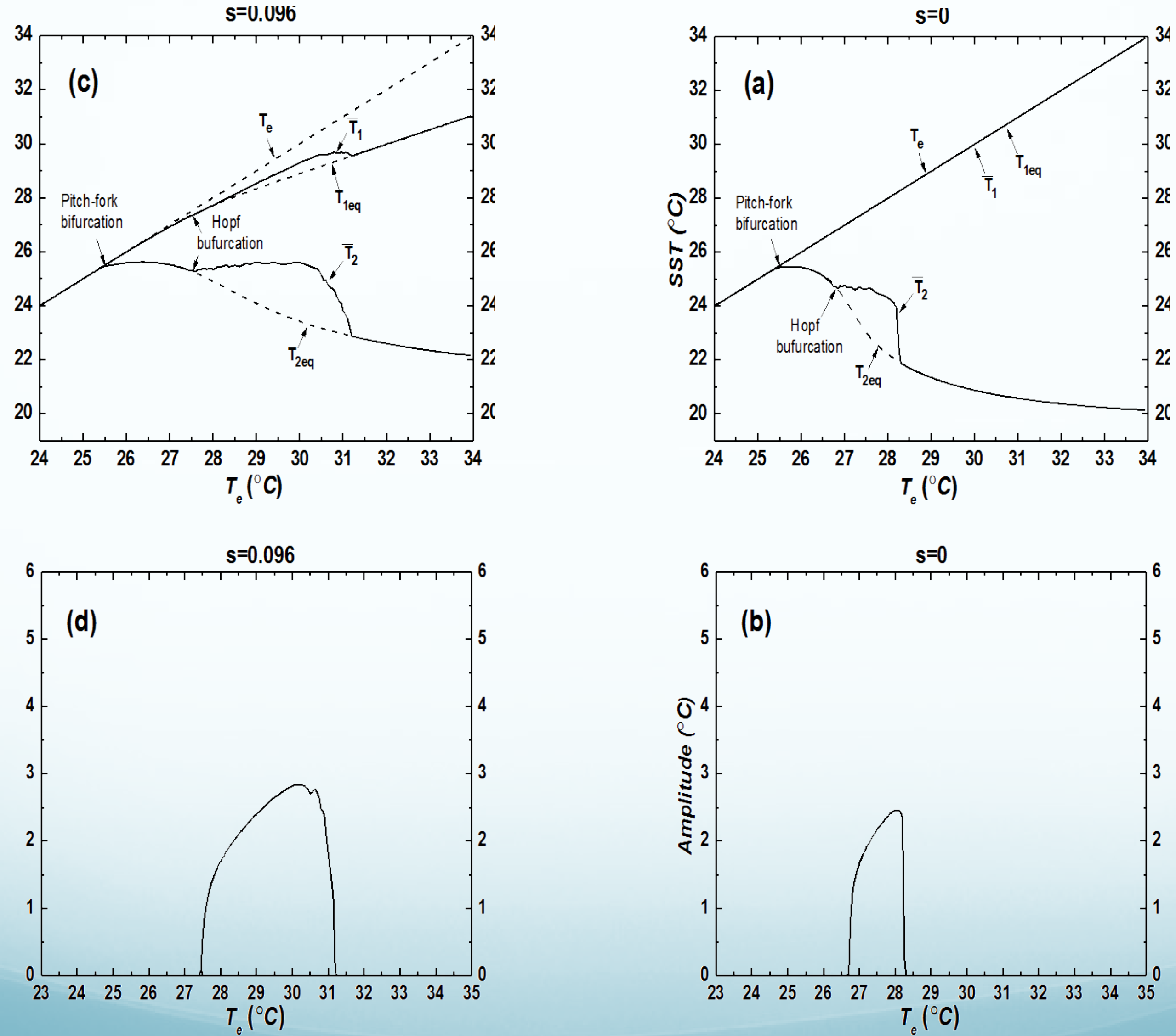
Decadal Variation in the STD of Nino3 SST

Decadal Variation in the Mean State

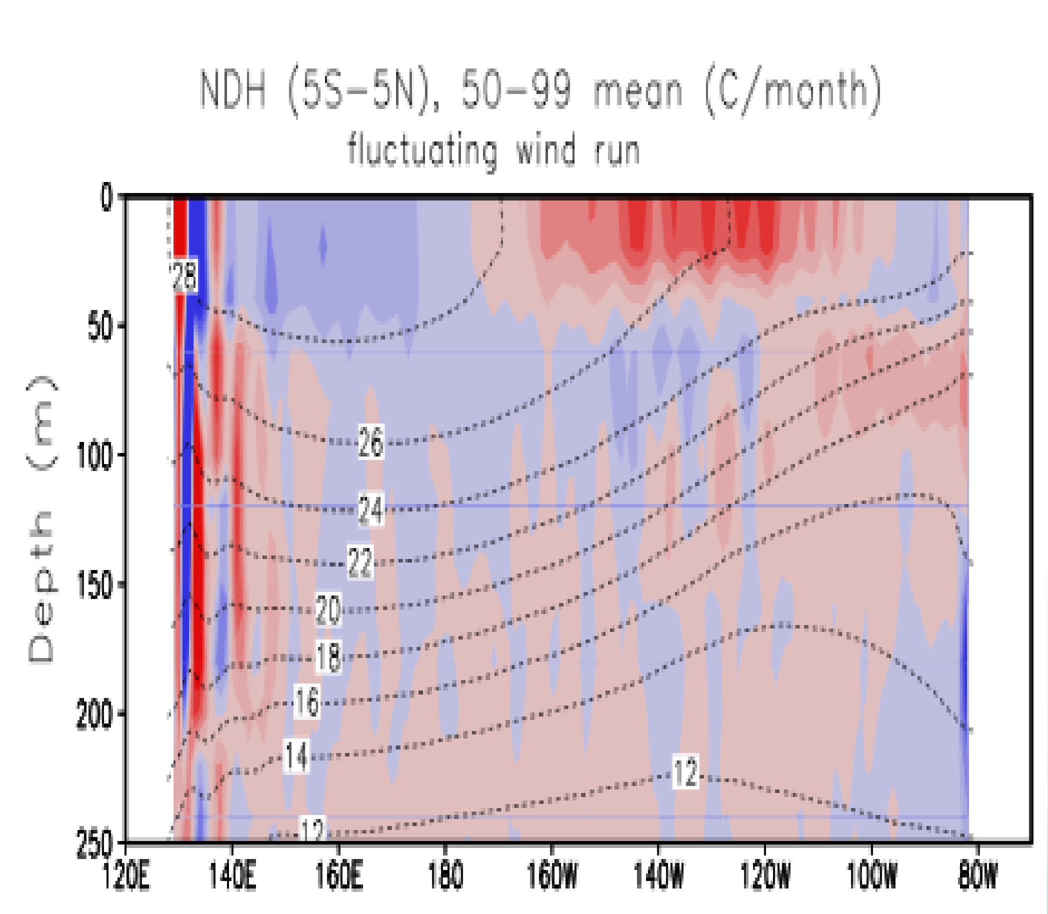


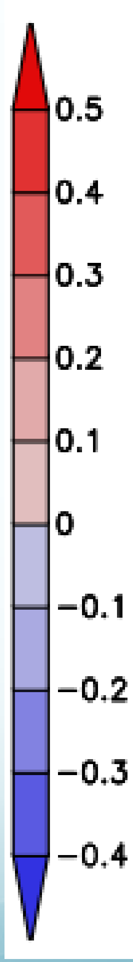
Tropical Pacific Climate as a Function of T_e

Sensitivity to Parameter S

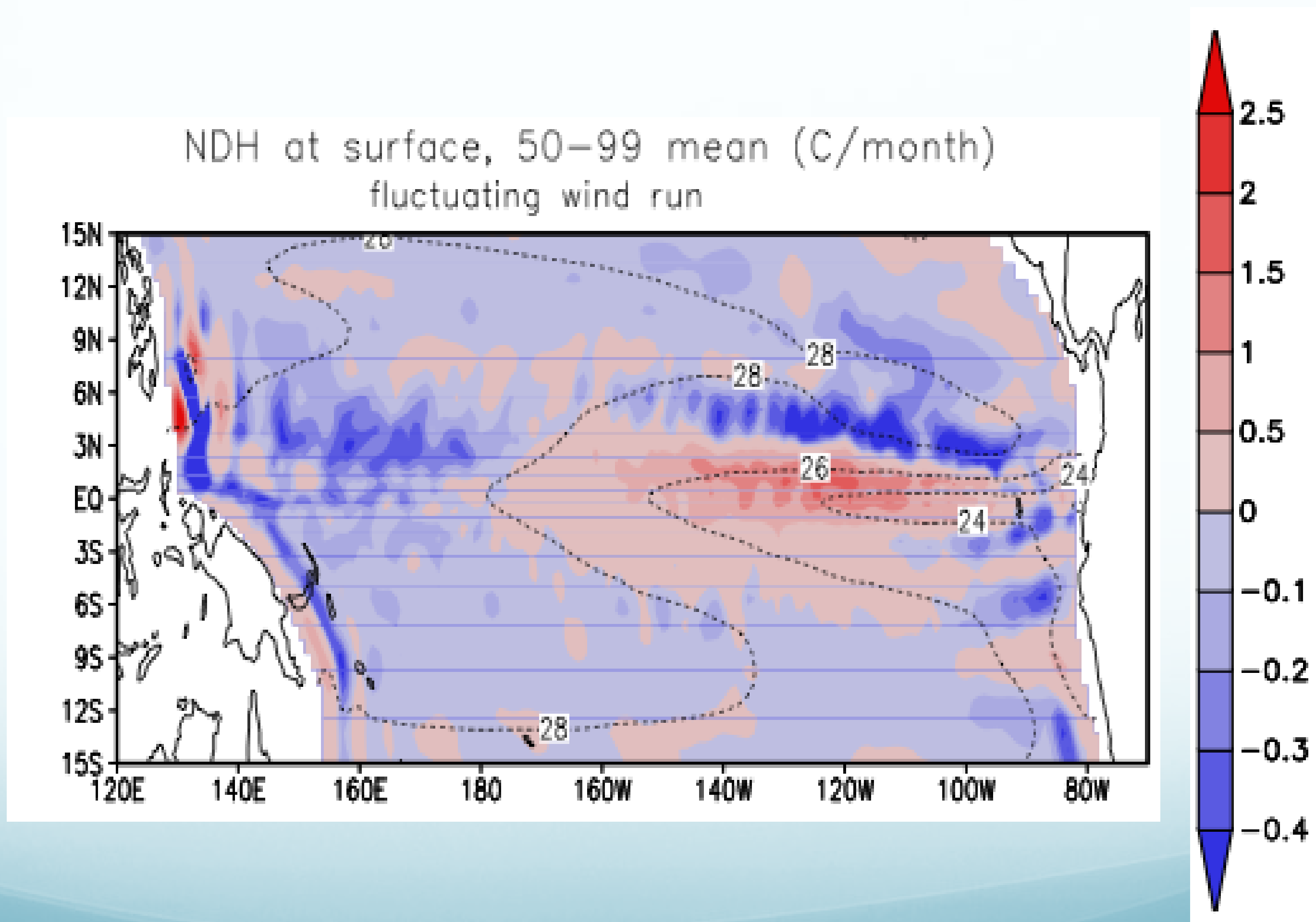


The Heating From ENSO Events (convergence of $\overline{V'T'}$)



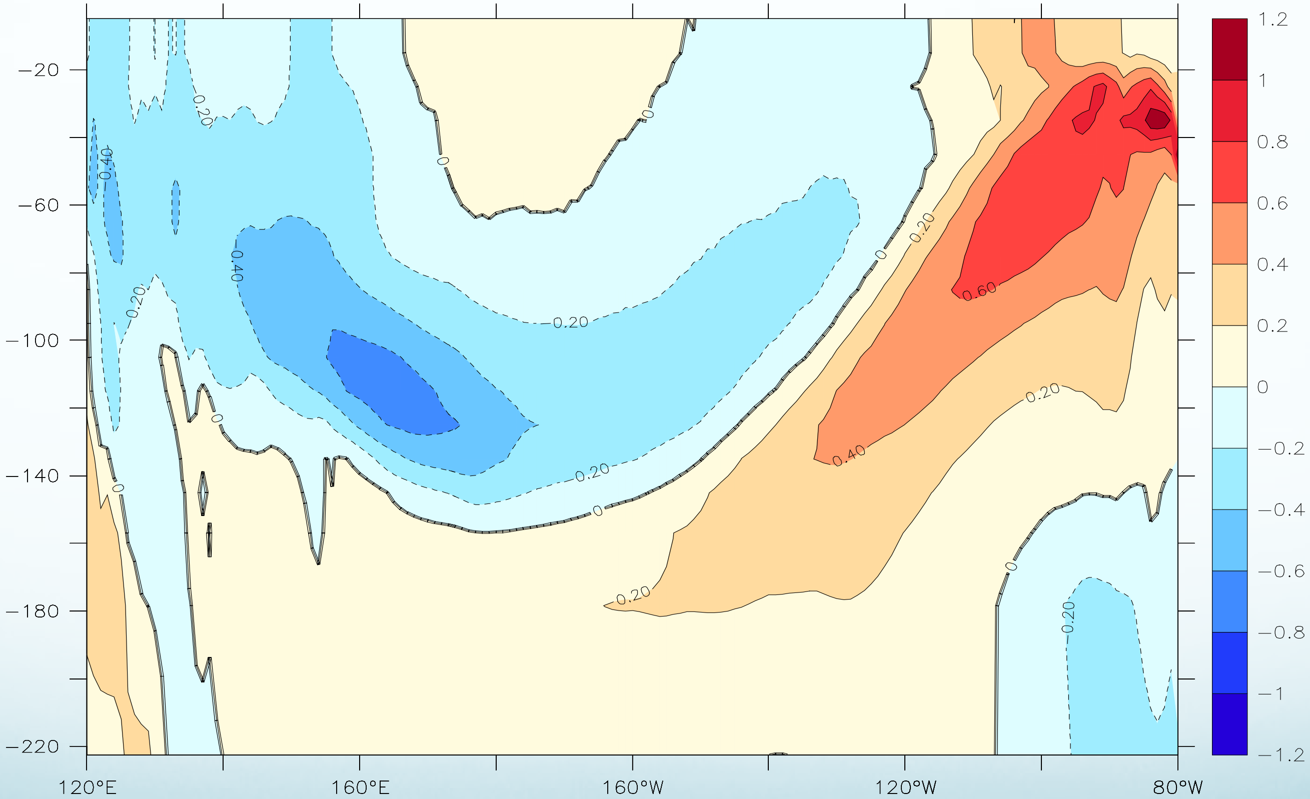


The Heating From ENSO Events (convergence of $\overline{V'T'}$)



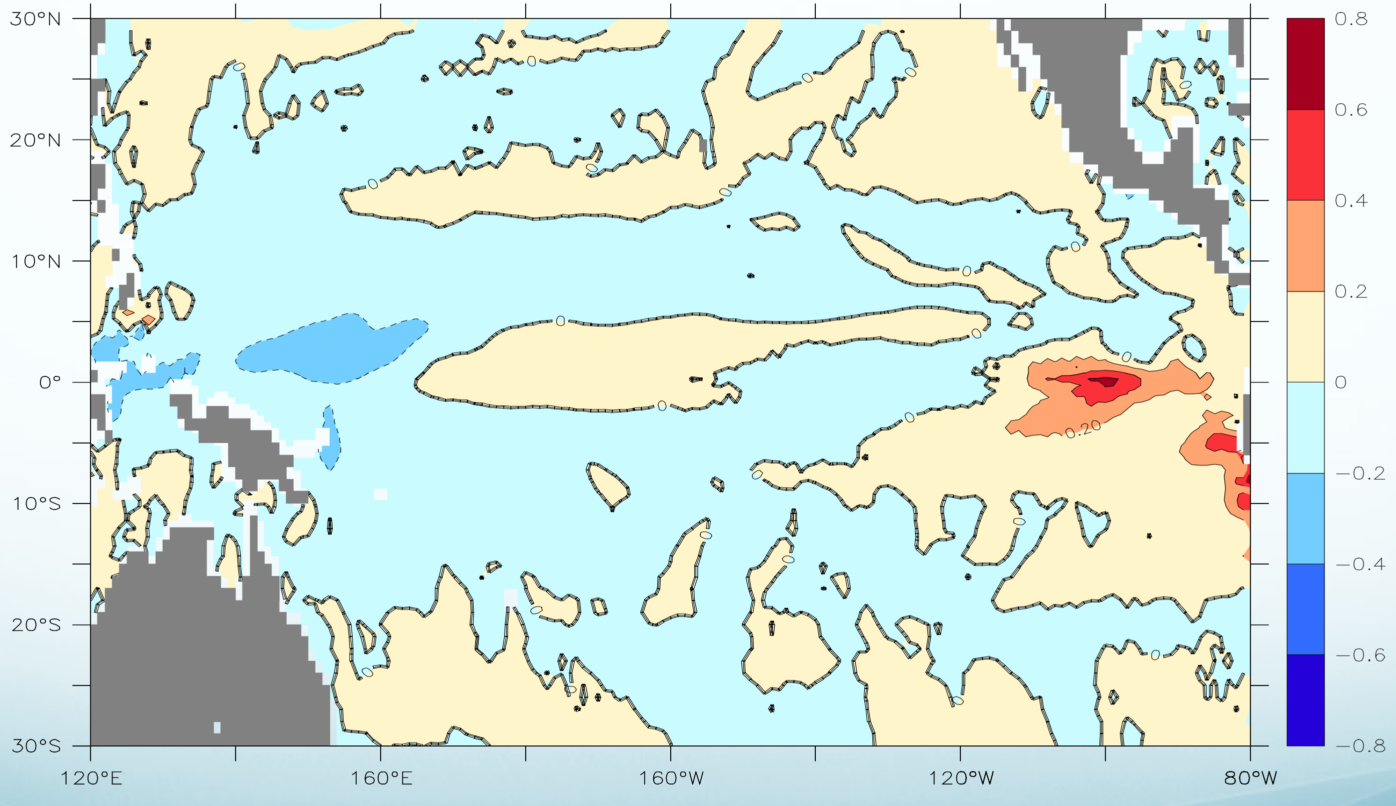
Upper T Difference Between Experiments with/without ENSO

From An IAP Model--LICOM2.0 (Hua et al. 2013)



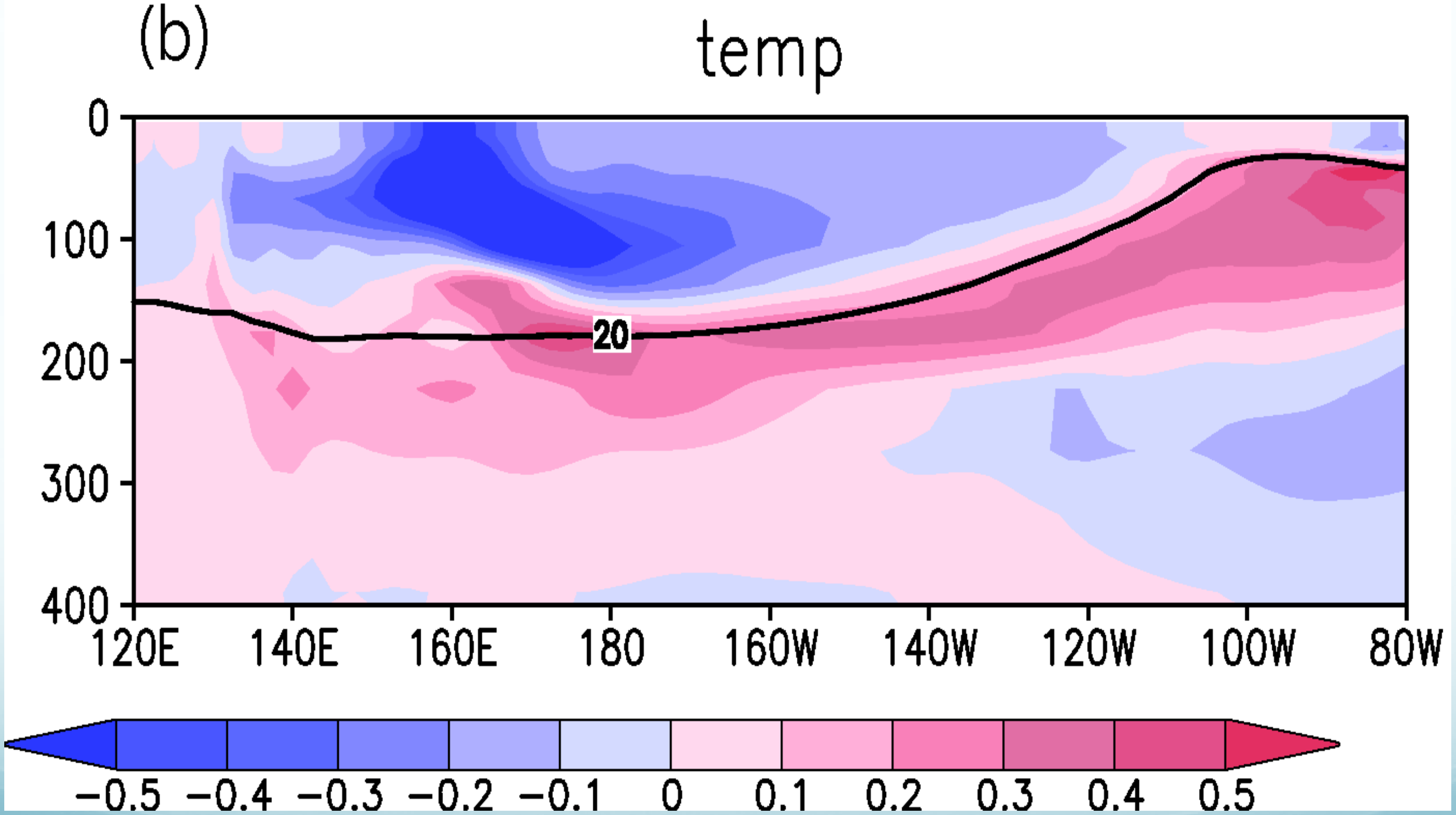
SST Difference Between Experiments with/without ENSO

From An IAP Model--LICOM2.0 (Hua et al. 2013)

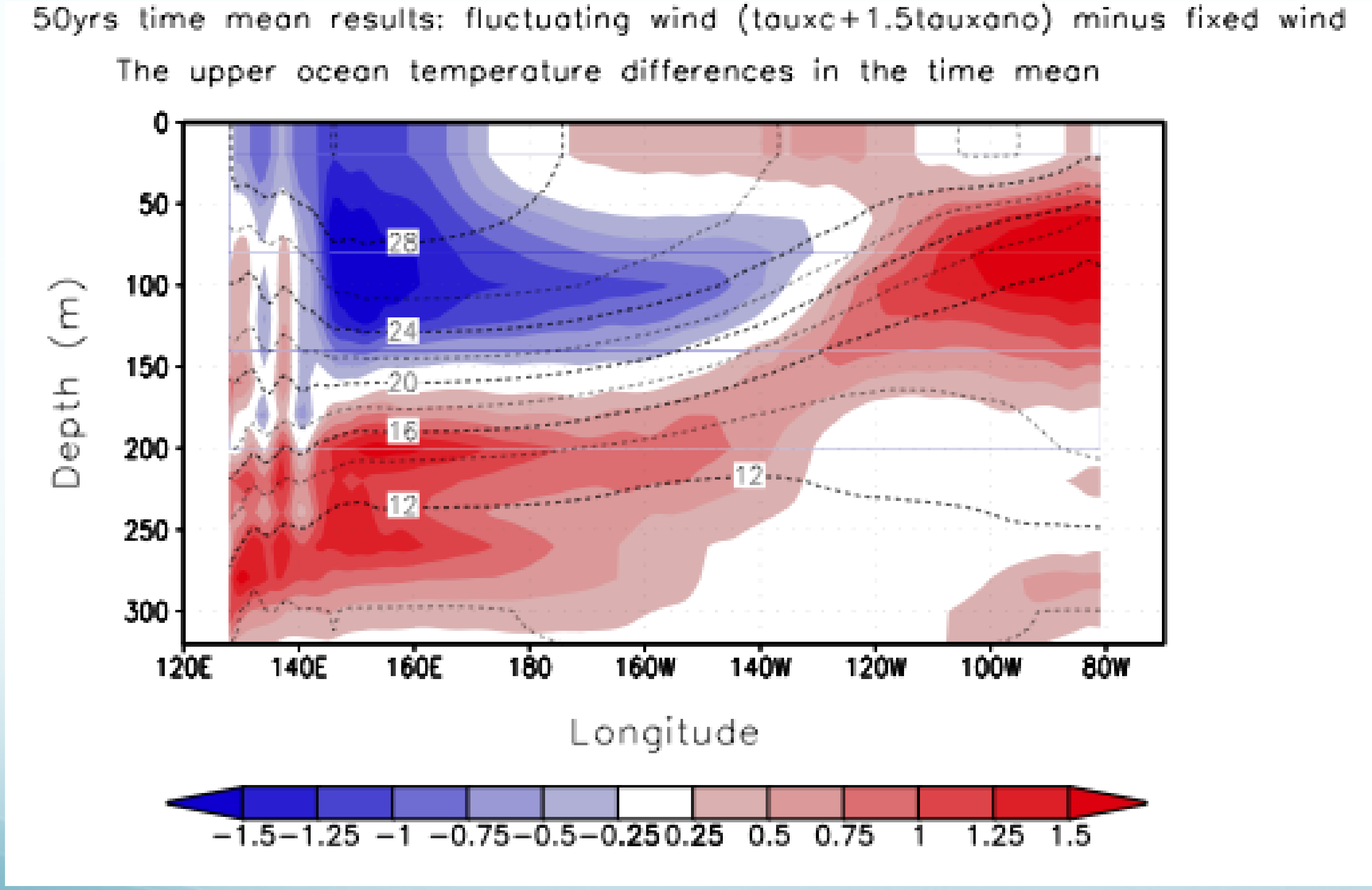


Upper T Difference Between Experiments with/without ENSO

From A GFDL Model—MOM3 (Ogata et al. 2013)

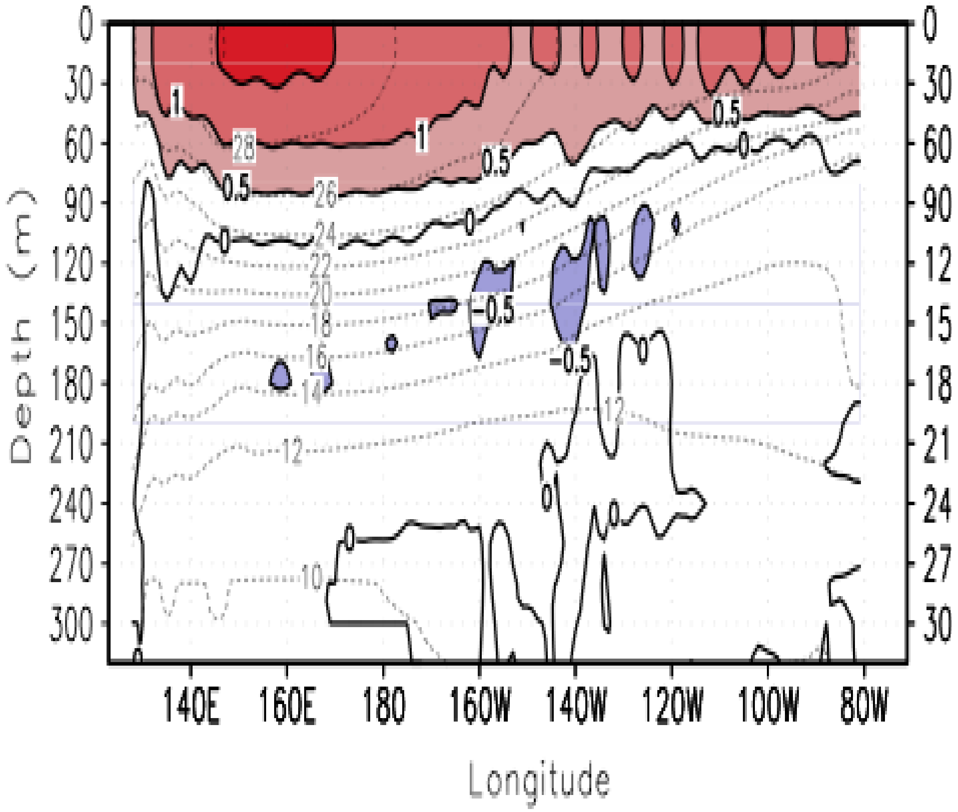


Upper T Difference Between Experiments with/without ENSO

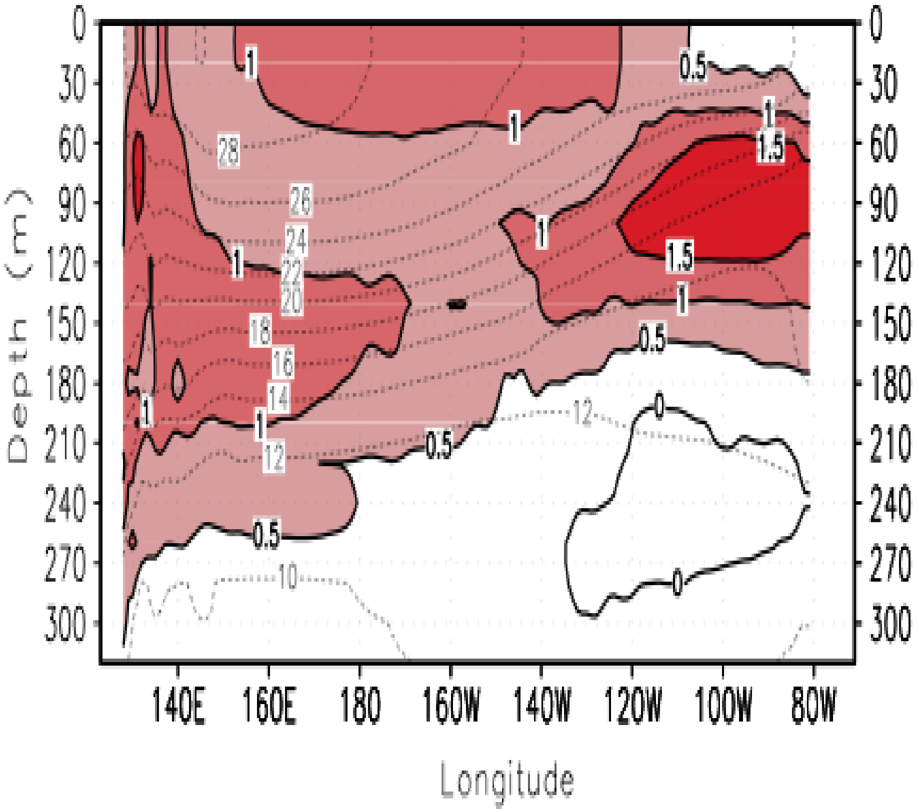


Response of the equatorial ocean temperature to tropical heating

Without ENSO



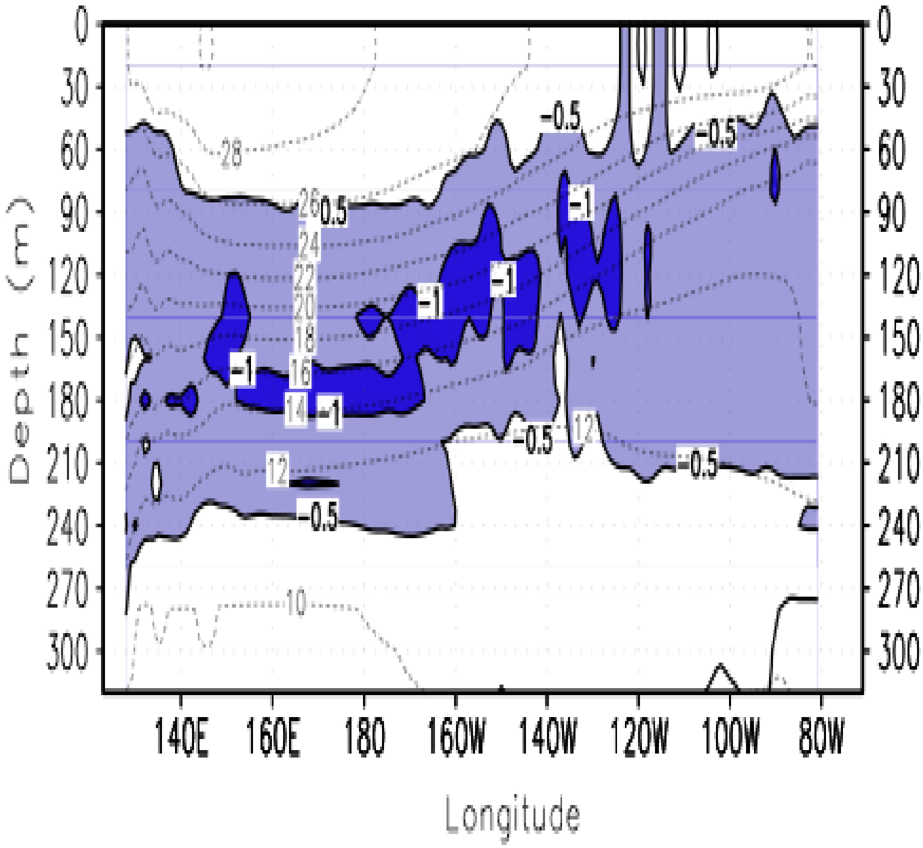
With ENSO



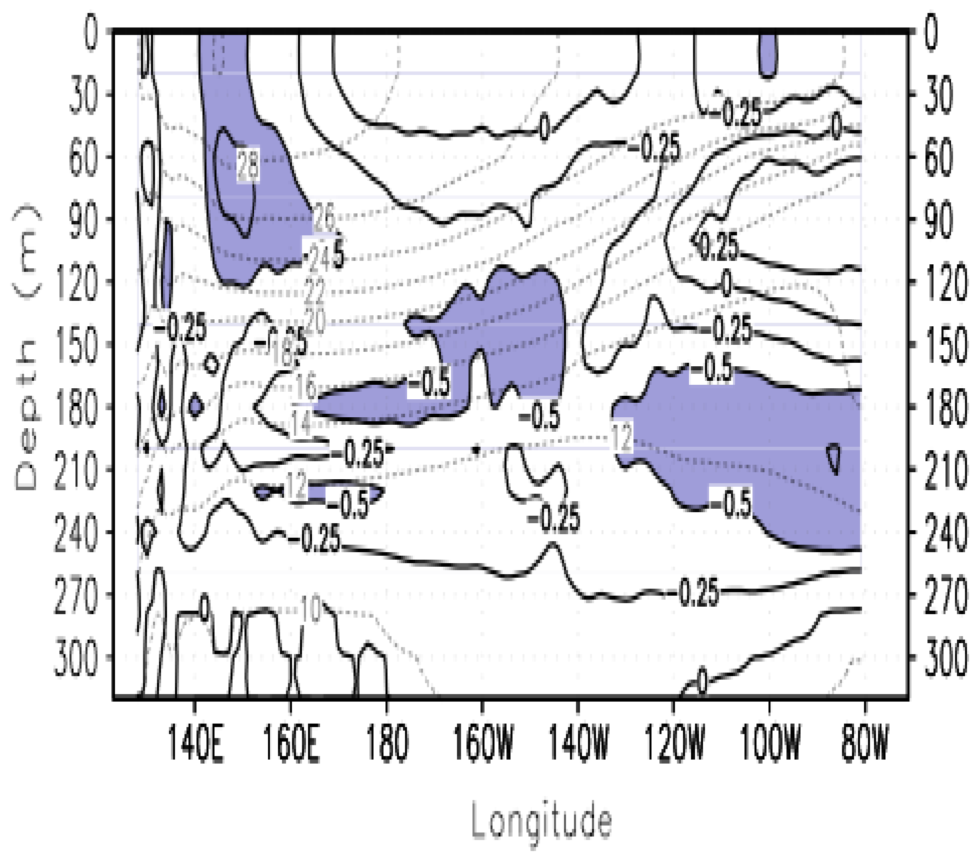
Sun and Zhang, 2006, GRL, 33, L07710, doi:10.1029/2005GL025296

Response in the upper ocean temperature to extratropical cooling

Without ENSO

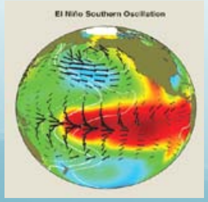


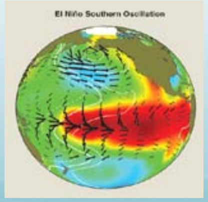
With ENSO

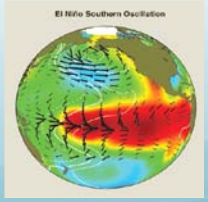


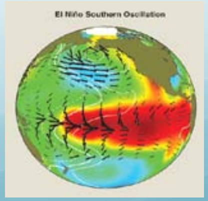
Why are we interested in the time-mean effect of *El Nino-Southern Oscillation*

Viewed on a decadal and longer time-sales, ENSO events are transients just as weather events viewed on the time-scale of a year or longer. We are interested in the time-mean effect of ENSO events for the same reason as we were interested in the time-mean effect of weather events. ***Do ENSO events play a role in maintaining the climatological state of the tropical Pacific, and if so, what is this role?***









Feedback from ENSO onto the mean state

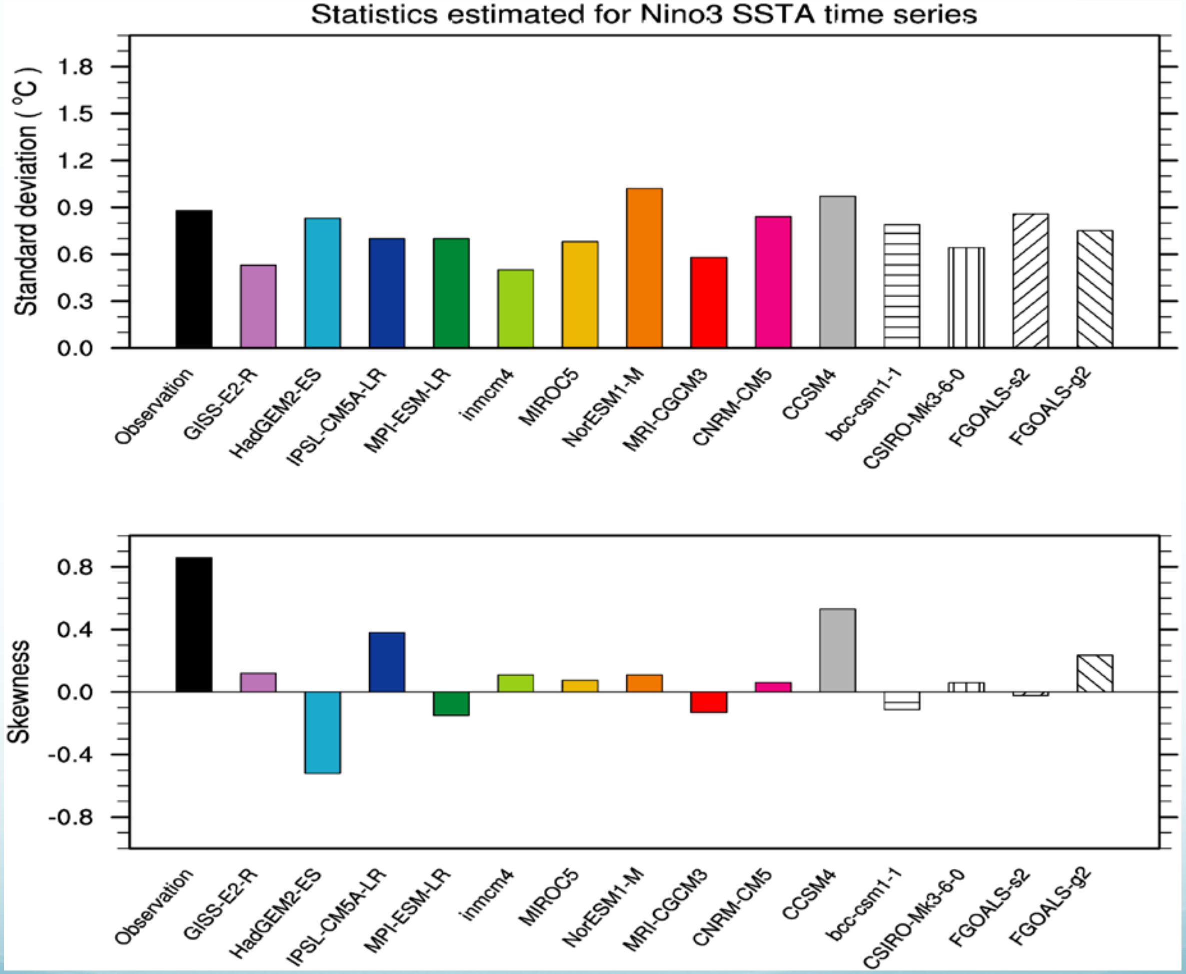
Response of Tw-Tc with and without ENSO

From Tropical Heating Experiments

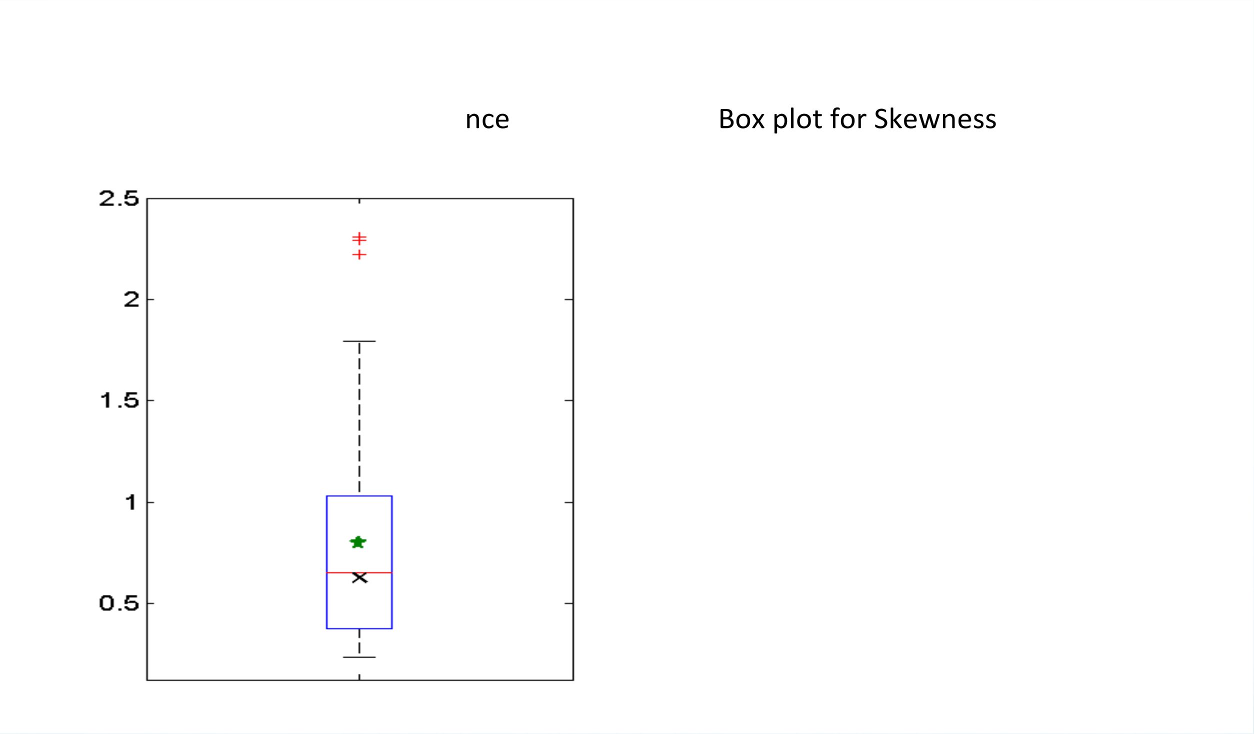
perturbation type	experiment type	change of Tw (°c)	change of Tc (°c)	change of Tw-Tc (°c)
Pair I (5°S-5°N)	No ENSO	1.03	0.0050	1.02
	With ENSO	0.81	0.76	0.053
Pair II (10°S-10°N)	No ENSO	1.38	0.036	1.34
	With ENSO	0.97	0.83	0.14
Pair III (15°S-15°N)	No ENSO	0.95	0.24	0.71
	With ENSO	0.55	0.63	-0.085

Sun and Zhang, 2006, GRL, 33, L07710, doi:10.1029/2005GL025296

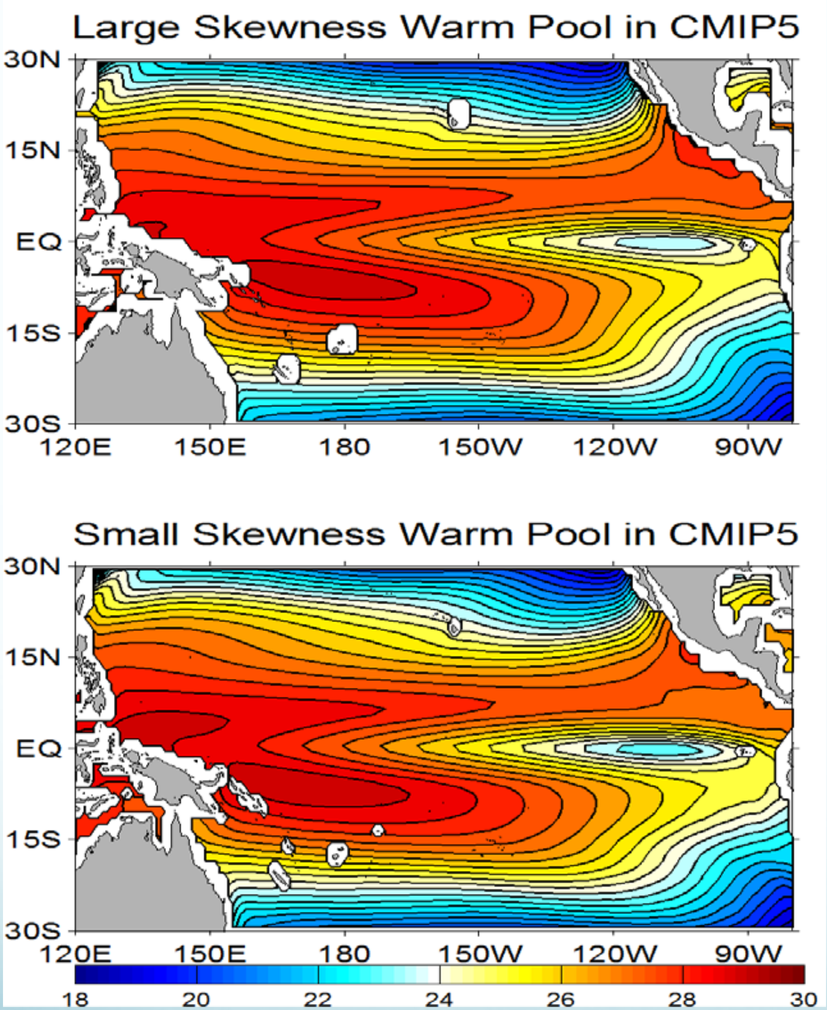
Underestimate ENSO Asymmetry in CMIP5 Models

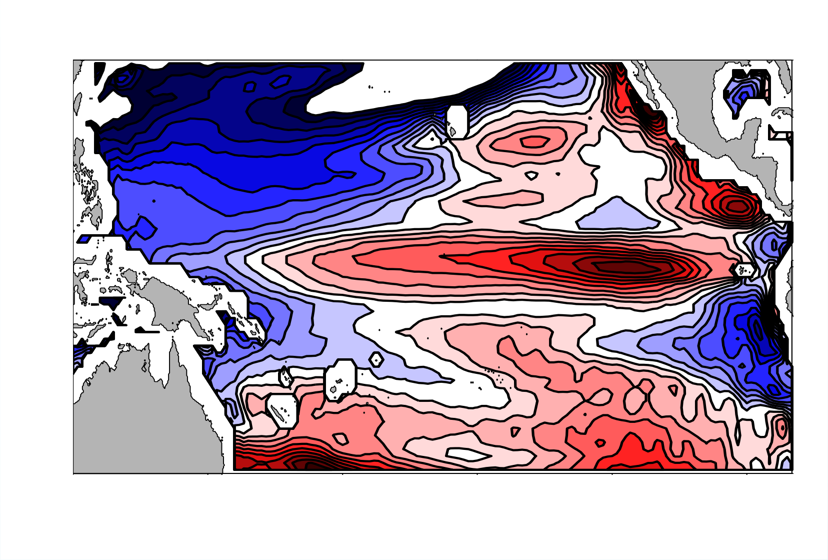


Underestimate ENSO Asymmetry in CMIP5 Models



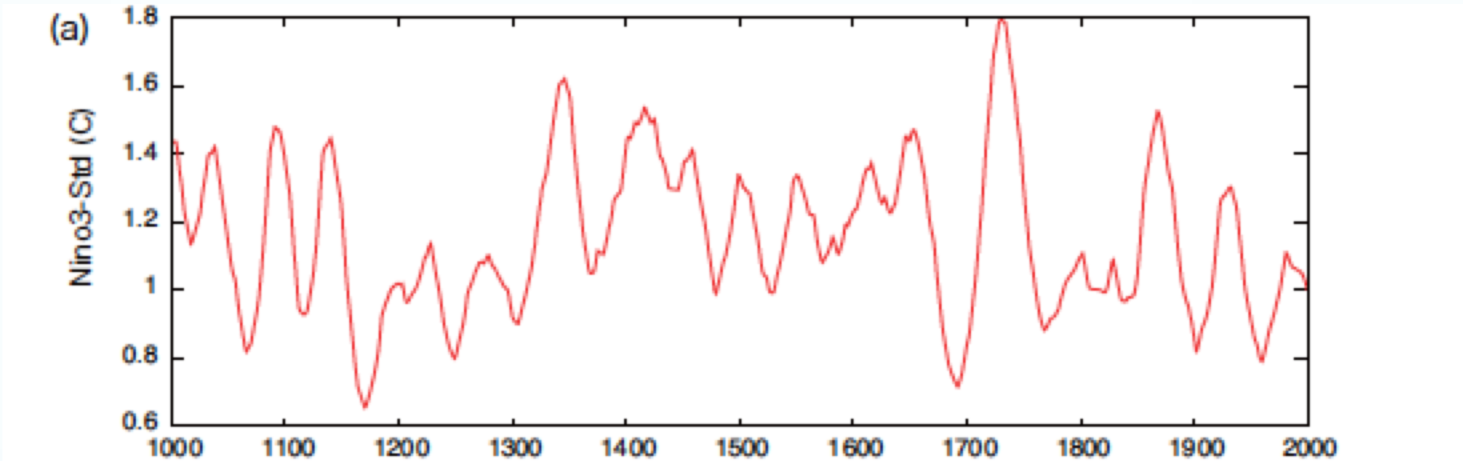
Results from CMIP5



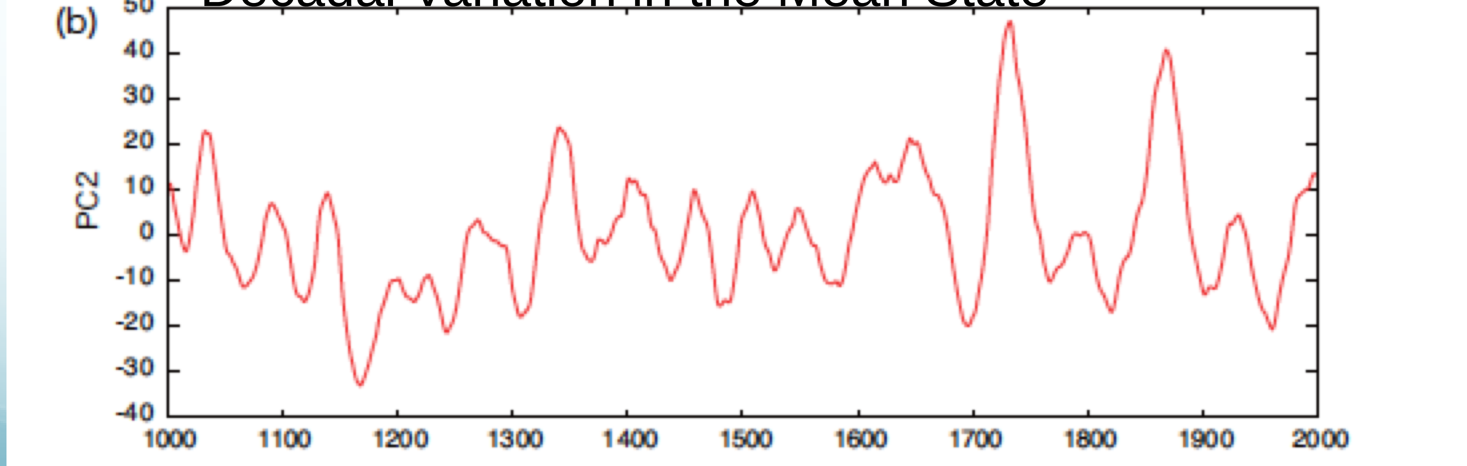


Who Drives Who in Decadal Changes in Tropical Pacific in GCMs?

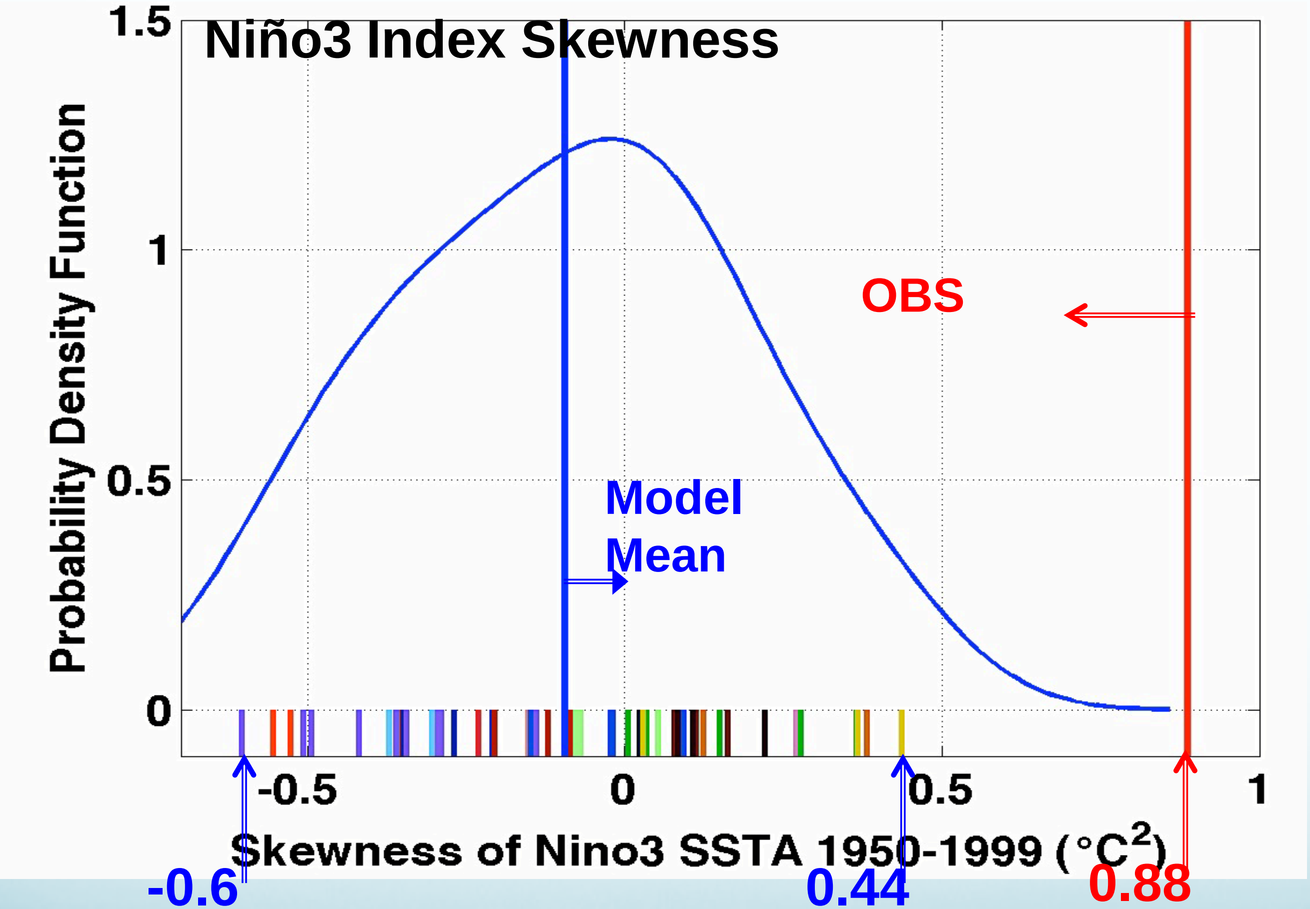
Decadal Variation in the STD of Nino3 SST



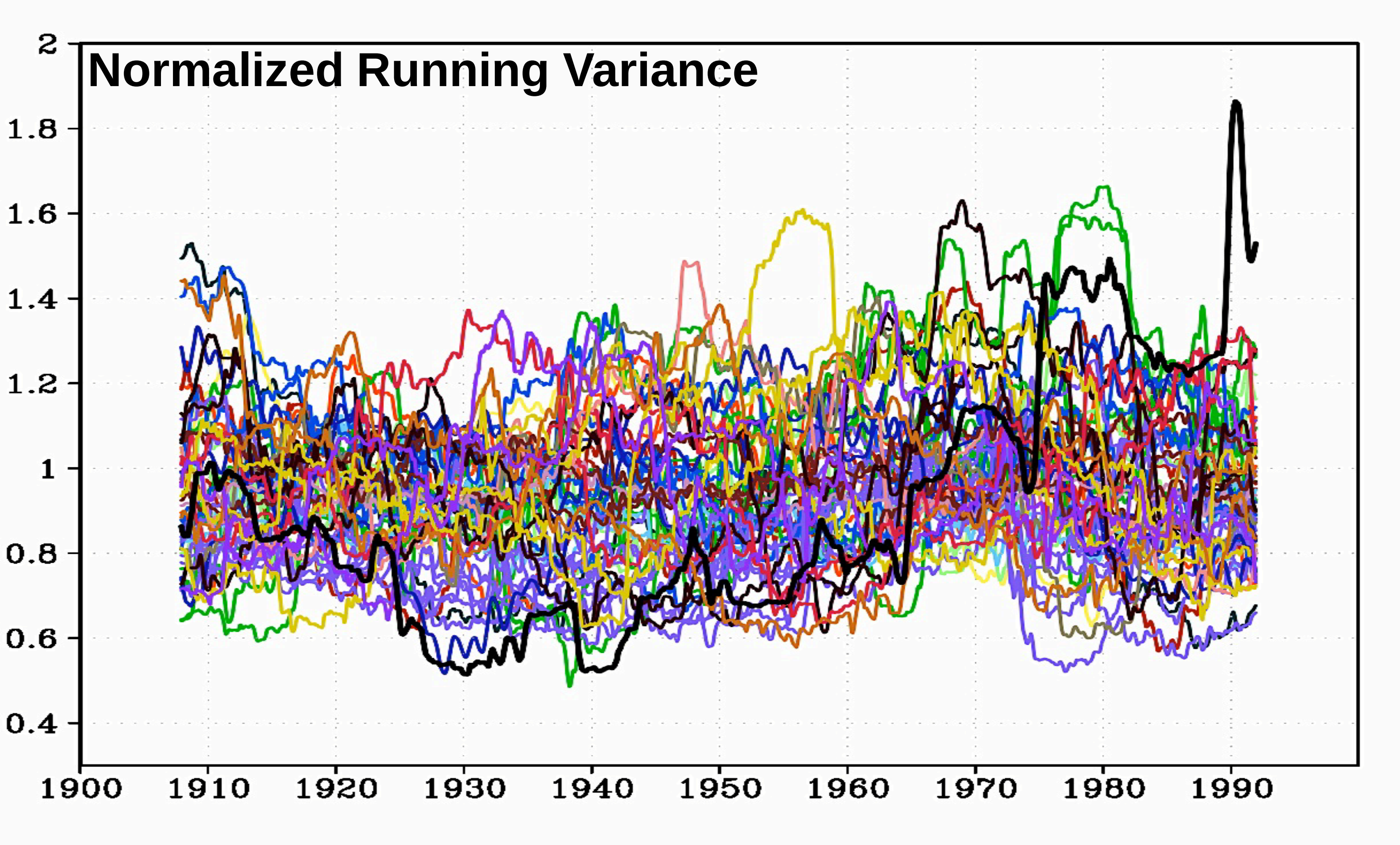
Decadal Variation in the Mean State



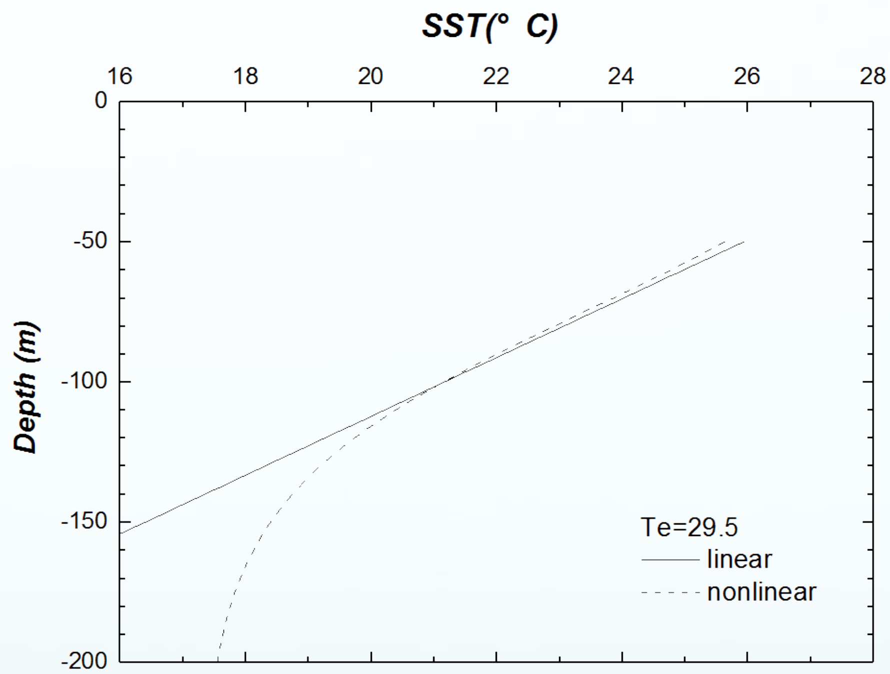
ENSO Asymmetry in IPCC AR4 Models



Variations in the Level of ENSO activity in the IPCC AR4 Models



The profile for the reference subsurface temperature



ENSO In the Forced Experiment