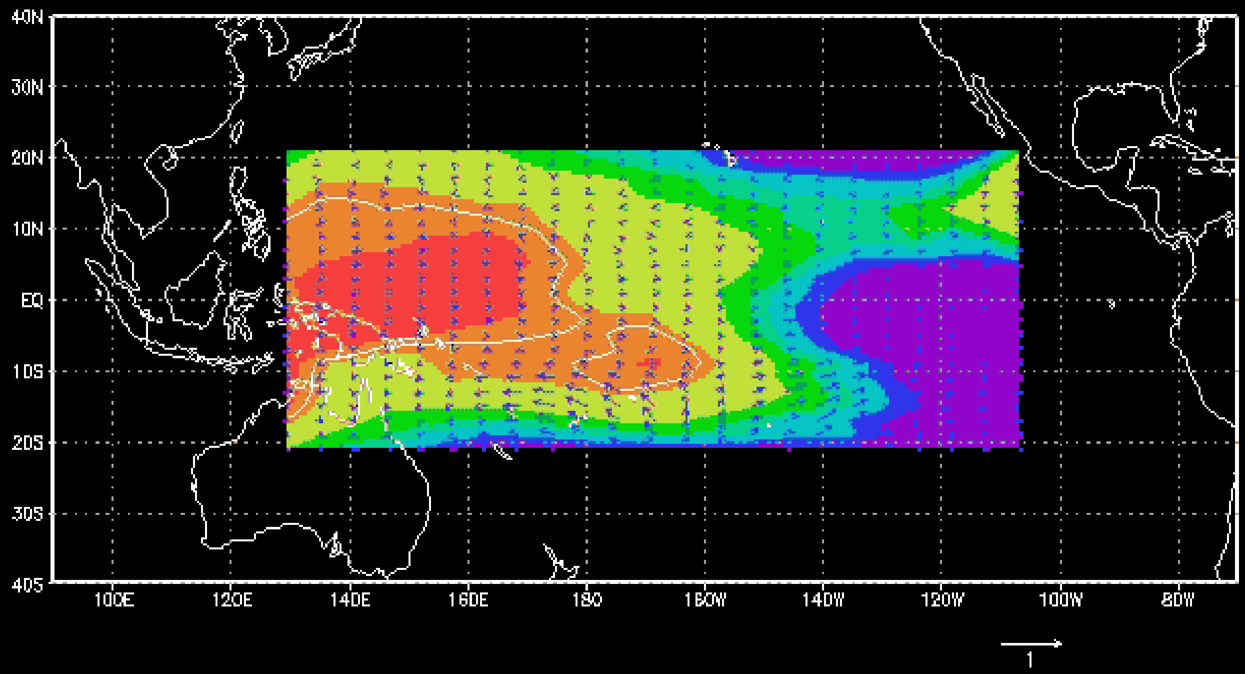
# Feedbacks between El Niño and the "noise" that drives it

## Modulation of westerly wind bursts by large-scale SST





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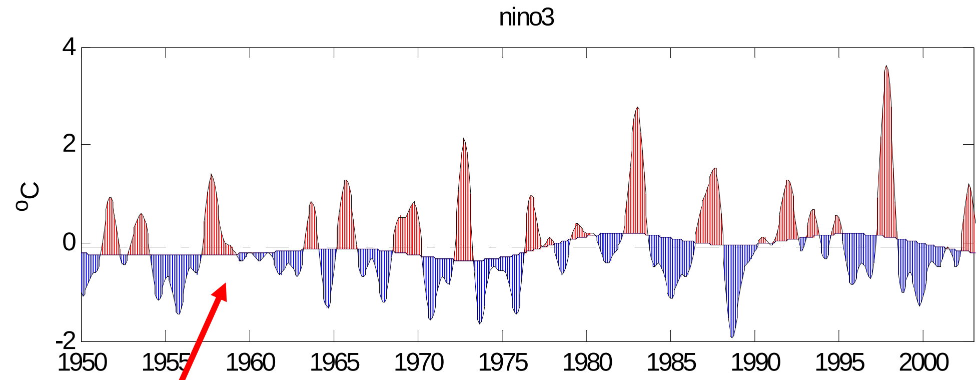
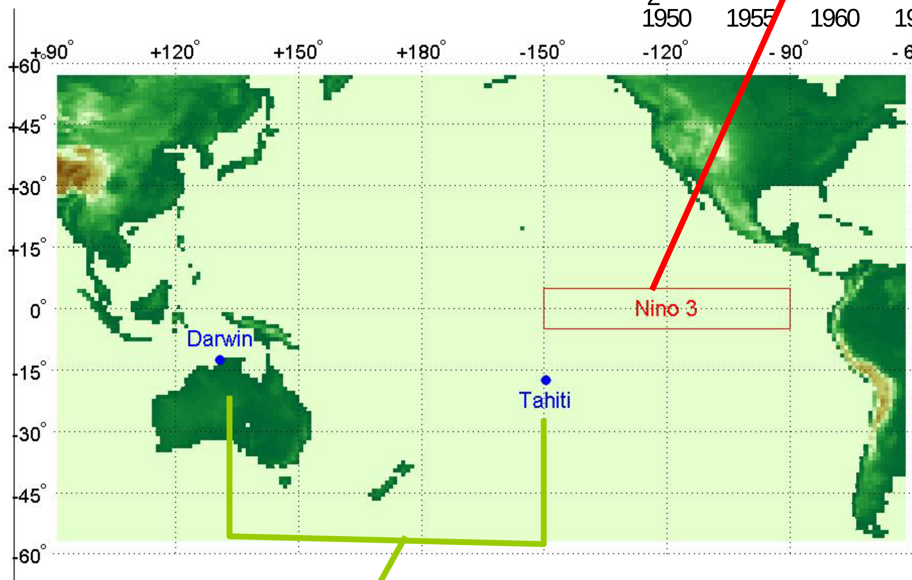
Lisan Yu (WHOI), Andrew Wittenberg (GFDL)

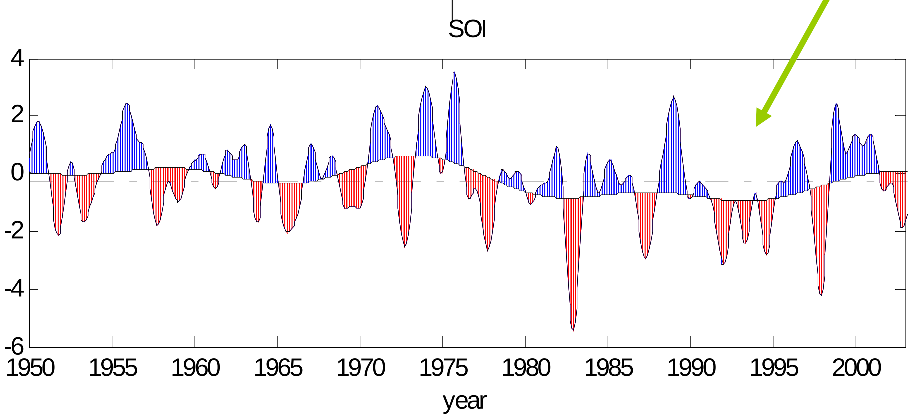

Boston University, October 17, 2005

# ENSO: El Niño and the Southern Oscillation




•Episodic warming of eastern tropical Pacific Ocean every 3-6 years (El Niño)



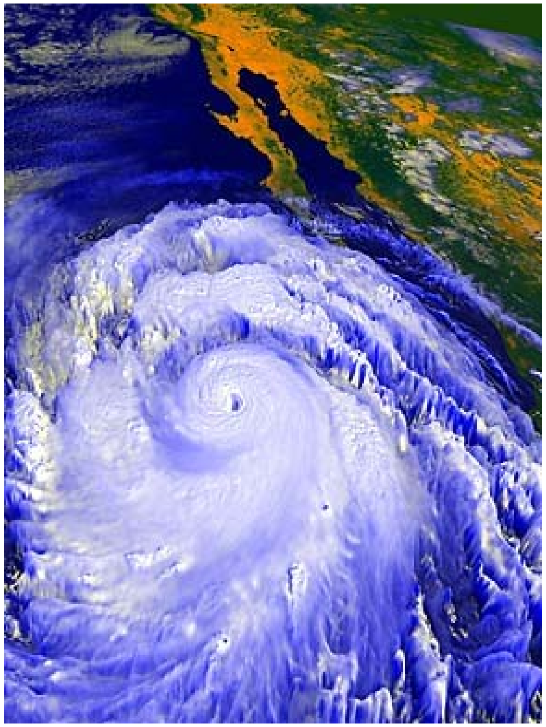




… and related seesaw-like behavior of atmospheric pressure (Southern Oscillation; Tahiti-Darwin sea level pressure=SOI)

# Significance of understanding ENSO

•ENSO is irregular and difficult to predict.

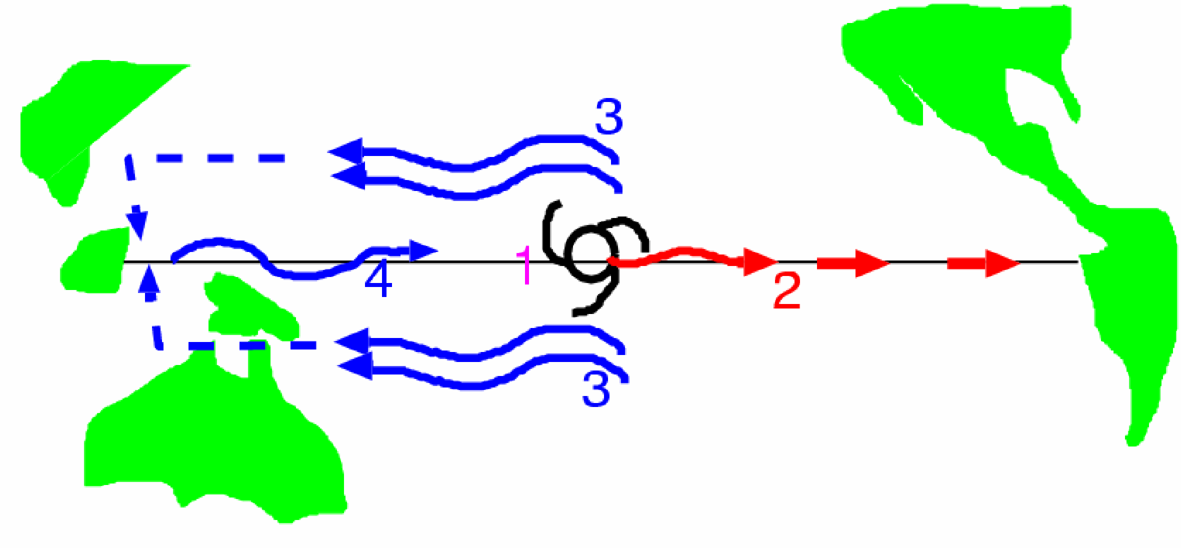
•El Nino events have dramatic impacts on global weather and climate. The poorly predicted 1998 El Nino had more energy than a million Hiroshima bombs: it killed 2,100 people and caused $33 billion damage



*source: nationalgeographic.com*

# ENSO Dynamics: 2 alternatives

•Coupled ocn-atm oscillation, delayed oscillator mechanism *(Battisti, 1988; Suarez and Schopf, 1988)*




**Self-sustained variation**

•Exists regardless of external forcing

•Irregularity due to low order **chaos** *(Tziperman et al., 1994,1995; Jin et al., 1994)*

**Stochastically (i.e., randomly) forced damped linear system**

•Dies w/out forcing

•Stochastic wind forcing *(Penland & Sardeshmukh, 1995; Moore & Kleeman, 1996; Thompson & Battisti, 2001)*. Non-normal amplification *(Farrell, 1988)*

# Westerly Wind Bursts

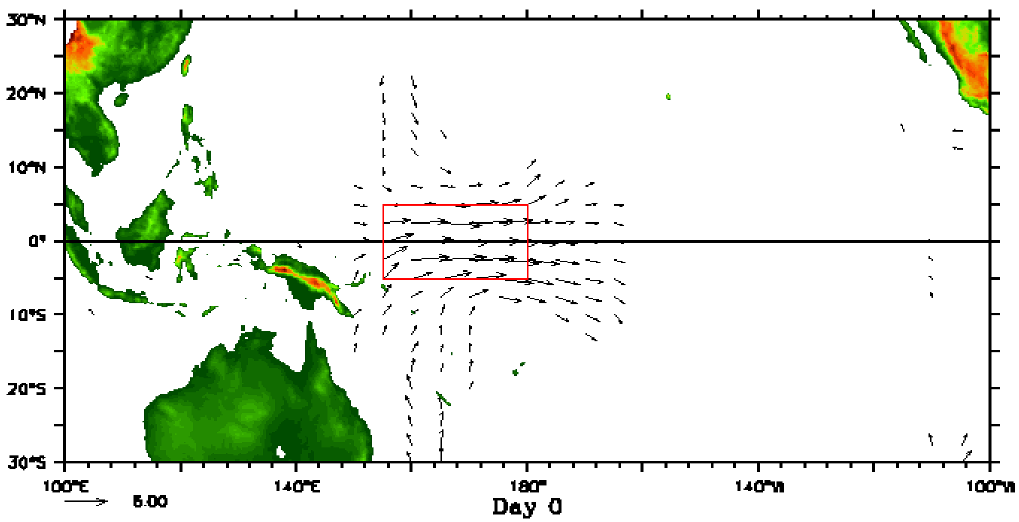
•WWBs last **6-20 days**. Max wind speed **8-20 m/s** (*Harrison & Vecchi 97)* (climatological winds: 1-3 m/s)

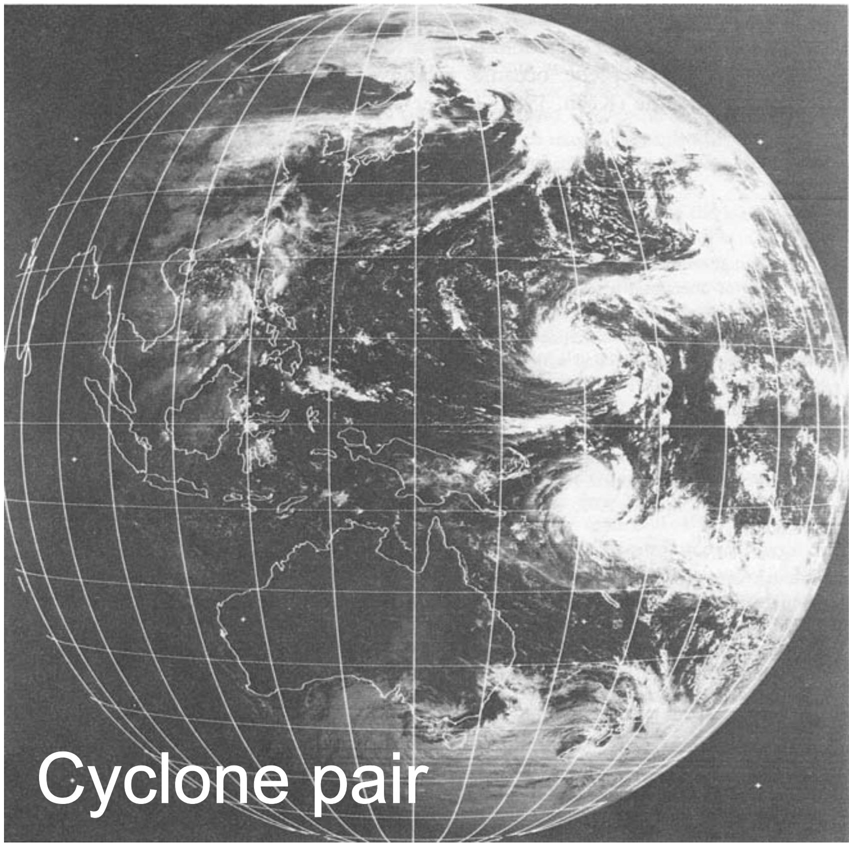
•~3 [0-8] WWBs each year *(Verbickas 98)*

•WWBs may be due to tropical **cyclones; MJO; cold surges** from midlatitudes, …

## Composite of typical WWB

*(Harrison and Vecchi, 1997)*



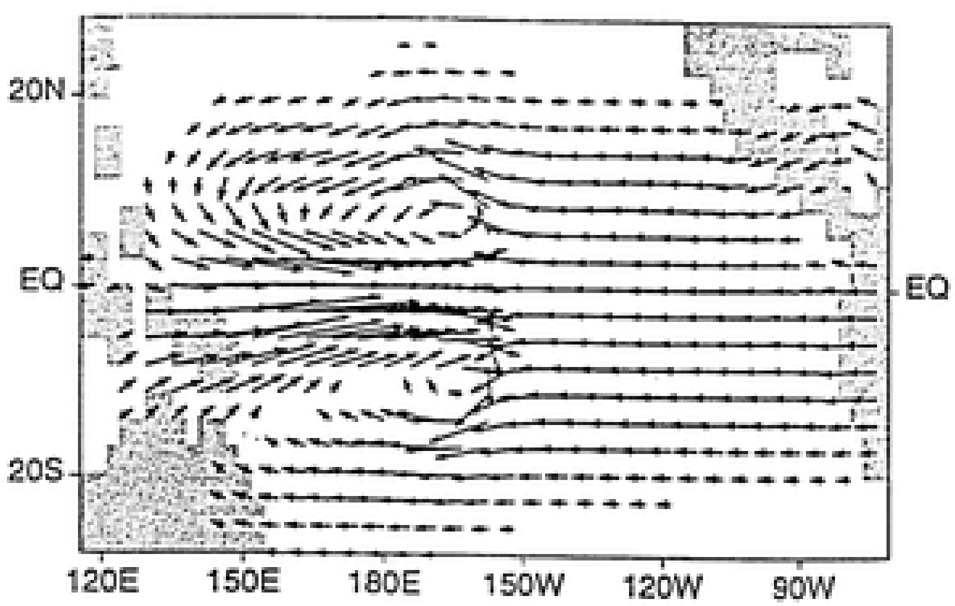
# WWB events can drive ENSO…

•Expect WWBs to excite Kelvin waves causing El Nino events. Indeed, observations *(Penland & Sardeshmukh 95)* and models *(Moore & Kleeman 99, 01)* suggest optimal ENSO forcing resembles WWB

•WWBs occur before every major ENSO event *(McPhaden 04)*

**Stochastic optimal in surface wind stress**

(Moore and Kleeman, 1999)




•Previous studies consider WWBs as noise external to the coupled system *(Penland & Sardeshmukh 95; Kessler et al 95; Battisti & Sarachik 95; Moore & Kleeman 96, 99; Eckert & Latif 97; Perigaud & Cassou 00; Thompson & Battisti, 01; Lengaigne et al. 04)*

•The dominant impact of WWBs on ENSO is normally seen as evidence for ENSO being stochastically driven. But is this really implied?

# …but ENSO may regulate WWBs

•More WWBs in El Niño years *(Verbickas, 1998; Vecchi and Harrison, 2000; Harrison and Vecchi, 1997)*

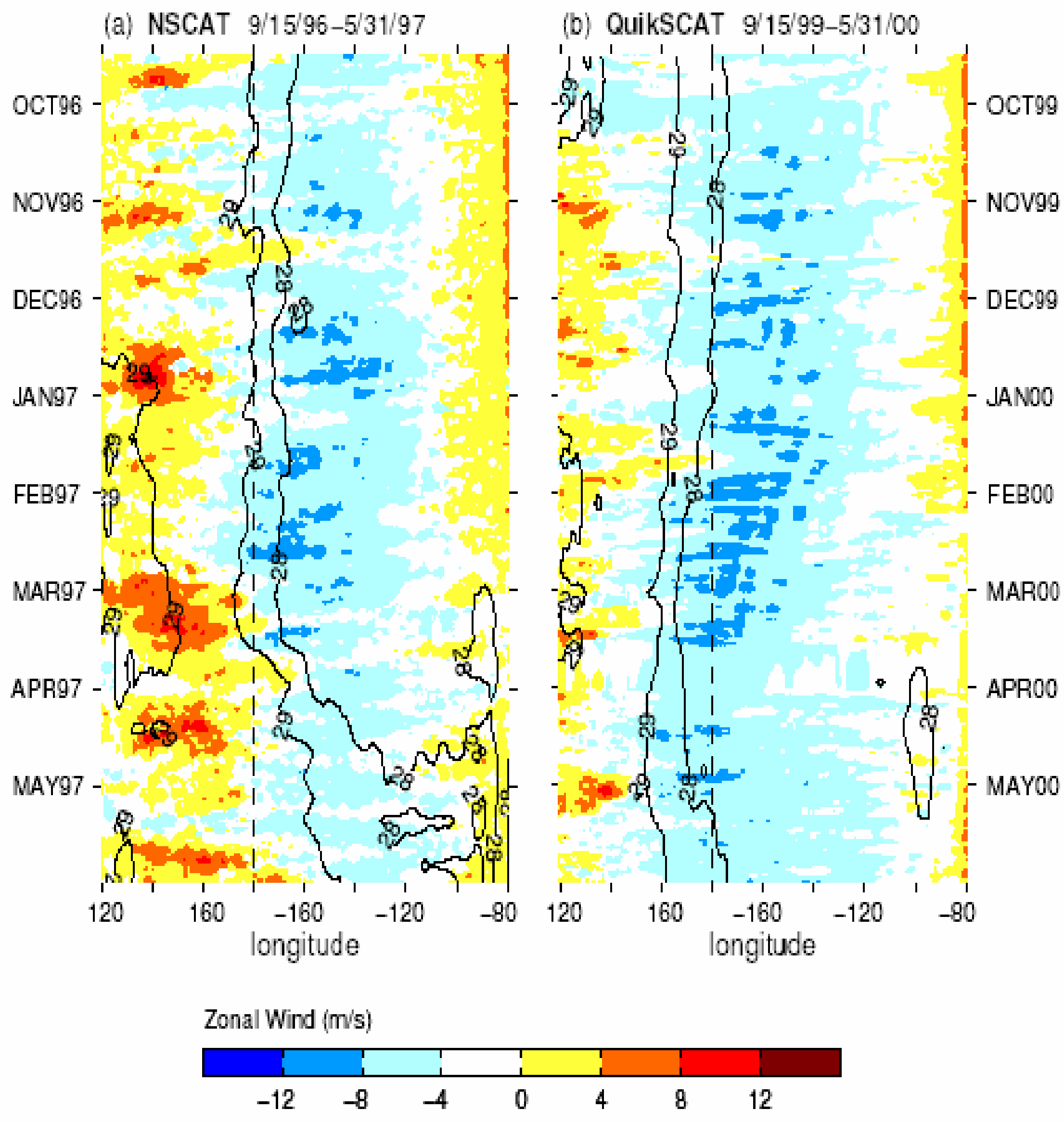
•Strong connection in data btwn pre-existing SST anomalies and WWB variability *(Vecchi and Harrison, 2000)*

•WWBs more prone to occur when warm pool extends eastward *(Yu et al., 2003)*

•WWBs are amplified given random forcing *(Moore and Kleeman, 1999)*

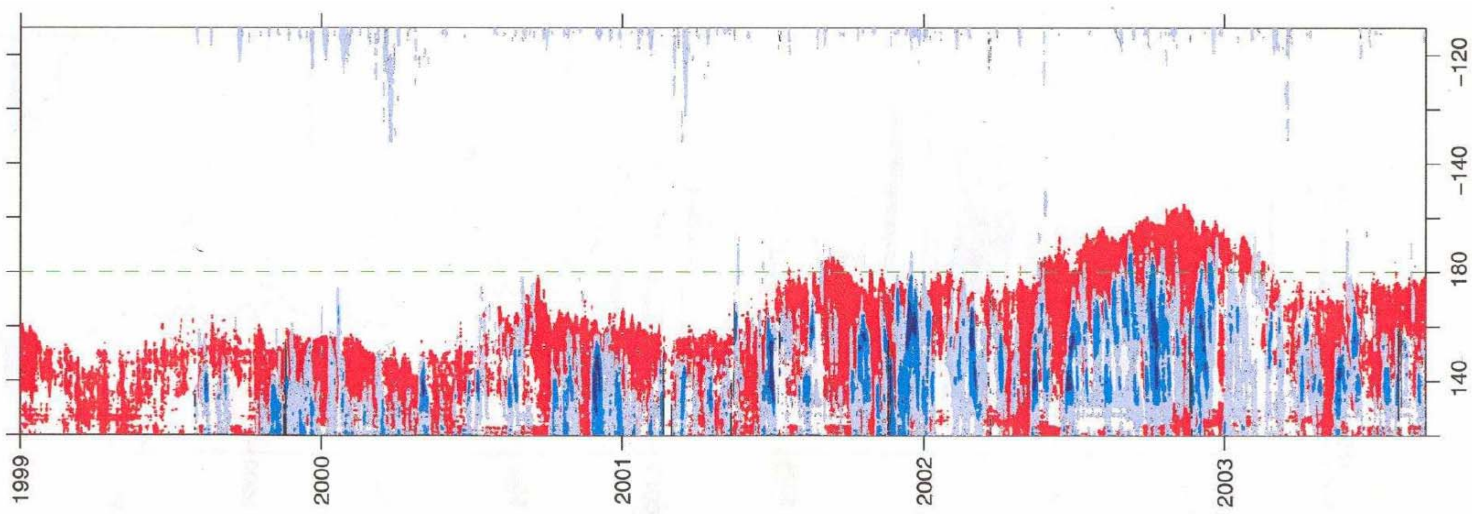
**Zonal winds and warm pool extension**

(Yu et al., 2003)

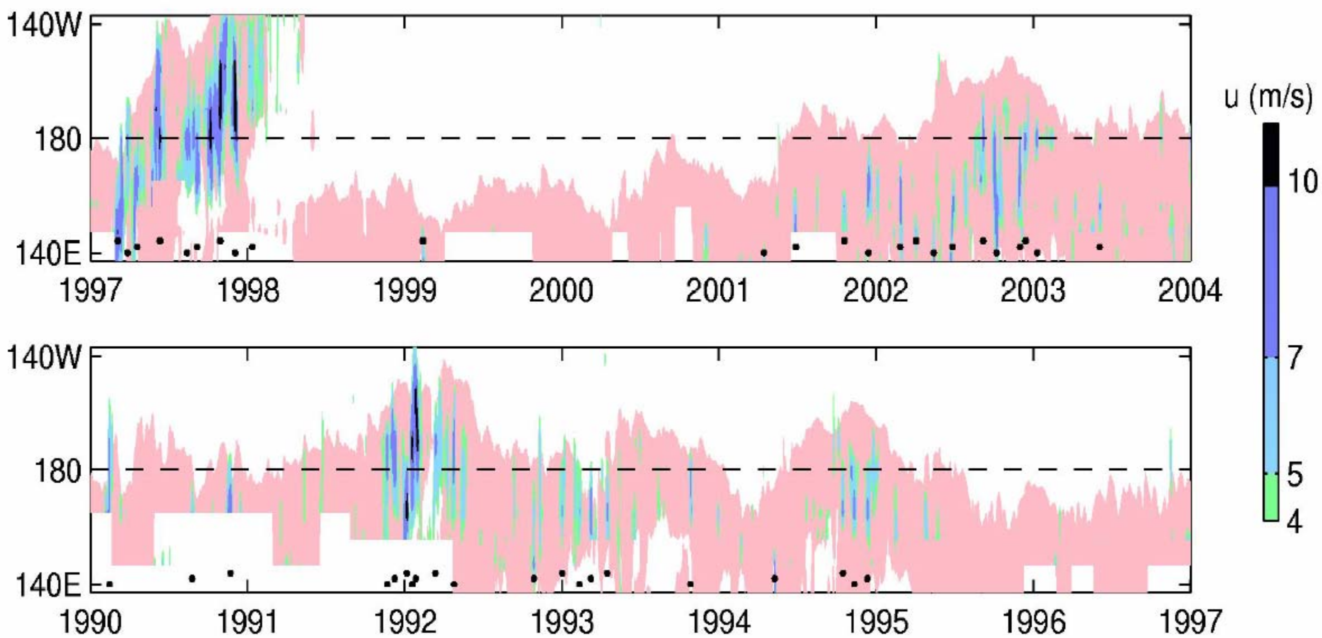


# WWBs more likely when warm pool extended

QuikSCAT $u_{eq}$>2m/s SST=29°



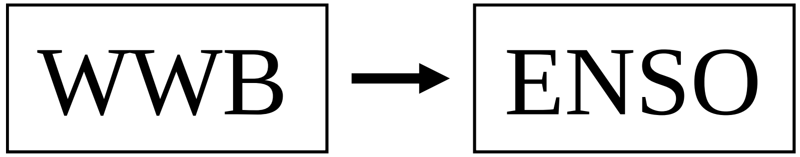

TAO $u_{eq\ anom}$>4m/s (green, blue) on SST=29° (pink)



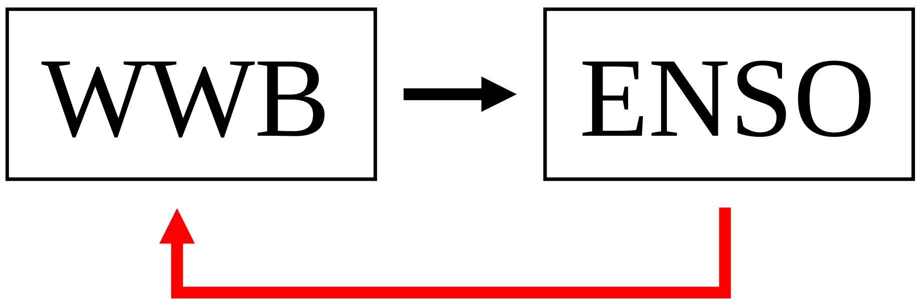

- WWBs are 3x more likely to occur when warm pool extends past the dateline

# Objective: Contrast two scenarios

1. ENSO is damped, WWBs are stochastic forcing




2. ENSO is damped without WWBs, but WWBs are modulated (determined) by the large scale SST

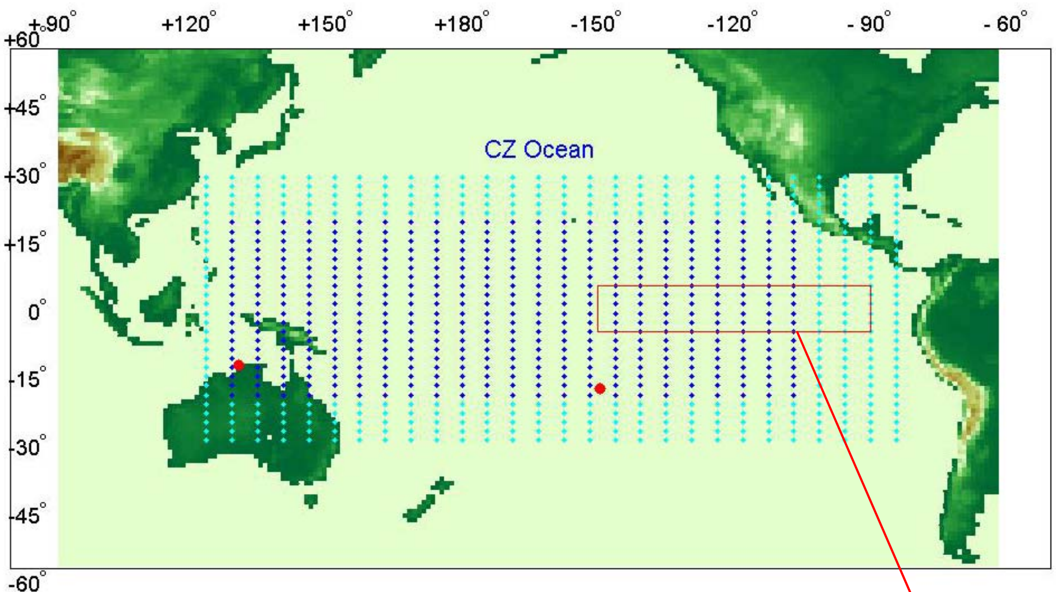



- Both are extreme & unrealistic scenarios! Still a useful & instructive comparison.
- This is not an effort to realistically simulate or predict WWBs/ENSO

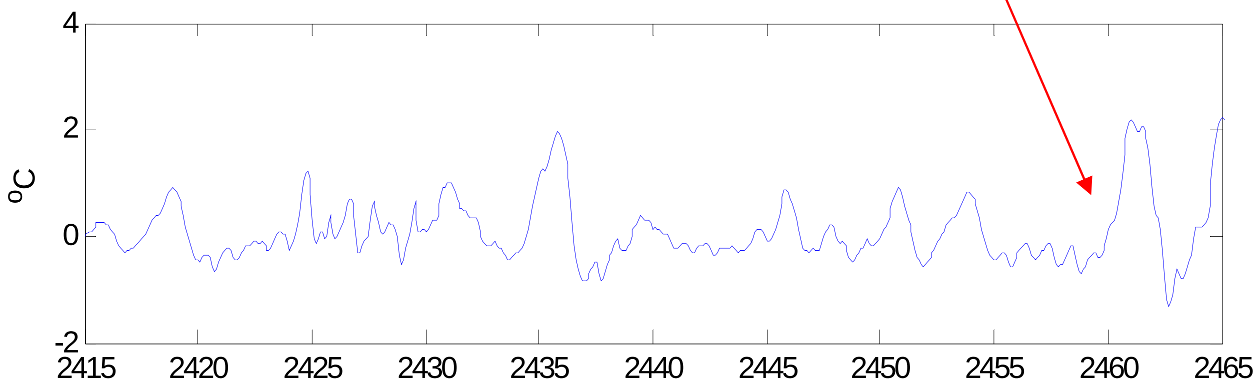
# Cane-Zebiak (1987) model of ENSO

- Intermediate complexity coupled model of the tropical Pacific ocean and atmosphere with no external forcing

- Gill *(1980)* atmosphere and one-and-a-half layer ocean




ZC model standard run nino3




- Ocean:

$$u_t - \beta y v = -g' h_x + \tau^{(x)}(\mathbf{u_a}) - ru$$

$$\beta y u = -g' h_y + \tau^{(y)}(\mathbf{u_a}) - rv$$

$$h_t = -H \nabla \bullet \mathbf{u} - rh$$

- Atmosphere:

$$-\beta y v_a = -\varphi_x - \varepsilon u_a$$

$$\beta y u_a = -\varphi_y - \varepsilon v_a$$

$$Q(\nabla \bullet \mathbf{u}_a, T) = -c_a^2 \nabla \bullet \mathbf{u}_a - \varepsilon \varphi$$

- SST: …

# Idealized WWB recipe

1. Stabilize CZ model to make it damped;
2. Consider WWBs as part of deterministic internal ENSO dynamics rather than common view of WWBs as external stochastic forcing
3. Add idealized **modulated WWBs** to Zebiak-Cane ENSO model, triggered when warm pool extends east of dateline at the equator. 60 day minimum separation; no WWBs during July-September. (~ as observed.)
4. Also consider stochastic WWBs: as above, but occurrence is stochastic in time (with same average frequency as modulated case)

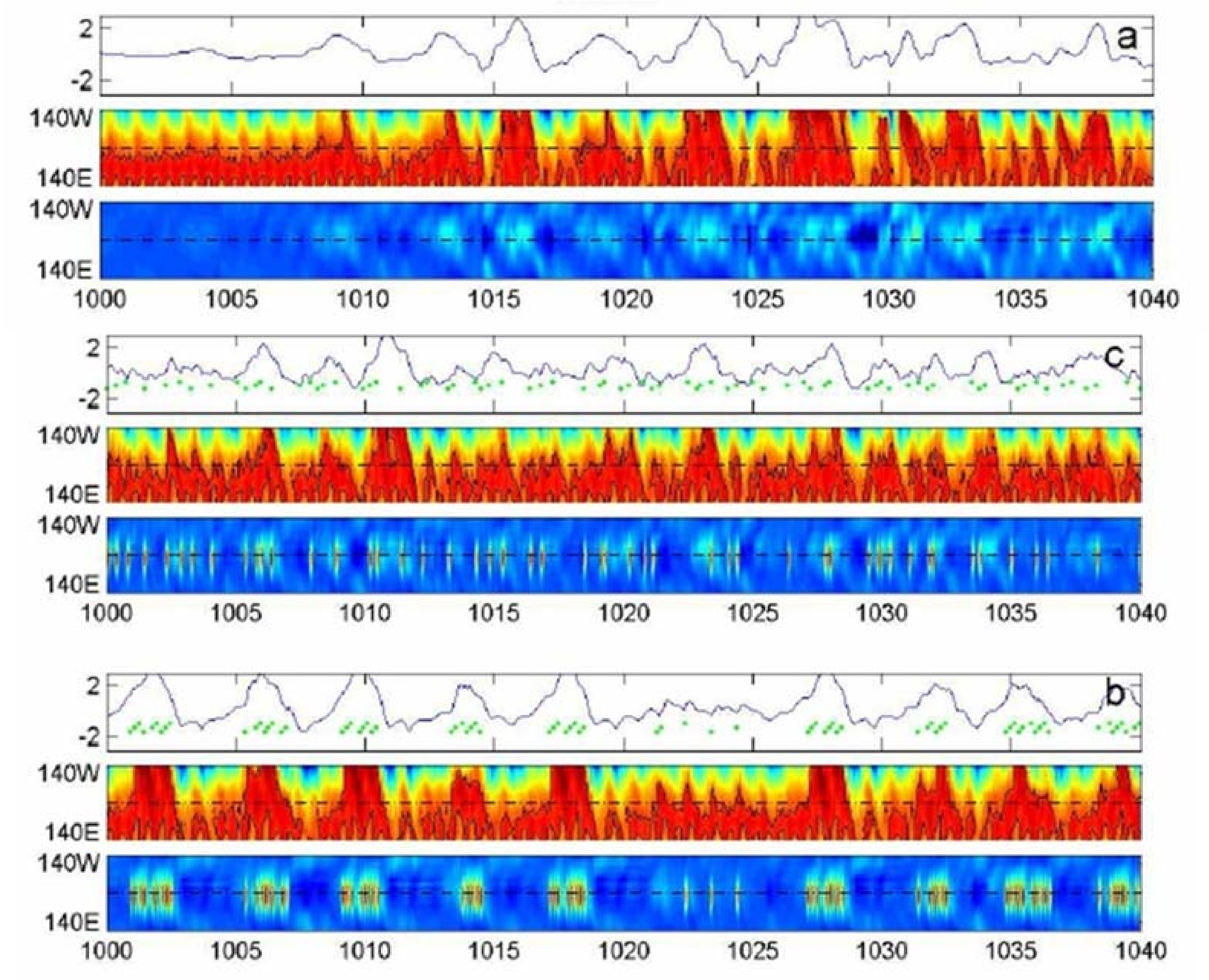
- **Can deterministic WWBs lead to self-sustained ENSO and irregularity?**
- **How does modulated (deterministic) WWB case compare with purely stochastic WWBs?**

# CZ model results: stochastic vs modulated WWBs

Standard CZ
std(nino3)=1.1°C

Stochastic WWBs
std(nino3)=0.78°C

Modulated WWBs
std(nino3)=1.4°C




*Eisenman, Yu, Tziperman (2005); in press J. Climate*

# Stochastic vs modulated WWBs: what do we see?

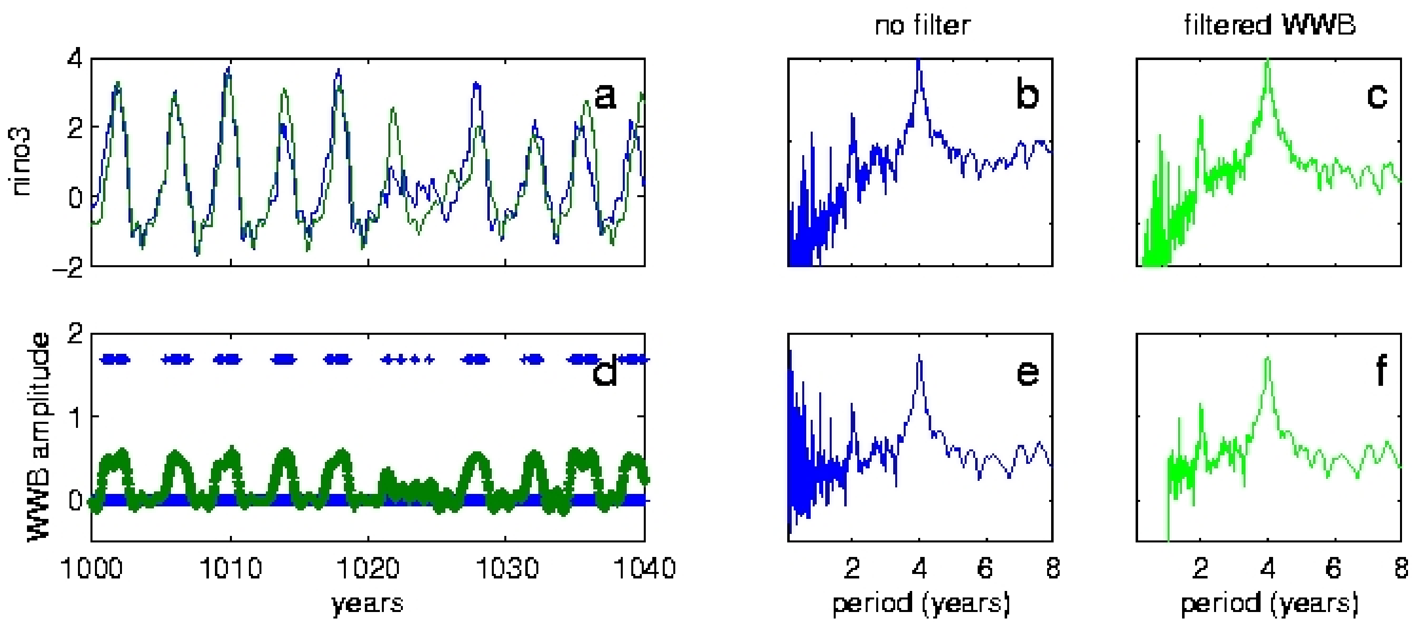
1. Deterministic WWB events make ENSO effectively self-sustained
2. Amplitude of ENSO is **twice as large** for modulated events, although there are the same number of events per year in the two scenarios
3. Irregularity is due to chaos

Why is ENSO response so much greater when WWBs are modulated?

Will deterministic WWBs in a more complicated model lead to self-sustained ENSO?

# Stochastic vs modulated: mechanism for the difference

- Amplitude of ENSO is twice as large when WWB events are modulated than when they are purely stochastic.
- Why? Is this a linear response to WWBs? Nonlinear?




Nino3 with a 1-yr filtering of WWB forcing: no change to ENSO

- The model ENSO responds linearly to WWBs.
- **The factor two in amplitude is because the WWB modulation by ENSO creates a larger low-frequency (2-4 yr) component in the WWB wind forcing.**

# GFDL Hybrid coupled model

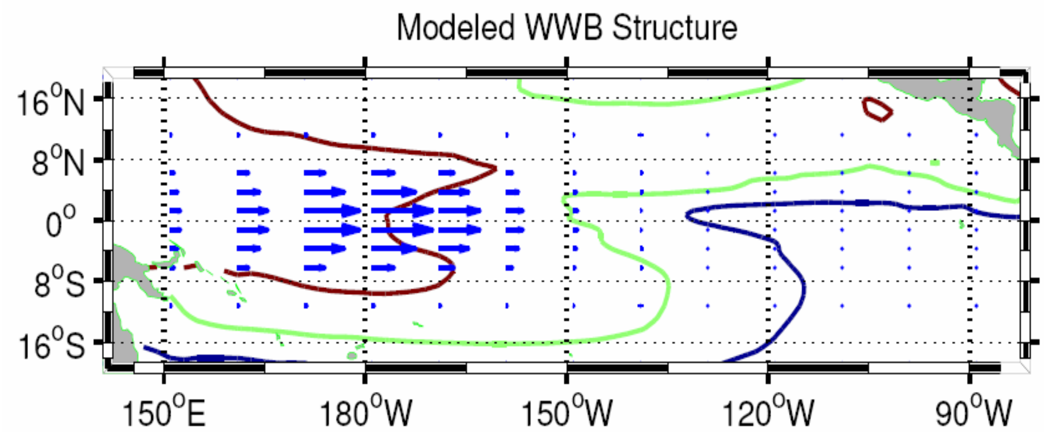
*(Harrison et al 02; Wittenberg 02; Griffies et al 05; Vecchi et al 06; Zhang et al 05)*

**Ocean:** GFDL MOM4

- Global domain; ½° resolution in tropics

**Atmosphere:**

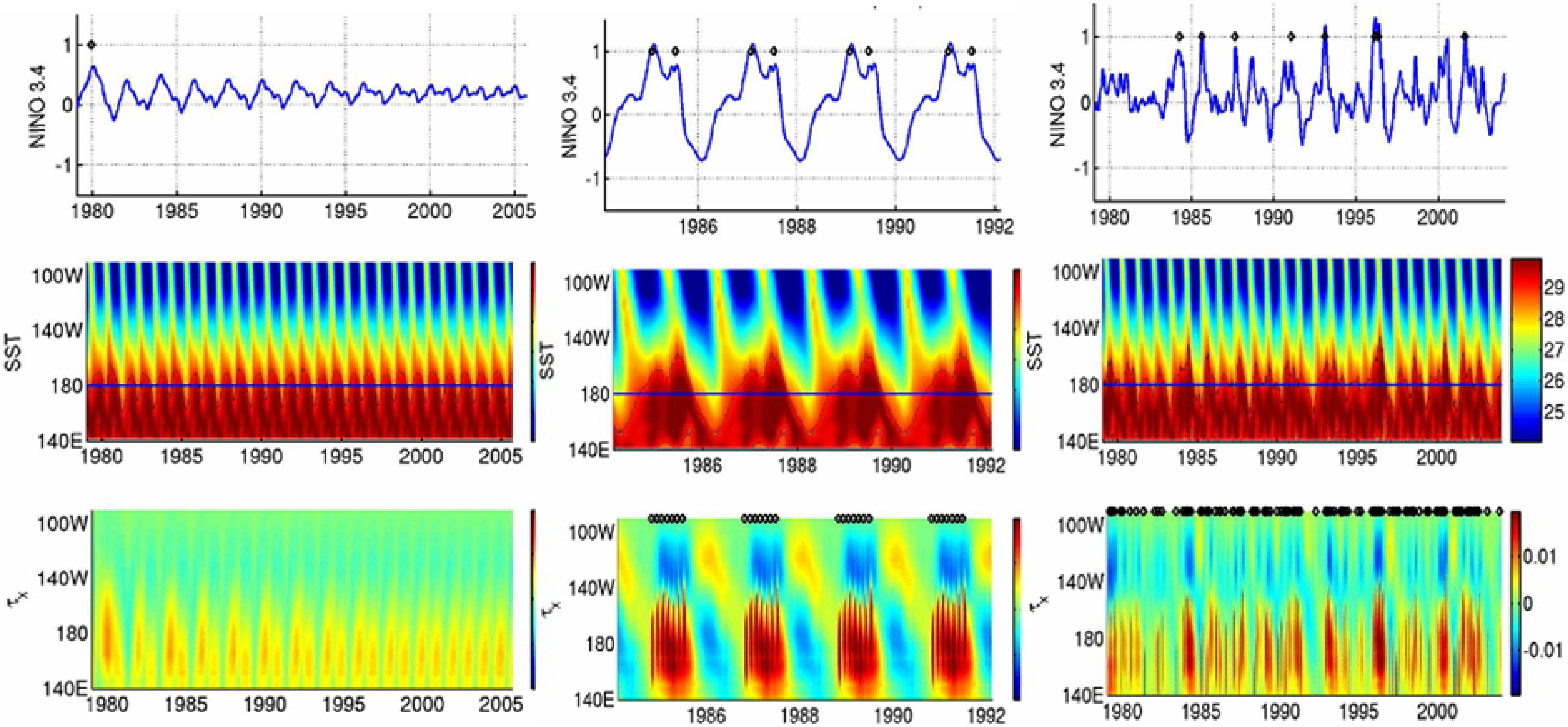
1. Statistical component
   - Linear regression of ECMWF tropical monthly mean wind stress (with WWBs subtracted) on SST (1979-2001)
2. WWB component
   - WWBs (resembling composite of observations) occur when warm pool extends, or stochastically




*Gebbie, Eisenman, Wittenberg, Tziperman; in prep*

# Hybrid coupled model results

no WWBs | modulated WWBs | stochastic WWBs




- Coupling strength determined from observations
- Decays to seasonal cycle

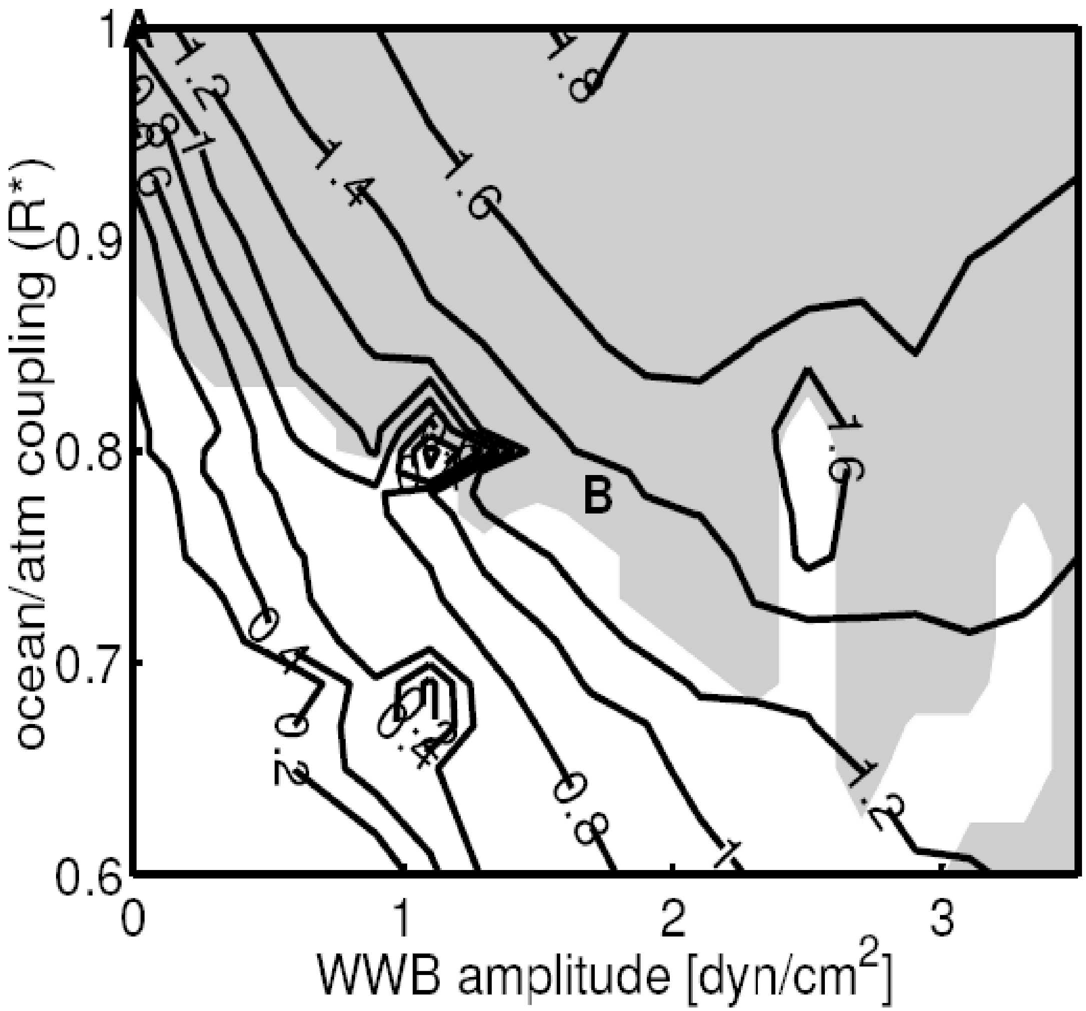
- std(NINO3)=0.6° C
- 3.5 WWBs/yr

- std(NINO3)=0.3° C
- 3.5 WWBs/yr

ENSO responds **twice** as strongly with modulated WWBs (as in CZ model)

# Results: rough equivalence between ocean-atm coupling and WWB amplitude

Introducing WWBs is similar to increasing the ocean-atmosphere coupling strength.



# Summary

• We treated WWBs as deterministic events regulated by large-scale SST, in contrast to usual view of WWBs as external stochastic forcing.

•We found, using intermediate complexity model and hybrid GCM

- Modulation of WWBs by warm pool leads to **twice as large** ENSO amplitude than purely stochastic WWBs

- Equivalence between air-sea coupling strength & WWB amplitude: WWBs, commonly seen as proof that ENSO is damped, may actually make ENSO self-sustained

- ENSO irregularity driven by deterministic WWBs is due to chaos

*Eisenman, Yu, Tziperman (2005); in press J. Climate*
*Gebbie, Eisenman, Wittenberg, Tziperman (2005); in prep*

# Conclusions

•Proposed paradigm: WWBs, normally seen stochastic, are modulated by the large-scale SST.

•This has major implications for ENSO modelling (including WWB modulation leads to twofold increase in ENSO amplitude) and dynamics (self-sustained vs stochastically forced)

•Actual WWBs are partially stochastic & partially modulated; need to include this view in ENSO prediction models