Mesoscale coupled ocean-atmosphere Interaction; Tropical Instability Waves and Atmospheric Feedback

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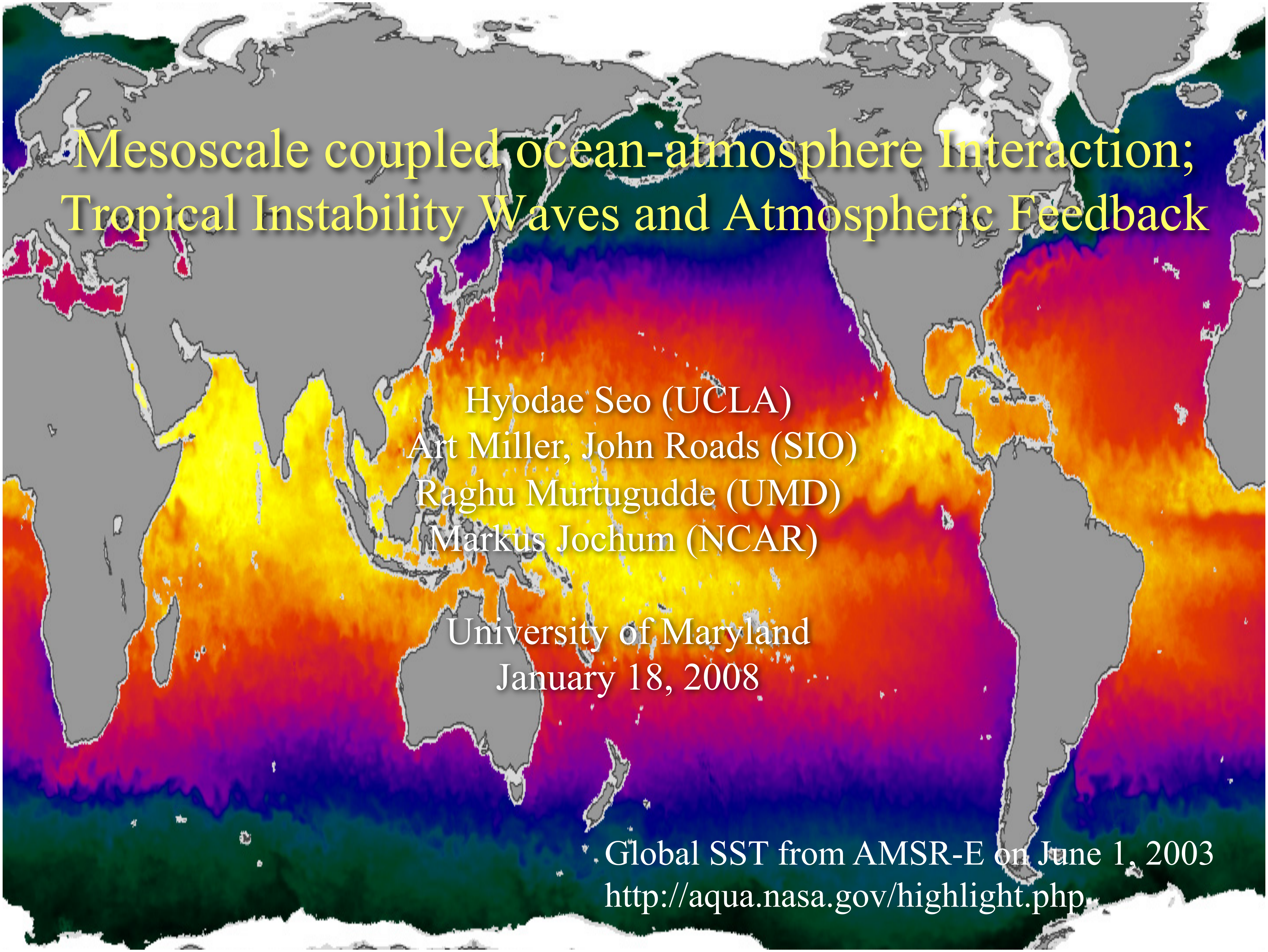
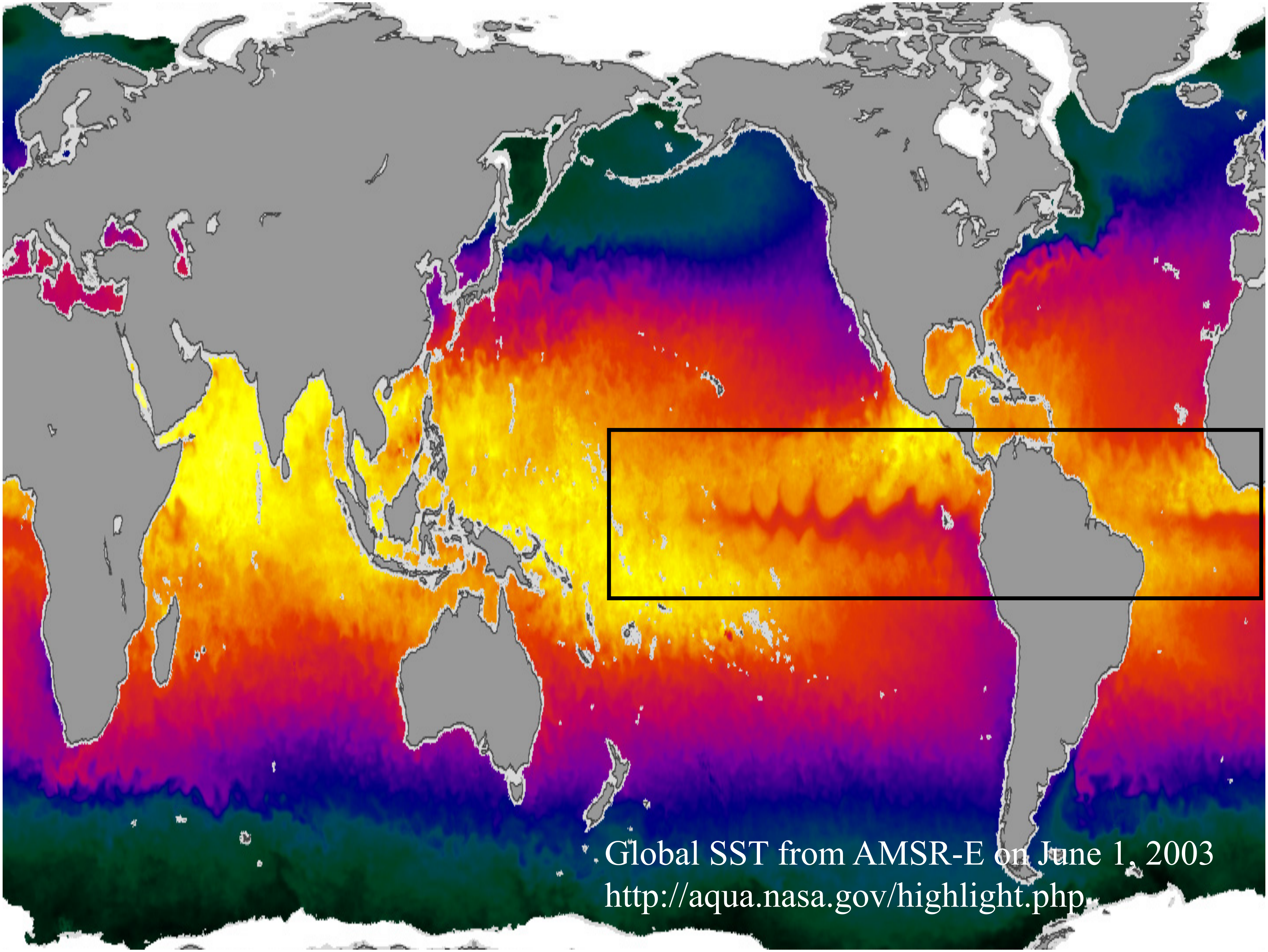
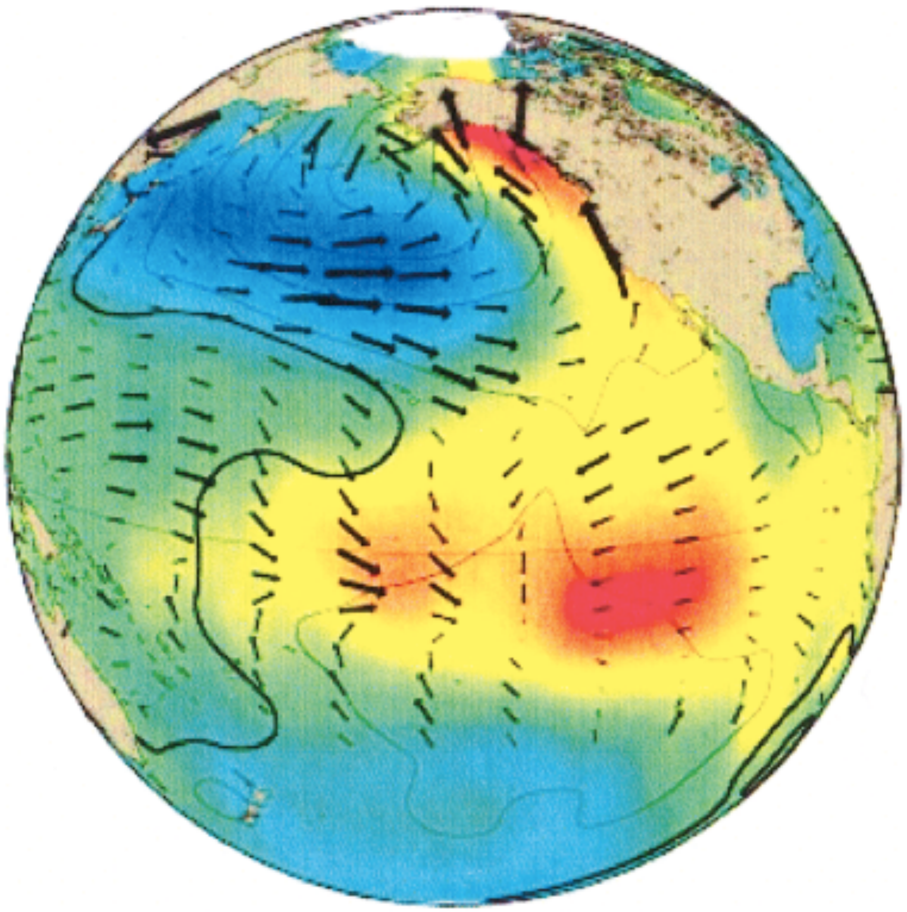


Global SST from AMSR-E on June 1, 2003
http://aqua.nasa.gov/highlight.php


Global SST from AMSR-E on June 1, 2003
http://aqua.nasa.gov/highlight.php

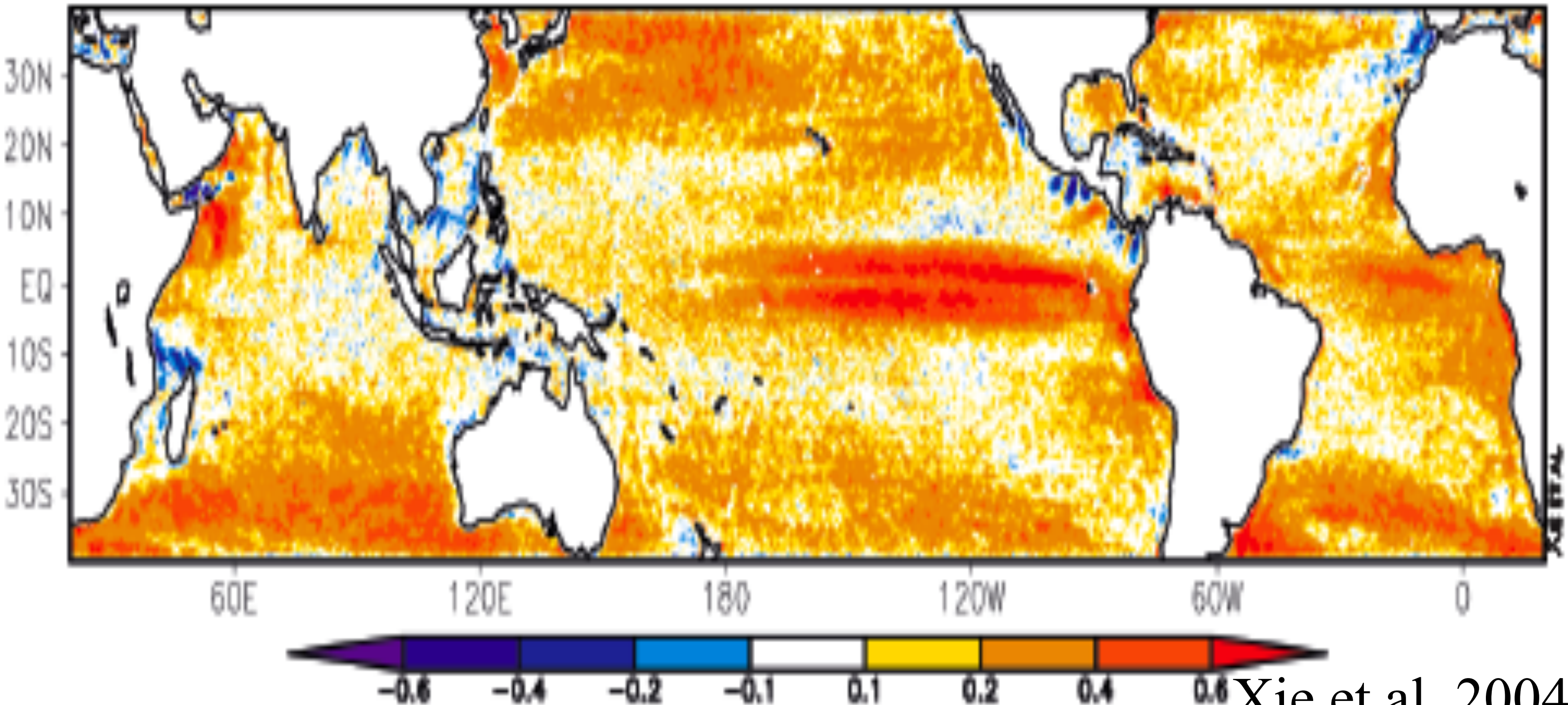
Relation of SST and wind speed on basin, seasonal scale



Matuna et al. 1999

- **Negative correlation:** **Atmospheric wind variability drives oceanic SST response through altered turbulent heat flux and possibly mixing process. (Atmosphere ➔ Ocean)**

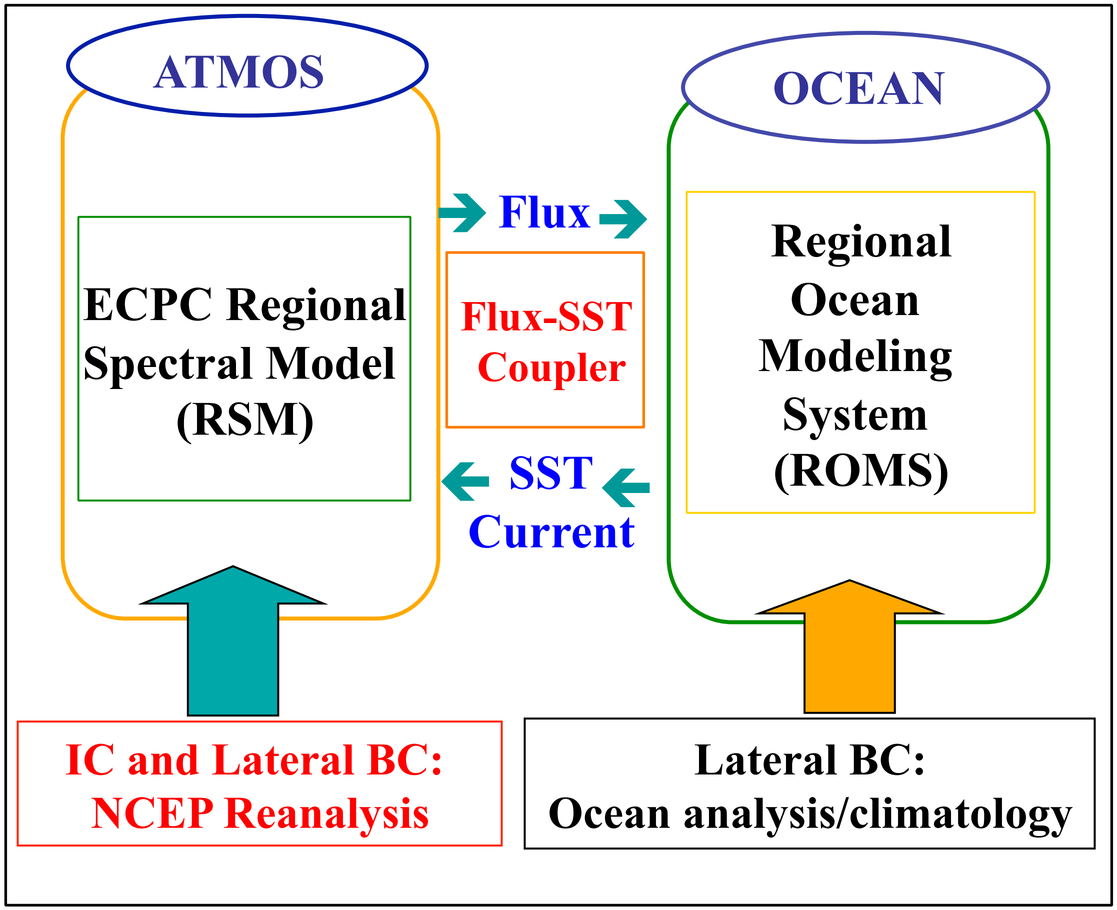
How about on oceanic mesoscale? (highpass filtering)



Xie et al. 2004

- **Correlation of SST (TMI) and wind speed (QuikSCAT) on <u>short/small scales</u>**
- **Positive correlation (Ocean ➔ Atmosphere)**
- **Negative correlation (Atmosphere ➔ Ocean)**

Scripps Coupled Ocean-Atmosphere Regional (SCOAR) Model



1) Higher model resolution

2) Dynamical consistency with the NCEP Reanalysis forcing

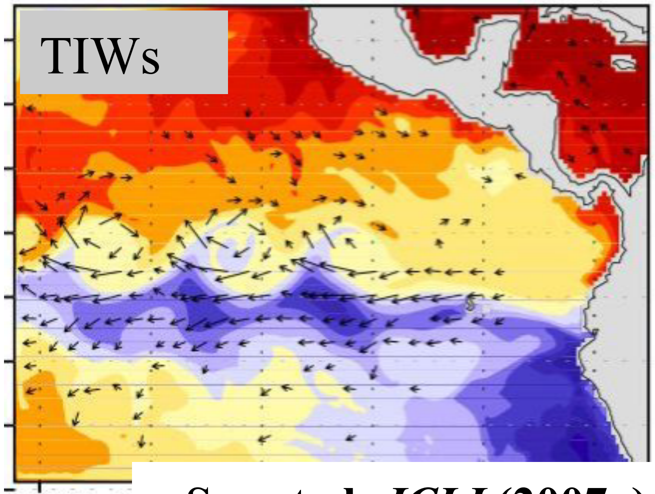
3) More complete and flexible coupling strategy

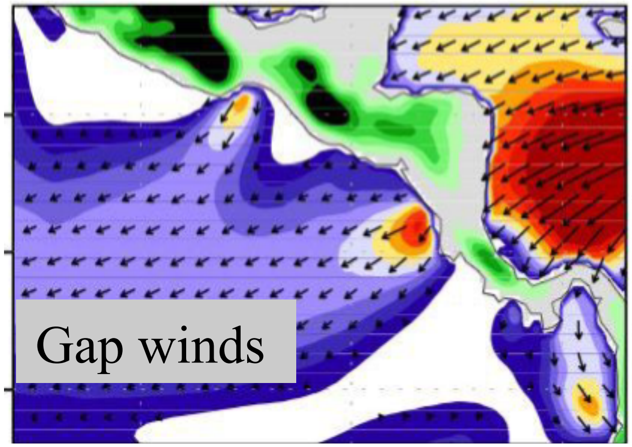
4) Parallel architecture

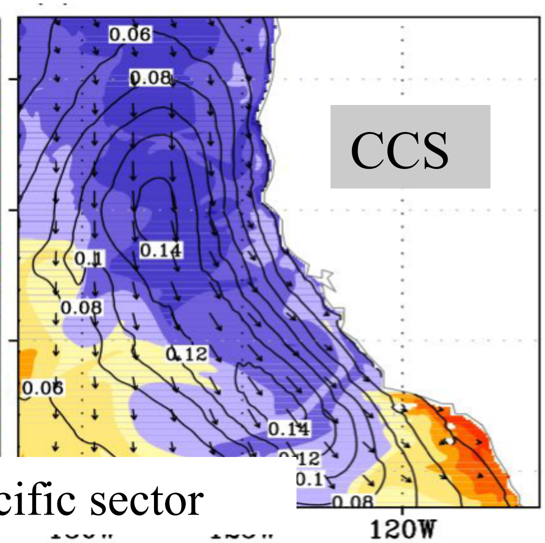
5) State-of-the-art physics

6) Greater portability

Purpose: Examine air-sea coupled feedback arising in the presence of oceanic and atmospheric mesoscale features

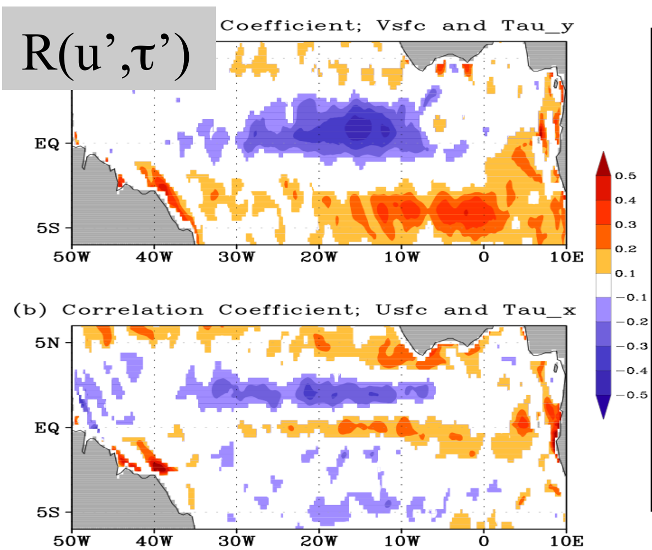


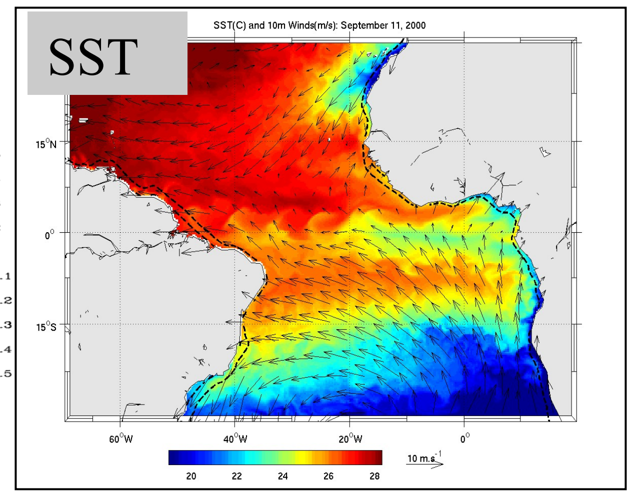


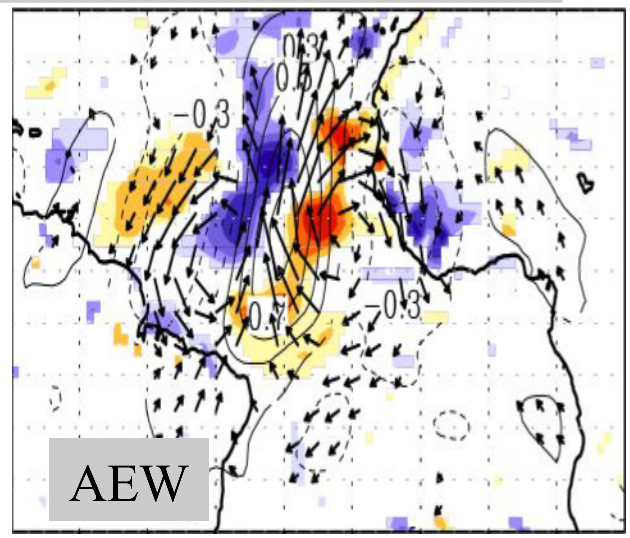


- **Seo et al. *JCLI* (2007a):** coupled processes in eastern Pacific sector

• Scripps Coupled Ocean-Atmosphere Regional (SCOAR) Model







- **Seo et al. *JCLI (2007b)***: **Atmospheric feedback** to TIWs

- **Seo et al. *GRL* (2006)**: Effect of **ocean mesoscale variability** on the tropical Atlantic climate

- **Seo et al. *JCLI* (*in press*)**: **African Easterly Waves** and ITCZ precipitation

Mesoscale ocean-atmosphere interaction: tropical instability waves and atmospheric feedback

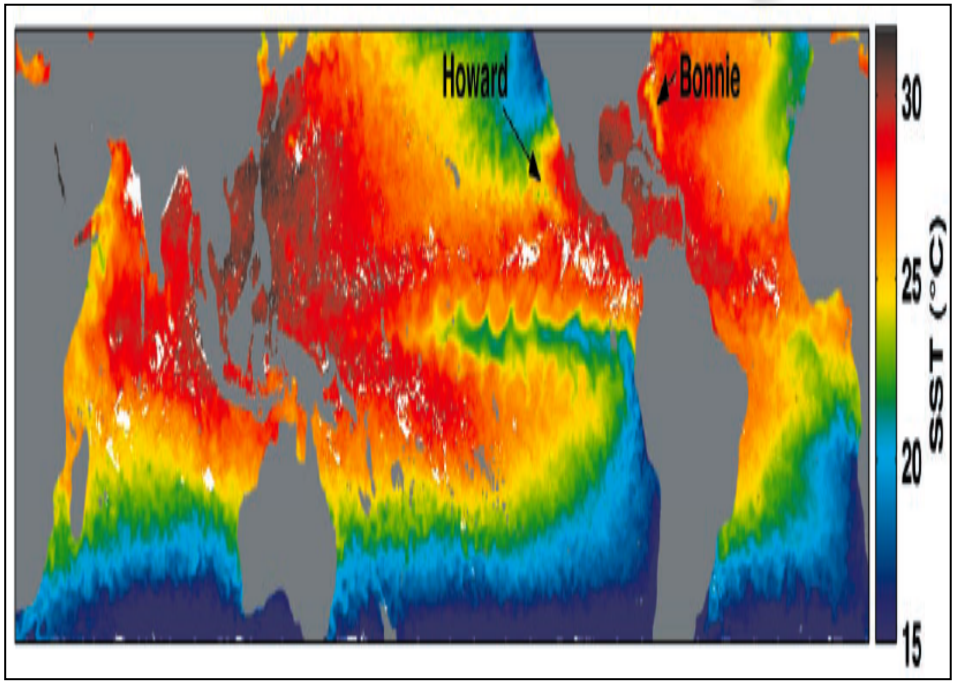
① Correlation of u'_{sfc} and τ'

② $\nabla \times \tau'$ and TIWs

③ LH' on SST of TIWs.

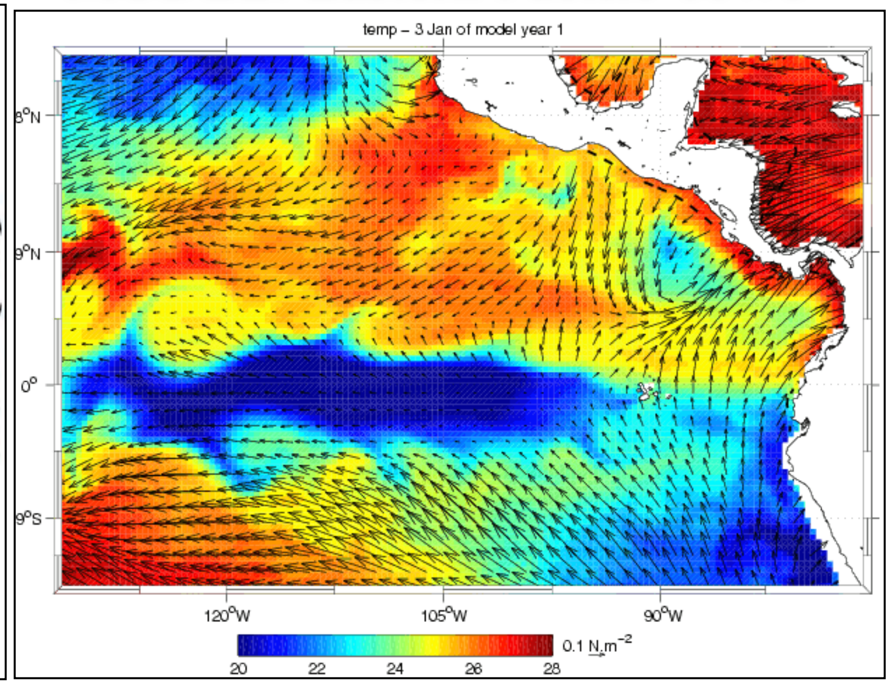
Tropical Instability Waves (TIWs);

OBS: TRMM Microwave Imager SST



Wentz et al. 2000;

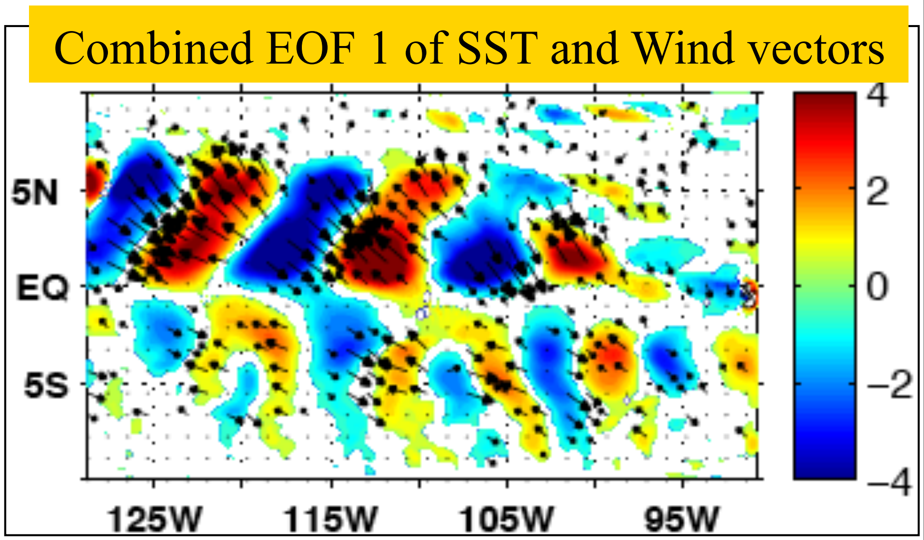
MODEL: Eastern Pacific TIWs

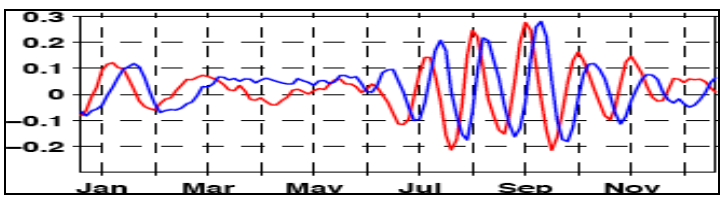


45 km ROMS + 50 km RSM, daily coupled

- Instability of equatorial currents and front
- Strong mesoscale ocean-atmosphere interactions

Feedback from wind response?





- **SST ➔ Wind**

1) Direct influence from SST

(Wallace et al. 1989;
Lindzen and Nigam 1987)

2) Modification of wind stress curl

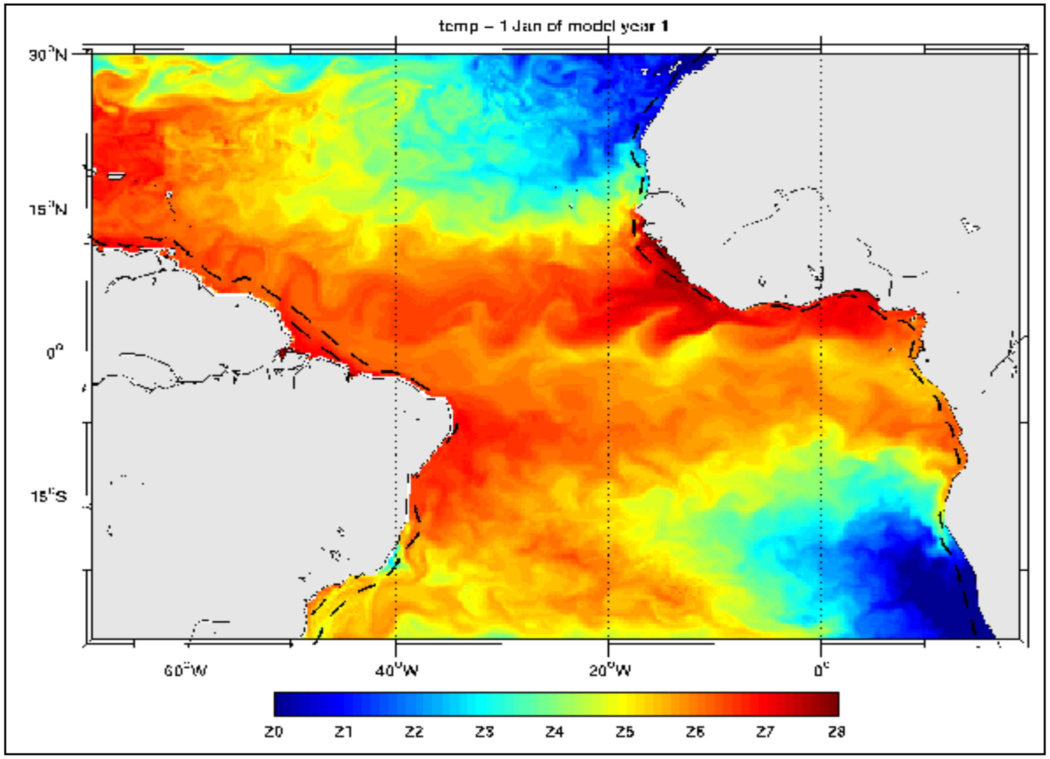
(Chelton et al. 2001)

- **An idealized study (Pezzi et al. 2004): wind-SST coupling (that includes both effects) *slightly* reduces variability of TIWs.**

- **But.. why?**

① Covariability (correlation) of u'_{sfc} and $\boldsymbol{\tau}'$

Covariability of u'_{sfc} and $\boldsymbol{\tau}'$



- Daily coupled 6-year simulations (1999-2004) 1/4° ROMS + 1/4° RSM
- Effect of **correlation** of $\boldsymbol{u'_{sfc}}$ and $\boldsymbol{\tau'}$ on the EKE of the waves

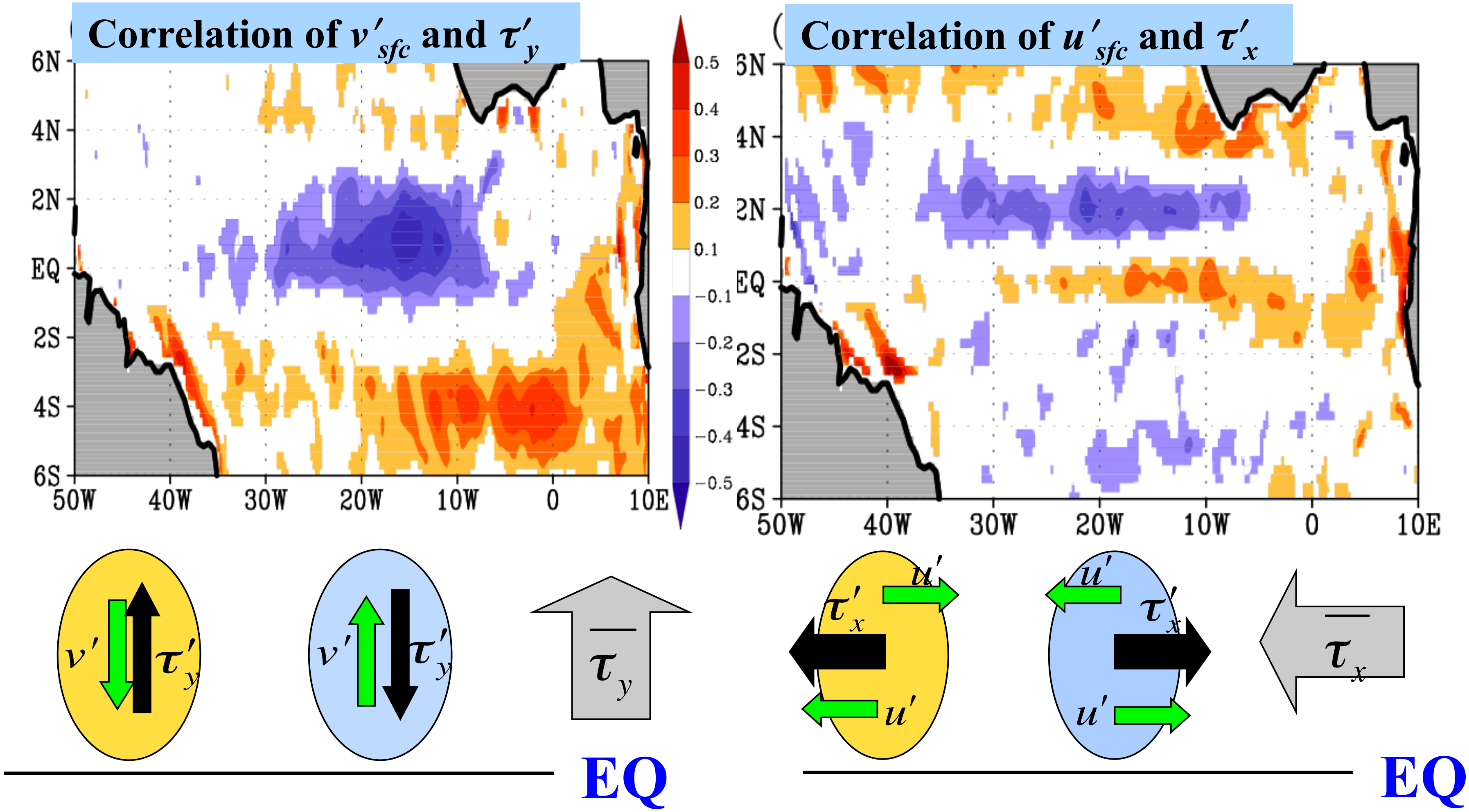
EKE Equation

$$\vec{U}\cdot\vec{\nabla}\vec{K}_e + \vec{u}'\cdot\vec{\nabla}\vec{K}_e = -\vec{\nabla}\cdot(\vec{u}'p') - g\rho'w' + \rho_o(-\vec{u}'\cdot(\vec{u}'\cdot\vec{\nabla}\vec{U}))$$

$$+\rho_o A_h \vec{u}'\cdot\nabla^2\vec{u}' + \rho_o\vec{u}'\cdot(A_v\vec{u}'_z)_z + \vec{u}'_{sfc}\cdot\vec{\tau}'_z$$

Masina et al. 1999;
Jochum et al. 2004;

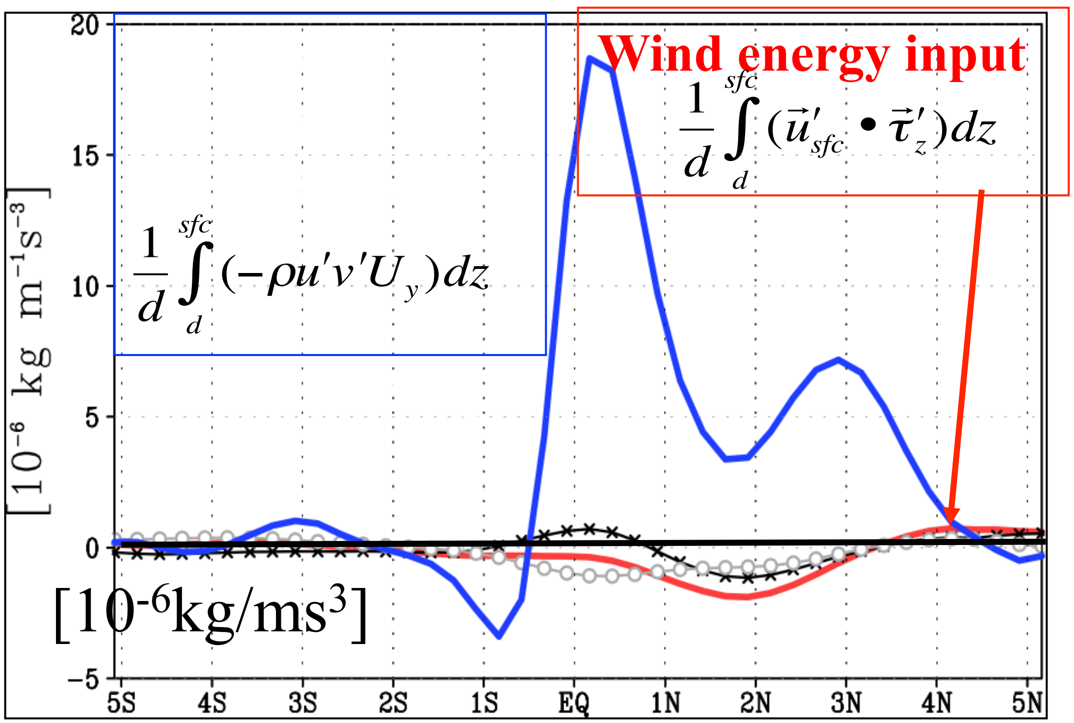
Correlation of TIW-current and wind response



- Wind and current are negatively correlated.
- Wind-current coupling ➔ Energy sink

EKE from the correlation of u'_{sfc} and τ'

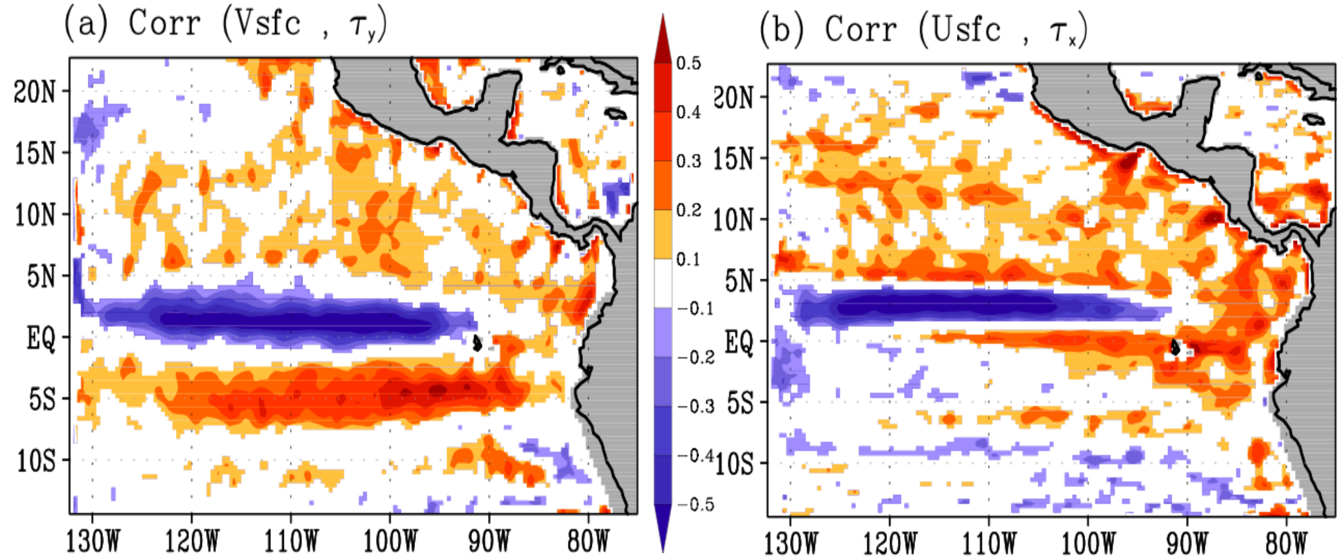
Averages: 30W-10W, 1999-2004, **0-150 m** depth

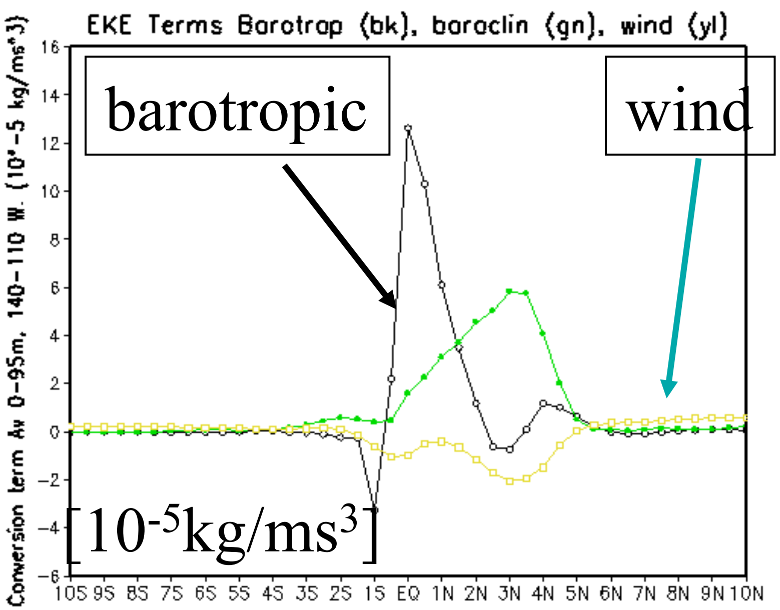


- Wind contribution to TIWs is ~10% of barotropic convergent rate.
- Small but important sink of energy
- Consistent with the previous study.

$$\vec{U}\cdot\vec{\nabla}\vec{K}_e + \vec{u}'\cdot\vec{\nabla}\vec{K}_e = -\vec{\nabla}\cdot(\vec{u}'p') - g\rho'w' + \rho_o(-\vec{u}'\cdot(\vec{u}'\cdot\vec{\nabla}\vec{U}))$$
$$+\rho_o A_h \vec{u}'\cdot\nabla^2\vec{u}' + \rho_o\vec{u}'\cdot(A_v\vec{u}'_z)_z + \vec{u}'_{sfc}\cdot\vec{\tau}'_z$$

How about the TIWs in the Pacific Ocean?





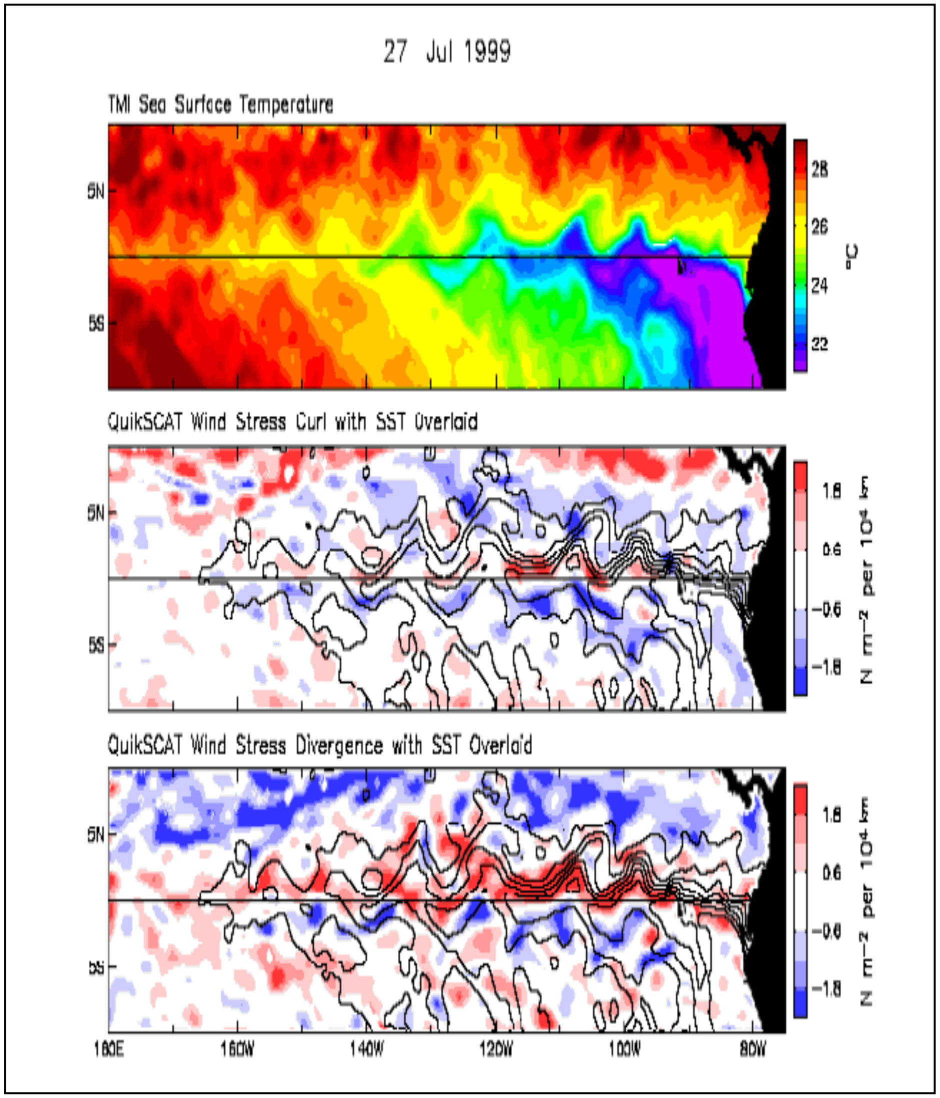
- IPRC Regional coupled model (IROAM) results are consistent with SCOAR results.
- Wind inputs are 10 times stronger in the Pacific.

IROAM results (from J. Small)

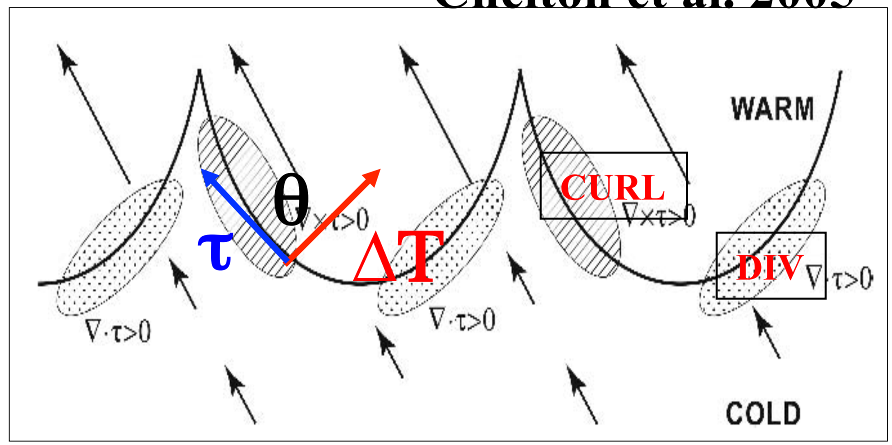
② Perturbation wind stress curl and TIWs

Coupling of SST gradient and wind stress derivatives

TRMM & QuikSCAT from D. Chelton



Chelton et al. 2005



- WSD is linearly related to Downwind SST gradient ➔

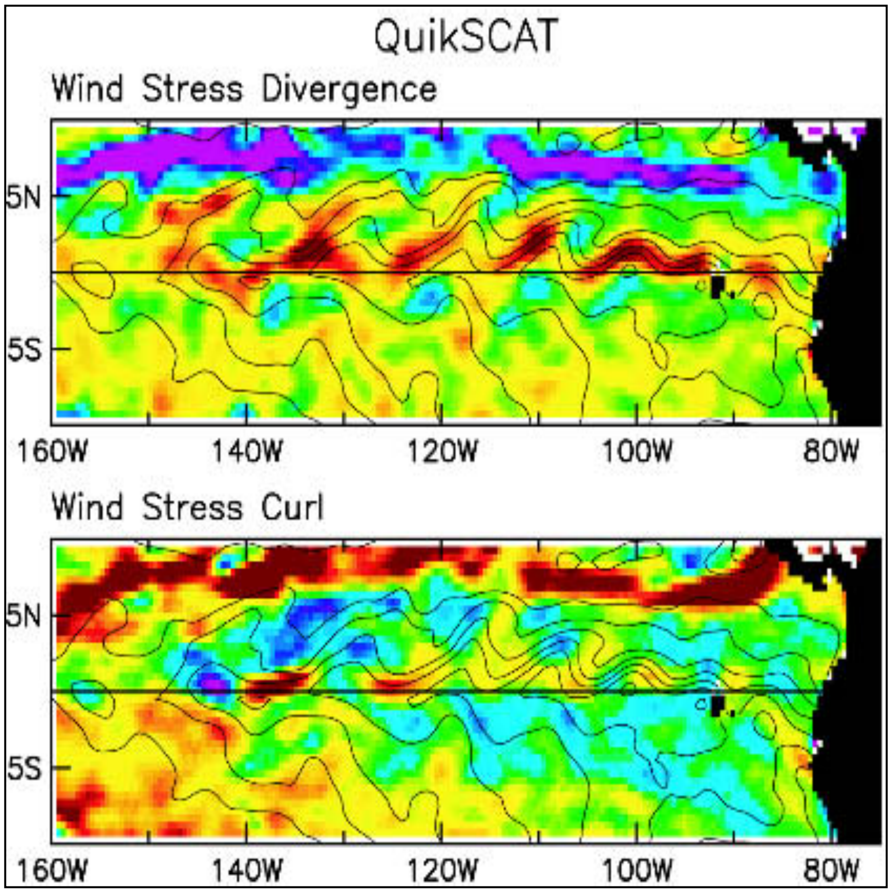
$$\nabla T \bullet \hat{\tau} = |\nabla T| \cos\theta$$

- WSC is linearly related to Crosswind SST gradient ➔

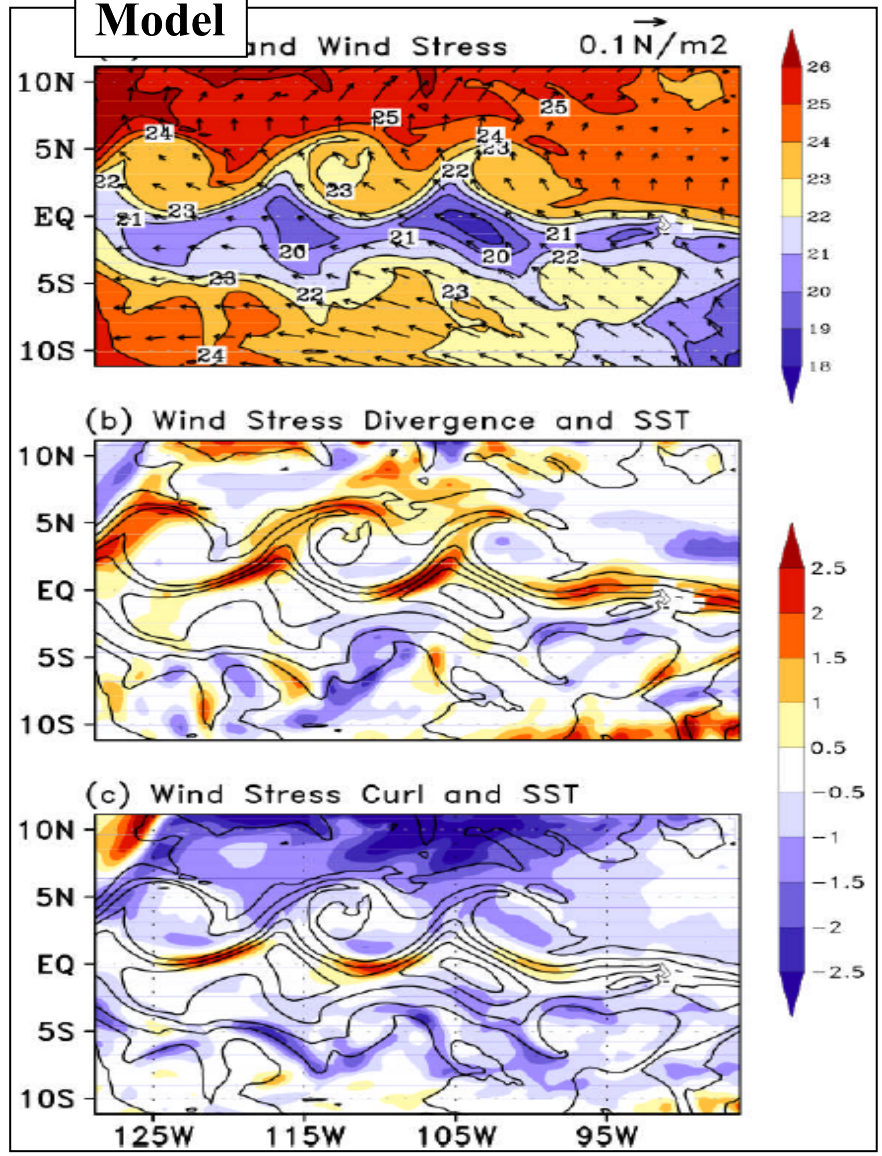
$$\nabla T \times \hat{\tau} \bullet \hat{k} = |\nabla T| \sin\theta$$

Coupling of SST gradient and wind stress derivatives

OBS: Chelton et al. 2005



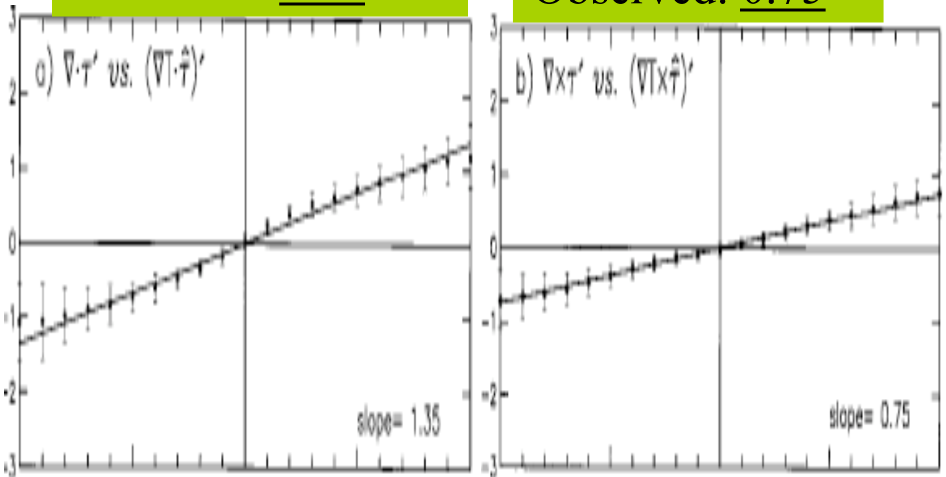
Model



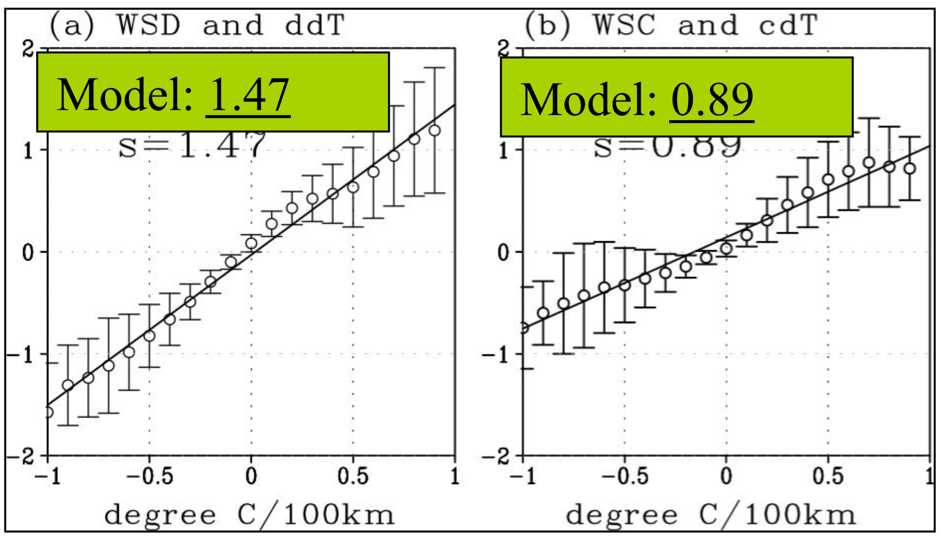
Coupling strength (coefficient)

WSD and DdT — Observed: 1.35

WSC and CdT — Observed: 0.75



Chelton et al. 2001



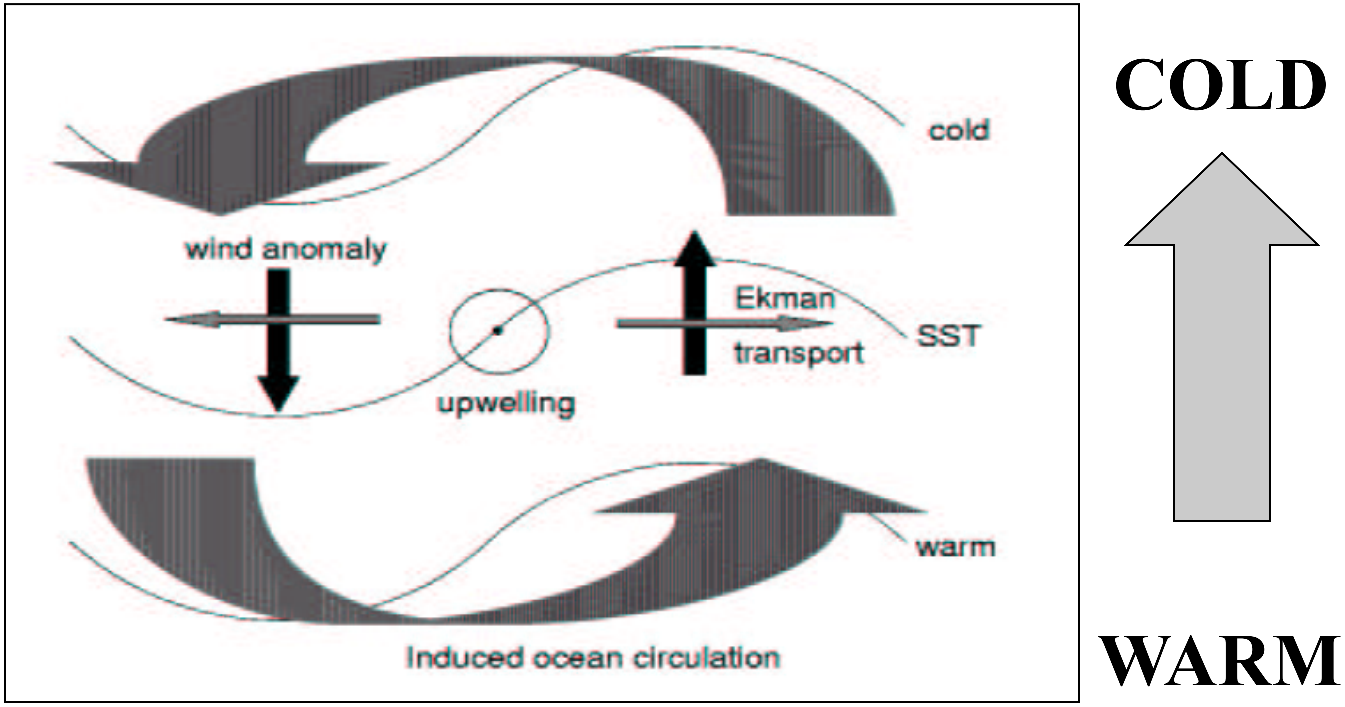
Model: 1.47

Model: 0.89

- 5S-5N, 125-100W, July-December, 1999-2003

- The SCOAR model well reproduced the observed linear relationship in the eastern tropical Pacific TIW case.

So, does this perturbation wind stress curl feed back on to TIWs?



- **Spall (2007):** Impact of the observed coupling on the baroclinc instability of the ocean
- Perturbation Ekman pumping *reduces* the growth rate of the most unstable wave.
- Condition: Southerly wind from cold to warm.

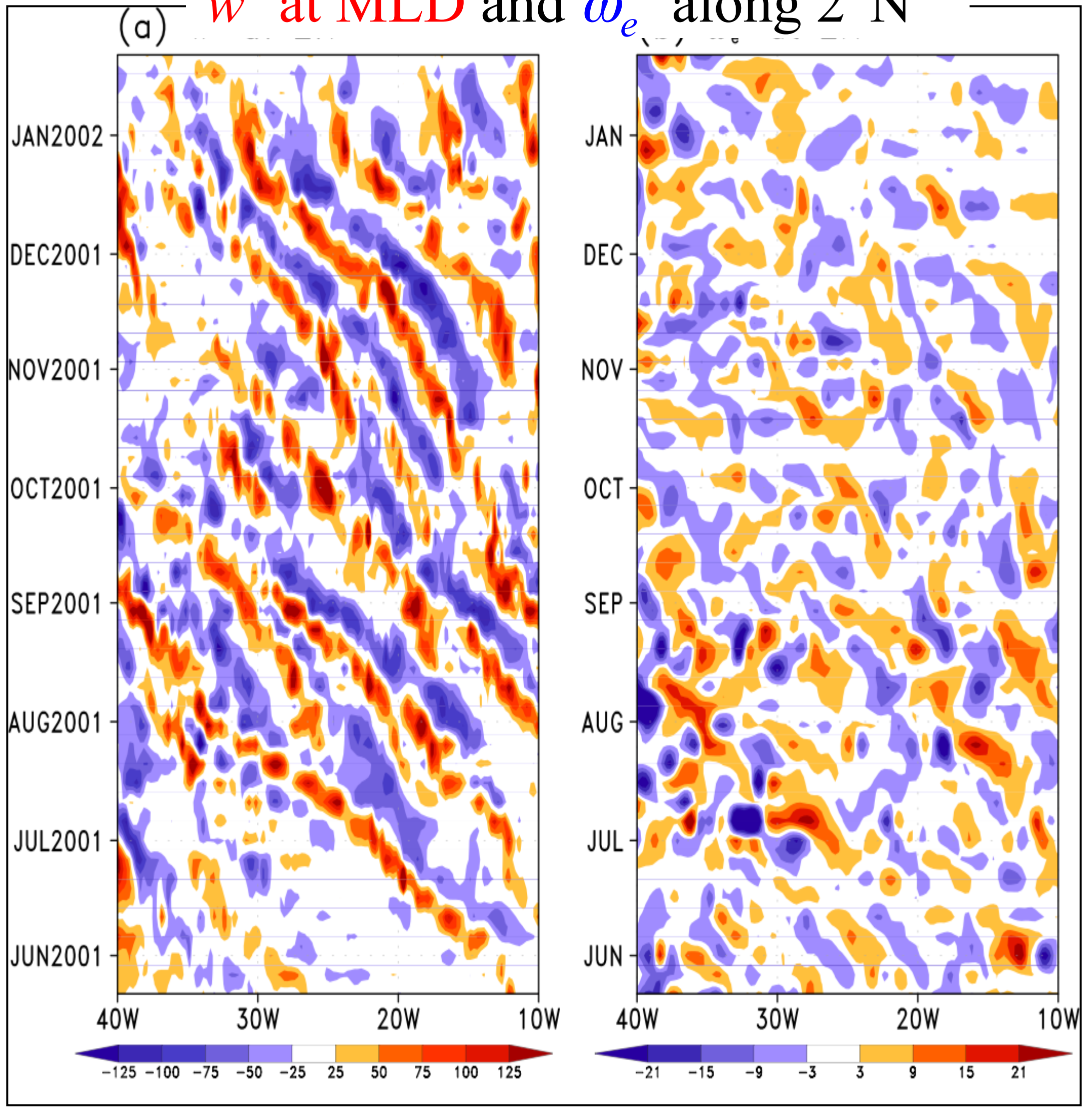
Feedback of perturbation Ekman pumping to TIWs

- Perturbation Ekman pumping velocity (ω_e') and perturbation vertical velocity (w') of $-g\rho' w'$.

- **Overall, ω_e' is much weaker than w'.**

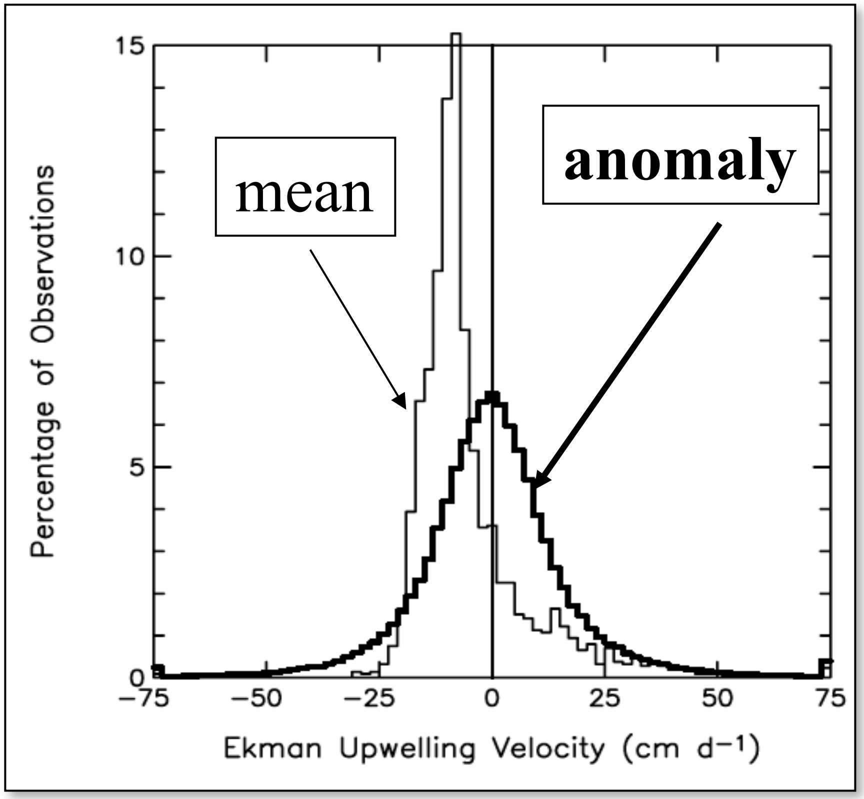
- Caveat: Difficult to estimate Ekman pumping near the equator, where wind stress curl is large.

w' at MLD and ω_e' along 2°N

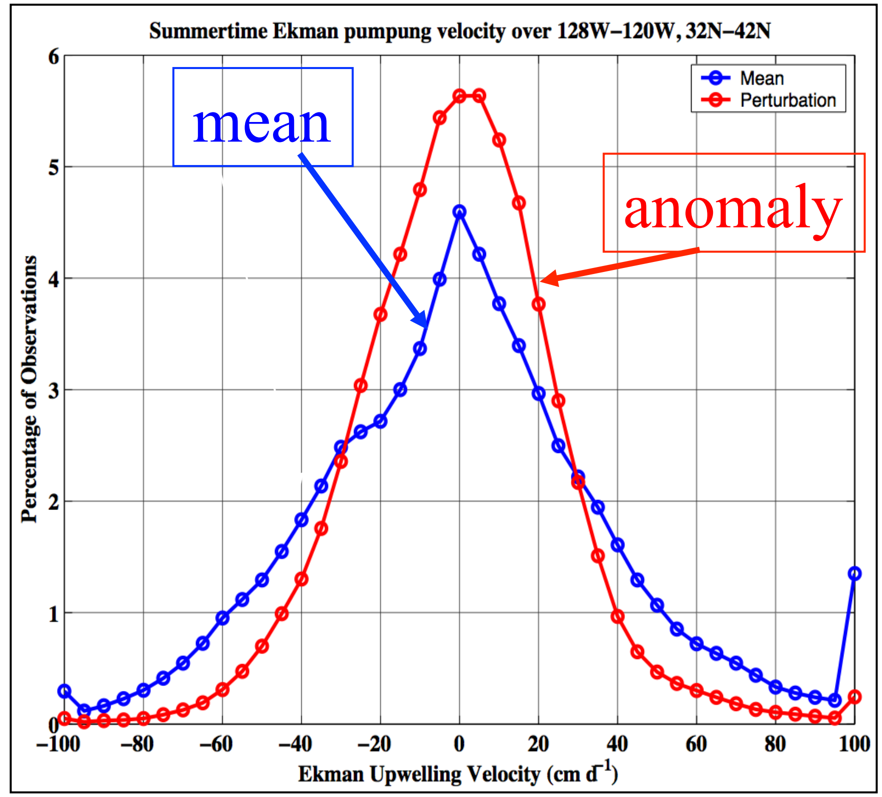


Unit: 10^{-6}m/s, Zonally highpass filtered, and averaged over 30W-10W

What about in the **mid-latitudes**, as in the CCS region?



(Chelton et al. 2007)



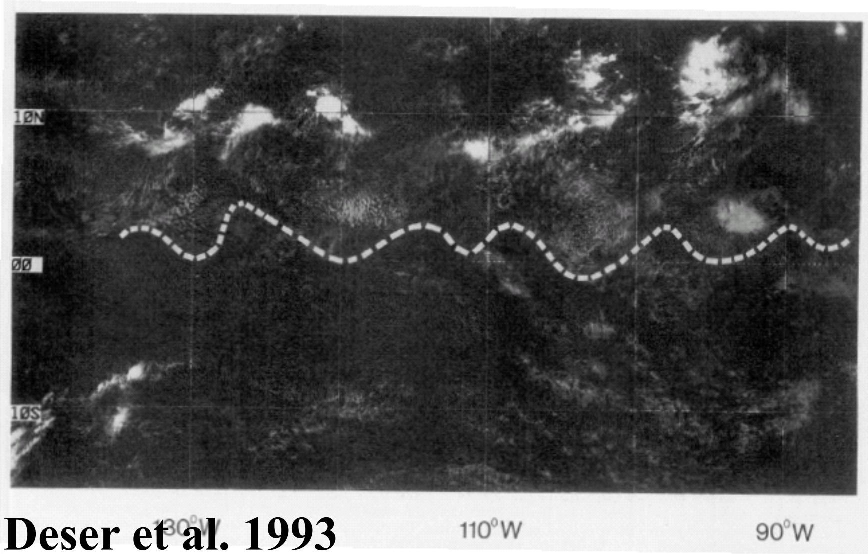
SCOAR Model

- SST-induced summertime Ekman upwelling velocity is as large as its mean. Feedback is important to ocean circulation and the SST.

③ Response and feedback of turbulent heat flux

Observations of radiative and turbulent flux

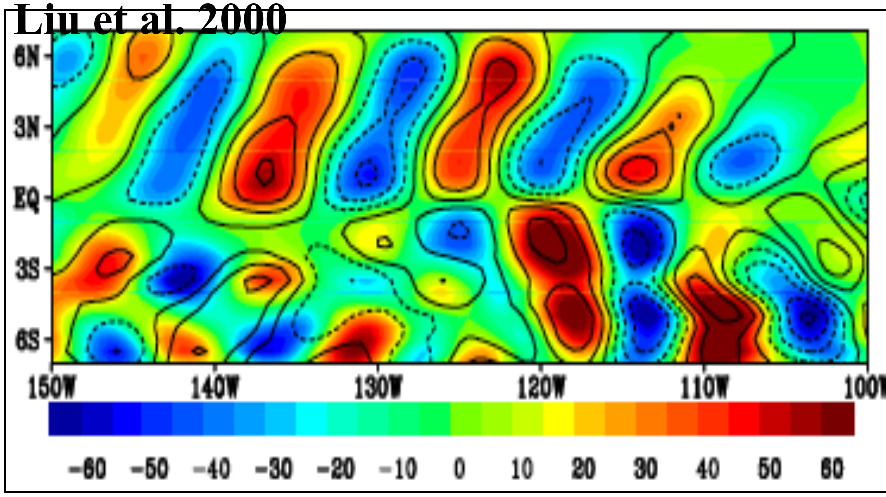
Solar heat flux and SST



Deser et al. 1993

Latent heat flux and SST

Liu et al. 2000



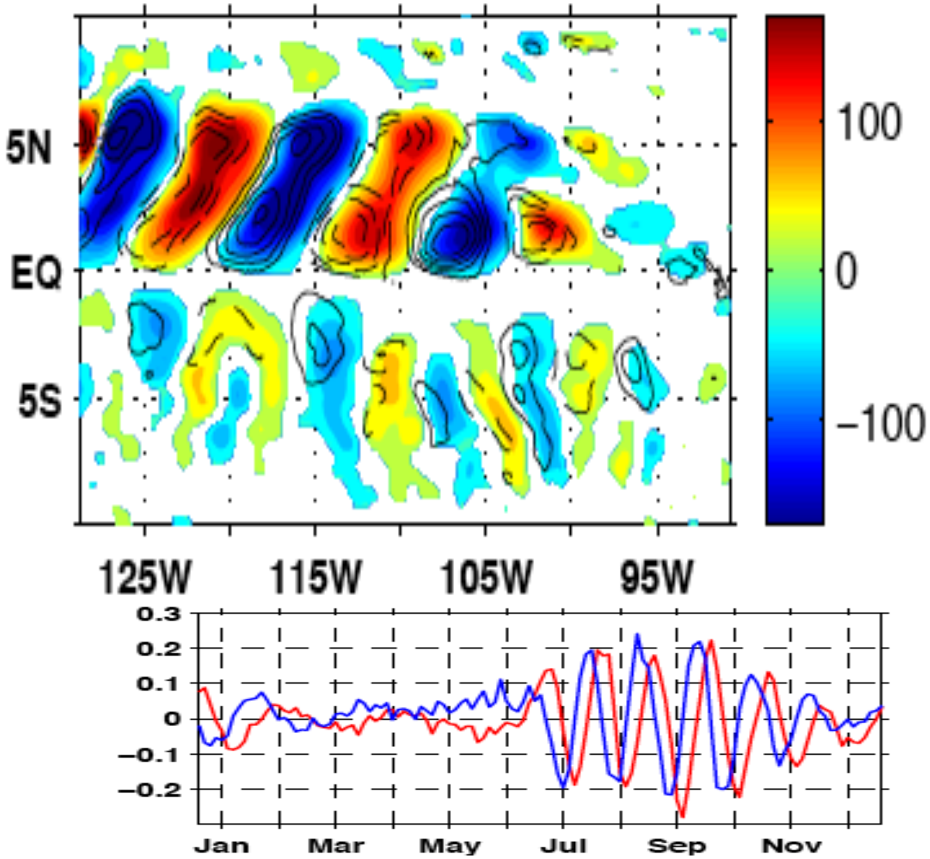
• Deser et al. (1993): changes in solar radiation of **~10 W/m²** due to 1K changes in SST
➔ **-0.75°C / month** (MLD=20m).

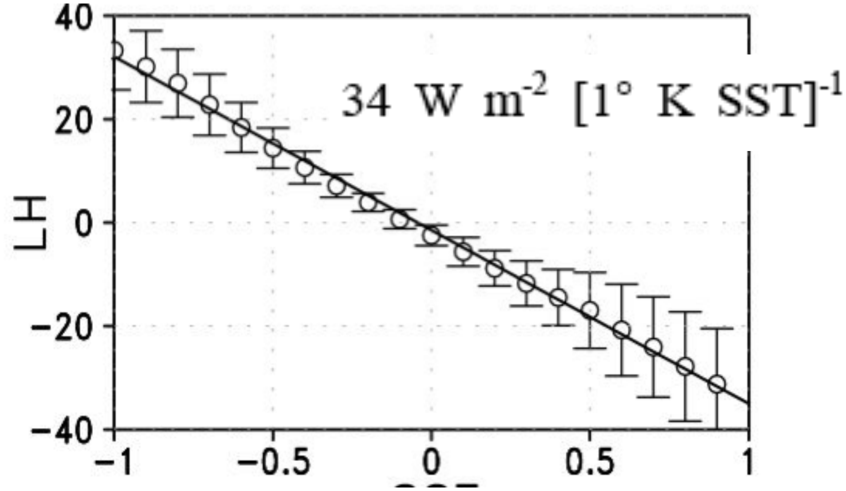
• Zhang and McPhaden (1995): **~50 W/m² per 1K** of latent heat flux.
• Thum et al. (2002) found a similar value and a simple heat balance results in **-0.5°C / month** (MLD=50m).

- Instantaneous damping of *local* SST by perturbation heat flux

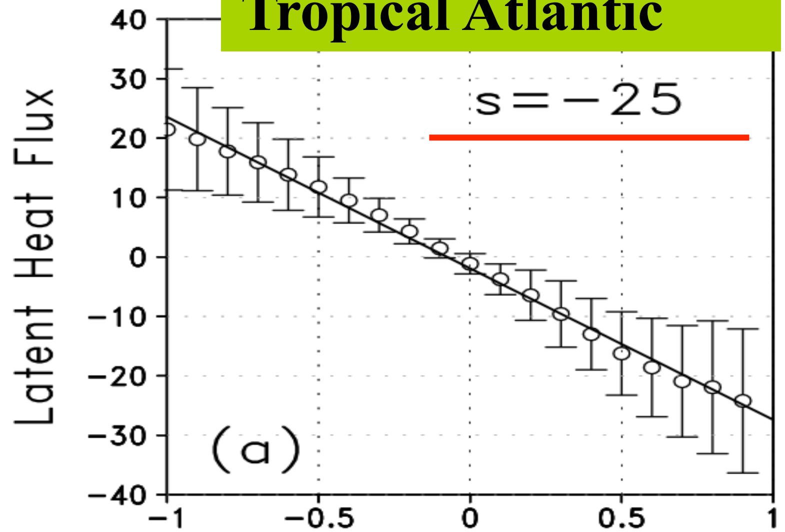
Coupling of SST and latent heat flux in SCOAR

Eastern Tropical Pacific





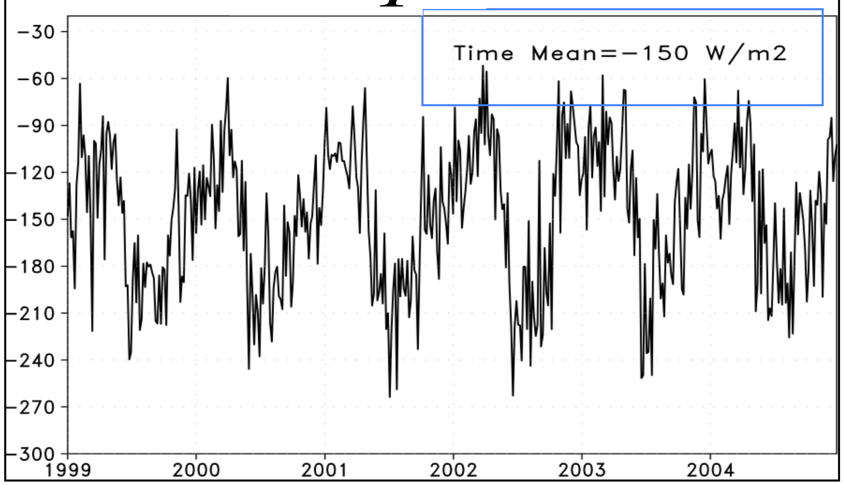
Tropical Atlantic



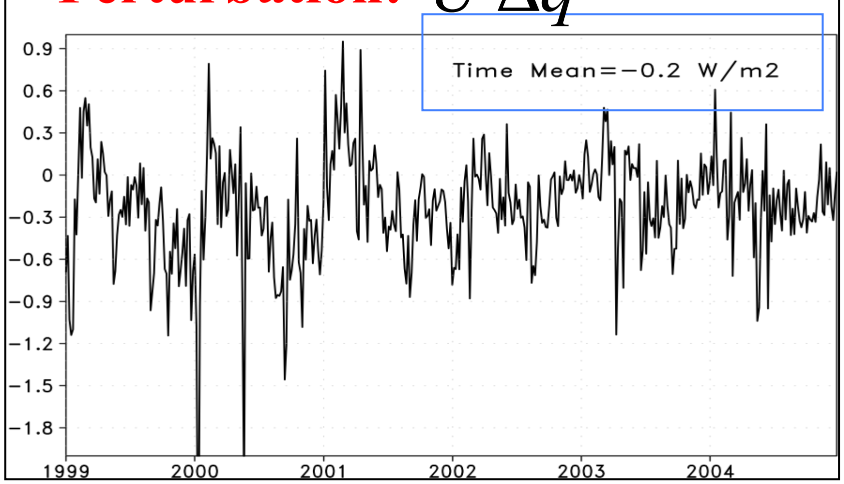
- Model results also suggest a damping by turbulent heat flux on the local SSTs.

③ Large-scale rectification from heat flux anomalies??

Mean: $\overline{U\Delta q}$



Perturbation: $U'\Delta q'$



Latent Heat Flux Parameterizations

$$LH = \rho L C_H U(\Delta q),$$

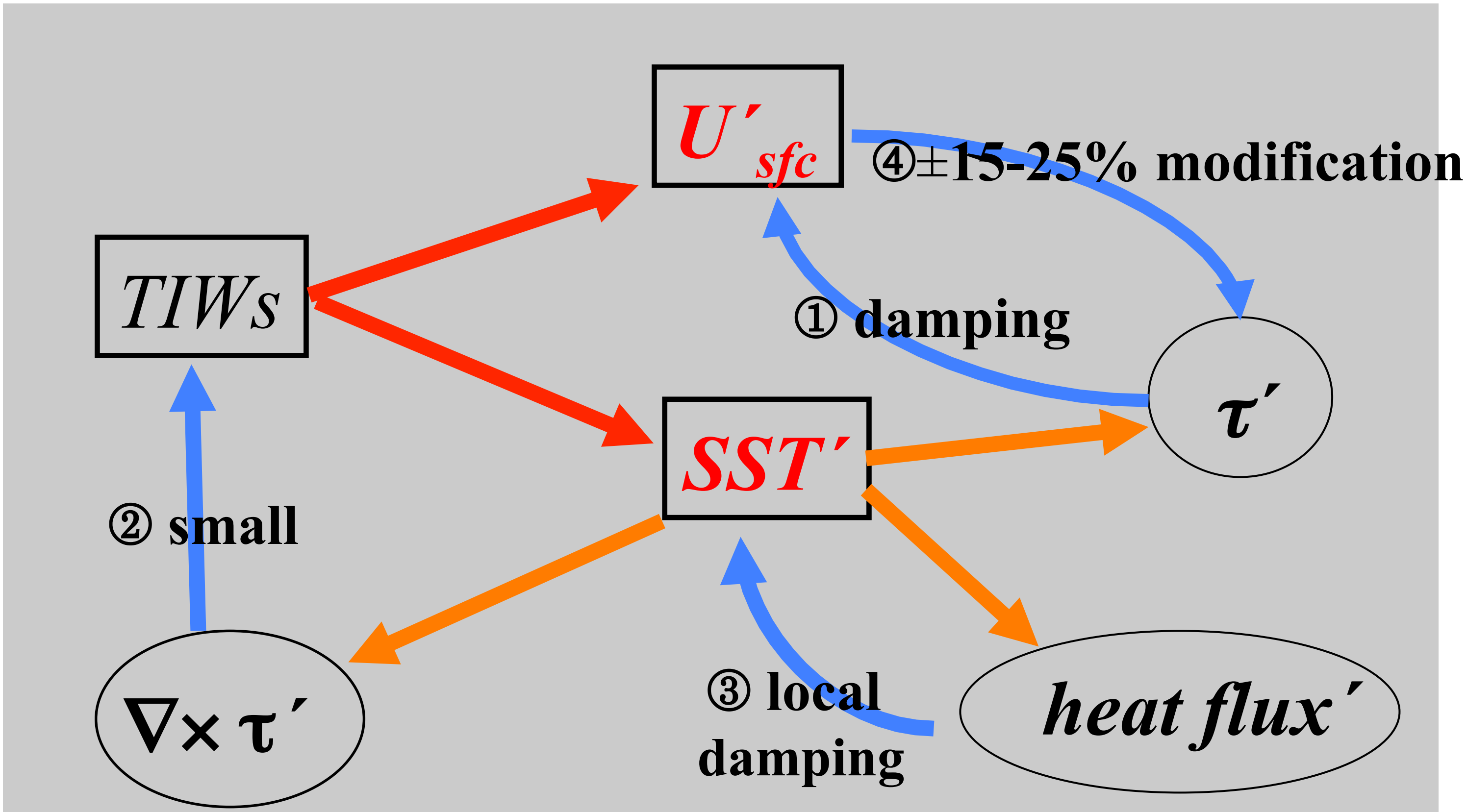
Reynolds averaging of LH ➔

$$\overline{LH} = \rho L C_H(\overline{U\Delta q} + \overline{U'\Delta q'}),$$

- Rectification by high-frequency (TIW-induced) LH' is small compared to mean LH.
- TIWs still operate over the large-scale SST gradient to modulate the temperature advection (Jochum and Murtugudde 2006, 2007).

6-year time series at 2°N averaged over 30°W-10°W

Summary; TIW-atmosphere coupling



① Wind response damps TIW-current: Small but significant damping

② Negligible contribution at 2N (difficult to estimate near the equator)

③ Damping of local SST (but small rectification to large-scale SST)

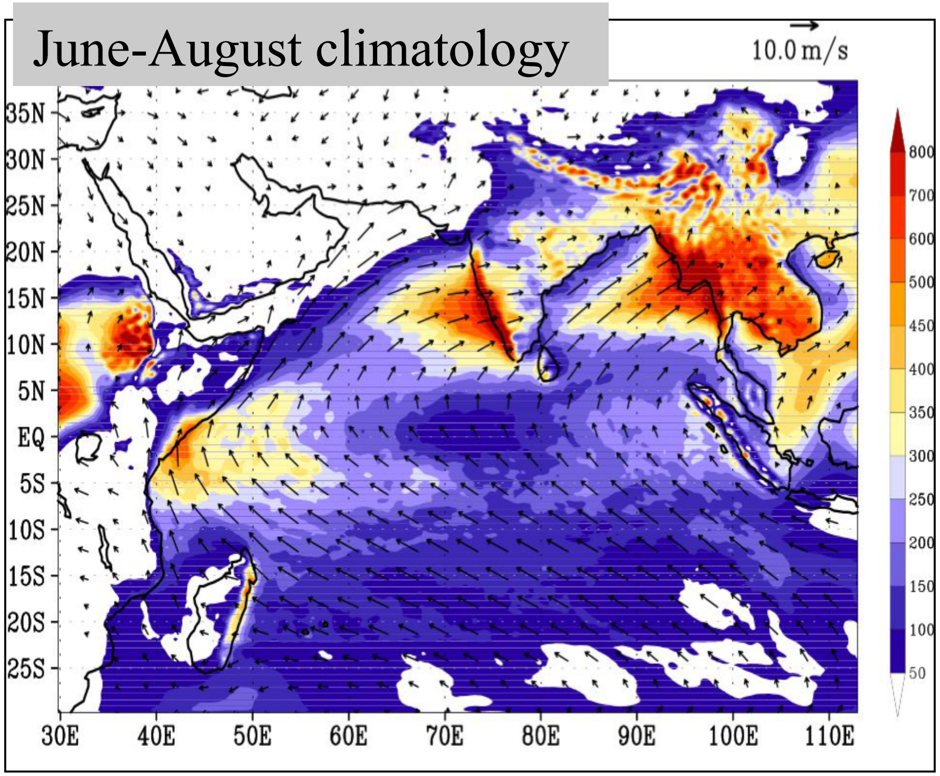
④ TIW-currents alter surface stress by ±15-25% depending on phase

Conclusion and outlook

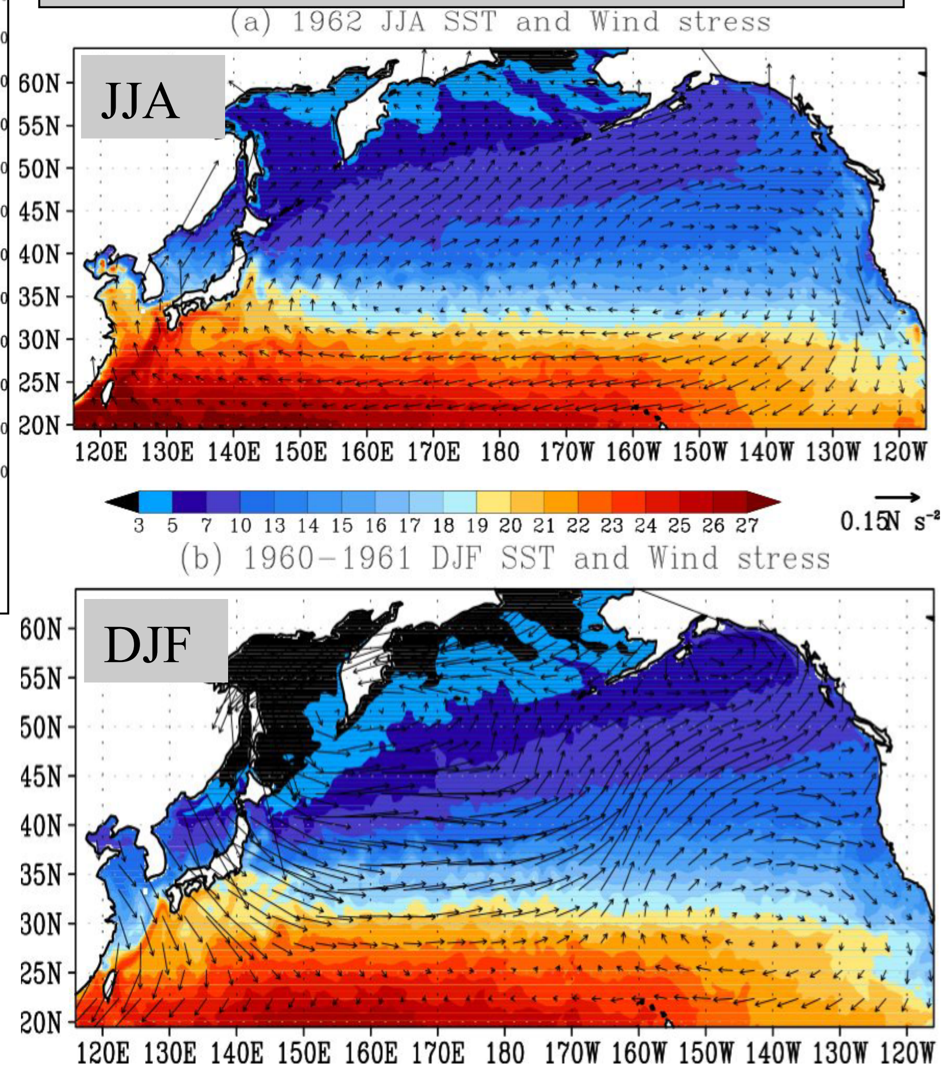
- Using this SCOAR model, we have studied
  1) mesoscale air-sea coupled feedbacks in the eastern Pacific sector, and
  2) connection with the large-scale climate variability in the tropical Atlantic sector.

- We continue to examine various aspects of coupled variability on many spatial and temporal scales occurring throughout the global ocean.

Some current works



North Pacific: Effect of eddies and the ocean atmosphere coupling on the KE variability and the downstream effect



Indian Ocean: Regional coupled processes in the western Arabian Sea, Bay of Bengal, and Southern IO. Their connection with the monsoonal and basin-scale variability.


Thanks!

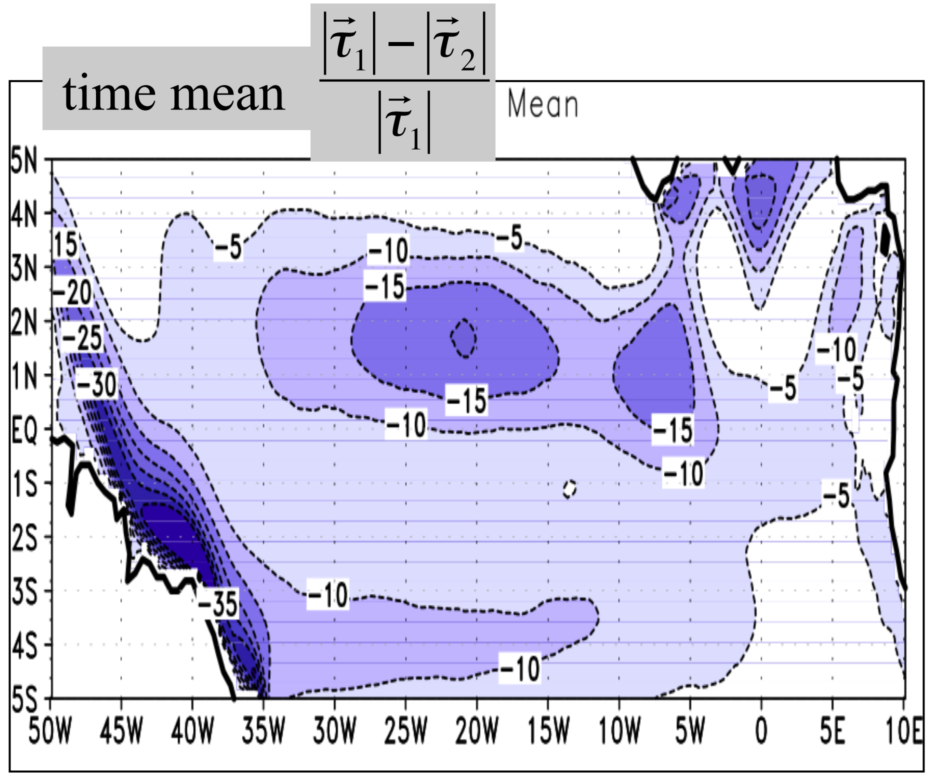
③ Impact of ocean current on the surface stress estimate

Kelly et al. (2001): wind difference measured from QuikSCAT and TAO array resembles mean equatorial surface currents.

③ Effect of ocean current on the surface stress estimate

$$|\vec{\tau}_1| = \rho C_d (\vec{u}_a - \vec{u}_o)^2$$
$$|\vec{\tau}_2| = \rho C_d (\vec{u}_a)^2$$

➔ $|\tau_1|$-$|\tau_2|$; effect of ocean currents (mean + TIW) on the surface wind stress



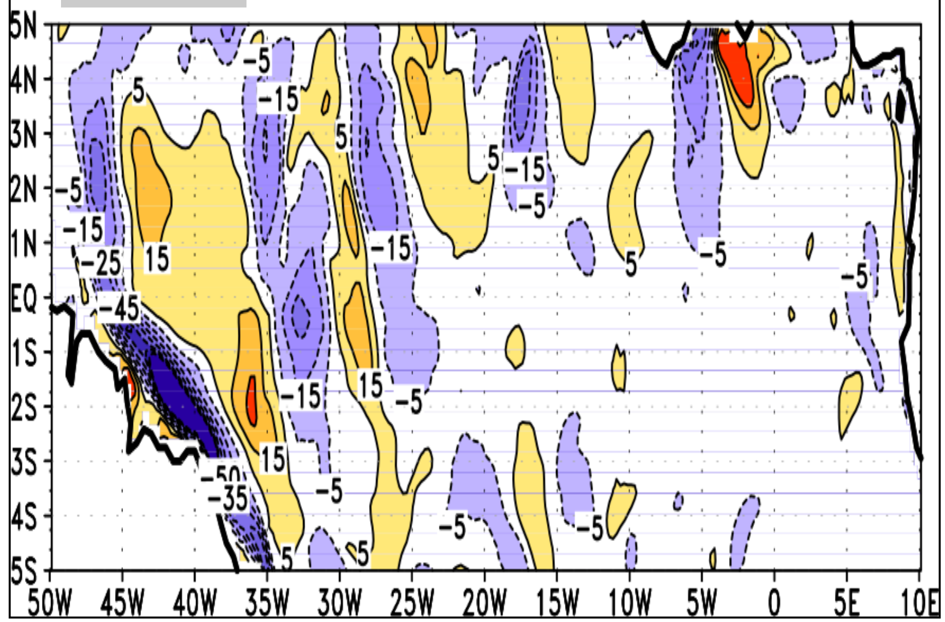
Ocean currents (mean + TIWs) reduce surface stresses by 15-20% (Pacanowski 1987; Luo et al. 2005; Dawe and Thompson 2006).

③ Effect of *perturbation* current on the surface stress estimate

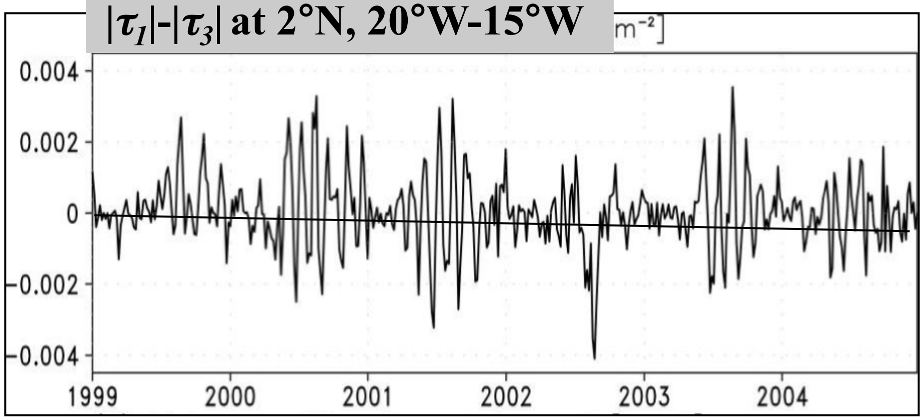
$$|\vec{\tau}_1| = \rho C_d(\vec{u}_a - \vec{u}_o)^2$$
$$|\vec{\tau}_3| = \rho C_d(\vec{u}_a - \vec{u}_{o\_lowpass})^2$$

➔ $|\tau_1|-|\tau_3|$; effect of perturbation ocean current velocity on wind stress

$\frac{|\vec{\tau}_1|-|\vec{\tau}_3|}{|\vec{\tau}_1|}$ on June 23, 2000



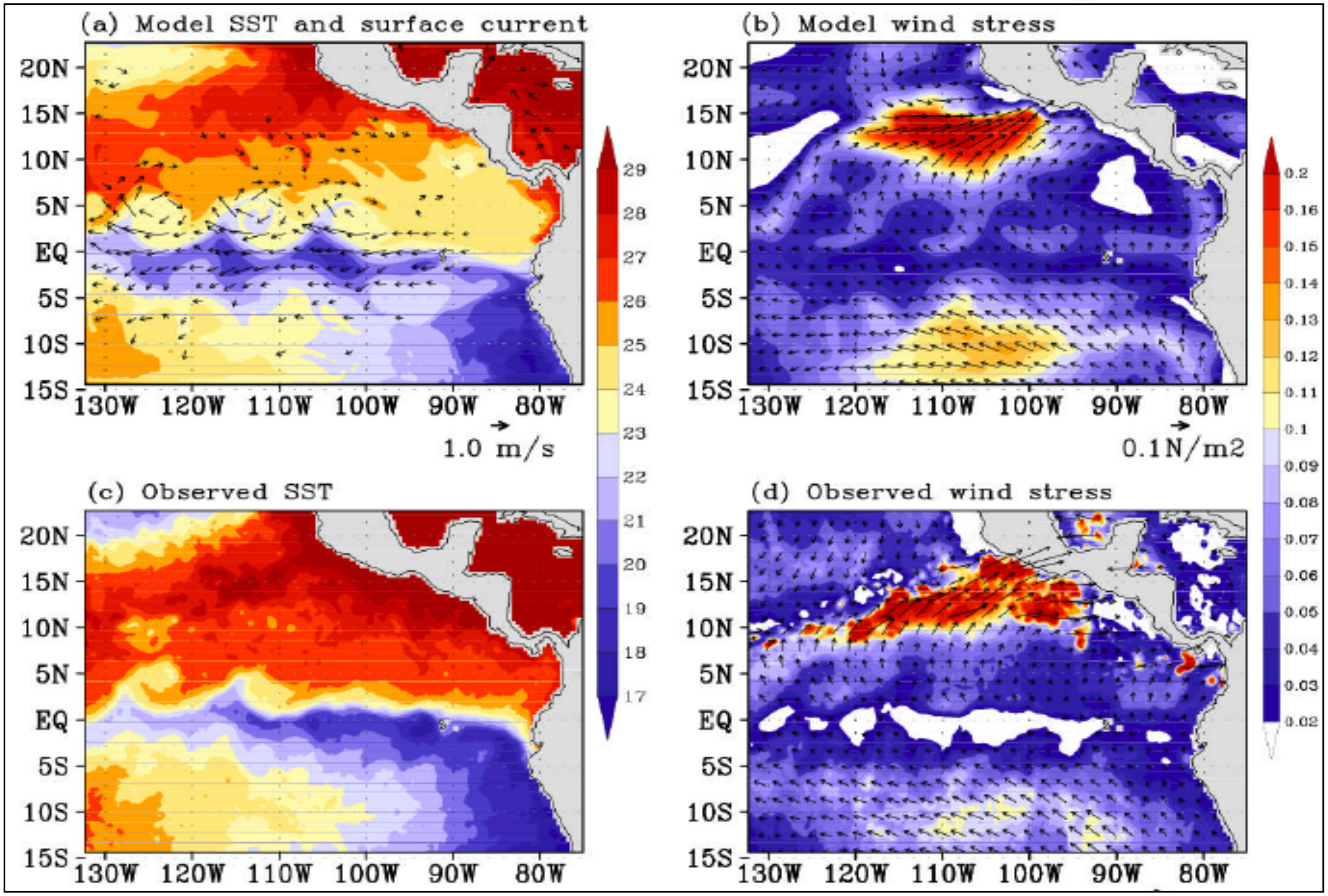
$|\tau_1|-|\tau_3|$ at 2°N, 20°W-15°W



Correlation with TIW currents : -0.83

TIW currents can modulate the surface stress estimate by ±15-25%. Consistency problem in a forced model with the QuikSCAT winds?

Modulation of SST and wind stress by TIWs



- 3-day averaged SST and wind stress centered on Sep. 3, 1999
- Stronger wind stress over the regions of warm water