Coupled Modeling of Mesoscale Air-Sea Interaction: Tropical Instability Waves

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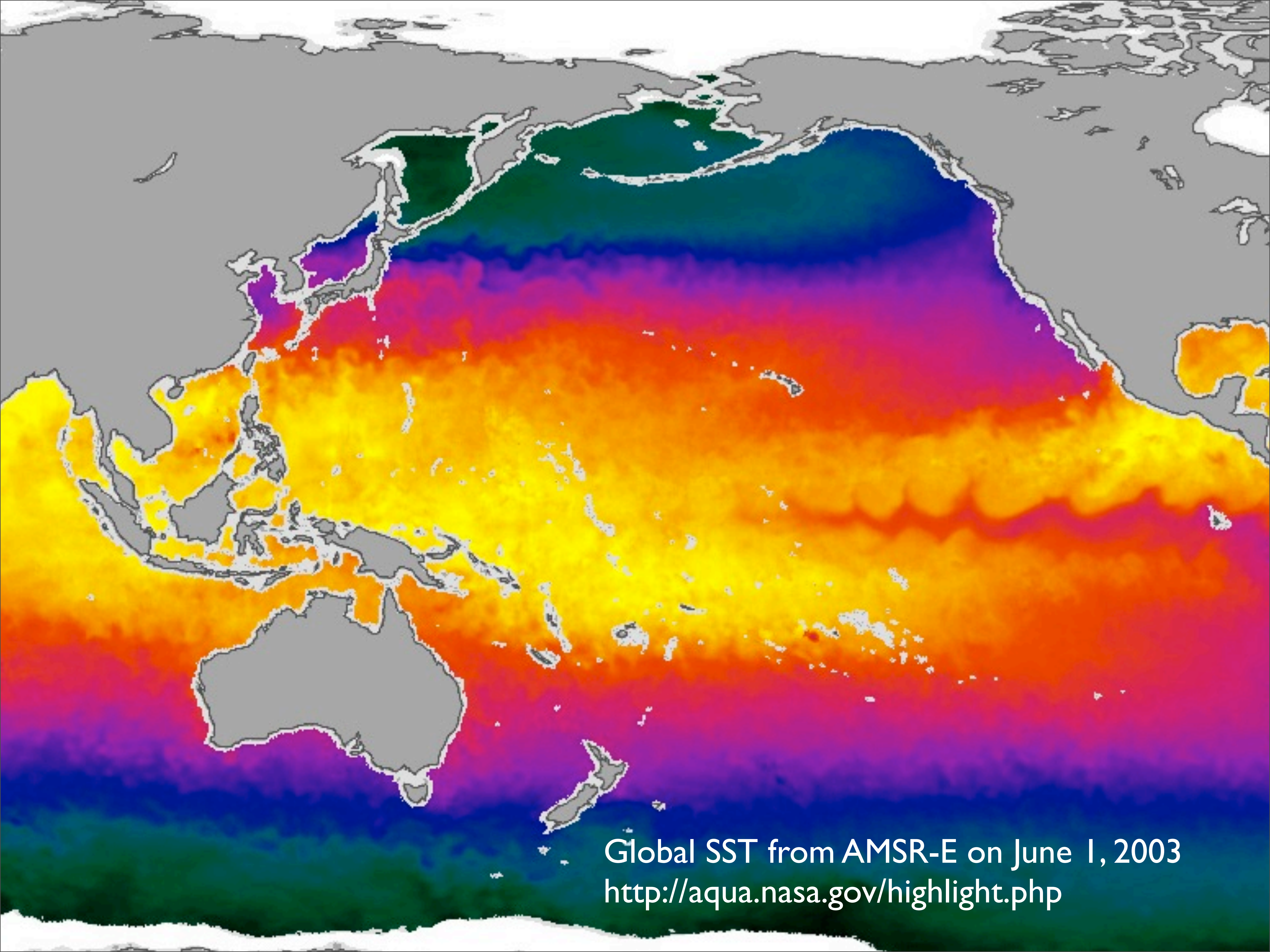
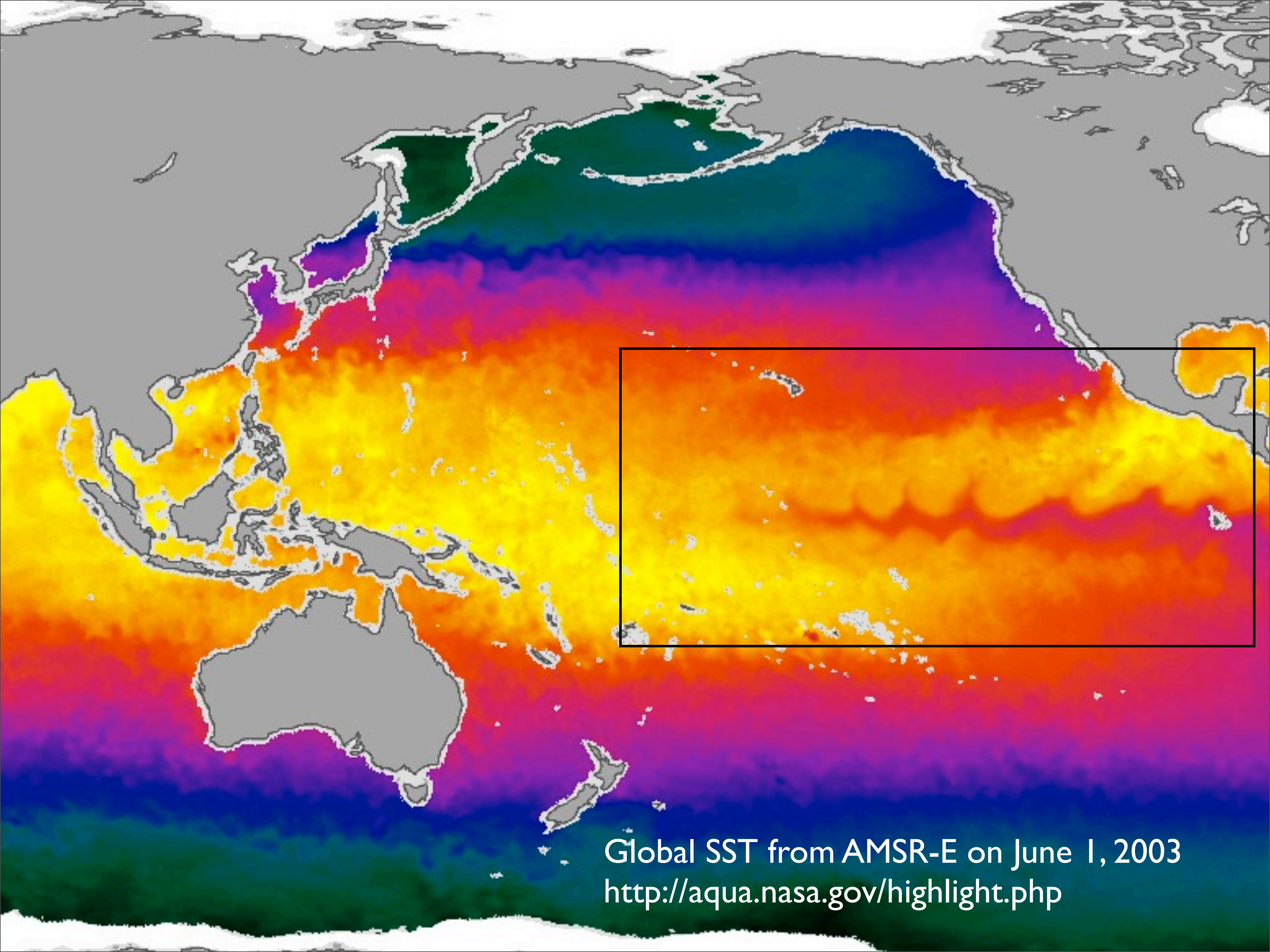


Global SST from AMSR-E on June 1, 2003
http://aqua.nasa.gov/highlight.php



Global SST from AMSR-E on June 1, 2003
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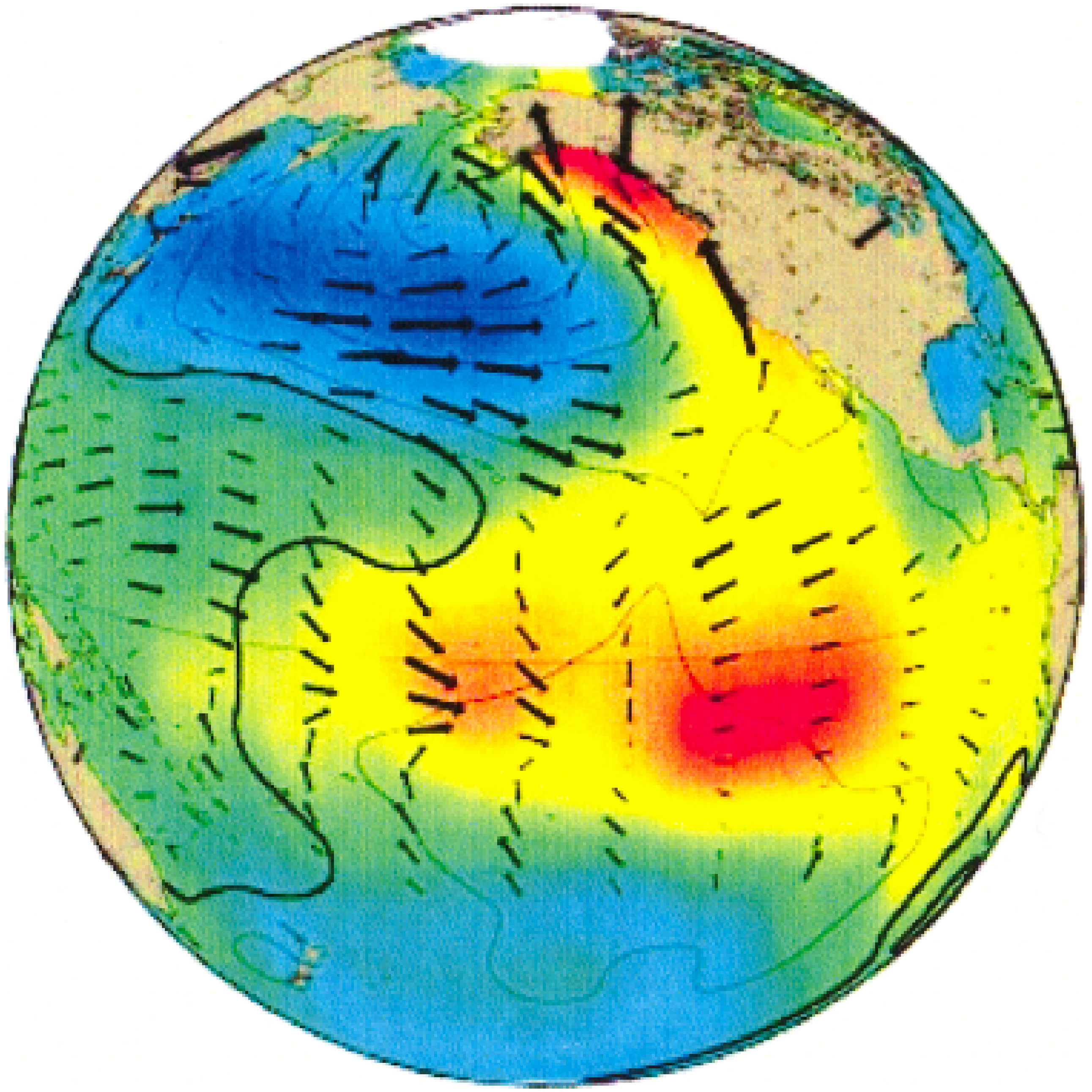
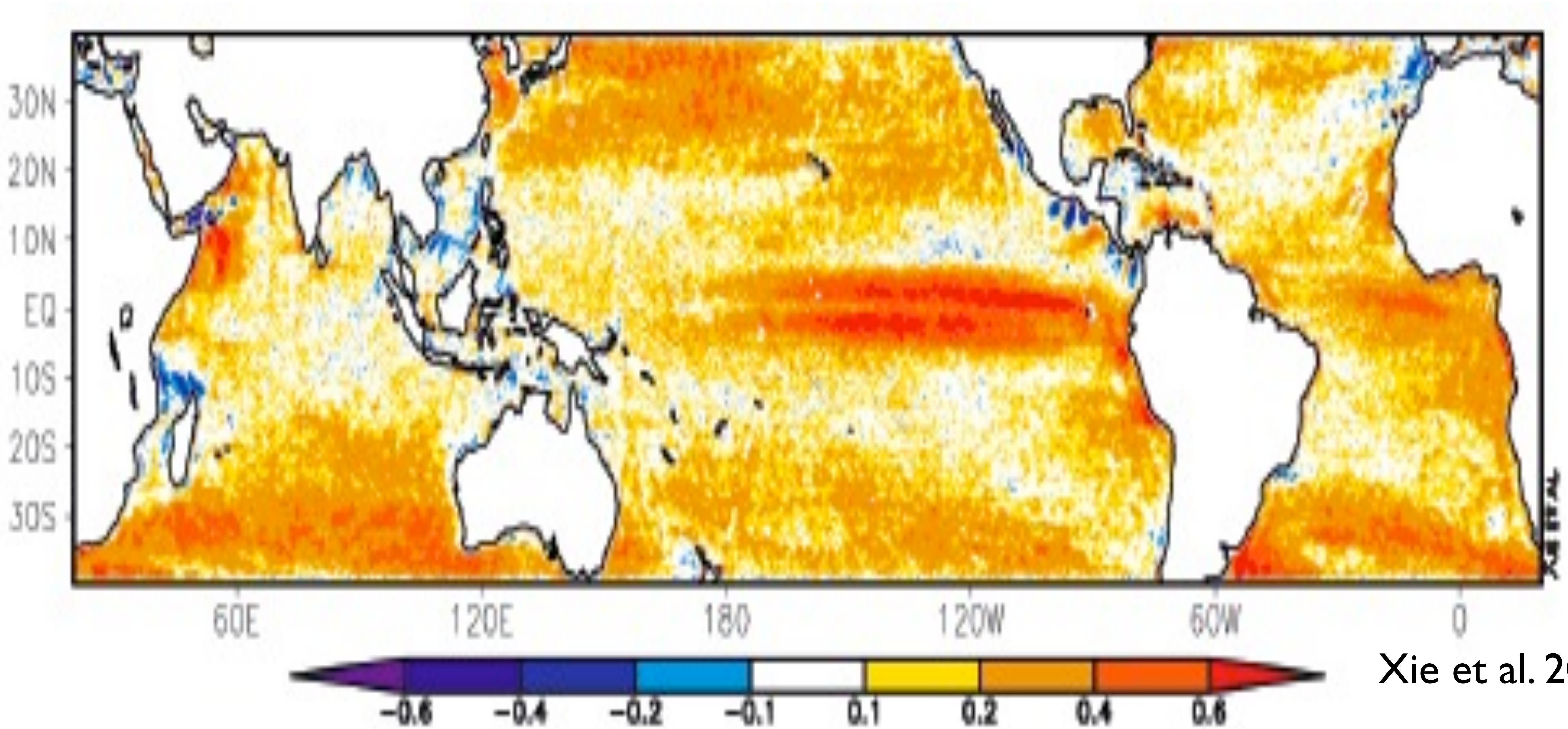
Relation of SST and wind speed on basin, seasonal or longer scale



Matuna et al. 1997

- Negative correlation: Atmospheric wind variability drives oceanic SST response through altered turbulent heat flux and oceanic mixing process.
- Forcing of atmosphere to ocean

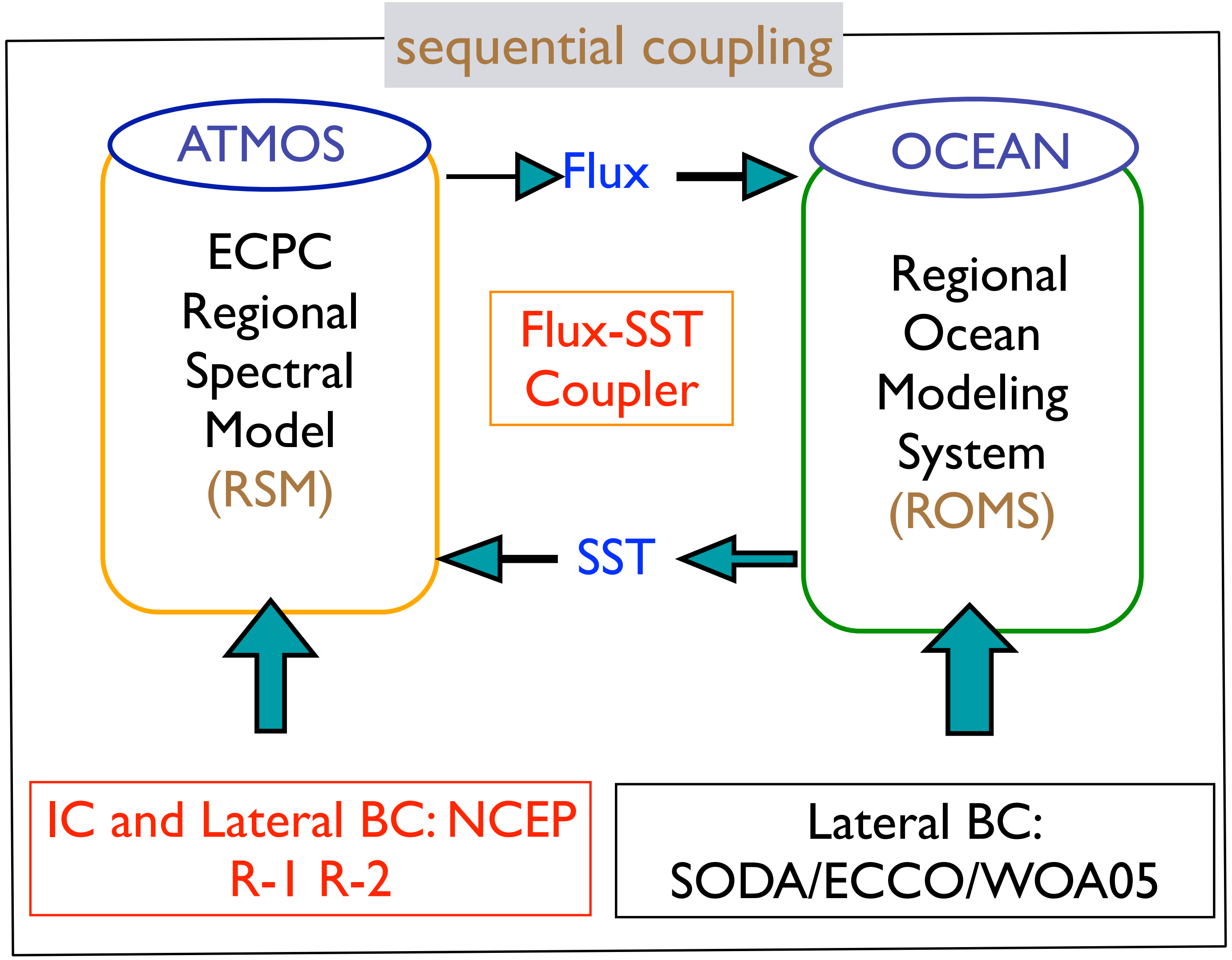
How about on oceanic mesoscale?



Xie et al. 2004

- Correlation of SST (TMI) and wind speed (QuikSCAT): Spatially high-pass filtered
- Positive correlation (Ocean → Atmosphere)
- Negative correlation (Atmosphere → Ocean)
- Daily to sub-seasonal timescale on oceanic eddy scale; O(10-1000km)
- Models require ocean eddy-resolving resolution and air-sea coupling

Scripps Coupled Ocean-Atmosphere Regional (SCOAR) Model



- Higher model resolution; Comparable resolution of ocean and atmosphere.
- Dynamical consistency with the NCEP Reanalysis forcing
- More complete and flexible coupling strategy
- Parallel architecture; running on NCAR's machines now.
- State-of-the-art physics implemented in RSM and ROMS
- Greater portability

• Why regional coupled model?

1. Study mesoscale coupled ocean-atmosphere interaction:
   e.g., TIWs, California Current eddies, gap winds: (Seo et al. 2007a, 2007b), Arabian Sea eddies: Seo et al. (2008)
2. connection with the regional climate:
   e.g., TIWs/eddies → Atlantic mean SST and position of ITCZ (Seo et al. 2006): AEWs → mean precipitation in ITCZ(Seo et al. 2008).

Mesoscale ocean-atmosphere interaction: TIWs and atmospheric feedback

Coupling of TIWs and wind

① Correlation of u'_{sfc} and τ'

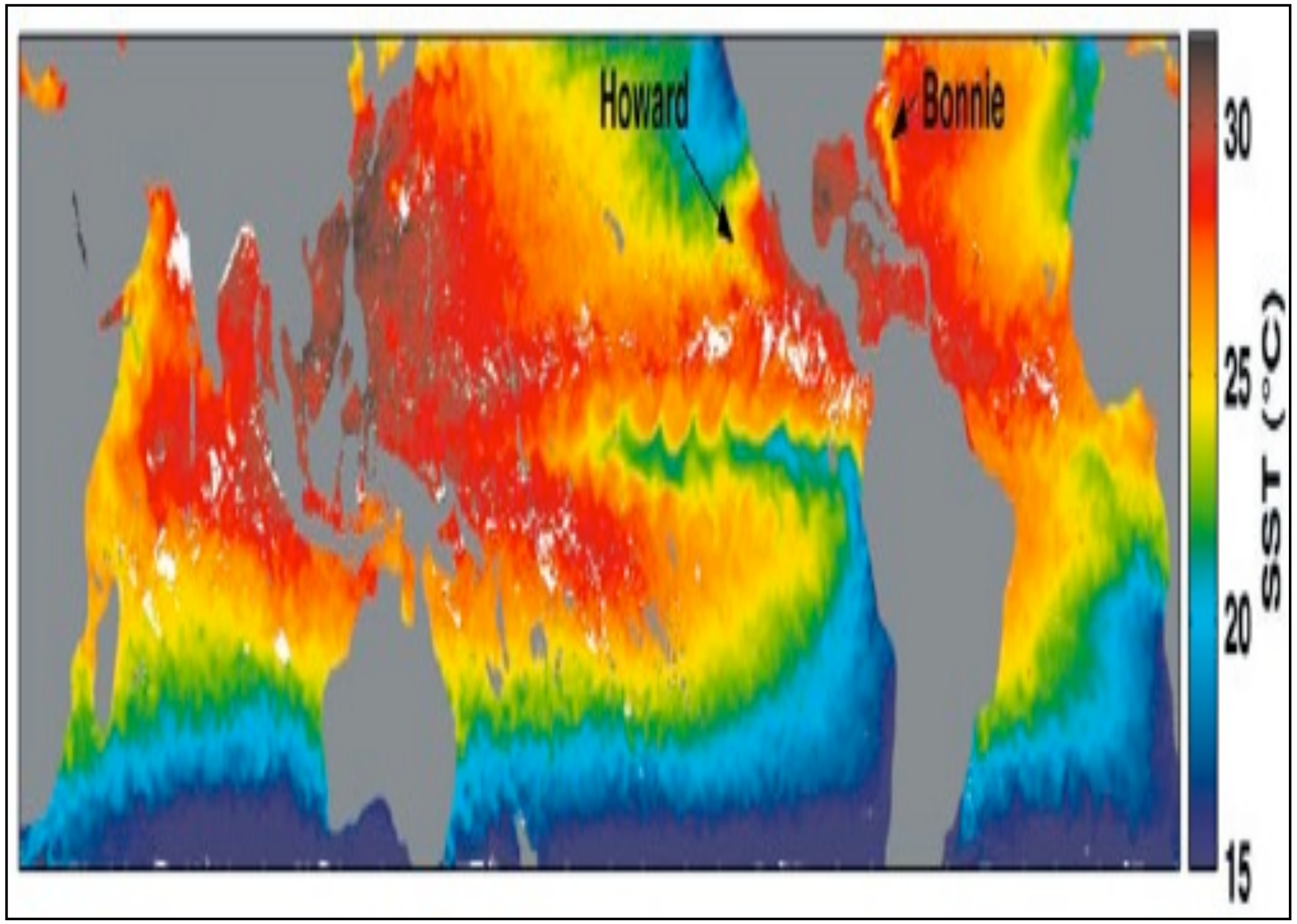
② τ' and TIWs

Coupling of TIWs and heat flux

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
- Important for heat and momentum balance in the equatorial Oceans
- Potential impact on ITCZ and ENSO

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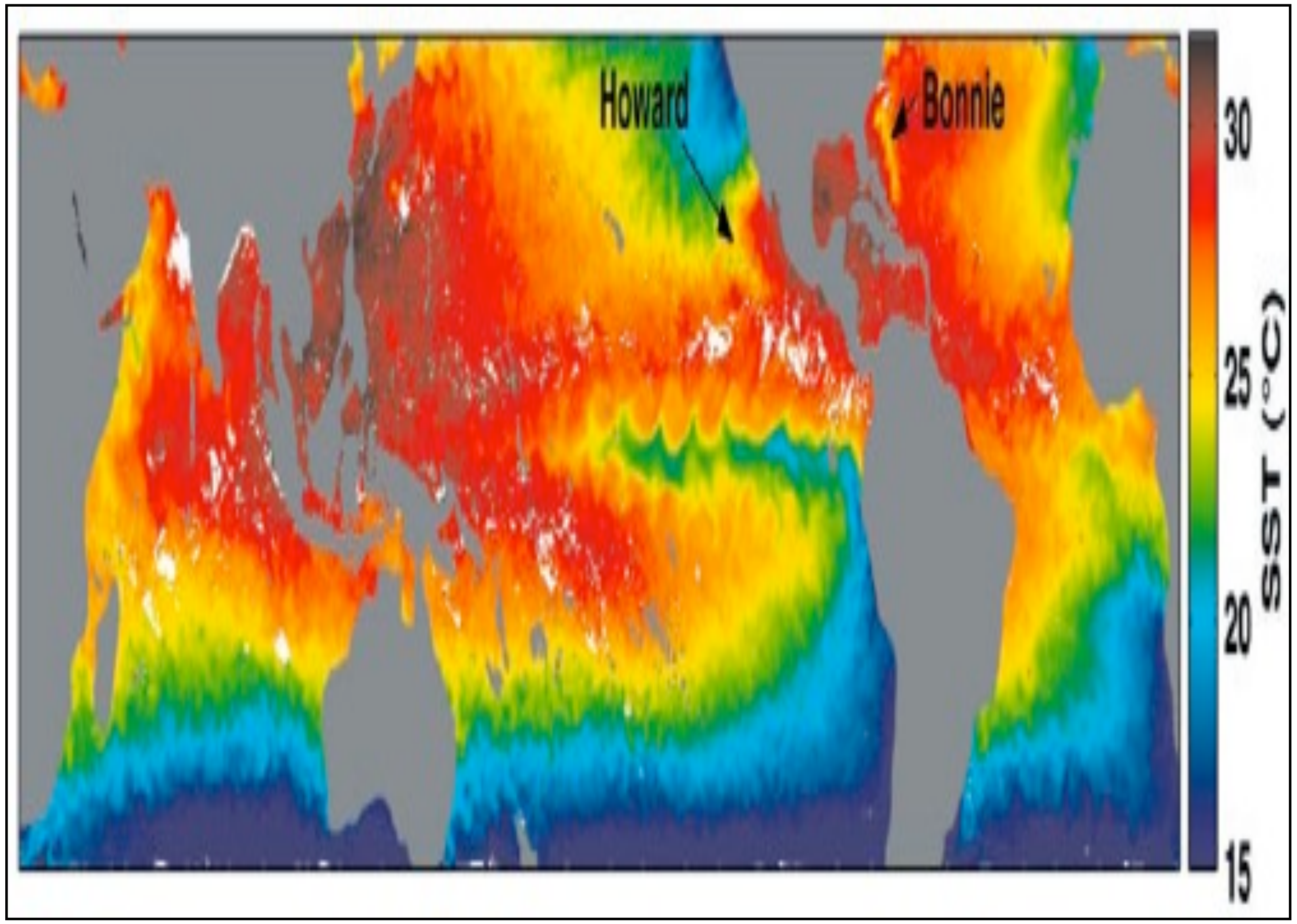

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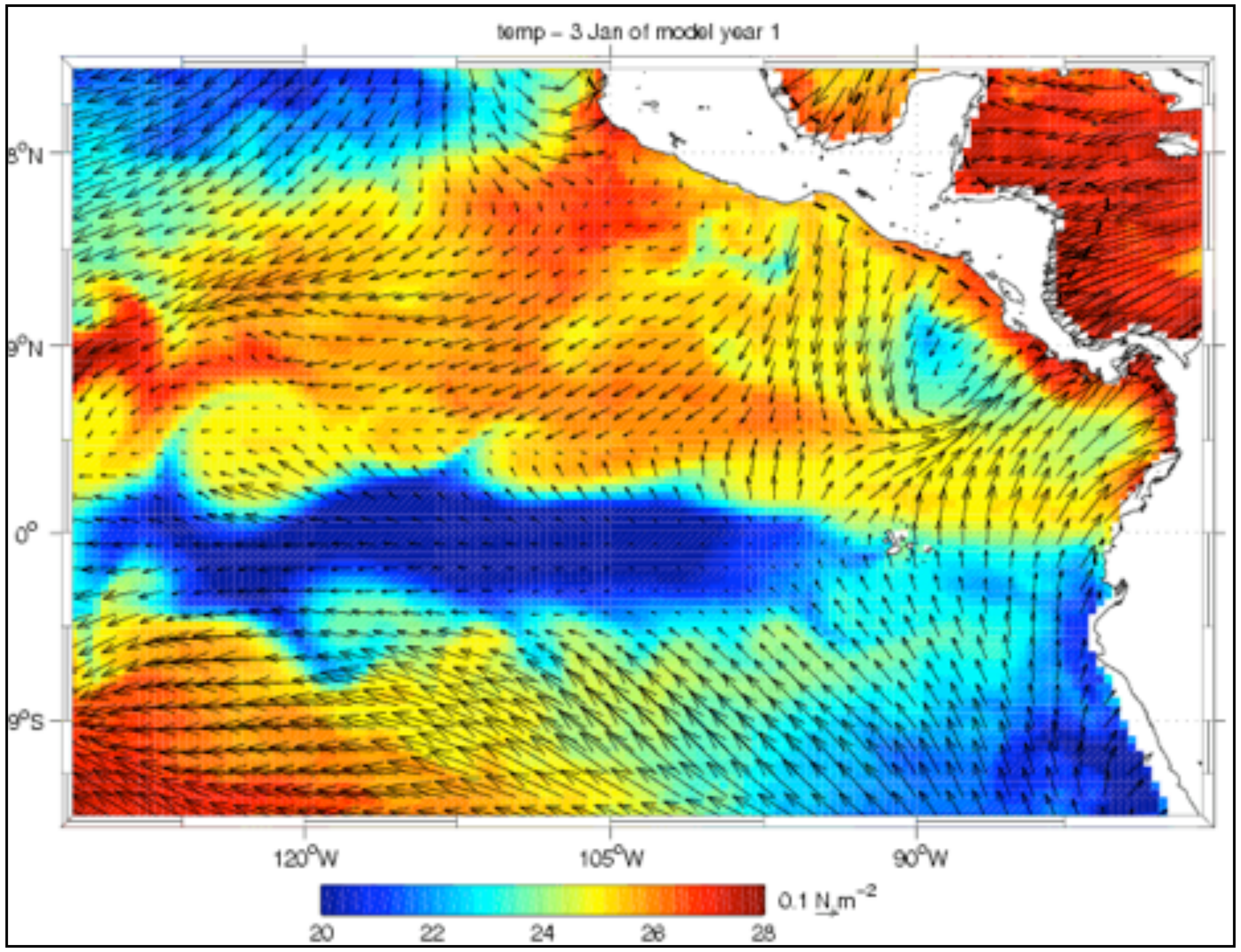

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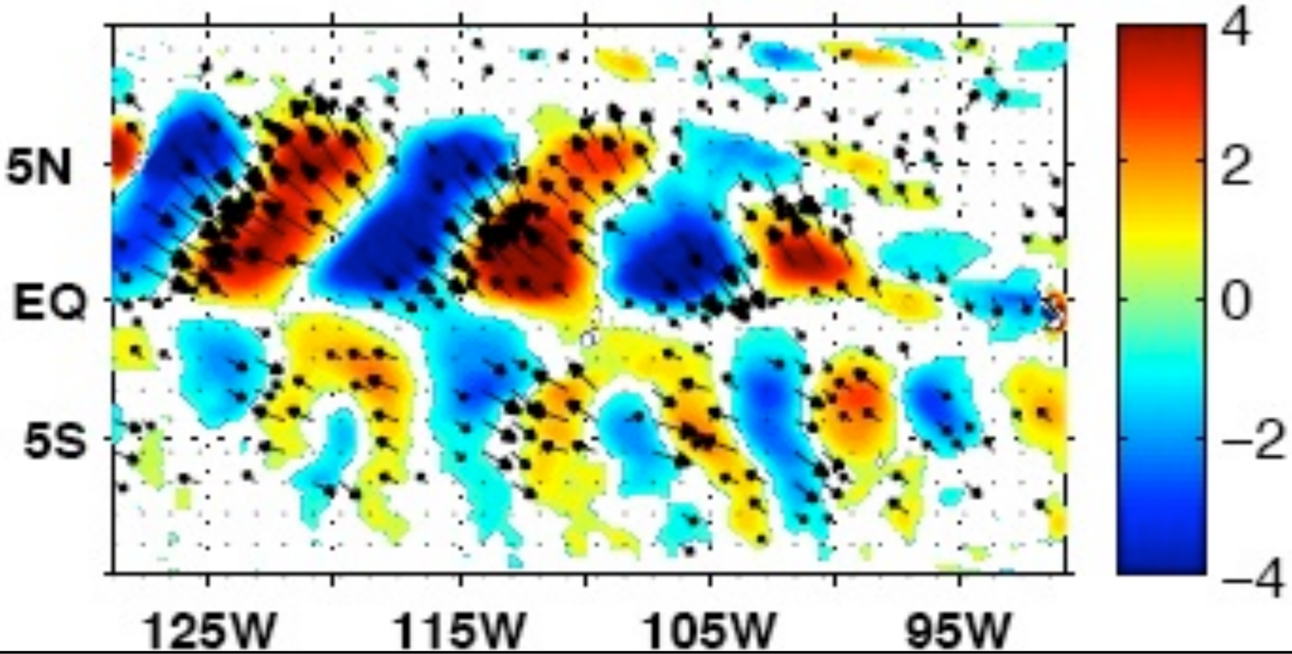
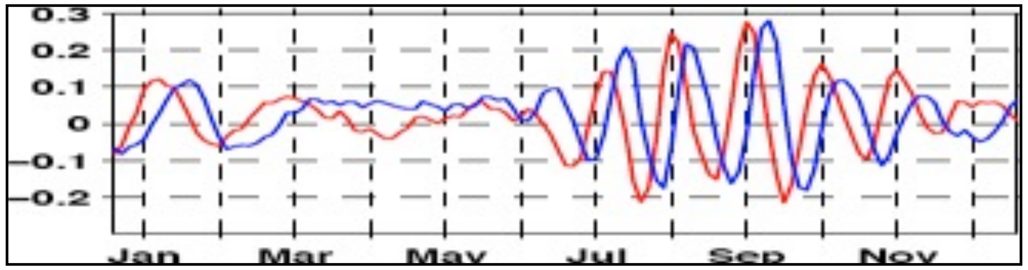
Feedback from wind response?

Combined EOF 1 of SST and Wind vectors





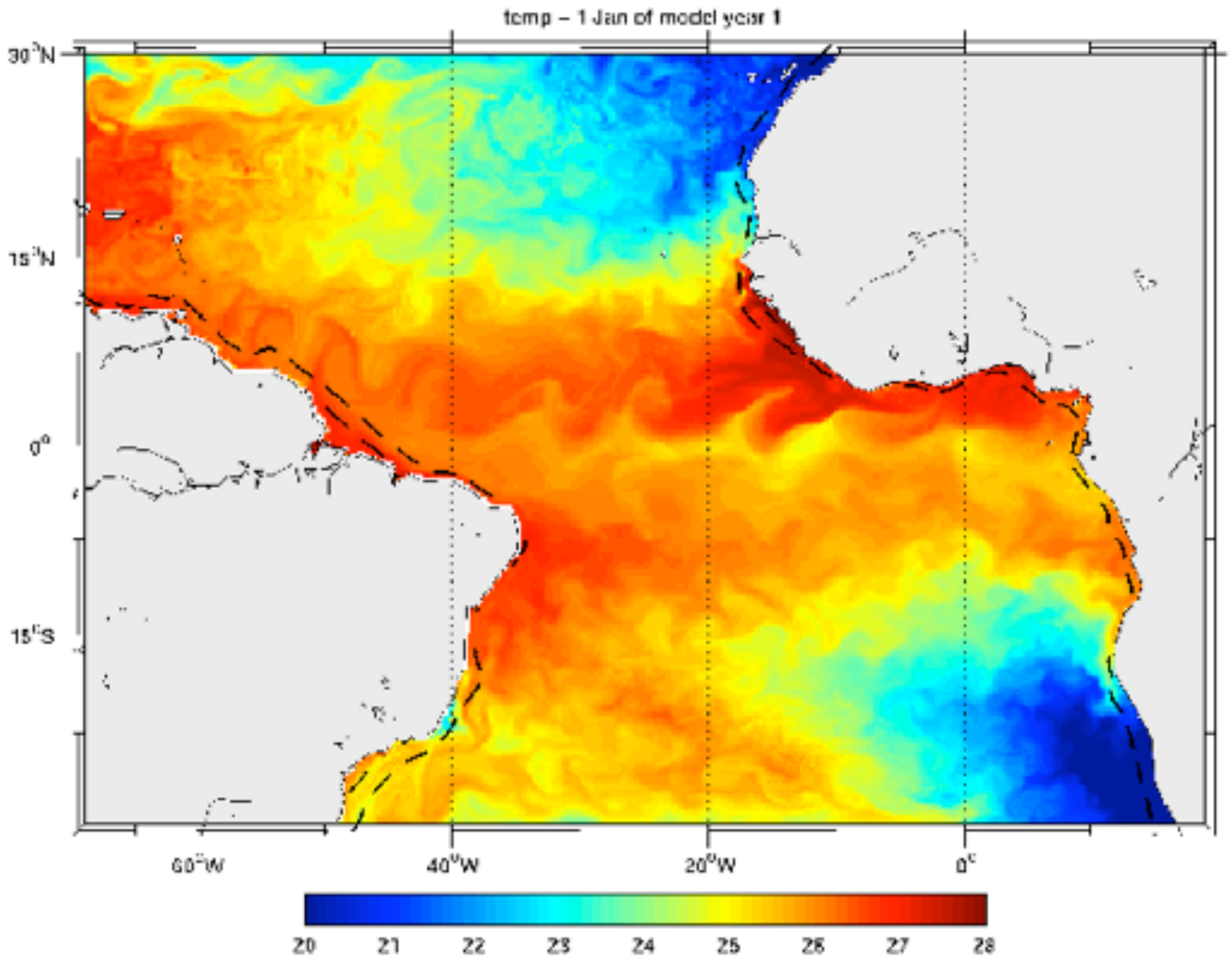
• SST ➔ Wind

1) Direct influence from SST (Wallace et al. 1989; Lindzen and Nigam 1987)

2) Modification of wind stress curl (Chelton et al. 2001)

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

Covariability of u'_{sfc} and τ'



- Daily coupled 6-year simulations (1999-2004) 1/4° ROMS + 1/4° RSM
- Effect of correlation of u'_{sfc} and τ' 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;

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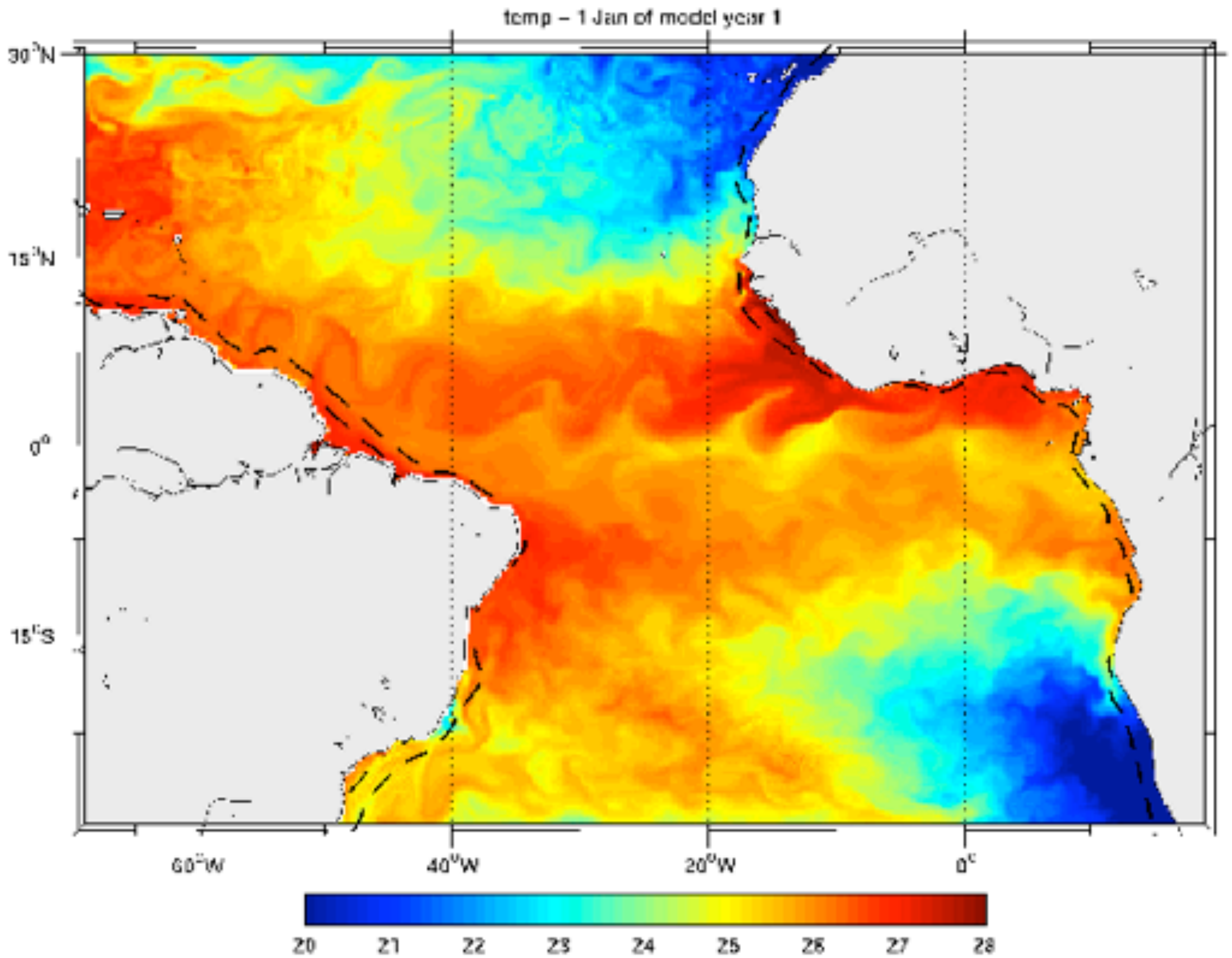

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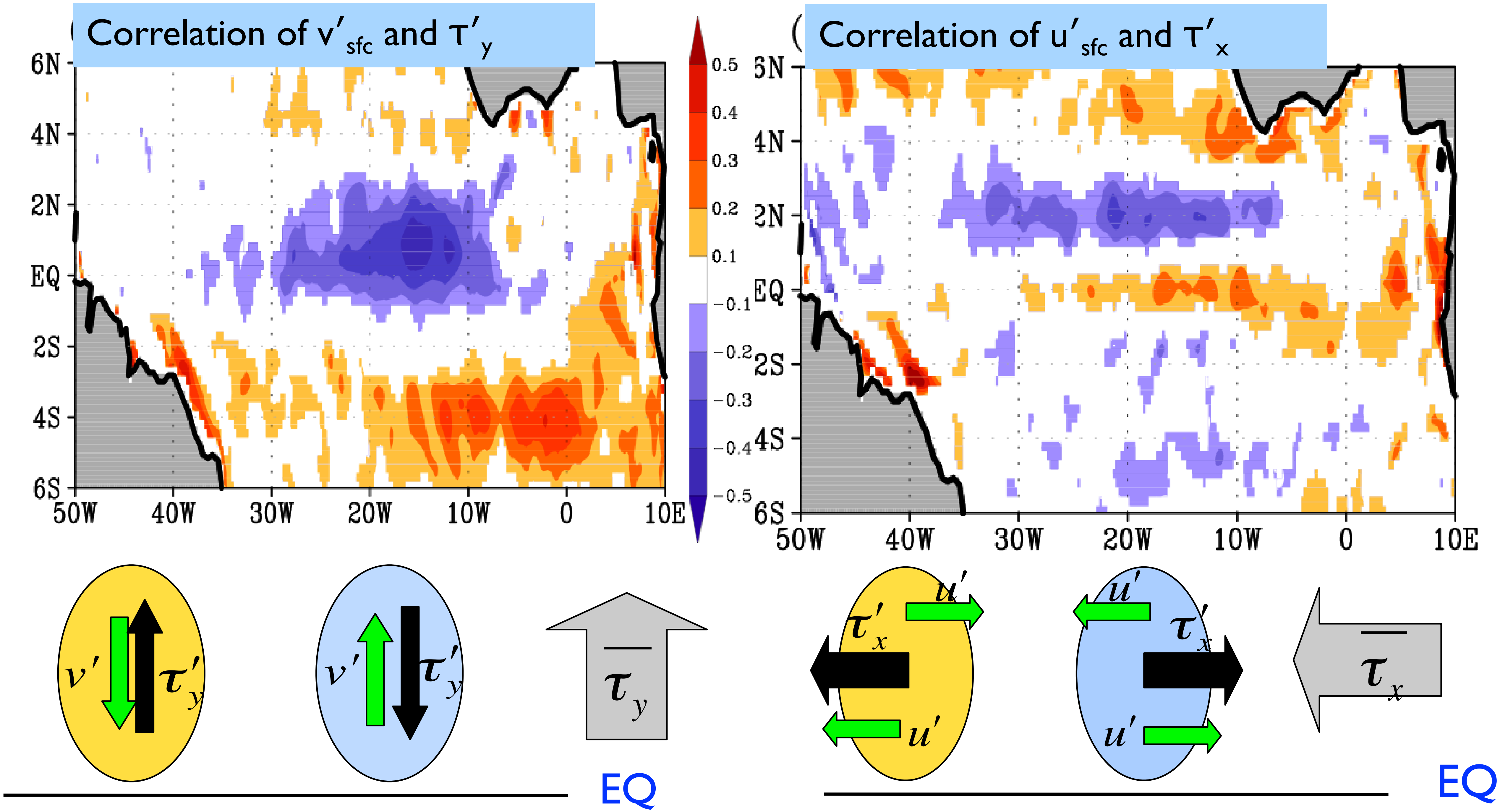
Masina et al. 1999;
Jochum et al. 2004;

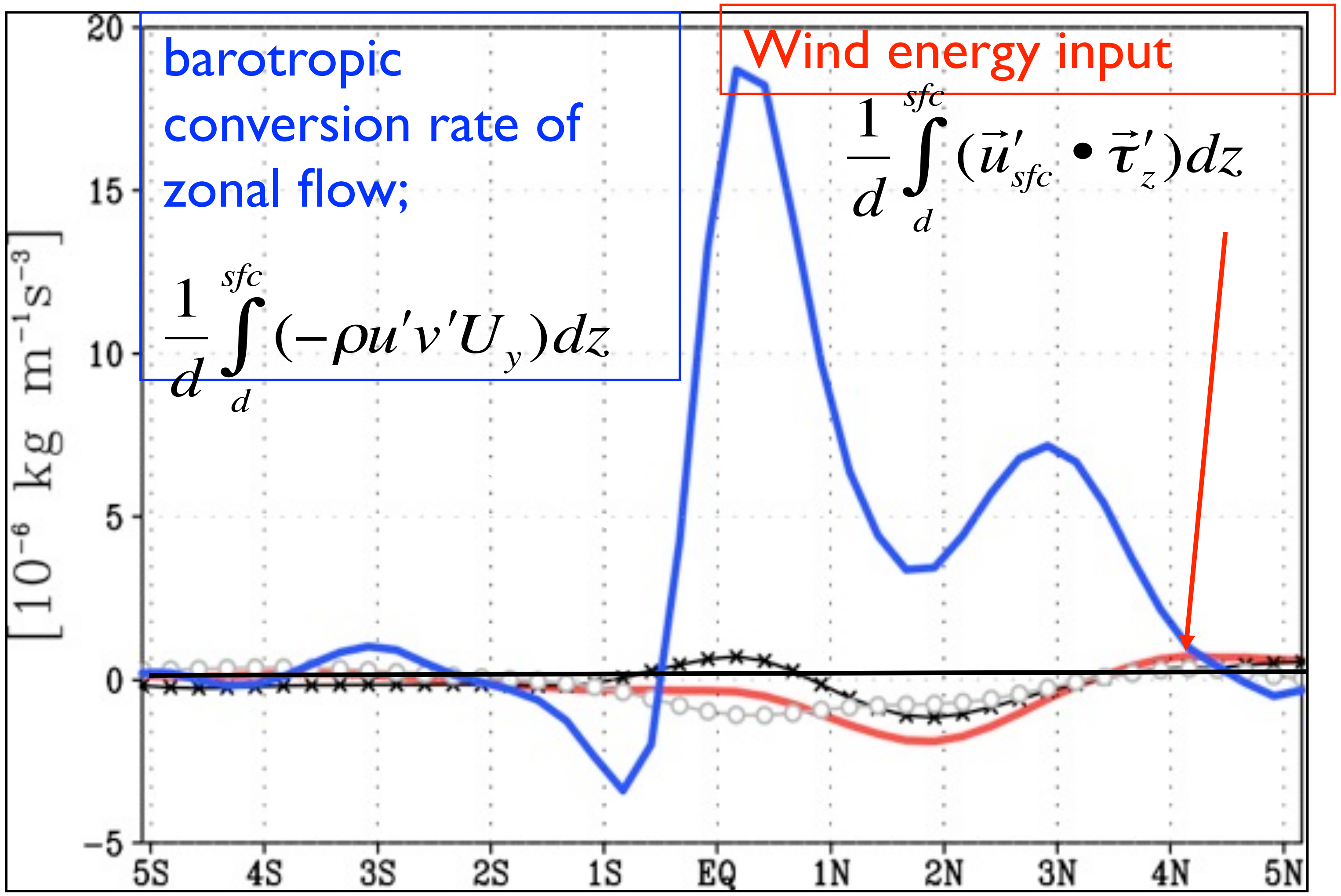
$u'_{sfc} \cdot \tau'$:Correlation of TIW-induced current and wind stress



- 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

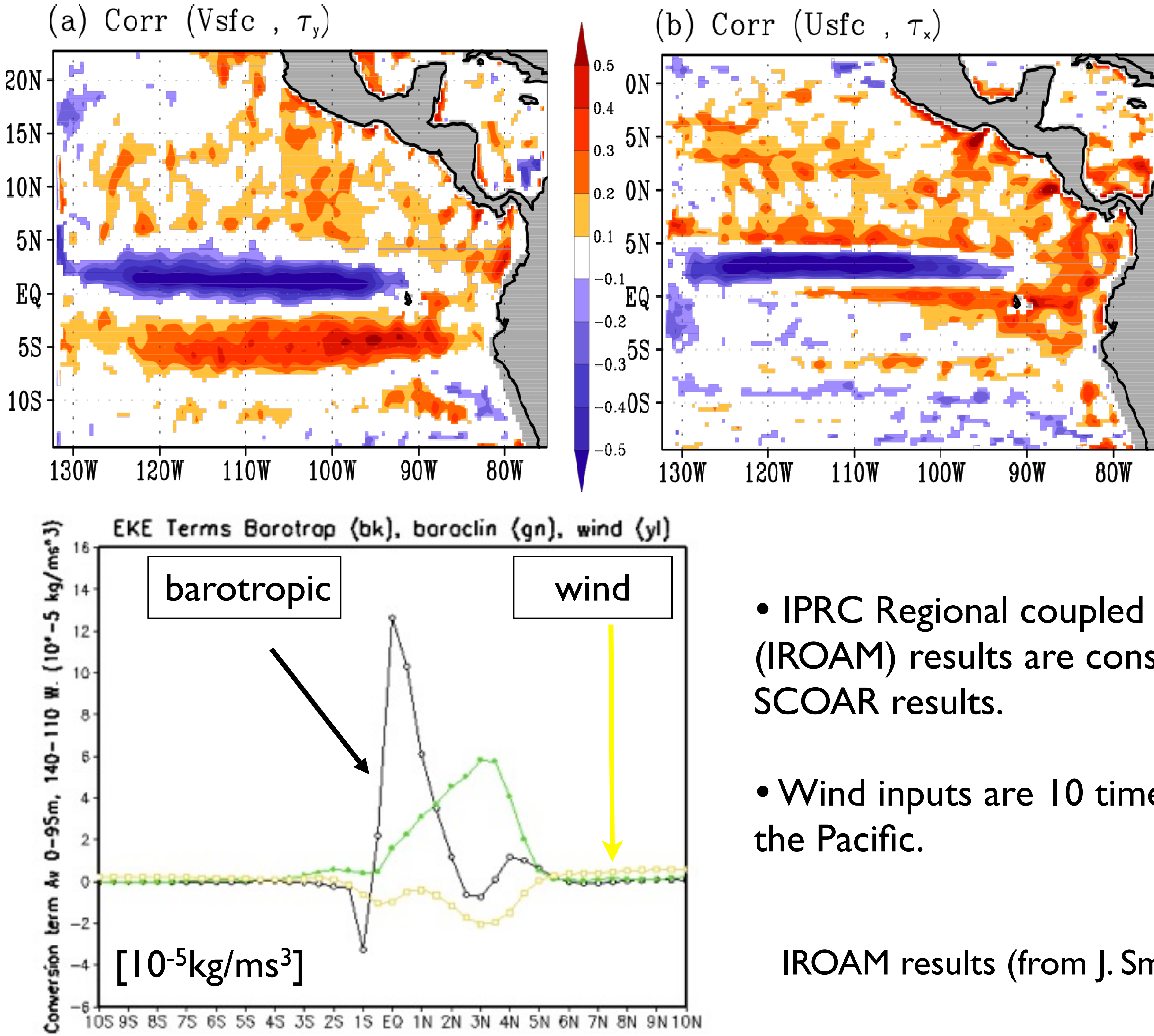


- In the Atlantic, wind contribution to TIWs is ~10% of barotropic convergent rate.
- Small but important sink of energy
- Consistent with the previous study.

$[10^{-6}kg/ms^3]$

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

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.

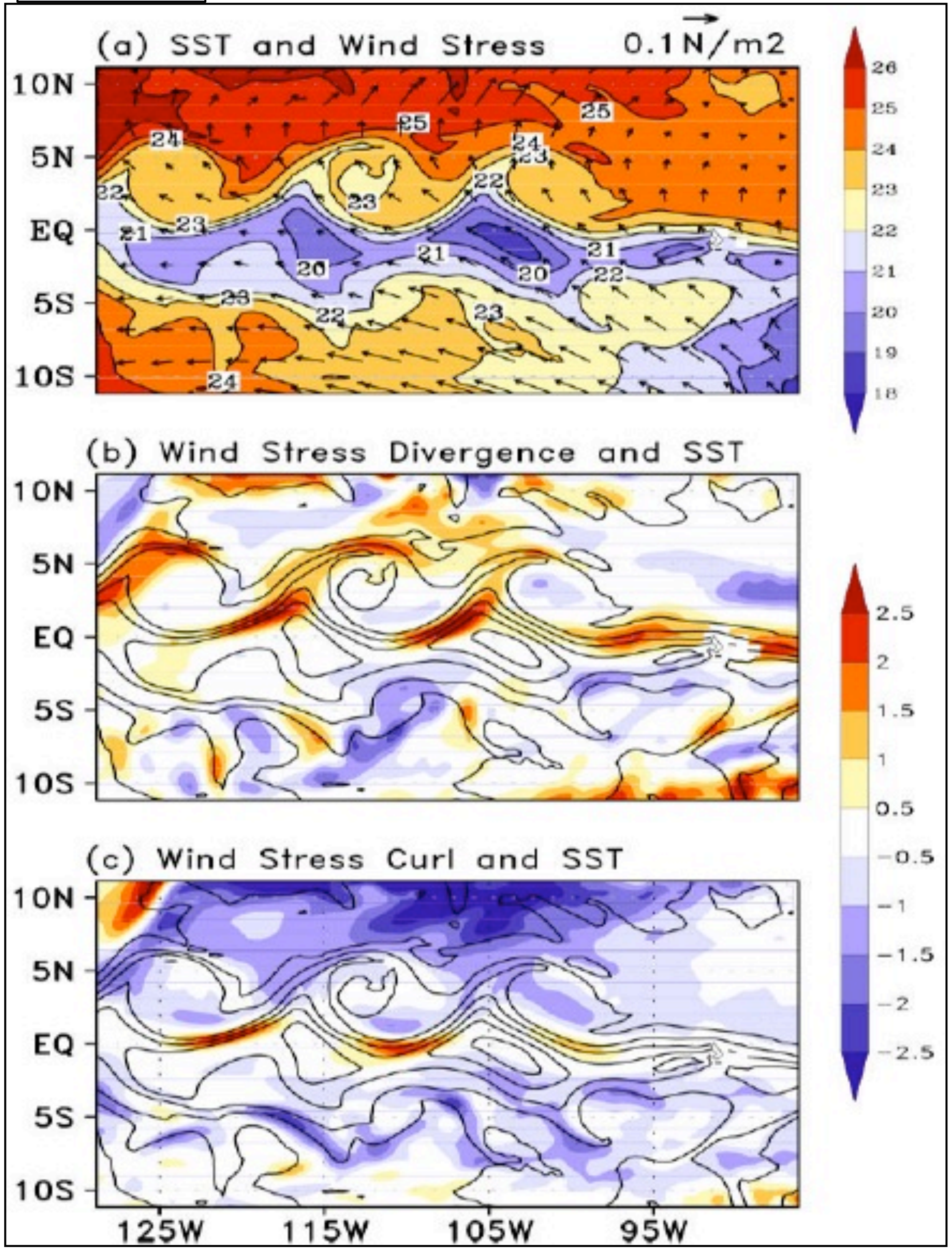
IROAM results (from J. Small)

Perturbation wind stress curl and TIWs

Coupling of SST gradient and wind stress derivatives

TRMM & QuikSCAT from D. Chelton

Model



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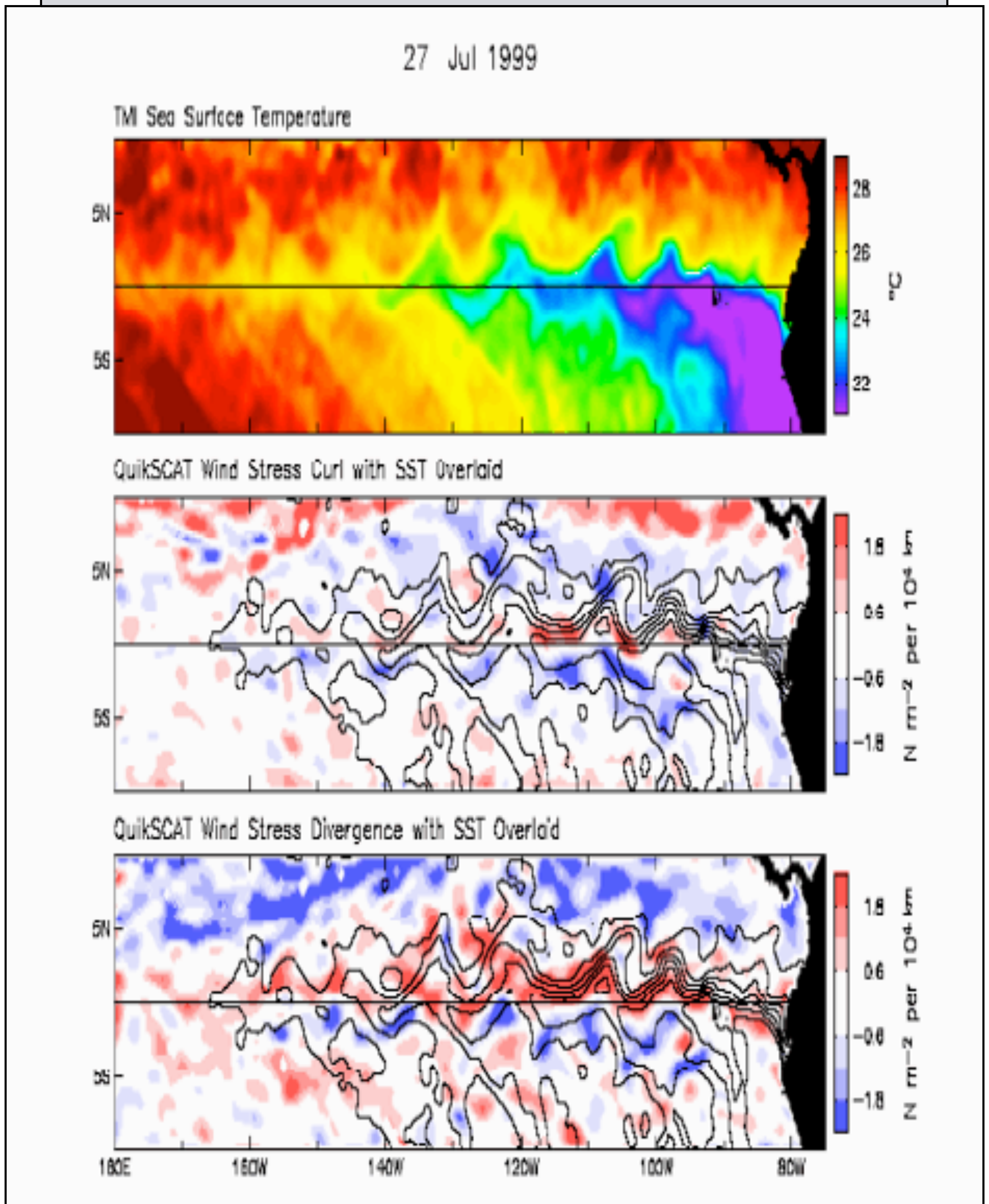

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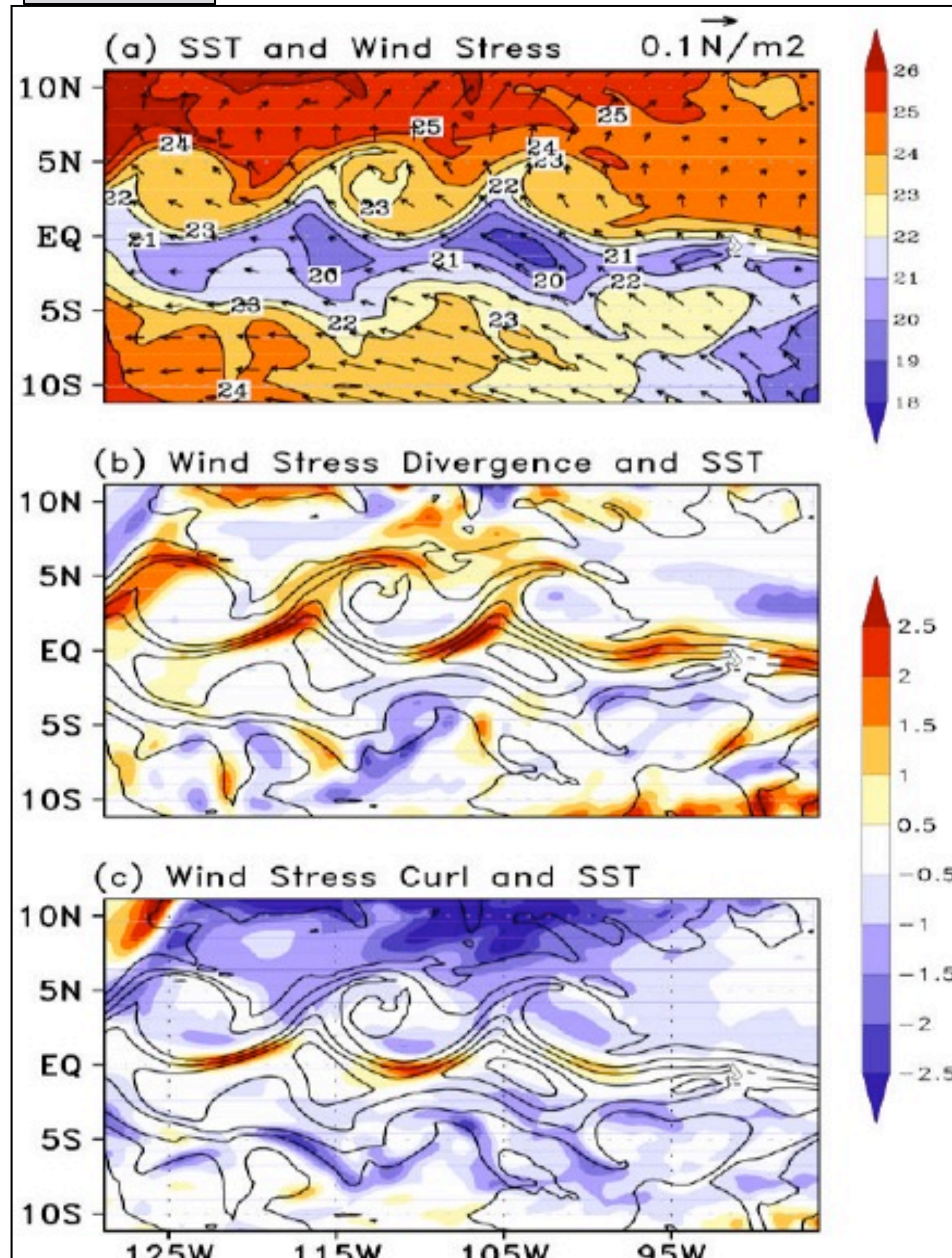
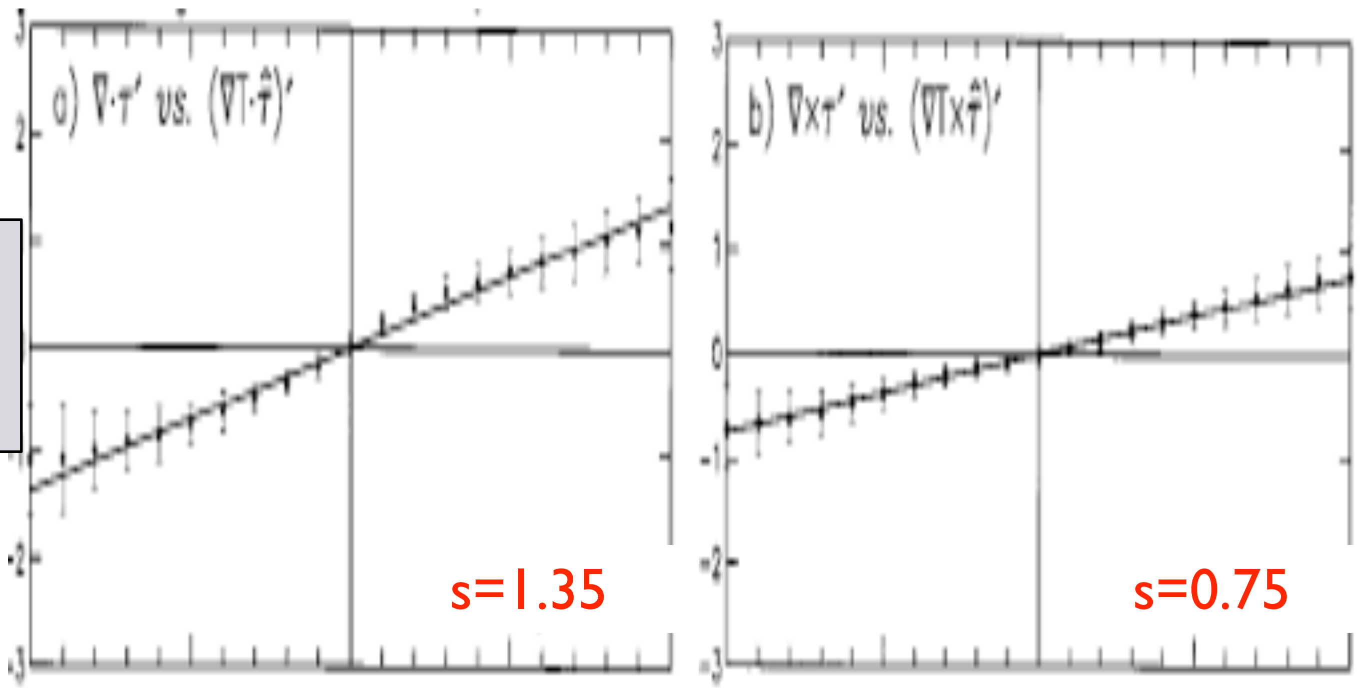


Coupling strength (coefficient)

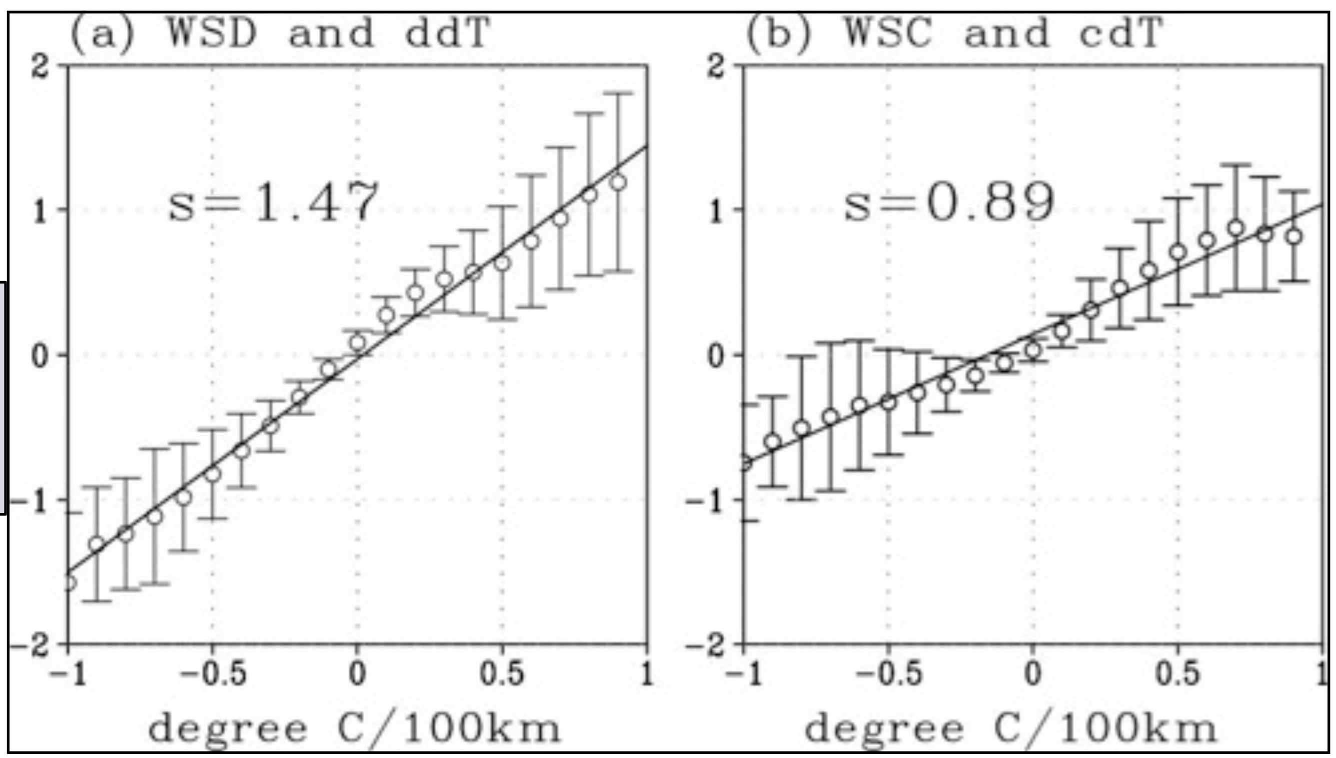
WSD and DdT

WSC and CdT

OBS:
Chelton et al. 2001



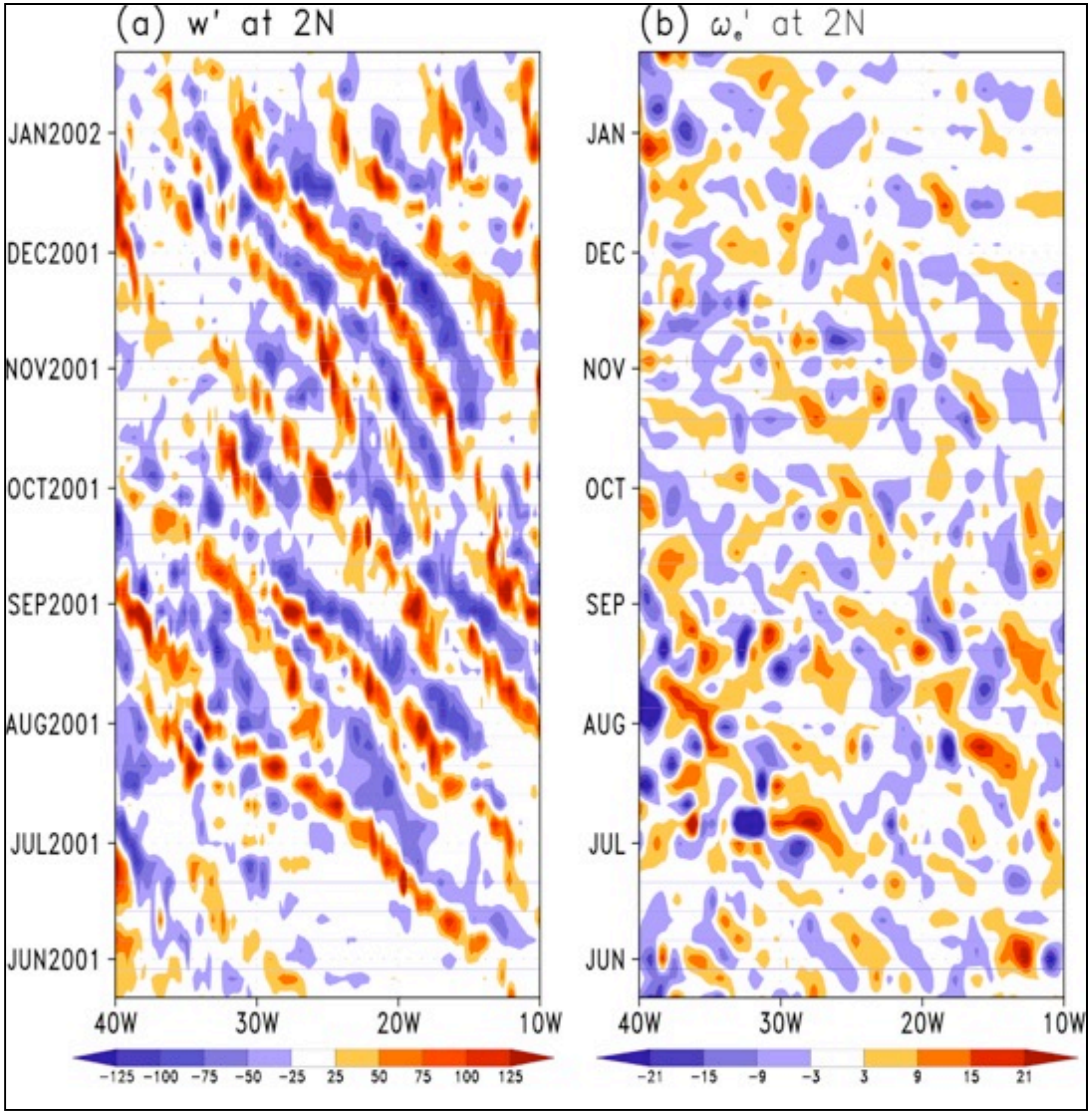
Model:
Seo et al. 2007



- 5S-5N, 125-100W, July-December, 1999-2003
- The SCOAR model well reproduced the observed linear relationship in the eastern tropical Pacific TIW case.

Feedback of perturbation Ekman pumping to TIWs

w' at MLD and ω_e' along 2°N



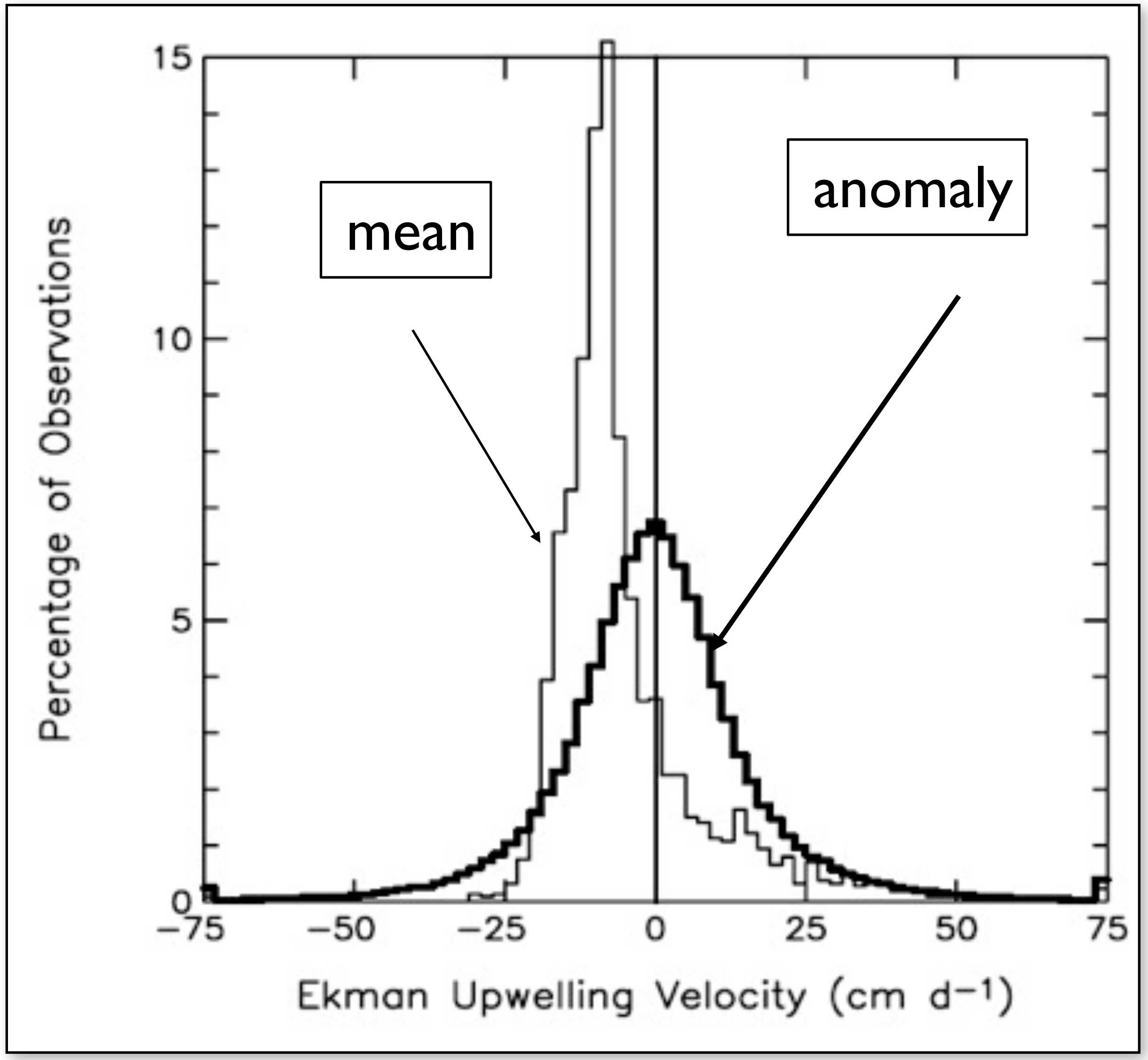
- Perturbation Ekman pumping velocity (ω_e') and perturbation vertical velocity (w') of $-g\rho' w'$.

- Overall, ω_e' is less spatially coherent and weaker in magnitude than w'.

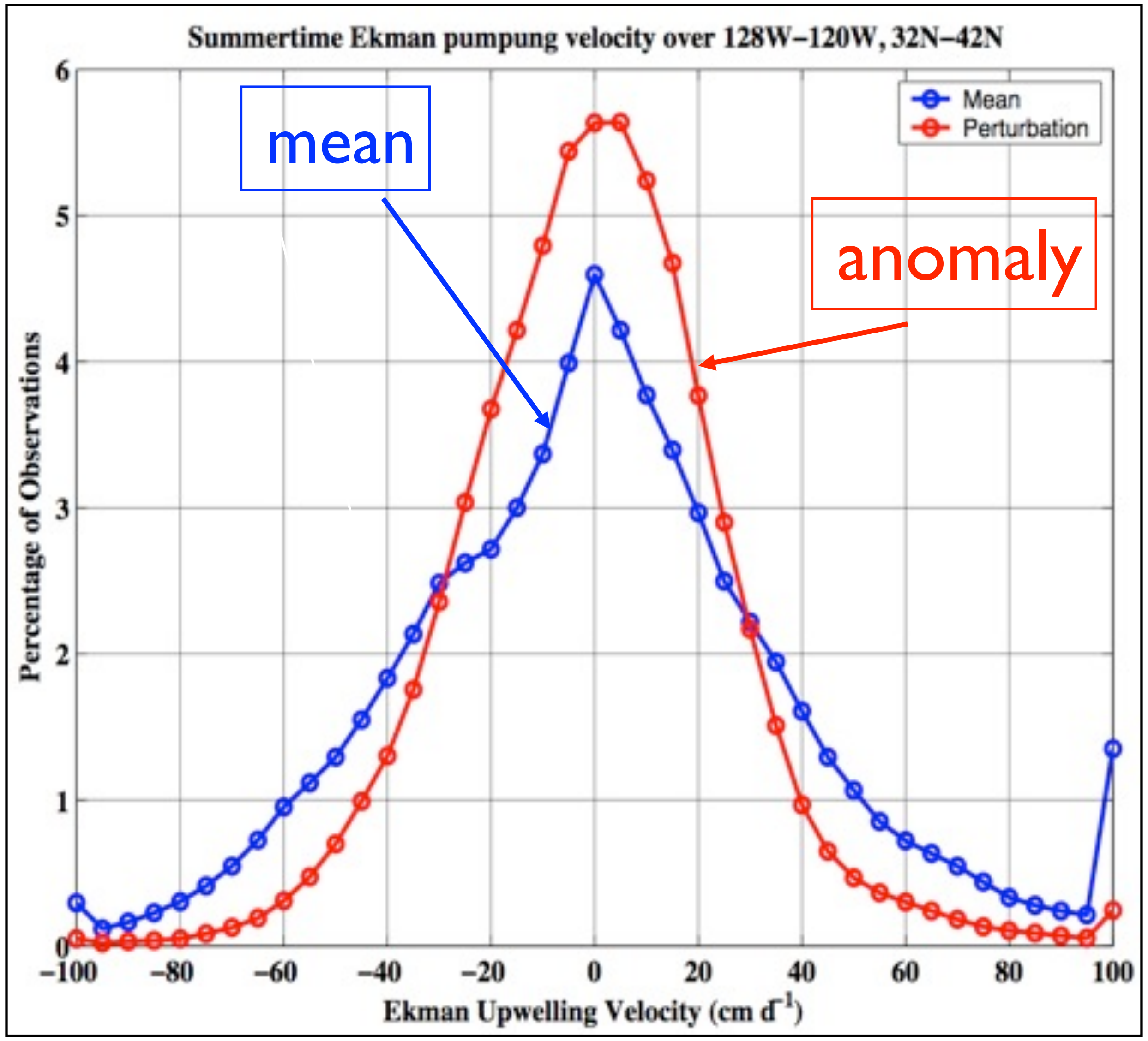
- Caveat: It is difficult to estimate Ekman pumping near the equator, where wind stress curl is at its maximum.

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

What about in the mid-latitude CCS region?



(Chelton et al. 2007)



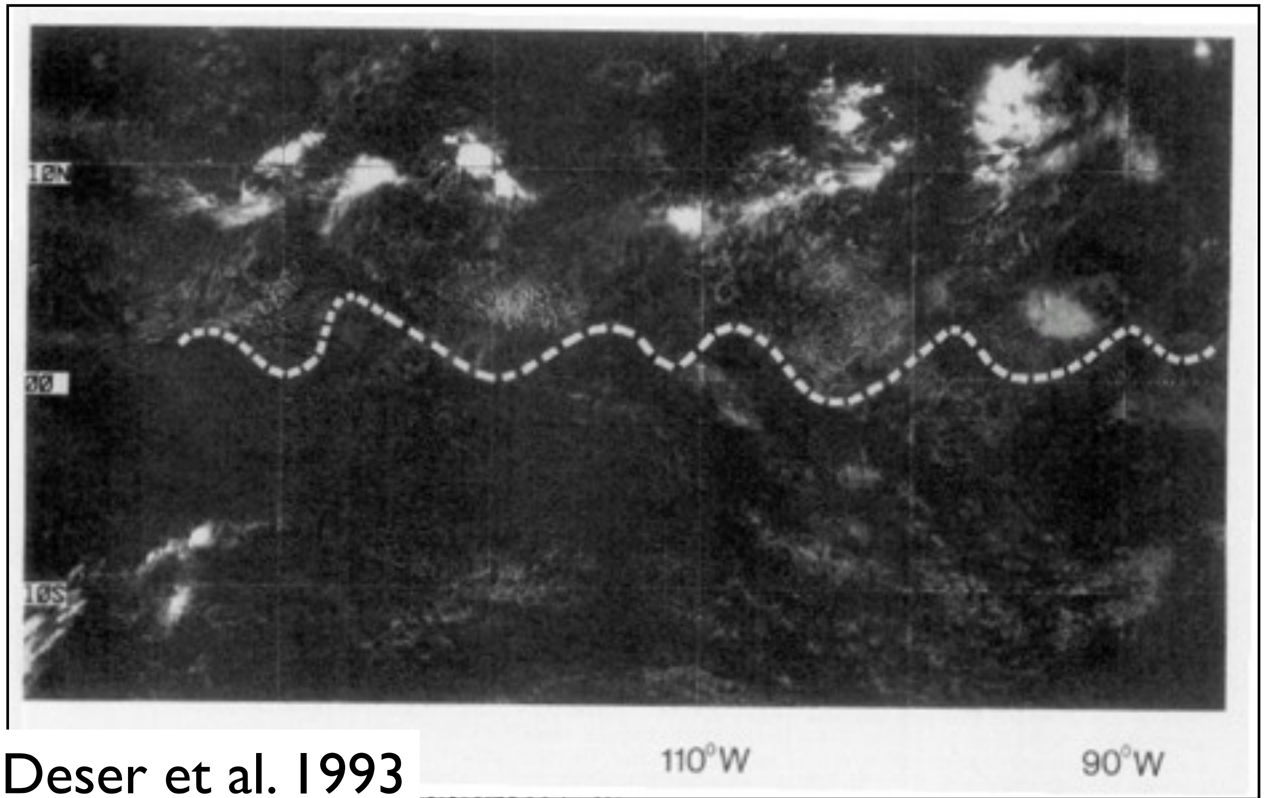
SCOAR Model

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

Feedback of turbulent heat flux?

Observations of radiative and turbulent flux

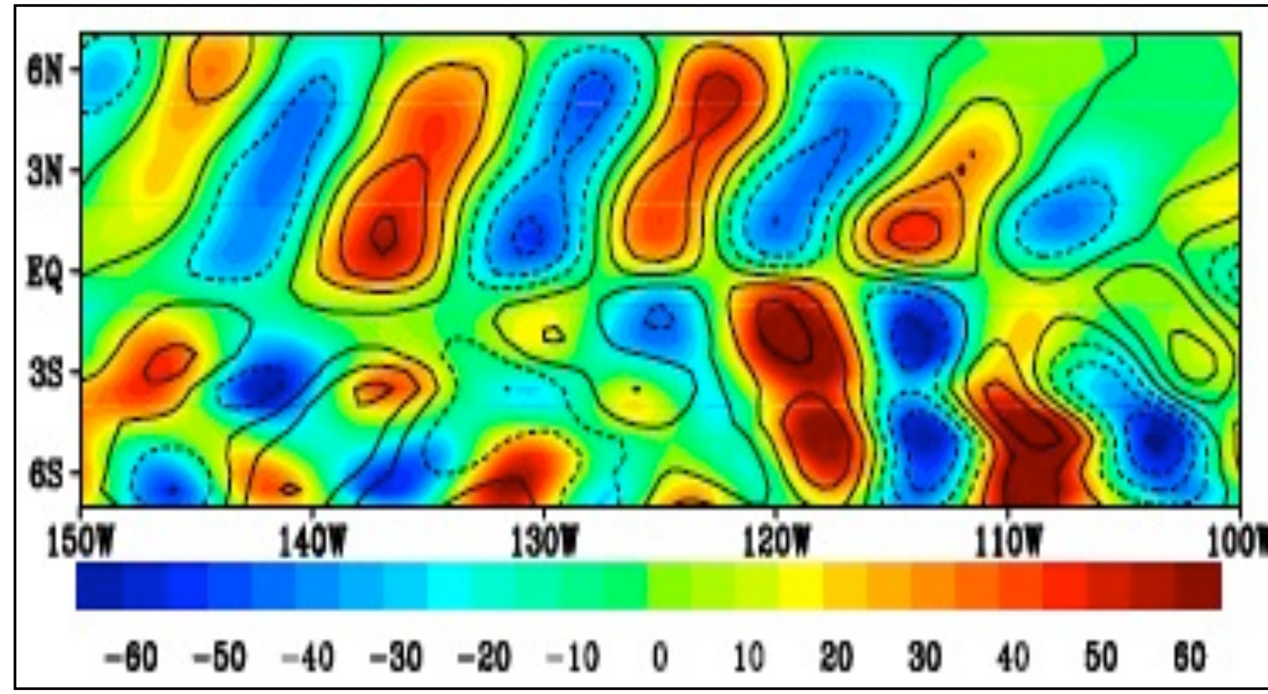
Solar heat flux and SST



Deser et al. 1993

Liu et al. 2000

Latent heat flux and SST



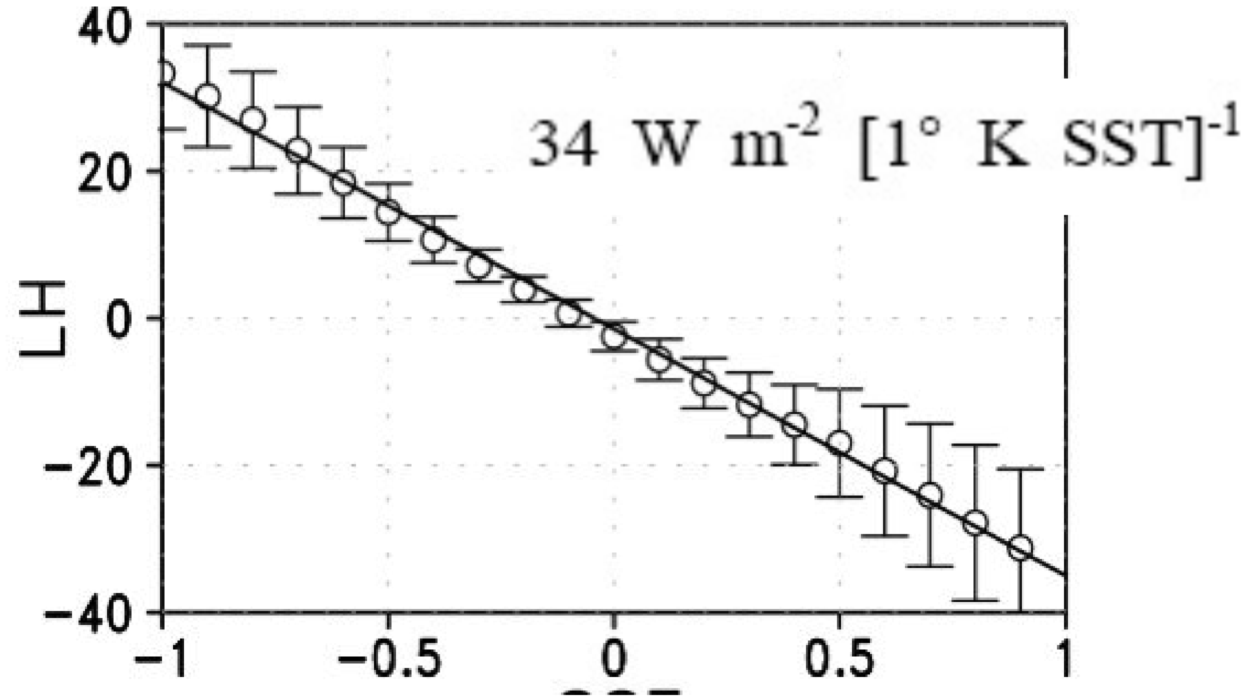
- Deser et al. (1993): changes in solar radiation of ~10 W/m^2 due to 1K changes in SST
- -0.75°C / month (MLD=20m).

- Zhang and McPhaden (1995): ~50 W/m^2 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).

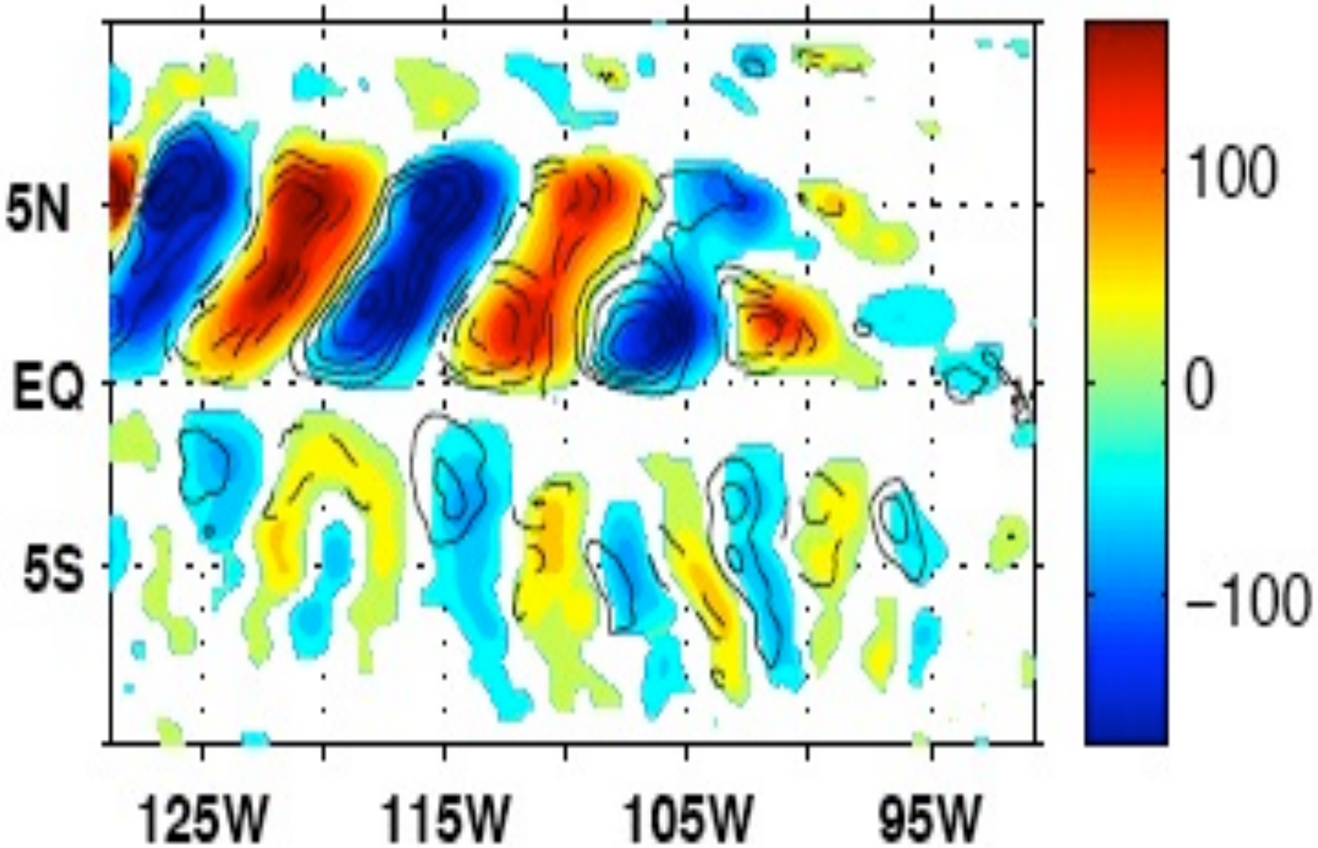
- *Instantaneous* damping of local SST by perturbation heat flux

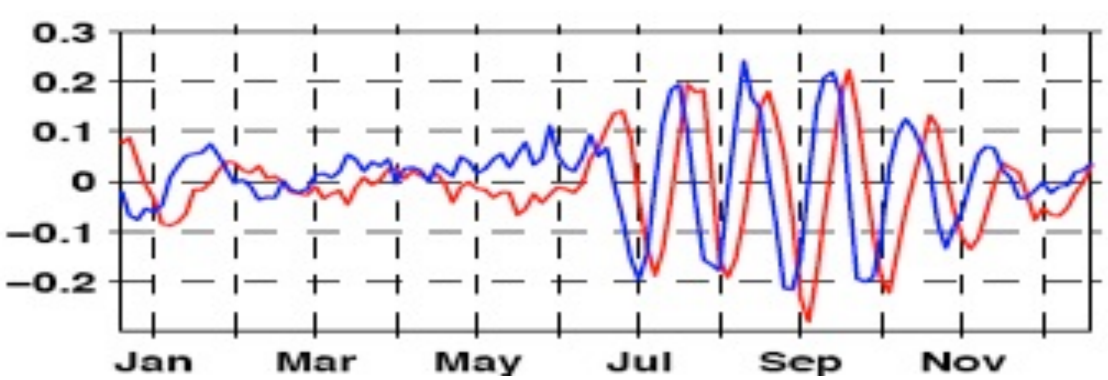
Coupling of SST and latent heat flux in SCOAR

OBS ~50 W/m^2 per 1K



Eastern Tropical Pacific





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

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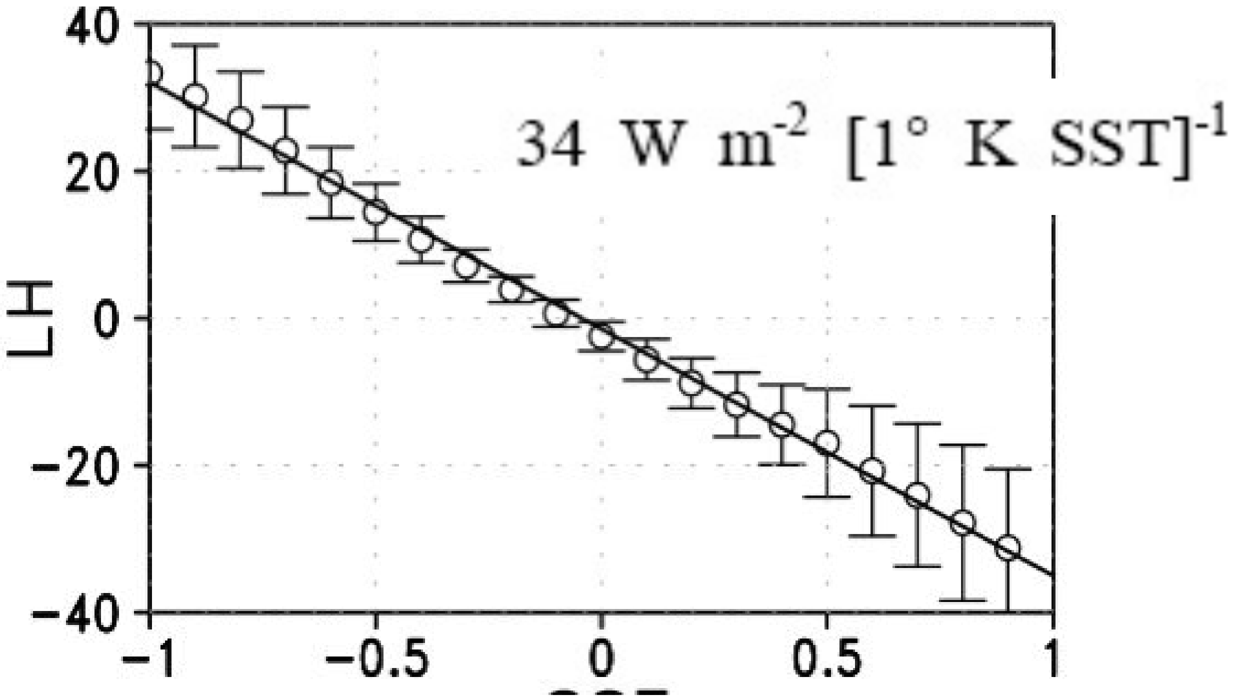

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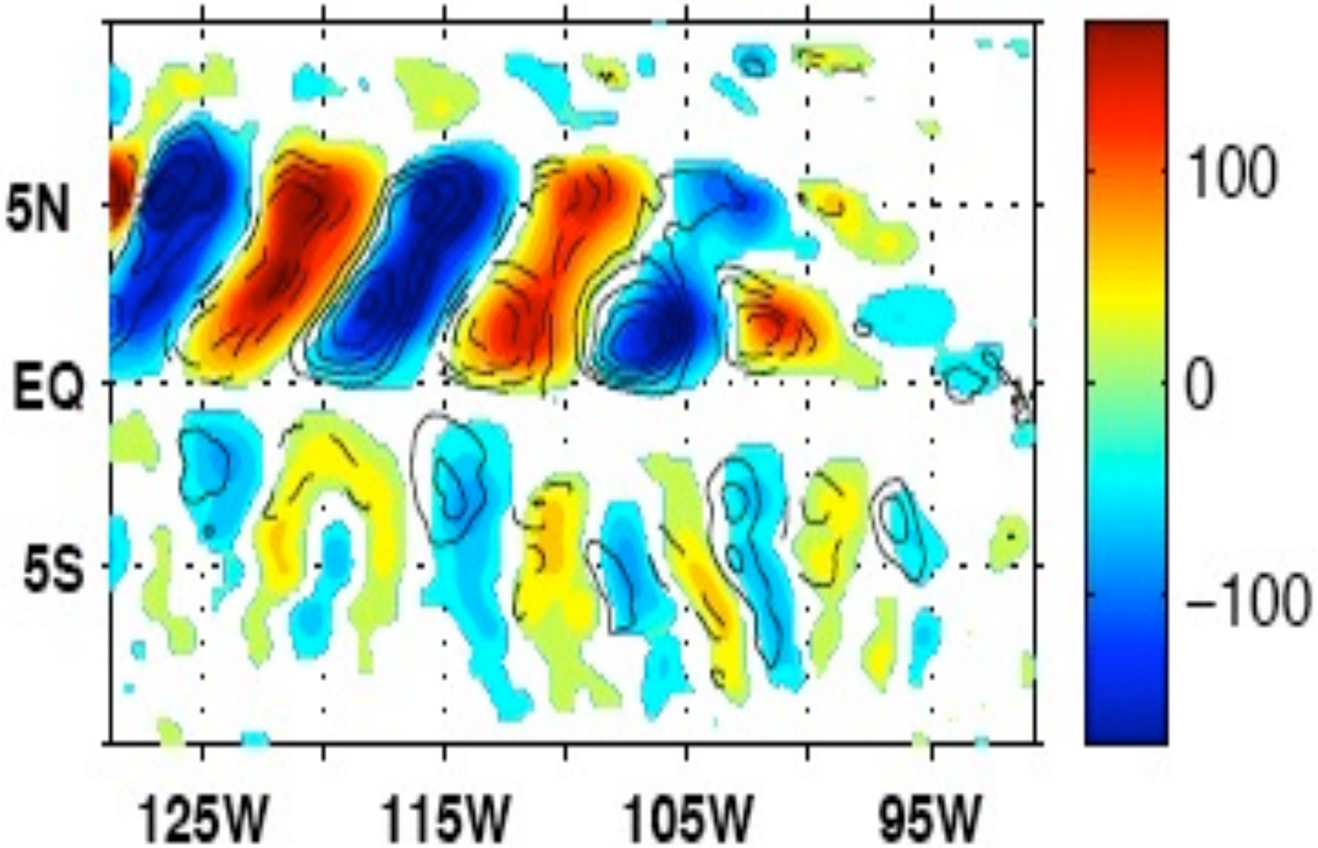
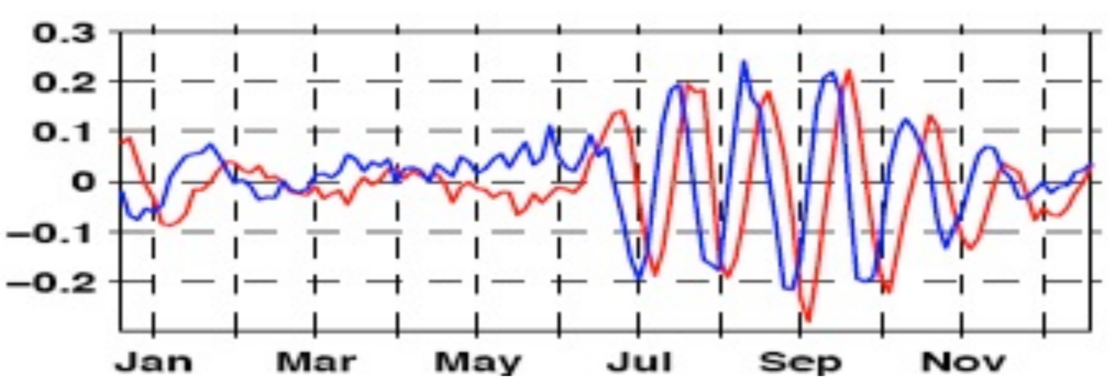
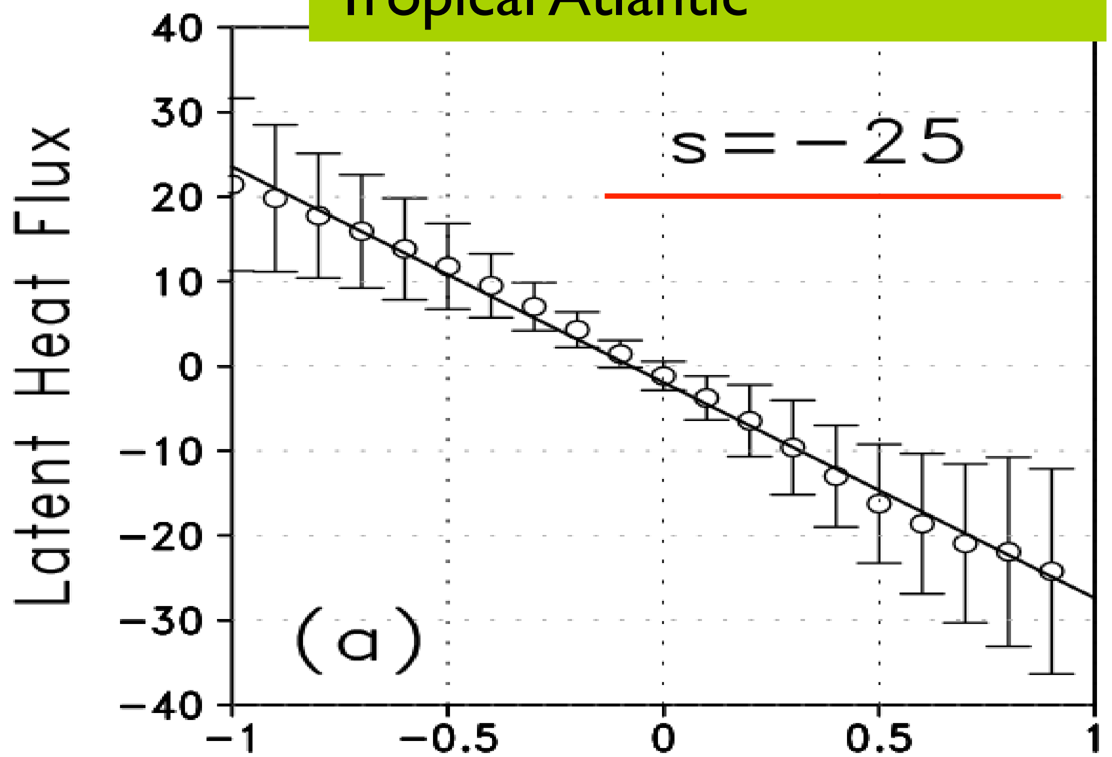




Tropical Atlantic



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Large-scale rectification from heat flux anomalies??

Latent Heat Flux Parameterizations ➔

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

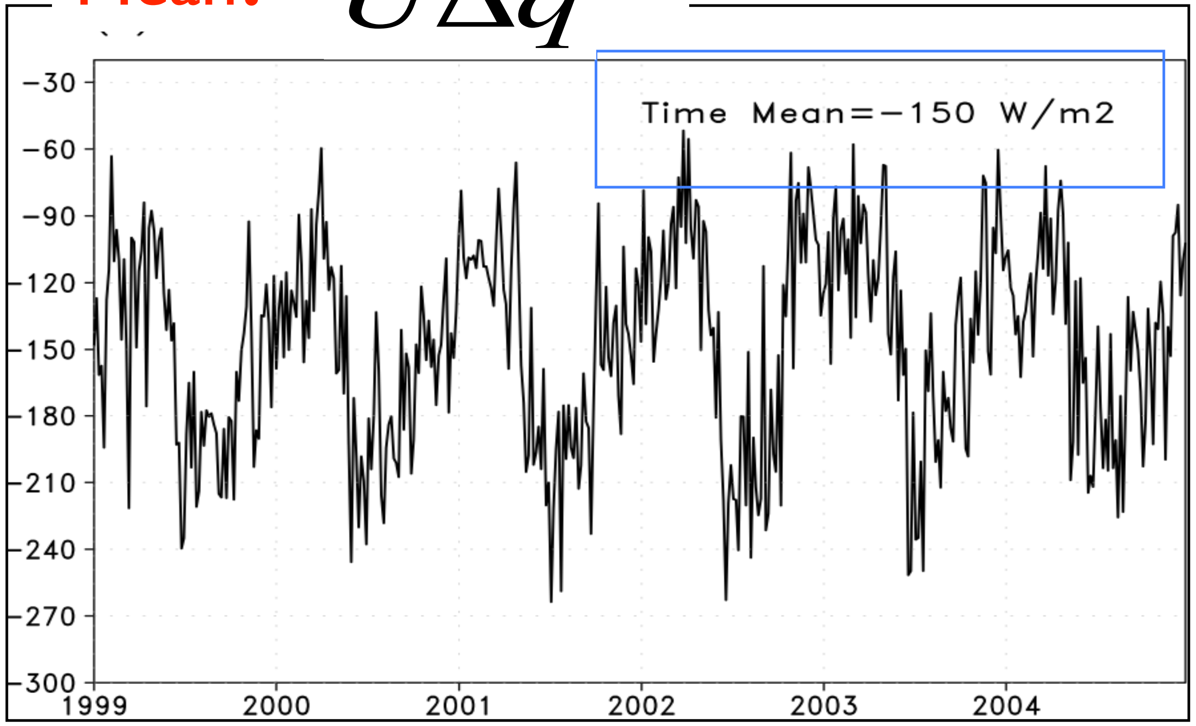
Reynolds averaging of LH ➔

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

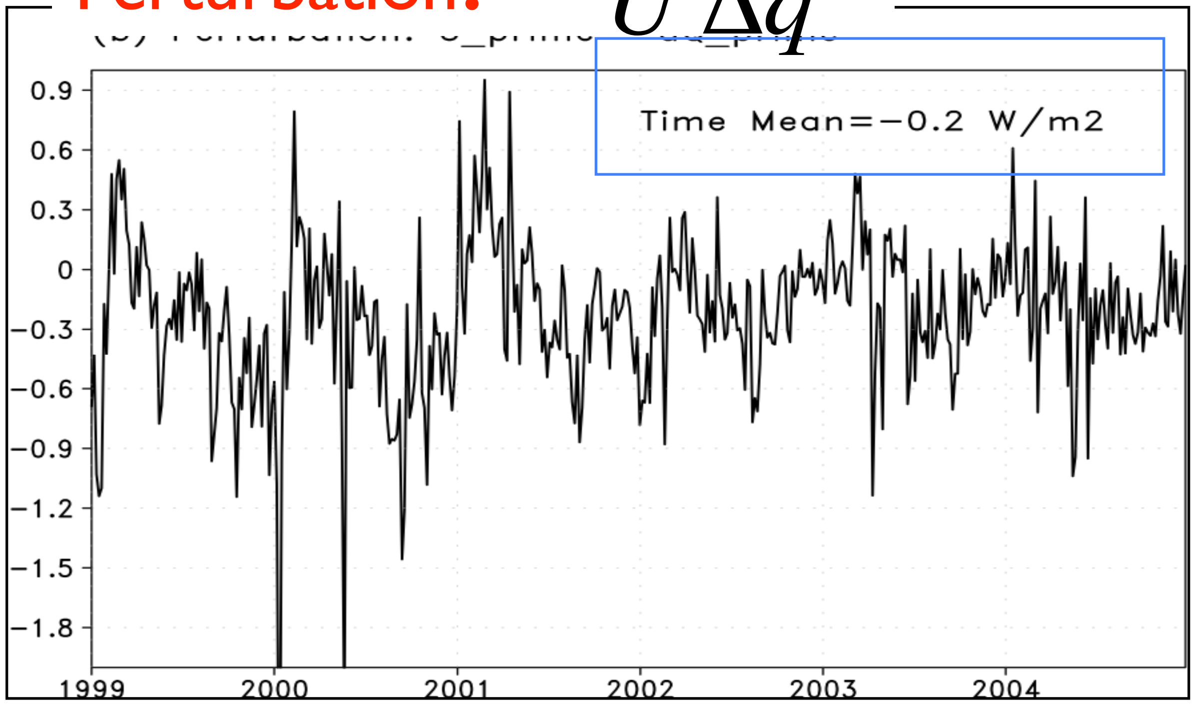
- Rectification by high-frequency (TIW-induced) LH′ is small compared to mean LH.
- TIWs still operate over the large-scale SST gradient to modulate the temperature advection (Jochum and Murtugudde 2006, 2007).

Large-scale rectification from heat flux anomalies??

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



Perturbation: $U'\Delta q'$



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

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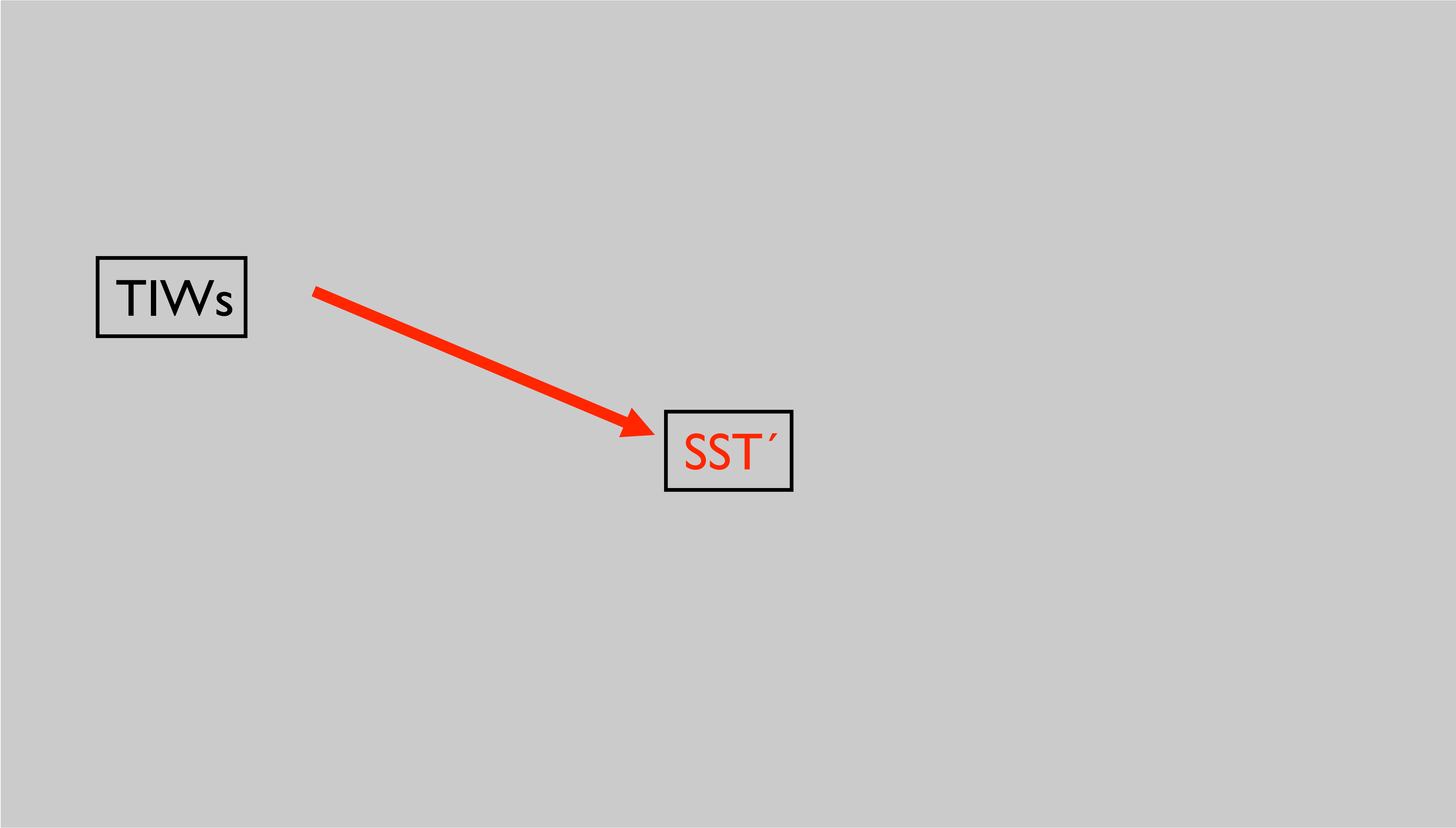

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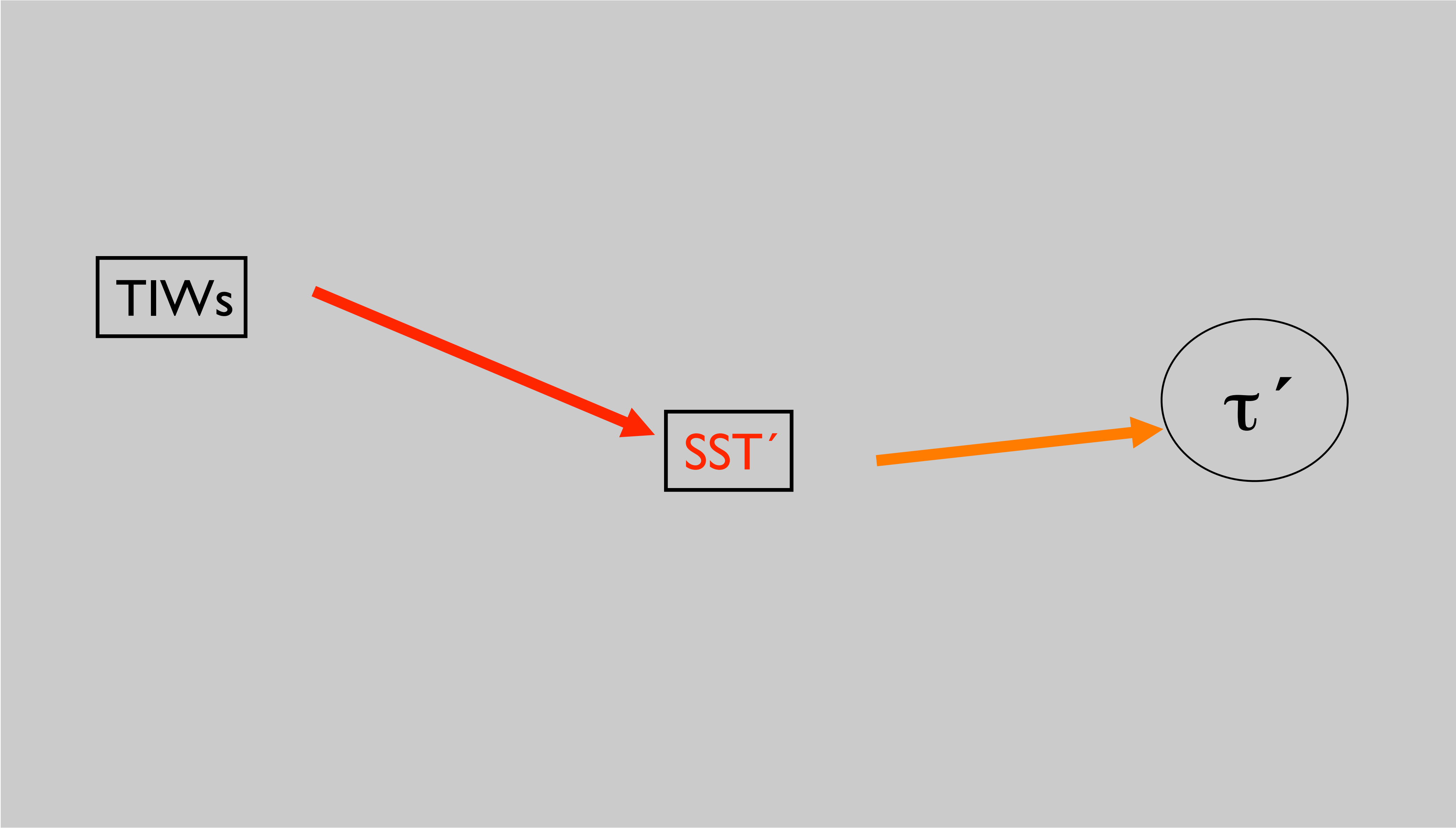

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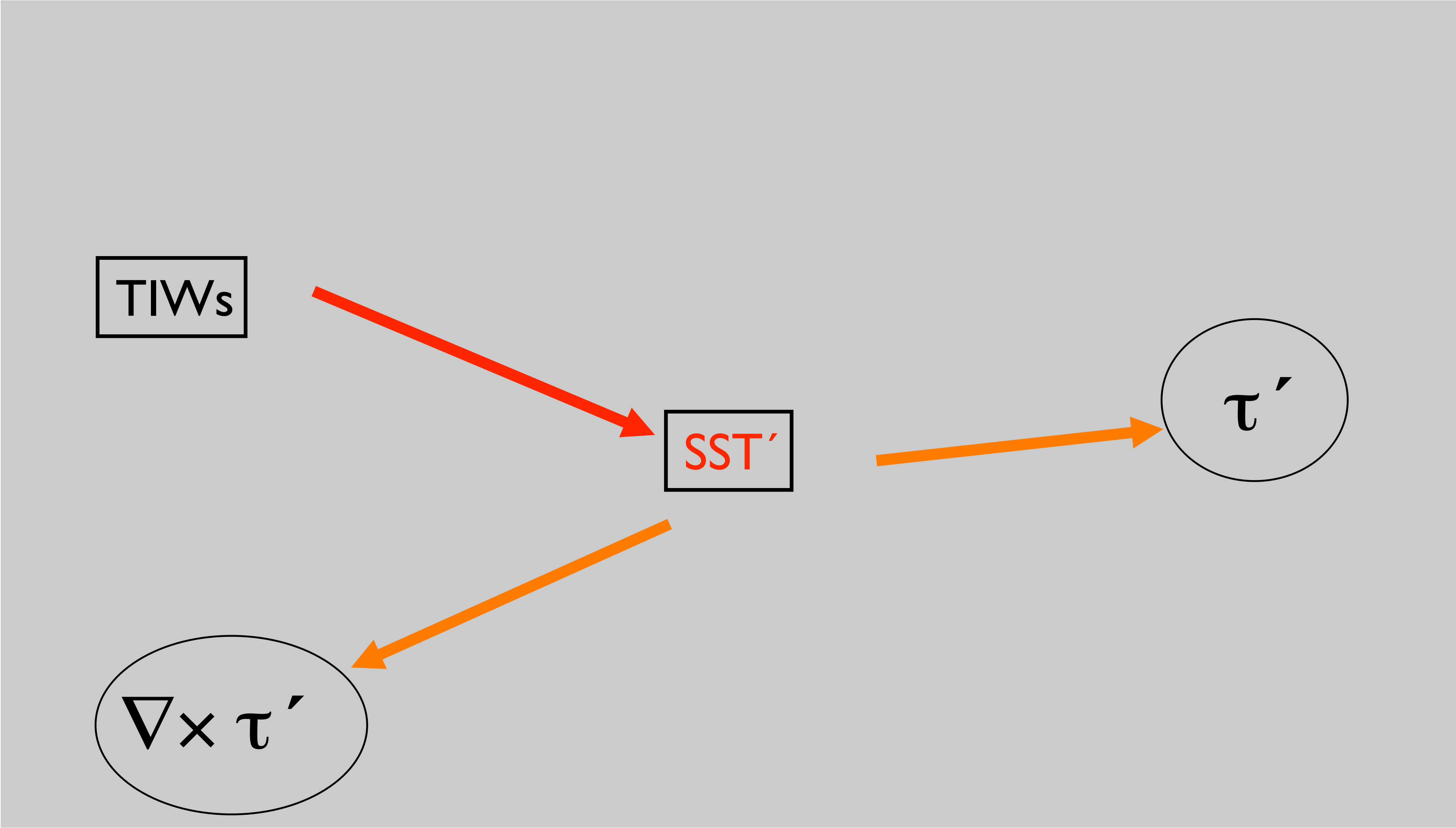

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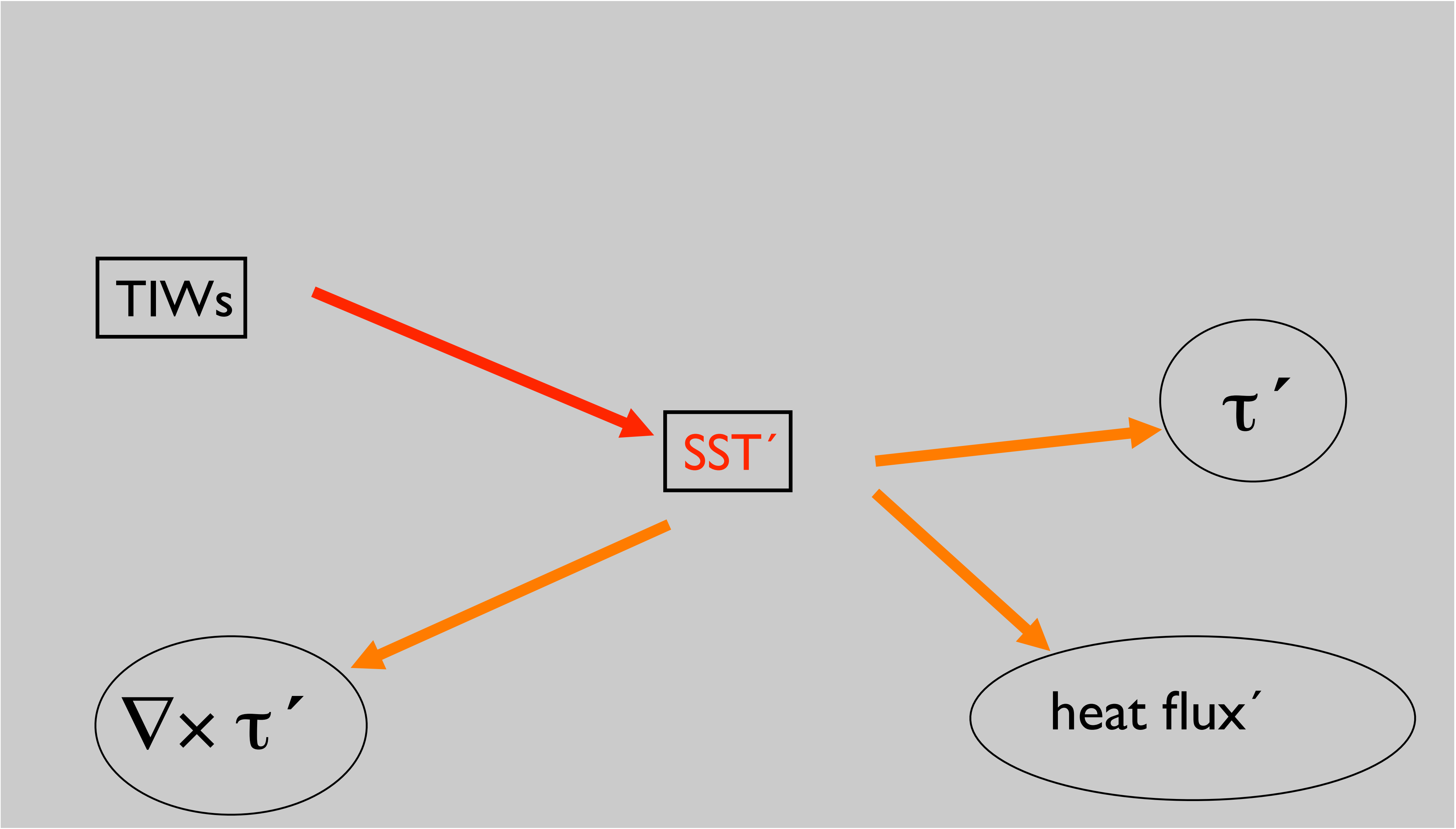

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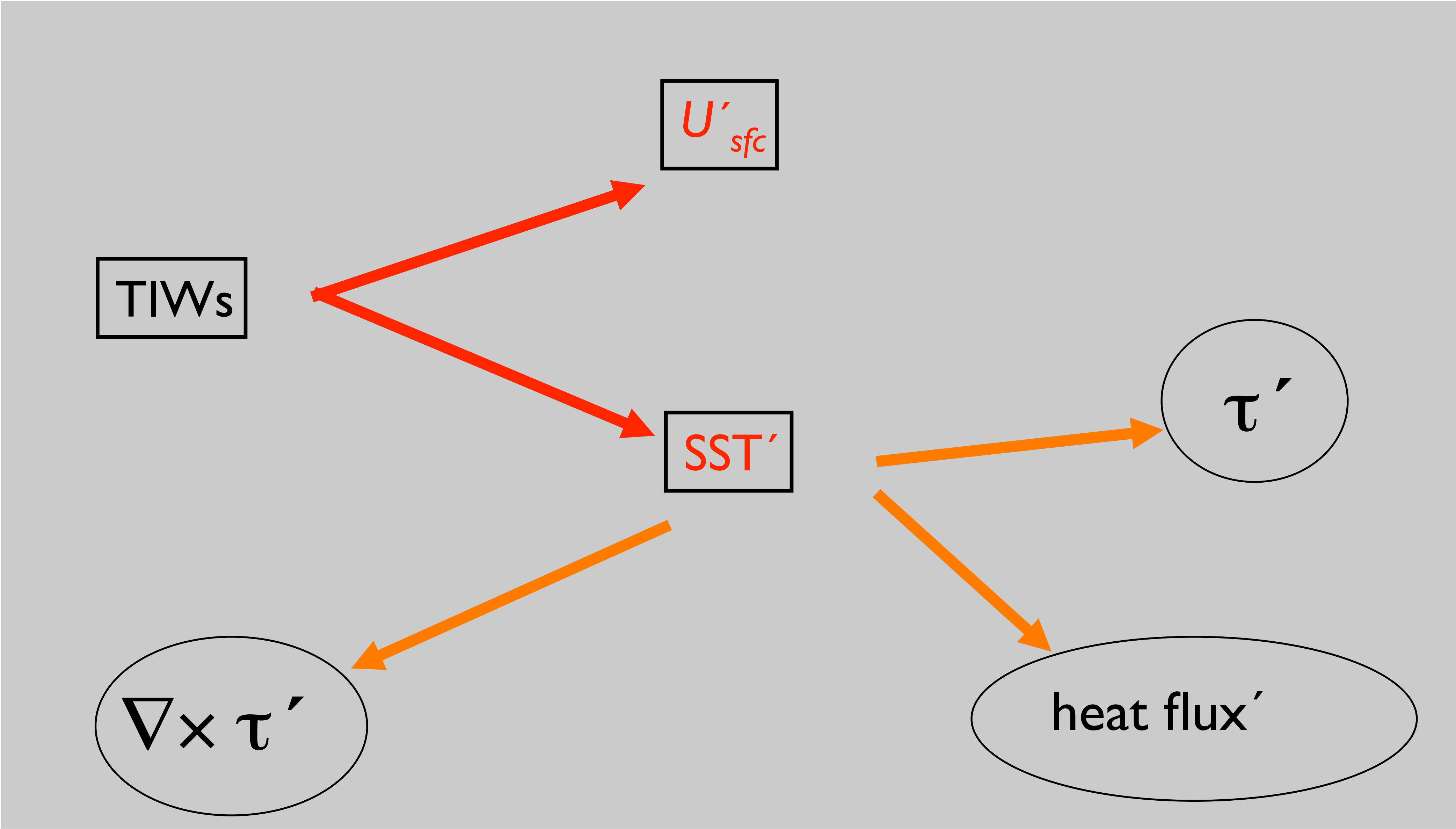

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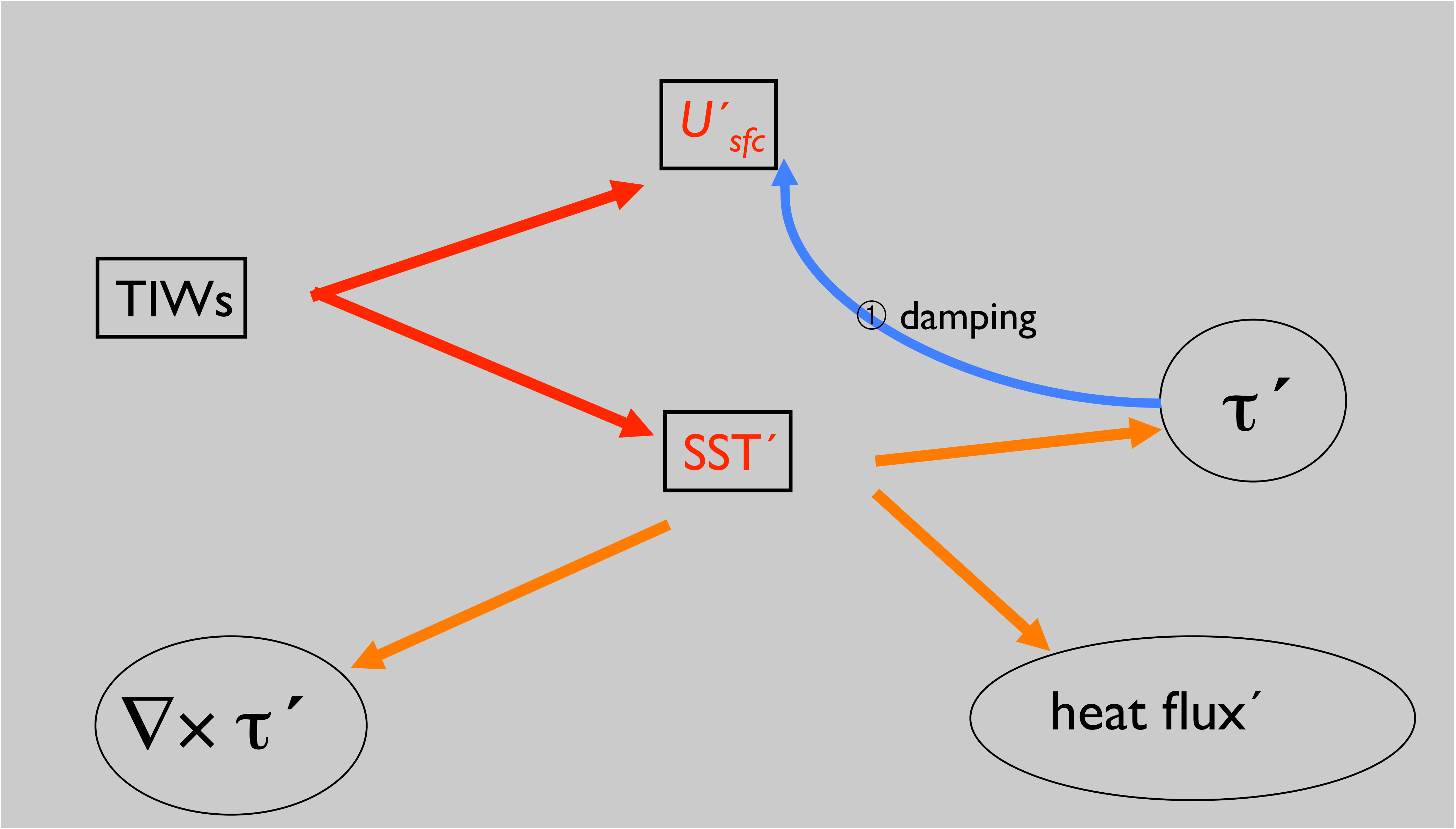

① Wind response damps TIW-current: Small but significant damping

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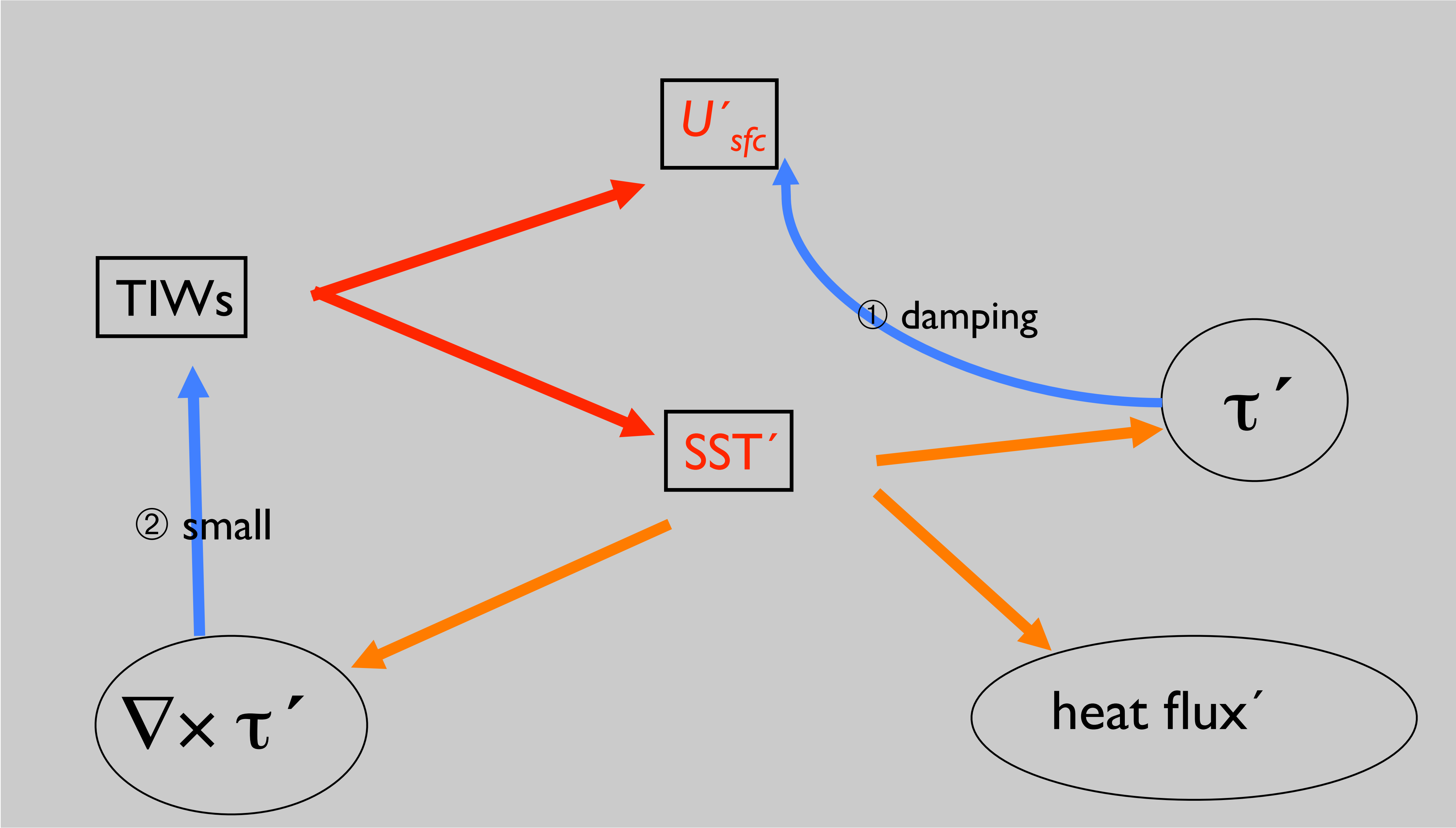

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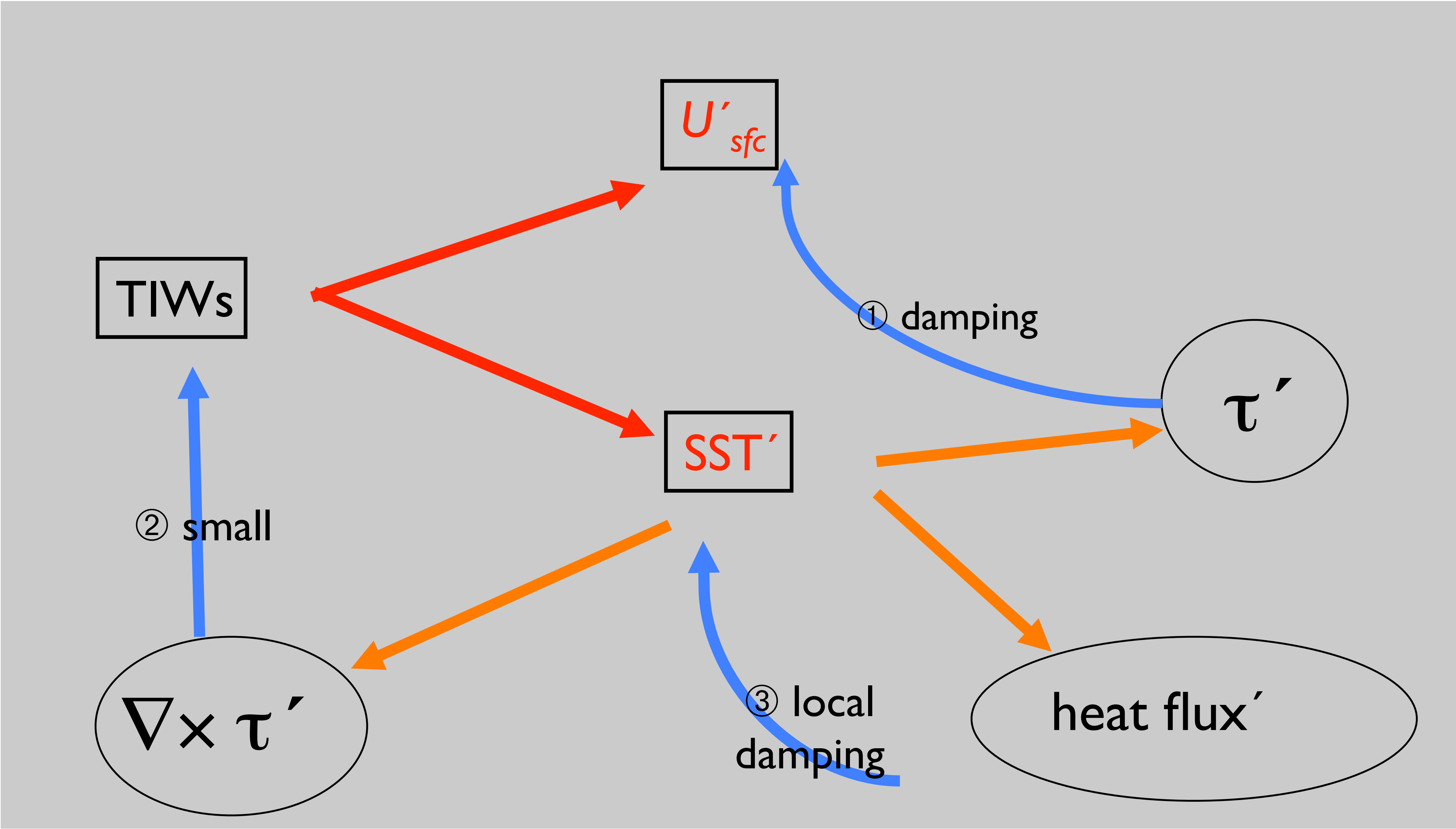

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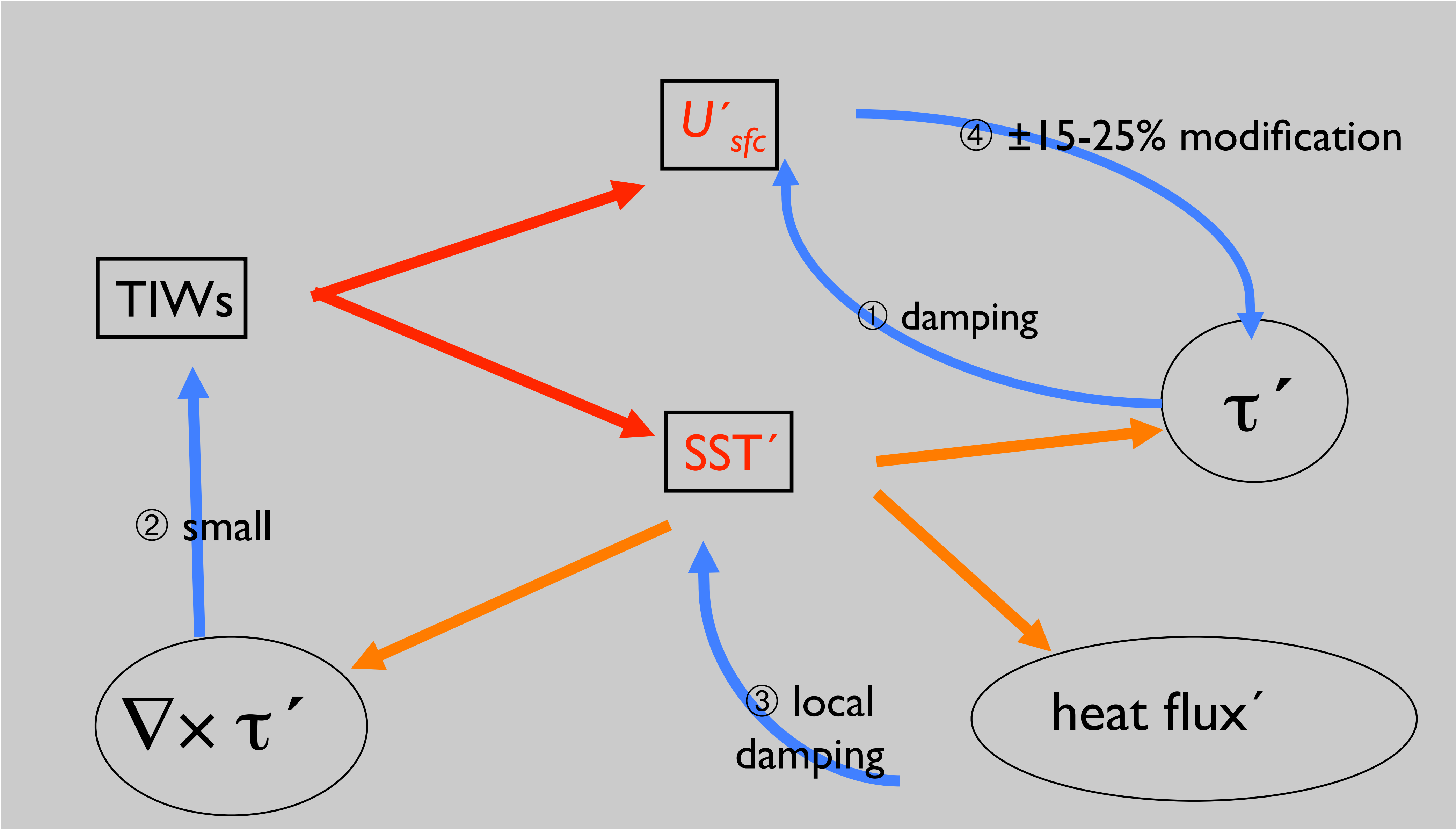

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④ TIW-currents alter surface stress by ±15-25% depending on phase

Conclusion and outlook

• Using this SCOAR model, we have shown that
1) TIWs triggers large perturbations in atmospheric boundary layer.
2) and this can feed back to the ocean, modulating the properties of the waves.

Questions
Any broader-scale implication due to the TIWs-atmosphere coupling?

a) Is there any deep response in atmosphere due to the TIWs?

b) How do TIWs affect the large-scale cross-equatorial winds and the location of ITCZ?

c) How do TIWs and heat flux into the thermocline modulate the ENSO on the inter-annual and decadal timescales?

Current work

The ongoing/future goals using the SCOAR model...

1) Continue to identify the regions of intense local air-sea interaction, and quantify the its overall influence on the regional ocean and the atmosphere.

2) Study the basin-scale climate variability involving the mesoscale air-sea interaction, which can the insights and guidelines for the GCMs.

Model domain and daily animation of 2006 (1/1-12/31)

- Identical 0.26°horizontal resolution
- 322*282*28* (20)
- Daily coupling
- 1993-2006
- OBC: East and South with monthly WOA05 T/S climatology
- No river runoff

1. Air-sea interaction and monsoon variability
2. Intra-seasonal o-a interaction and MJO and ITF.
3. Bay of Bengal salinity and SST
4. Tropical cyclones in the SWIO and BoB

* color shade: SST (22.5-30C)
* black arrow: 10m winds
* purple contours: rainfall (50,100,200 mm/day)

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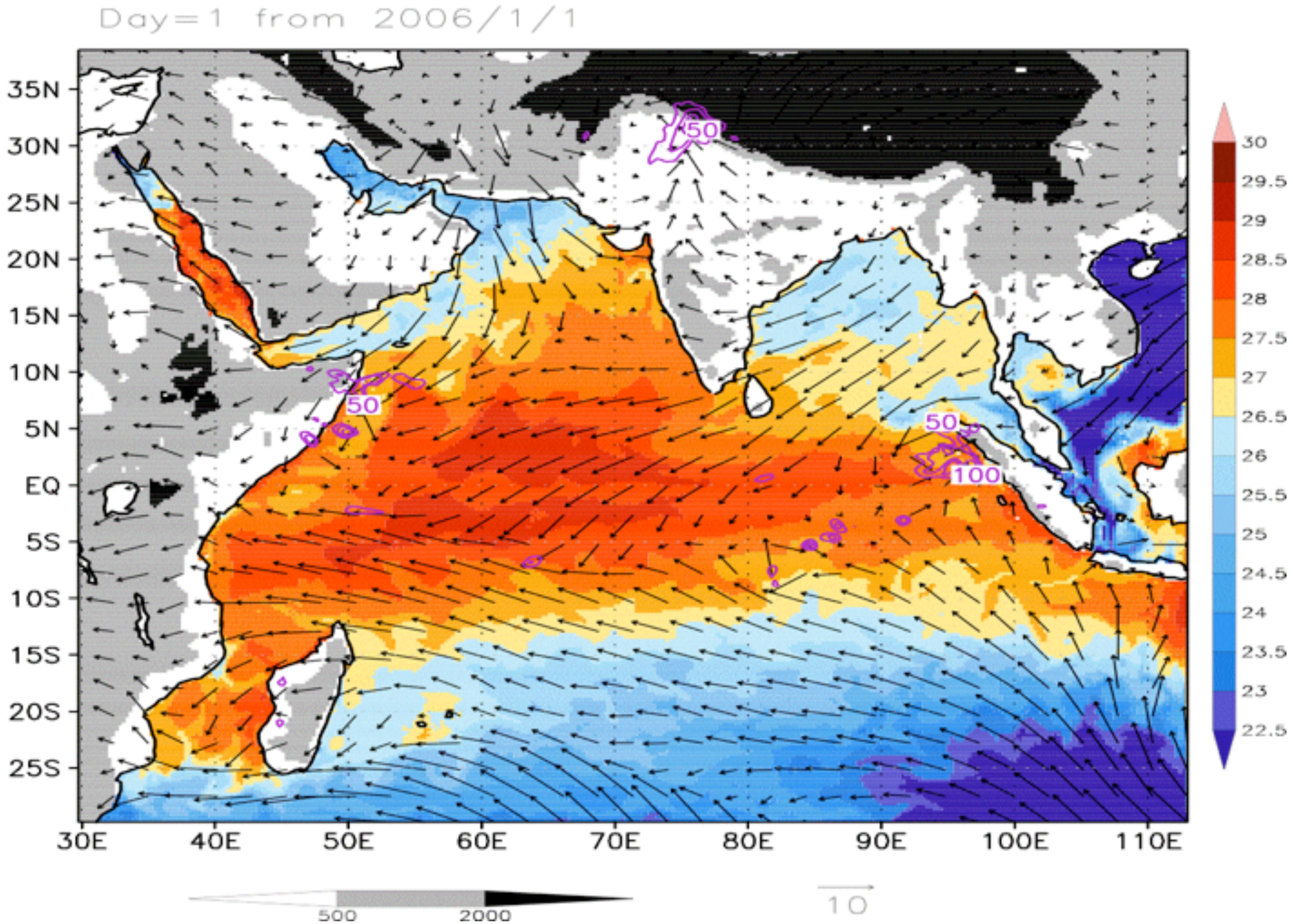

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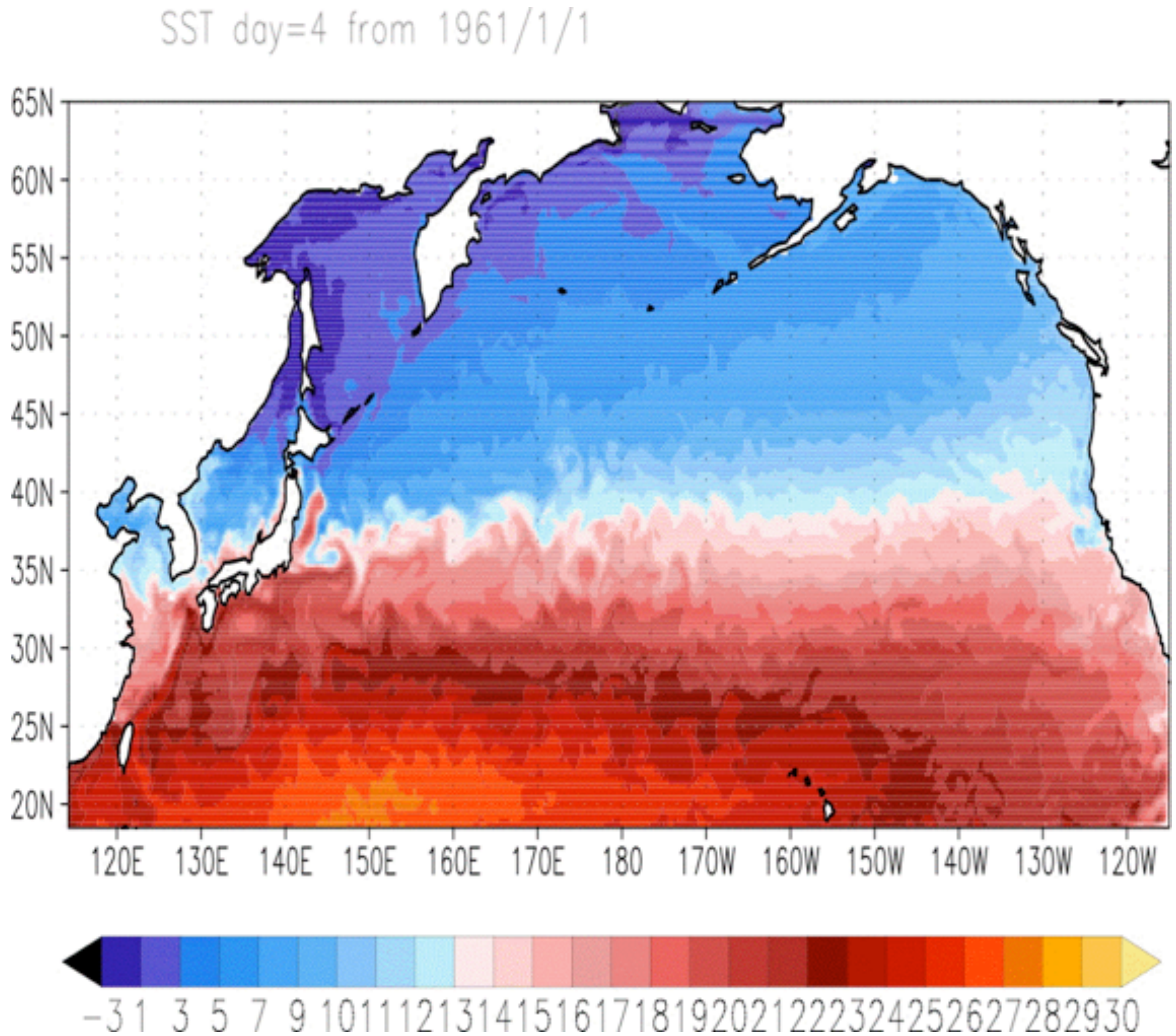
- No river runoff

1. Air-sea interaction and monsoon variability
2. Intra-seasonal o-a interaction and MJO and ITF.
3. Bay of Bengal salinity and SST
4. Tropical cyclones in the SWIO and BoB

* color shade: SST (22.5-30C)
* black arrow: 10m winds
* purple contours: rainfall (50,100,200 mm/day)

North Pacific Decadal Coupled Variability using SCOAR

with Niklas Schneider and Art Miller



- Goal: Study the effects of eddies and the local ocean-atmosphere coupling over the Kuroshio Extension variability on the downstream influence in Gulf of Alaska and California

- 1/4° Ocean + 1° ATM.
- Daily coupling
- 1960-1967 (goal: 1960-Present)


Thanks!