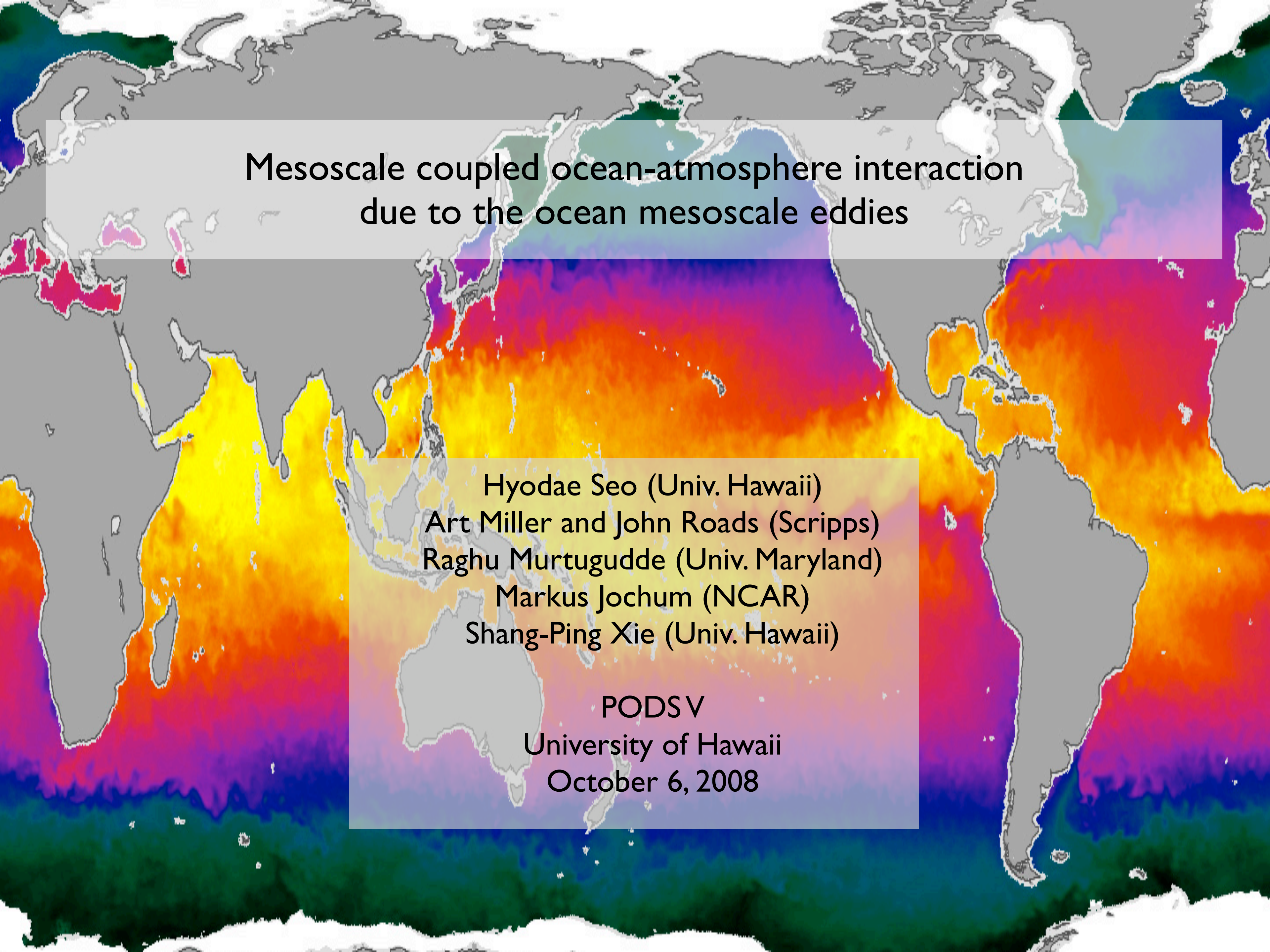
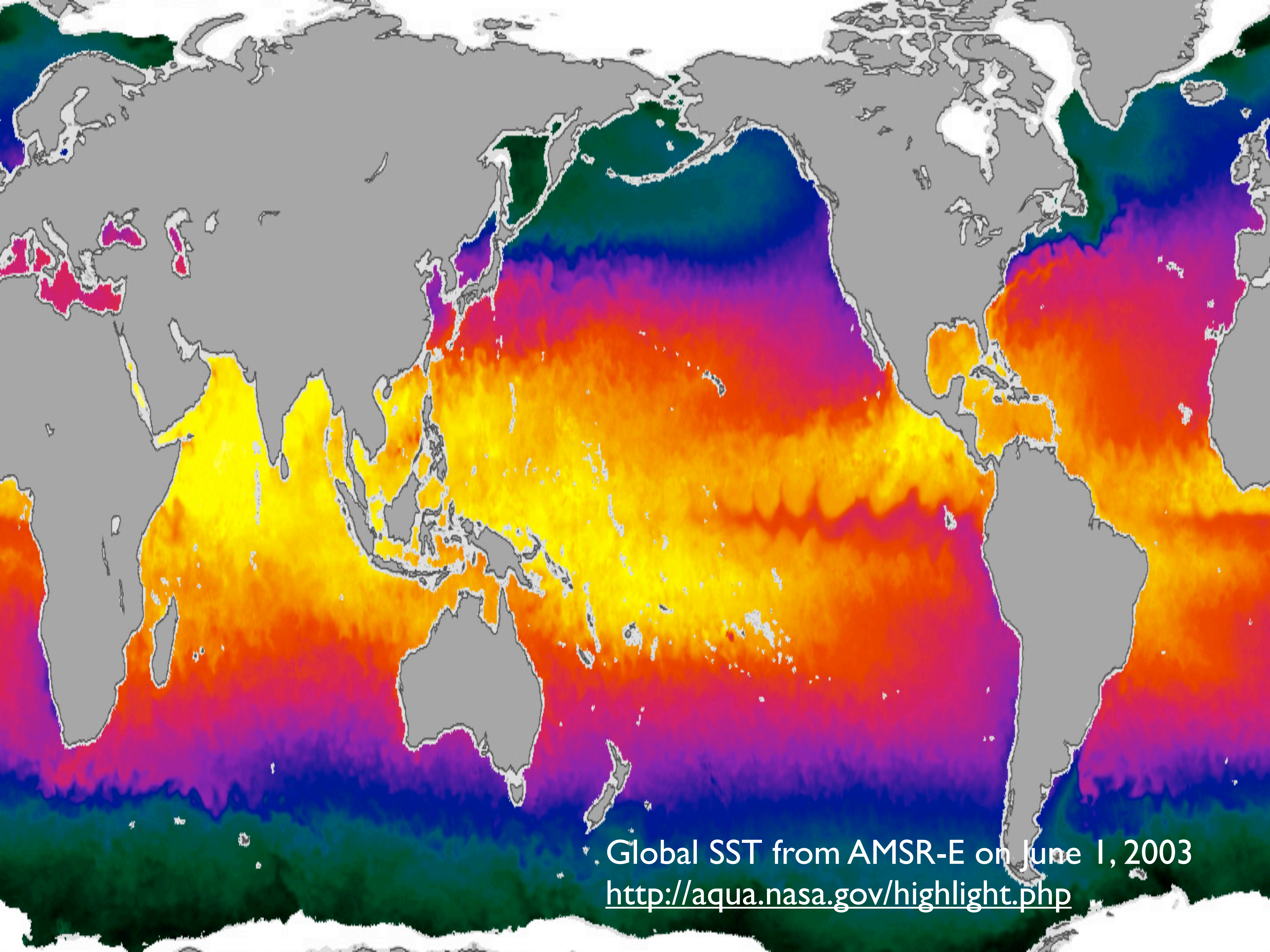


Mesoscale coupled ocean-atmosphere interaction due to the ocean mesoscale eddies

Hyodae Seo (Univ. Hawaii)
Art Miller and John Roads (Scripps)
Raghu Murtugudde (Univ. Maryland)
Markus Jochum (NCAR)
Shang-Ping Xie (Univ. Hawaii)

PODS V
University of Hawaii
October 6, 2008

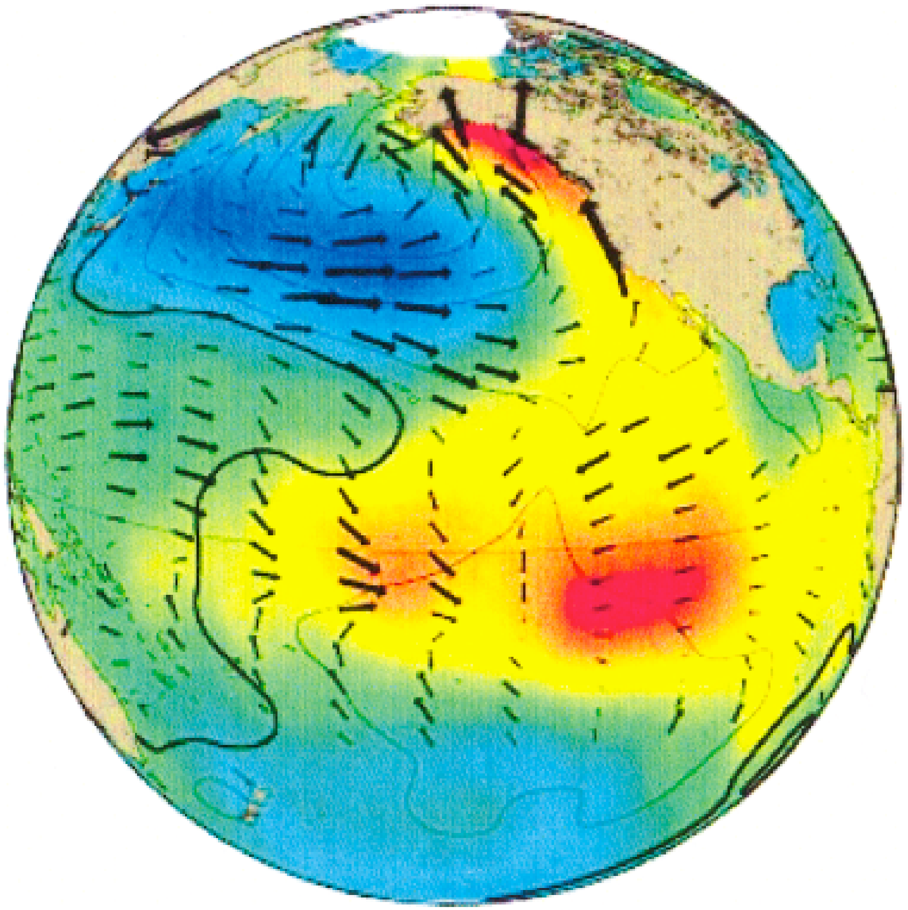


Global SST from AMSR-E on June 1, 2003
http://aqua.nasa.gov/highlight.php

Overview of my talk

- What is mesoscale ocean-atmosphere coupled feedback?
- Why do we need a high-resolution coupled model?
- Examples of mesoscale coupled feedback studies
  - Tropical Instability Waves (TIWs)
  - Cold filaments in western Arabian Sea
    - Dynamic feedback
    - (Thermodynamic feedback)
- Summary and some remaining questions.

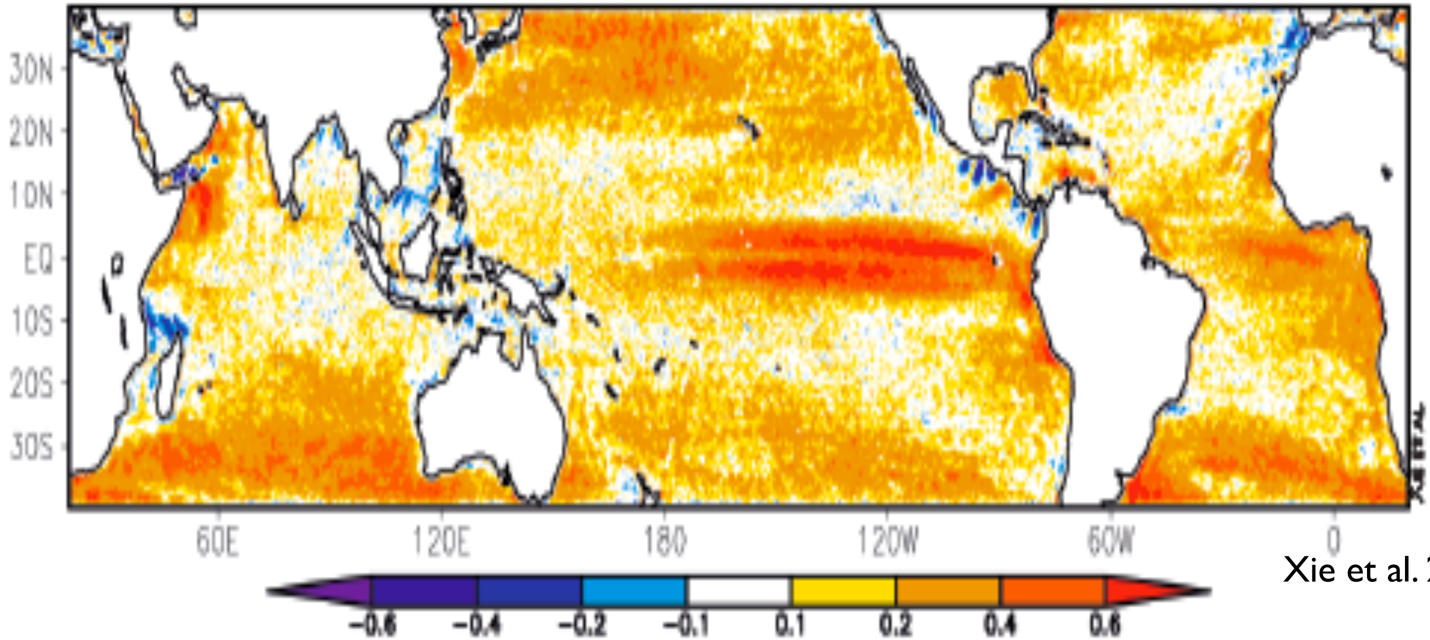
Relation of SST and wind speed on basin, longer scale



Matuna et al. 1997

- SST, Wind, SLP regressed onto the Pacific Decadal Oscillation Index
- Negative correlation of wind and SST:
- Atmospheric wind variability drives SST response through altered turbulent heat flux and oceanic mixing process.
- Atmosphere forcing the ocean

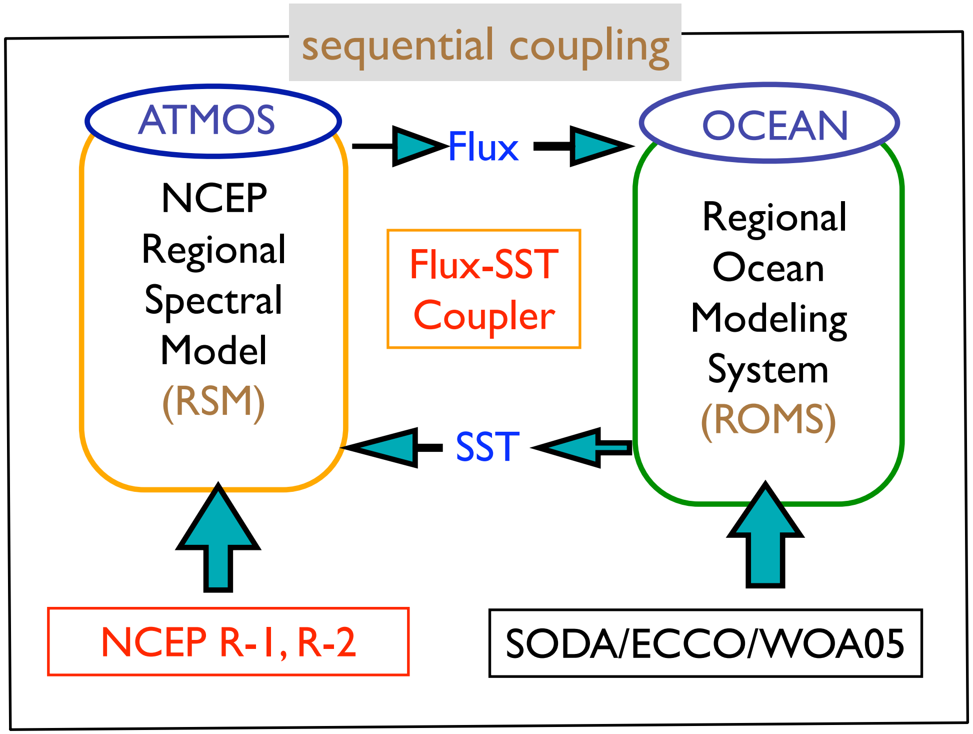
How about on oceanic mesoscale?



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 seasonal timescale on oceanic eddy scale; O(10-1000km)
- Triggered by SST fronts or mesoscale coastal orography
- Ocean models resolve TIWs (or at least wiggles), yet coupled feedback is substantially underestimated due to a lack of coherent atmospheric response.
- Models should capture this fully coupled process.

Scripps Coupled Ocean-Atmosphere Regional (SCOAR) Model



- Higher model resolution BOTH in the ocean and atmosphere.
- Dynamical consistency with the NCEP Reanalysis forcing
- More complete and flexible coupling strategy
- Parallel architecture
- State-of-the-art physics implemented in RSM and ROMS
- Potential for incorporating ecosystem and biogeochemistry models, ocean wave models, and land-surface models.
- **Greater portability**

1. Mesoscale ocean-atmosphere interaction
2. Large-scale climate variability
3. Coastal prediction system

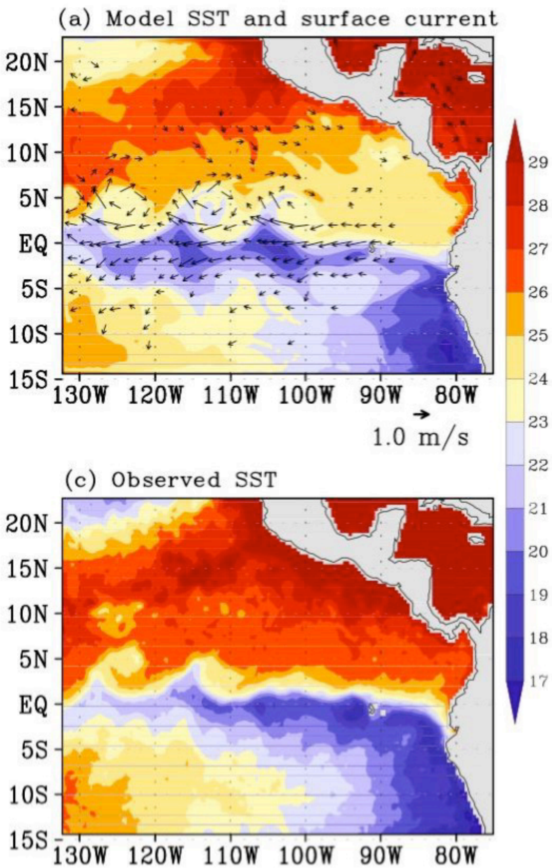
Seo, Miller and Roads, 2007a: The Scripps Coupled Ocean-Atmosphere Regional (SCOAR) model, with applications in the eastern Pacific sector. JCLI

Examples...

Feedback of Tropical Instability Wave - induced Atmospheric Variability onto the Ocean.

Seo, Jochum, Murtugudde, Miller, and Roads, 2007b JCLI

Tropical Instability Waves (TIWs) in the eastern equatorial Pacific



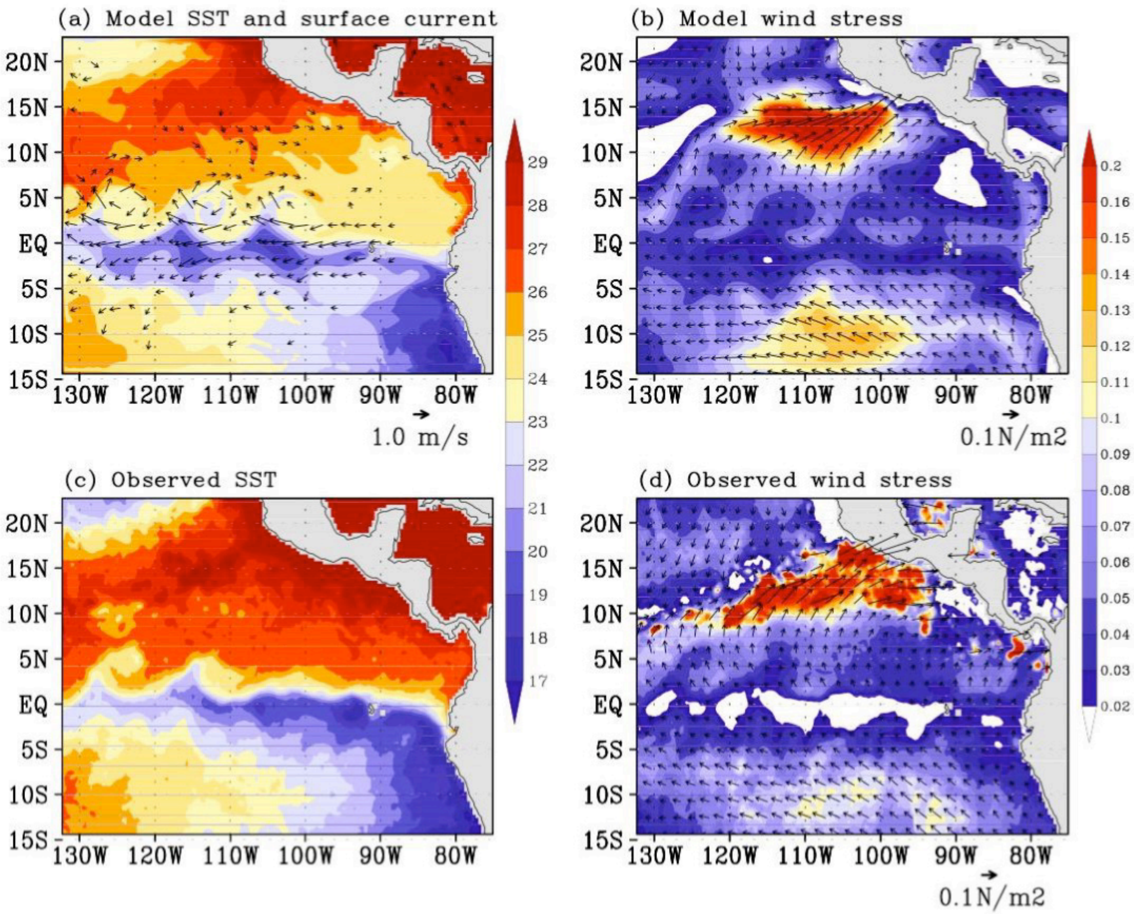
- SCOAR Eastern Pacific TIWs Model (45 km ROMS + 50 km RSM, daily coupled)

- (top) 3-day averaged SST, wind stress vectors, ocean current centered on Sep. 3,1999

- (bottom) TMI SSTs and QuikSCAT wind stresses

- Instability of equatorial currents and front
- Westward propagation, ~1000 km, 0.5m/s, strong during the boreal fall/winter
- O(1) impact for heat and momentum balance in the equatorial oceans
- Profound impact on the marine ecosystem and biogeochemical cycle
- Large-SSTA & Weak-wind: ➔ Strong mesoscale ocean-atmosphere interactions

Tropical Instability Waves (TIWs) in the eastern equatorial Pacific

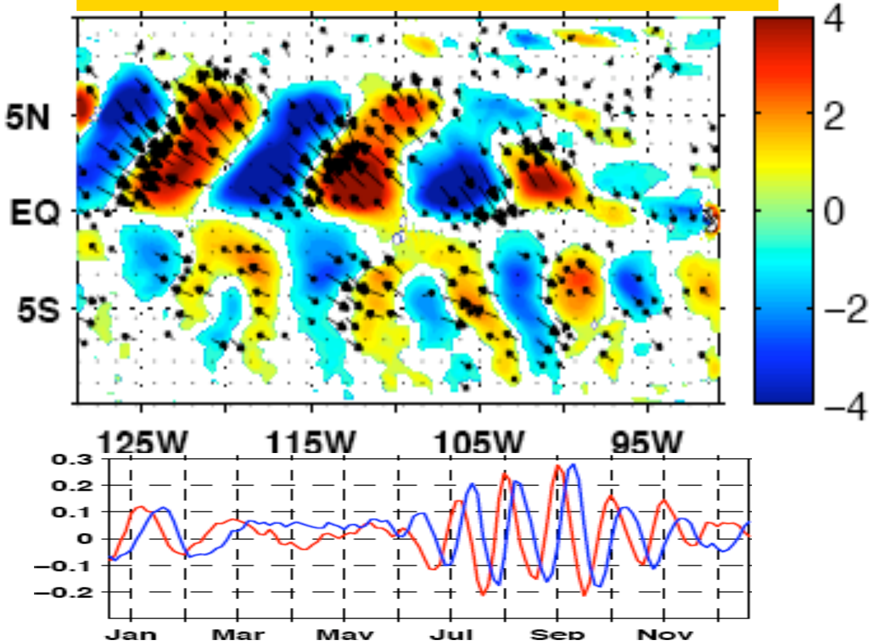


- SCOAR Eastern Pacific TIWs Model (45 km ROMS + 50 km RSM, daily coupled)
- (top) 3-day averaged SST, wind stress vectors, ocean current centered on Sep. 3,1999
- (bottom) TMI SSTs and QuikSCAT wind stresses

- Instability of equatorial currents and front
- Westward propagation, ~1000 km, 0.5m/s, strong during the boreal fall/winter
- O(1) impact for heat and momentum balance in the equatorial oceans
- Profound impact on the marine ecosystem and biogeochemical cycle
- Large-SSTA & Weak-wind: ➔ Strong mesoscale ocean-atmosphere interactions

Influence of SST on the surface winds

Combined EOF 1 of SST and Wind vectors



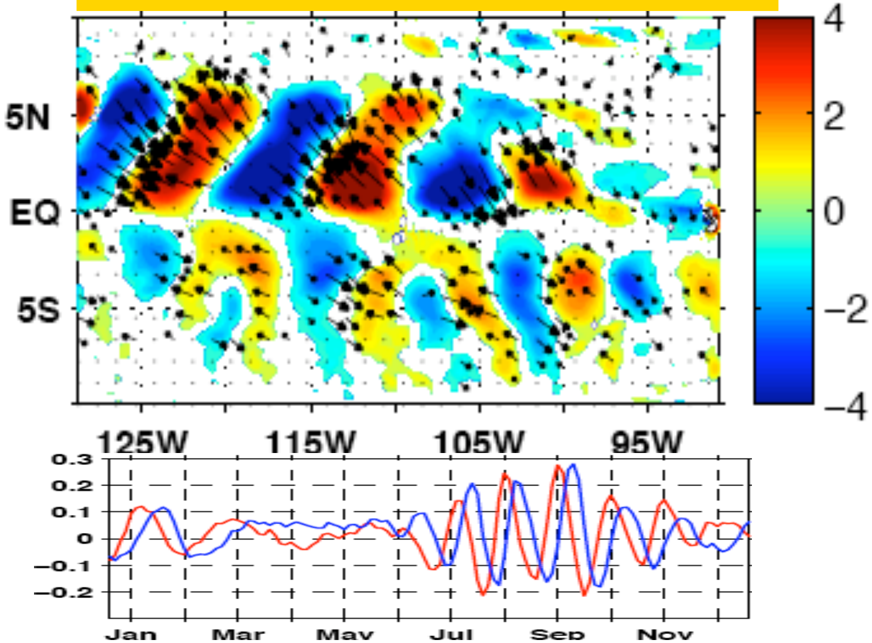
- SST ➔ Wind

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

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

Influence of SST on the surface winds

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)

Feedback to TIWs through ①

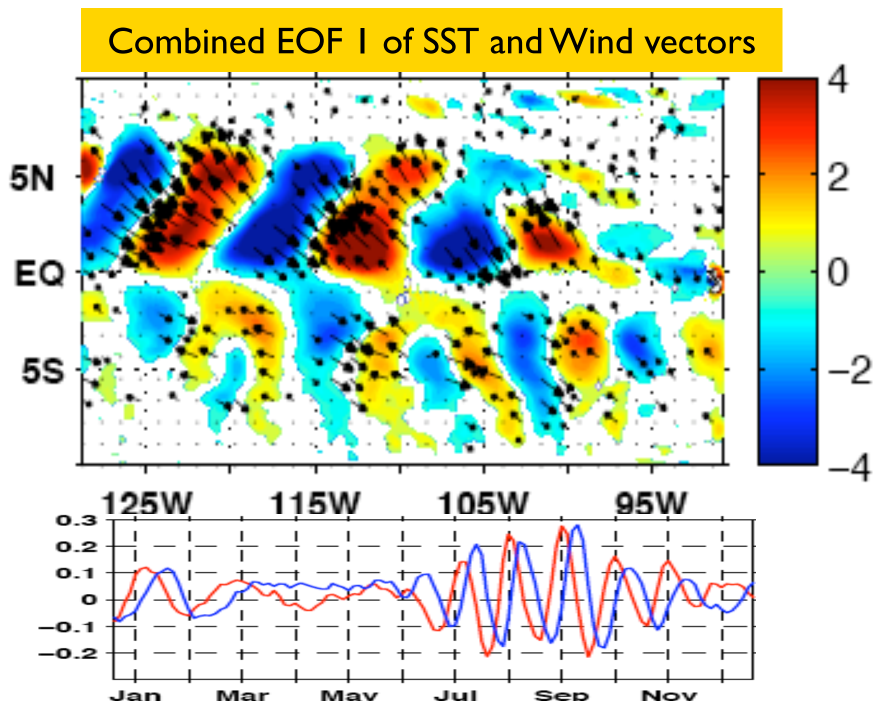
EKE Equation

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

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

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

Influence of SST on the surface winds



- 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)

Feedback to TIWs through ①

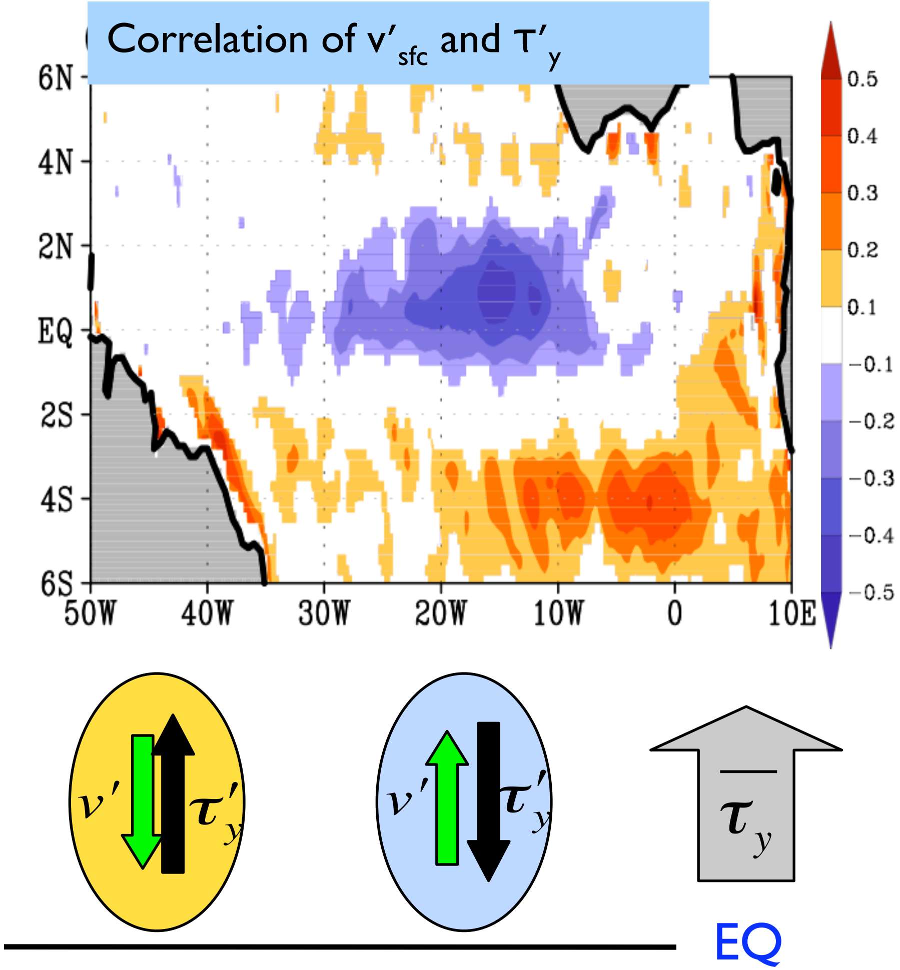
EKE Equation

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

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

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

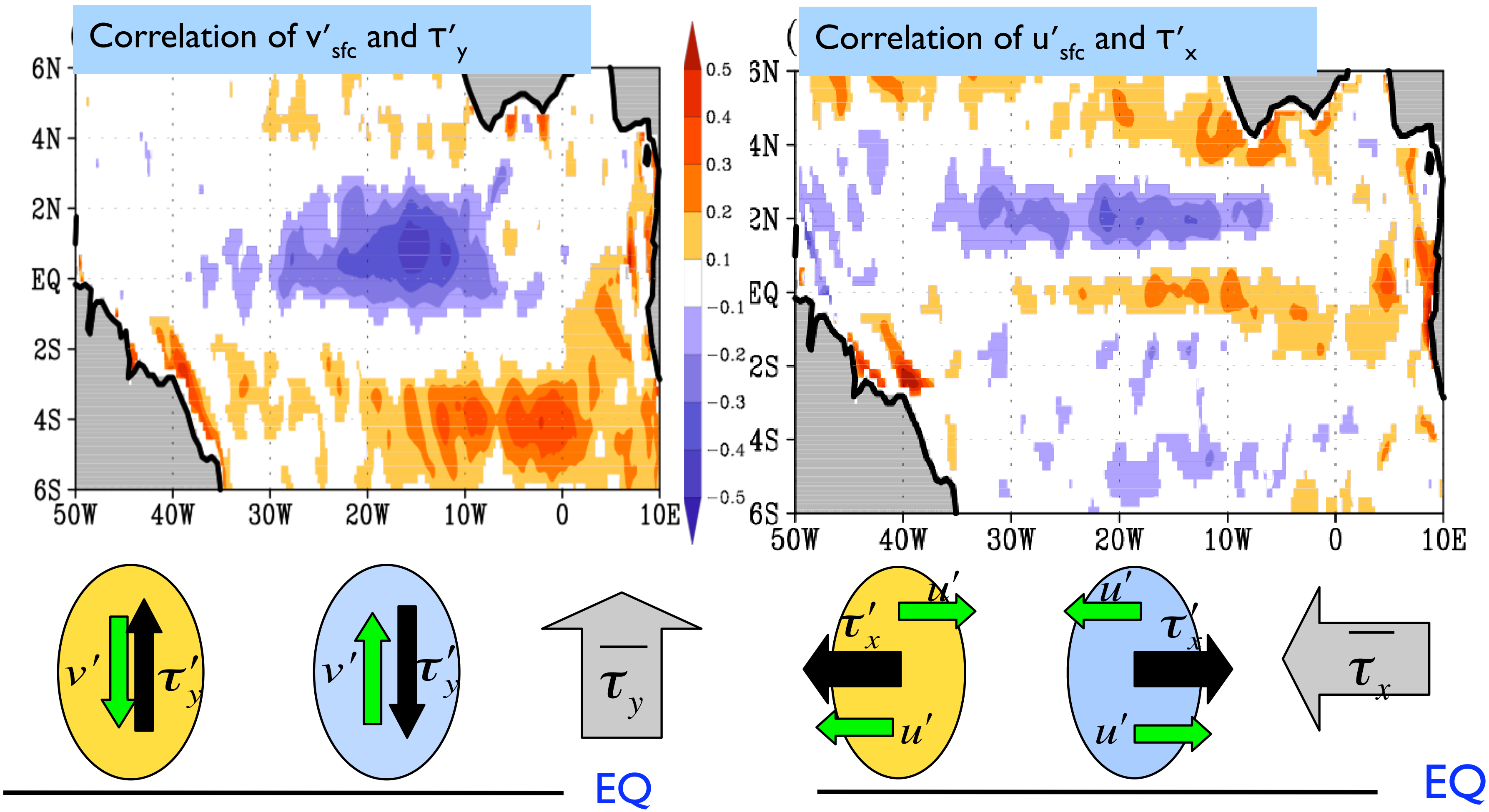
$u'_{sfc} \cdot \tau'$:Correlation of TIW-induced current and wind stress



- Wind and current are negatively correlated.
- Wind-current coupling → energy sink

Atlantic TIWs, 25 km resolution
ROMS/RSM: 1999-2004

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

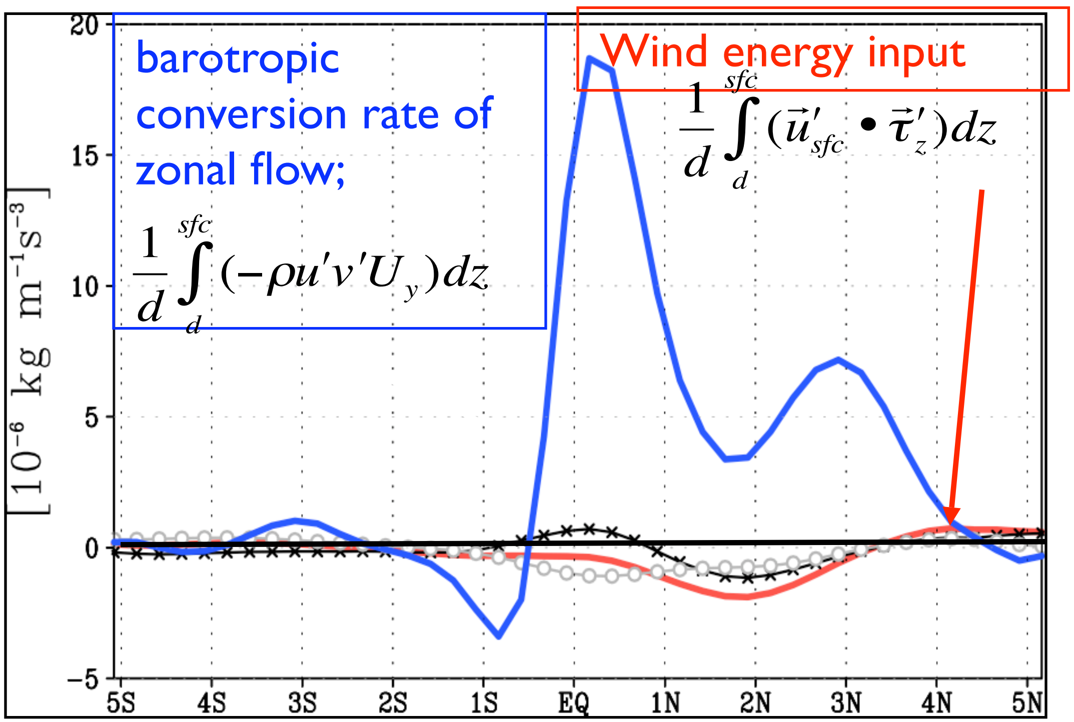


- Wind and current are negatively correlated.
- Wind-current coupling ➔ energy sink

Atlantic TIWs, 25 km resolution
ROMS/RSM: 1999-2004

EKE from the correlation of $u'_{sfc} \cdot \tau'$

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

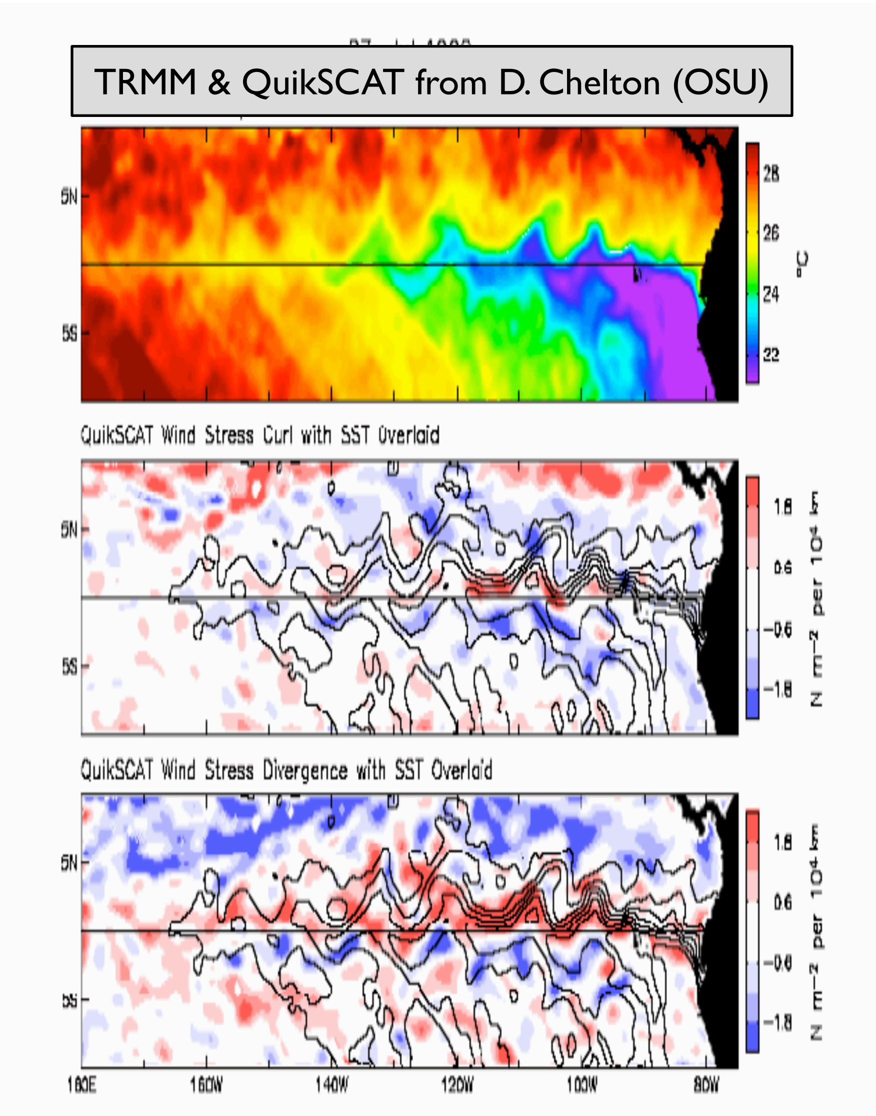


- Barotropic conversion rate of the zonal flow is the largest source term in the EKE budget of the waves (Weisberg and Weingartner 1998; Jochum et al. 2004)
- In the Atlantic, wind contribution to TIWs is ~10% of barotropic convergent rate.
- Small but important sink of energy

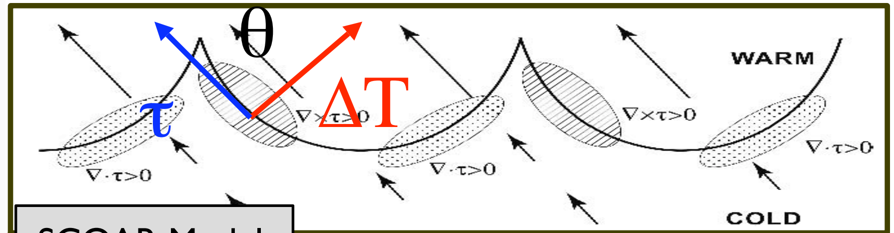
Perturbation wind stress curl and TIWs

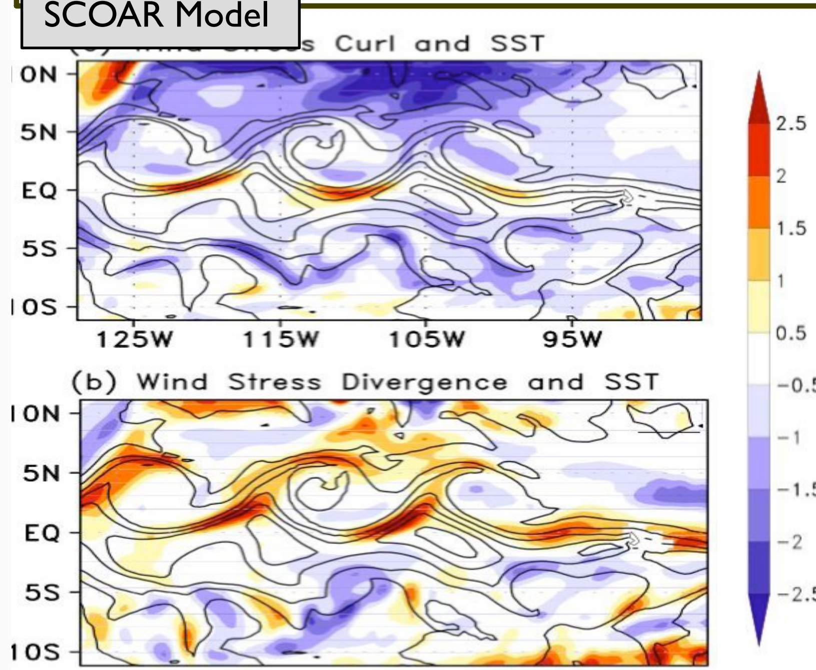
(② $\nabla\times\tau$ and ∇SST)

Coupling of SST gradients and wind stress derivatives



- WSD ~ Downwind SST gradient → $\nabla T \bullet \hat{\tau} = |\nabla T| \cos\theta$
- WSC ~ Crosswind SST gradient → $\nabla T \times \hat{\tau} \bullet \hat{k} = |\nabla T| \sin\theta$

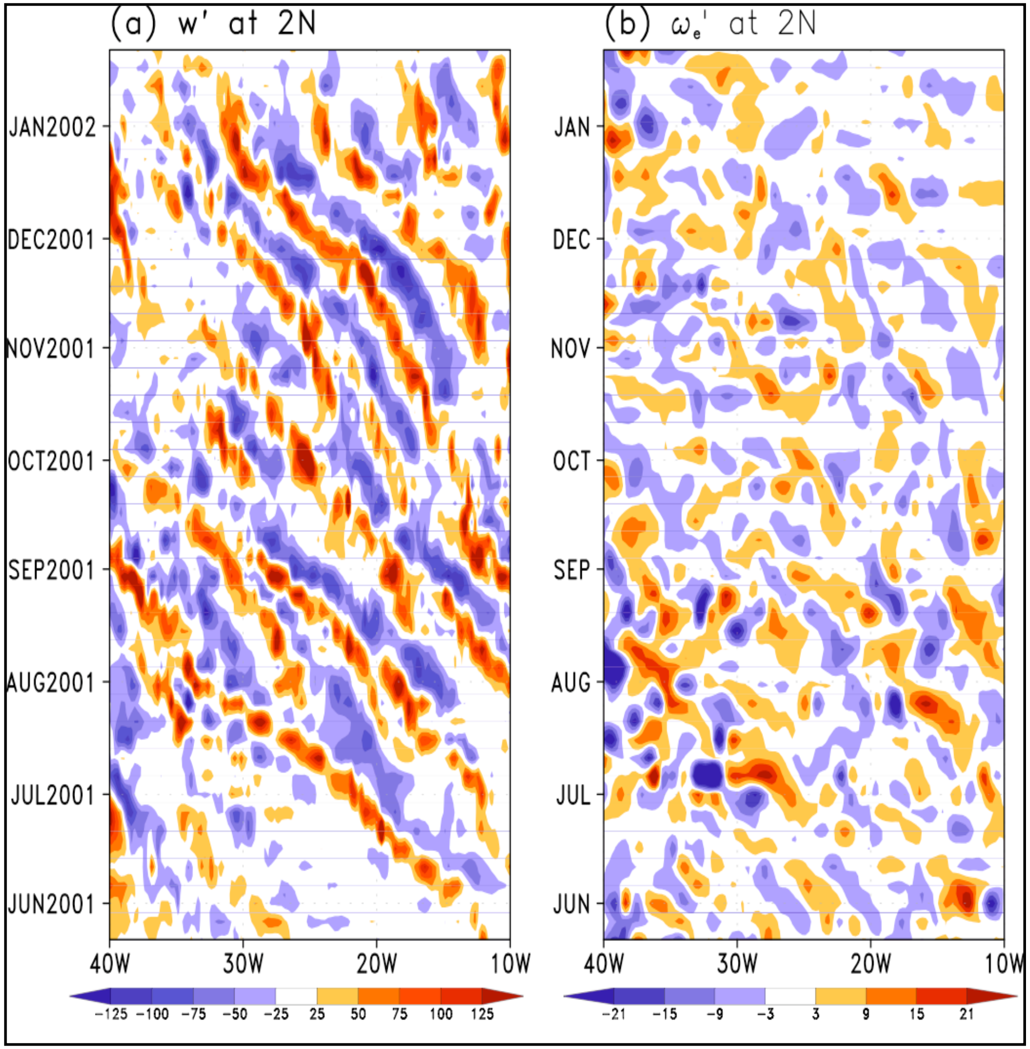




- **Question: How does perturbation wind stress curl affect the TIWs through Ekman pumping?**

Feedback of perturbation Ekman pumping to TIWs

w′ at MLD and ω_e' along 2°N



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

- Overall, Wek′ is less spatially coherent and weaker in magnitude than W′.

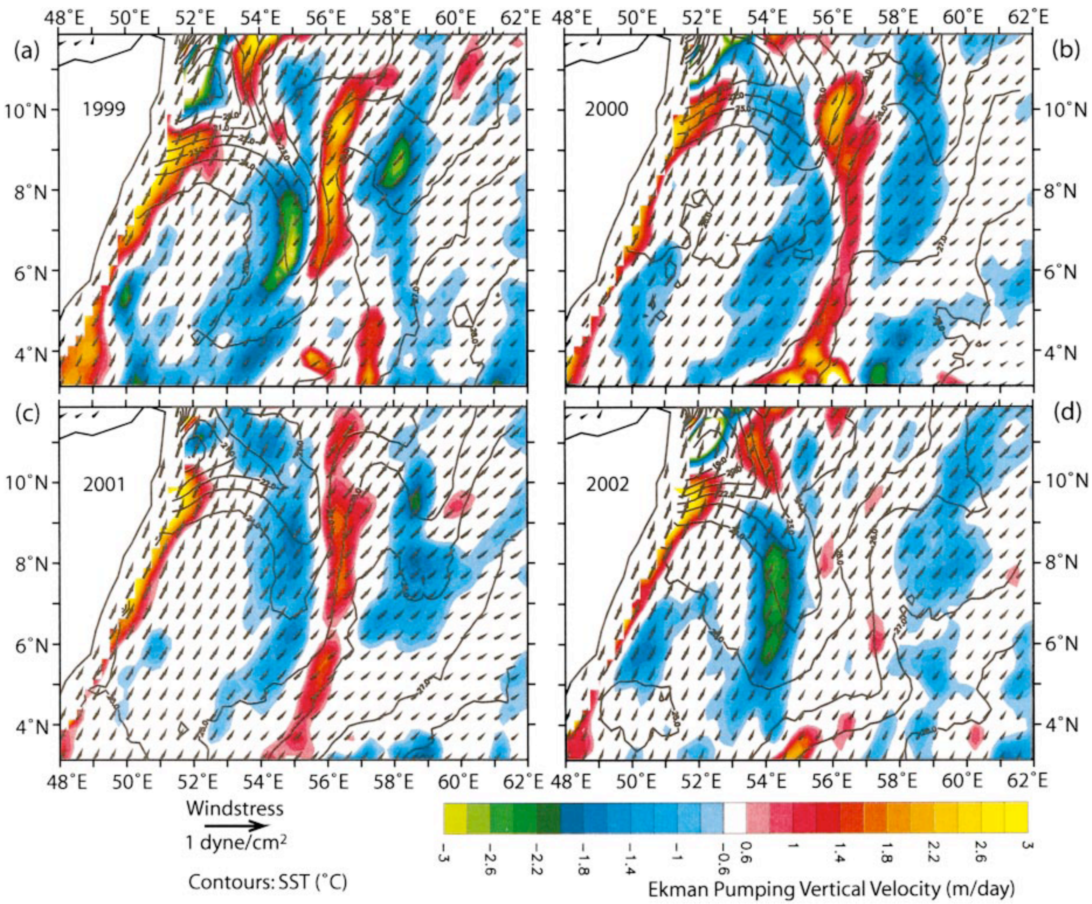
- Caveat: It is difficult to estimate Ekman pumping near the equator, where wind stress curl is at its maximum.

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

What about other regions, far away from the equator?
Western Arabian Sea?

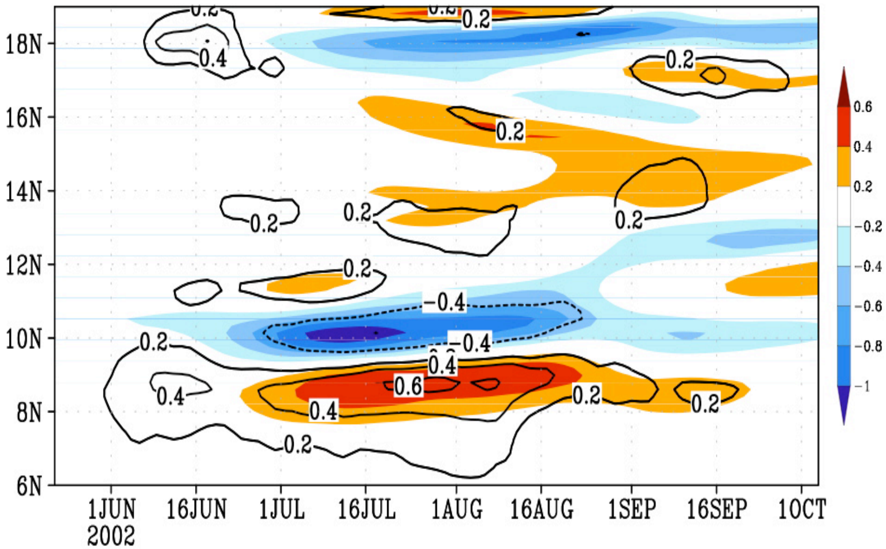
Seo, Murtugudde, Jochum, and Miller, 2008:
Modeling of mesoscale coupled ocean-atmosphere interaction and its feedback to ocean in the western Arabian sea. Ocean Modelling

Observed summertime Ekman pumping velocity in the vicinity of cold filaments in Arabian Sea (Vecchi et al. 2004, JCLI)

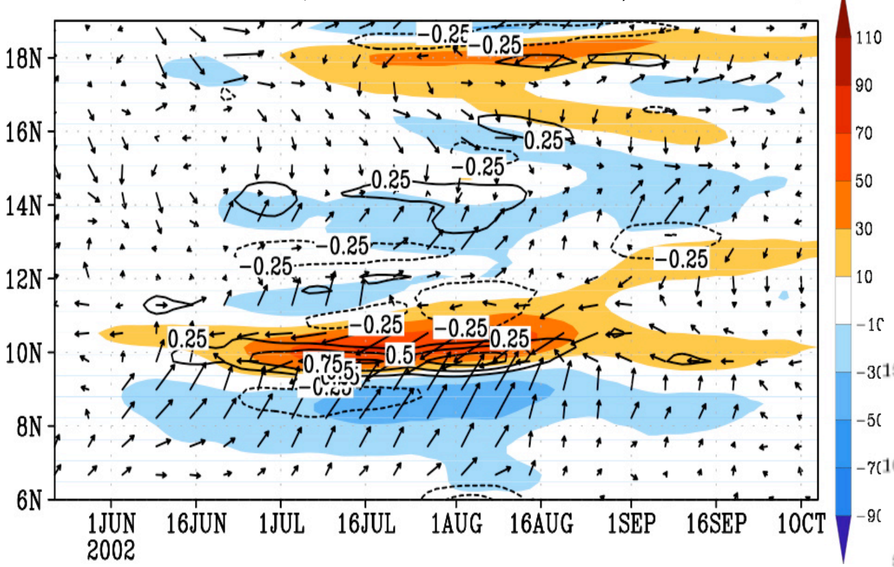


- Observed generation of Ekman upwelling/downwelling velocity of 2-3 m/day over cold filaments
- This *Wek* is *additional* to the large-scale Ekman pumping, persisting over a month following SSTs.
- Main question: how important is this *Wek* for the oceanic vertical structure and velocity?

SST, WIND SPEED

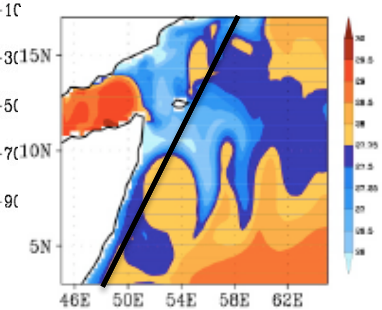


LATENT HEAT, WIND VECTORS, WE 0.4 m/s



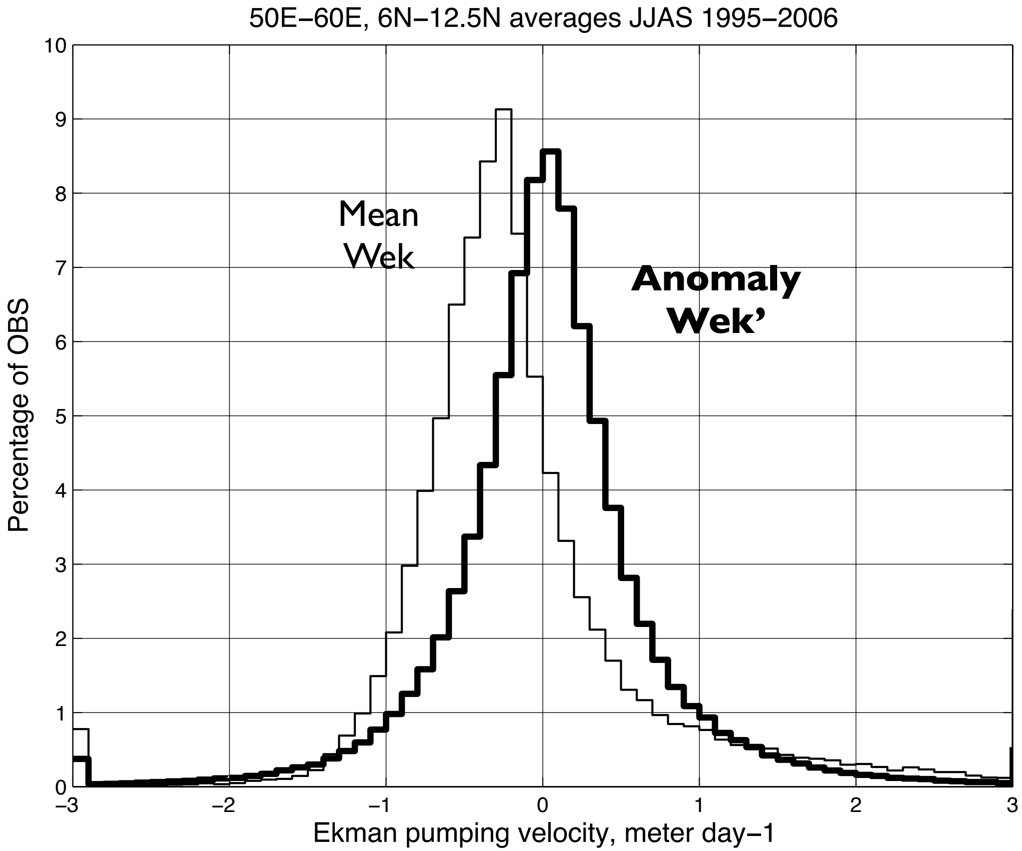
Covariability of ocean and atmosphere

- Cold filament develops in the beginning of June and reaches its maximum (<1°C) in July.
- In-phase response from the surface wind: southwesterly over warm water and northeasterly over cold water.
- Out-of-phase response from the latent heat flux: a damping effect.
- Large Ekman pumping velocity along the max. SST gradient.



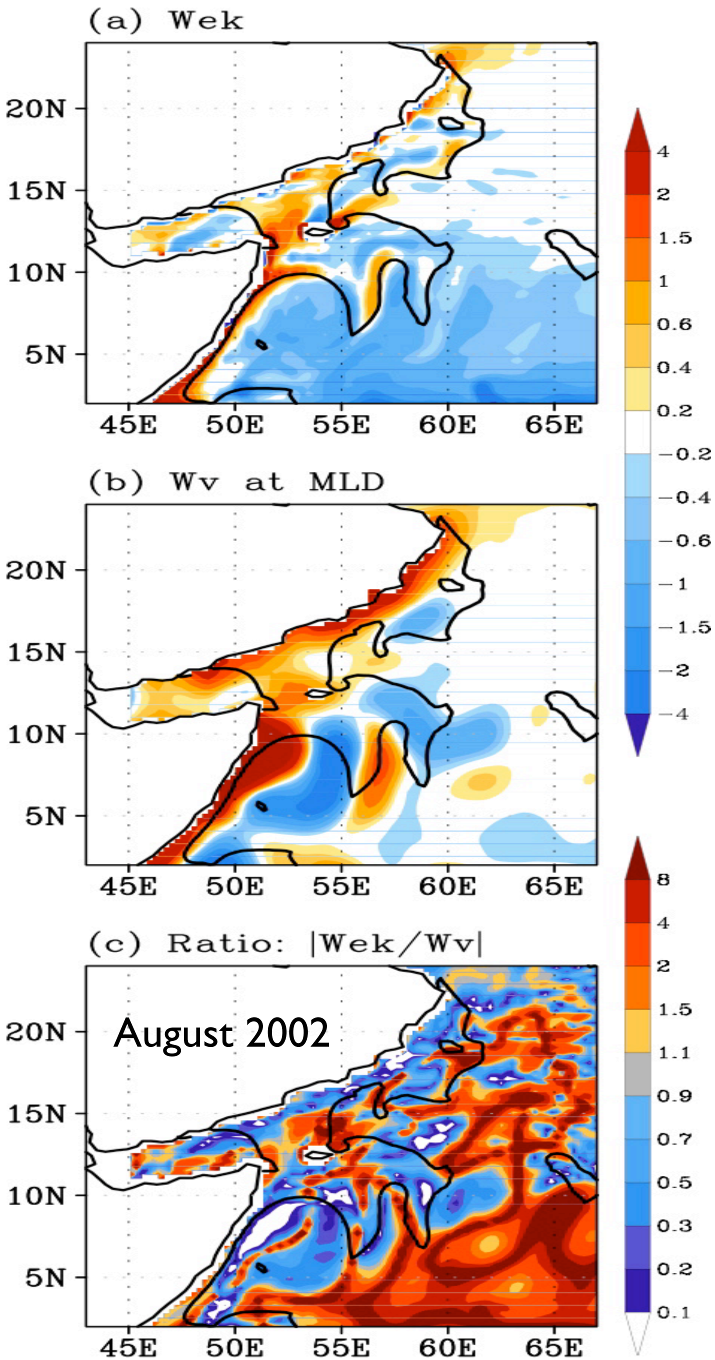
Daily 6/1/2002-8/31/2002
25km resolution RSM/ROMS daily coupled

Model: How does Ekman pumping velocity due to the mesoscale eddies compare with that due to the large-scale mean wind?



- PDFs of Wek (thin line) computed from summertime mean wind stresses, and (thick line) computed from anomalous wind stresses exhibit a comparable dynamic ranges.
- The RMS value of *Wek'* is 0.8 m/day. Approximately 10% of the mean Wek exceeds this RMS value
- Greater than 18% of the *Wek'* (both positive and negative) is larger than this RMS value.
- *Wek'* could be as important as mean Wek.

JJAS 1995-2006
Similar analyses by O'Neill et al. (2003) for Southern Ocean and Chelton et al. (2005) for CCS.



Direct comparison of *Wek* with the oceanic vertical velocity (*W* at the base of mixed layer)

- W is ~±2-3 m/day in the vicinity of cold filaments but generally small in the open ocean
- The ratio is largely 10-30% near the cold filaments ➔ Oceanic mesoscale eddies induce additional Wek through the observed relation.
- This can potentially affect the evolution of oceanic mesoscale eddies (Vecchi et al . 2004)

Summary and some remaining questions

Summary and some remaining questions

- Today, I have mostly described the *high-frequency* coupled feedback.
  ➔ Lower atmosphere displays a coherent response to the oceanic mesoscale feature with some subsequent feedback effect to ocean dynamically and thermodynamically.

Summary and some remaining questions

- Today, I have mostly described the *high-frequency* coupled feedback.
  ➔ Lower atmosphere displays a coherent response to the oceanic mesoscale feature with some subsequent feedback effect to ocean dynamically and thermodynamically.

- We don't know much about the large-scale/low-frequency rectification effect.
  a) Do TIWs (cold filaments) induce any deep response in atmosphere?

  b) How do TIWs (cold filaments) affect the the location of the ITCZ (axis of Findlater Jet?)

  c) How do TIWs (cold filaments) modulate the interannual variability in the Pacific (summer monsoon and indian rainfall)?


Thanks!