Coupled modeling of eddy-wind interaction in the California Current System
— Impact on eddy kinetic energy and Ekman pumping

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Eddy-wind interaction

$$\tau = \rho\, C_D\, (U_a - U_o)\, |U_a - U_o|$$

Eddy-wind interaction

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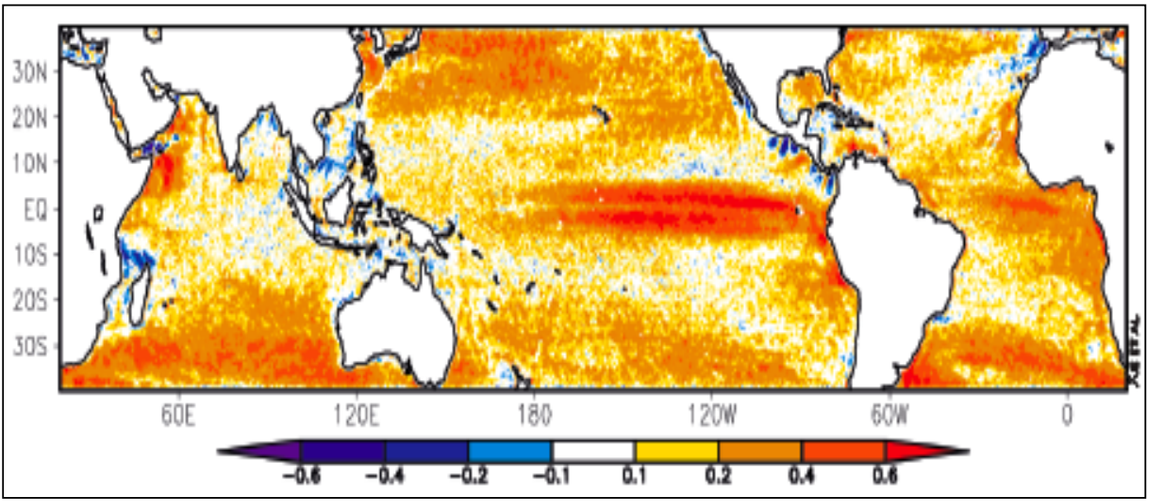
$U_a = U_{ab} + \underline{U_{aSST}}$

Satellite observations: Xie 2004

Correlation (SST & wind): high-passed



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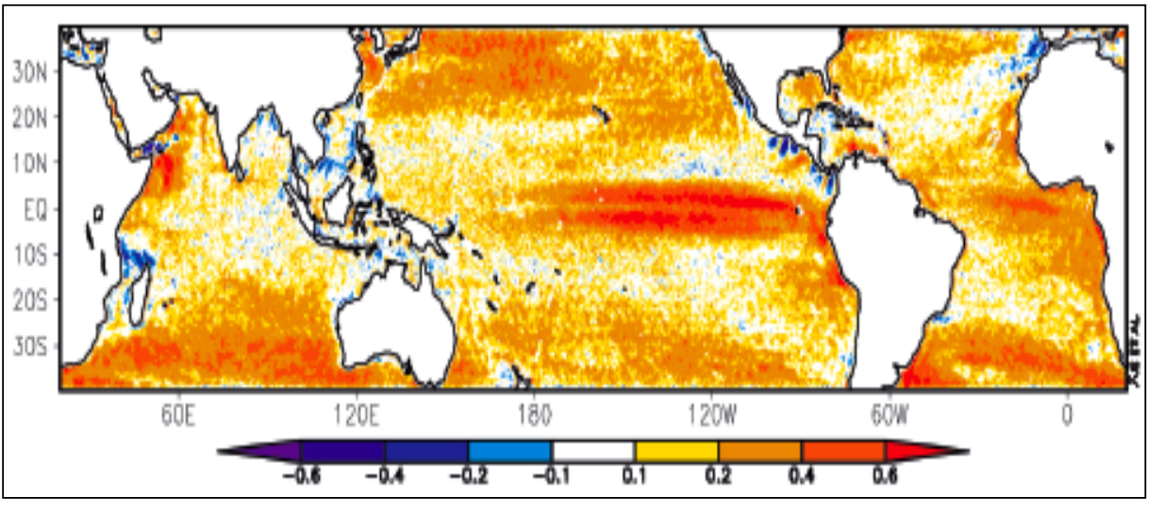
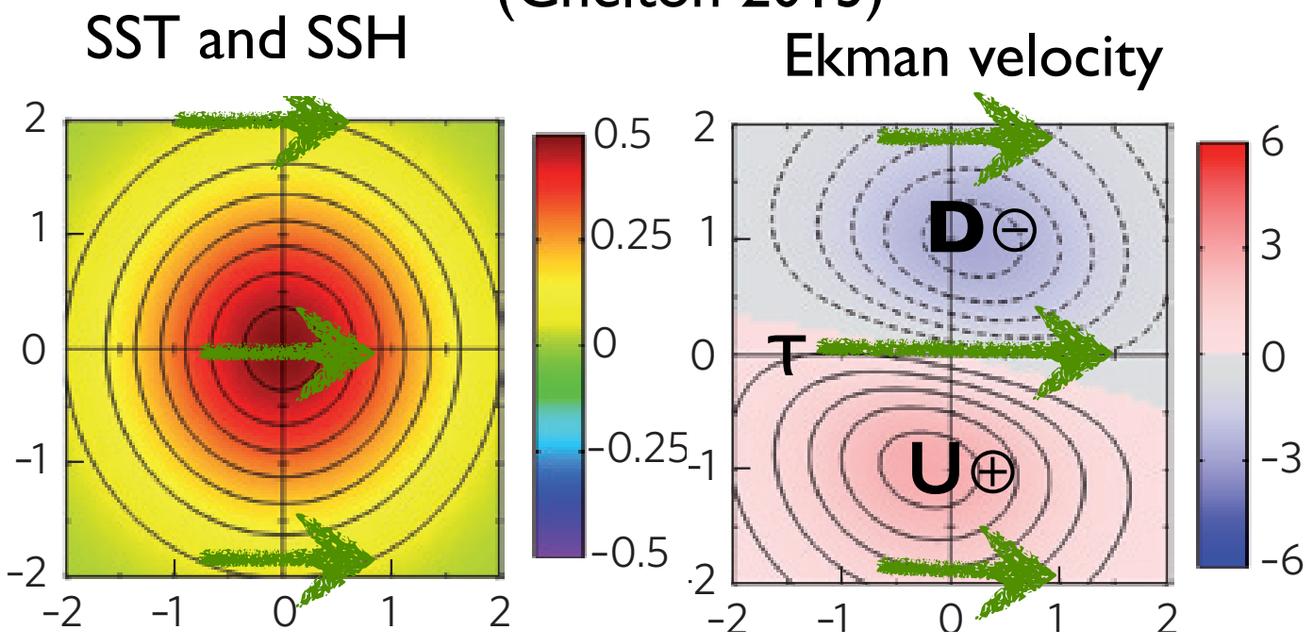


An anticyclonic eddy in the Southern Ocean (Chelton 2013)



northward propagation of an anticyclonic eddy

Eddy-wind interaction

$$\tau = \rho C_D (U_a - U_o) |U_a - U_o|$$

$U_o = U_{ob} + U_{oe}$

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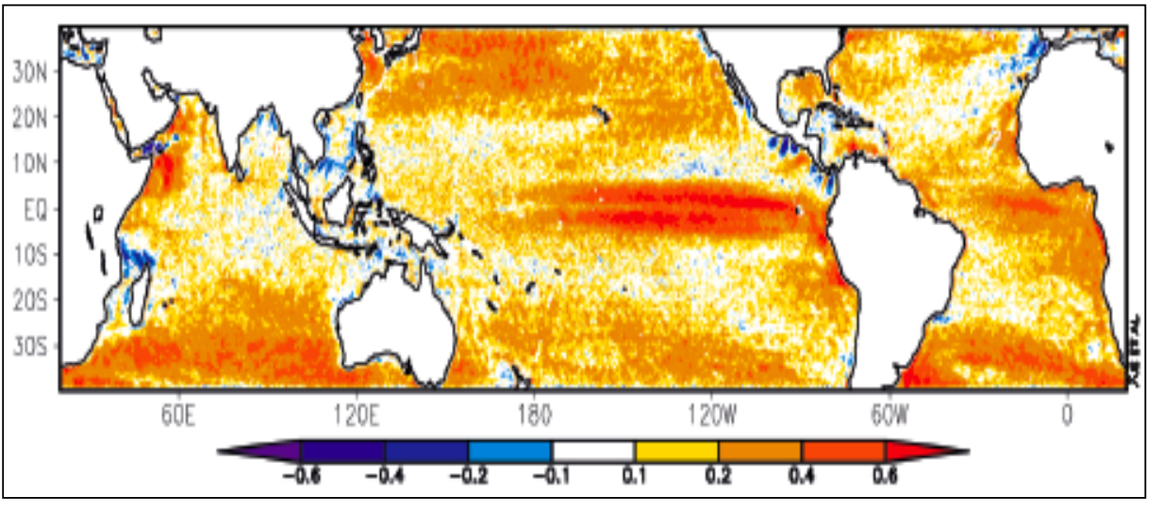

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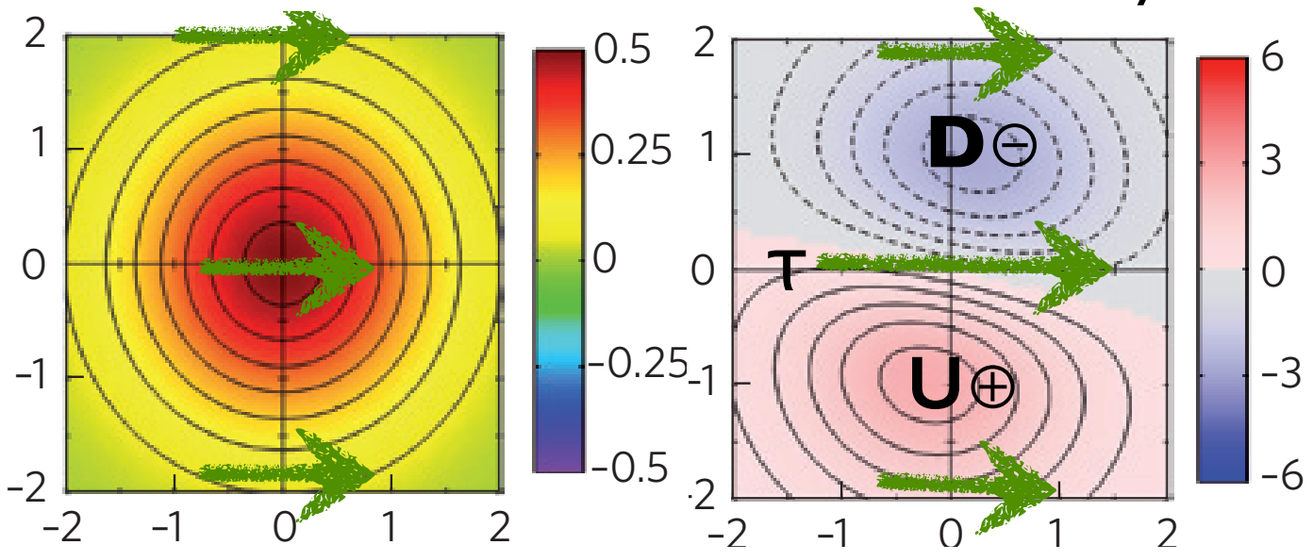
SST and SSH

Ekman velocity



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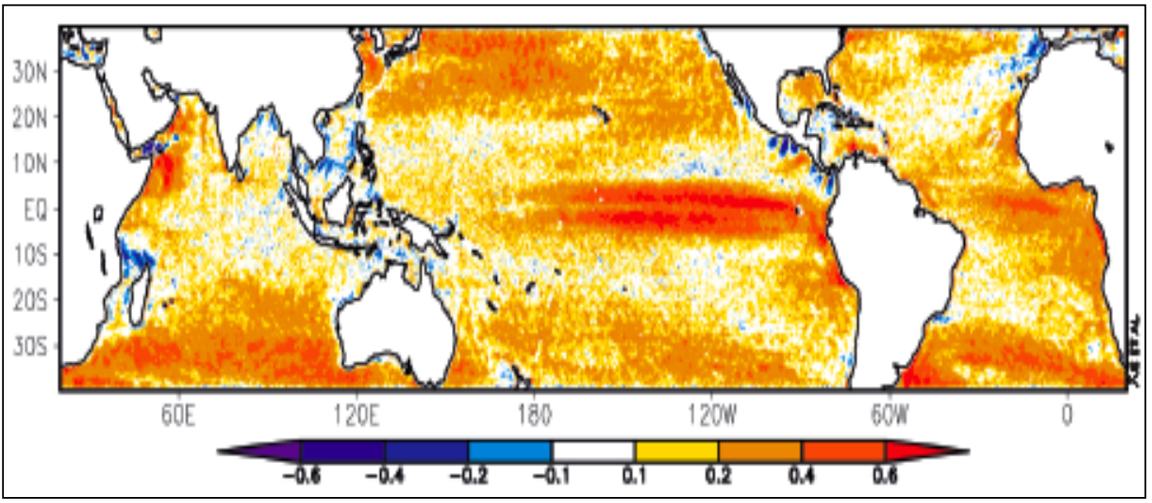

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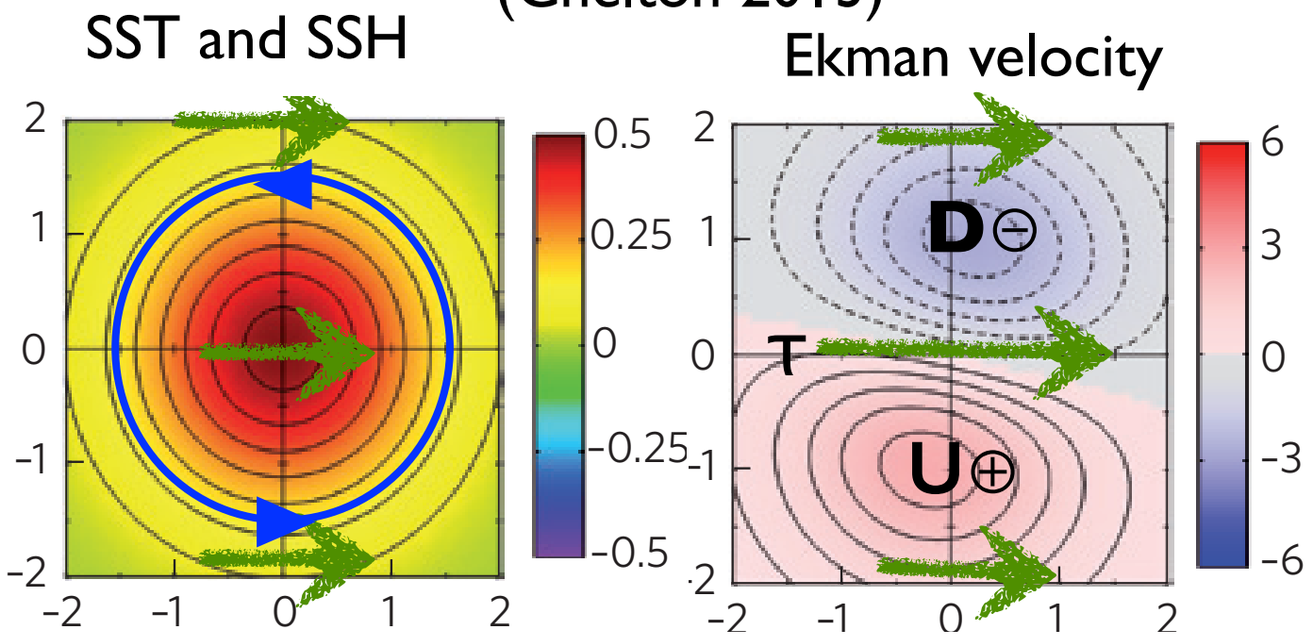

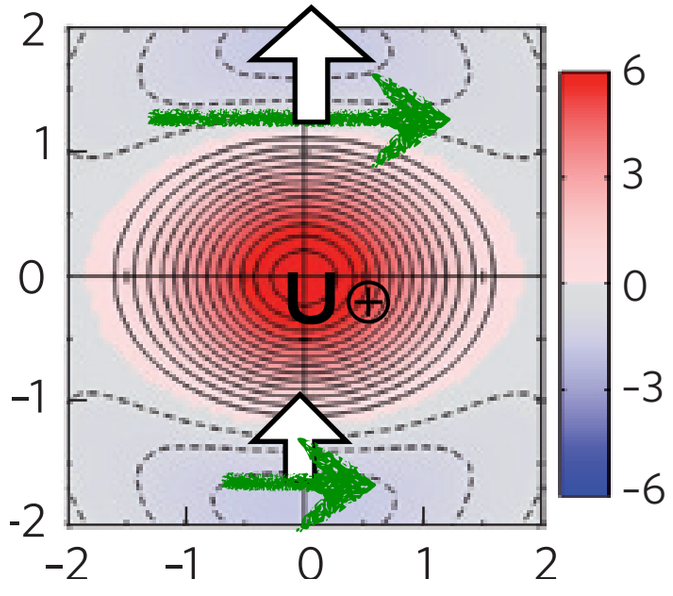

northward propagation of an anticyclonic eddy

Upwelling at the center: decaying of an anticyclonic eddy

$W_e = \tau / [\rho(f+\zeta)]$

Eddy-wind interaction

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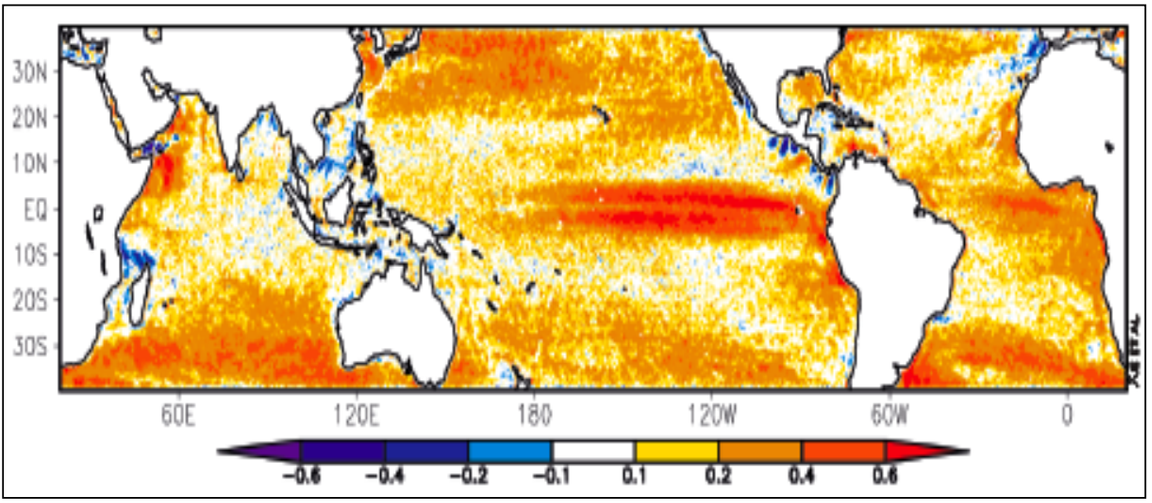

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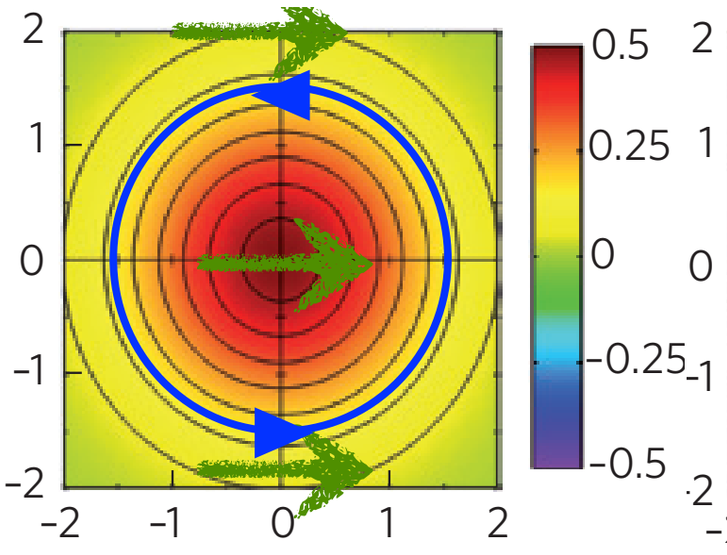
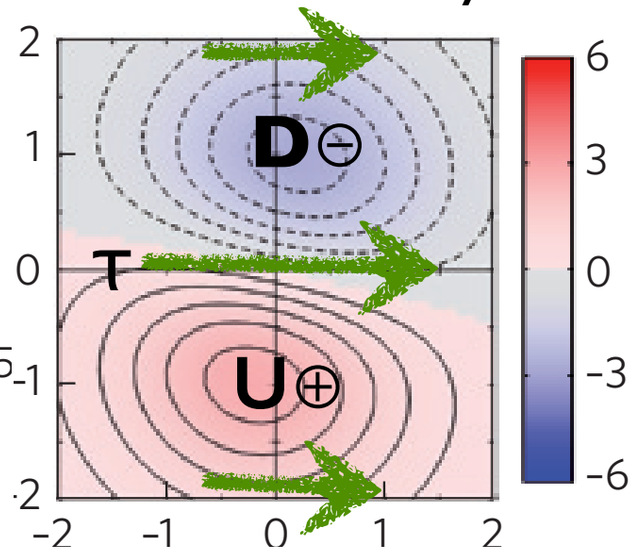
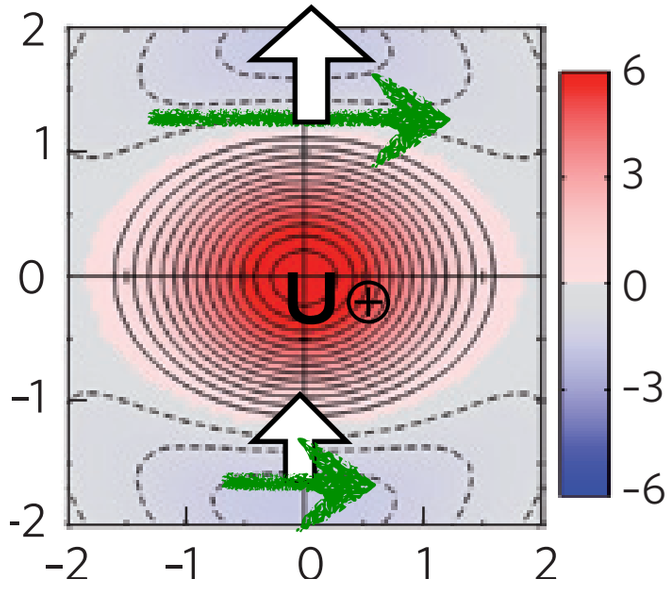


Ekman velocity





northward propagation of an anticyclonic eddy

Upwelling at the center: decaying of an anticyclonic eddy

$W_e = \tau/[\rho(f+\zeta)]$

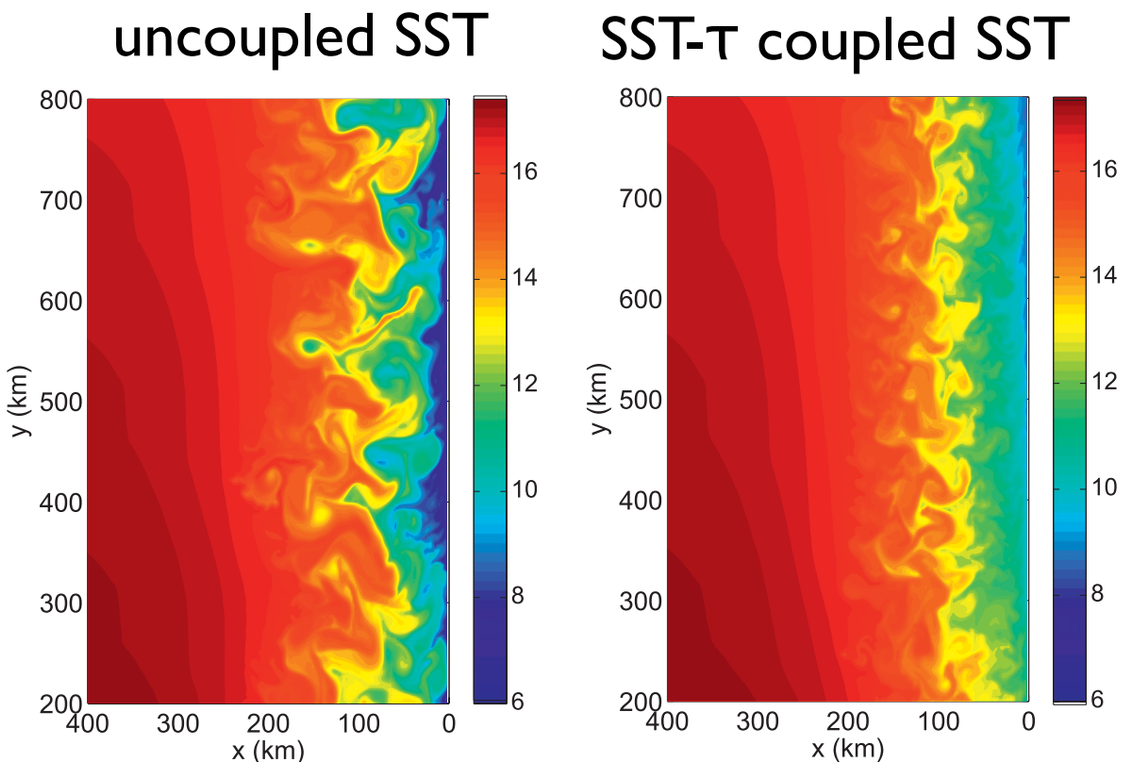
Different feedbacks due to SST- and current-induced eddy-wind interactions!

Key question:

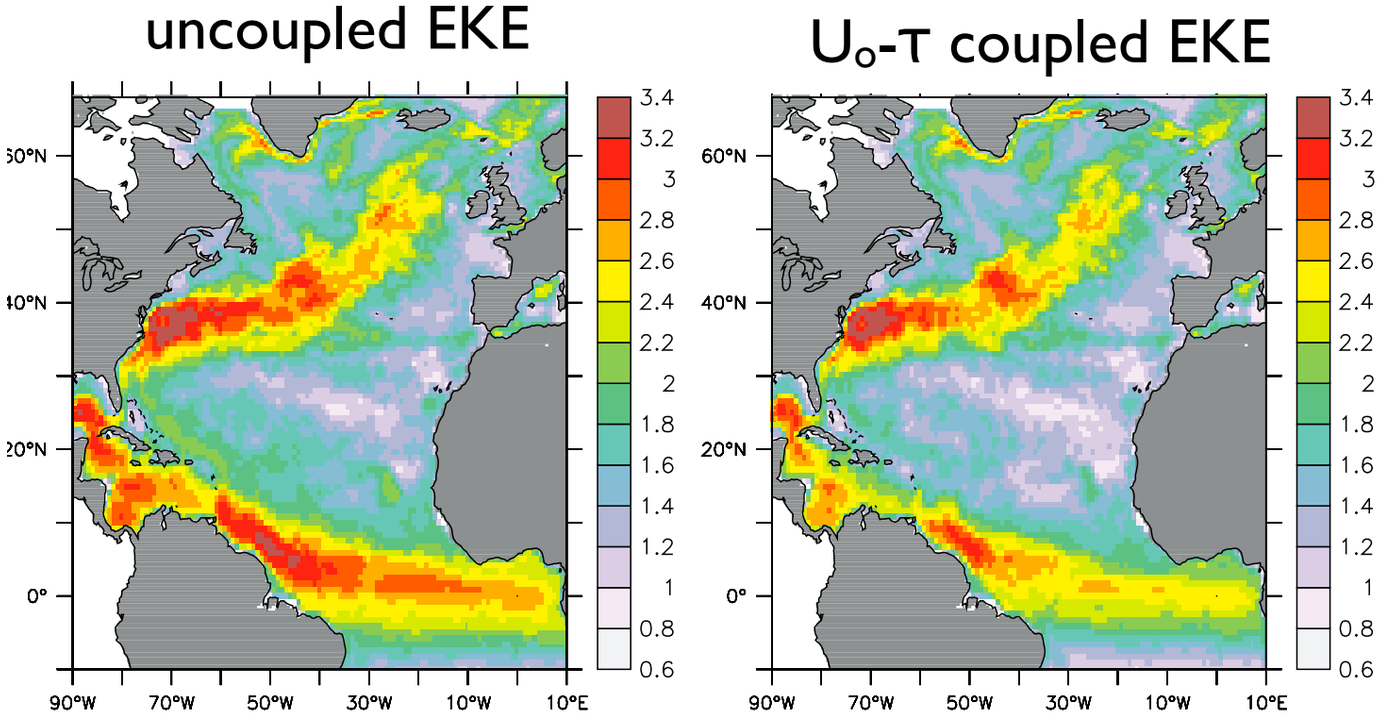
relative impact of τ_{SST} and τ_{cur} on the eddy dynamics?

Previous studies on impacts of τ_{SST} and τ_{cur}

- Previous ocean-modeling studies show weakened eddy variability with inclusion of τ_{SST} and τ_{cur}.



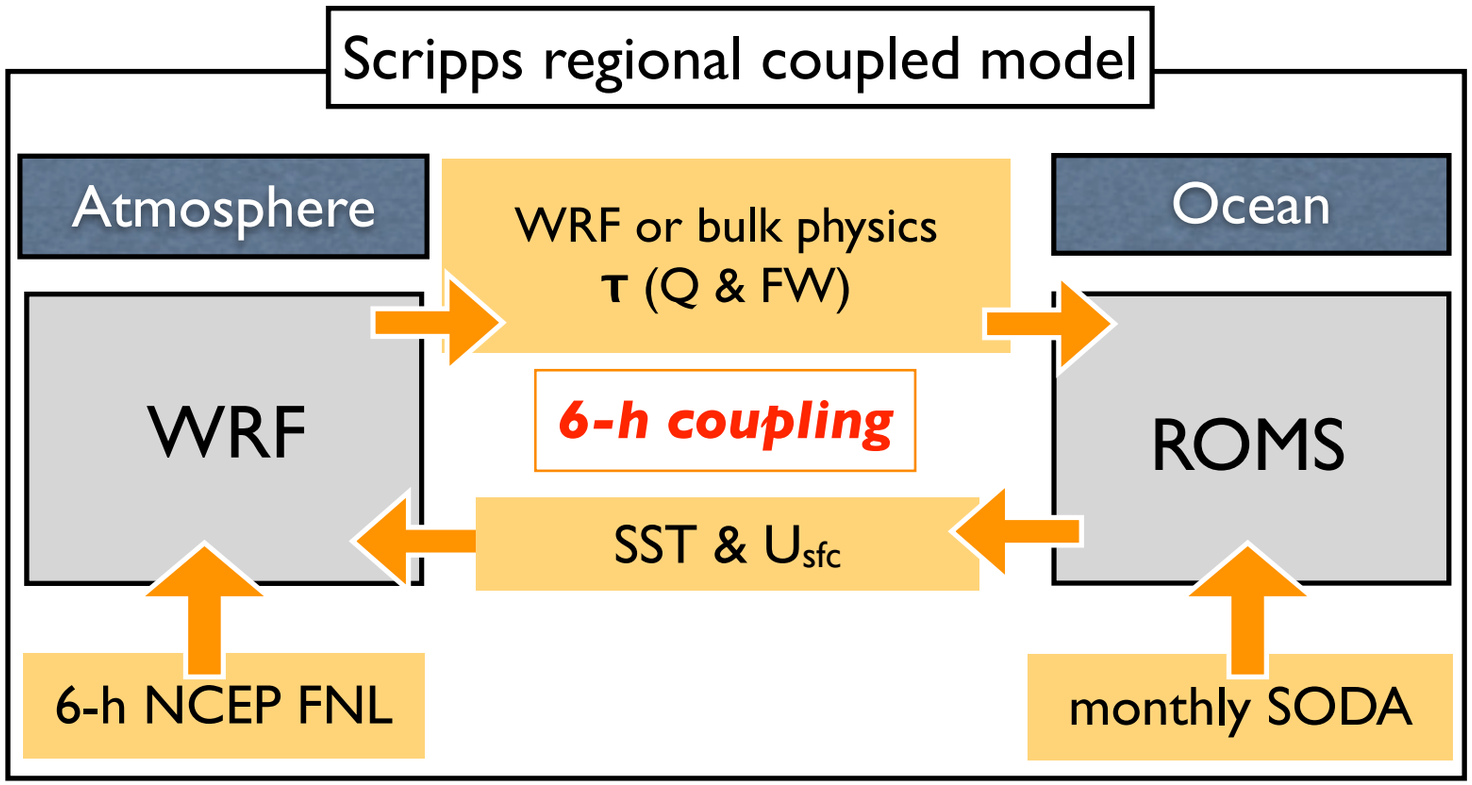
effect of τ_{SST}: *Jin et al. (2009)*



effect of τ_{cur}: *Eden and Dietze (2009)*

- This study examines the relative importance of τ_{SST} vs τ_{cur} using a fully coupled regional model.

Scripps regional coupled model and experiments



- Seo et al. 2007, 2014
- 7 km O-A resolutions
- 6-yr integration (2005-2010)

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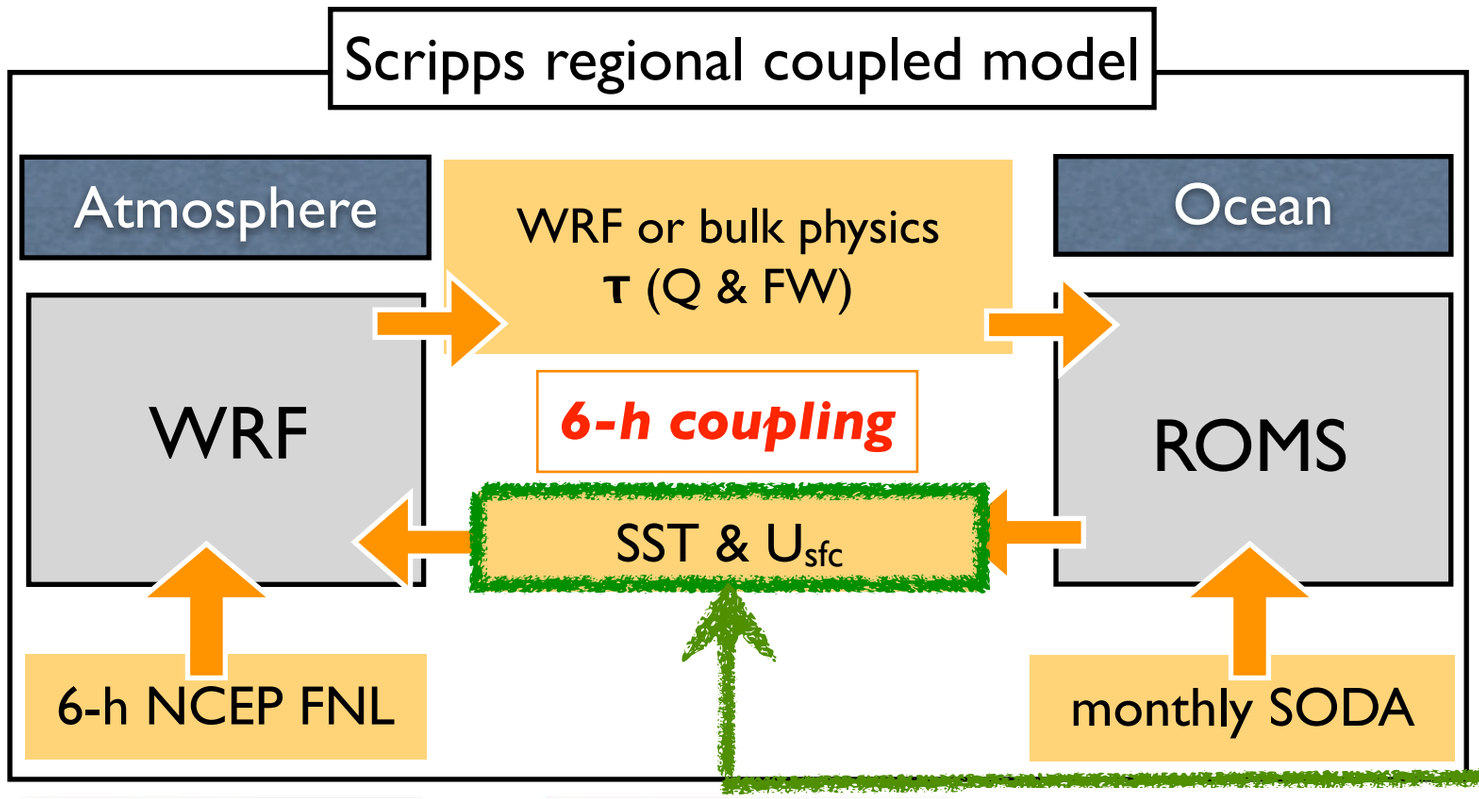

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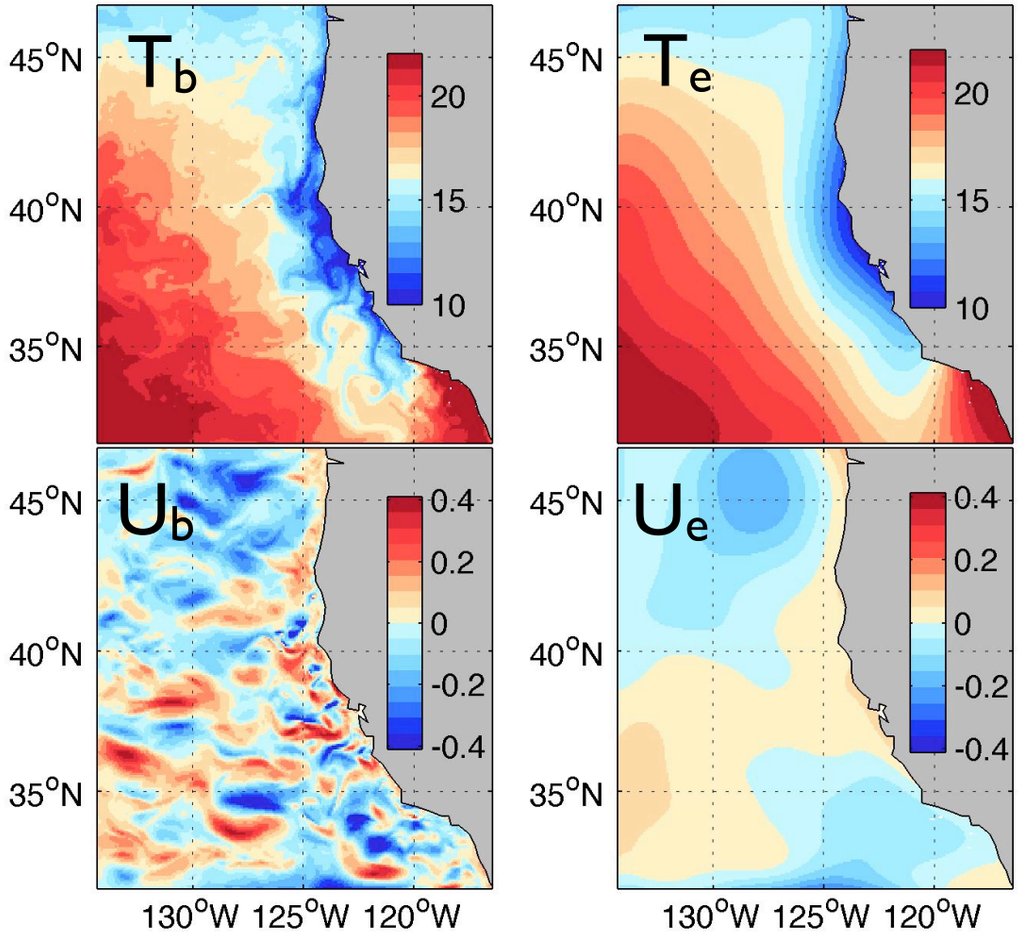
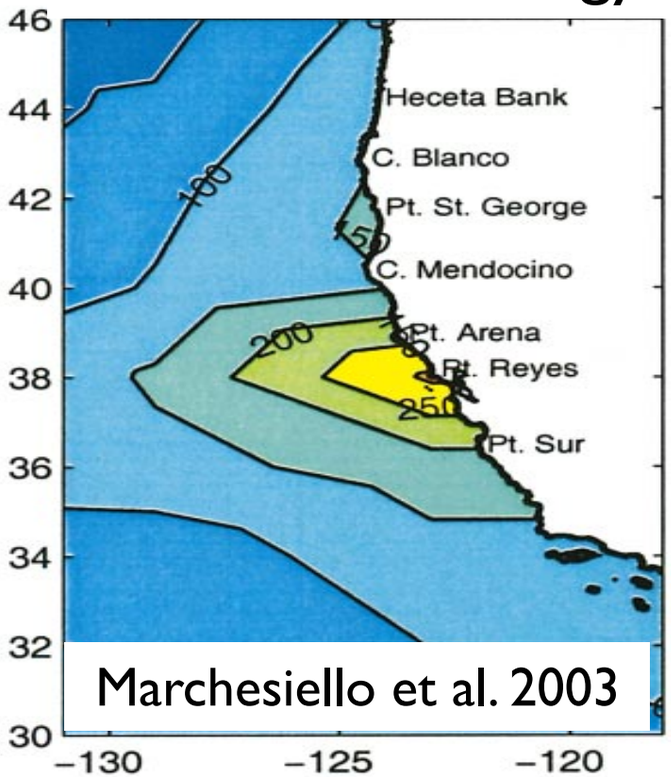
Removal of eddies with 5° loess filter (Putrasahan et al. 2013)



Exps	τ formulation includes			
CTL	T_b	T_e	U_b	U_e
noT_e	T_b		U_b	U_e
noU_e	T_b	T_e	U_b	

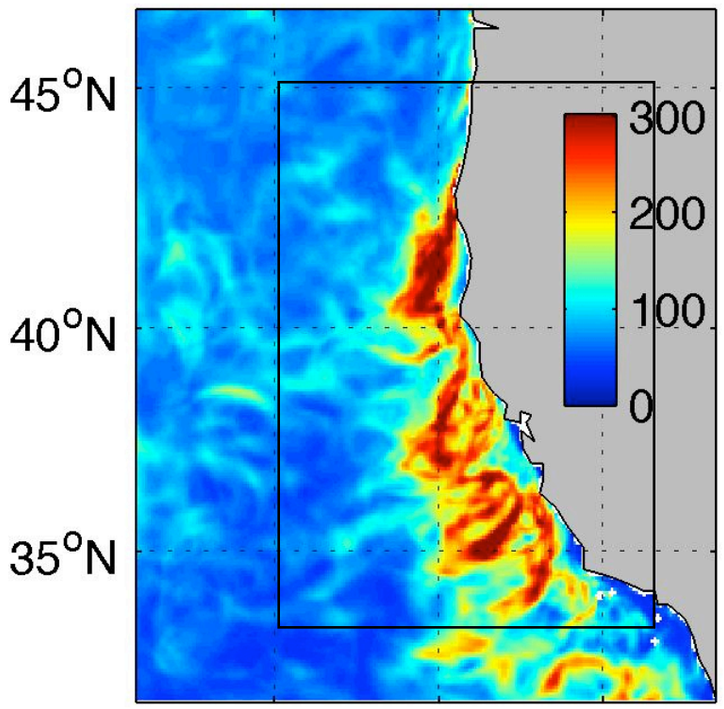
EKE significantly reduced by current effect on wind stress

Drifter climatology

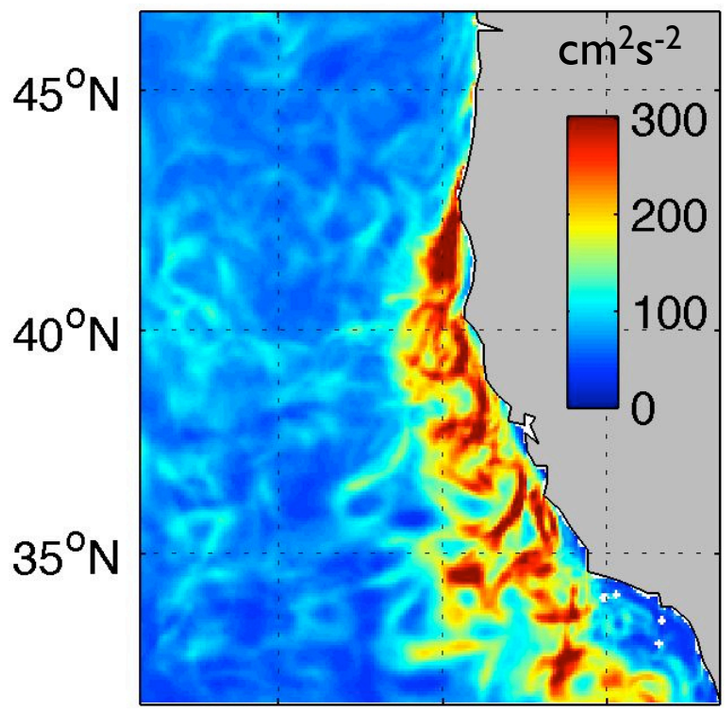


Marchesiello et al. 2003

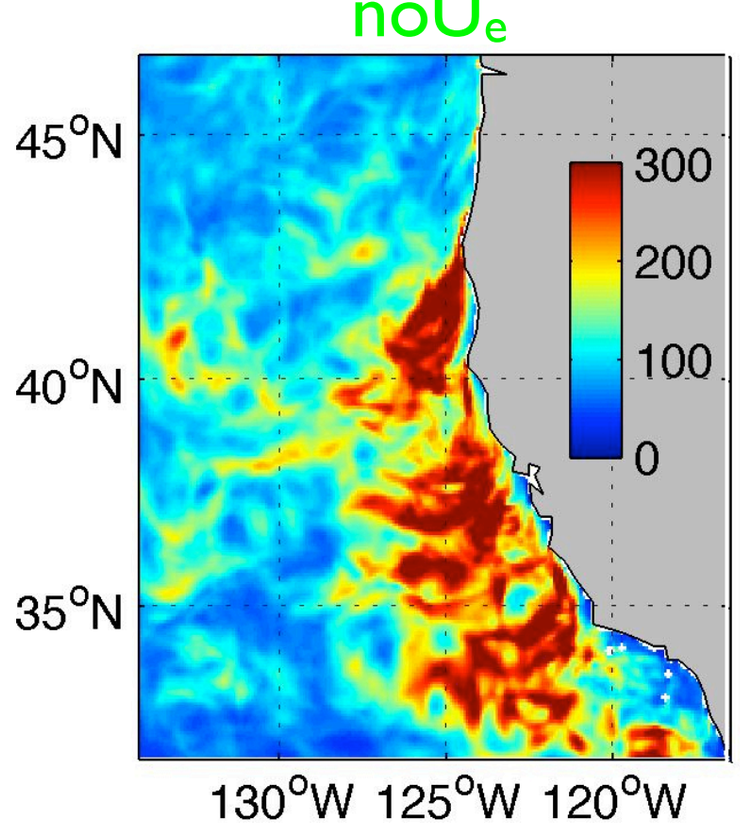
CTL



noT$_e$



noU$_e$



- T$_e$ no impact
- <u>25% weaker</u> EKE with U$_e$
- Surface current dissipates the EKE

JAS 2005-2010

Eddy kinetic energy budget

$$Ke_t + \vec{U}\cdot\vec{\nabla}\vec{K}e + \vec{u}'\cdot\vec{\nabla}\vec{K}e + \vec{\nabla}\cdot(\vec{u}'p') =$$

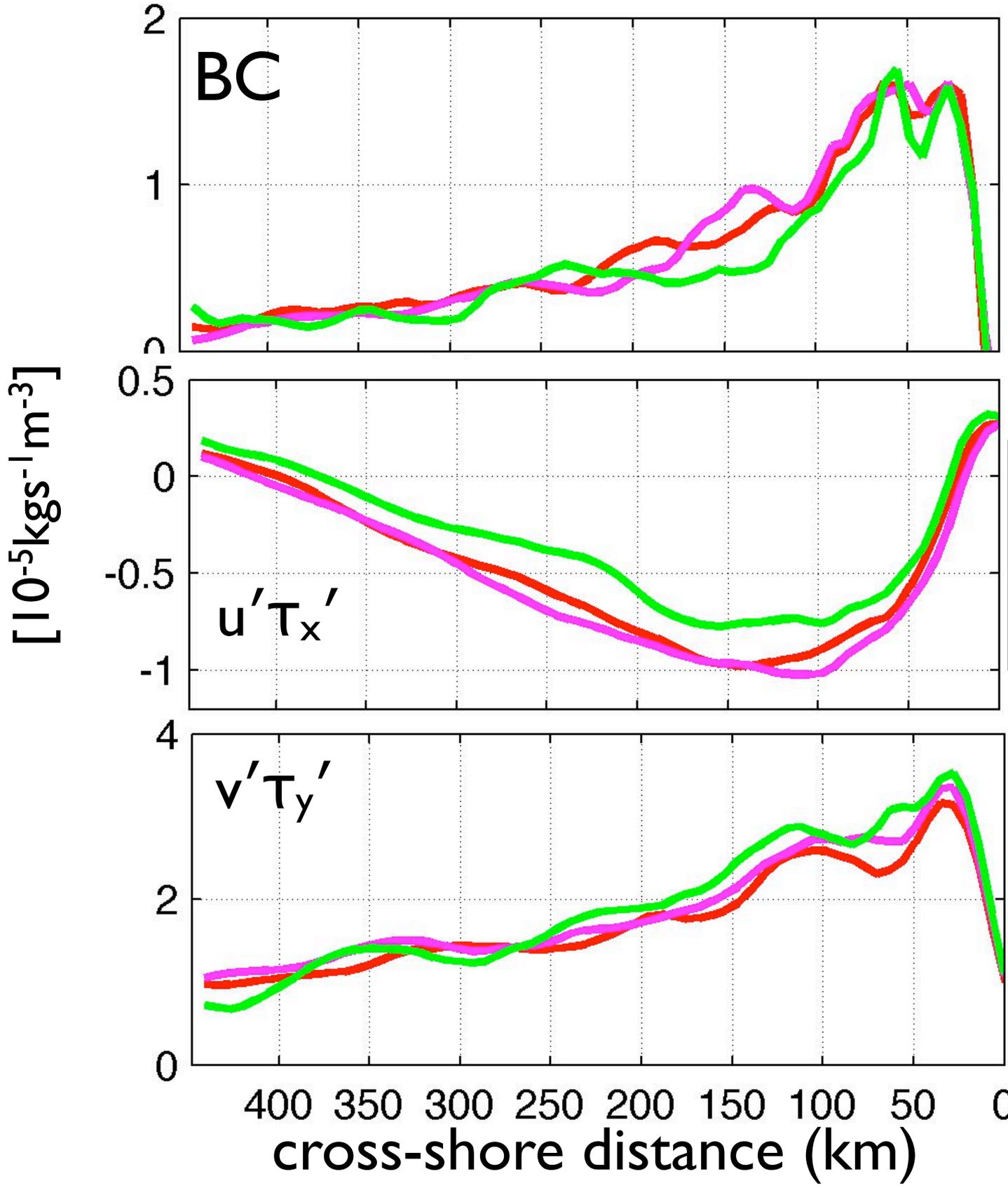
$$+\rho_o(-\vec{u}'\cdot(\vec{u}'\cdot\vec{\nabla}\vec{U})) - g\rho'w' + \vec{u}'\cdot\vec{\tau}' + \varepsilon$$

$\underline{K_m \rightarrow K_e}$
barotropic conversion (BT)

$\underline{P_e \rightarrow K_e}$
baroclinic conversion (BC)

Eddy-Wind terms:
Wind work (P) if positive
Eddy drag (ε) if negative

Reduced EKE is primarily due to enhanced eddy drag



CTL=0.58 ← lower EKE

noT_e=0.58

noU_e=0.51 ← higher EKE

CTL: somewhat higher level of

BC: cannot explain the lower EKE.

CTL=−0.47

noT_e=−0.53

noU_e=−0.33

With U_e, 42% stronger eddy drag

CTL=1.74

noT_e=1.86

noU_e=1.90

With U_e, 16% reduction in wind work

Eddy-induced Ekman pumping velocity

Stern (1965) & Gaube et al. (2014)

$$
\begin{aligned}
W_{tot} &= \frac{1}{\rho_o}\nabla\times\left(\frac{\boldsymbol{\tau}}{(f+\zeta)}\right) \\
\tilde{W}_{tot} &= W_{cur}+W_{SST} \\
&= \underbrace{\frac{\nabla\times\tilde{\boldsymbol{\tau}}}{\rho_o\,(f+\zeta)}}_{W_{lin}} \underbrace{-\frac{1}{\rho_o\,(f+\zeta)^2}\left(\tilde{\tau}^y\frac{\partial\zeta}{\partial x}-\tilde{\tau}^x\frac{\partial\zeta}{\partial y}\right)}_{W_{\zeta}} + \underbrace{\frac{\beta\tilde{\tau}^x}{\rho_o\,(f+\zeta)^2}}_{W_{\beta}} + \underbrace{\frac{\nabla\times\boldsymbol{\tau}'_{SST}}{\rho_o\,(f+\zeta)}}_{W_{SST}}.
\end{aligned}
$$

background wind stress

W_{lin}: Curl-induced linear Ekman pumping

W_{ζ}: Vorticity gradient-induced nonlinear Ekman pumping

W_{β}: β Ekman pumping (negligible)

W_{SST}: SST-induced Ekman pumping (Chelton et al. 2004)

Eddy-induced Ekman pumping velocity

Stern (1965) & Gaube et al. (2014)

$$W_{tot} = \frac{1}{\rho_o}\nabla \times \left(\frac{\boldsymbol{\tau}}{(f+\zeta)}\right)$$

$$\tilde{W}_{tot} = W_{cur} + W_{SST}$$

background wind stress

$$= \underbrace{\frac{\nabla \times \tilde{\boldsymbol{\tau}}}{\rho_o (f+\zeta)}}_{W_{lin}} \underbrace{- \frac{1}{\rho_o (f+\zeta)^2}\left(\tilde{\tau}^y \frac{\partial \zeta}{\partial x} - \tilde{\tau}^x \frac{\partial \zeta}{\partial y}\right)}_{W_{\zeta}} + \underbrace{\frac{\beta \tilde{\tau}^x}{\rho_o (f+\zeta)^2}}_{W_{\beta}} + \underbrace{\frac{\nabla \times \boldsymbol{\tau}'_{SST}}{\rho_o (f+\zeta)}}_{W_{SST}}.$$

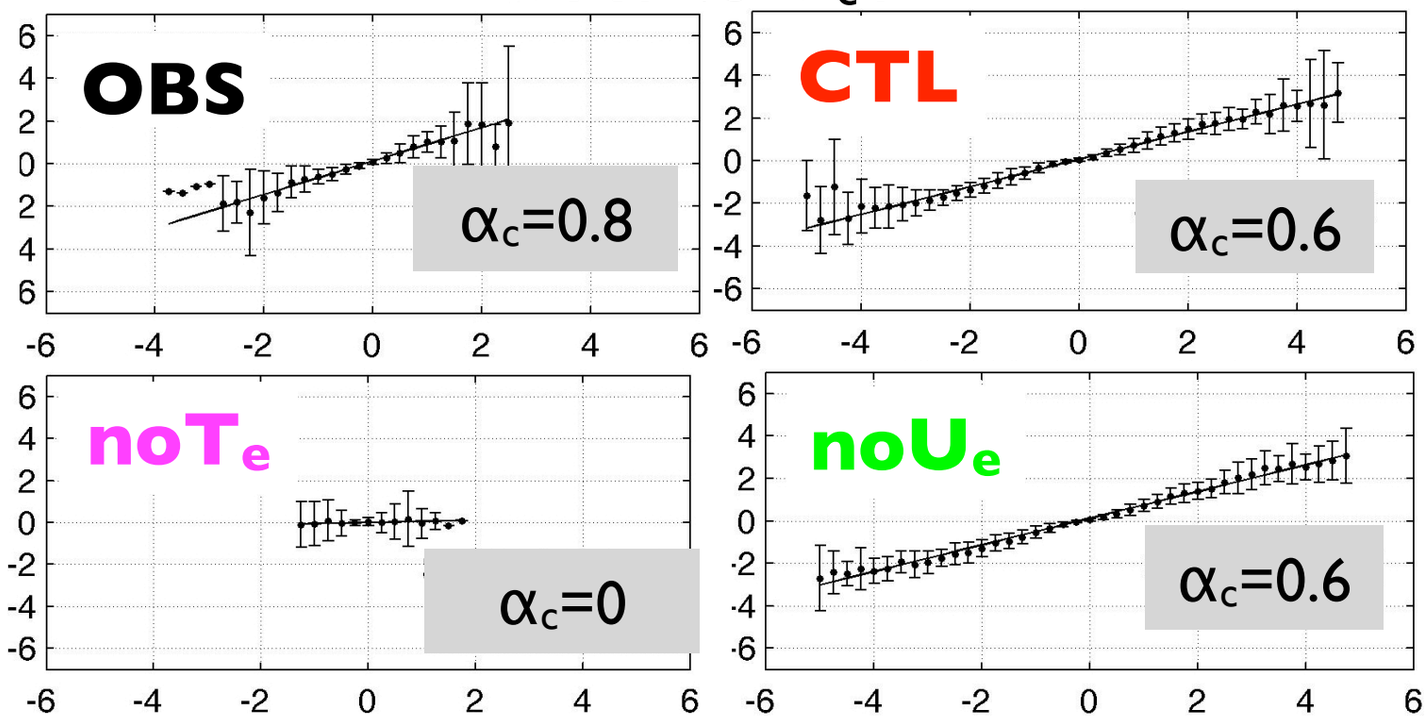
Curl-induced linear Ekman pumping

Vorticity gradient-induced nonlinear Ekman pumping

β Ekman pumping (negligible)

SST-induced Ekman pumping (Chelton et al. 2004)

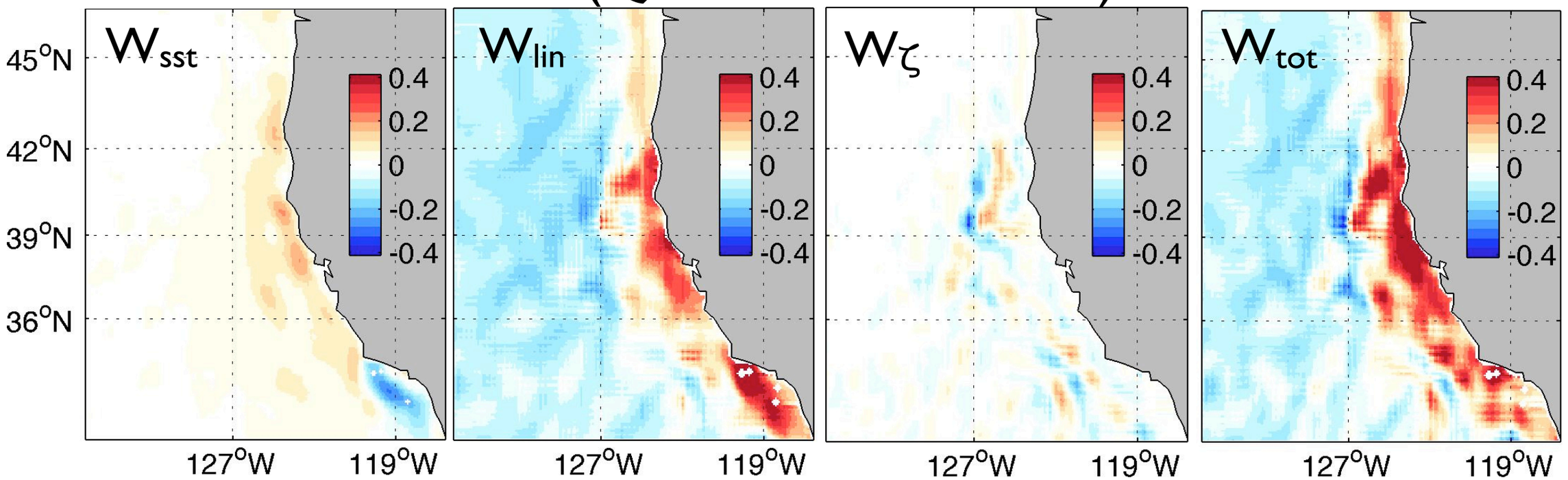
$\nabla \times \tau'$ vs $\nabla_c T'$



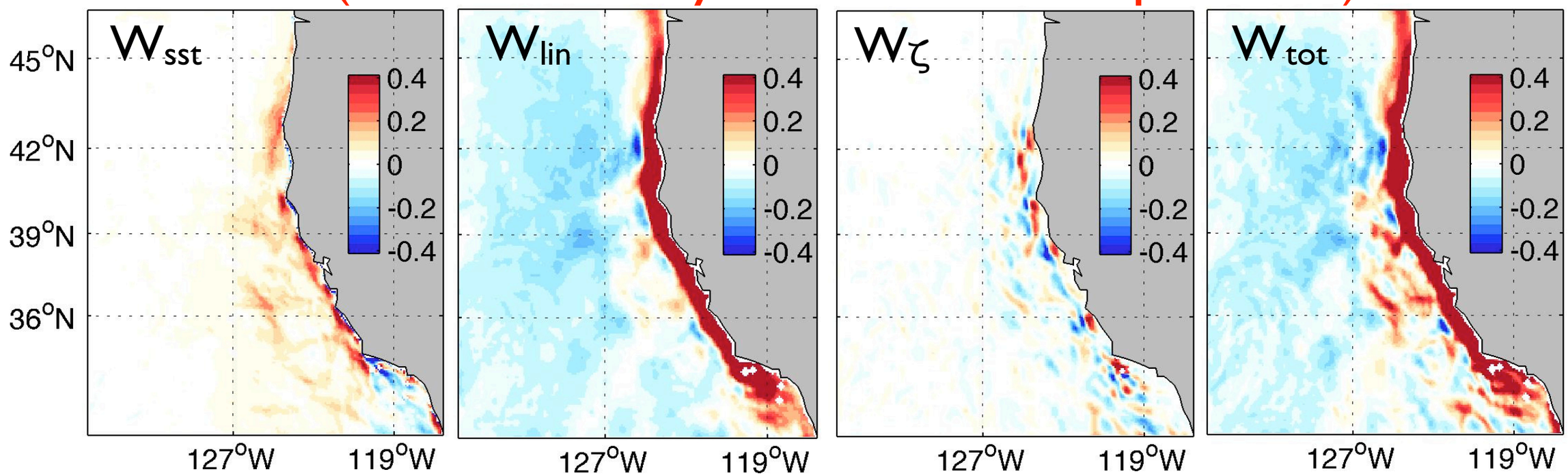
$$W_{SST} = \frac{\nabla \times \tau'_{SST}}{\rho_o (f+\zeta)} \approx \frac{\alpha_c \nabla_c SST}{\rho_o (f+\zeta)}$$

Ekman pumping velocity JAS climatology

OBS (QuikSCAT & AVISO)



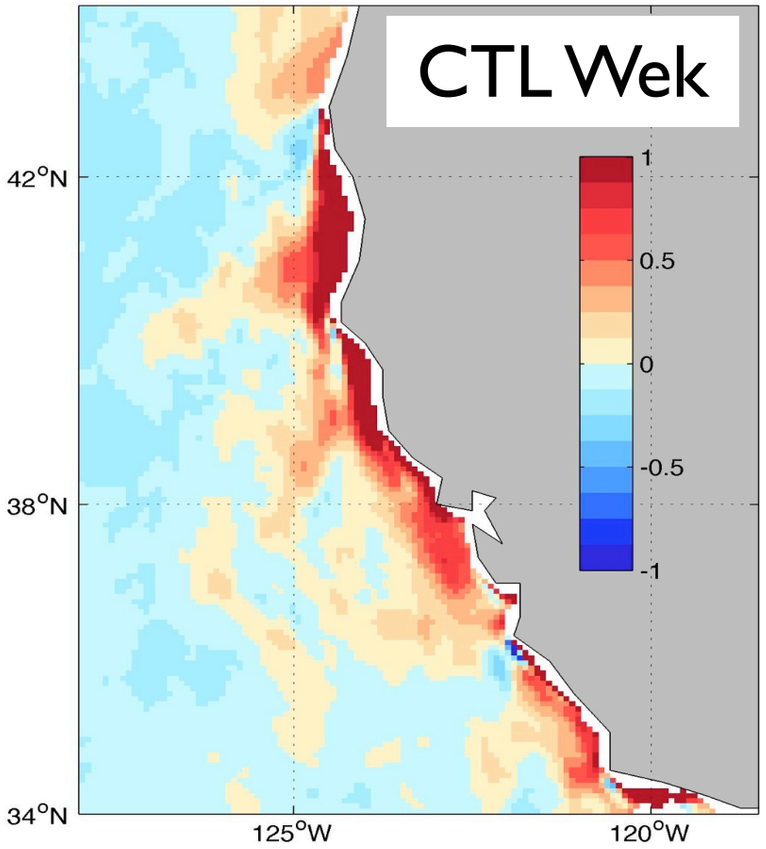
CTL (with both eddy current and temperature)

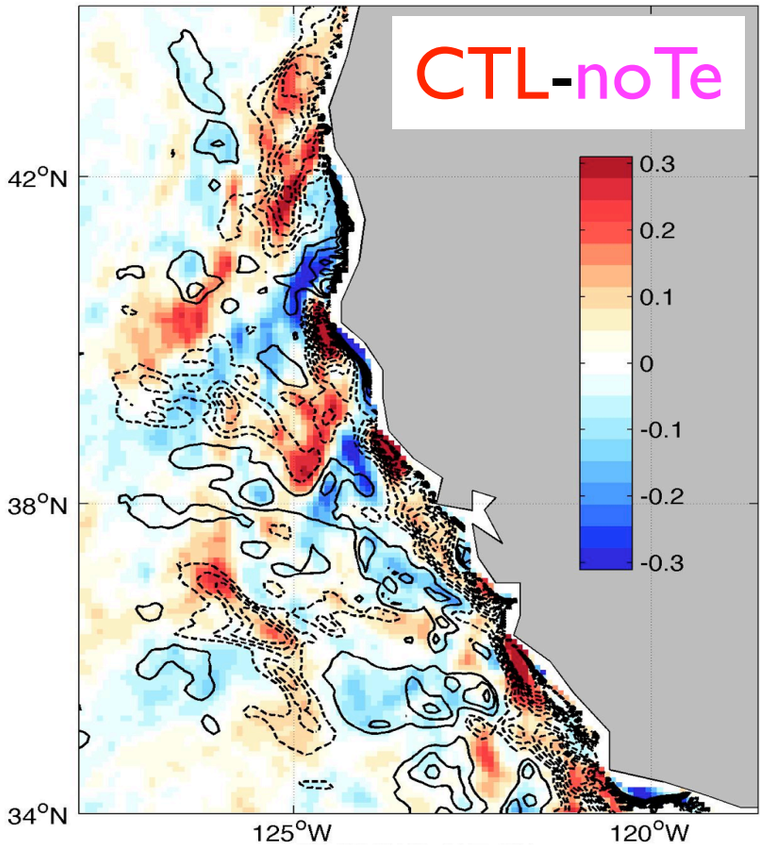


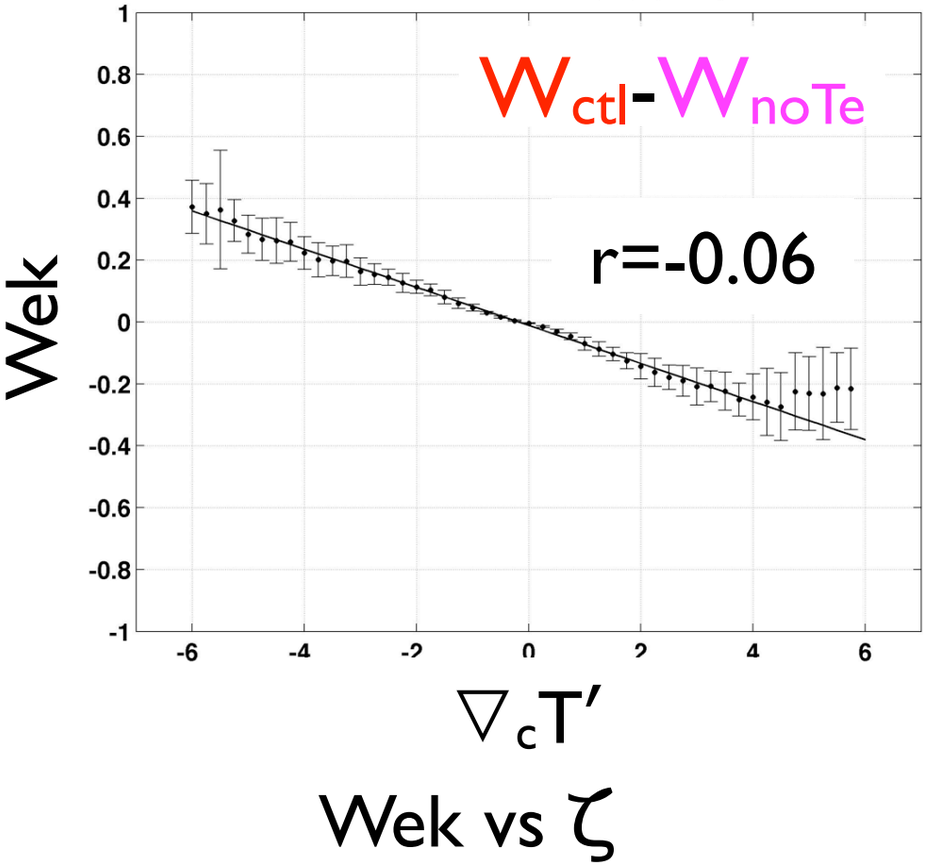
m/day

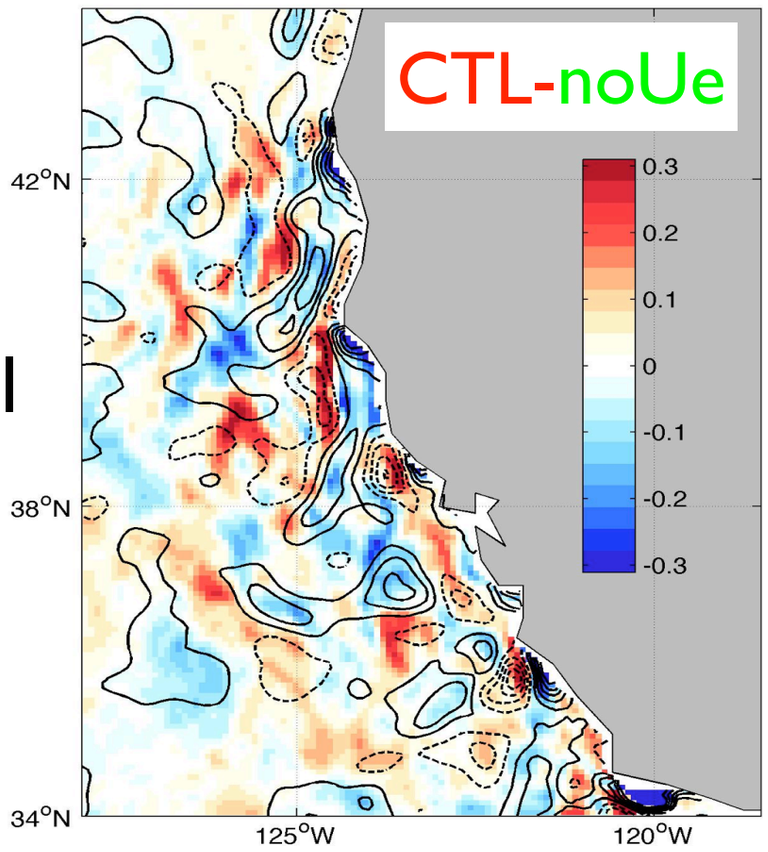
JAS 2005-2009

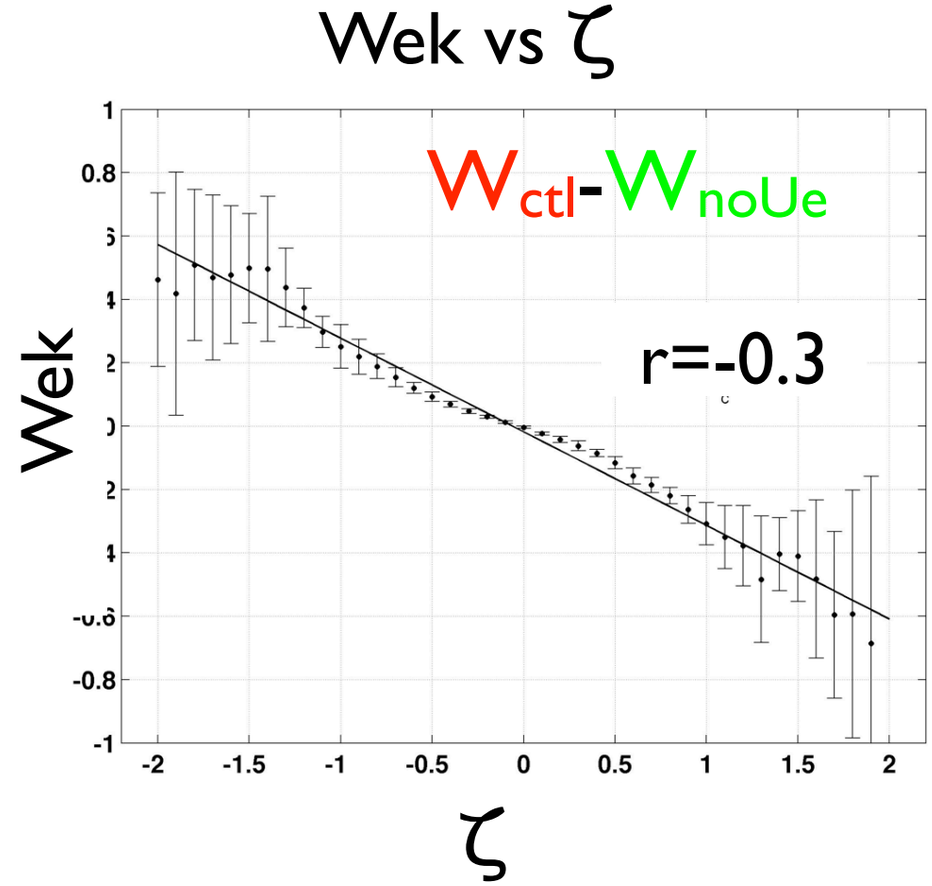
SST- and current-induced Ekman pumping velocity











- SST and current induce perturbation Wek of comparable magnitudes but with distinctive spatial patterns.
  - indicative of different feedback processes

JAS 2005-2009

Summary

- Surface EKE is weakened almost entirely due to mesoscale current effect on wind stress.
  - SST has no impact (at odds with some previous studies)
  - EKE budget: eddies primarily enhance the eddy drag, and weaken the wind work of secondary importance.
- Change in eddy drag means changes in Ekman pumping velocities
  - Eddy-current and eddy-SST produce Ekman pumping velocity climatologies of comparable magnitudes and different distributions.
  - Implying different feedback processes, a subject of ongoing study.

Thanks!

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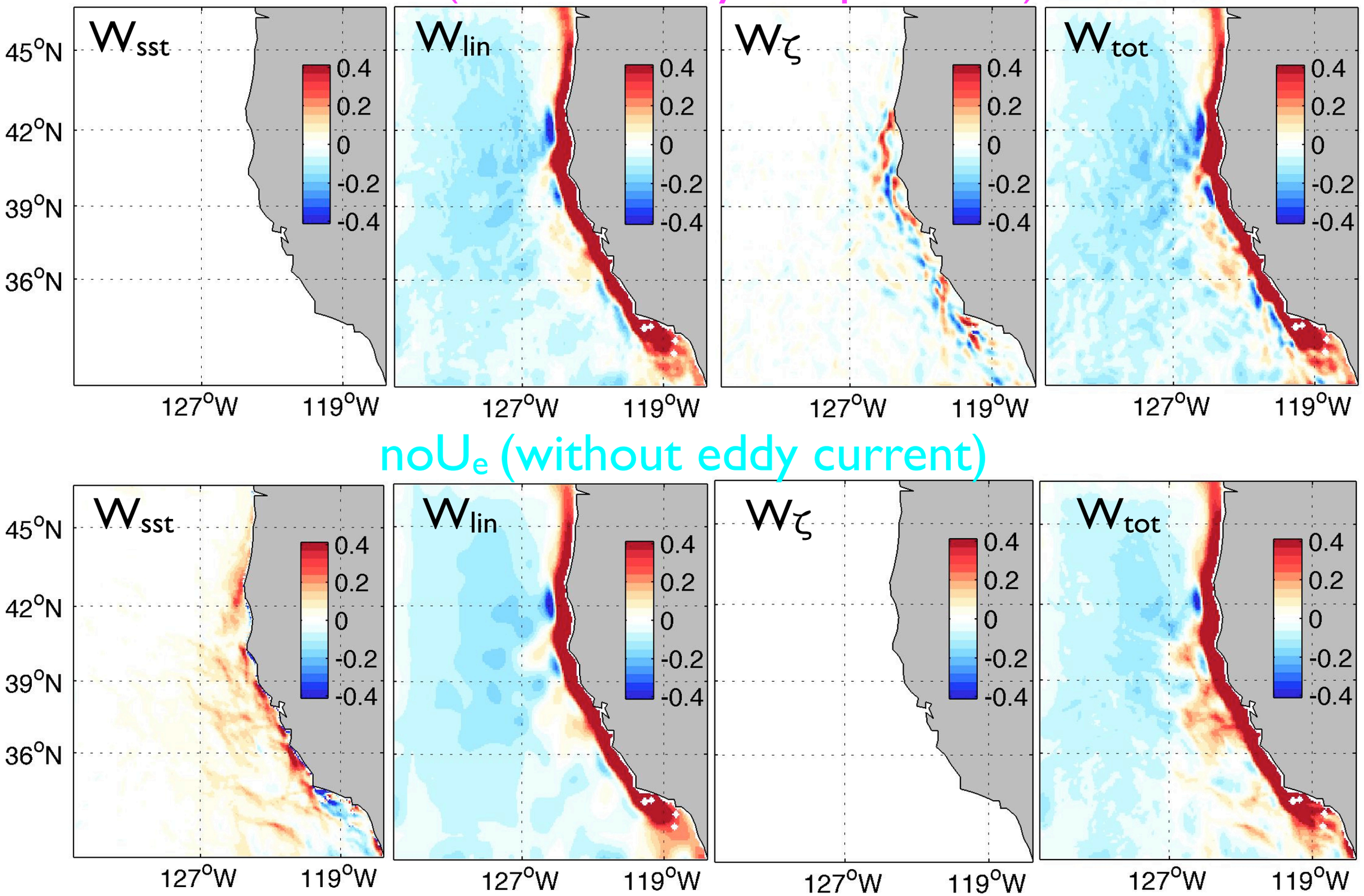
This study gratefully acknowledges NSF OCE-09060770.

Ekman pumping velocity JAS climatology

noT_e (without eddy temperature)

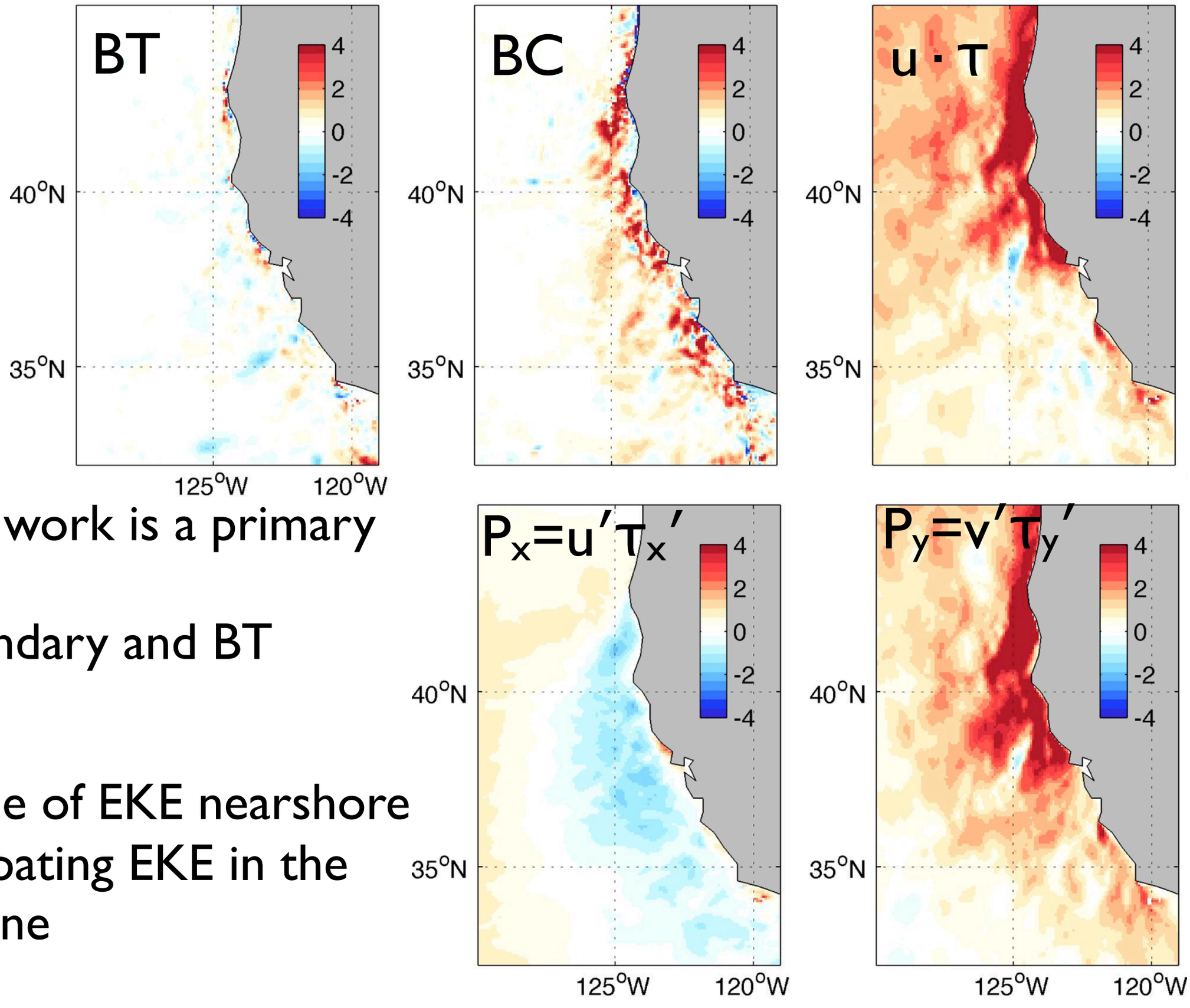


noU_e (without eddy current)

m/day

JAS 2005-2009

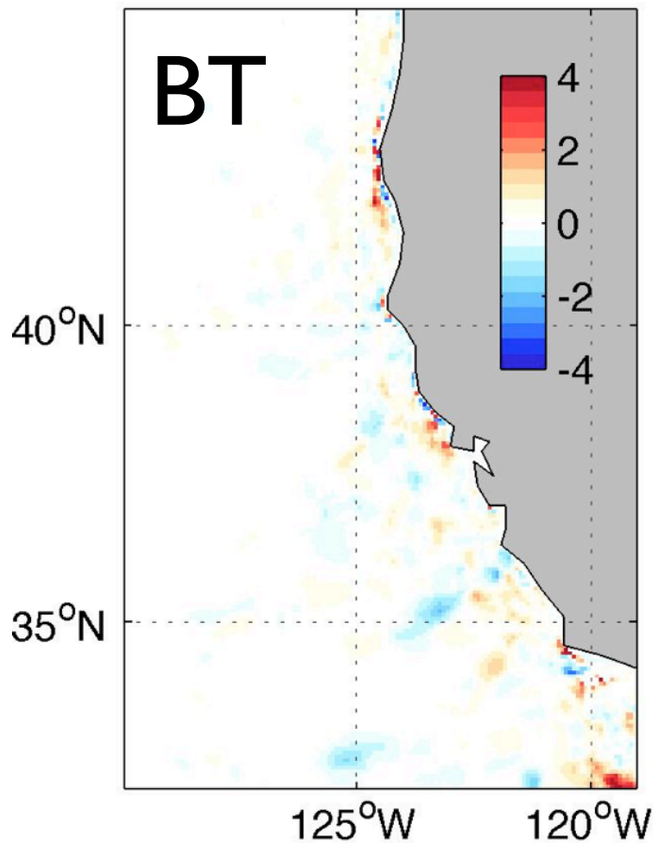
Summertime EKE budget in CTL

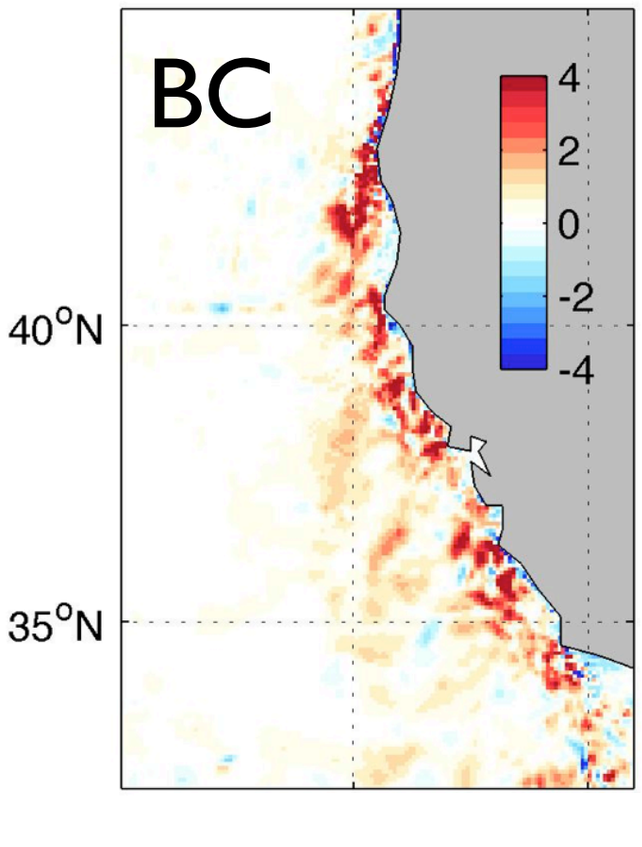


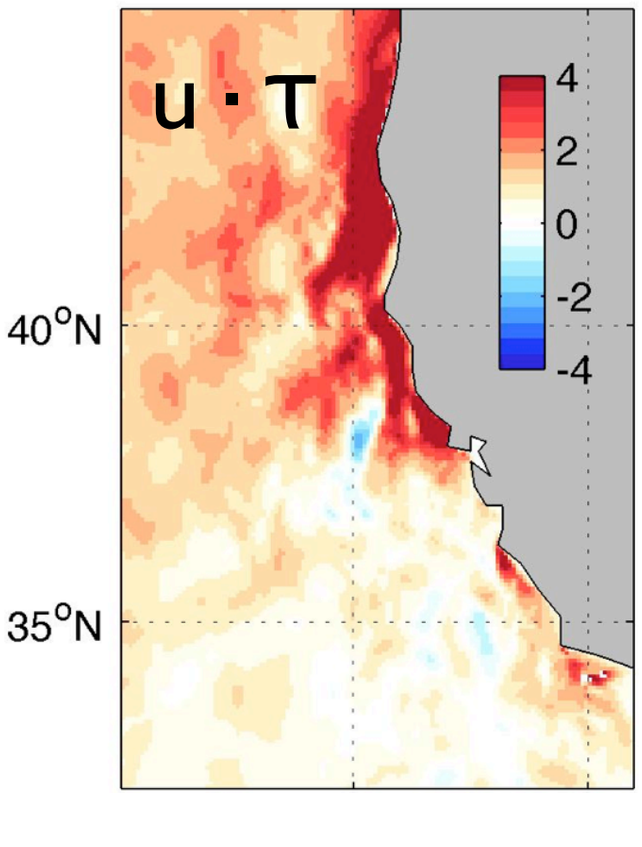
- Eddy wind work is a primary source
  - BC secondary and BT negligible

- $v'\tau_y'$: Source of EKE nearshore
- $u'\tau_x'$: Dissipating EKE in the upwelling zone

Summertime EKE budget in CTL







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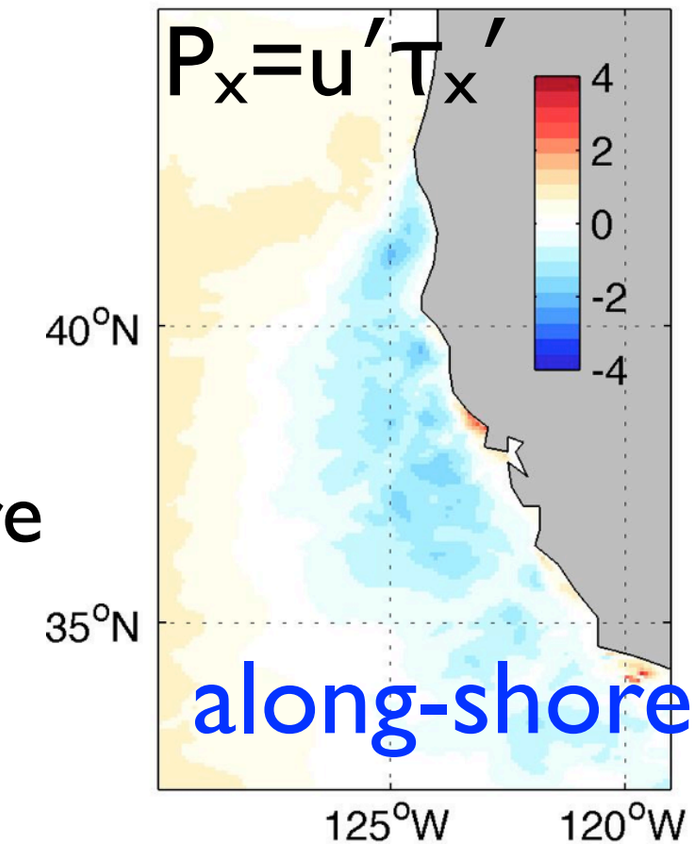

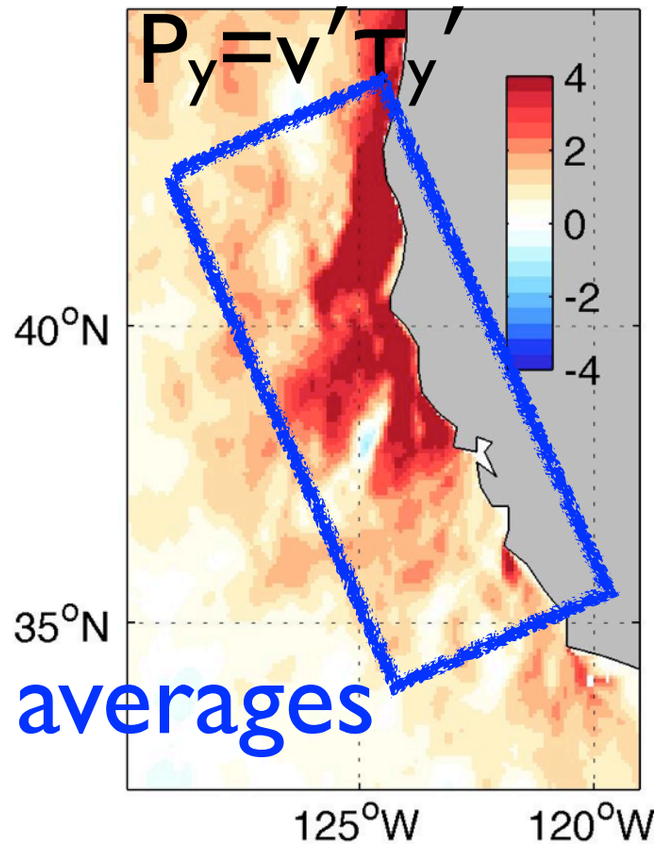

along-shore averages