Regional coupled modeling of eddy-wind interaction in the California Current System
— Eddy kinetic energy and Ekman pumping

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Eddy-wind interaction: wind stress

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

Eddy-wind interaction: wind stress

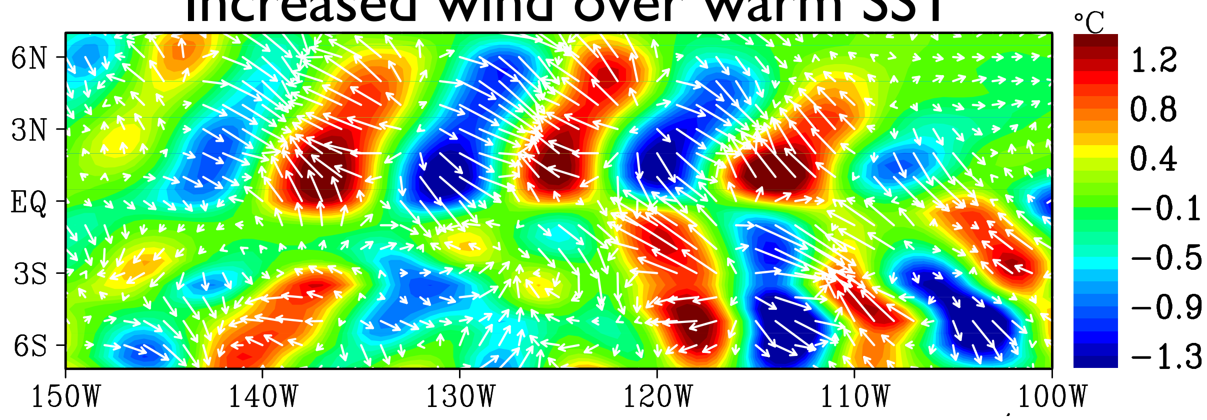
$$\tau=\rho C_D(U_a - U_o)\,|U_a - U_o|$$

10m wind

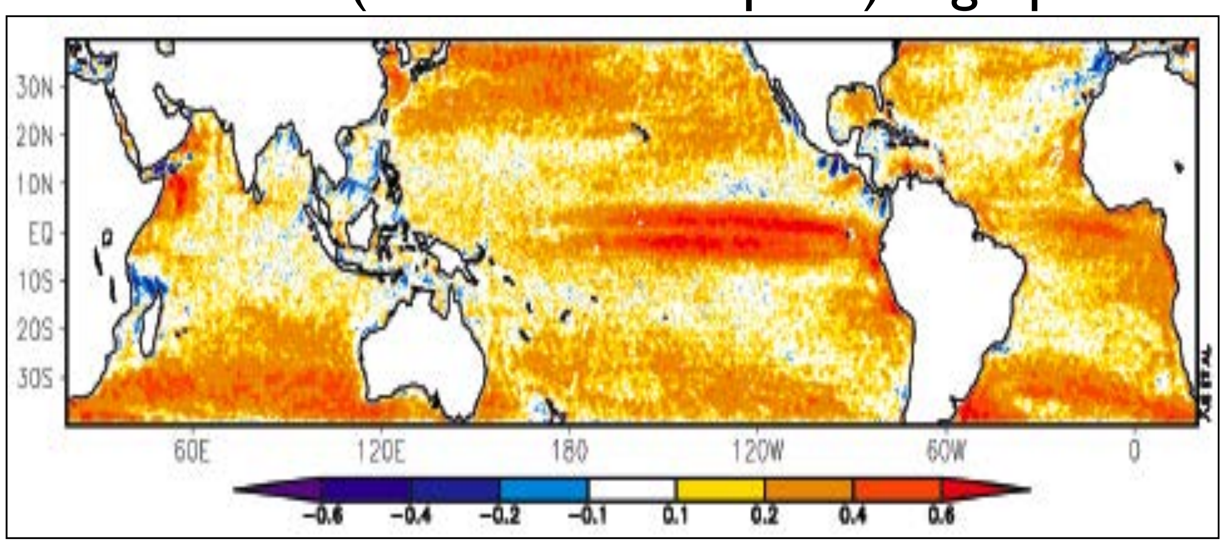
$U_a = U_{ab} + \underline{U_{aSST}}$

Wallace et al (1998)

Increased wind over warm SST



Correlation (SST and wind speed): high-passed



Xie 2004

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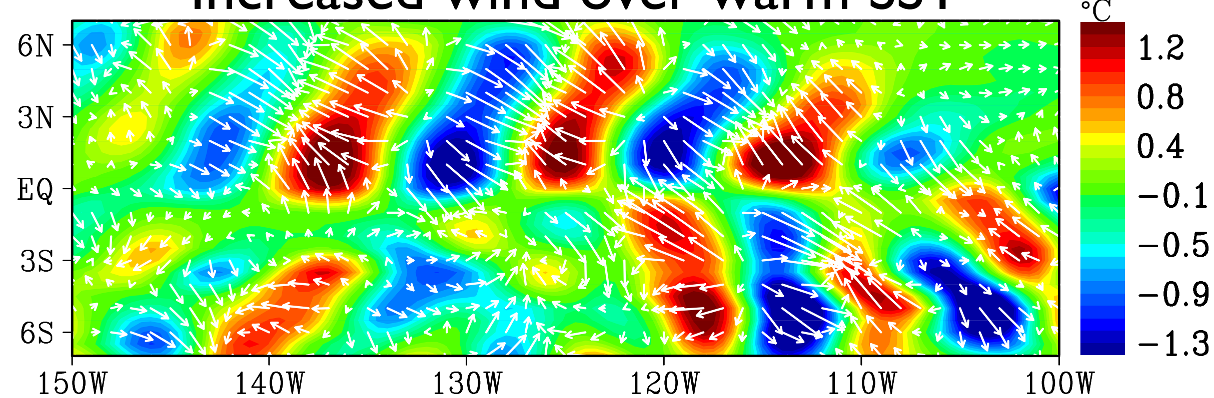

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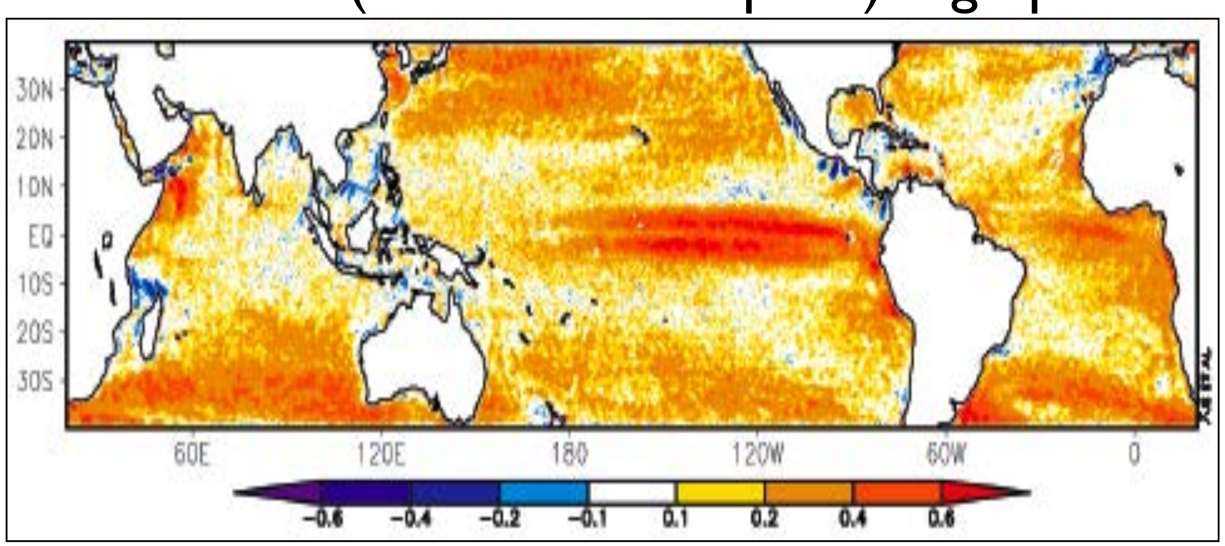
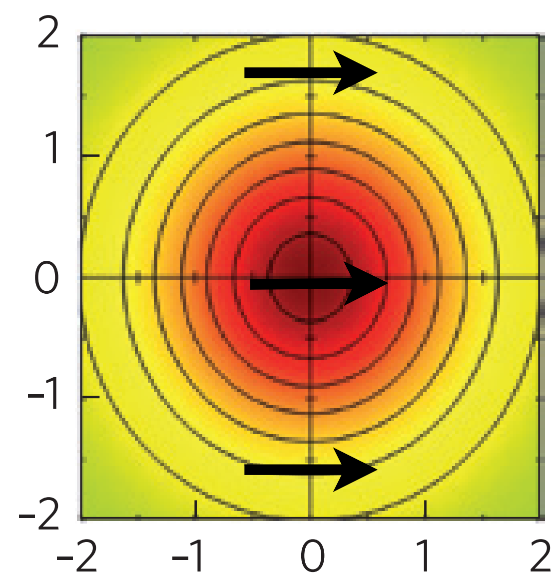


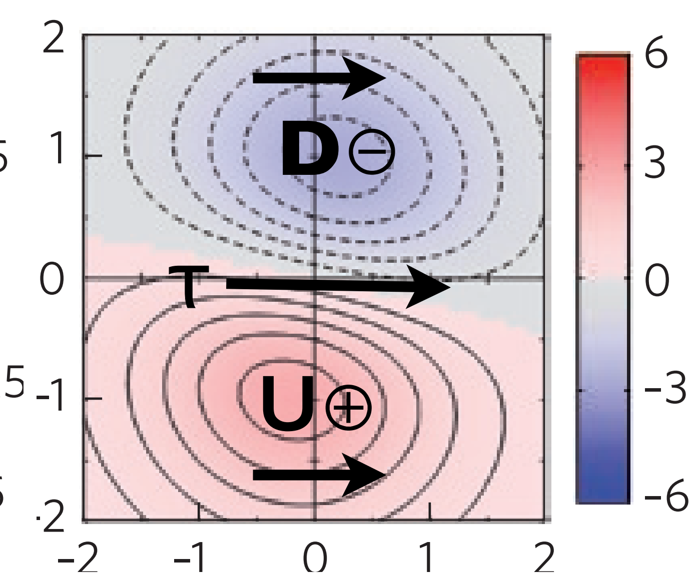
Xie 2004

Uniform eastward wind over an anticyclonic eddy in the Southern Ocean (Chelton 2013)

SST and SSH



Dipole Ekman velocity



Ekman pumping anomaly 90° out of phase with SSH → propagation of an eddy

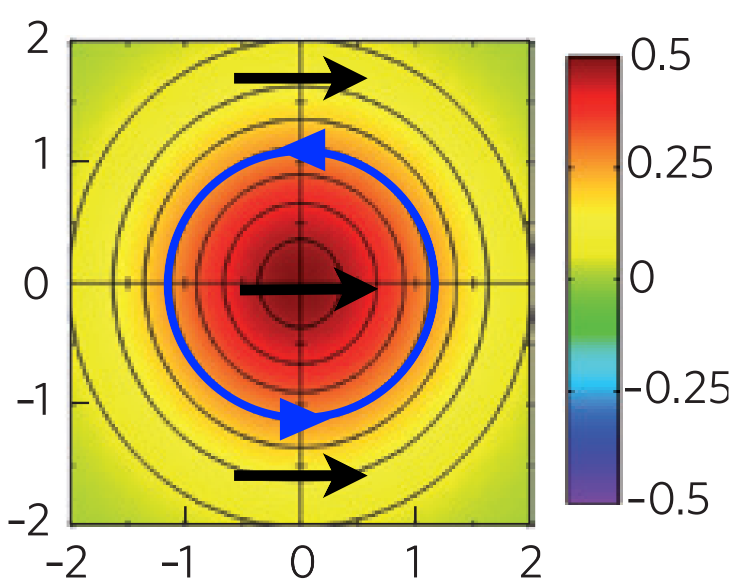
Eddy-wind interaction: wind stress

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

surface current
$U_o = U_{ob} + U_{oe}$
$(U_{ob} \ll U_{oe})$

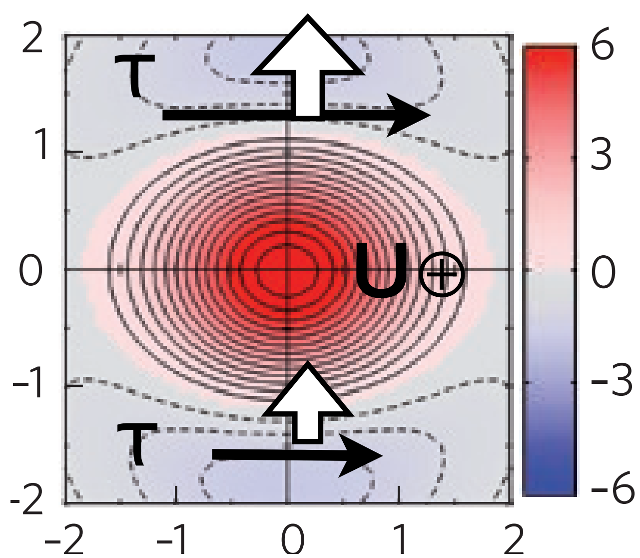
$$W_e = \tau / [\rho (f + \zeta)]$$

SST and SSH



surface current

Monopole Ekman velocity



Upwelling at the center of an anti-cyclonic eddy: damping of an eddy

Eddy-wind interaction: wind stress

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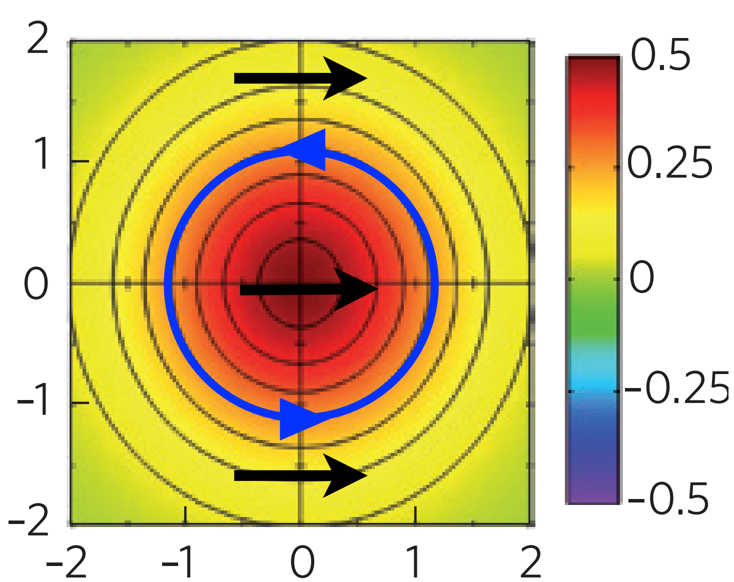

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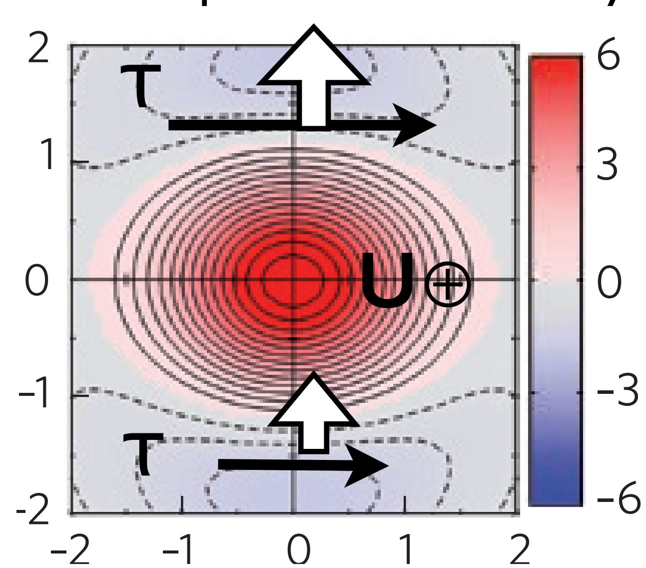

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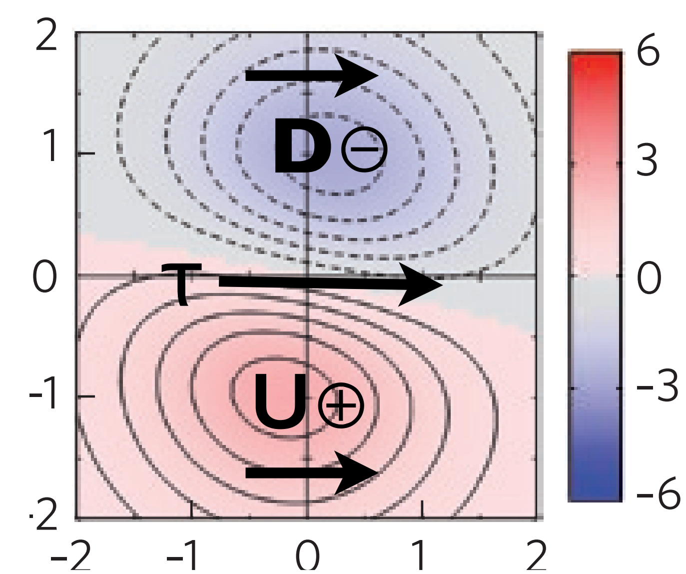

Feedback to ocean would be different!

Eddy-wind interaction: wind stress

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resulting wind stress

$\tau \approx \tau_b + \tau_{SST} + \tau_{oe}$

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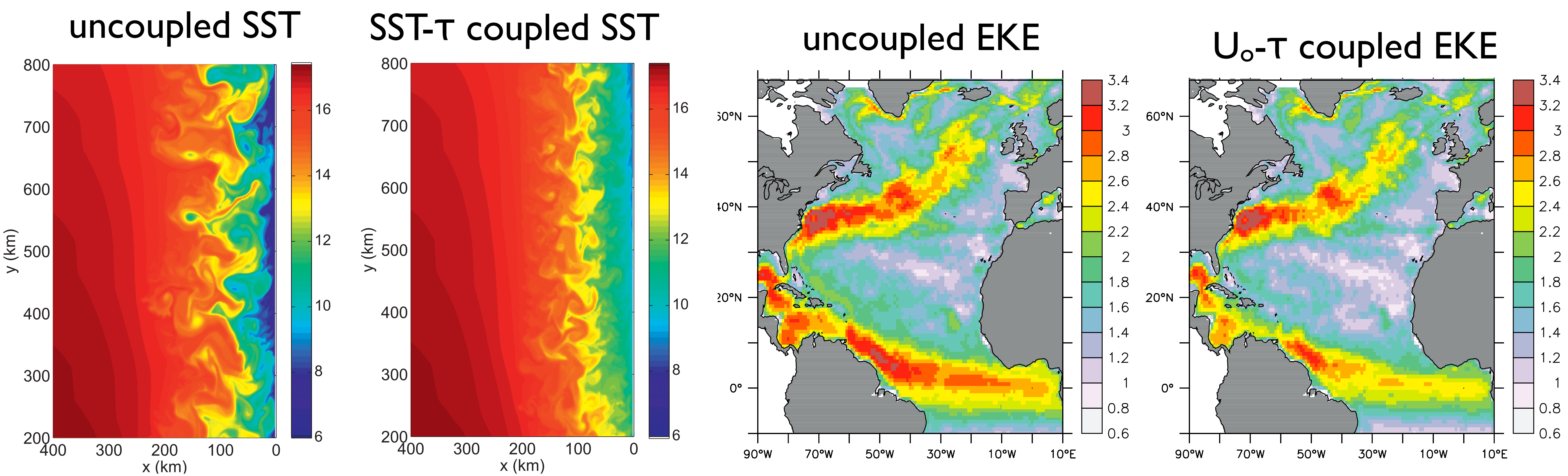
Effects of τ_{SST} and τ_{cur} on the ocean?

EKE and Ekman pumping

Result from previous studies and the goal of this study

- Previous studies considered either SST or U_o in τ formulation in ocean-only models and saw weakened eddy variability.

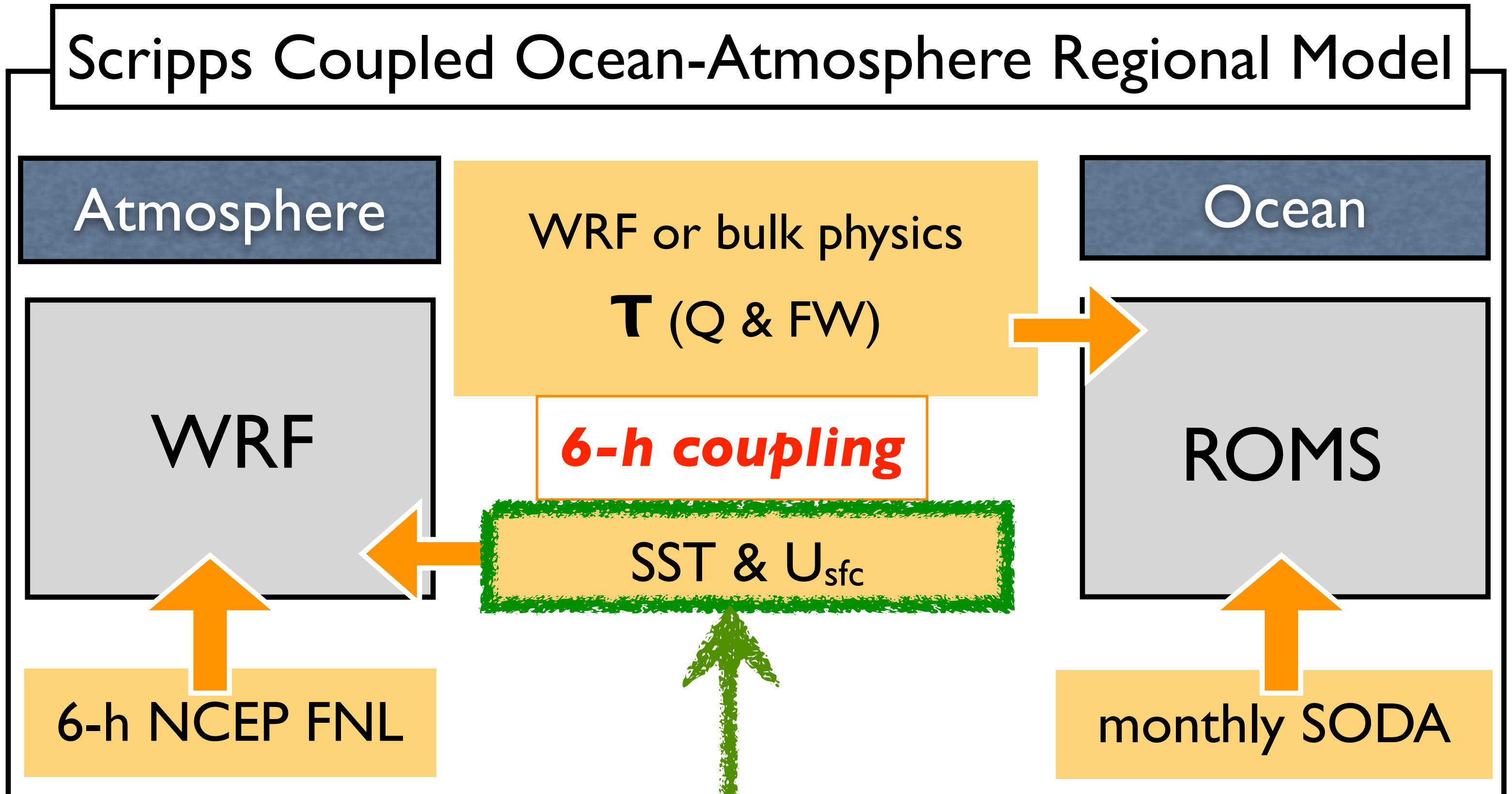


SST-τ coupling: *Jin et al. (2009)*

U_o-τ coupling: *Eden and Dietze (2009)*

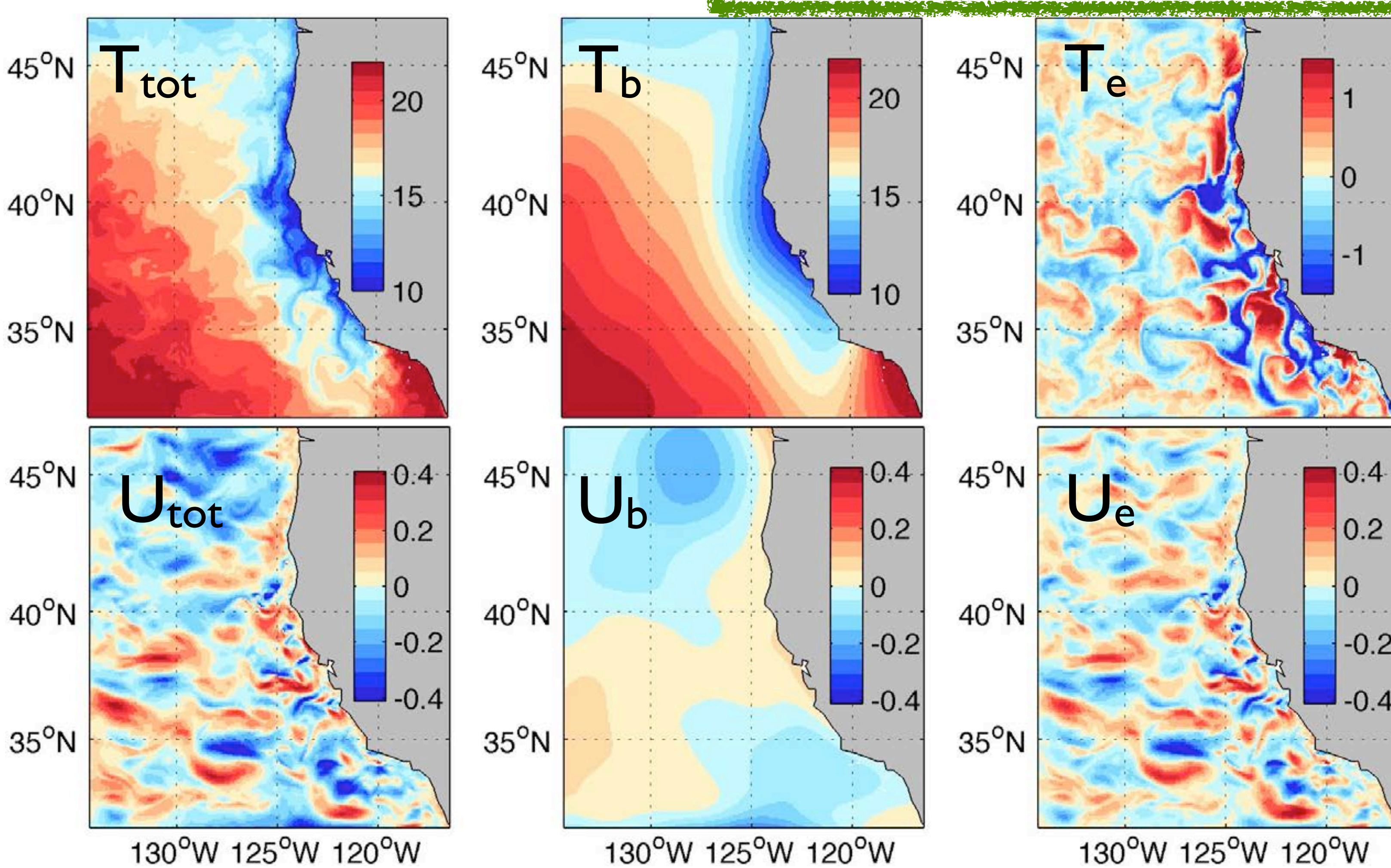
- This study examines the relative importance of SST and u_{sfc} in a fully coupled regional model.

Regional coupled model



- Seo et al. 2007, 2014
- An input-output based coupler; portable & flexible

- 7 km O-A resolutions & matching mask
- 6-yr integration (2005-2010)



Smoothing of mesoscale SST and U_o (Putrasahan et al. 2013)

5° loess smoothing
(~3° boxcar smoothing)

Experiments

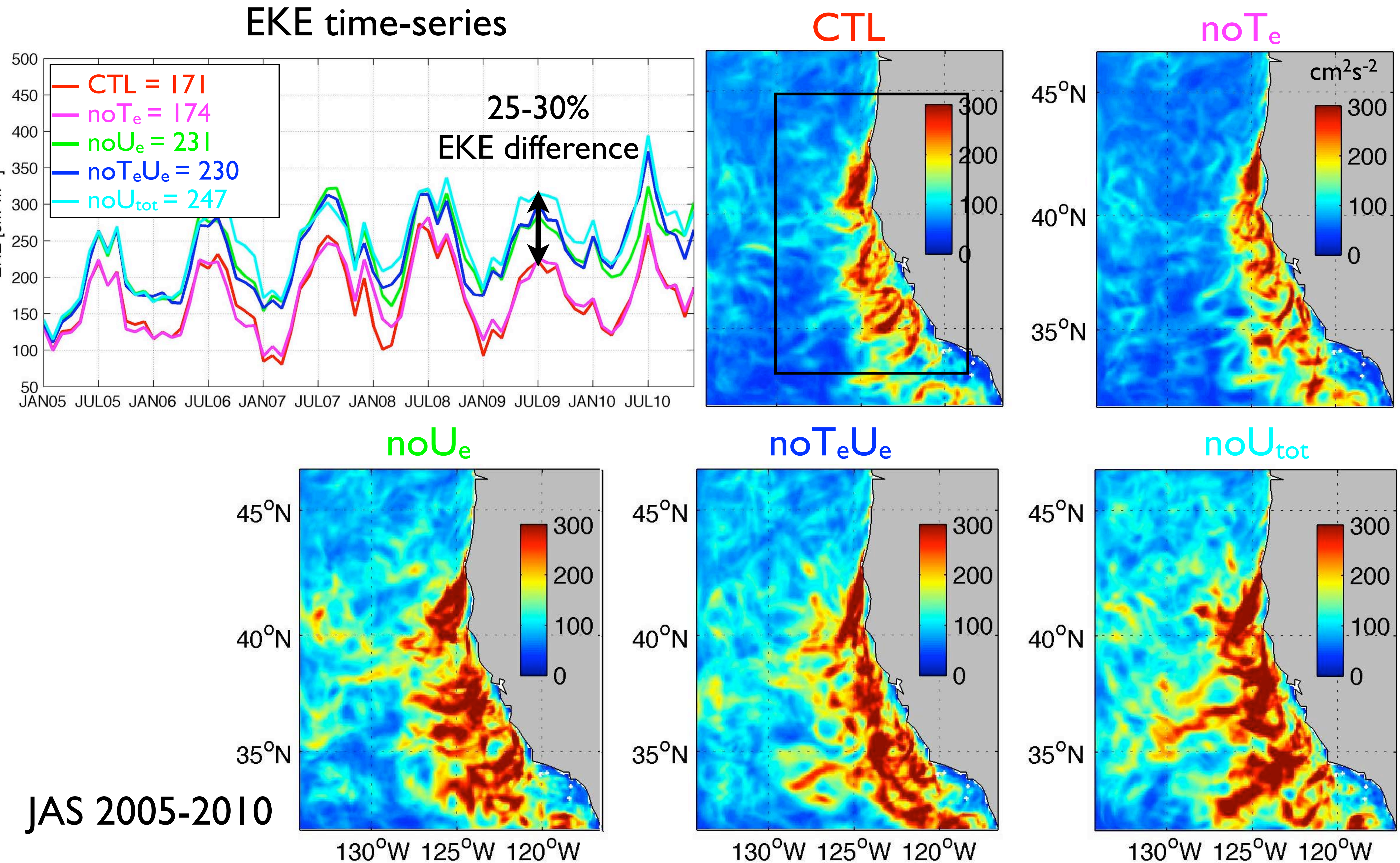
$$\tau=\rho C_D(U_a-U_o)|U_a-U_o|$$

$T_{tot} = T_b + T_e$

$U_{tot} = U_b + U_e$ 5° loess filtering (≈ 3° boxcar smoothing)

Experiments	τ formulation includes			
CTL	T_b	T_e	U_b	U_e
noT_e	T_b	T_e	U_b	U_e
noU_e	T_b	T_e	U_b	U_e
noT_eU_e	T_b	T_e	U_b	U_e
noU_{tot}	T_b	T_e	U_b	U_e

Summer surface eddy kinetic energy



• T_e no impact • 25% weaker EKE with U_e • 30% weaker EKE with U_b+U_e

Eddy kinetic energy budget

advection by mean and eddy current (offshore)

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

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

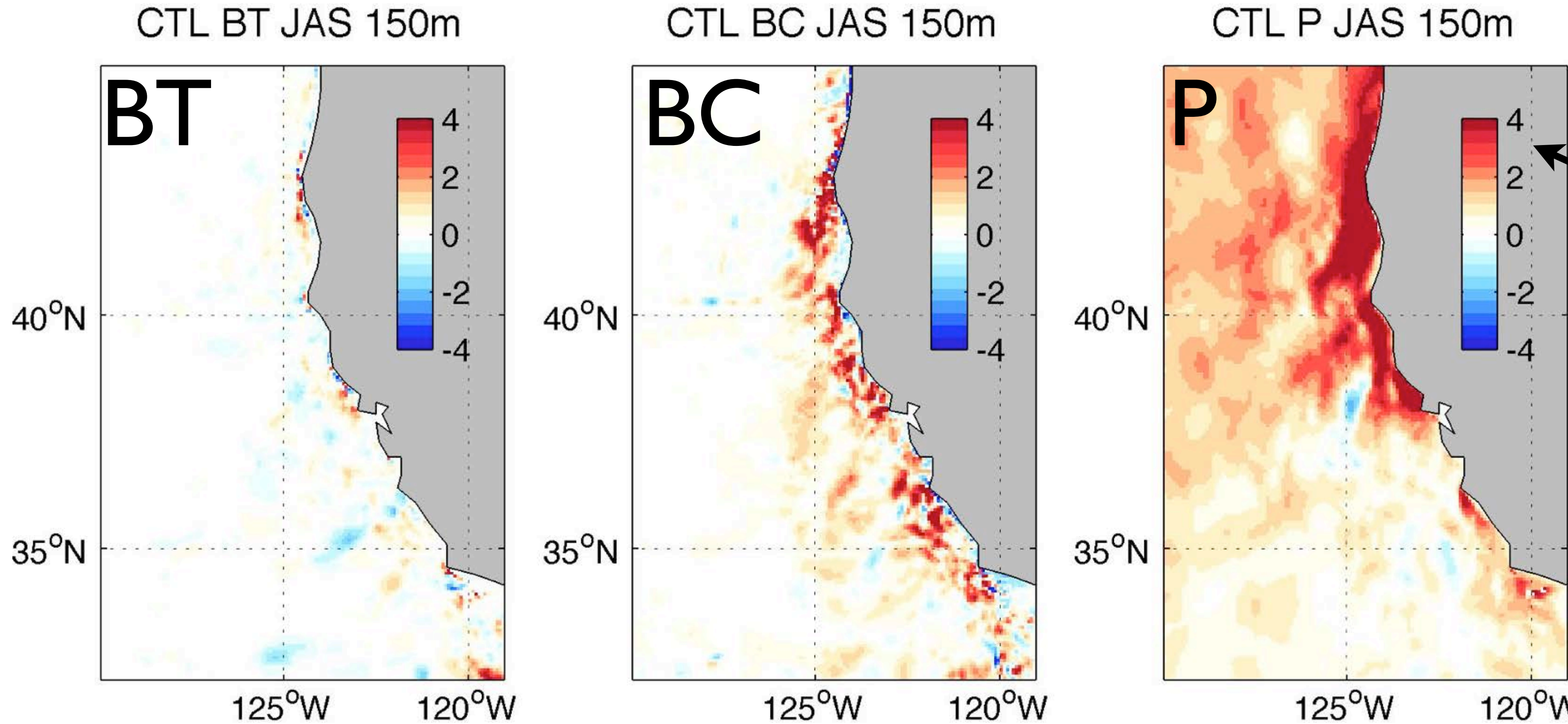
$P_e \rightarrow K_e$
baroclinic conversion (BC)

$K_m \rightarrow K_e$
barotropic conversion (BT)

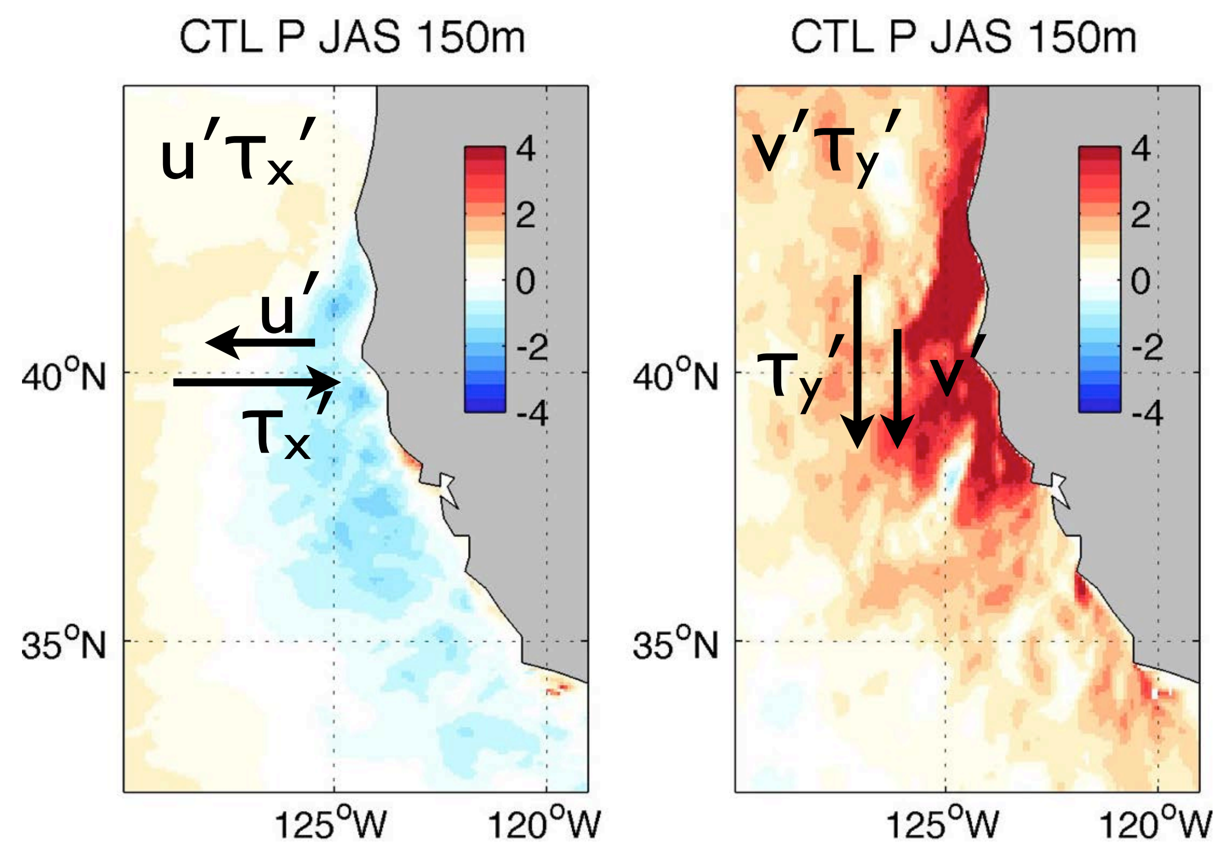
wind work (P) if positive (eddy drag if negative)

Upper 100 m average
H~fL/N, where $f=10^{-4}$, $L=10^4$m, $N=10^{-2} \rightarrow H=10^2$m

EKE budget: CTL



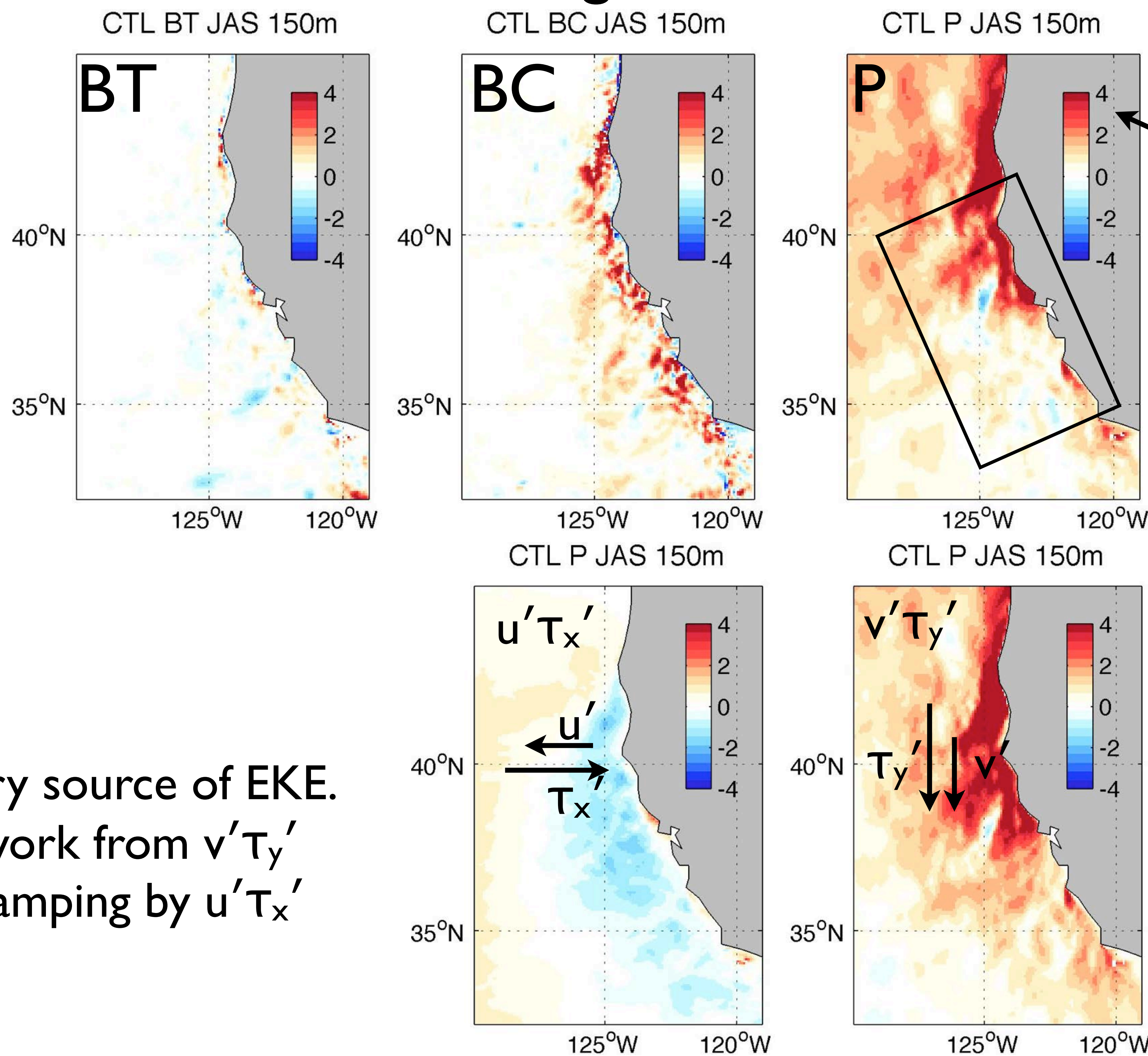
Significant difference in only P



- P a primary source of EKE.
  - Wind work from $v'\tau_y'$
  - Eddy damping by $u'\tau_x'$

150 m average

EKE budget: CTL



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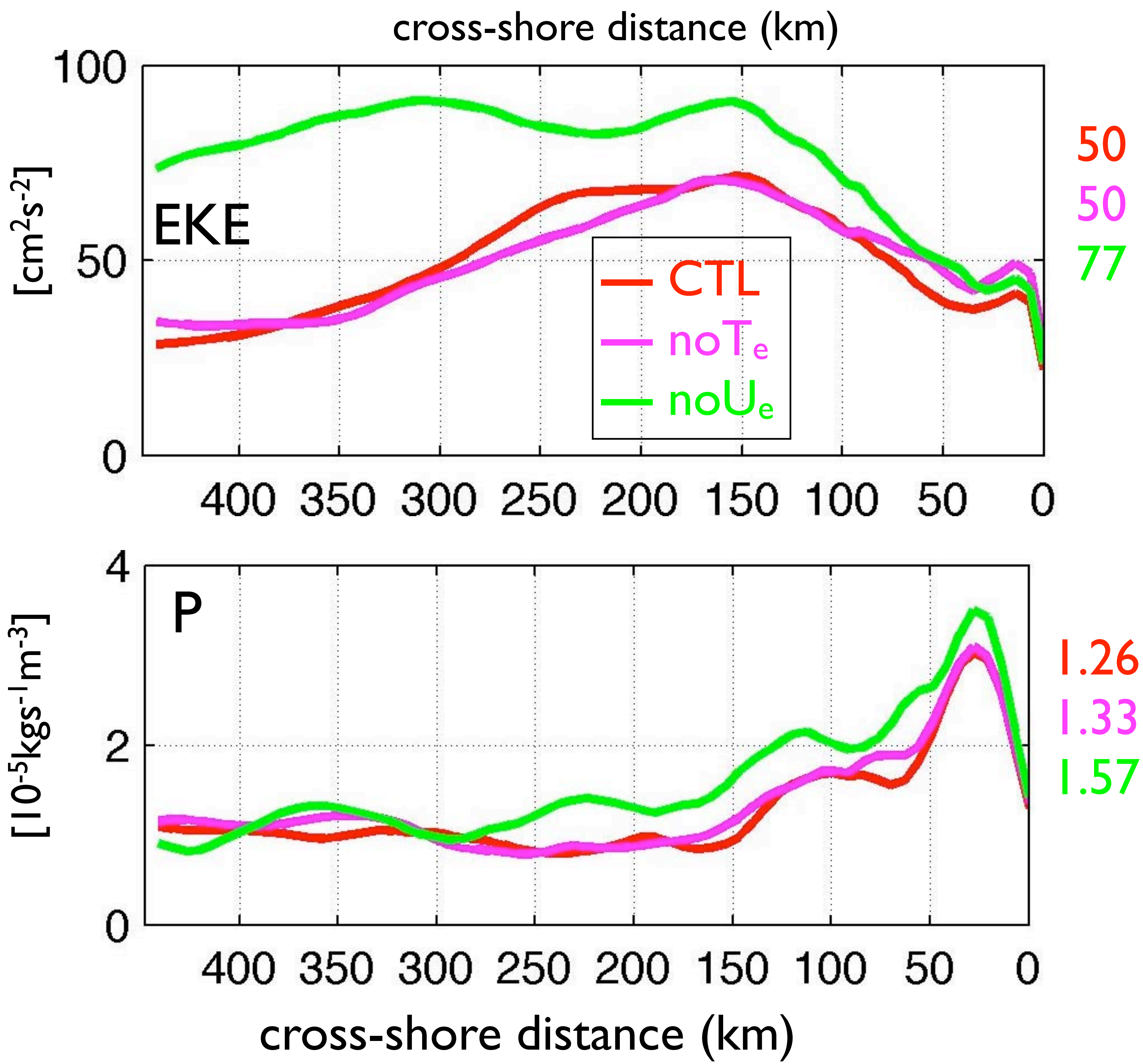
150 m average

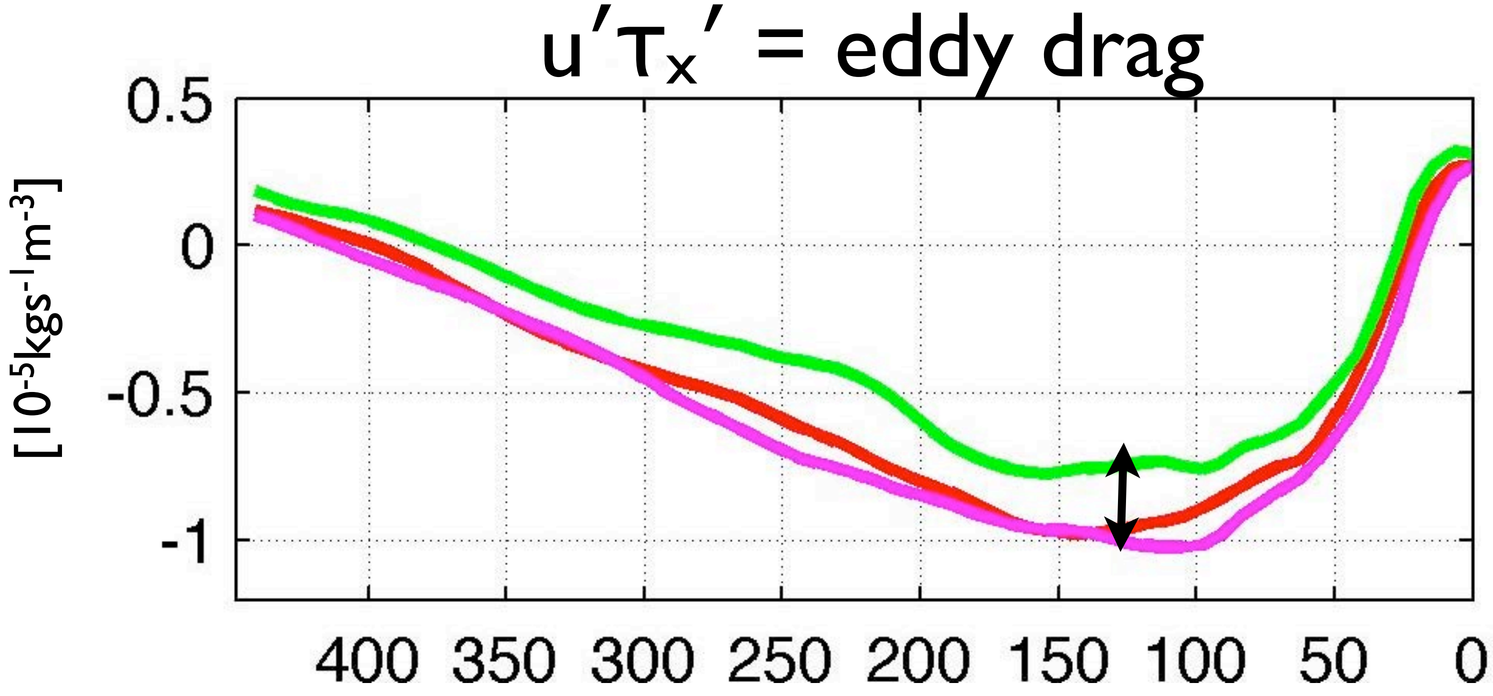
Cross-shore distribution of EKE and P



- P and BC maximum near the coast (20-30 km).

- $noU_e \rightarrow$ CTL:
  - P decreases by 20%

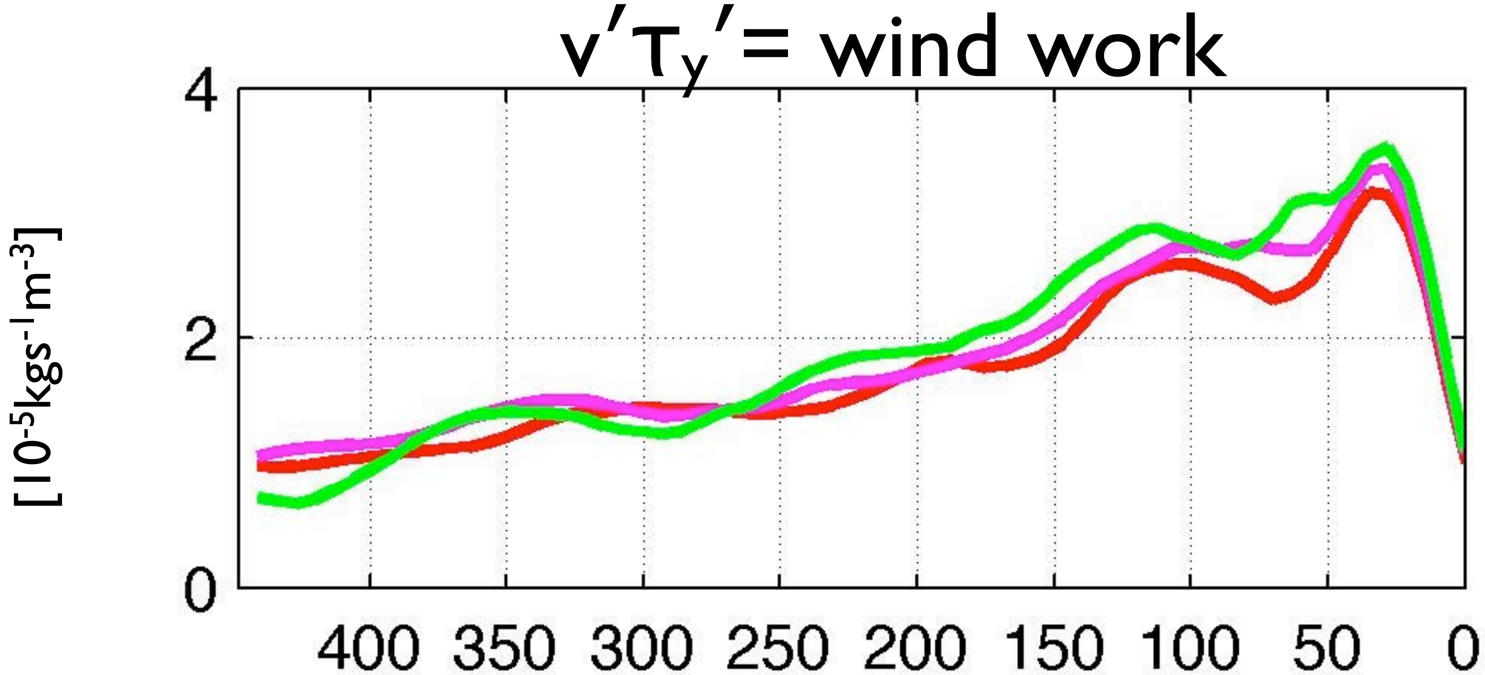
Eddy drag and wind work



eddy drag

CTL=−0.47
noT$_e$=−0.53
noU$_{e}$=−0.33

42% stronger eddy drag



wind work

CTL=1.74
noT$_e$=1.86
noU$_{e}$=1.90

16% weaker wind work

Ue: increases the eddy drag and weakens the wind work

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

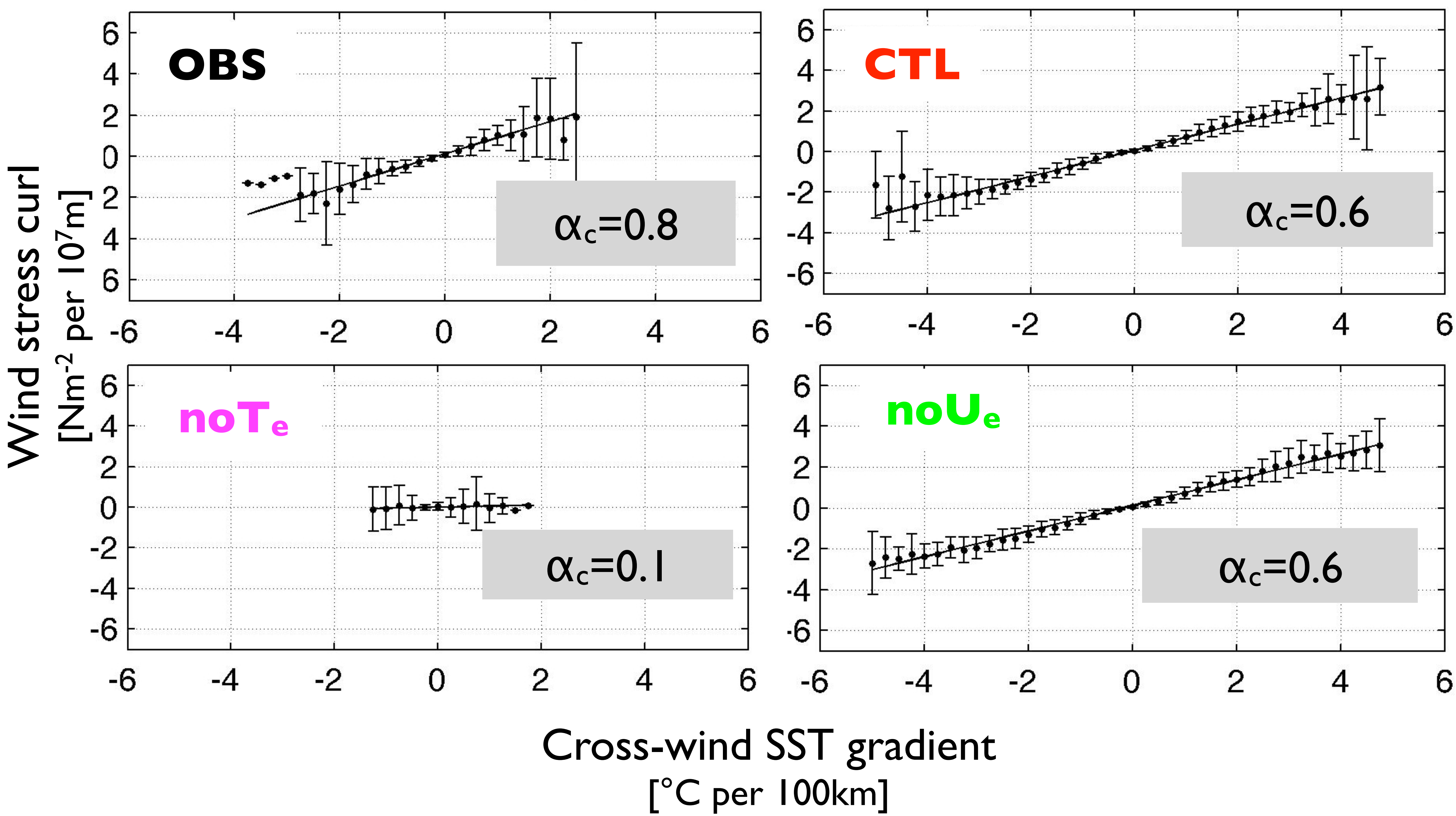
β Ekman pumping (negligible)

SST induced Ekman pumping (Chelton et al. 2004)

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

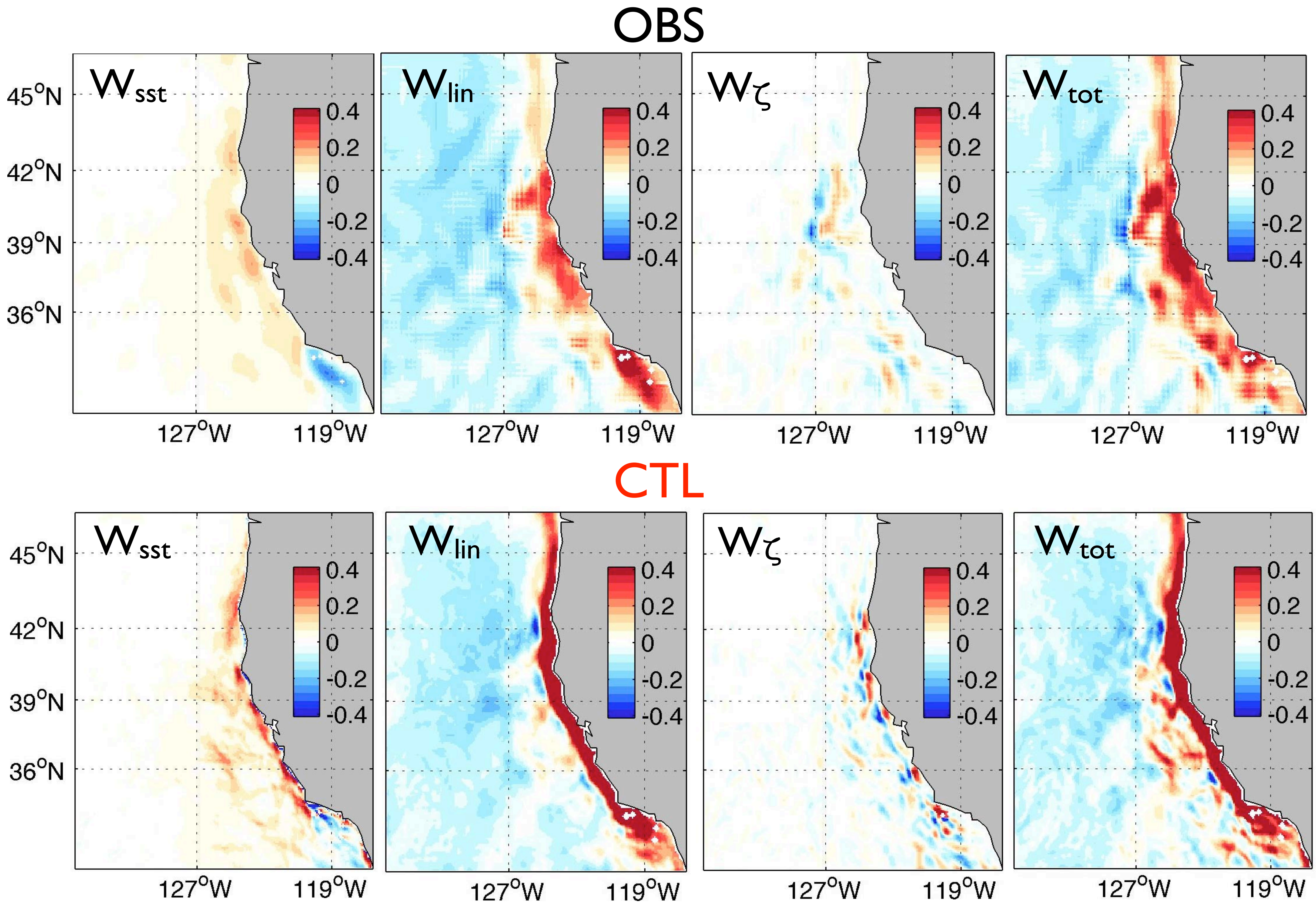
Wind stress curl and cross-wind SST gradient

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



JAS 2005-2009; QuikSCAT wind stress and TRMM SST

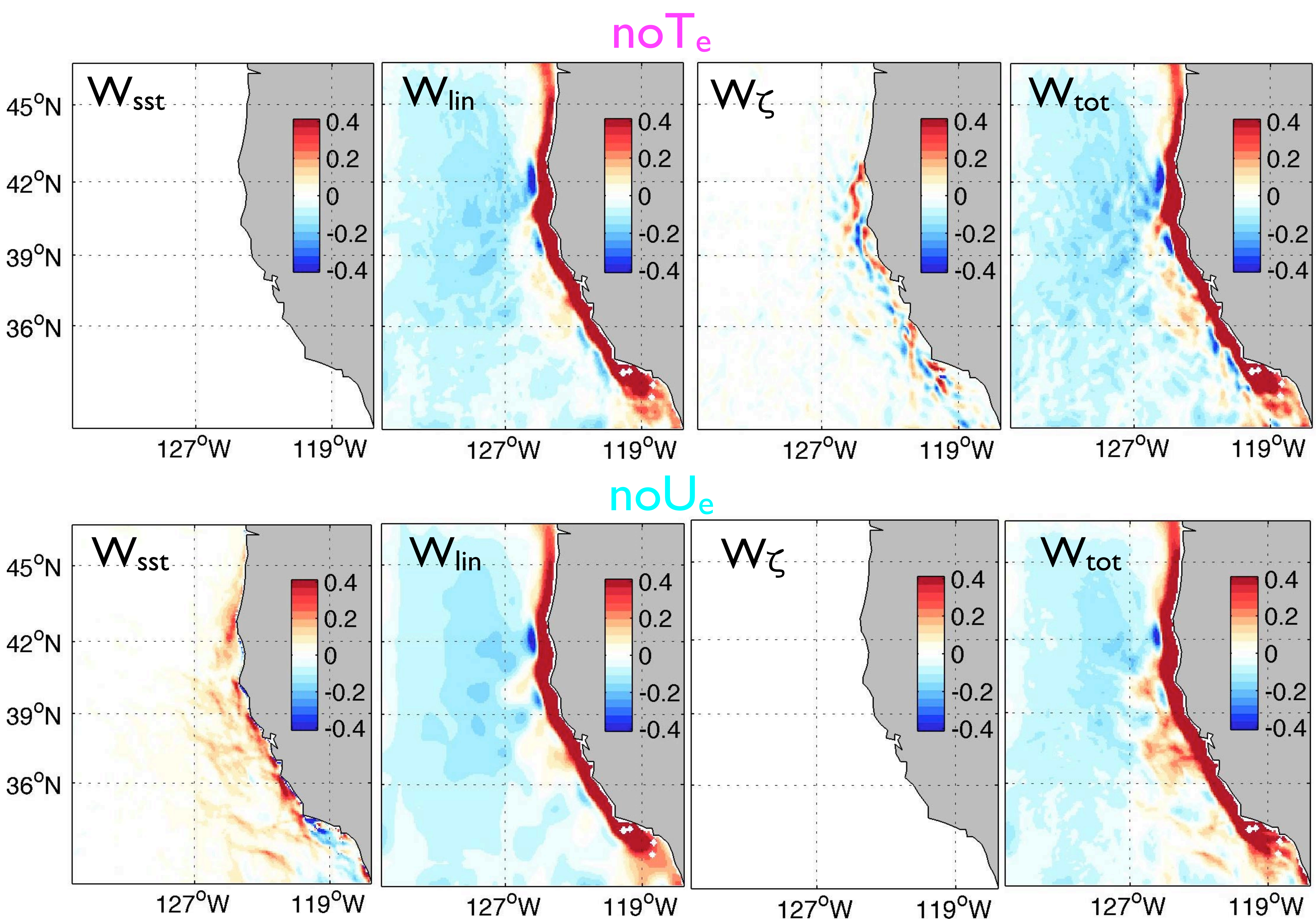
Ekman pumping velocity JAS climatology



m/day

JAS 2005-2009

Ekman pumping velocity JAS climatology

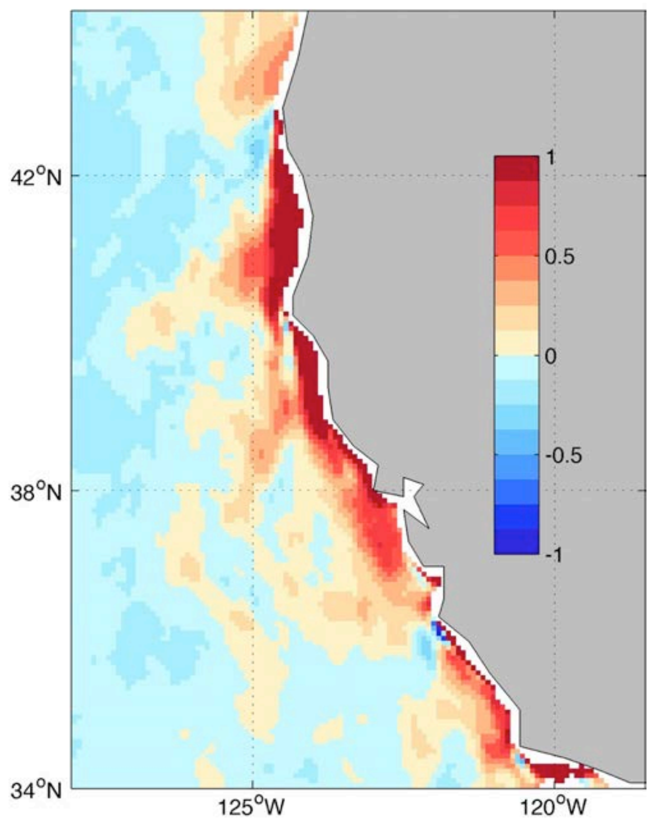


m/day

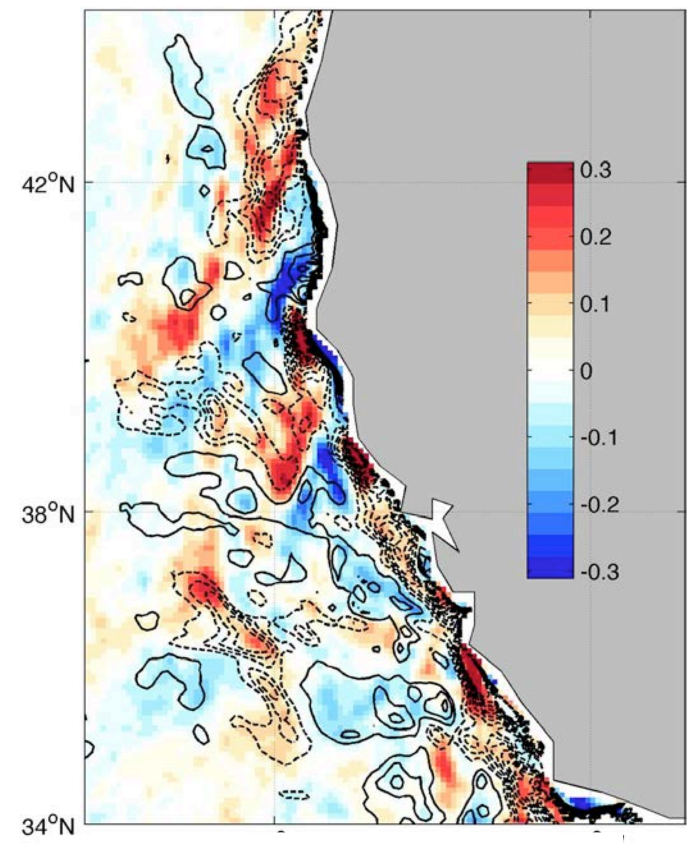
JAS 2005-2009

Long-term effect of SST and vorticity on Ekman pumping velocity

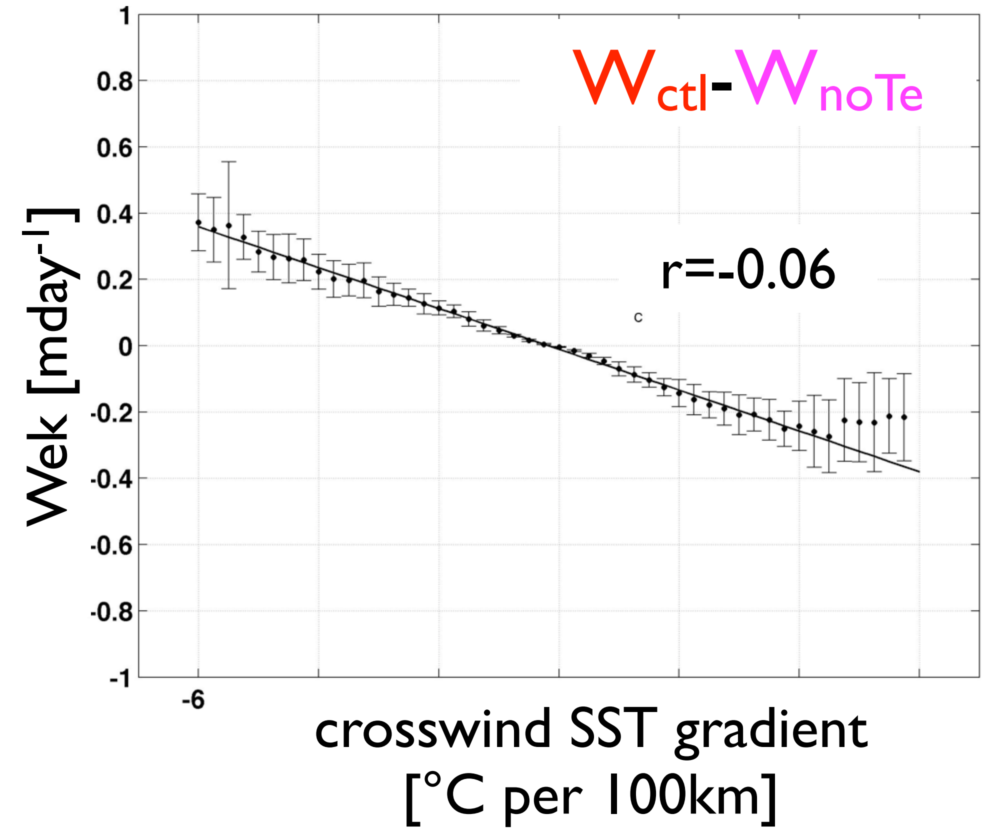
Wek from CTL



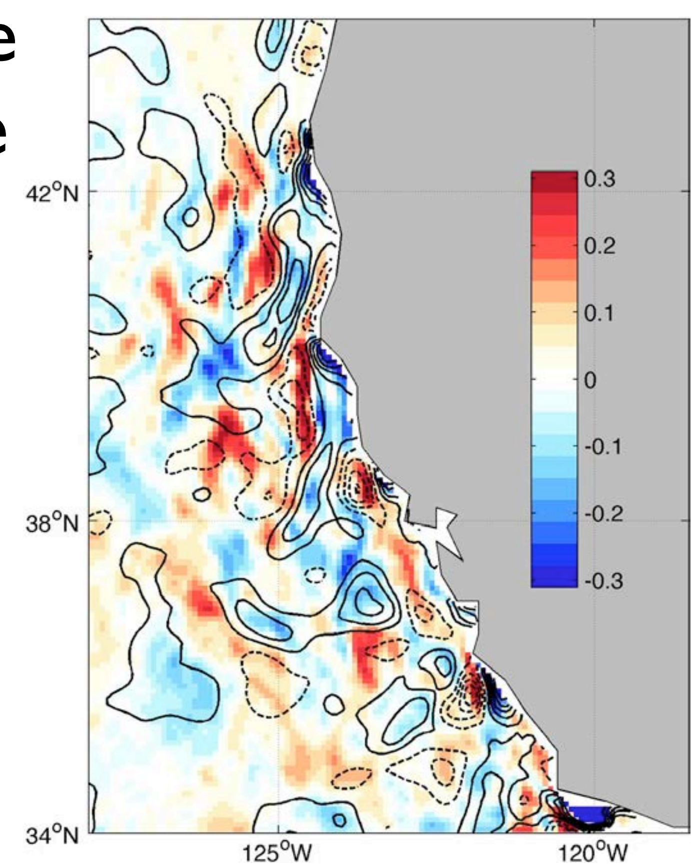
Wek: CTL-noTe



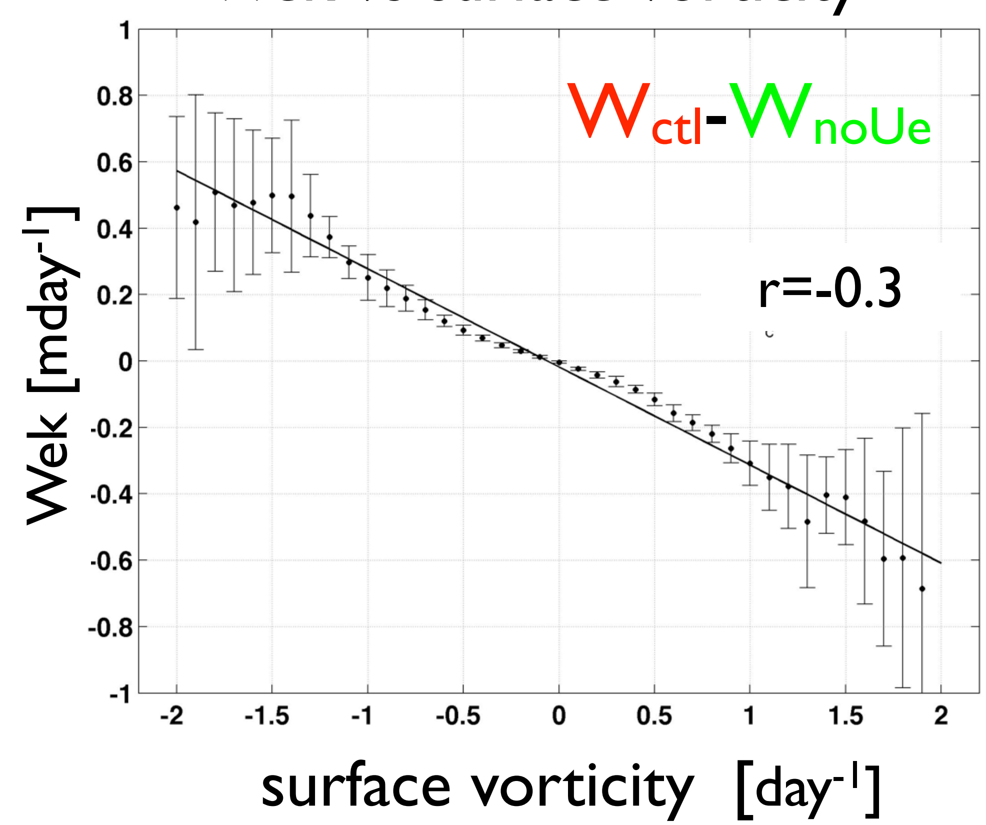
Wek vs crosswind SST gradient



Wek: CTL-NoUe



Wek vs surface vorticity



- SST and vorticity induce the Wek response of comparable magnitudes but of different spatial pattern.
  - indicative of different feedback processes

JAS 2005-2009

Summary

- Examined the *relative* importance of τ_{SST} vs τ_{cur} in EKE and Ekman pumping velocity in the CCS using a regional coupled model.

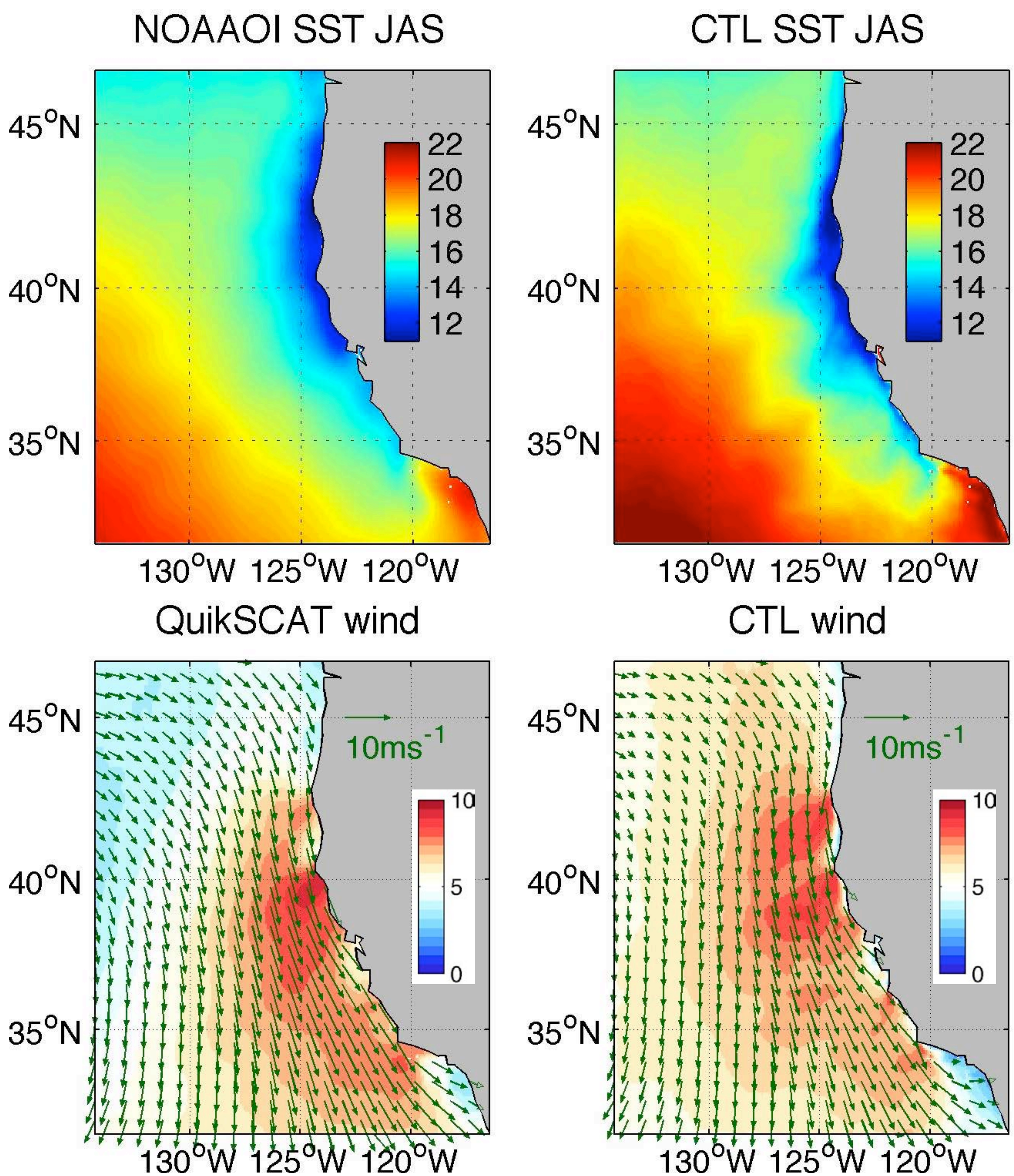
- Surface EKE is weakened almost entirely due to mesoscale current.
  - SST has no impact.

- EKE budget: enhanced eddy drag and reduced wind work.

- W_{SST} reflects the crosswind SST gradient, while W_{ζ} surface vorticity
  - Associated patterns of change imply different feedback processes.
  - Further investigation on the mechanisms for feedback is underway.

Thanks!

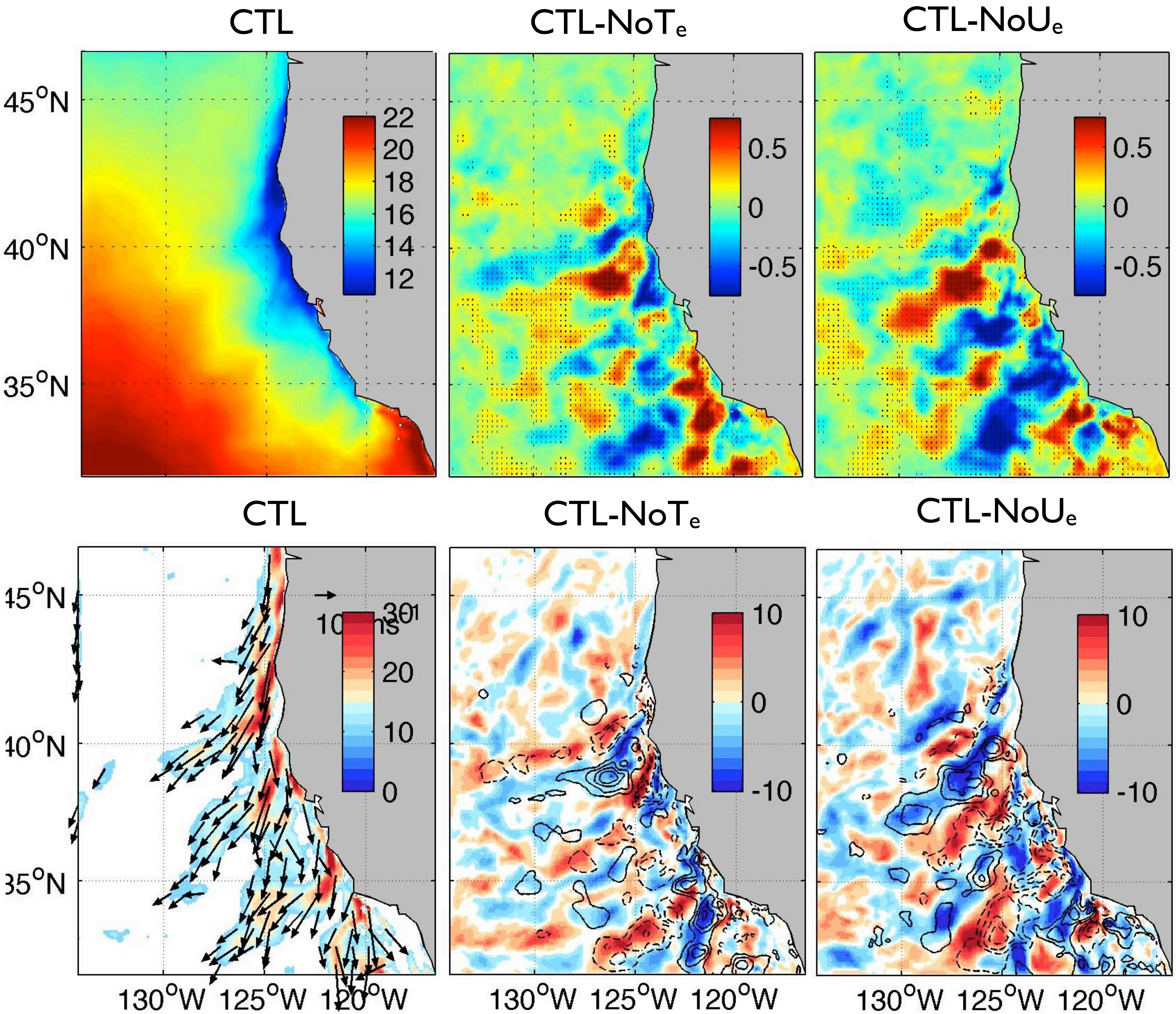
Summertime climatology: coastal upwelling



- CTL yields reasonable representation of the observed summertime upwelling condition in CCS.

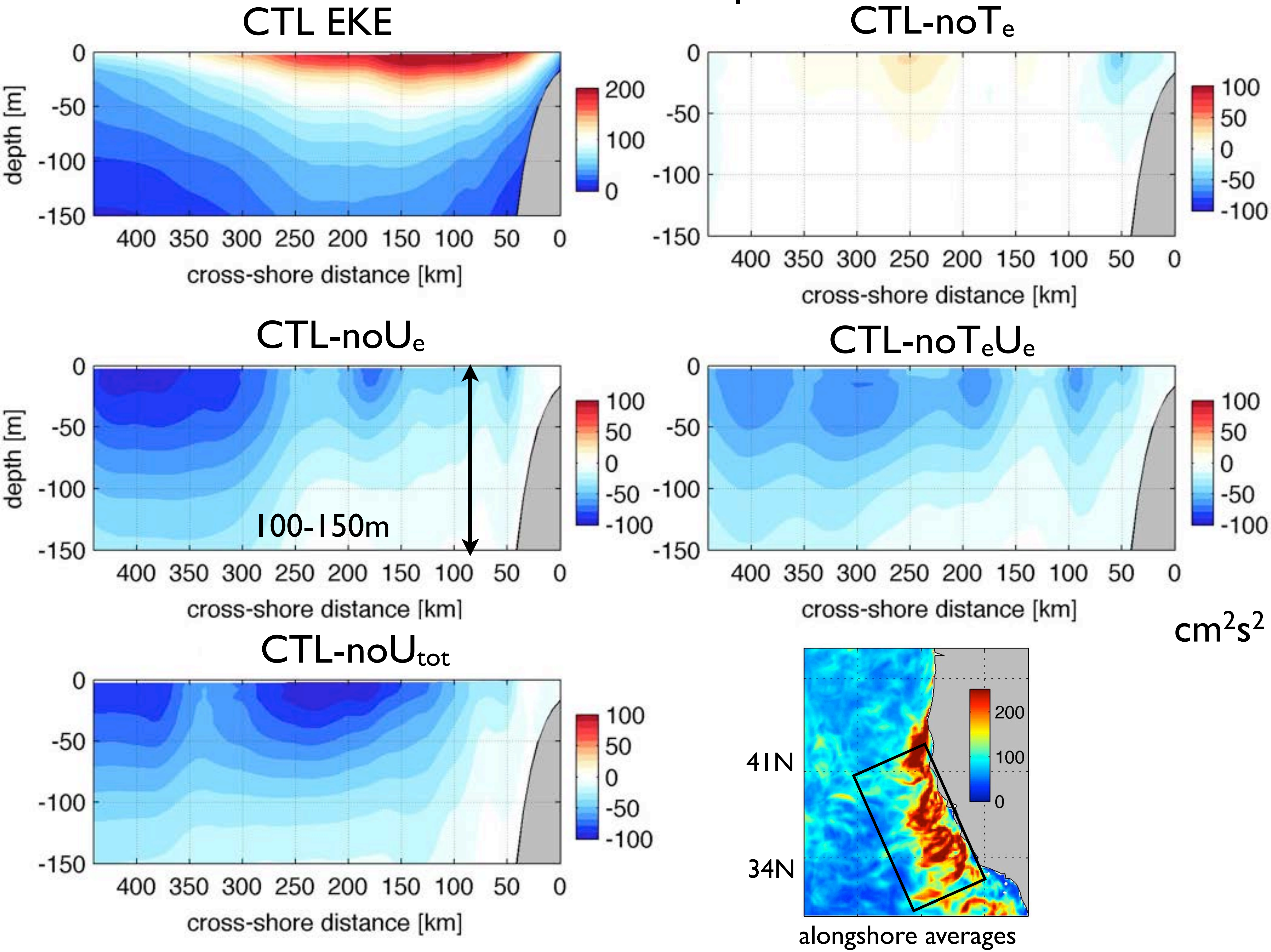
JAS 2005-2010

Change SST and surface current

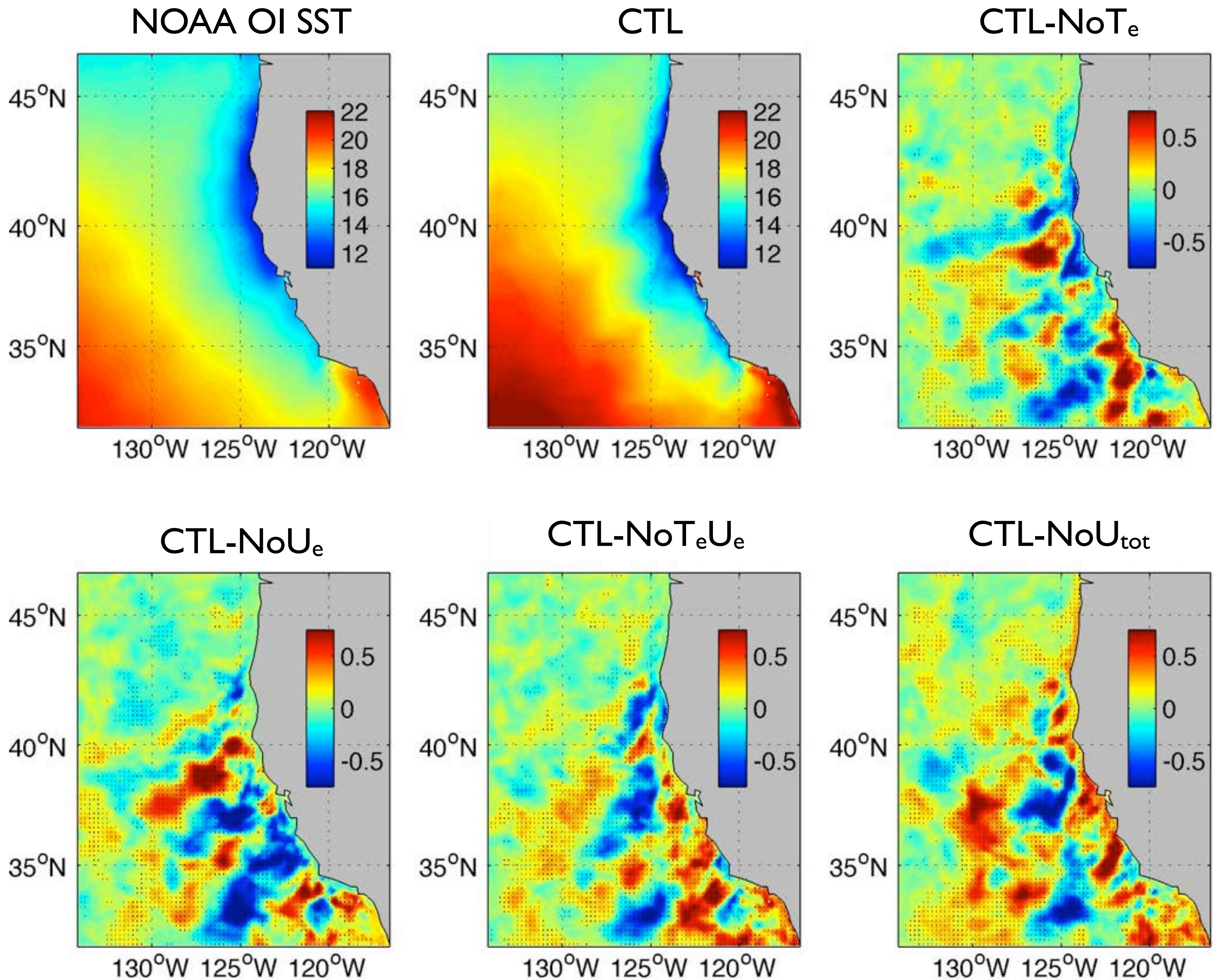


Change in SST pattern reflects the change in surface current: advection by mean and eddies.

Cross-shore vs depth EKE



Change in JAS SST

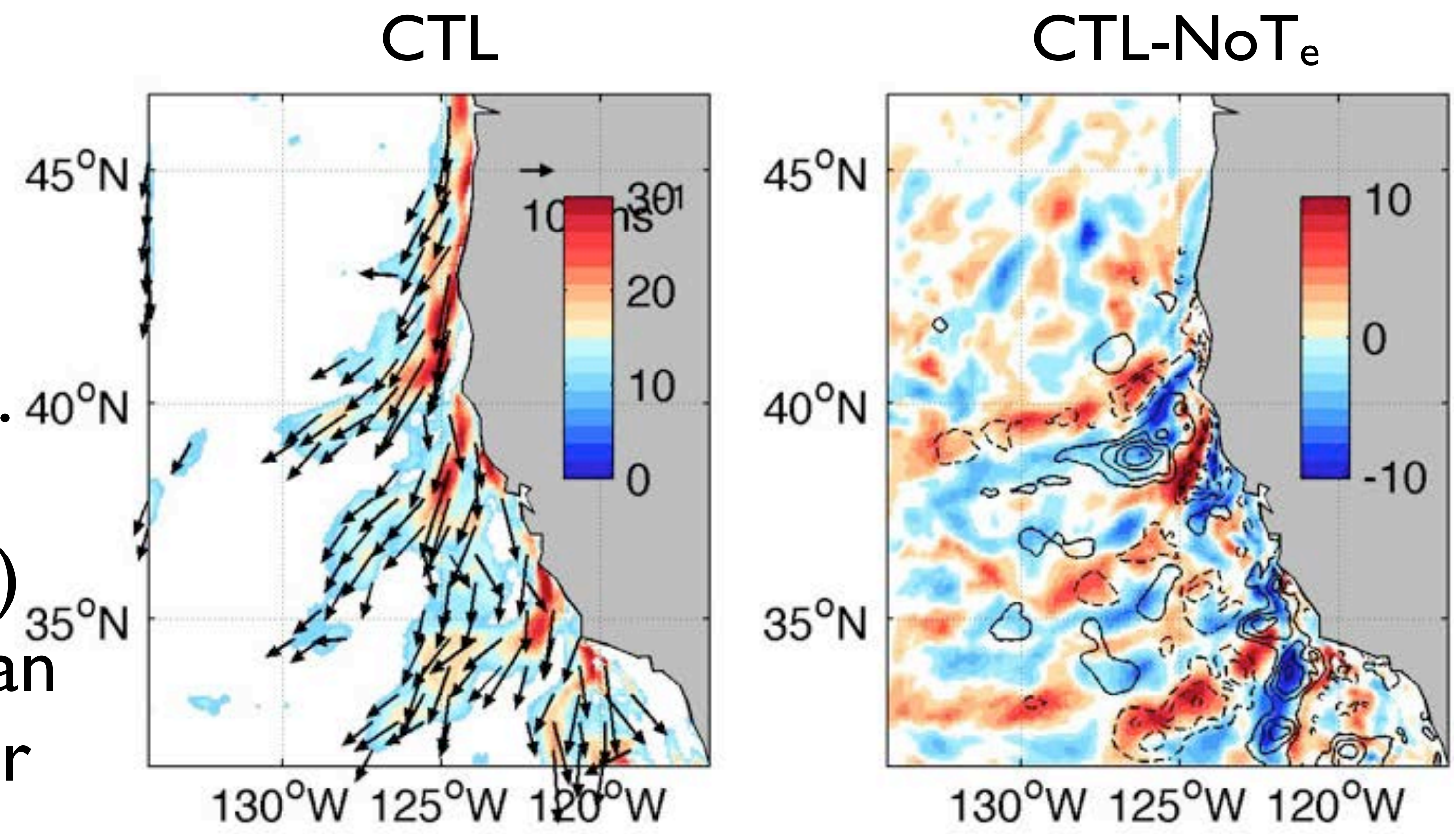


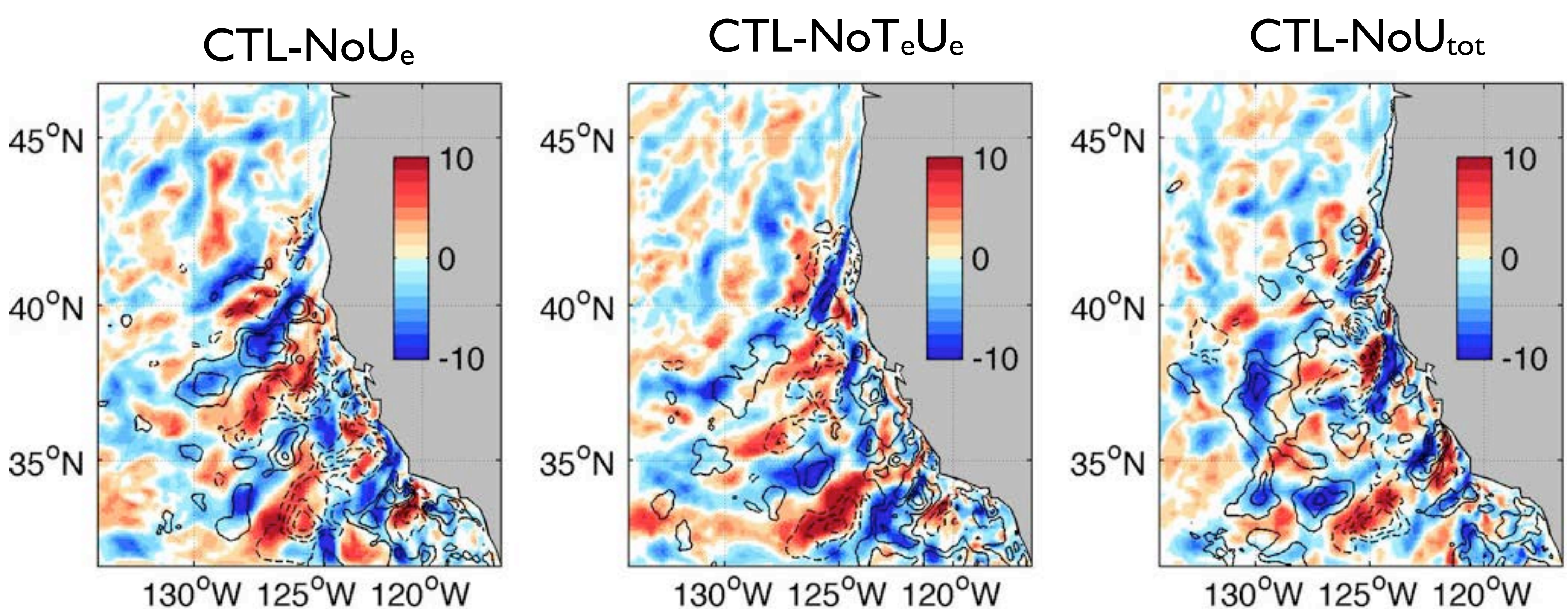
Change JAS Surface current

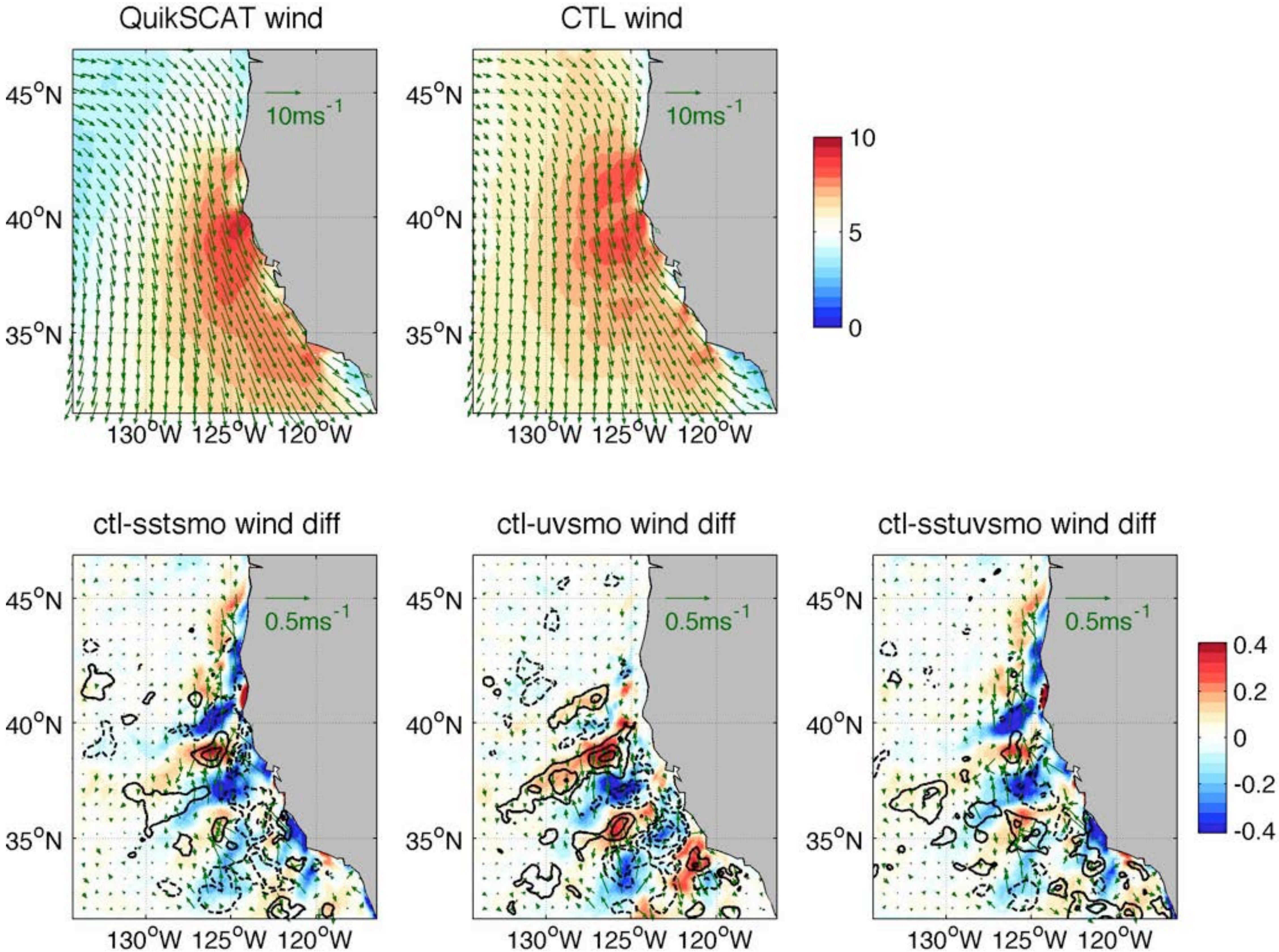
Overlaid with contours for SST difference

Surface currents show both alongshore and offshore component (Ekman current).

Change in offshore (onshore) temperature advection by mean current mainly responsible for the change in SST







wind speed (and also stress) is ENHANCED (REDUCED) over warm (cold) SST. It is a response to change in SST, damping the SST anomaly.