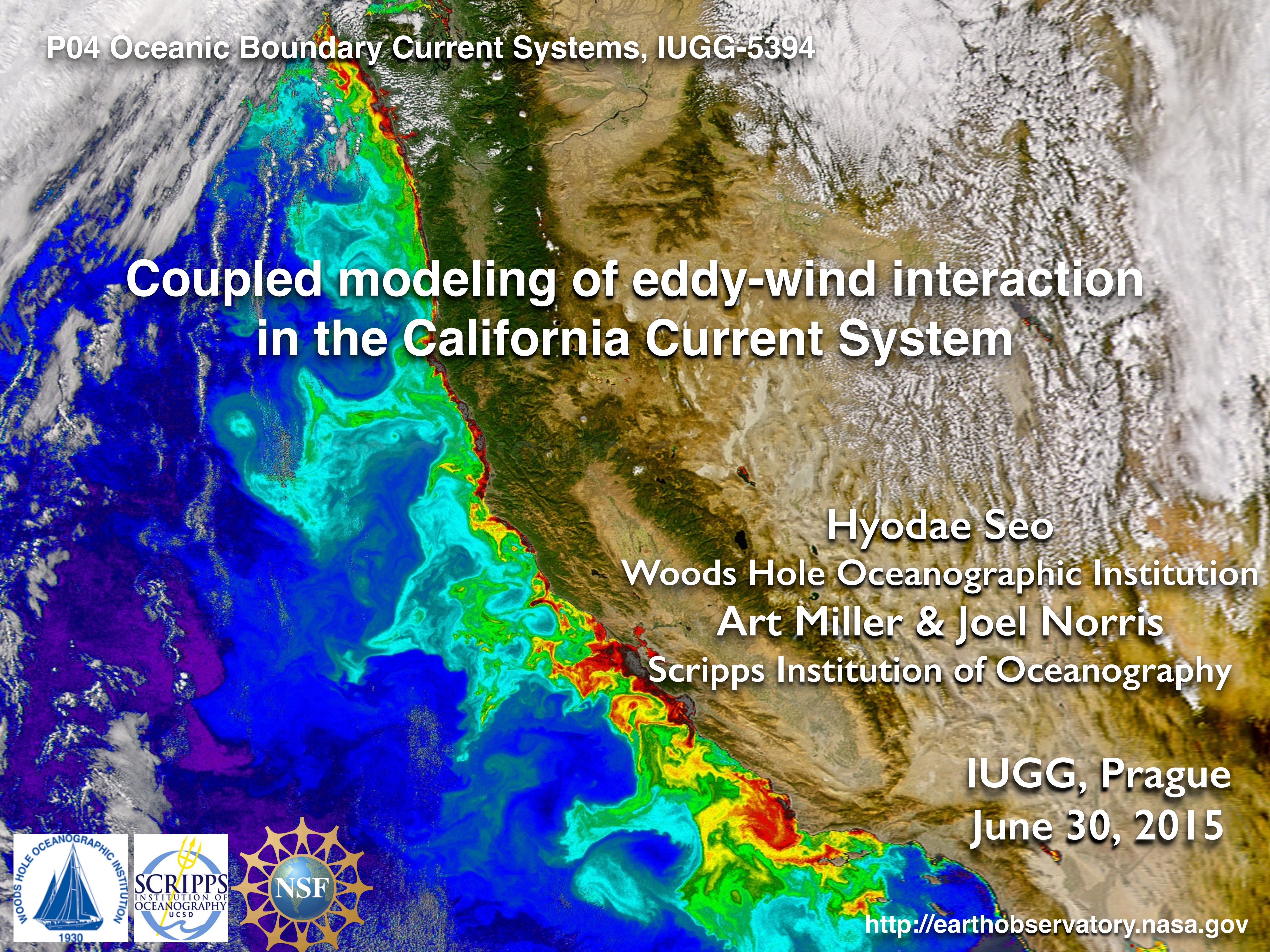
P04 Oceanic Boundary Current Systems, IUGG-5394

Coupled modeling of eddy-wind interaction in the California Current System

Hyodae Seo
Woods Hole Oceanographic Institution
Art Miller & Joel Norris
Scripps Institution of Oceanography

IUGG, Prague
June 30, 2015



http://earthobservatory.nasa.gov

Eddy-driven air-sea interactions thru wind stress

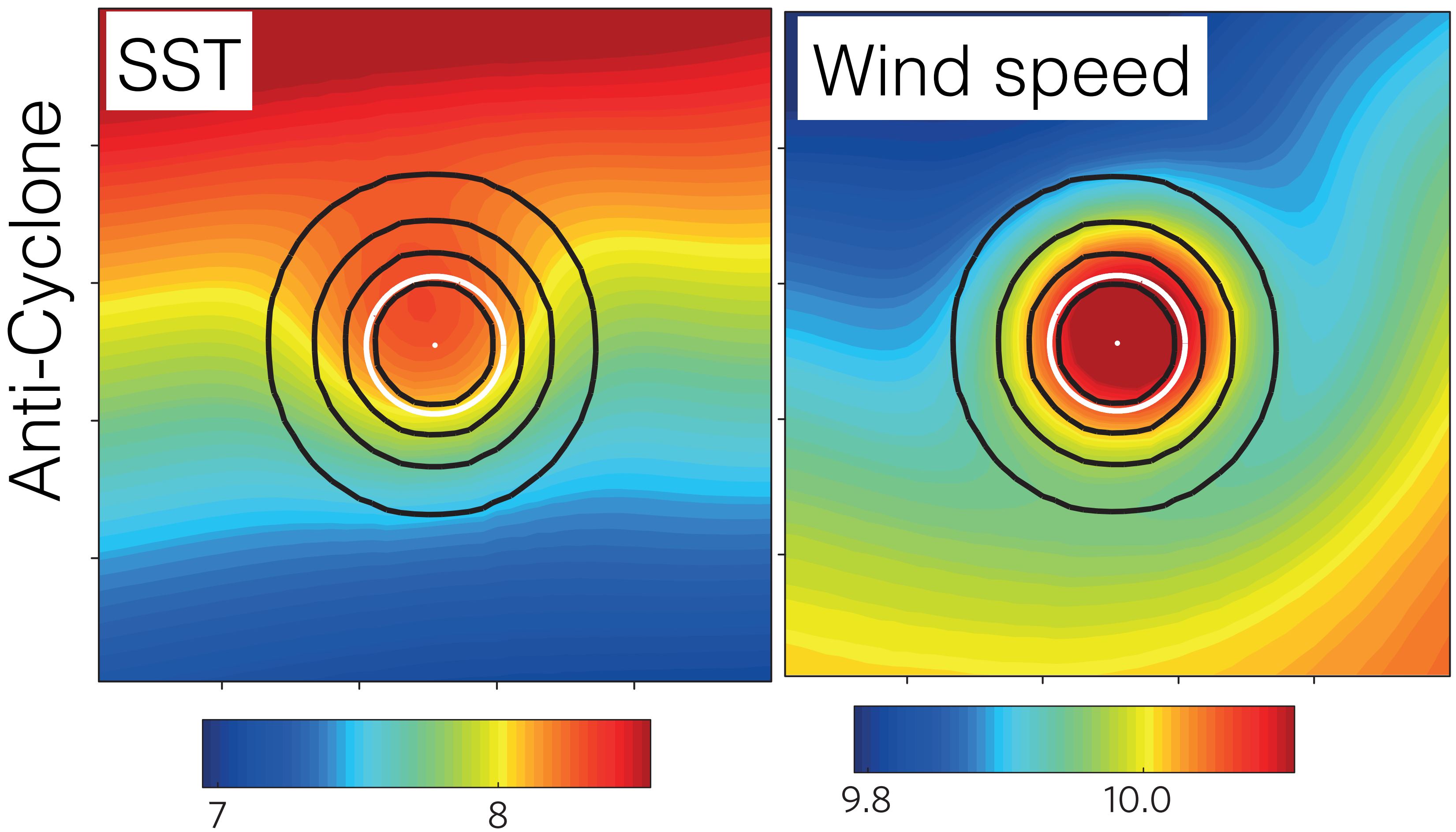
$$\tau = \rho C_D (U_a - U_o) |U_a - U_o|$$

surface current

10m wind

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

Composites in the Southern Oceans



Frenger et al. 2013

Eddy-driven air-sea interactions thru wind stress

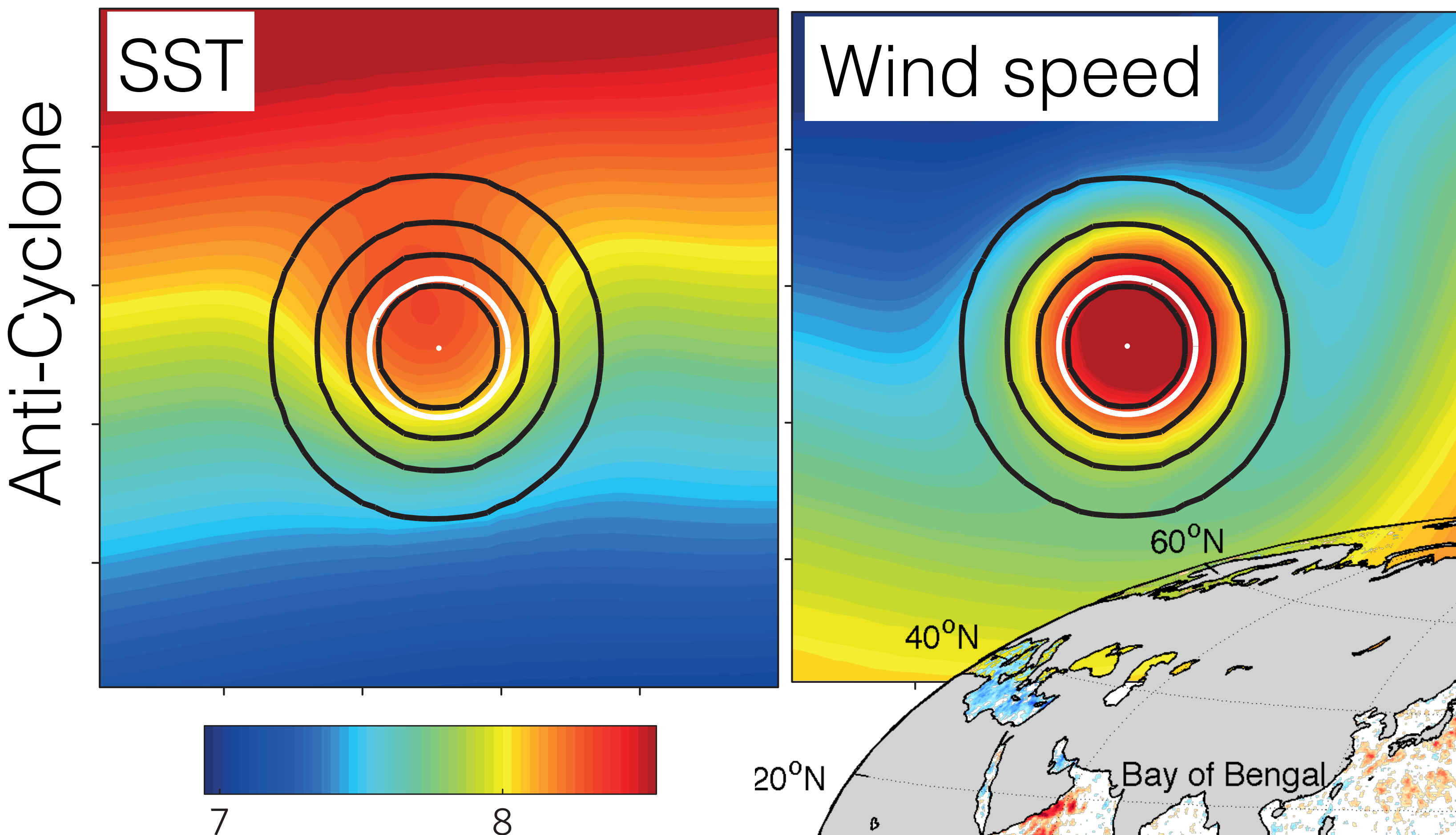
$$\tau = \rho\, C_D\, (U_a - U_o)\, |U_a - U_o|$$

surface current

10m wind

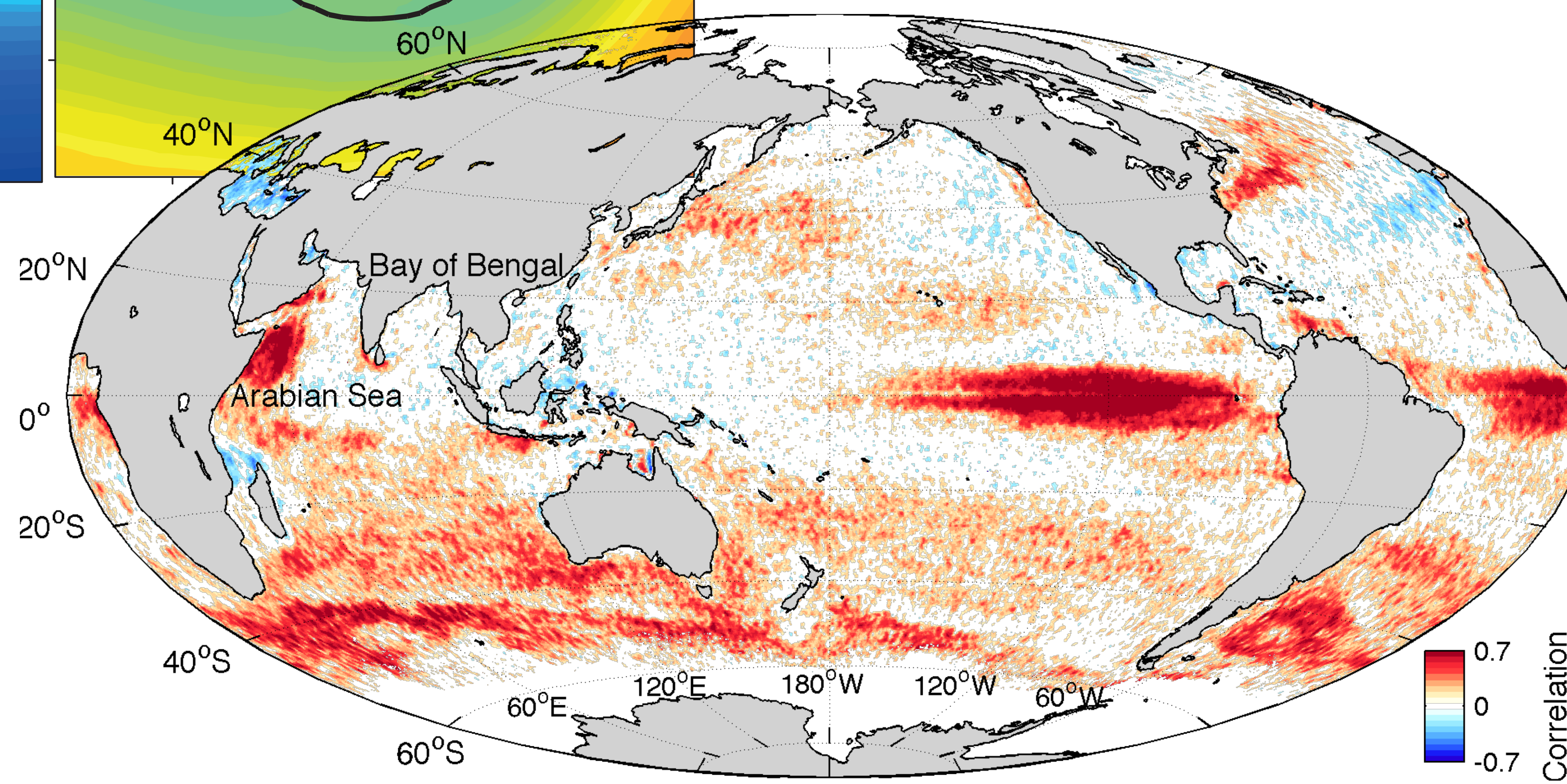
$$U_a = U_{ab} + \underline{U_{aSST}}$$

Composites in the Southern Oceans



Frenger et al. 2013

Positive correlation between JJA high-passed SST & wind



Eddy-driven Ekman pumping (W_{ek})

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

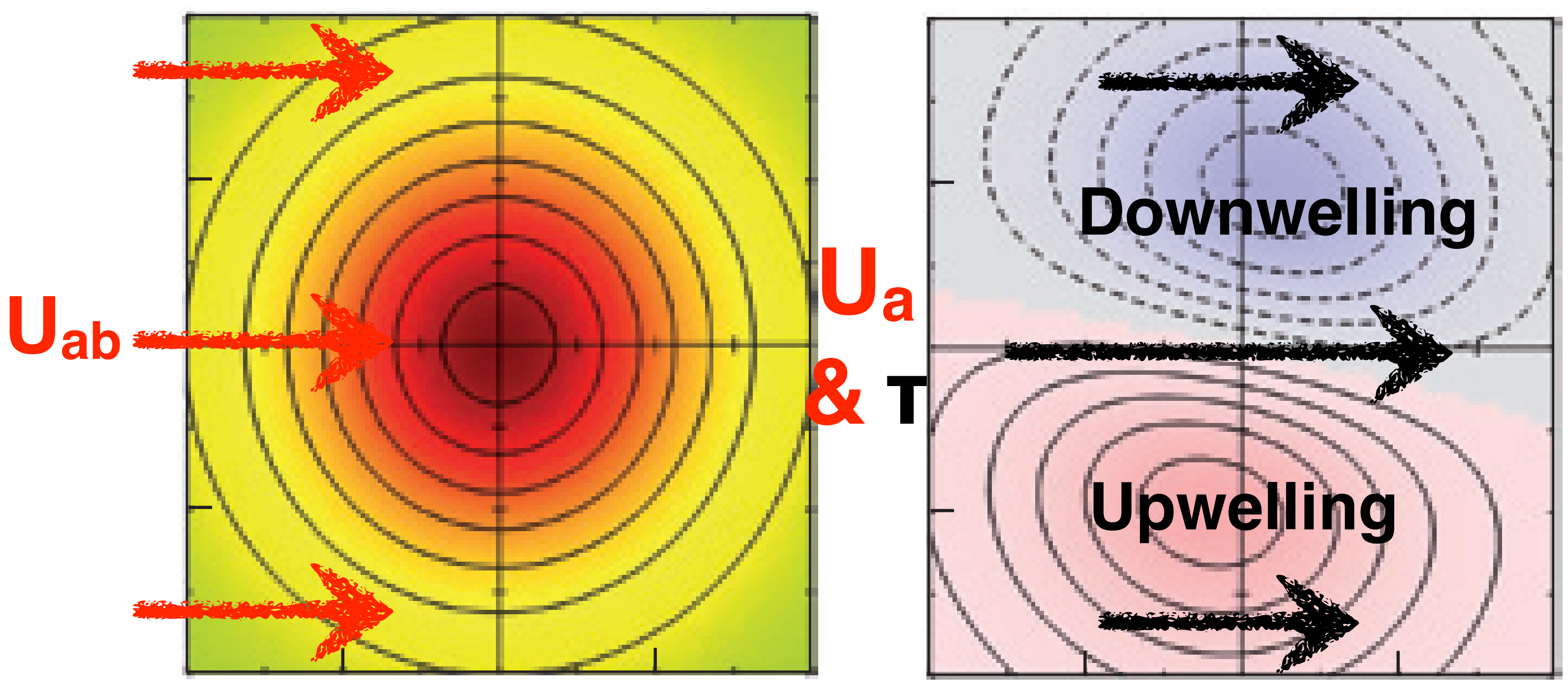
10m wind

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

An anticyclonic eddy in the Southern Ocean (Chelton 2013)

SST and SSH

Dipole W_{ek}



Affect the propagation

Eddy-driven Ekman pumping (W_{ek})

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

surface current

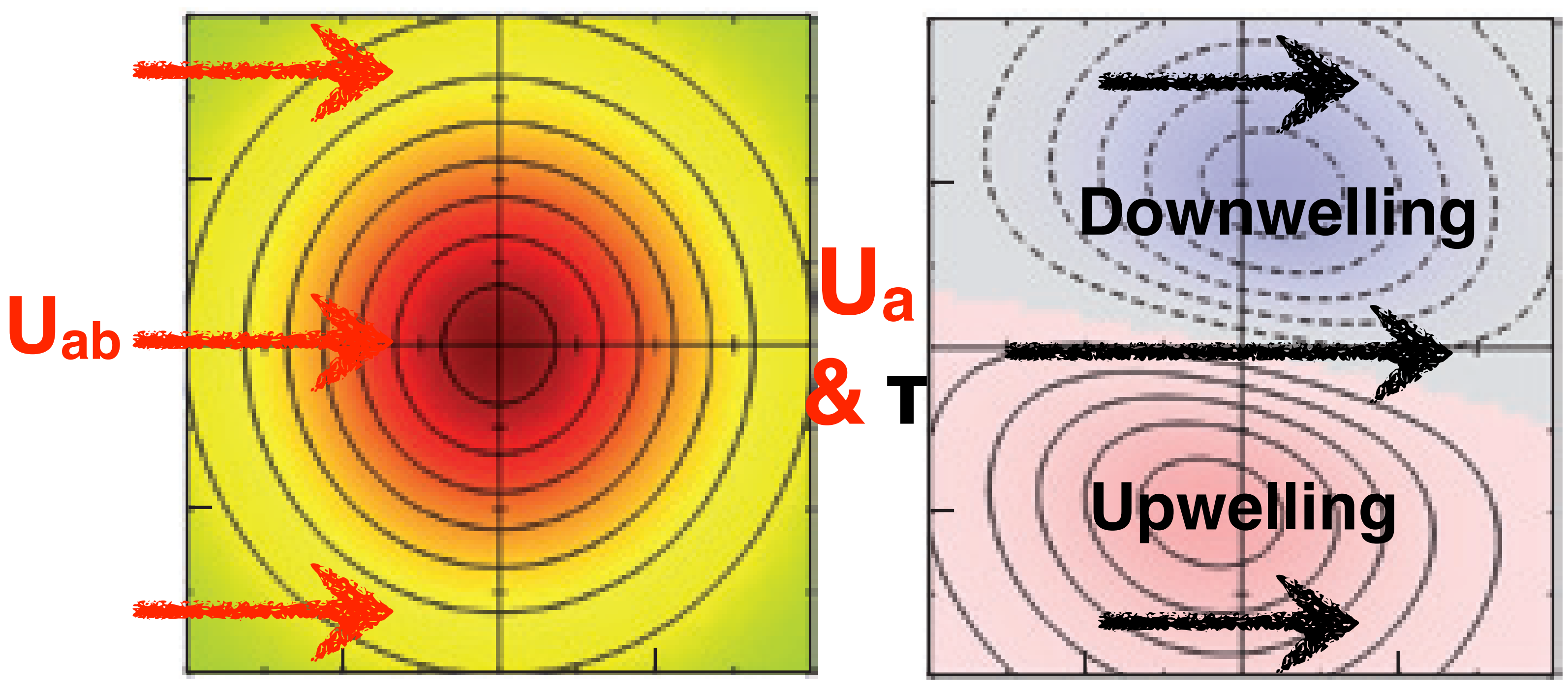
$U_o = U_{ob} + U_{oe}$

10m wind

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

An anticyclonic eddy in the Southern Ocean (Chelton 2013)

SST and SSH　　Dipole W_{ek}



Affect the propagation

Eddy-driven Ekman pumping (W_{ek})

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

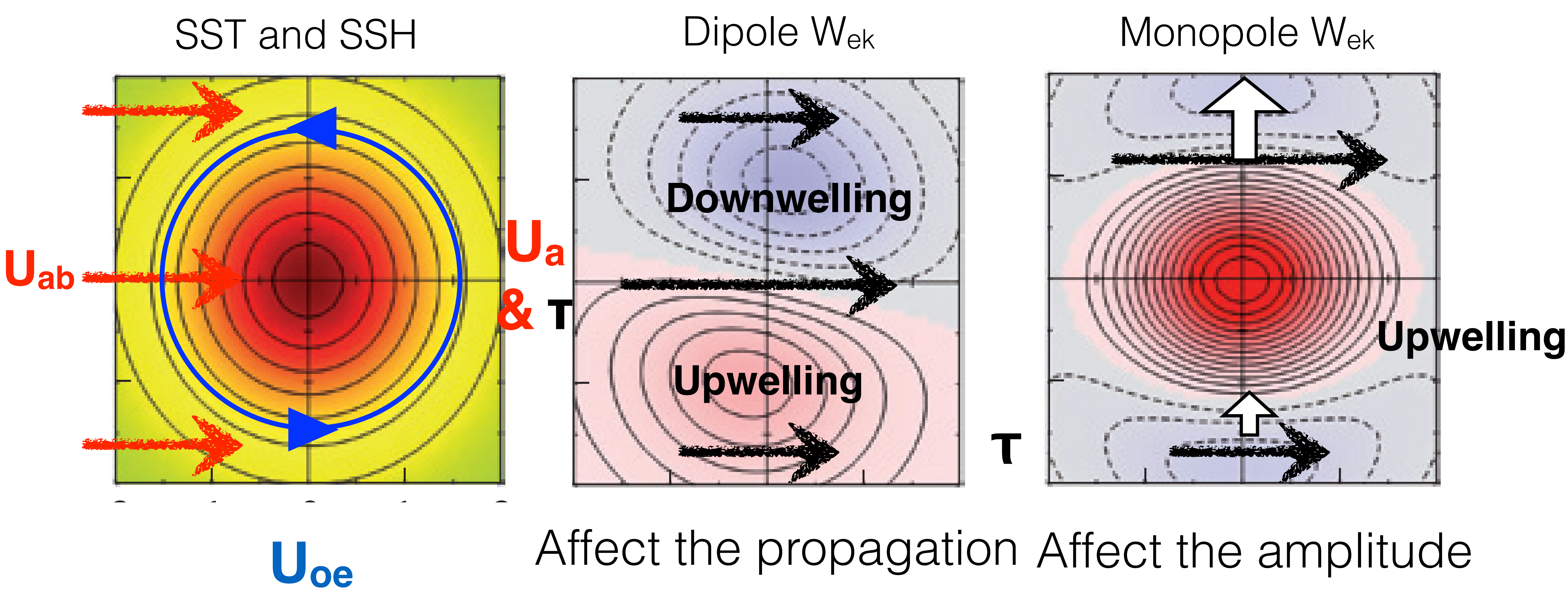
surface current

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

10m wind

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

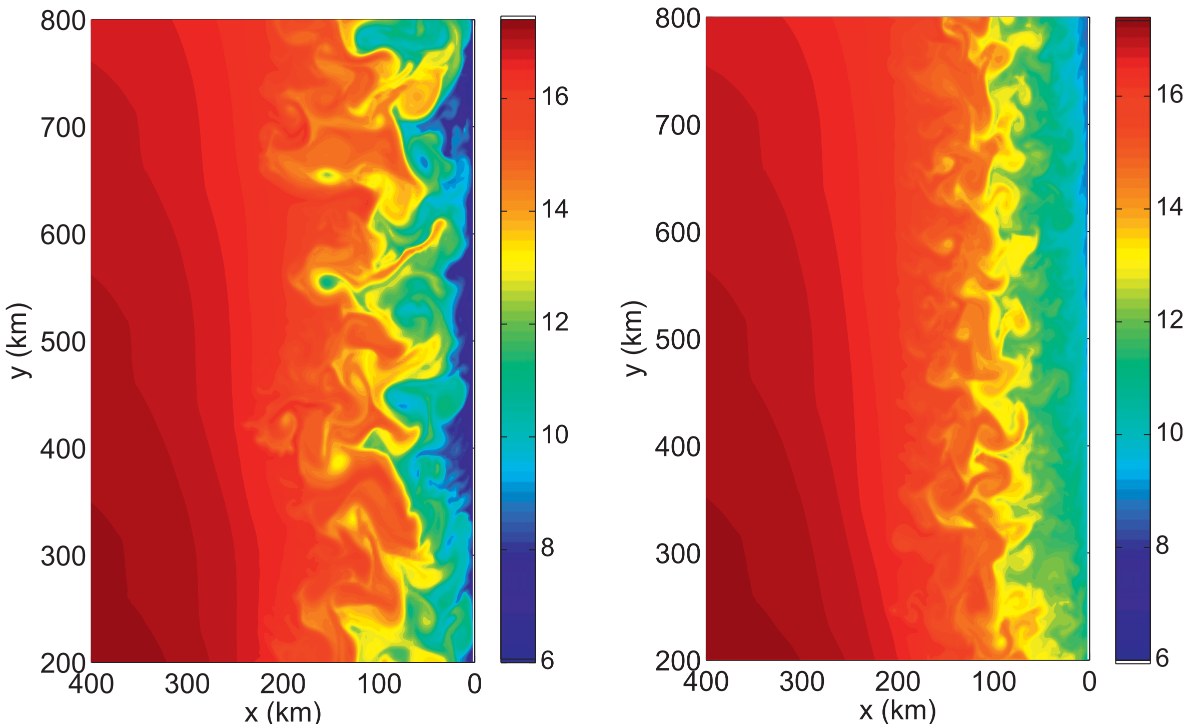
An anticyclonic eddy in the Southern Ocean (Chelton 2013)



Previous studies on impacts of eddy-wind coupling

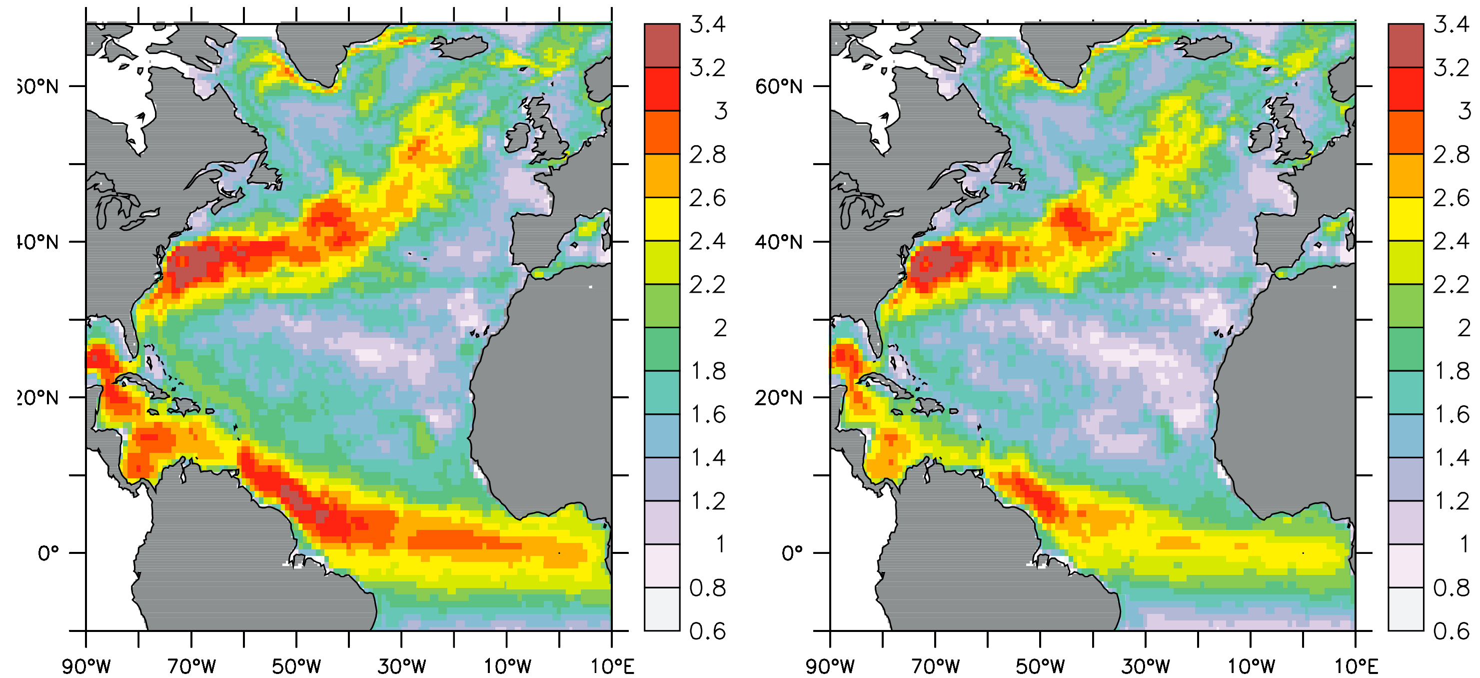
- Either coupling effect weakens the eddy activity.

uncoupled SST   SST-τ coupled SST



Jin et al. (2009)

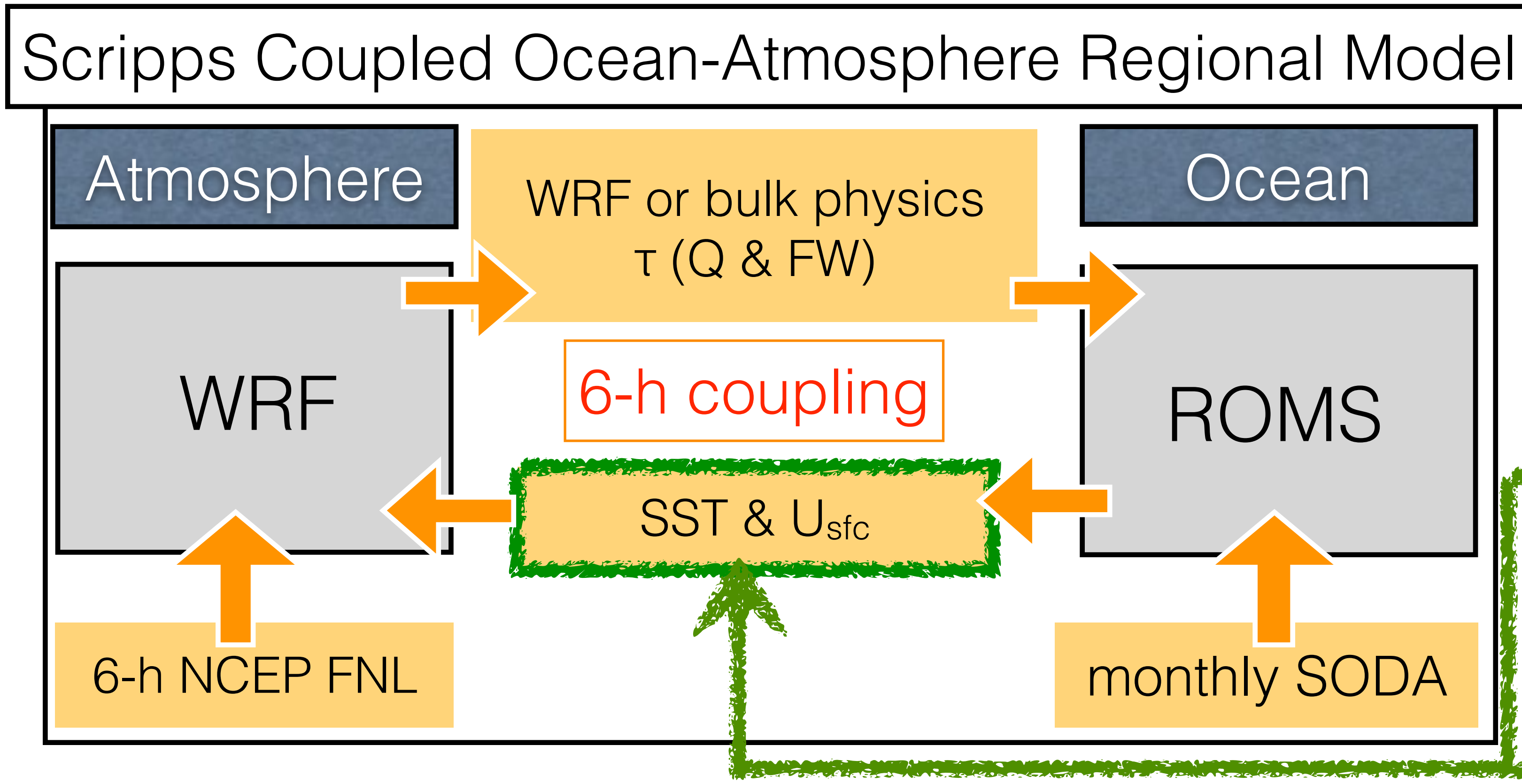
uncoupled EKE U_O-τ coupled EKE



Eden and Dietze (2009)

- This study examines the *relative* importance SST and current-driven coupling on EKE *in a fully coupled regional model*.

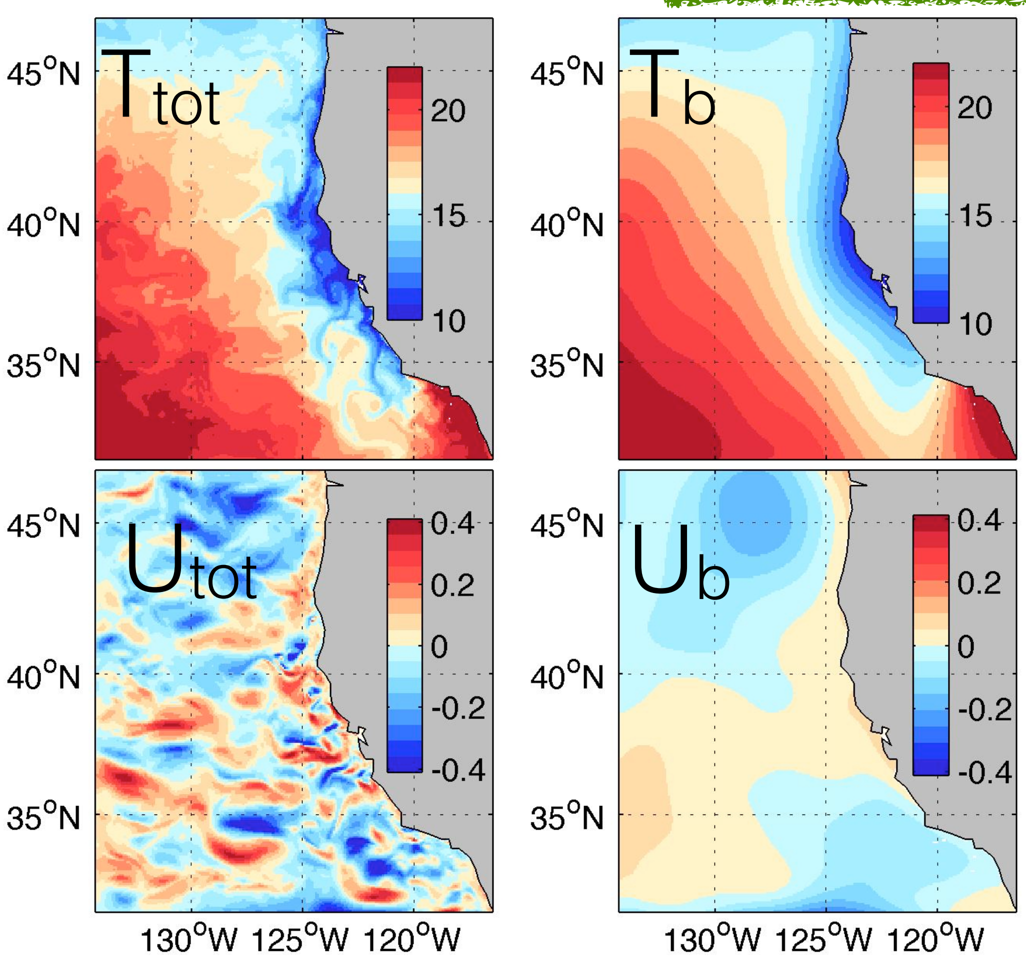
Quantifying the effect of eddy-driven air-sea coupling



- Seo et al. 2007, 2014
- 7 km O-A resolutions

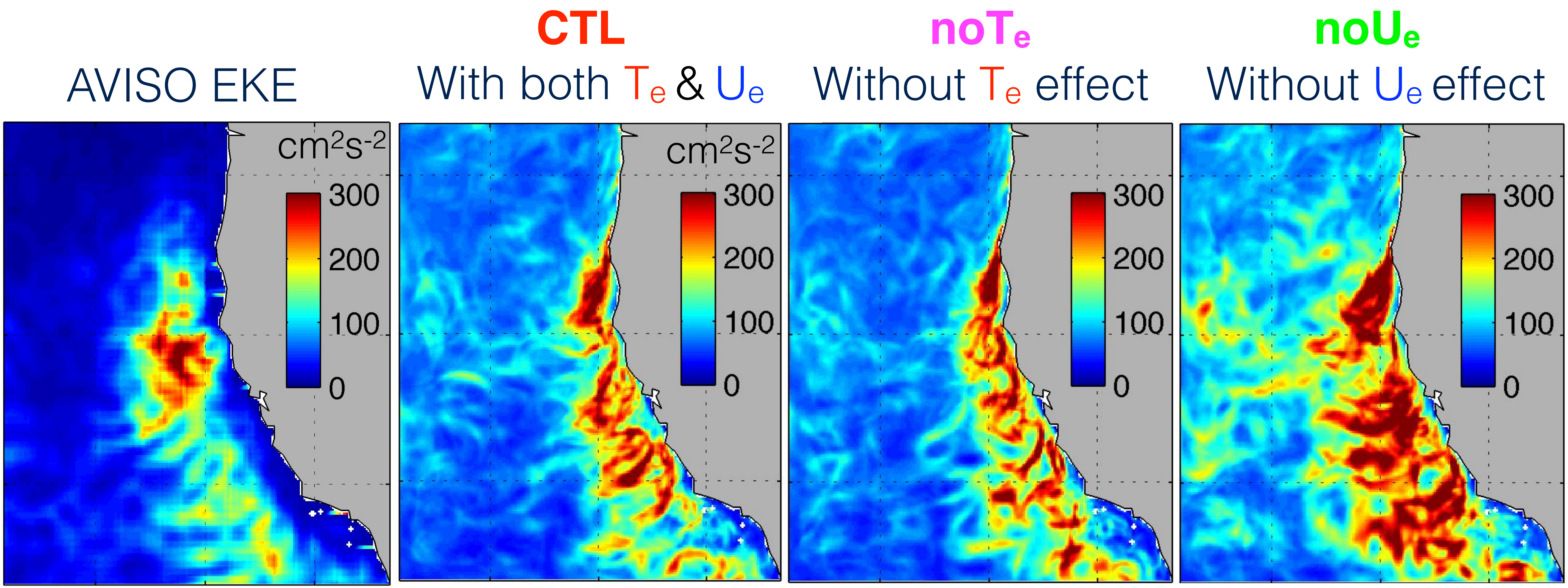
Smoothing (3°×3°) of small-scale SST and U_o (Putrasahan et al. 2013):

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



Exp	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

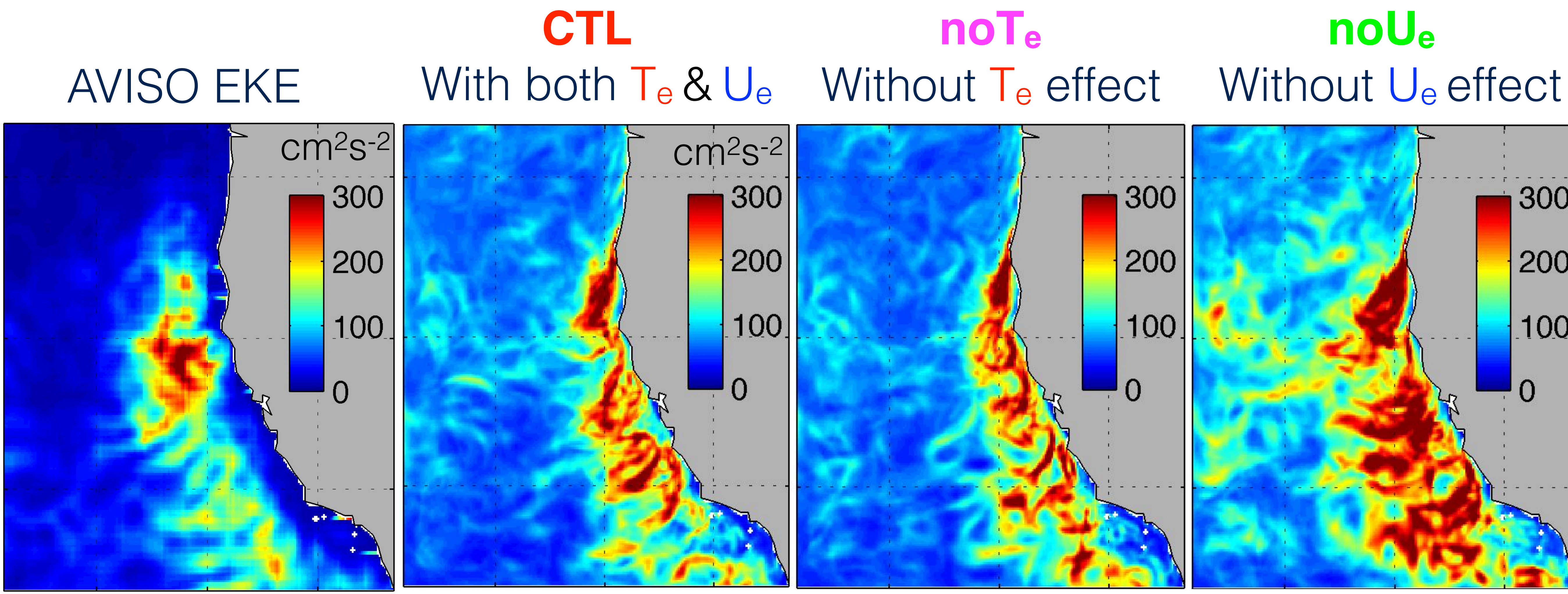
Summertime EKE in the CCS



42% reduction of EKE by U_o but U_a has no strong effect

JAS 2005-2010

Summertime EKE in the CCS



42% reduction of EKE by U_o but U_a has no strong effect

EKE budget

$P_e \rightarrow K_e$ baroclinic conversion (BC)

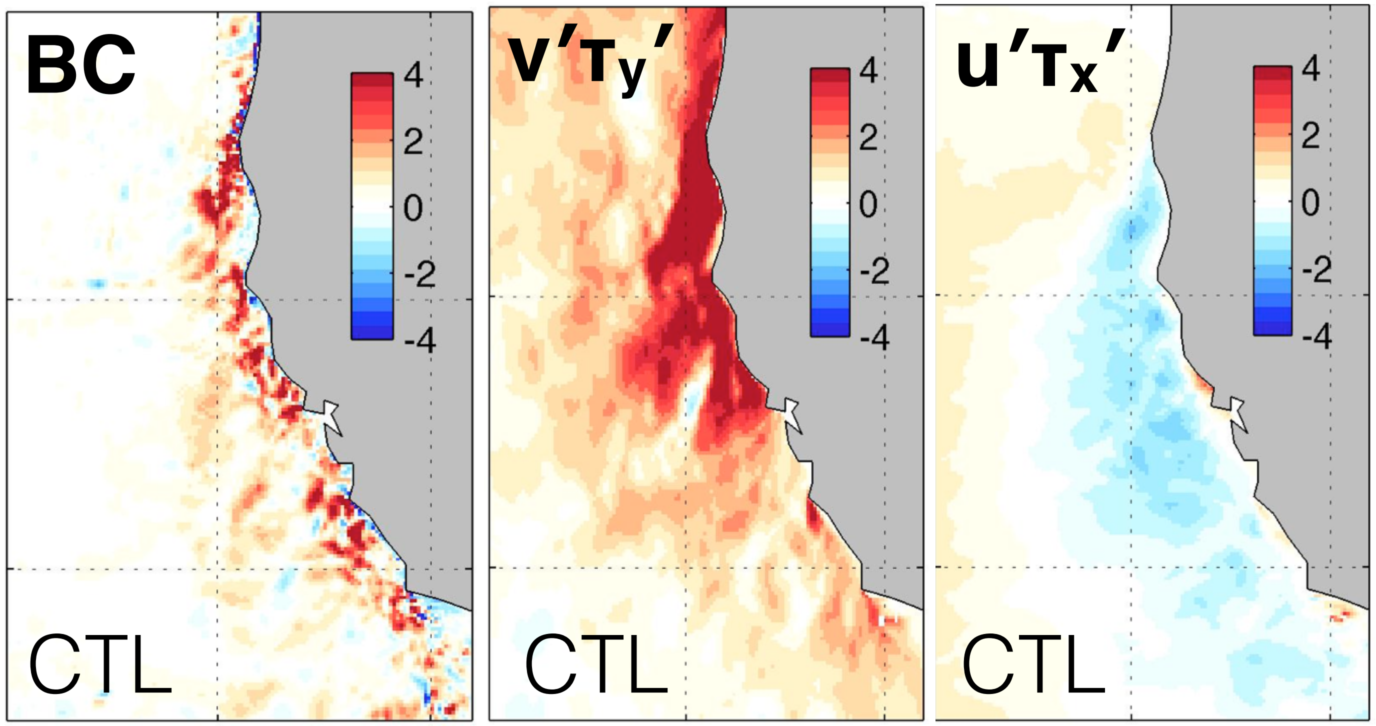
$$Ke_t + \vec{U}\cdot\vec{\nabla}Ke + \vec{u}'\cdot\vec{\nabla}Ke + \vec{\nabla}\cdot(\vec{u}'p') = +\rho_o(-\vec{u}'\cdot(\vec{u}'\cdot\vec{\nabla}\vec{U})) - g\rho'w' + \vec{u}'\cdot\vec{\tau}' + \varepsilon$$

$K_m \rightarrow K_e$ barotropic conversion (BT)

Wind work (P) if +ve; Eddy drag (ε) if -ve

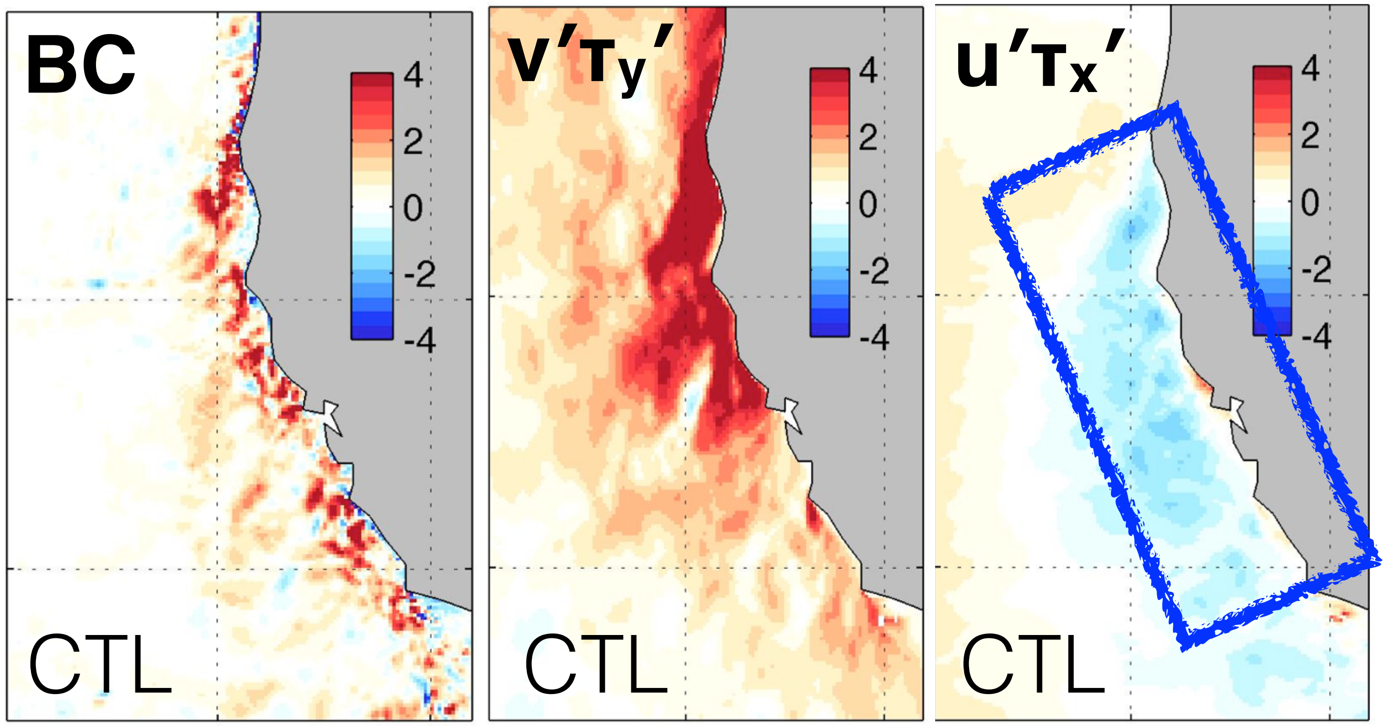
JAS 2005-2010

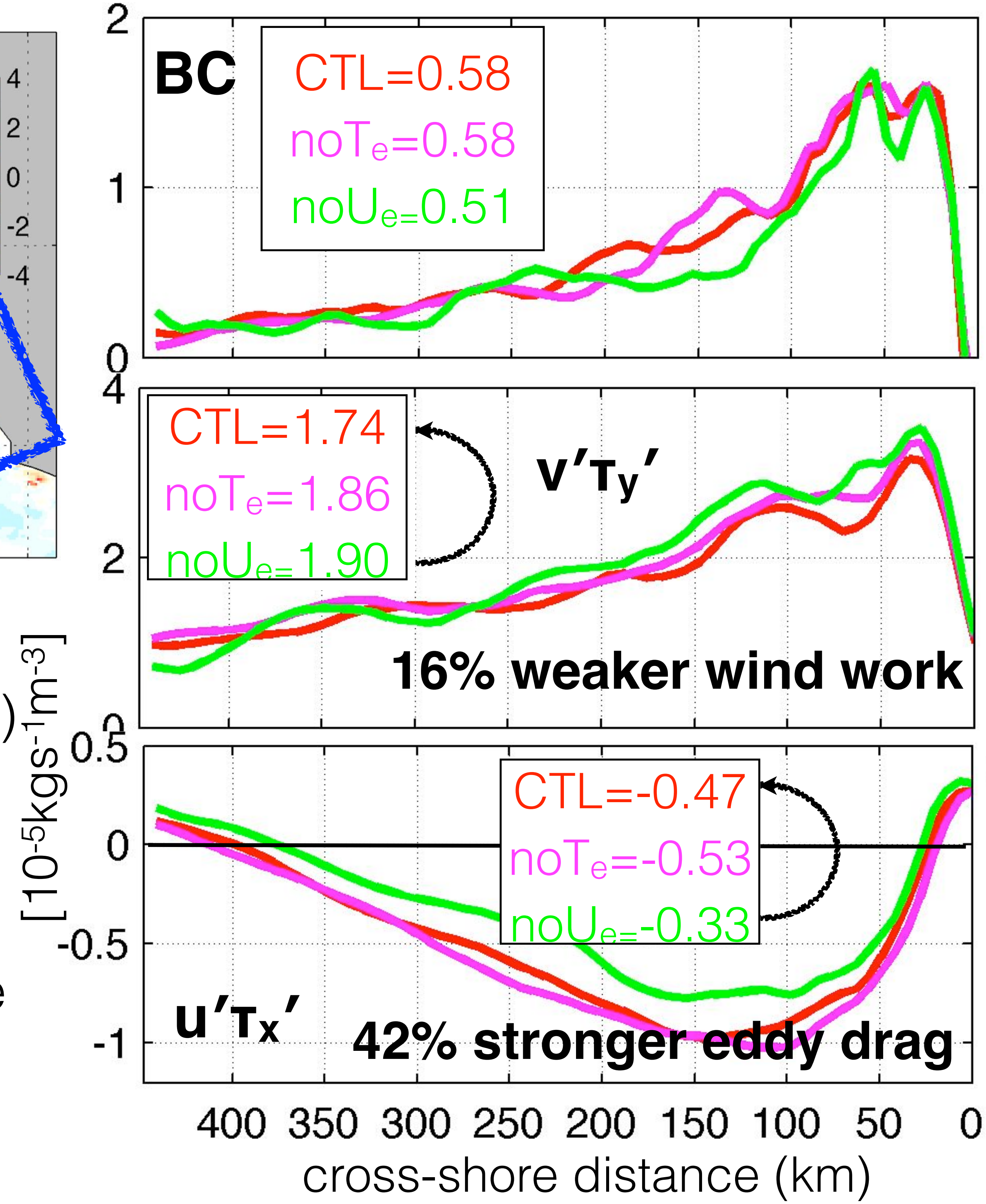
Reduced EKE in CTL is primarily through enhanced eddy drag



- $v'T_y$ dominant energy input (wind work)
- BC converts P_e to K_e
- $u'T_x$ dissipates the EKE (eddy drag)

Reduced EKE in CTL is primarily through enhanced eddy drag





- v'T_y dominant energy input (wind work)
- BC converts P_e to K_e
- u'T_x dissipates the EKE (eddy drag)

- BC unlikely to explain the EKE change
- Eddy drag increases by 42% with U_e
- Wind work is reduced by 16% with U_e

Eddy-driven Ekman pumping velocity

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

Stern 1965
Gaube et al. 2015

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

background wind stress

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

Curl-induced linear Ekman pumping

Vorticity gradient-induced nonlinear Ekman pumping

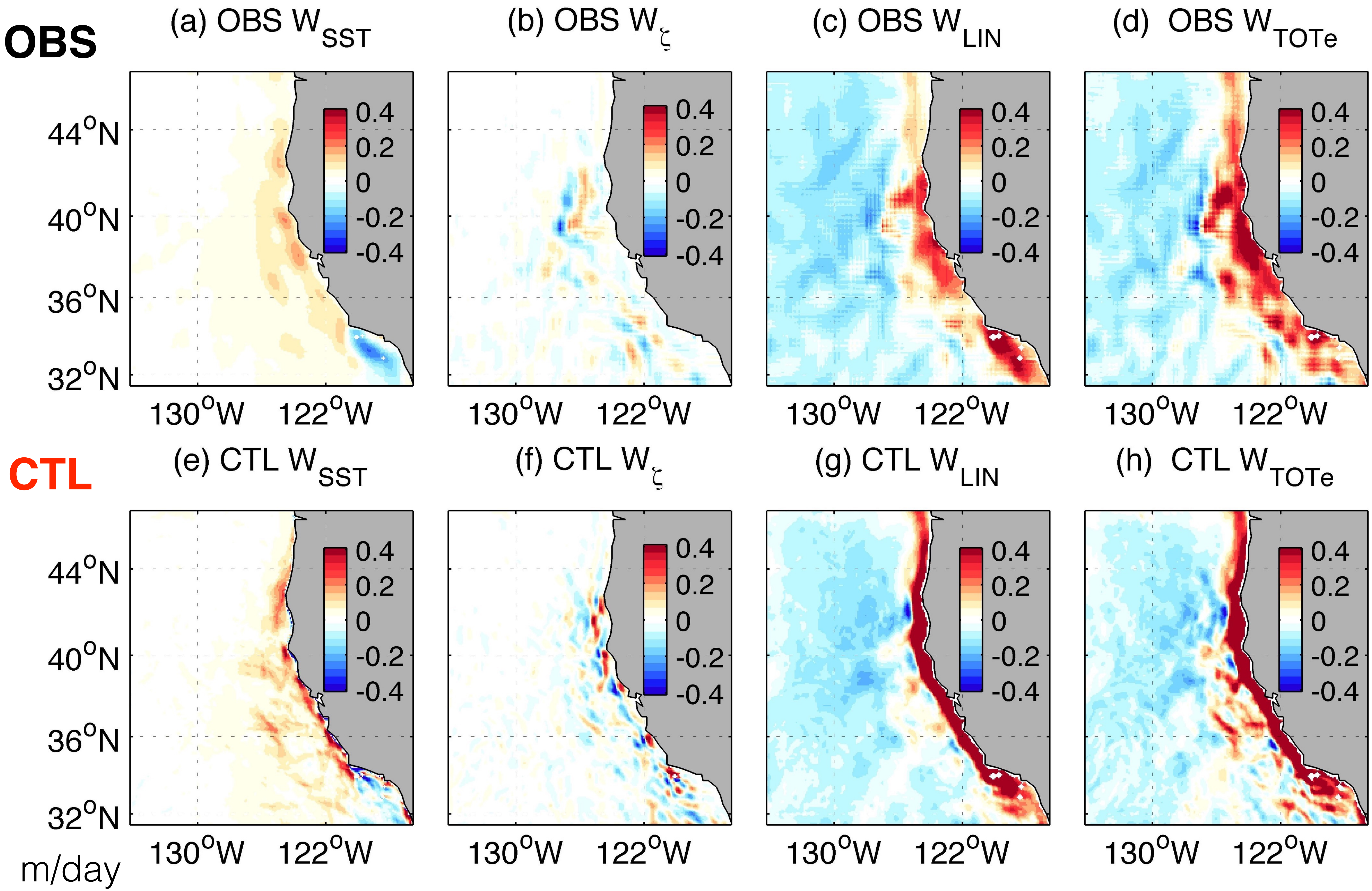
SST induced Ekman pumping

Chelton et al. 2007

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

$$W_{TOTe} = \underbrace{\frac{\nabla \times \tau_b}{\rho_0 (f+\zeta)}}_{W_{LIN}} + \underbrace{\frac{\nabla \times \tau_e}{\rho_0 (f+\zeta)}}_{W_{SST}} - \underbrace{\frac{\tau_b \times \nabla \zeta}{\rho_0 (f+\zeta)^2}}_{W_{\zeta}}$$

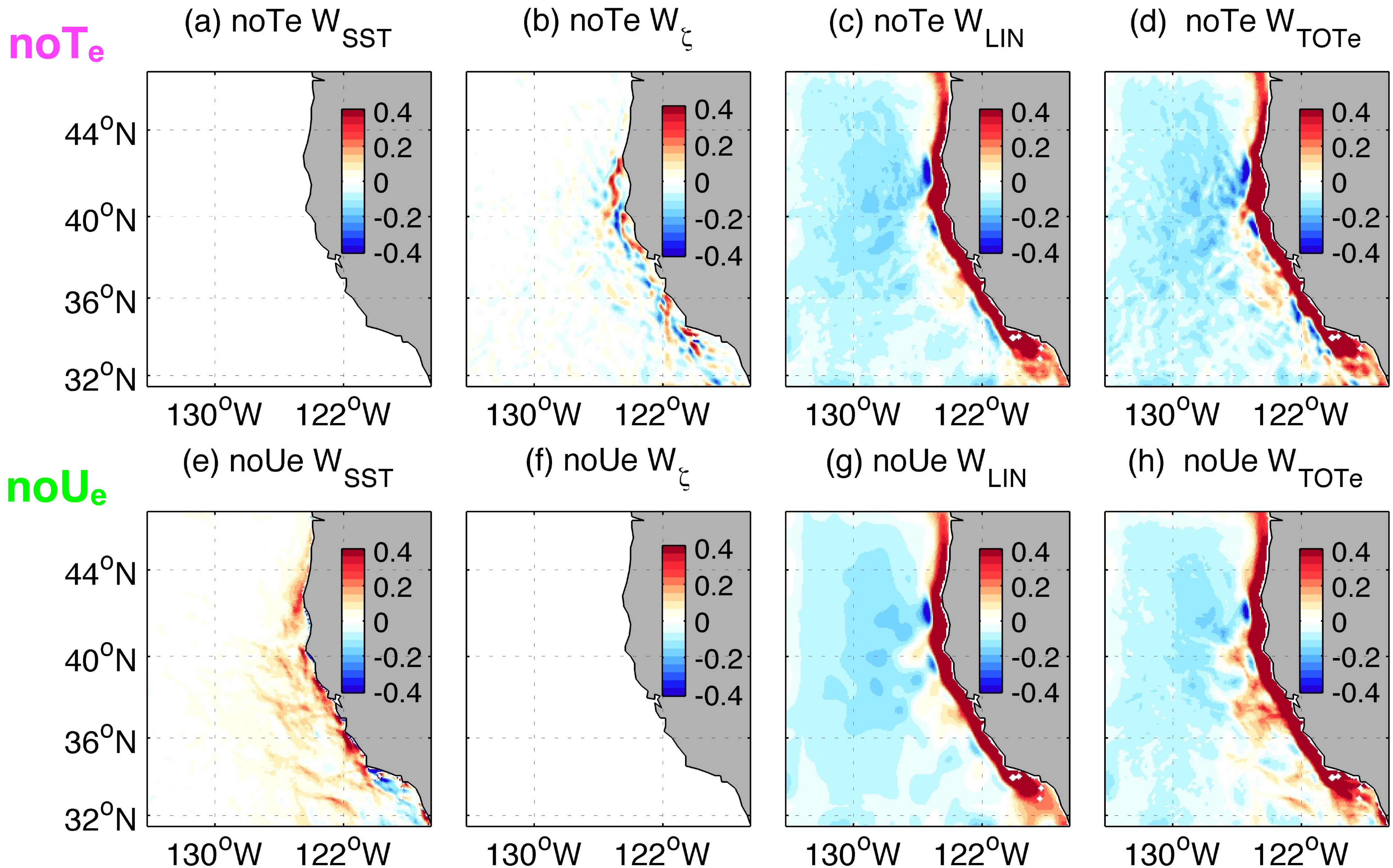
Estimated Ekman pumping velocity



JAS 2005-2009: OBS based on AVISO SSH & QuikSCAT wind stress

$$W_{TOTe} = \underbrace{\frac{\nabla\times\tau_b}{\rho_0(f+\zeta)}}_{W_{LIN}} + \underbrace{\frac{\nabla\times\tau_e}{\rho_0(f+\zeta)}}_{W_{SST}} - \underbrace{\frac{\tau_b\times\nabla\zeta}{\rho_0(f+\zeta)^2}}_{W_\zeta}$$

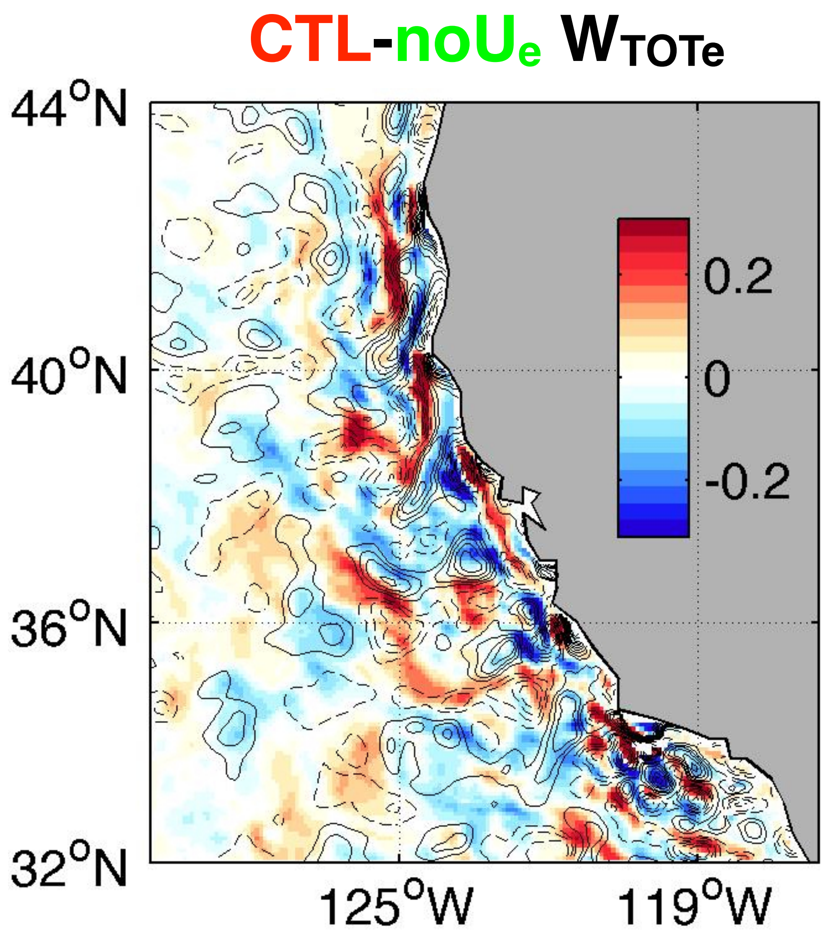
Estimated Ekman pumping velocity

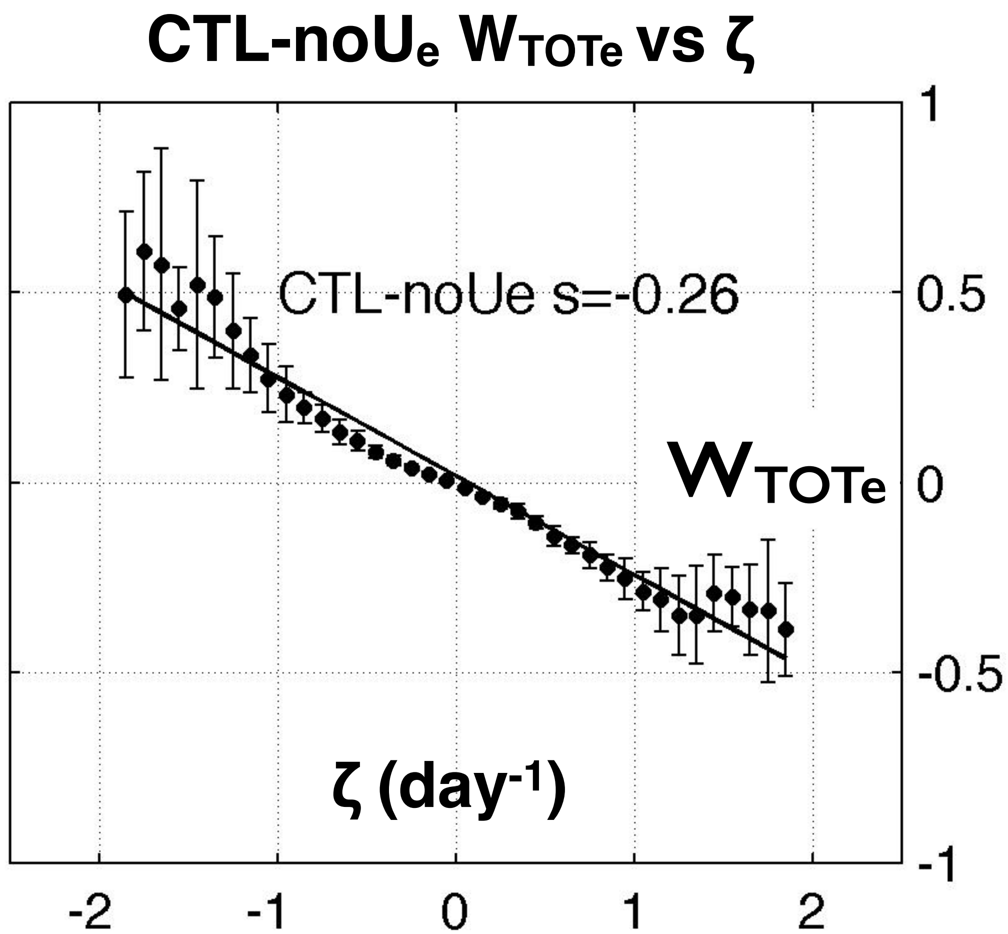


m/day

JAS 2005-2009

Implied feedback to eddy activity

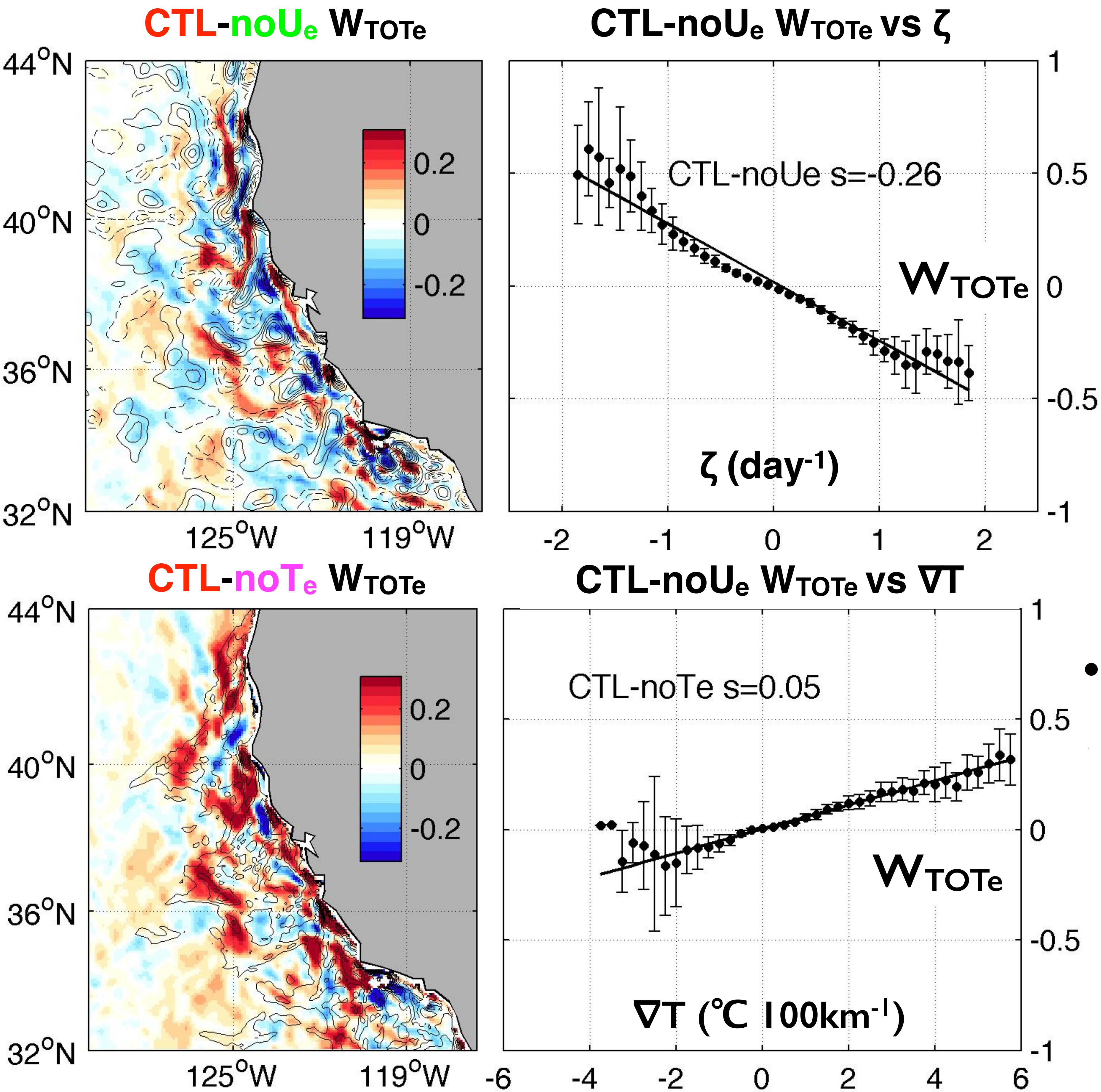




- Downwelling (upwelling) in the cyclonic (anticyclonic) regime
  → **Weakens the amplitude**

JAS 2005-2009

Implied feedback to eddy activity



- Downwelling (upwelling) in the cyclonic (anticyclonic) regime

  → **Weakens the amplitude**

- Ekman upwelling and downwelling over the maximum SST gradients

  → **Influences the propagation**

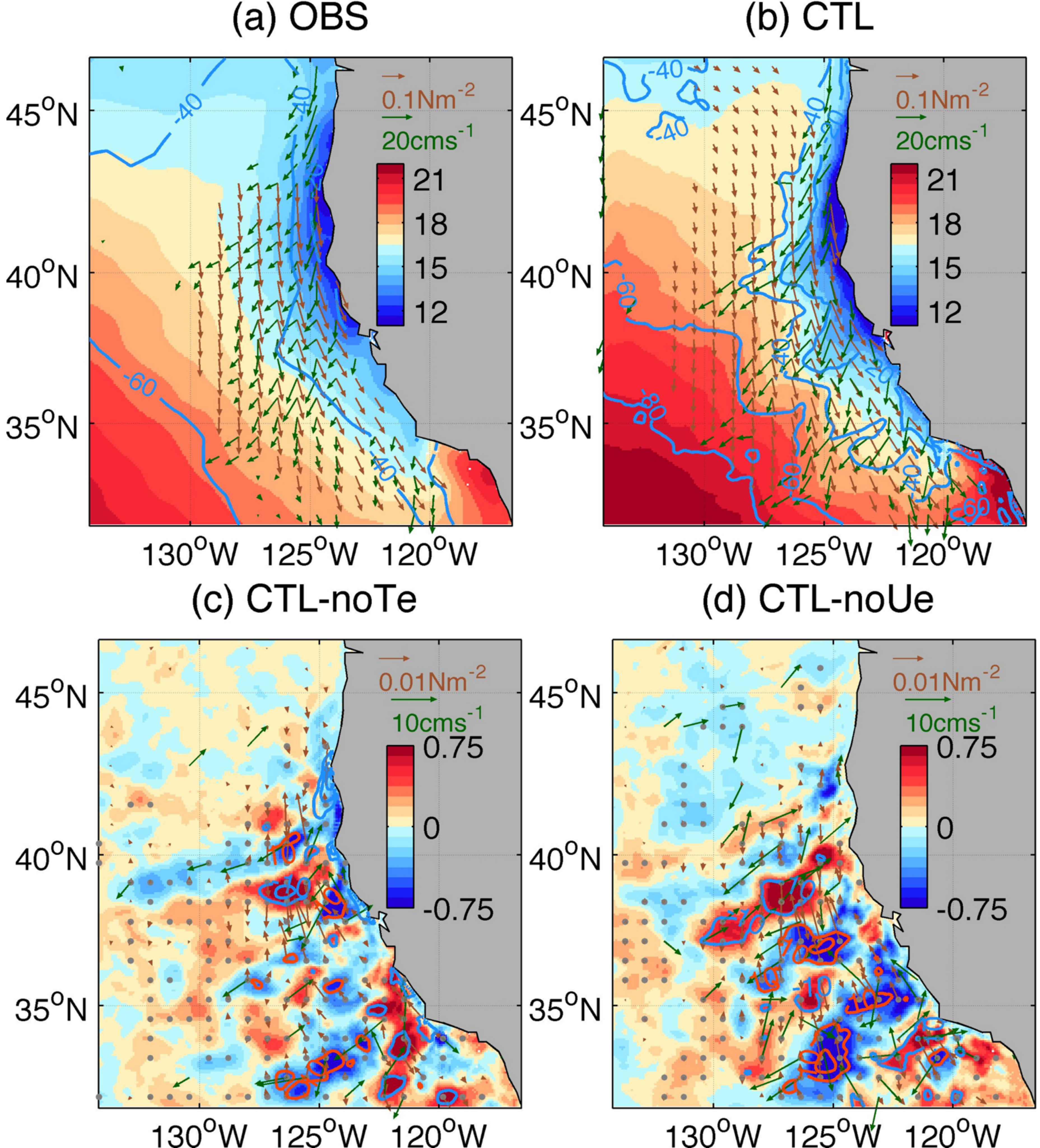
JAS 2005-2009

Summary

- **Weakened EKE is almost entirely due to eddy current effect on wind stress.**
  - SST has no impact.
  - EKE budget: eddies primarily **enhance the surface drag**, and also weaken the wind work (of secondary importance).
- Eddies modify W_{ek} via their current and SST.
  - **Current-induced W_{ek} suppresses the eddy activity;**
  - **SST-induced W_{ek} influences the eddy propagation**;
    - No impact on the area-averaged EKE statistics
- **Robust results** with varied smoothing scales.
- In other boundary current system (Kuroshio, GS, etc).
- Coupled effects on the atmosphere (i.e, SST gradient and storm track)

Thanks!

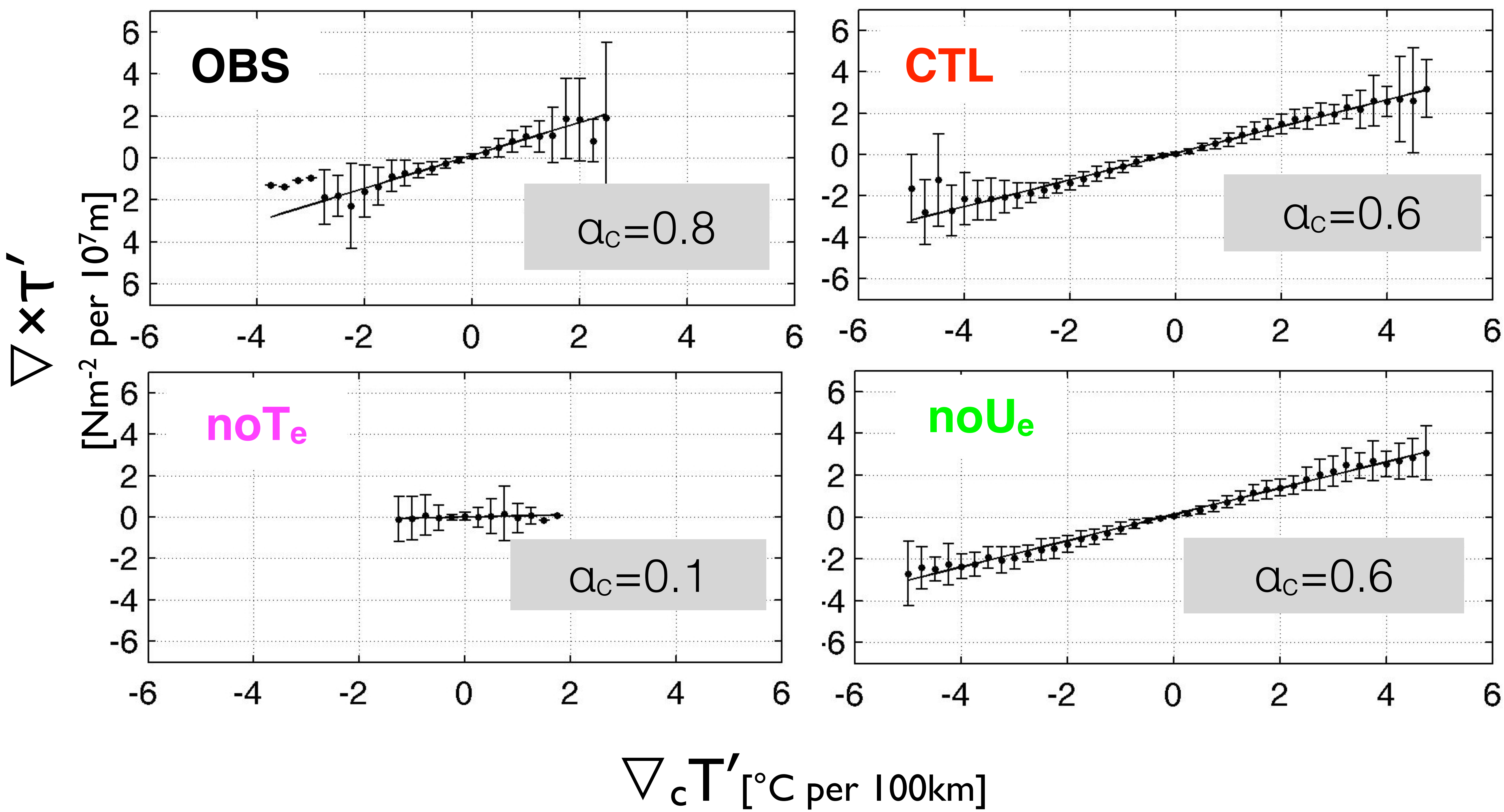
hseo@whoi.edu


(a) OBS
(b) CTL
(c) CTL-noTe
(d) CTL-noUe
0.1Nm-2
20cms-1
0.01Nm-2
10cms-1
21
18
15
12
0.75
0
-0.75
45°N
40°N
35°N
130°W
125°W
120°W

Estimating eddy SST-driven Ekman pumping velocity

Chelton et al. 2007

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



JAS 2005-2009: OBS based on QuikSCAT wind stress and TRMM SST