Dynamics and impacts of

Eddy-driven air-sea interaction

in the California Current System

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WHOI PO Seminar
April 26, 2016

http://earthobservatory.nasa.gov


O-A interaction on coastal upwelling
Broad-scale vs eddy-scale
SST vs surface current
O(10km)
O(10³km)
SeaWiFS surface
chlorophyll concentration
http://earthobservatory.nasa.gov

Eddy-driven air-sea interaction: wind and wind stress

$$\tau = \rho_a C_D (W - U)\,|W - U|$$

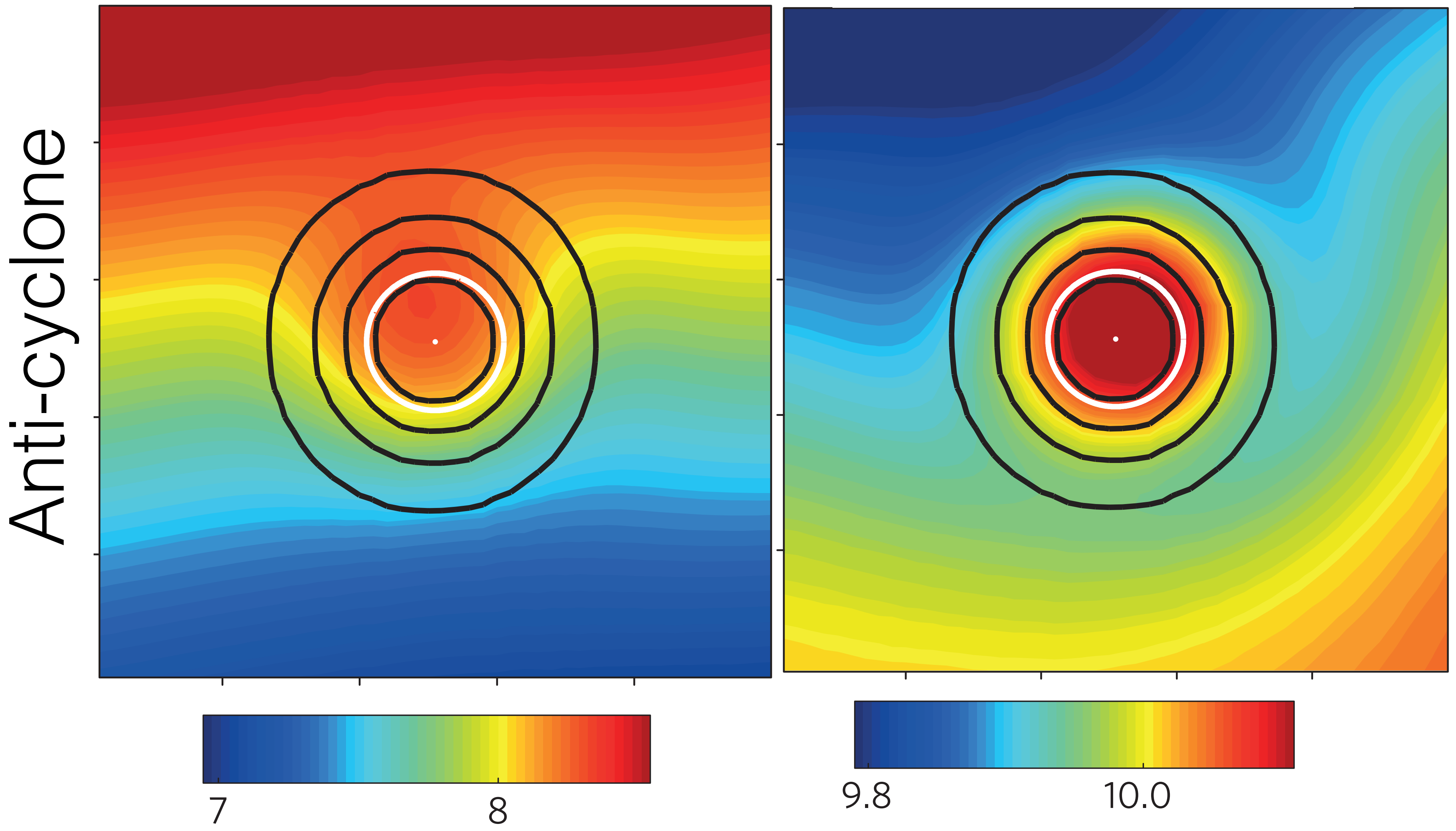
surface current

10m wind

$W = W_b + \underline{W_{SST}}$

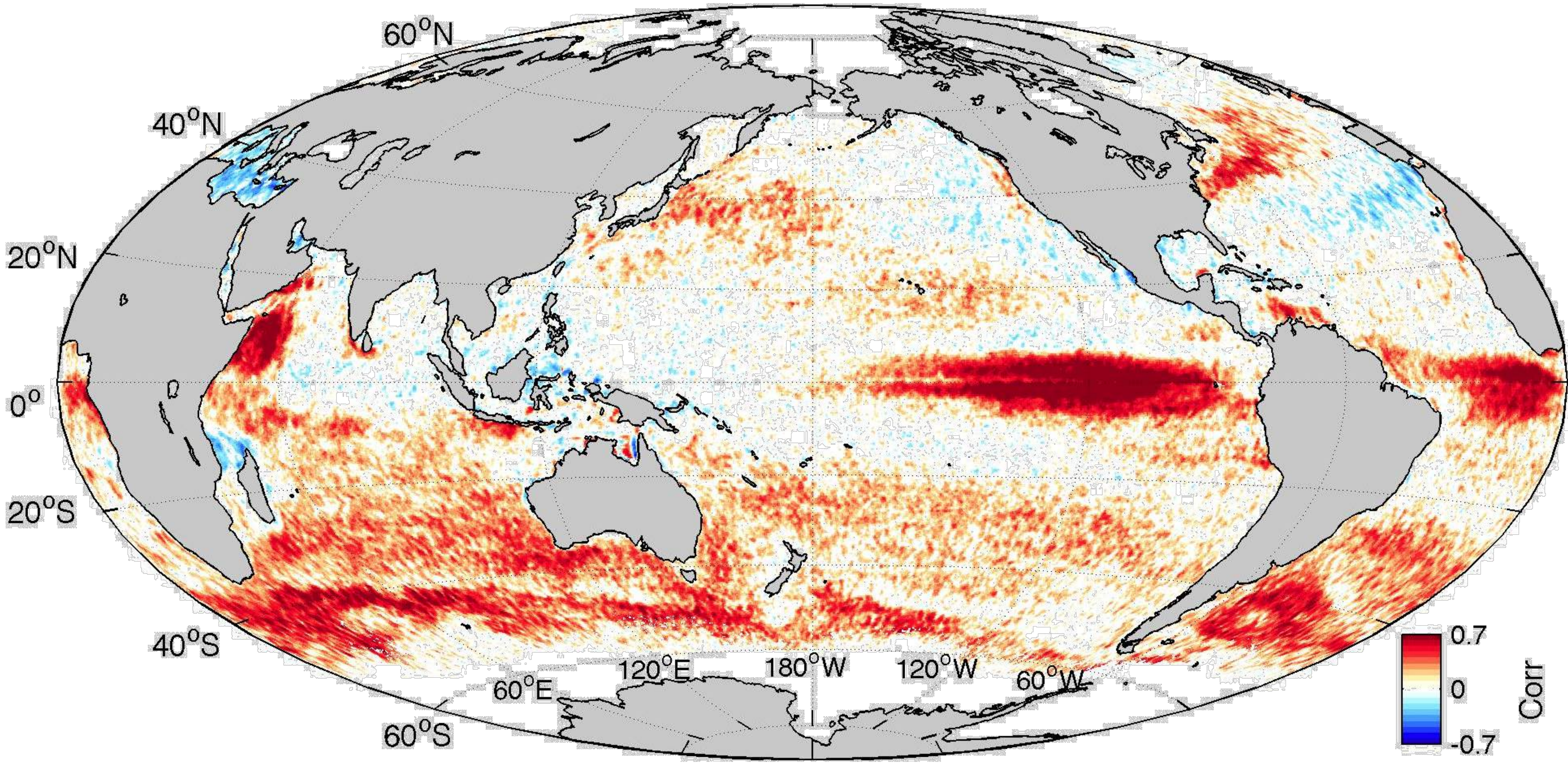
Eddy composites in the Southern Oceans

SST Wind speed



Frenger et al. 2013

Correlation bet'n highpass filtered SST & W



Eddy-driven air-sea interactions: Ekman pumping velocity

$$\tau = \rho_a C_D (W - U) |W - U|$$

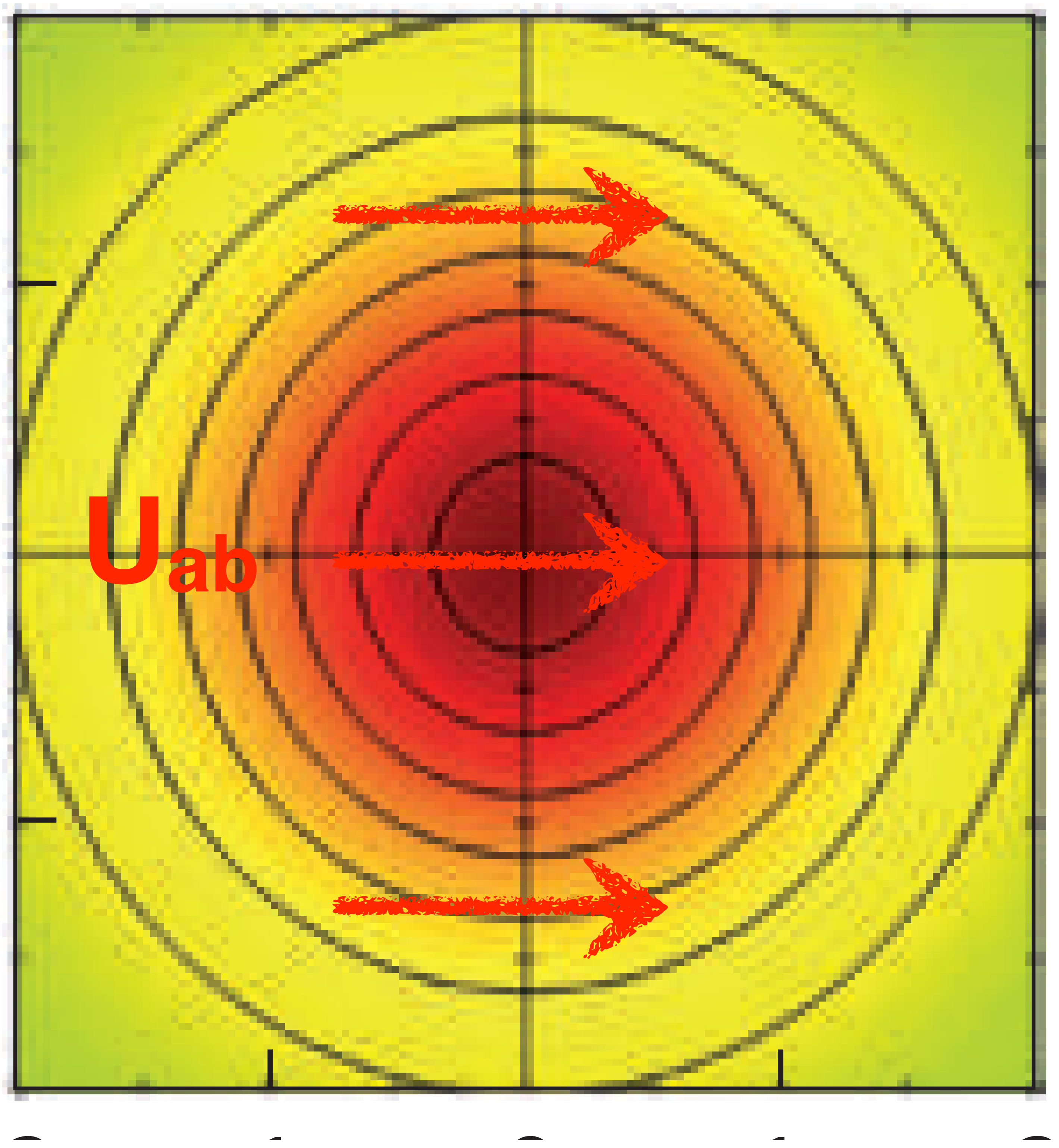
surface current (U)

10m wind (W)

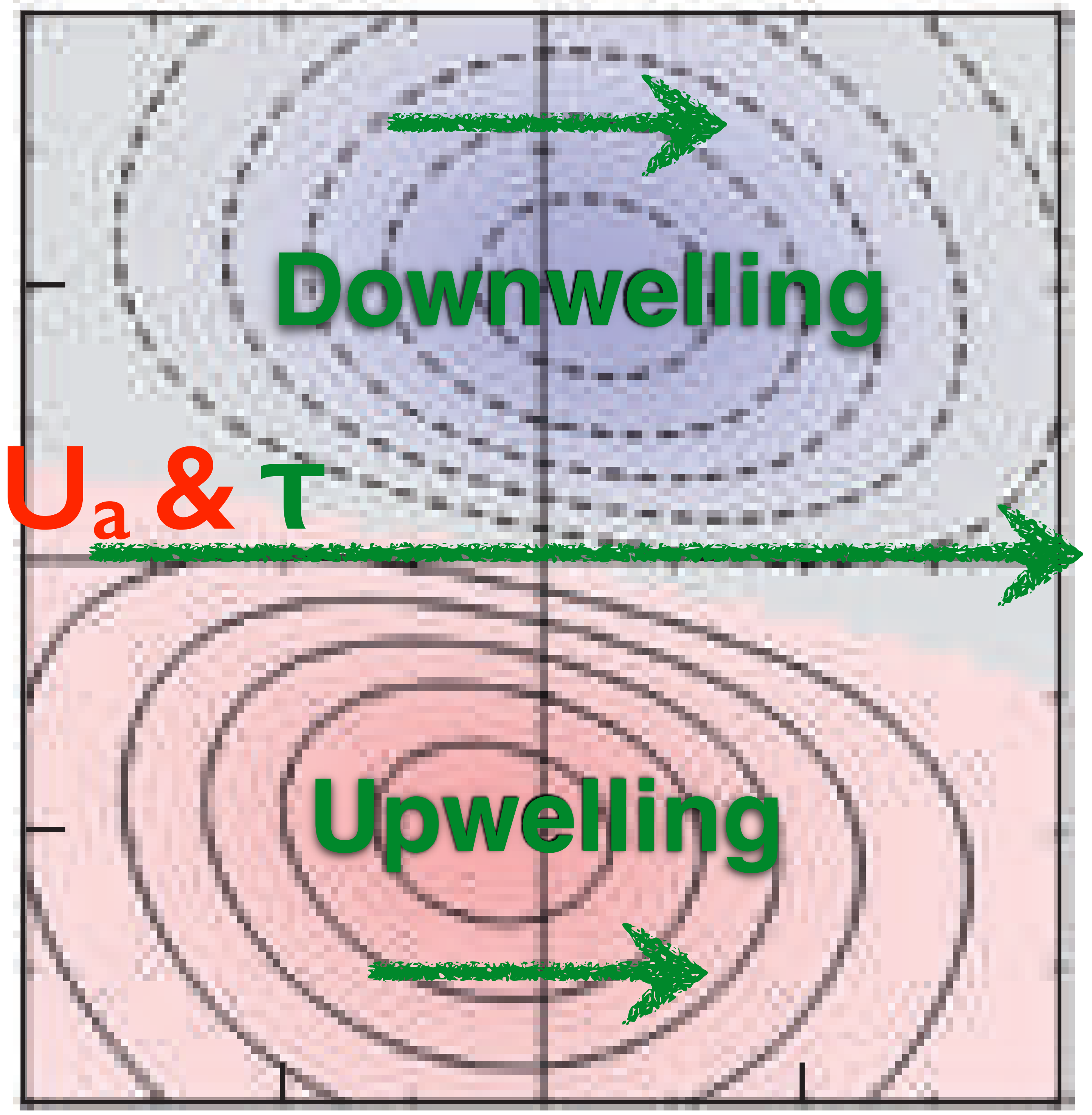
$W = W_b + \underline{W_{SST}}$

Consider an idealized anticyclonic warm-core eddy in the Southern Ocean (Chelton 2013)

SST and SSH



Dipole Ekman pumping



Ekman pumping anomaly in quadrature with SSH
→ northward propagation of a warm-core anticyclonic eddy

Eddy-driven air-sea interactions: under-stress

$$\tau = \rho_a C_D (W - U) |W - U|$$

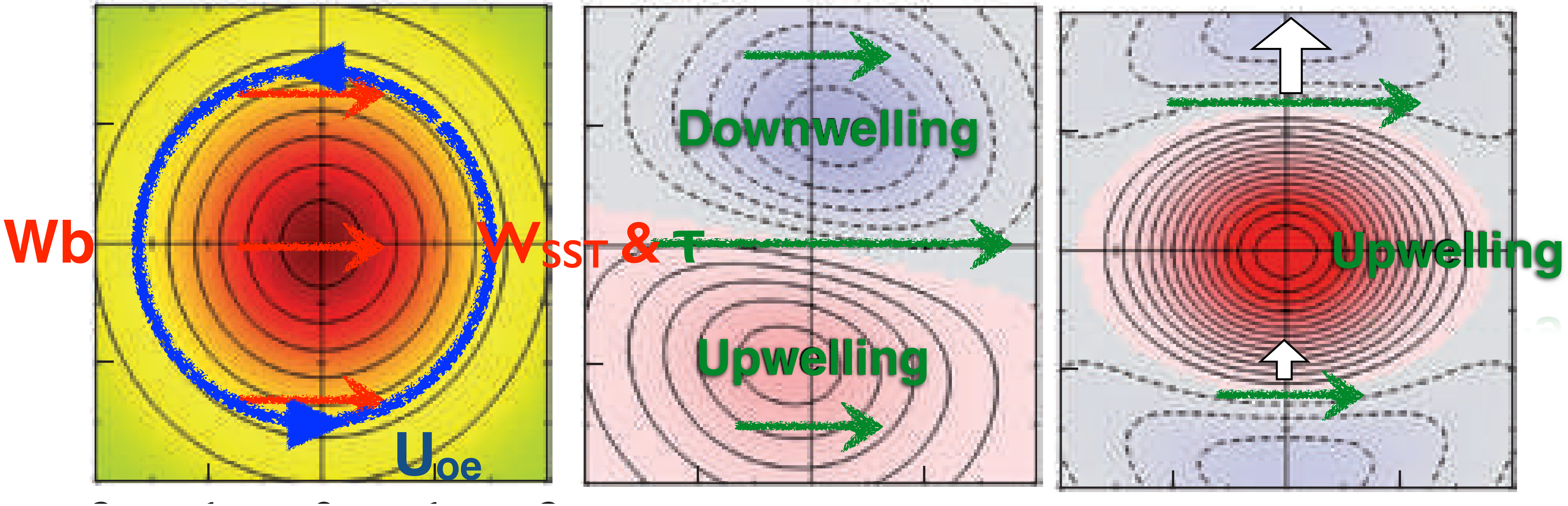
surface current

$U = U_b + U_e$

10m wind

$W = W_b + \underline{W_{SST}}$

SST and SSH | T_e-τ | U_e-τ

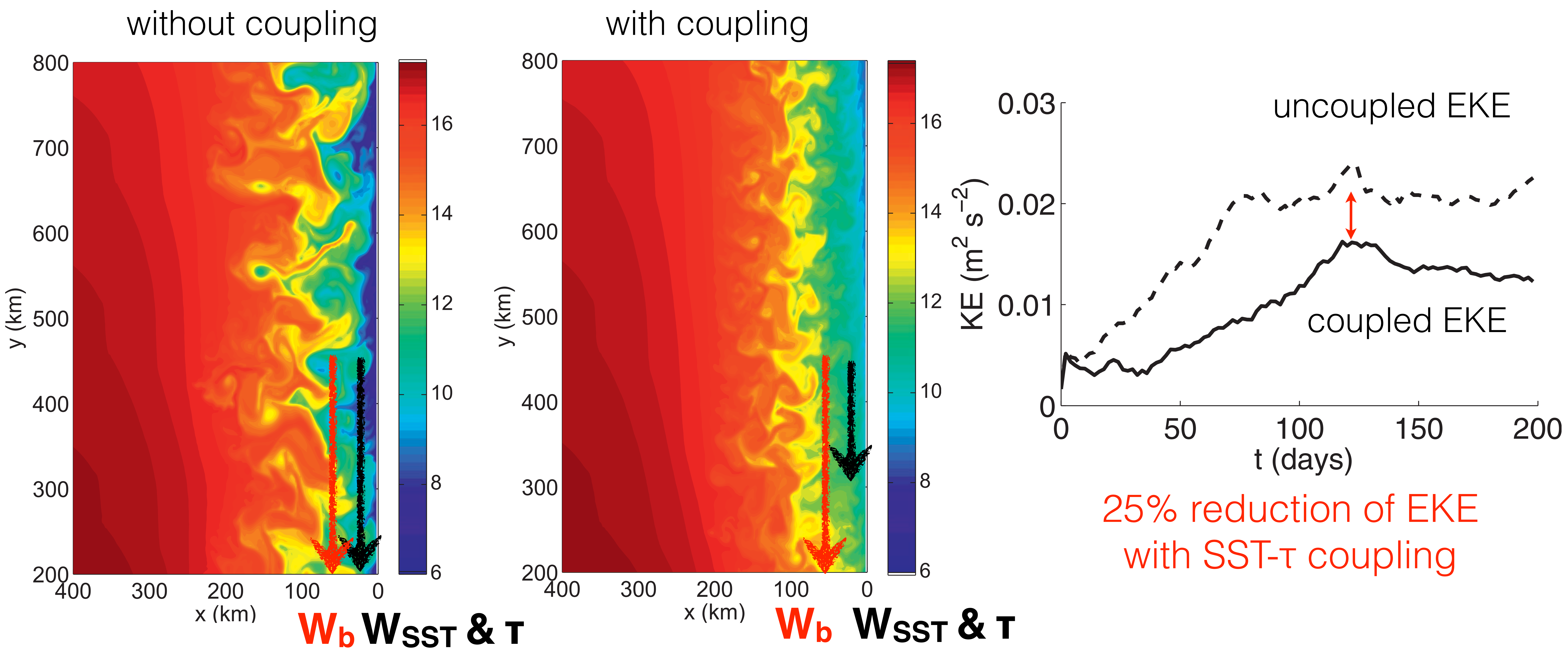


Affect the propagation

Reduce the eddy-amplitude

Previous studies: Jin et al. (2009)

SST-wind coupling effect in an idealized ocean model

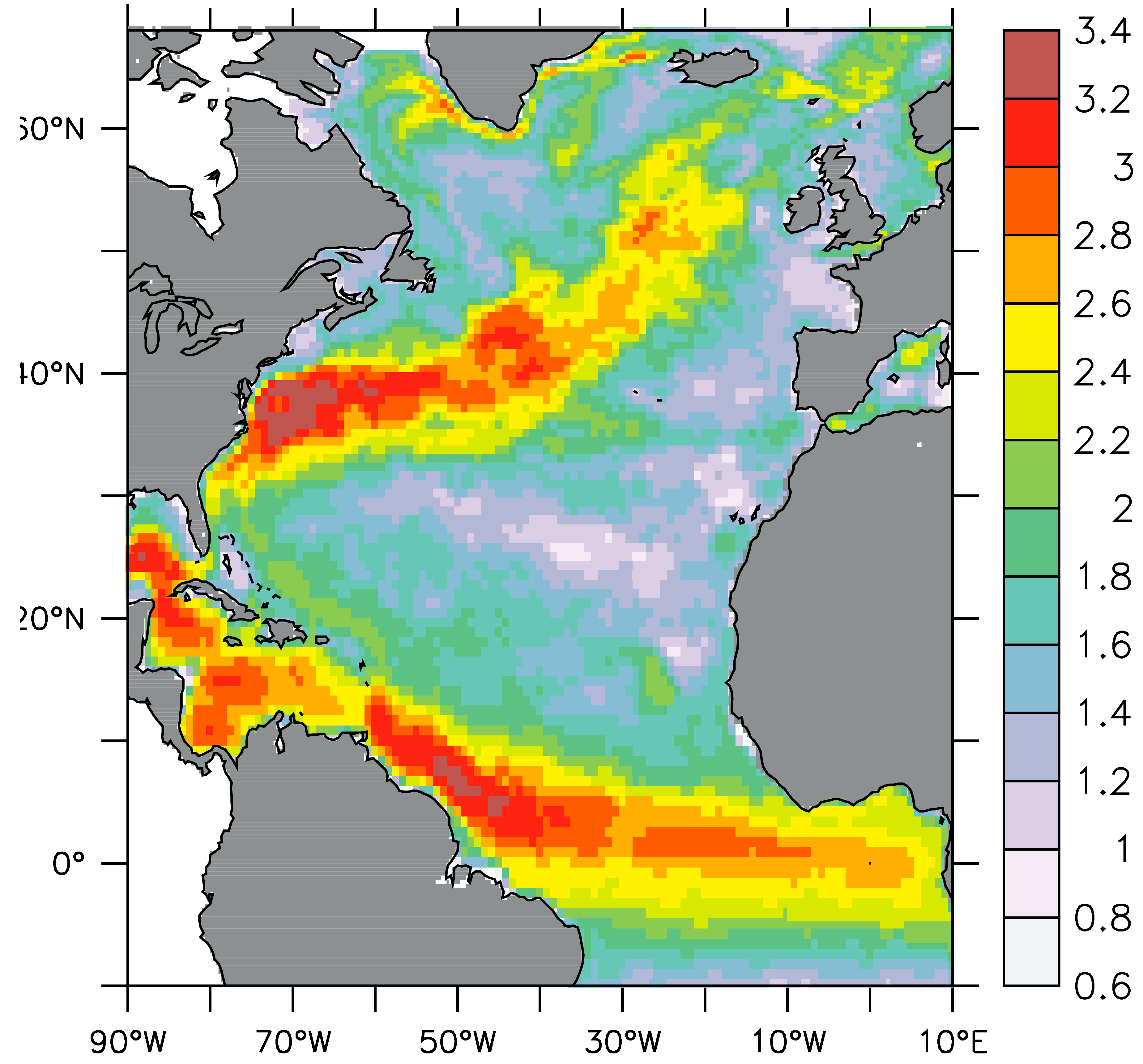


- SST-wind coupling weakens the alongshore wind stress, *baroclinic instability* and EKE.
- No distinction between the effects of background-scale and eddy-scale SSTs

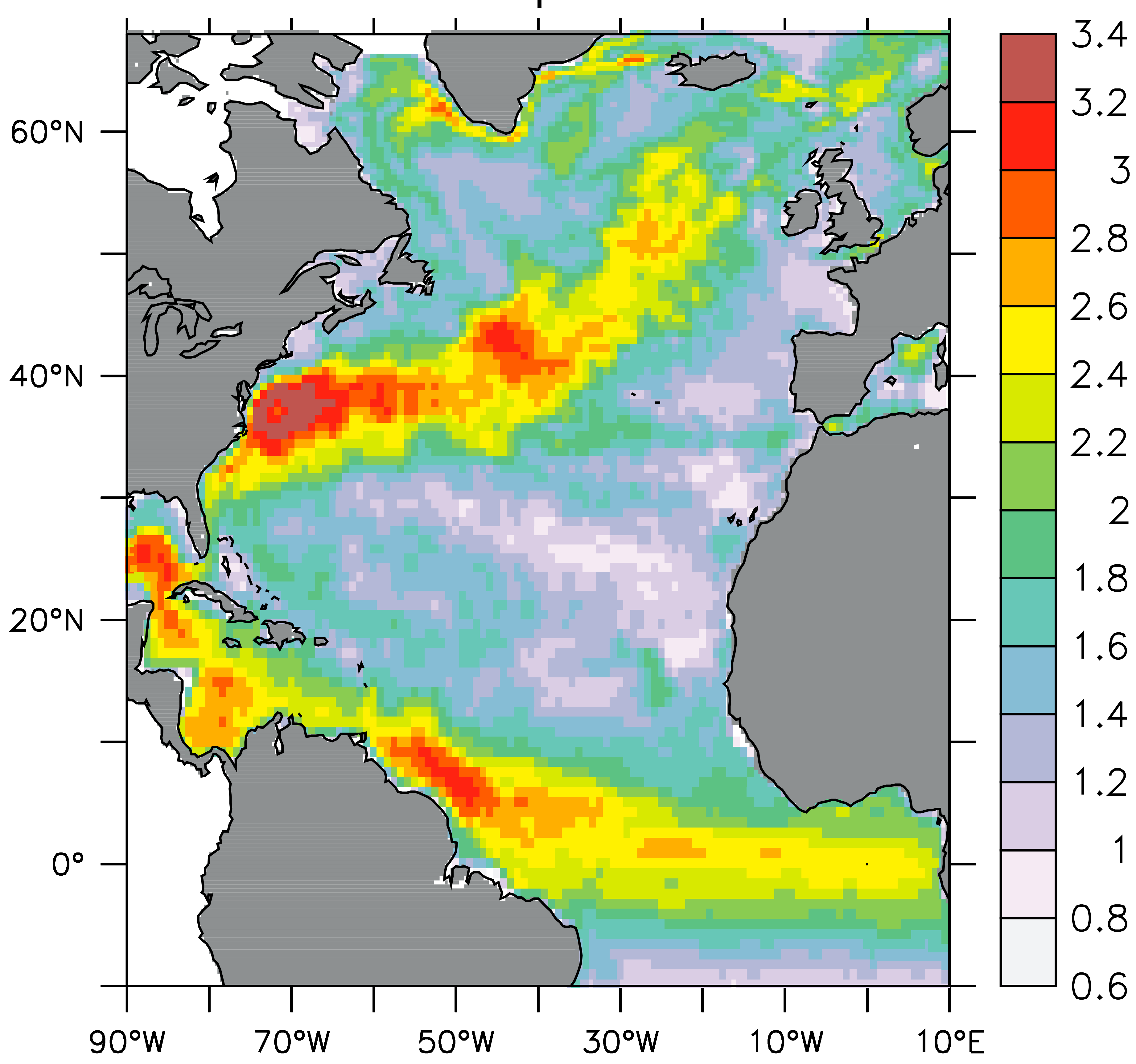
Previous studies: Eden and Dietze (2009)

U-τ coupling effect also damps the EKE in an OGCM

uncoupled EKE



U-τ coupled EKE



- 10% reduction in EKE in the mid-latitudes and ~50% in the tropics
- Primarily due to increased eddy drag (τ′· u′, direct effect)
- Change in baroclinic and barotropic instability of secondary importance

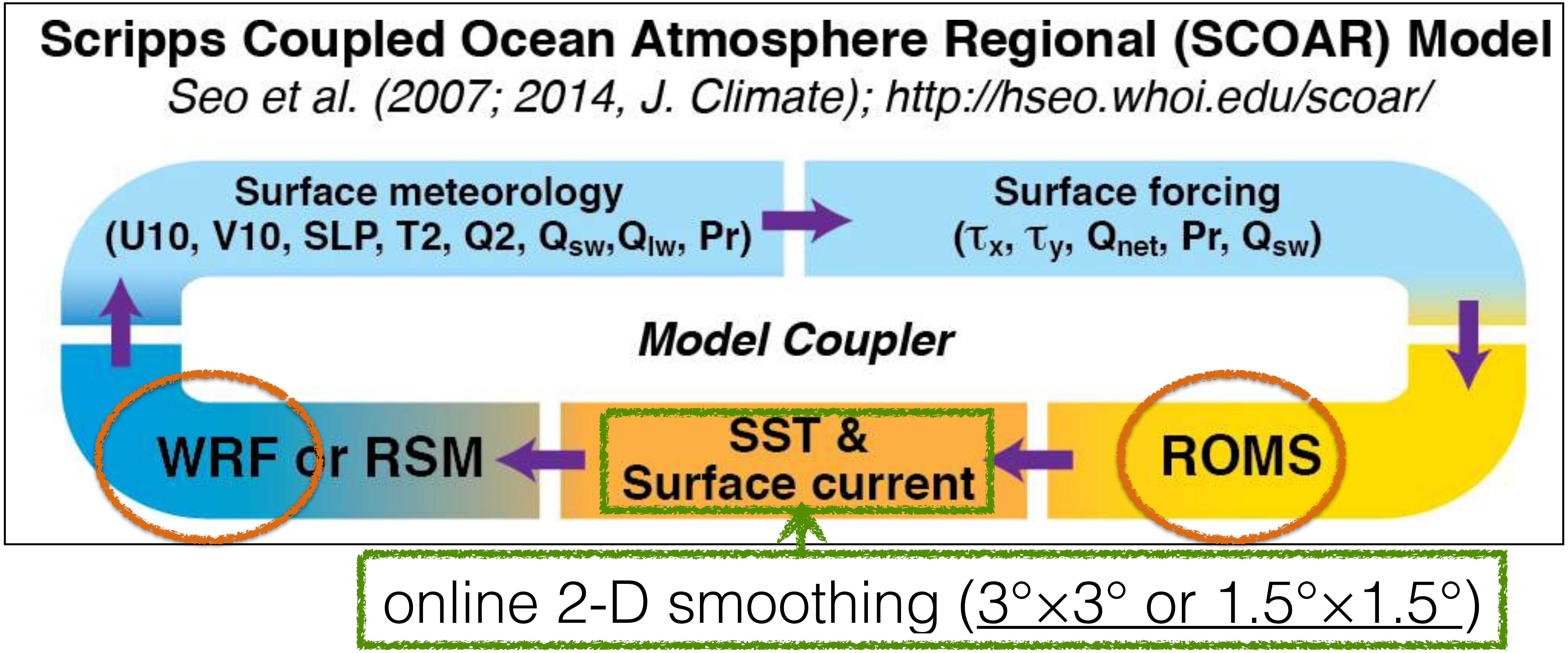
- Again, no separation between background and small-scale currents.

Goal

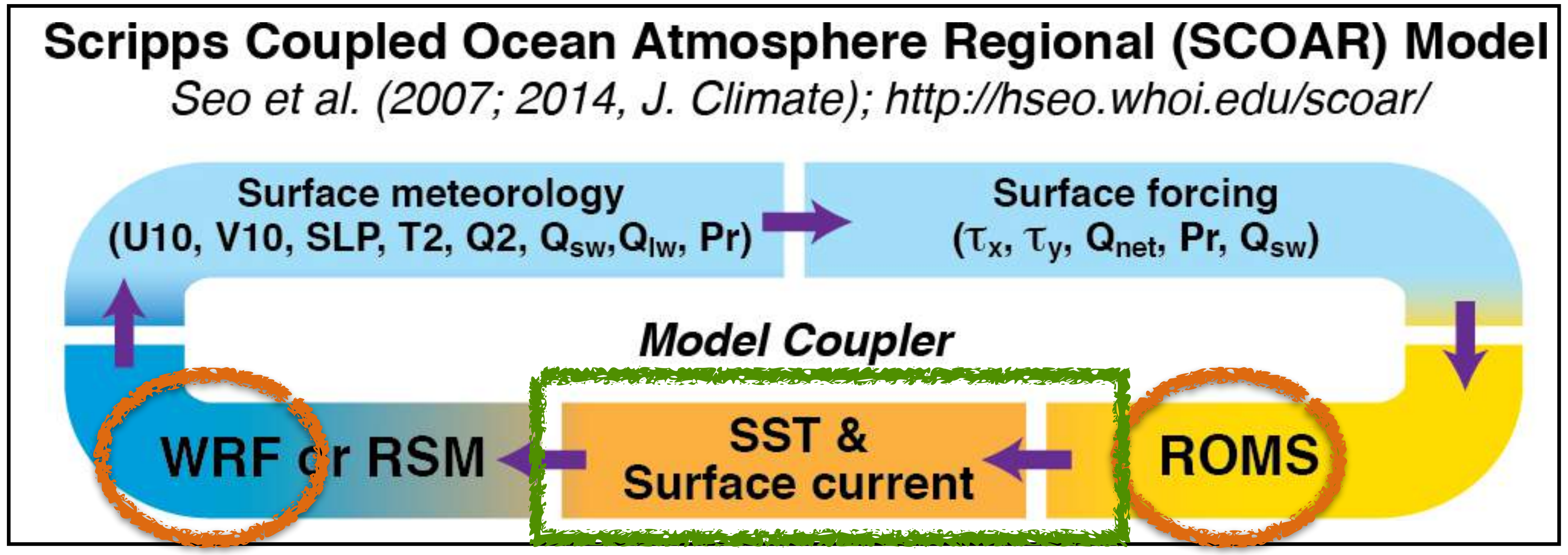
Examine effect of *eddy-driven* air-sea interaction
through SST and surface current
on energetics of the CCS and Ekman pumping

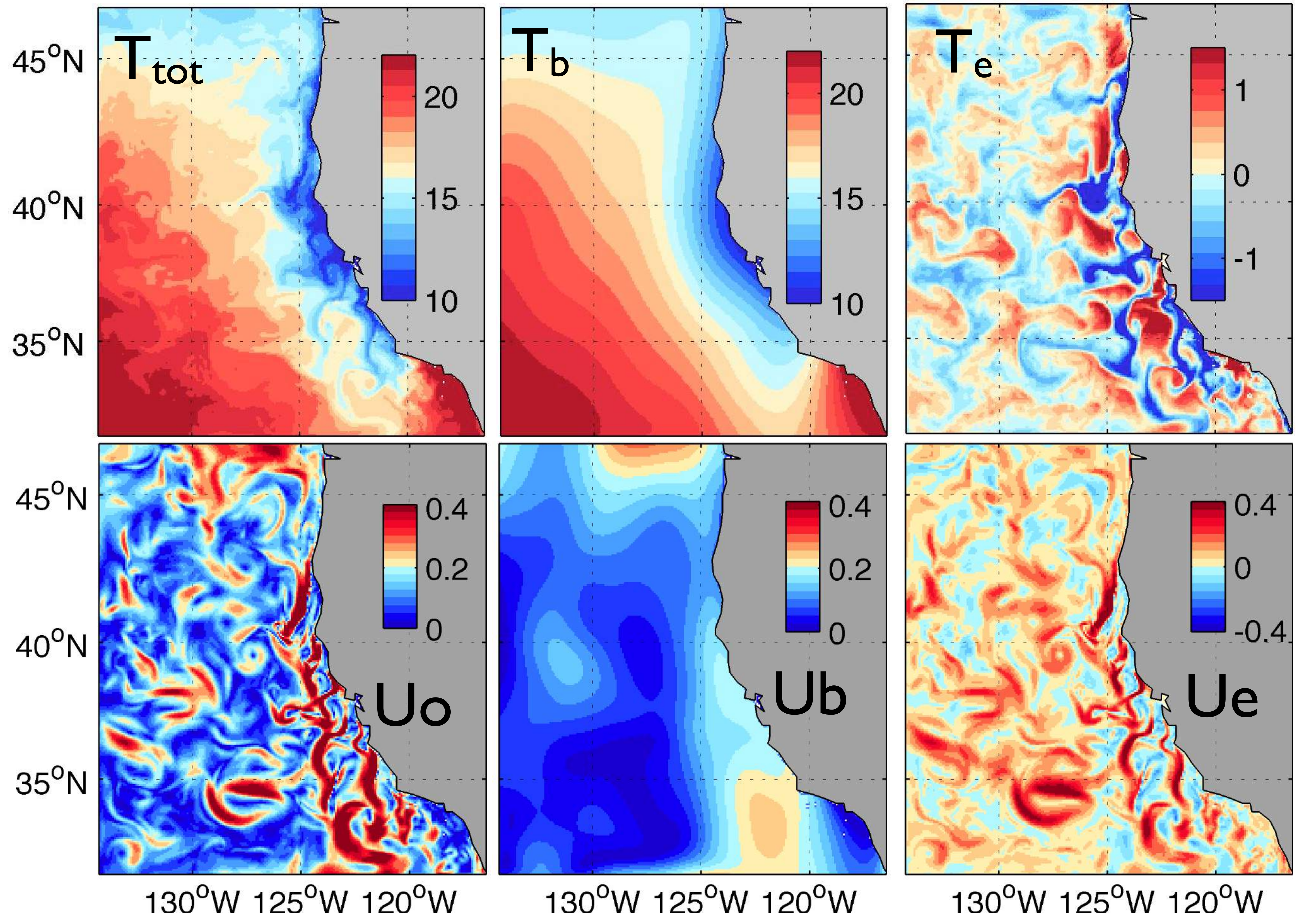
Numerical modeling study of eddy-wind interaction:

High-res. O-A coupled model with separation of the spatial scale of O-A coupling



- WRF-ROMS at 7 km resolutions represents the small-scale eddies and their interaction with the atmosphere
- Driven by NCEP-FNL and SODA
- A 2D online smoothing to suppress the small-scale coupling; the large-scale coupling is preserved
- Features up to 300 or 150km are considered small-scale (eddy or meso-scale)





Experiments

$$\tau = \rho_a C_D (W-U)|W-U|$$

Experimen	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	
no$T_e U_e$	T_b		U_b	
noU_{tot}	T_b	T_e		

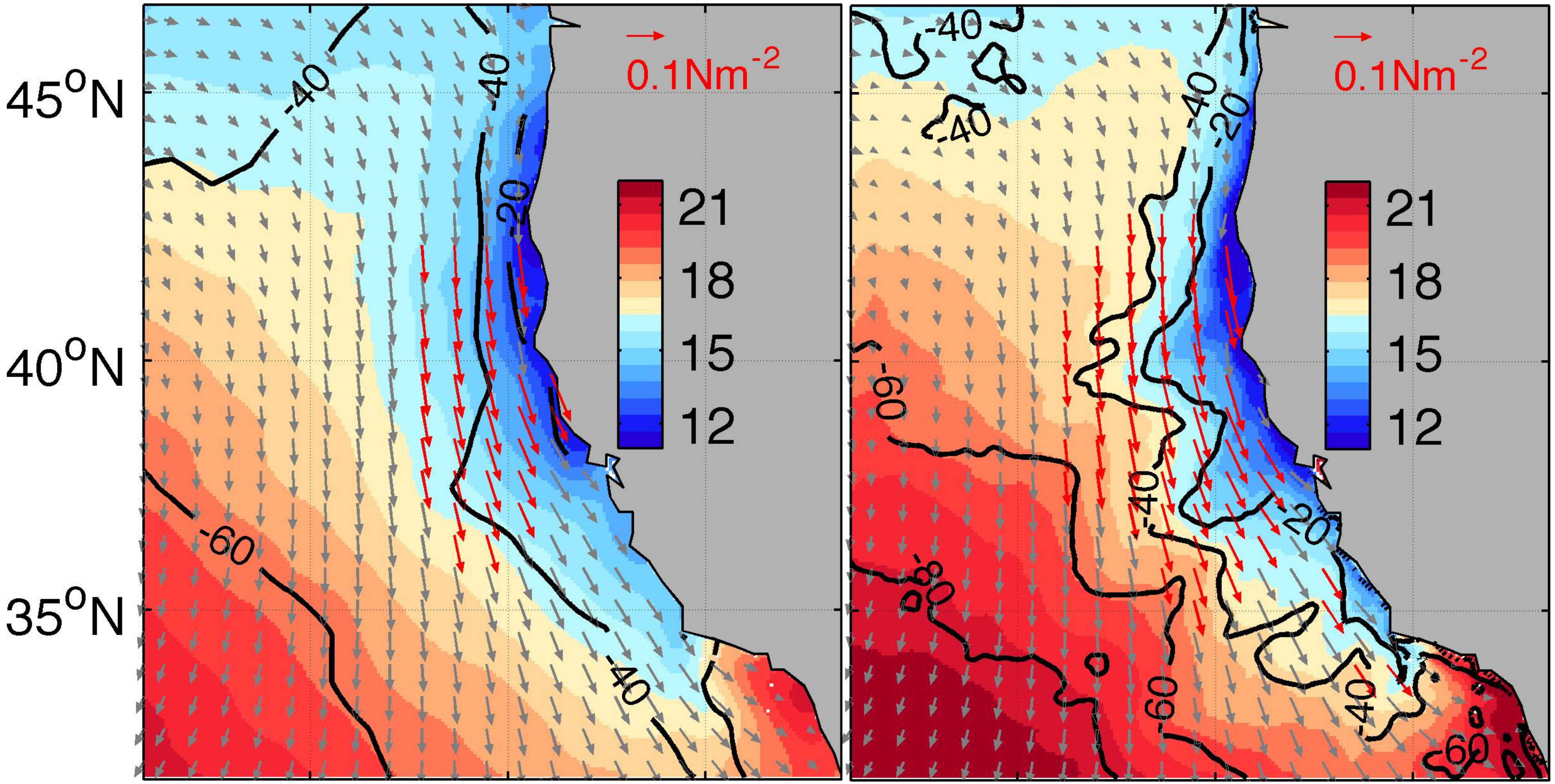
6-yr simulations: 2005-2010

CTL-noT_e: effect of T_e

CTL-noU_e: effect of U_e

Simulated summertime climatology:

SST, wind stress, and latent heat flux

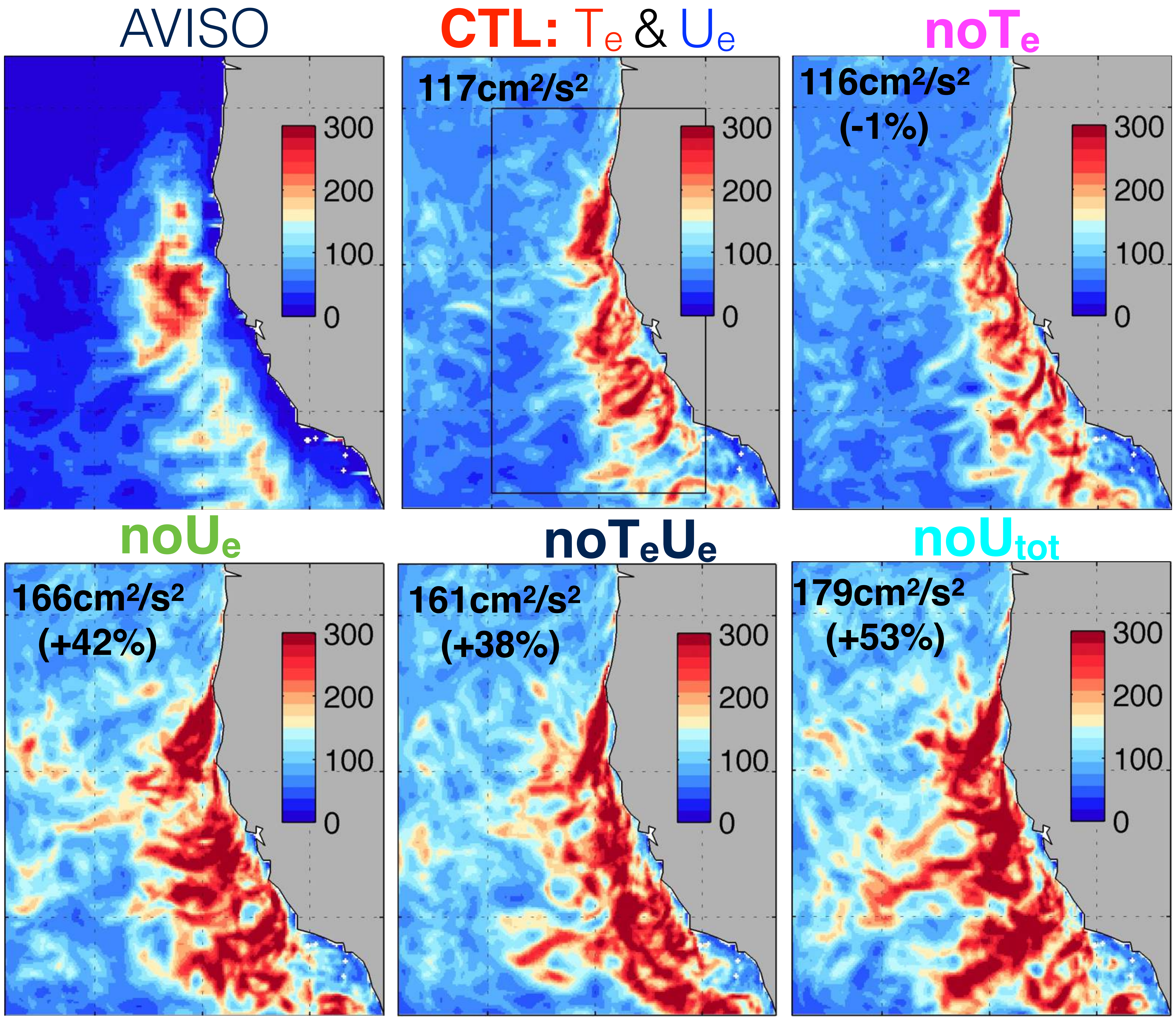


2005-2010 JJAS

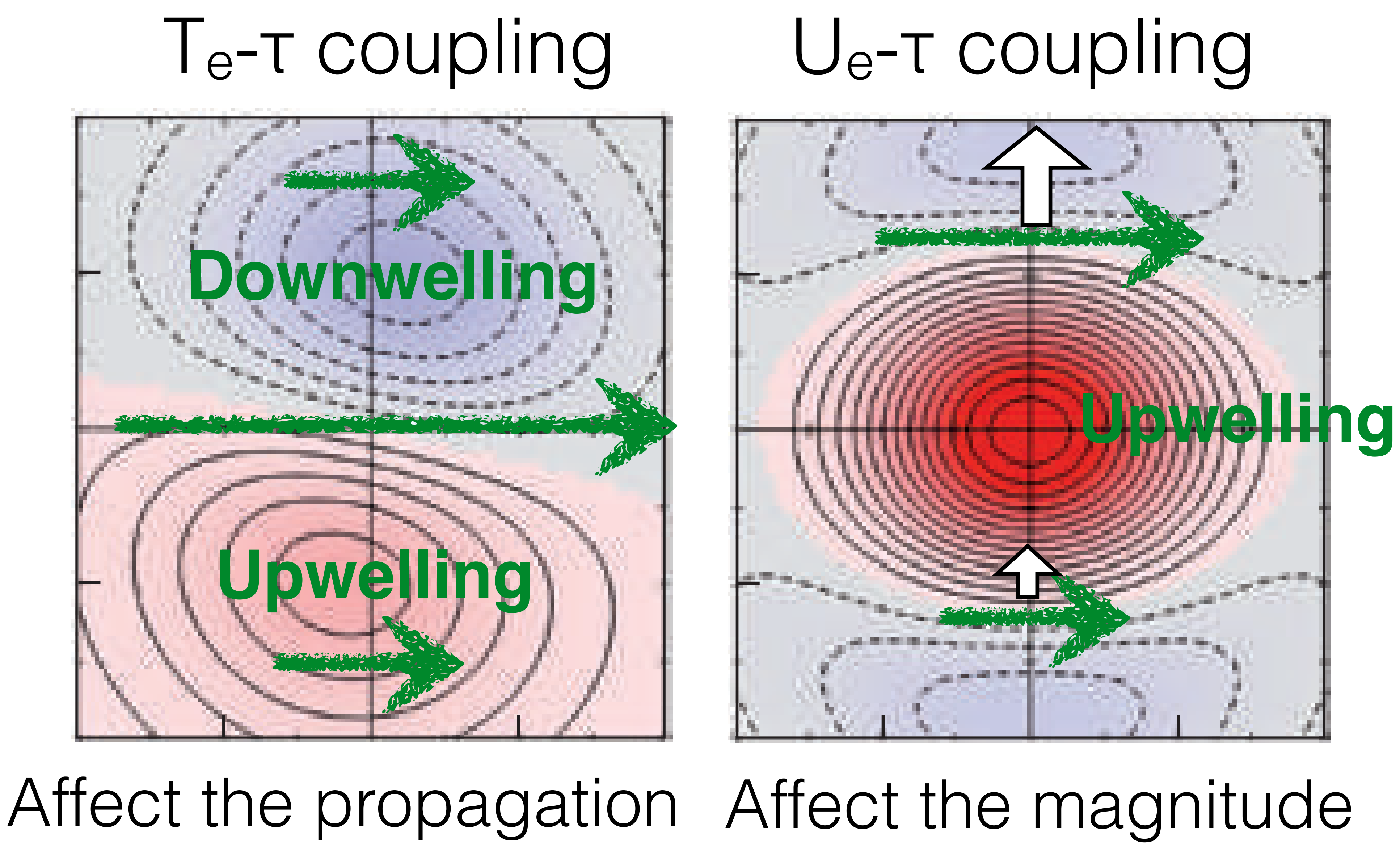
SODA SST, QuikSCAT wind stress and OAFLUX LH

Summertime eddy kinetic energy

JAS 2005-2010



- T_e-τ has no impact on EKE
- U_e-τ reduces the EKE substantially
- U_{tot}-τ reduces the EKE only slightly more (additional 10%)
  → The EKE reduction by under-stress occur largely on eddy-scales



Weakened EKE with U_e-τ:
EKE budget and Ekman pumping

Eddy energetics

along-shore averages

$$\mathrm{BT} = -(\overline{u'u'}\,\overline{U}_x + \overline{u'v'}\,\overline{U}_y + \overline{u'w'}\,\overline{U}_z + \overline{v'u'}\,\overline{V}_x + \overline{v'v'}\,\overline{V}_y + \overline{v'w'}\,\overline{V}_z), \quad \text{and}$$

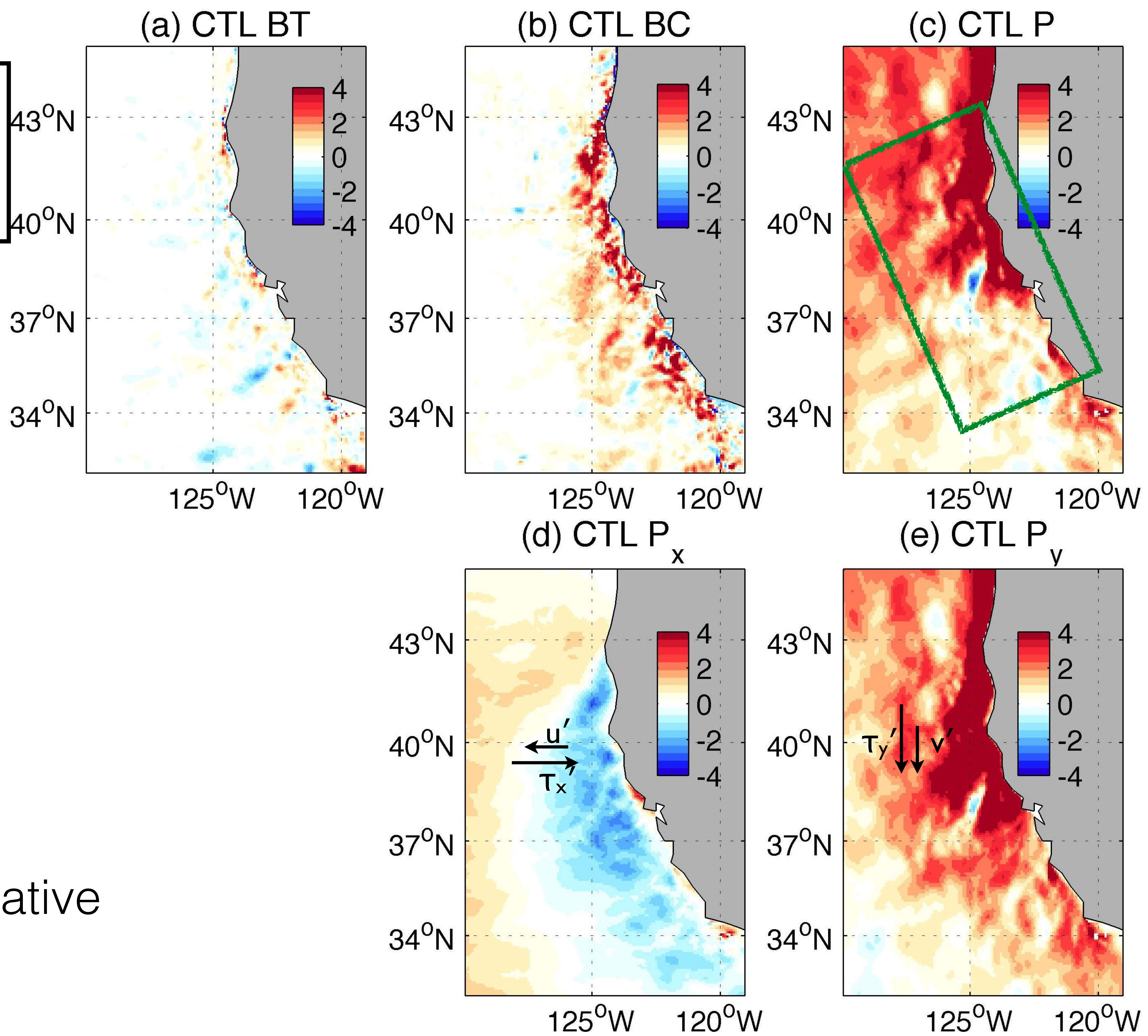
$K_m \rightarrow K_e$ barotropic conversion (BT)

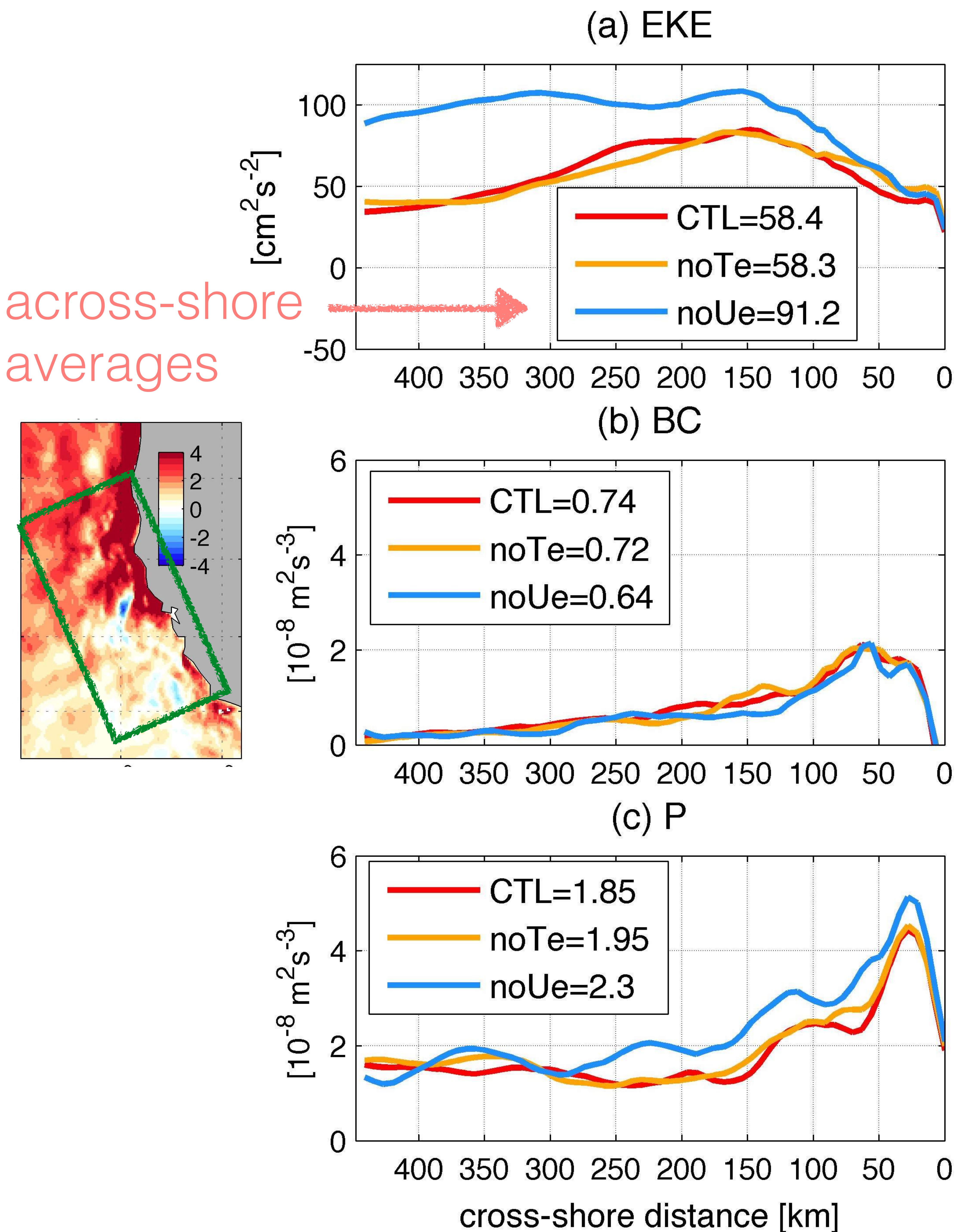
$$\mathrm{BC} = -\frac{g}{\rho_0}\overline{\rho' w'},$$

$P_e \rightarrow K_e$ baroclinic conversion (BC)

$$P = \frac{1}{\rho_0}(\overline{u'\tau'_x} + \overline{v'\tau'_y}).$$

Wind work if positive, eddy drag if negative



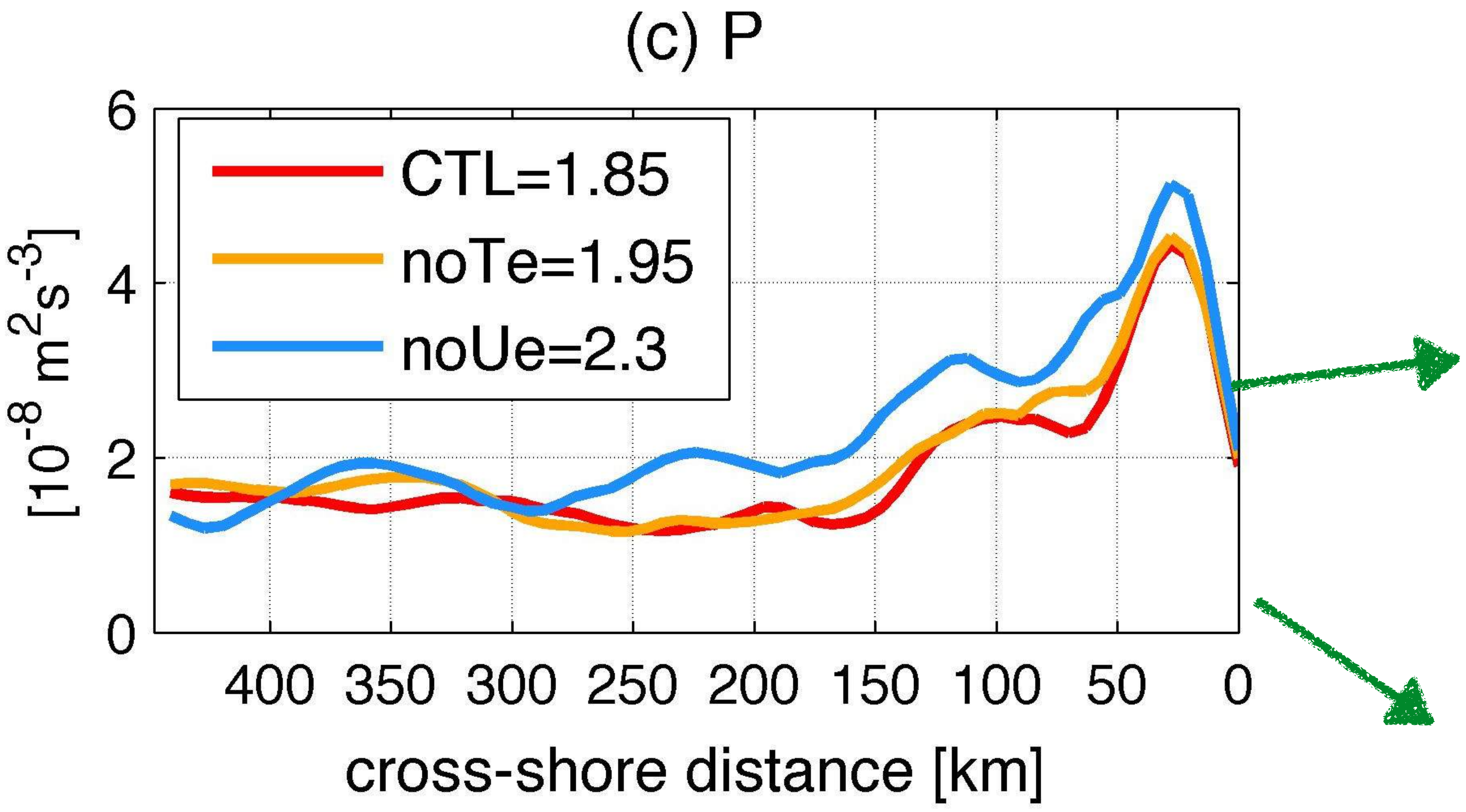


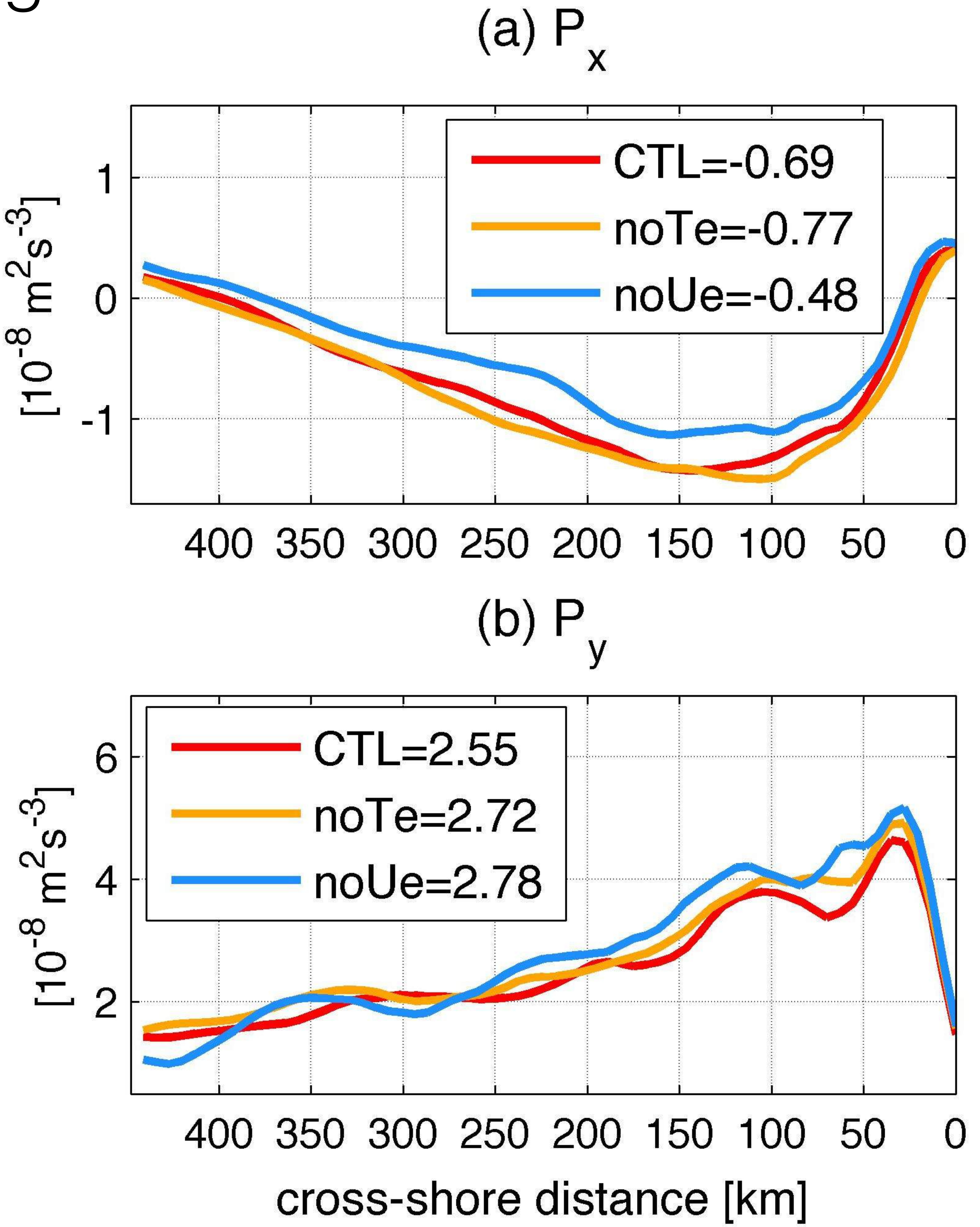
Across-shore distribution of EKE budget terms

- **Baroclinic conversion**
  - Only a small reduction in noUe
    → cannot explain the higher EKE

- **Eddy-wind interaction**
  - 24% increase in noUe
    → over the eddy-rich coastal zone (up to ~300 km)
    → Ue-τ reduces the wind work

Ue-τ coupling increases the eddy drag and reduces the momentum input





- In noUe, 30% weaker eddy drag
- In noUe 7-10% stronger wind work
  → Changes in absolute magnitude are comparable

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

$$\approx \frac{\nabla \times \boldsymbol{\tau}_{SST}}{\rho_0(f+\zeta)} - \frac{1}{\rho_0(f+\zeta)^2}\left(\tilde{\boldsymbol{\tau}}_y \frac{\partial \zeta}{\partial x} - \tilde{\boldsymbol{\tau}}_x \frac{\partial \zeta}{\partial y}\right) + \frac{\nabla \times \tilde{\boldsymbol{\tau}}}{\rho_0(f+\zeta)} + \frac{\beta \boldsymbol{\tau}^x}{\rho_0(f+\zeta)^2}$$

W_{SST} ↑ SST induced Ekman pumping Chelton et al. (2001)

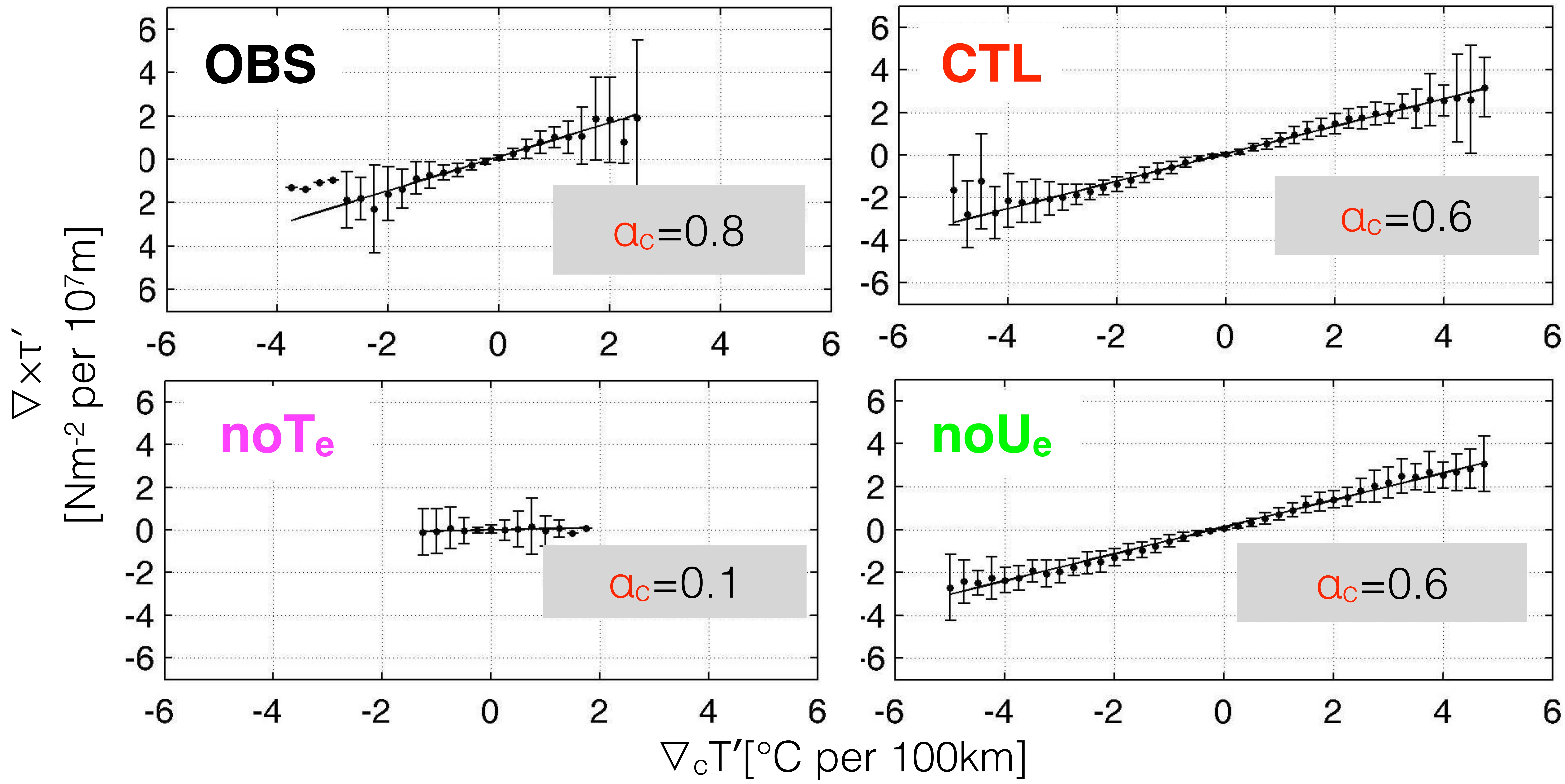
W_{ζ} ↑ Surface vorticity gradient-induced nonlinear Ekman pumping

W_{LIN} ↑ Curl-induced linear Ekman pumping

W_{β} ↑ β Ekman pumping (negligible)

Estimating eddy SST-driven Ekman pumping velocity

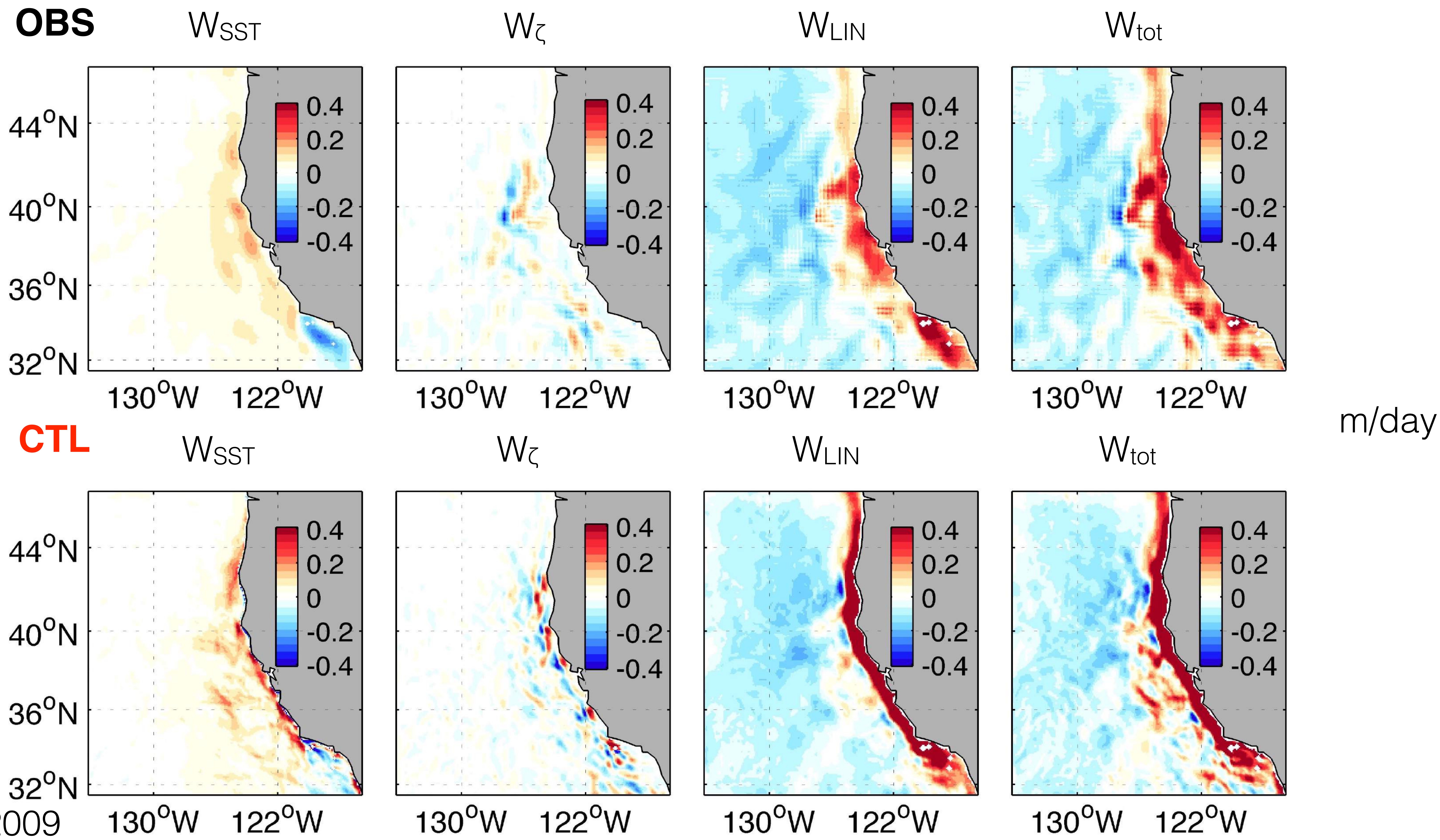
$$W_{SST} = \frac{\nabla \times \tau'_{SST}}{\rho_o (f + \zeta)} \approx \frac{\alpha_c \nabla_c SST}{\rho_o (f + \zeta)}$$



JAS 2005-2009

OBS based on QuikSCAT wind stress and TRMM SST

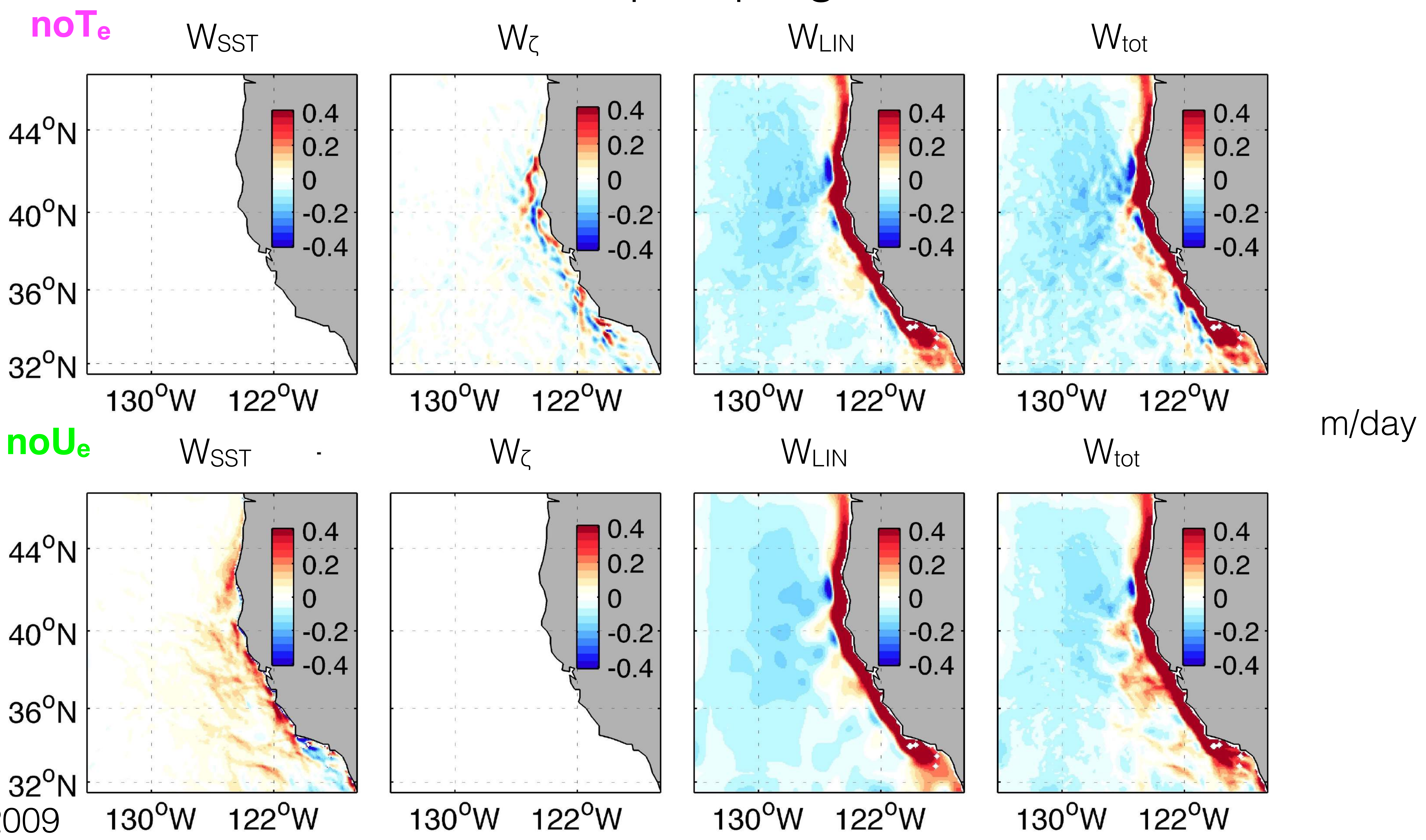
Estimated Ekman pumping velocities



Based on AVISO SSH & QuikSCAT wind stress

JAS 2005-2009

Estimated Ekman pumping velocities

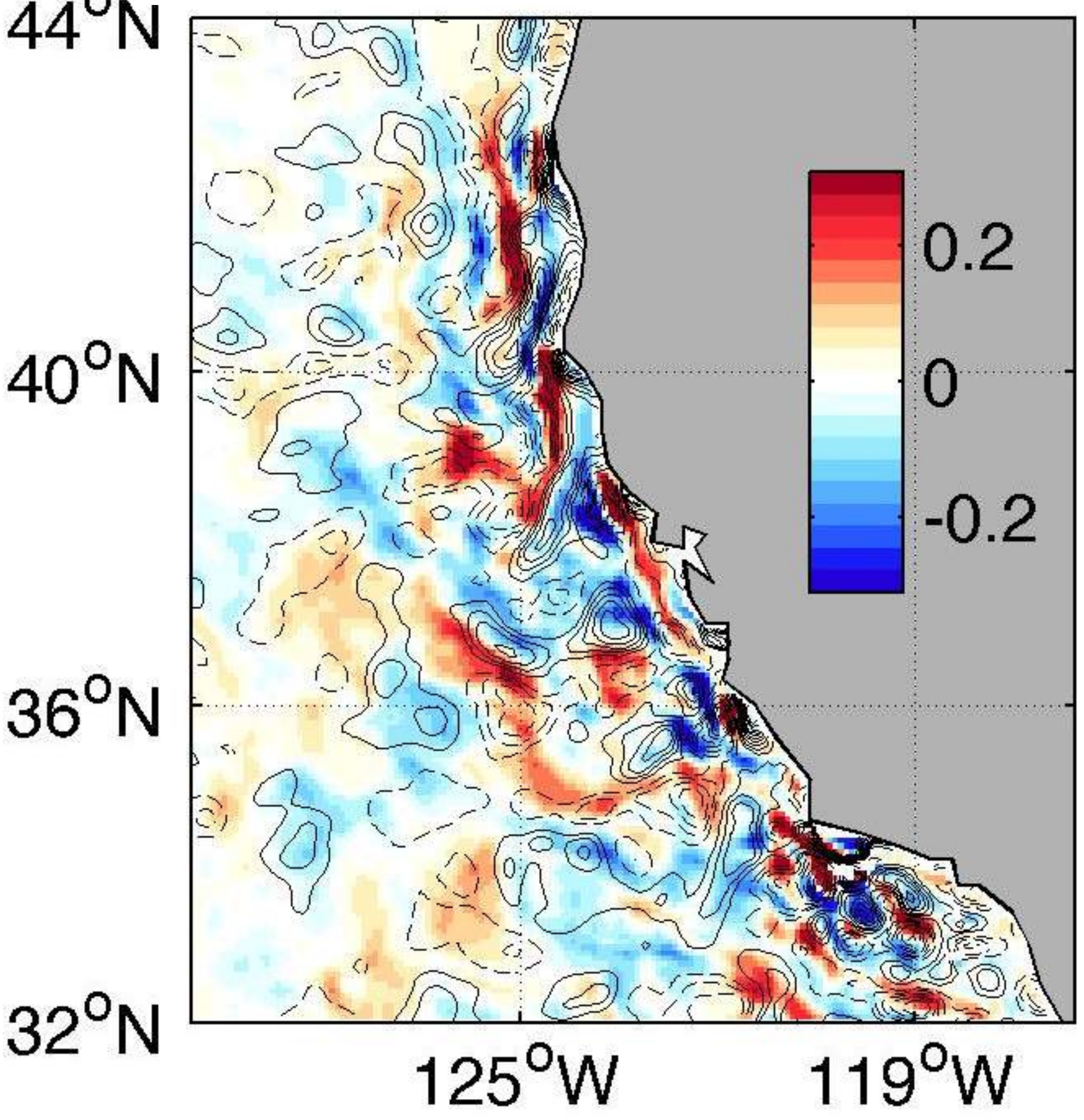


JAS 2005-2009

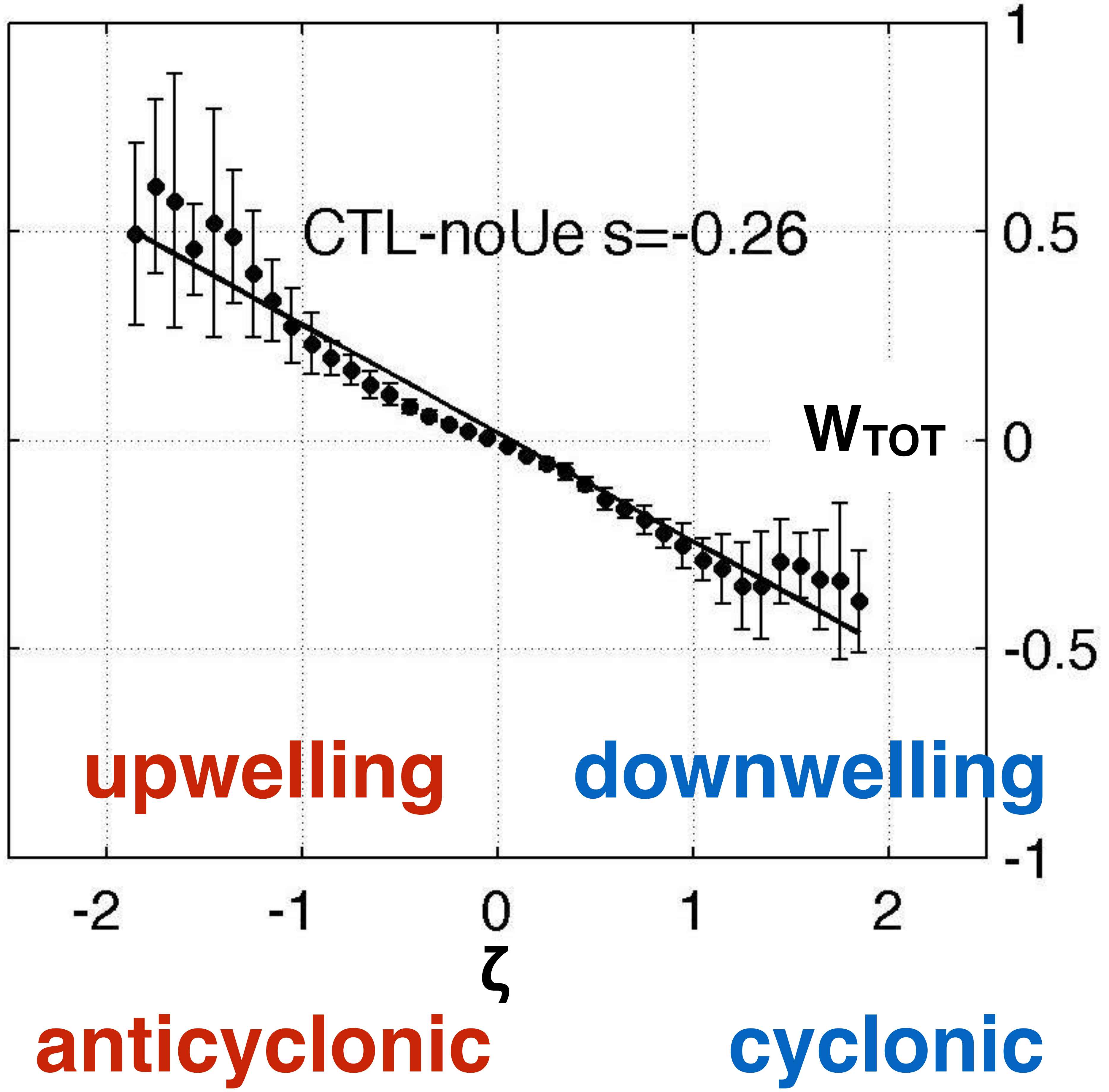
Inferred feedback to eddy activity through W_ζ

Total Ekman pumping velocity difference

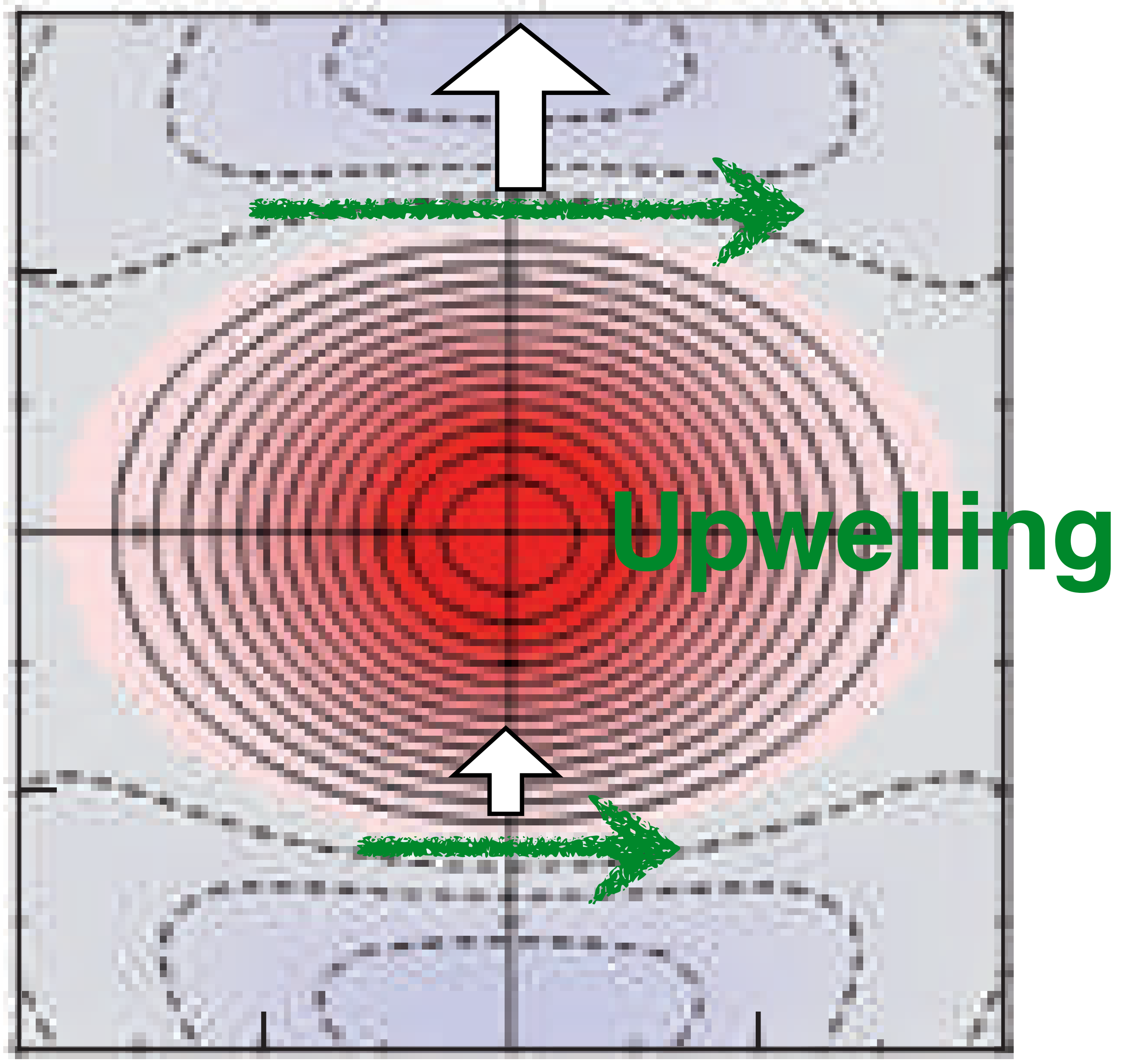
CTL-noU$_e$ W$_{TOT}$ & ζ



CTL-noU$_e$ W$_{TOT}$ vs ζ



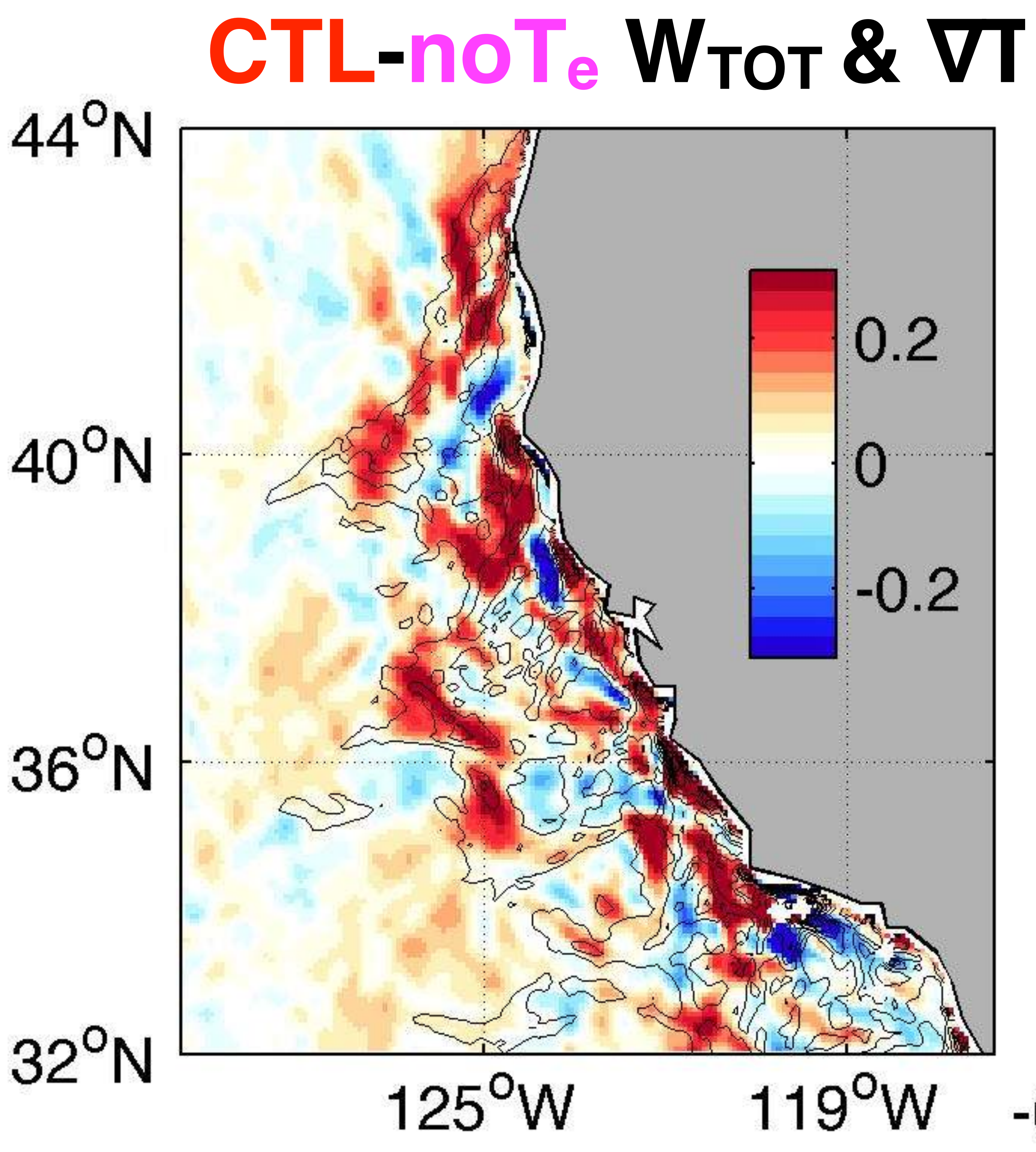
Downwelling over cyclonic vorticity anomaly → Ue-τ weakens the amplitude of the eddies

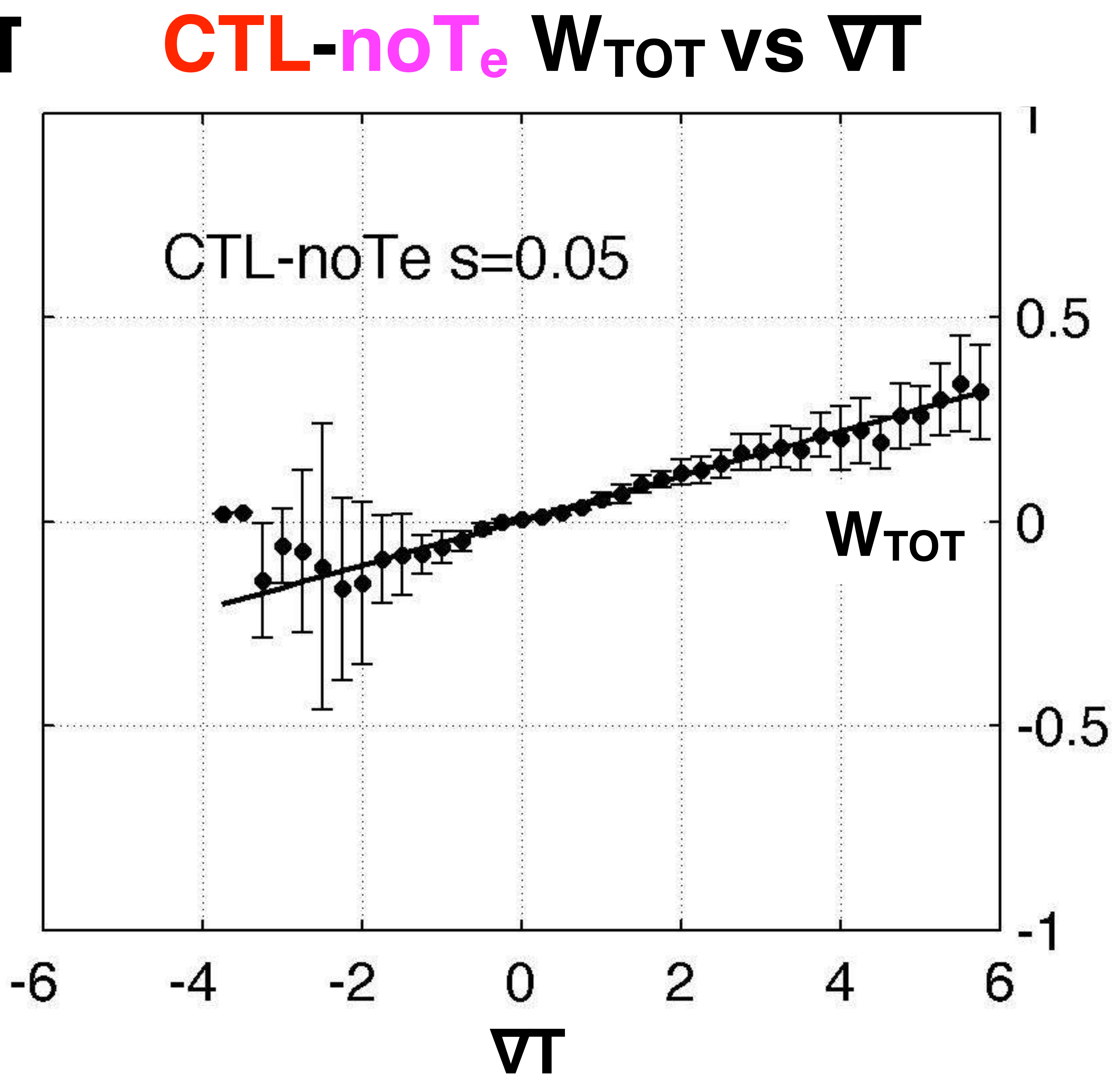


JAS 2005-2010

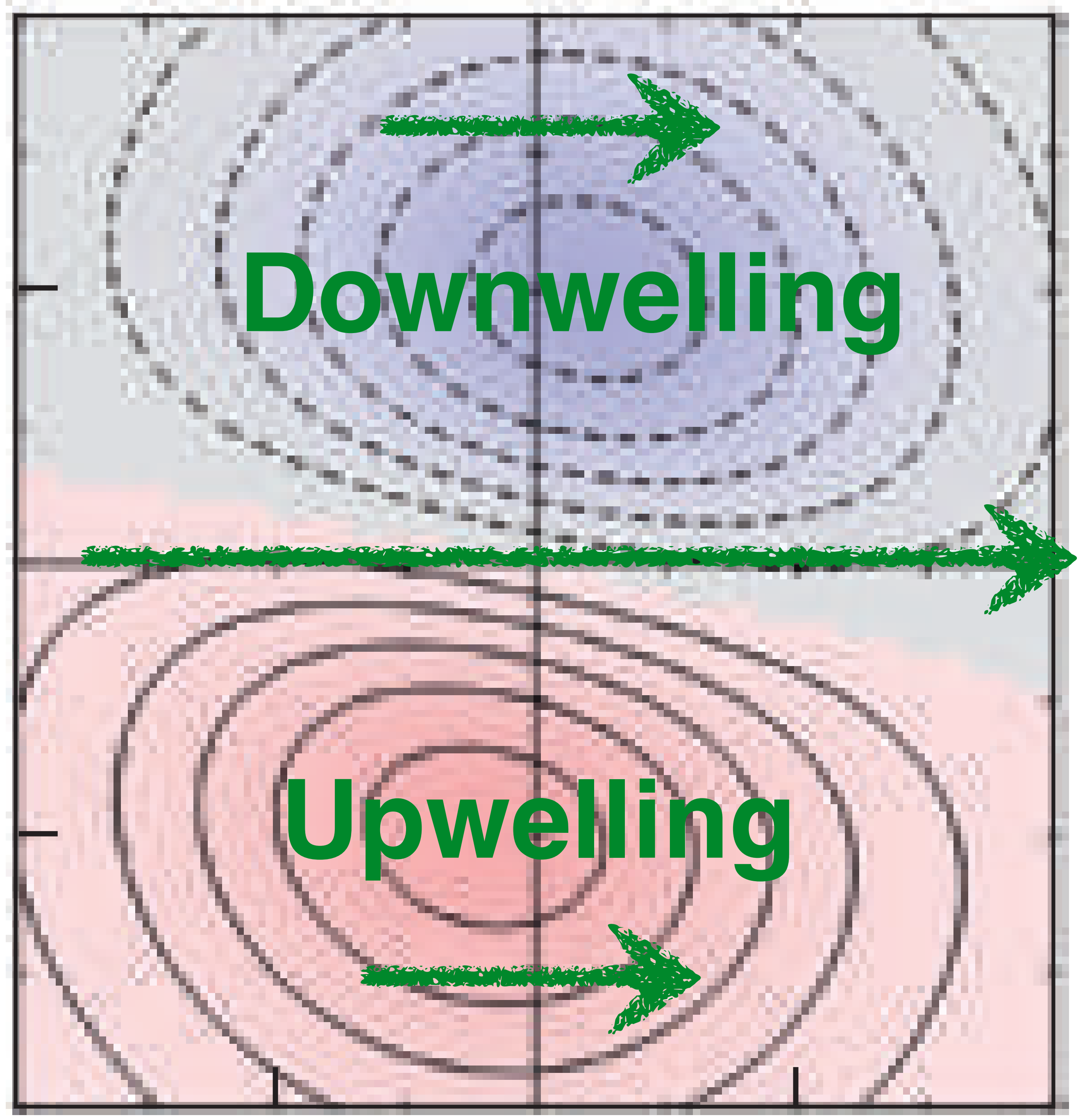
Inferred Feedback to eddy activities through W_{SST}

Total Ekman pumping velocity difference





Ekman pumping acting on the maximum SST gradients → If anything, it influences the geostrophic current in which eddies are embedded



JAS 2005-2010

Summary and Discussion

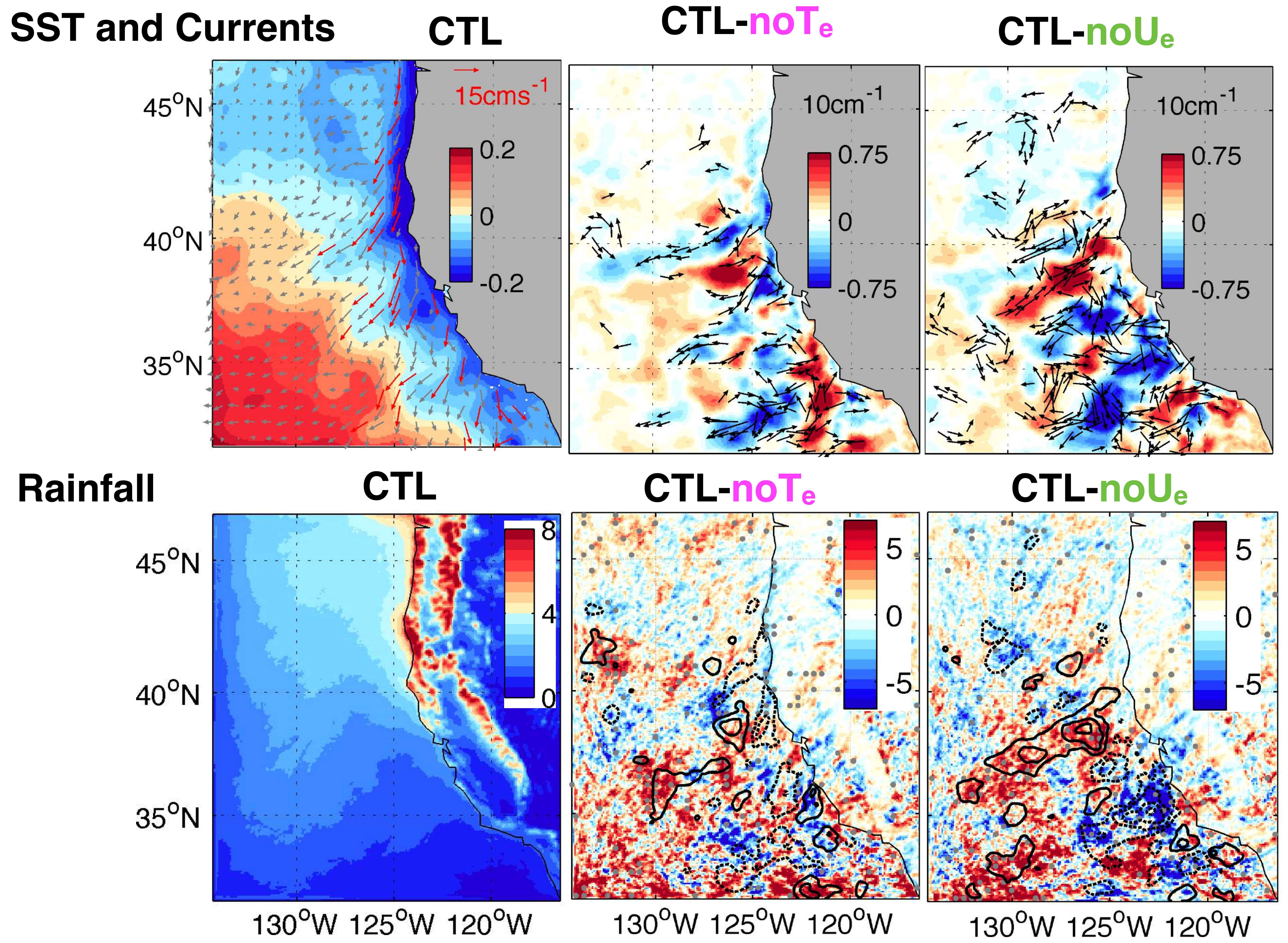
A significant role of eddy-driven air-sea interaction through surface current in the energetics of the CCS and the Ekman pumping velocity

- The weakened EKE due to reduced wind momentum input and enhanced eddy drag (nearly of equal importance).

- Eddies modify Ekman vertical velocities
  - W_ζ suppresses the eddy activity
  - W_{SST} may influences the eddy propagation
    - Eddy-centric analysis to examine the changes in propagation characteristics of the eddies (e.g., Gaube et al. 2015; Renault et al. 2016)

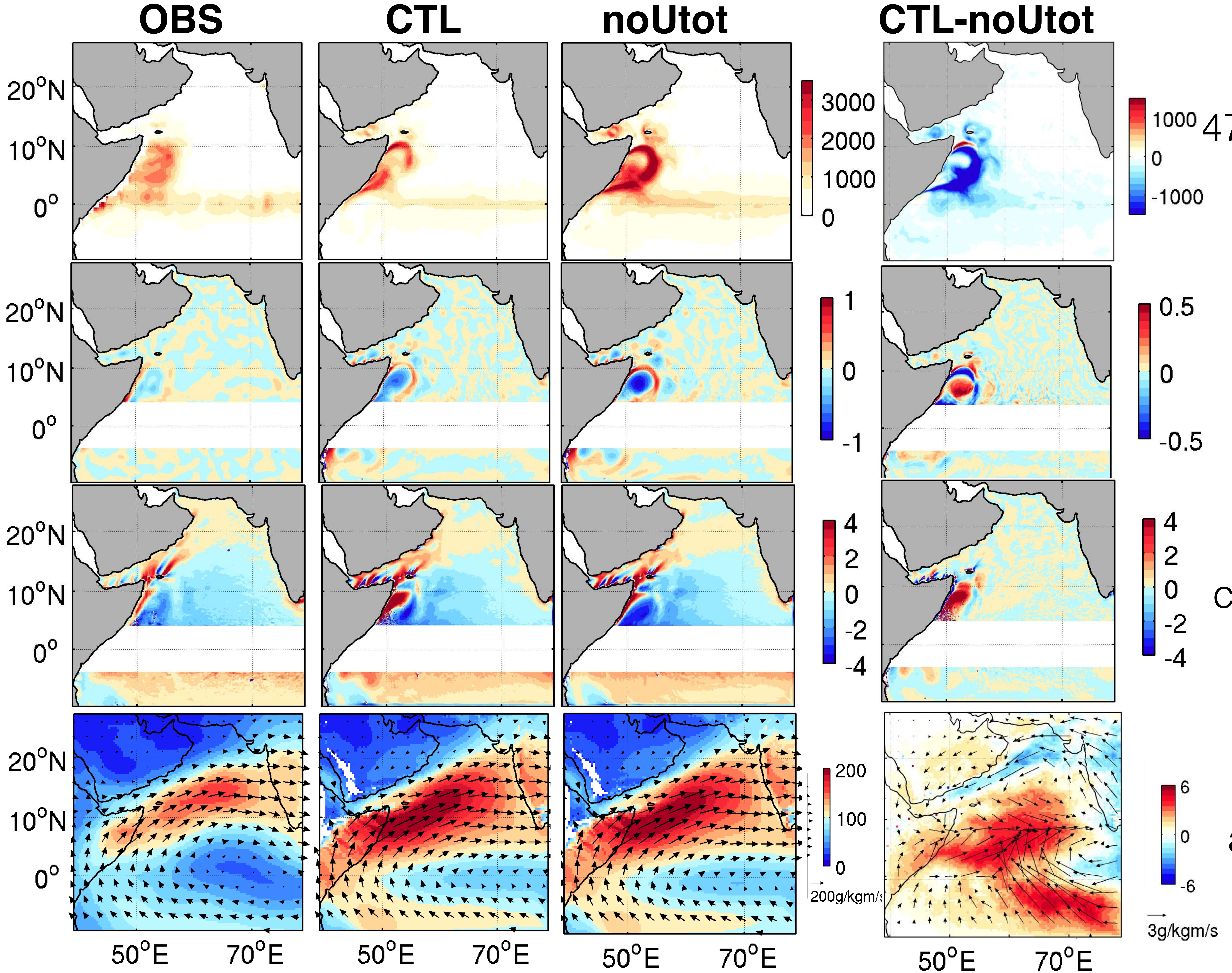
- Would the eddy-wind interactions affect the atmosphere beyond the boundary layer?

Rectified changes in SST and rainfall



- SST anomalies are driven by the changes in offshore temperature advection in the mixed layer.
- Small (3-7%) change in rainfall, but it does reflect the local SST anomaly.

Ongoing work: Arabian Sea circulation system and the Findlater Jet



EKE (Somali Current)

47% weaker flow fields

ζ/f

Weaker Great Whirl anticyclone

total Ekman pumping

Stronger cyclonic forcing over the GW

Moisture transport by the Findlater Jet

Some intensification and shift in the FJ moisture transport

Planned work: WBCs and the midlatitude storm track

WBC downstream influence on the weather system development

Thanks!

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Seo, Miller, Norris, 2016:
Eddy-wind interaction in the California Current System: dynamics and impacts
J. Phys. Oceanogr., 46, 439-459