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The combined effects of SST and oceanic currents on eddy-scale air-sea interactions : a modeling study

F. Lemarié^{1,2}, F. Colas^{3,1}, J.C. McWilliams¹

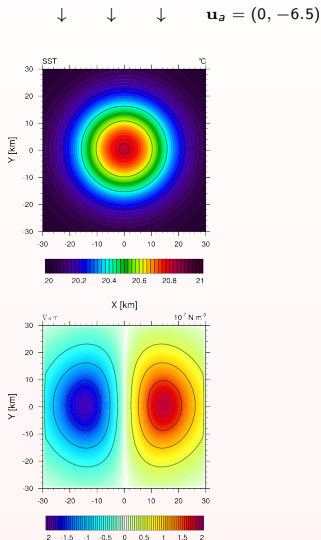
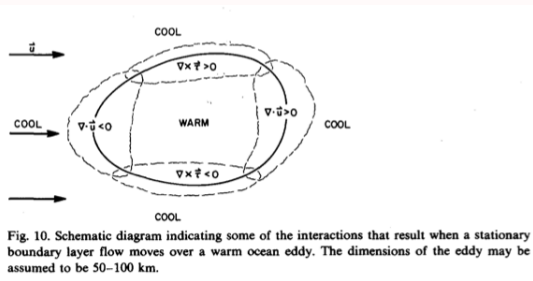
- ¹ UCLA Department of atmospheric and oceanic sciences
- ² INRIA Grenoble (MOISE) / Laboratoire Jean Kuntzmann
- ³ IRD, LOCEAN, Paris

- ▶ Investigate air-sea interactions in mesoscale eddies from two fully-coupled simulations for summertime off US west coast ($\Delta x_{\text{oce}} = \Delta x_{\text{atm}} = 5\text{km}$).
 - Quantify the influence of oceanic surface currents on air-sea momentum transfer.
 - Determine the eddy-related SST and surface currents influence on air-sea interactions
 - Evaluate results against existing observational studies (AMSR, QuikSCAT)

Thermal Coupling (1/2)

Businger J. & Shaw W., 1984. *The response of the marine boundary layer to mesoscale variations in sea-surface temperature. DAO*

⇒ Surface layer / SST coupling through sea-state dependent drag coefficient



Thermal Coupling (2/2)

D. Chelton et al., 2007. *Summertime coupling between sea surface temperature and wind stress in the california current system.* JPO

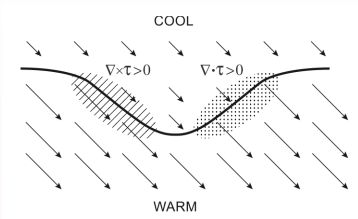
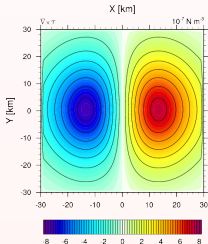
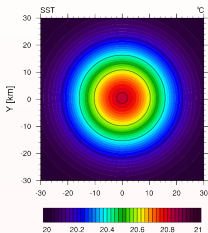


Fig. 3. Schematic summary of the influence of SST on winds near a meandering SST front. The wind stress magnitudes (represented by the lengths of the vectors) are relatively strong over warm water and weak over cold water, which generates local curl and divergence of the wind stress. The curl is strongest where the winds blow parallel to isotherms (hatched region) and the divergence is strongest where winds blow perpendicular to isotherms (stippled region). The wind stress curl and divergence are therefore linearly related to the local crosswind and downwind components of the SST gradient, respectively (see Fig. 7 below).

⇒ expected to be a PBL mixing / SST coupling

$$\begin{cases} \nabla \times \boldsymbol{\tau} = c_1 \nabla \text{SST} \times \hat{\boldsymbol{\tau}} \\ \nabla \cdot \boldsymbol{\tau} = c_2 \nabla \text{SST} \cdot \hat{\boldsymbol{\tau}} \end{cases}$$

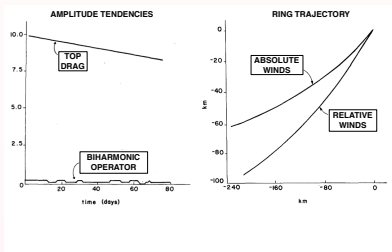
↓ ↓ ↓ $\mathbf{u}_a = (0, -6.5)$



"Top" drag [a.k.a. understress (Bye, 1986)] (1/2)

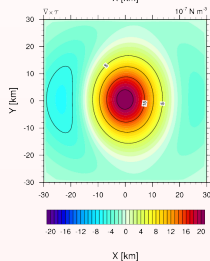
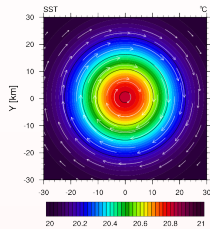
Dewar & Flierl, 1987. *Some Effects of the Wind on Rings*. JPO

$$\begin{aligned}\tau_\lambda &= \rho_a C_D \|\mathbf{u}_a - \lambda \mathbf{u}_o\| (\mathbf{u}_a - \lambda \mathbf{u}_o) \\ &= \rho_a u_*^2 (\mathbf{u}_a, \lambda \mathbf{u}_o) \left(\frac{\mathbf{u}_a - \lambda \mathbf{u}_o}{\|\mathbf{u}_a - \lambda \mathbf{u}_o\|} \right)\end{aligned}$$



⇒ the air-sea interface exerts a drag on both the atmosphere (via wind stress) and the ocean (via understress).

$$\downarrow \quad \downarrow \quad \downarrow \quad \mathbf{u}_a = (0, -6.5)$$



"Top" drag [a.k.a. understress (Bye, 1986)] (2/2)

Duhaut & Straub, 2006. *Wind stress dependence on ocean surface velocity : Implications for mechanical energy input to ocean circulation*. JPO

$$\tau_{\text{diff}} \equiv \tau_0 - \tau_1 \approx \rho_a C_D \|\mathbf{u}_a\| \mathbf{u}_o + \rho_a C_D (\mathbf{u}_o \cdot \hat{\mathbf{u}}_a) \mathbf{u}_a$$

$$\mathbf{P}_{\text{diff}} \equiv \tau_{\text{diff}} \cdot \mathbf{u}_o \approx \rho_a C_D \|\mathbf{u}_a\| [\|\mathbf{u}_o\|^2 + (\mathbf{u}_o \cdot \hat{\mathbf{u}}_a)^2]$$

$\Rightarrow \mathbf{u}_o$ -dependence in τ_1 acts to reduce the power source

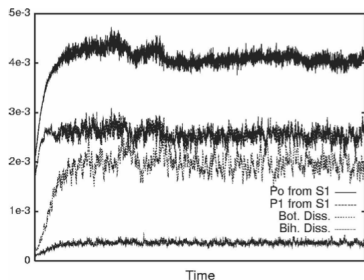
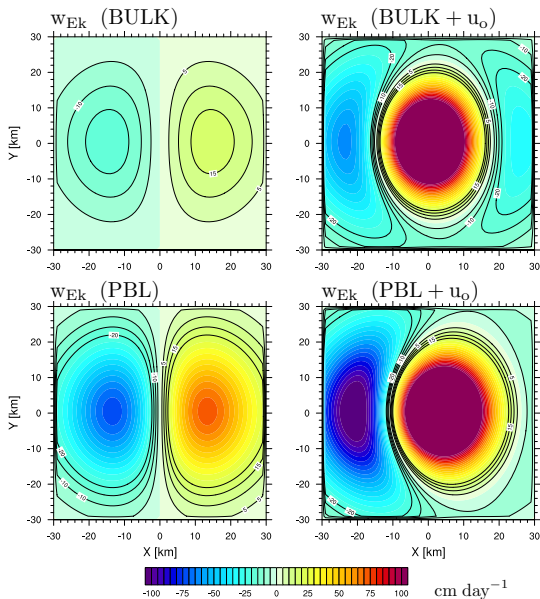


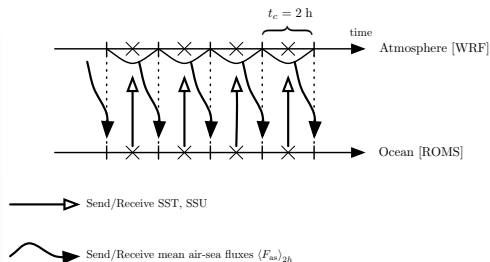
FIG. 2. Time series of various terms in the energy equation (W m^{-2}) for simulation S1: P_0 (top curve), P_1 (second from top), bottom dissipation (third from top), and lateral dissipation (bottom).

Ekman pumping velocity



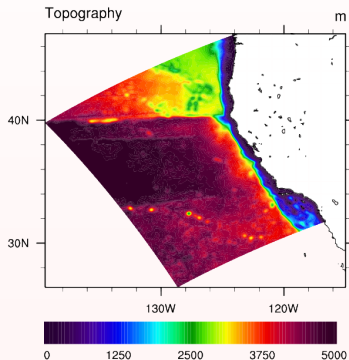
Numerical simulations and coupling strategy

Summertime off US West coast



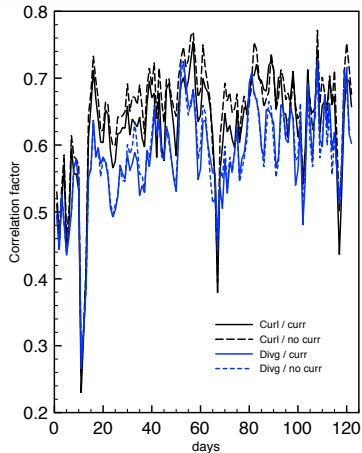
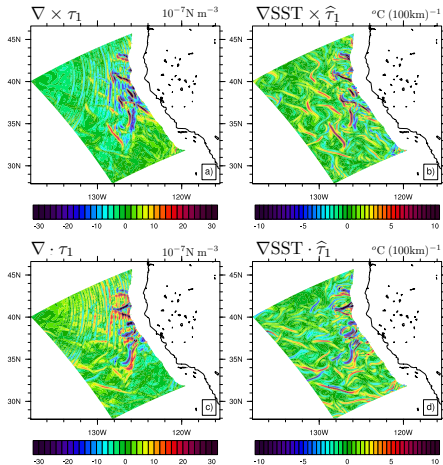
- previously used in (Boé et al., 2011)
- modified **bulk and tridiagonal solver** to include the effect of currents on wind stress
- simulations from Jun. to Sept. 2006

- intense frontal activity (Castelao et al., 2006)
- high wind steadiness (about 0.96)
- low gustiness (0.3)



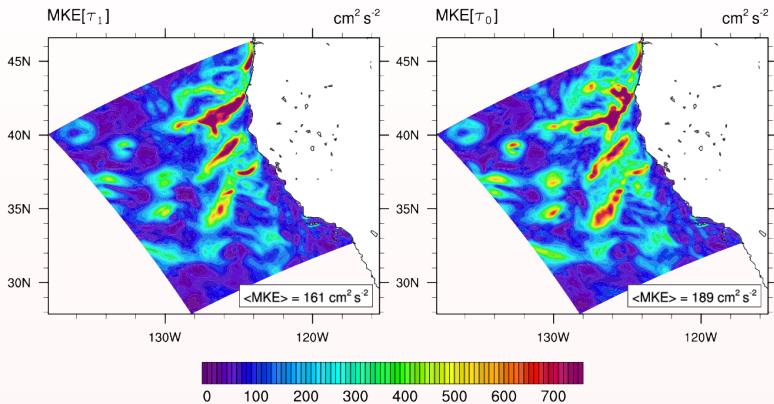
Mesoscale wind-SST coupling relation

$$\begin{cases} \nabla \times \tau & = c_1 \nabla \text{SST} \times \hat{\tau} \\ \nabla \cdot \tau & = c_2 \nabla \text{SST} \cdot \hat{\tau} \end{cases}$$



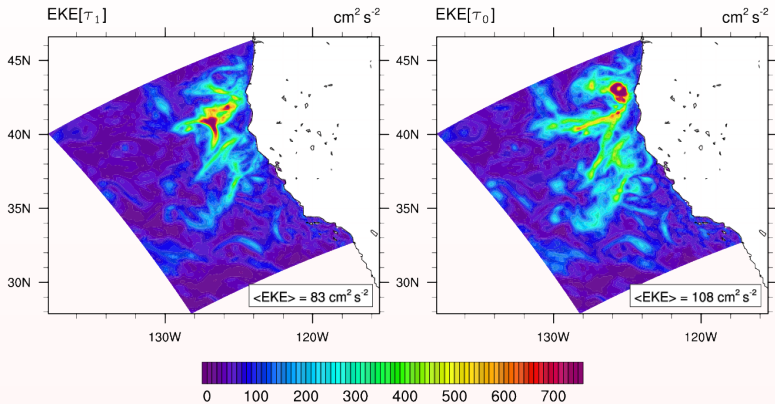
⇒ wind-SST coupling spectrally broad band across scales

Mean kinetic energy $\frac{(\overline{u_o})^2}{2}$



⇒ MKE reduction of approximately 15%

Eddy-kinetic energy $\frac{\overline{u_o'^2}}{2}$



⇒ EKE reduction of approximately 20%

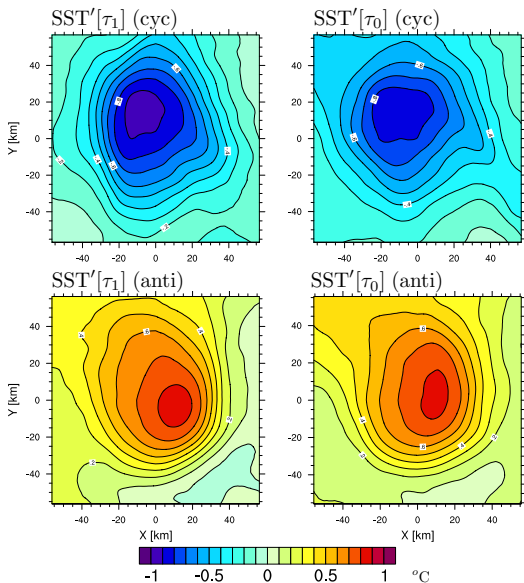
Eddy-scale interactions

- Composite averaging in an eddy-centric coordinate
- Identify mesoscale eddies by closed SLA-contours [Kurian et al., 2011]
- Additional constraints on distance to the coast and wind direction

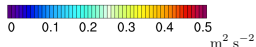
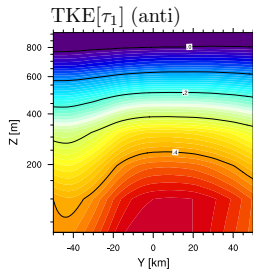
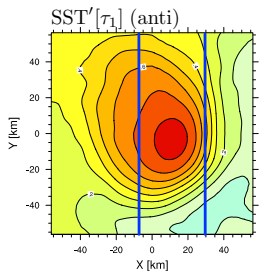
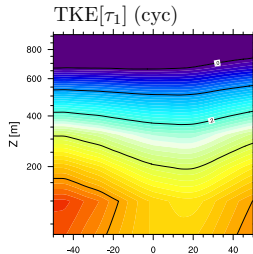
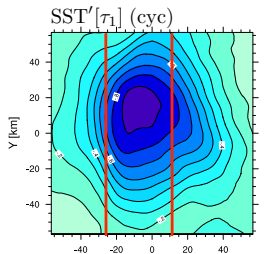
	USW5[τ_1]		USW5[τ_0]	
	cyc	anti	cyc	anti
total	692	1058	794	1336

TABLE : Number of detected eddies in USW5[τ_1] and USW5[τ_0] .

SST anomalies

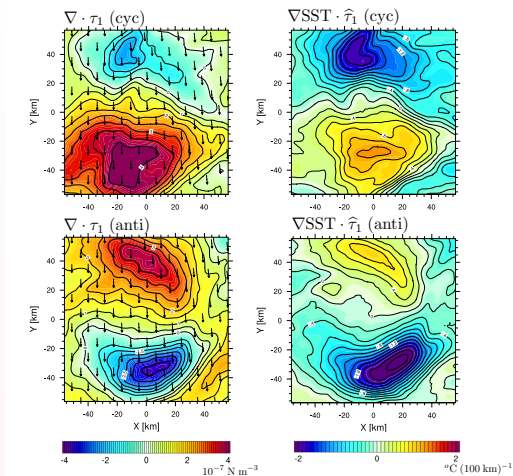


PBL mixing (1/2)



PBL mixing (2/2)

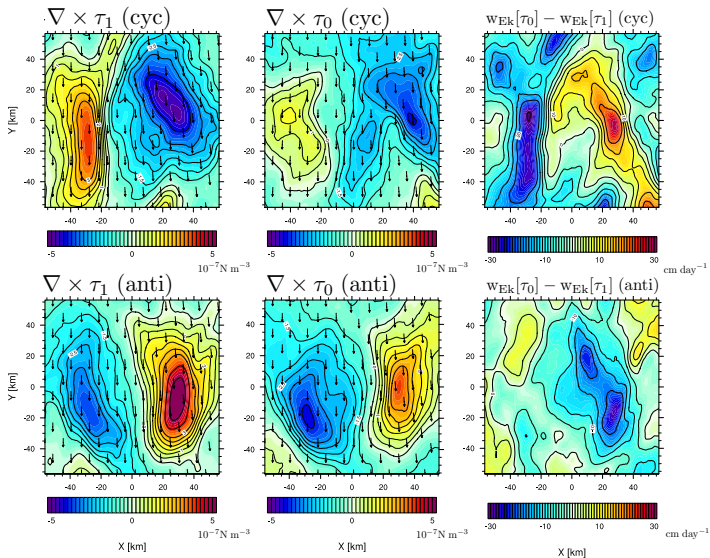
$$\nabla \cdot \tau = c_2 \nabla \text{SST} \cdot \hat{\tau}$$



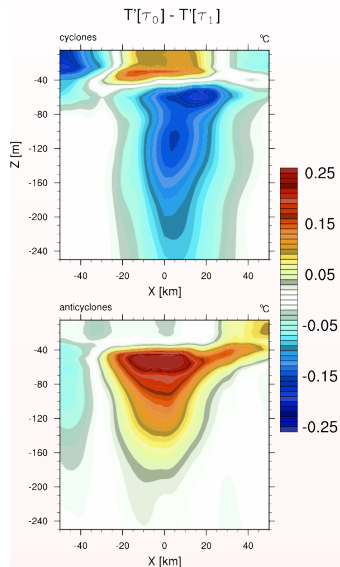
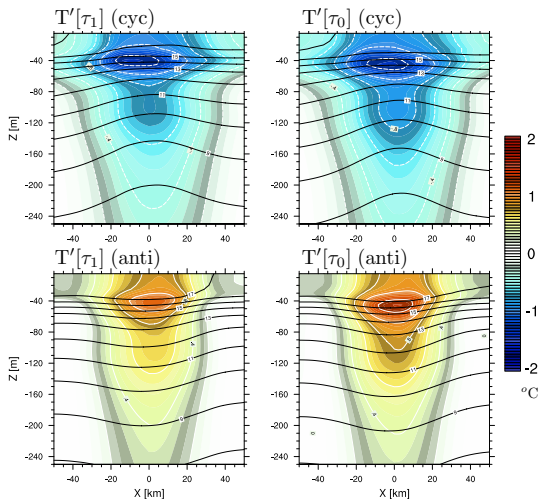
Corr \approx 0.9, Coeff = $0.0244 \text{ N m}^{-2} \text{ }^{\circ}\text{C}^{-1}$

($c_2 = 0.0222 \text{ N m}^{-2} \text{ }^{\circ}\text{C}^{-1}$, Chelton et al., 2007 from observations)

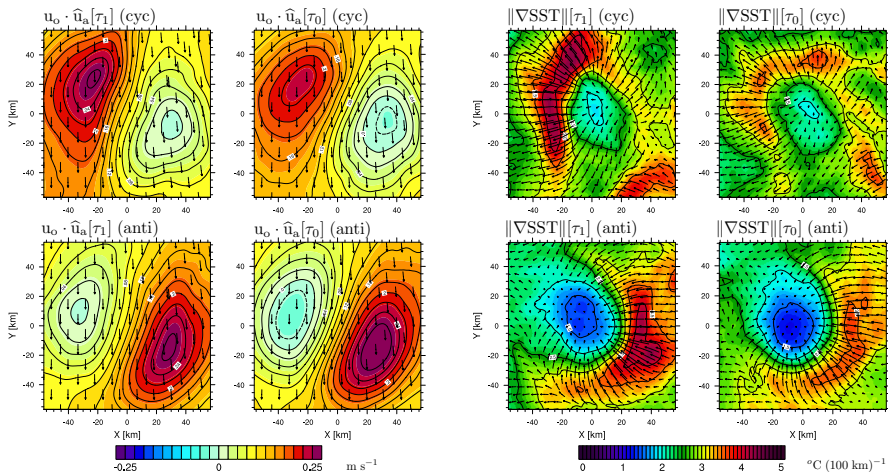
Composite wind stress curl



Temperature anomalies

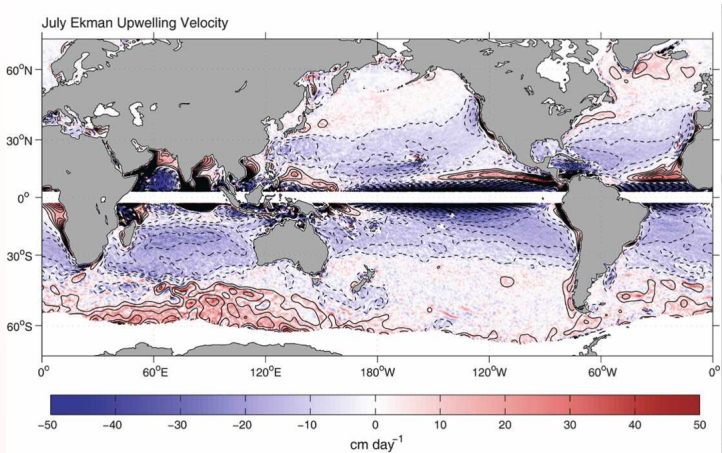


SST fronts and currents



⇒ fronts tend to be intensified where the currents are aligned with wind stress

Large-scale winds



⇒ Eddy-induced Ekman pumping has same order of magnitude as the one associated with SCOW wind stress

Conclusions

- The coupled model reproduces the known air-sea interactions
 - u_o -dependence induces a reduction of oceanic motions
 - PBL anomalies over oceanic fronts
 - Eddy-induced Ekman pumping
- Fronts distribution and intensity are altered by air-sea coupling
- Same resolution is required in the ocean and the atmosphere to represent most of those effects

Perspectives :

- Test in a climate-type global eddying model to assess the large scale impact (ANR PULSATION, S. Masson)
- Open question on the best practice to force an eddying oceanic model (Bulk ? CheapAML ? [Deremble et al., 2011] ??? Coupled)

Bulk formulation

Starting from the Reynolds averaged equations the following assumptions (supposed valid in the atmospheric surface layer) are done

- hydrostaticity + Boussinesq assumption
- horizontal homogeneity
- quasi-stationarity
- Coriolis force and HPG are negligible
- valid only at a certain distance from the air-sea interface, above the direct influence of the surface roughness elements.

B. Large, Ocean Weather Forecasting : An Integrated View of Oceanography :

"The sign of turbulent fluxes can be uncertain on time scales less than 10 minutes and hourly fluxes are more relevant"

"When averaging, the uncertainty should diminish as wave effects start to average out"

"The transfer coefficients C_D and C_H are determined empirically from measurements averaged over about an hour (e.g. Large and Pond 1981) and are not applicable for instantaneous output from an atmospheric model grid point."