Effect of Eddy-Wind Interaction on Ekman pumping and Eddy Kinetic Energy in the California Current System: A Regional Coupled Modeling Study

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Surface wind stress

\[ \tau = \rho \ C_D (U_a - U_o) \ |U_a - U_o| \]

resulting wind stress
\[ \tau \approx \tau_b + \tau_{SST} + \tau_{ob} + \tau_{oe} \]

ocean surface current
\[ U_o = U_{ob} + U_{oe} \]

10m wind speed
\[ U_a = U_{ab} + U_{aSST} \]

(Chelton et al. 2001)

Effects of \( \tau_{SST} \) and \( \tau_{CUR} \) on the ocean?
SST-τ coupling effect: Jin et al. (2009) 
an idealized ocean model with empirical coupling of SST and τ

- Reduces alongshore wind stress, baroclinic instability and Ekman transport
10% reduction in EKE in the mid-latitude and ~50% in the tropics
Primarily due to increased eddy drag ($\mathbf{\tau}' \cdot \mathbf{u}'$, direct effect)
Change in baroclinic and barotropic instability (indirect effect) of secondary importance
Result from previous studies and goal of this study

- Previous studies considered either SST or $u_{sfc}$ in $\tau$ formulation in ocean-only models and saw weakened eddy variability.
- This study examines the relative importance of SST and $u_{sfc}$ ($u_{ob}$ vs $u_{oe}$) in a fully coupled model, where wind speed adjusts to SST.
Regional coupled model

Scripps Coupled Ocean-Atmosphere Regional Model

- Atmosphere
  - WRF
    - 6-h NCEP FNL
  - SST & U_sfc
    - atmos. states (WRF PBL/sfc schemes) or sfc. fluxes (bulk param)

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

- Seo et al. 2014 (WRF-ROMS)
- An input-output based coupler; portable, flexible, expandable

- Smoothing of mesoscale SST and sfc current (Putrasahan et al. 2013)
Experiments

\[ \tau = \rho C_D (U_a - U_o) |U_a - U_o| \]

\( T_{\text{tot}} = T_b + T_e \)

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

<table>
<thead>
<tr>
<th>Experiments</th>
<th>( T_b )</th>
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Experiments

\[ \tau = \rho C_D (U_a - U_o) |U_a - U_o| \]

\[ T_{\text{tot}} = T_b + T_e \]
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effect of mesoscale surface temperature \((T_e)\)
Experiments

\[ \tau = \rho C_D (U_a - U_o) |U_a - U_o| \]

\[ T_{\text{tot}} = T_b + T_e \]
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effect of mesoscale surface current \((U_e)\)
Experiments

\[ \tau = \rho C_D (U_a - U_o) |U_a - U_o| \]

\[ T_{tot} = T_b + T_e \]
\[ U_{tot} = U_b + U_e \]

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effect of mesoscale surface temperature \((T_e)\) and current \((U_e)\)
Experiments

\[ \tau = \rho C_D (U_a - U_o) |U_a - U_o| \]

\[ T_{\text{tot}} = T_b + T_e \]
\[ U_{\text{tot}} = U_b + U_e \]

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effect of total surface current \((U_{\text{tot}}=U_e+U_e)\)
• $T_e$ no impact
• 25% weaker EKE with $U_e$
• 30% weaker EKE with $U_b+U_e$
Cross-shore vs depth EKE

CTL EKE

CTL-noTe

CTL-noUe

CTL-noTeUe

CTL-noUtot

cm²s²

alongshore averages
Eddy kinetic energy budget

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

\[-g \rho' w' + \rho_o (\bar{u}' \cdot (\bar{u}' \cdot \nabla \bar{U})) + \bar{u}' \cdot \bar{\tau}' + \varepsilon\]

baroclinic conversion (BC)

barotropic conversion (BT)

wind work (P)
(or eddy drag)

Significant difference in only P

Upper 100 m average

\[ H \approx fL/N, \text{ where } f=10^{-4}, L=10^4 \text{m}, N=10^{-2} \rightarrow H=10^2 \text{m} \]
Comparison of wind work ($P = \tau' \cdot u'$)

- No significant change associated with $T_e$
- 17% weaker $P$ with $U_e$
- 23% weaker $P$ with $U_b+U_e$

### Table

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<th>Exp</th>
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<tr>
<td>CTL</td>
<td>1.33</td>
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<tr>
<td>no$T_e$</td>
<td>1.38</td>
</tr>
<tr>
<td>no$U_e$</td>
<td>1.61</td>
</tr>
<tr>
<td>no$T_eU_e$</td>
<td>1.62</td>
</tr>
<tr>
<td>no$U_{tot}$</td>
<td>1.73</td>
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[10^{-5} \text{ kgs}^{-1}\text{m}^{-3}]
Cross-shore distribution of EKE and $P$

- Positive $P (u' \cdot \tau')$ with the maximum near the coast (20-30 km).
  - $v'$ is a linear response to $\tau_y'$, increasing EKE.

- $P$ decreases by 20-25% 100-300 km offshore with $U_e + U_b$
Zonal and meridional components of wind work

Both directions contribute equally to the decreased P and EKE.

\[ P_x = u' \cdot \tau_x' \]

\[ P_y = v' \cdot \tau_y' \]

\[ u' \cdot \tau_x' \]

\[ v' \cdot \tau_y' \]

- Decrease in P (or increase in eddy drag) by \( u' \cdot \tau_x' \) is -0.14

- Decrease in P by \( v' \cdot \tau_y' \) is -0.16

\[
\begin{align*}
\text{CTL} & = -0.47 \\
\text{noTe} & = -0.53 \\
\text{noUe} & = -0.33 \\
\text{noTeUe} & = -0.38 \\
\text{noUt} & = -0.31
\end{align*}
\]

\[
\begin{align*}
\text{CTL} & = 1.74 \\
\text{noTe} & = 1.86 \\
\text{noUe} & = 1.90 \\
\text{noTeUe} & = 1.97 \\
\text{noUt} & = 2.0
\end{align*}
\]
Change in offshore (onshore) temperature advection by mean current mainly responsible for the cold (warm) SST.
Summary

• Examined the relative importance of $\tau_{SST}$ vs $\tau_{current}$ in the EKE in the CCS using a fully coupled SCOAR model.

• Surface EKE is weakened by $\sim$25% due to mesoscale current.
  • $\sim$5% further weakening by background current.
  • SST has no impact.

• EKE budget analysis: wind work ($P = \tau' \cdot u'$) is weakened with the mesoscale current (17%) and background current (23%)
  • SST has no impact.
  • Comparable contribution from zonal (eddy drag) and meridional (wind work) direction.

• Change in SST pattern is related to change in mean and eddy horizontal temperature advection.
Thanks!