Coupled Ocean-Atmosphere Interactions over Oceanic Boundary Currents

Impact of ocean eddy-forced wind stress variability
- California Current System (Seo et al. 2016, JPO)
- Somali Current (Seo 2017, JCLI)
- East India Coastal Current (Seo et al. 2019, DSR-II)

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Two ways an ocean eddy influences wind stress

Ekman vertical velocity

No net effect on eddy intensity but shifts the position

\[ \tau = \rho_a C_D (W - U)^2 \]

\[ W = W + W' \]

\[ U = U + U' \]

SST-wind coupling

Gaussian warm-core eddy

SSTA=0.63C, \( u_g = 0.13 \text{m/s} \), wind=7m/s
Correlation bet’n high-pass filtered wind speed and SST

2000-2009 daily QuikSCAT WS NOAA-OI SST

1000 km zonal highpass filter

95% significance level

Seo 2017
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SSTA=0.63C \( u_g = 0.13 \) m/s, wind=7m/s

**Current-wind coupling**

Ekman vertical velocity

Reduces the eddy activity and increases the stratification
Correlation bet’n relative vorticity and wind stress curl

2000-2009 daily AVISO SSH and QSCAT curl

N/m² per 10^4 km
Can we quantify these two distinctive coupled effects on the ocean boundary currents and atmosphere?
Effect of total ocean currents on stability of flows: Well-known

\[ \tau = \rho_a C_D (W - U)^2 \]

CTL

\[ \tau = \rho_a C_D W^2 \]

noRW

Histogram of Rossby number

Seo et al. 2019
With the RW effect, depth-integrated EKE is reduced.

- AVISO
- CTL
- noRW

Reduction nearly by 100%

CCS 53%
SC: 26%

EKE damping largely due to reduction in eddy wind work in the KE budget
Testing the effect of “eddy-mediated” air-sea coupling in a coupled model with an online eddy filtering

2D Loess smoothing at each coupling to remove the fine-scale ocean variability “seen” by the atmosphere.

Use half-power filter cutoff wavelength of **300-500 km**

Putrasahan et al. (2013); Seo et al. (2016); Seo (2017)
Impact of “mesoscale SST”-wind coupling

- Mesoscale SST-wind coupling shift the position of the eddy fields, with no apparent difference in intensity.

**Surface EKE**

- **OSCAR**: Shows a higher EKE concentration near the equator, with a peak around 15°N.
- **CTL**: The EKE distribution is similar to OSCAR, with a peak around 15°N but slightly lower intensity.
- **noTe**: The EKE distribution is shifted downstream, with a peak around 15°N and a slightly higher intensity compared to OSCAR and CTL.

**SSH 15cm**

- **Downstream shifted Great Whirl**: The SSH map shows a downstream shift in the eddy field, with SSH values decreasing from west to east.
- **SSH 15cm**: The SSH distribution is consistent with the downstream shift in the Great Whirl, with SSH values decreasing from west to east.

- **CTL noTe**: The SSH distribution shows a downstream shift, with SSH values decreasing from west to east.

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“Mesoscale current”-wind coupling also affects the upper ocean stratification

Decreased MLD: CTL-noRW

Increased N^2 in the upper 300m

N^2: Increased just below the MLD & decreased near the thermocline

$\Delta N^2$: CTL-noRW

contour of $\Delta$MLD=2m

MLD shoals by 15% south of the separated EICC latitude due to upward displacement of the isopycnals below ML
Why upward displaced isopycnals within the anticyclonic eddies?

\[
W_{\text{tot}} = \frac{\nabla \times \tau}{\rho_0 (f + \zeta)} + \frac{1}{\rho_0 (f + \zeta)^2} \left( \tau_x \frac{\partial \zeta}{\partial y} - \tau_y \frac{\partial \zeta}{\partial x} \right) + \frac{\beta \tau_x}{\rho_0 f^2} + \frac{\alpha_T \nabla S}{W_{\text{SST}}}.
\]

Ekman upwelling induced by the mesoscale current-wind coupling raises the upper isopycnals under an anticyclonic eddy.

Small in the BoB

McGillicuddy (2015)
Summary

- Modulation of wind stress by mesoscale processes in the boundary current systems is recognized as a key player in the kinetic energy balance.
  - **Dependent on spatial scales**, strongest in the BoB at Ro~0.5 to 1.

- Mesoscale SST and current influence the wind stress different way, resulting in **distinct feedback impacts** on the oceans.
  - SST-wind affects the positions (GW shifted downstream, SC separation delayed)
  - Current-wind attenuates the intensity and increases the stratification under anticyclones.

- (not discussed today) Eddy-mediated air-sea coupling exerts **rectified effects** on ocean circulation/SST, inducing spatially coherent atmospheric responses.
  - Winter storminess and rainfall in the US West Coast (Seo et al. 2016)
  - Summer Monsoon Findlater Jet in the Arabian Sea (Seo 2017)

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Impact on the atmosphere? Yes, some downstream influence…

- Small (~5%) but significant changes in the axis of the FJ and the moisture transport
Impact on the atmosphere? Yes, some downstream influence.

- Some rectified effects on mean SST and rainfall; O(5%) changes to the mean.

- The spatial coherency between the offshore patterns and near-coastal patterns suggests a coastal land influence of the perturbed mean SST due to air-sea interaction.
Reduction of EKE and eddy wind work most effective at wavelengths of \(~80-100\) km, the 1st baroclinic Rossby deformation radius at 16N.