Eddy-driven air-sea interaction and feedback in the western Arabian Sea

Hyodae Seo
Physical Oceanography Department
Woods Hole Oceanographic Institution

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Air-sea interaction in the Arabian Sea

- Cold, salty, deep ML by the Findlater Jet
- Unstable boundary current, coastal upwelling, and strong eddy activity
- **Strong eddy-driven air-sea coupling**
  - affecting energetics of the current system, the low-level structure of the FJ, and the monsoon rainfall

**Arabian Sea**

Xie et al. 2006
Eddy-driven air-sea interactions thru wind stress

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

Composites in the Southern Oceans

- SST
- Wind speed

Anti-Cyclone

Positive correlation between JJA high-passed SST & wind

Frenger et al. 2013

10m wind

\[ U_a = U_{ab} + U_{aSST} \]
Eddy-driven Ekman pumping

\[ \tau = \rho C_D (U_a - U_0) |U_a - U_0| \]

*surface current

\[ U_0 = U_{ob} + U_{oe} \]

*10m wind

\[ U_a = U_{ab} + U_{aSSST} \]

An anticyclonic eddy in the Southern Ocean (Chelton 2013)

SST and SSH

Dipole

Monopole

Affect the propagation

Affect the amplitude
Eddy-driven Ekman pumping in the AS

25km SCOAR regional coupled model simulation for the Indian Ocean

- Ekman velocities of 2-3 m/day over the cold filament, persisting >1 month

\[ W_{ek} = \frac{\nabla \times \tau}{\rho_0 f} \]

\[ W_{ek} = \frac{\nabla \times \tau}{\rho_0 (f + \zeta)} \]

Day=173 from 6/1/2002 to 8/31/2002

SST & SSH

Wek m/day

w at the bottom of ML

\( \zeta/f \)

- SST and surface current both important for Ekman pumping

Relative effects of eddy-driven air-sea interaction via SST and surface current?
Quantifying the effect of eddy-driven air-sea coupling

Scripps Coupled Ocean-Atmosphere Regional Model

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

WRF or bulk physics

\[ \tau (Q & FW) \]

Ocean

6-h coupling

SST & U_{sfc}

\[ \text{Ttot}, \text{Tb}, \text{Te}, \text{Ub}, \text{Ue} \]

6-h NCEP FNL

\[ \text{monthly SODA} \]

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

Exp | τ formulation includes
--- | ---
CTL | T_{b}, T_{e}, U_{b}, U_{e}
nOT_{e} | T_{b}, T_{e}, U_{b}, U_{e}
nO{U_{e}} | T_{b}, T_{e}, U_{b}, U_{e}
Summertime EKE in the CCS

- 42% reduction of EKE by $U_o$ effect, but $U_a$ has no strong effect
- Changes in baroclinic and barotropic energy conversion are small.
- The EKE reduction is largely explained by the enhanced eddy surface drag.

EKE budget:

$$K_e + \bar{U} \cdot \nabla K_e + \bar{u}' \cdot \nabla K_e + \nabla \cdot (\bar{u}' p') = + \rho_o (\bar{u}' \cdot (\bar{u}' \cdot \nabla \bar{U})) - g \rho' w' + \bar{u}' \cdot \bar{\tau}' + \epsilon$$
Eddy-driven Ekman pumping velocity

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

Stern 1965

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

background wind stress

\[ = \frac{\nabla \times \tilde{\tau}}{\rho_o (f + \zeta)} - \frac{1}{\rho_o (f + \zeta)^2} \left( \tilde{\tau}_y \frac{\partial \zeta}{\partial x} - \tilde{\tau}_x \frac{\partial \zeta}{\partial y} \right) + \frac{\beta \tilde{\tau}_x}{\rho_o (f + \zeta)^2} + \frac{\nabla \times \tau'_{SST}}{\rho_o (f + \zeta)}. \]

\[ W_{LIN} \quad W_{\zeta} \quad W_{\beta} \quad W_{SST} \]

Curl-induced linear Ekman pumping

Vorticity gradient-induced nonlinear Ekman pumping

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

Chelton et al. 2007

\[ \beta \text{ Ekman pumping (negligible)} \]

SST induced Ekman pumping

\[ \text{Ekman pumping} \]
Estimating eddy SST-driven Ekman pumping velocity

\[ W_{SST} = \frac{\nabla \times \tau'_{SST}}{\rho_0 (f + \xi)} \approx \alpha_c \nabla c_{SST} / \rho_0 (f + \xi) \]

Chelton et al. 2007

\[ \alpha_c = 0.8 \]
\[ \alpha_c = 0.6 \]

JAS 2005-2009: OBS based on QuikSCAT wind stress and TRMM SST
The estimated Ekman pumping velocity

\[ W_{\text{TOTe}} = \left( \frac{\nabla \times \tau_b}{\rho_0 (f + \zeta)} \right) + \left( \frac{\nabla \times \tau_{\epsilon}}{\rho_0 (f + \zeta)} \right) - \frac{\tau_b \times \nabla \zeta}{\rho_0 (f + \zeta)^2} \]

JAS 2005-2009: OBS based on AVISO SSH & QuikSCAT wind stress
5. Impact on Ekman pumping velocity

The change in wind stress via SST and surface current leads to anomalous Ekman pumping. This section examines the relative contribution from the SST and surface current on the Ekman pumping velocities in the CCS and how they are related to the eddy energetics in the CCS.

When the Rossby number (\( Ro = \frac{\zeta}{f}, \) the ratio of relative (\( \zeta \)) to planetary (\( f \)) vorticity) is not small, the Ekman pumping depends on the total vorticity \( f + \zeta \) (Stern 1965; Mahadevan et al. 2008), such that the total Ekman pumping velocity \( (W_{TOT}) \) can be approximated following Gaube et al. (2015) as

\[
W_{TOT} = \nabla \times \tau_b \rho_0 \left(f + \zeta\right) + \nabla \times \tau_e \rho_0 \left(f + \zeta\right) - \tau_b \times \nabla \zeta \rho_0 \left(f + \zeta\right)^2 + \beta \tau_x \rho_0 \left(f + \zeta\right)^2.
\]

The estimated total Ekman pumping velocity \( (W_{TOT}) \) is the sum of the linear Ekman pumping and the nonlinear Ekman pumping. The third term, negligible, is associated with the interaction between \( \beta \) and the zonal wind stress. Since the SST effect on wind stress curl is included in the first term, Gaube et al. (2015) separated it from the background linear wind stress curl by spatially filtering out the SST-induced wind stress \( \tau_e \) from the background wind stress \( \tau_b \). We use the 5° lowess filter in this analysis. Therefore, the estimated total Ekman pumping velocity is

\[
W_{TOT} = \nabla \times \tau_b \rho_0 \left(f + \zeta\right) + \nabla \times \tau_e \rho_0 \left(f + \zeta\right) - \tau_b \times \nabla \zeta \rho_0 \left(f + \zeta\right)^2 + \beta \tau_x \rho_0 \left(f + \zeta\right)^2.
\]
Summary and Research Plan

• AS is eddy-rich. Understanding dynamics and impact of **eddy-driven air-sea interaction (both thermal and momentum)** is of my primary interest.

• From the NASCar measurements, I am interested in knowing the observed spatial-temporal structure of meso- and submeso-scale eddies and surface Ekman currents.

• From regional model simulations, I will examine
  • Local impact on the energetics and stability of the current system
  • Influence on the Findlater Jet and the downstream monsoon rainfall
Thanks
hseo@whoi.edu