Wind drift and air-sea coupling in simulations of the northern California Current System

R. M. Samelson, D. B. Chelton, E. D. Skyllingstad, L. W. O’Neill

rsamelson@coas.oregonstate.edu

IOVWST Meeting
Portland, ME
May 2019
Coupled ocean-atmosphere simulations

WRF atmosphere (12 km)  
ROMS ocean (2 km)  
COAWST coupled framework

Ocean simulation initialized from interpolated HYCOM analysis in October 2008; coupled model simulation begins 7 March 2009.

Analysis period: Jun – Sep 2009.

Five different WRF PBL schemes: YSU, GBM, UW, MYJ, MYNN2

Coupling coefficients computed for northern CCS region for anomalies of monthly means from seasonal (JJAS) means.
Coupling coefficients (divergence and curl)

SST-stress

$\text{div } \tau$ vs. DWSST  $\text{curl } \tau$ vs. CWSST

![Graphs showing coupling coefficients](image)

$10^7 \times \text{div stress} - 10^5 \times \text{DW}$

$10^7 \times \text{curl stress} - 10^5 \times \text{CW}$

### SST-stress

- $\text{div } \tau$ vs. DWSST
  - GBM: 1.53
  - Obs: 3.42

- $\text{curl } \tau$ vs. CWSST
  - GBM: 1.55
  - Obs: 2

### Wind Stress

- $10^5 \times \text{div } u_{10N} - 10^5 \times \text{DW}$
  - GBM: 0.69
  - Obs: 0.97

- $10^5 \times \text{curl } u_{10N} - 10^5 \times \text{CW}$
  - GBM: 0.62
  - Obs: 0.56

### SST

- $10^5 \times \text{div } u_{10} - 10^5 \times \text{DW}$
  - GBM: 0.45
  - Obs: 0.97

- $10^5 \times \text{curl } u_{10} - 10^5 \times \text{CW}$
  - GBM: 0.39
  - Obs: 0.56
Coupling coefficients (divergence and curl)

**a)** div stress (x - CCS8; solid - QSCAT)

**b)** curl stress (o - CCS8; solid - QSCAT)

**c)** div $u_{10N}$, div $u_{10}$ (x - CCS8; solid - QSCAT)

**d)** curl $u_{10N}$, curl $u_{10}$ (o - CCS8; solid - QSCAT)

stress

10-m ENS wind

10-m wind

div vs. DWSST

curl vs. CWSST
Coupling coefficients (divergence and curl)

Stress

- div vs. DWSST (x)
- curl vs. CWSST (o)

10-m ENS wind

Agulhas Return Current (Perlin et al. 2014)

Stronger ARC mean winds → stronger heat flux anomaly → stronger coupling?
Model wind coupling coefficients vs. height

Div u                  curl u (vorticity)

1500 m

pressure (height)

1500 m

pressure (height)

DWSST  CWSST  DWSST  CWSST

mid-level reversal
Coupling coefficients vs. height – log-Ekman model

SST-Ek-VG-a

Div \(u\) curl \(u\) (vorticity)

DWSST

CWSST

-2x
1500 m

mid-level reversal

Case-a: \(\text{Div } u_p\) or \(\text{Curl } u_p\)

Case-a: \(\text{Div } u_p\) or \(-\text{Curl } u_p\)

Oregon State University
College of Earth, Ocean, and Atmospheric Sciences

NASA
Surface current coupling

The wind stress should (does; see e.g., Edson et al. 2013) depend on the difference between surface wind and surface current...

...so compute stress based on relative wind, the difference of 10-m wind and ocean surface current.
Surface current coupling – CCS model

Offshore decay of EKE enhanced with surface current coupling, likely related to systematic damping of mesoscale eddies from relative wind effect (e.g., Gaube et al., 2015)
Surface current coupling

The wind stress should (does; see e.g., Edson et al. 2013) depend on the difference between surface wind and surface current…

…but, what is this surface current?

That is, what is the relevant surface current in the context of momentum coupling to the atmosphere?

The ocean surface current includes the wind drift…but the wind drift depends on the wind (or wind stress)…. 
Wind drift at sea surface

The oil-spill rule: “3% of the wind speed, 15 degrees to the right (NH) of the wind.”

- J. Wu, JFM, 1975.

New analytical result based only on universality and symmetry arguments (Samelson, JPO, submitted):

$$\bar{U}_*(0) = \frac{\alpha}{1+\alpha} (V*_{G} - U*_{G}) \approx \alpha V*_{G}, \quad \alpha = \frac{u_*}{v_*} = \left( \frac{\rho_a}{\rho_o} \right)^{1/2}$$

For $\rho_a = 1.25 \text{ kg m}^{-3}$ and $\rho_o = 1025 \text{ kg m}^{-3}$, $\alpha \approx 0.035 \ (3.5\%)$. The directional offset arises from the rotation of the 10-m wind relative to the geostrophic wind.
Wind drift – double log-Ekman layer

**Speed profile:**
- Atmos
- Ocean

**Direction profile:**
- Atmos
- Ocean

**Zonal geostrophic wind (0°)**

**Surface wind drift**

**Velocity hodograph:**
- Atmos
- Ocean

**Stress hodograph:**
- Atmos
- Ocean

**Zonal geostrophic wind (0°)**
Surface current coupling

Oil-spill rule: 3% of 7 m s\(^{-1}\) = 21 cm s\(^{-1}\)
This is comparable to typical mesoscale surface geostrophic currents, so the effect (question) cannot be ignored.

Edson et al. 2013:

“When \(C_{DN}\) is computed using relative wind, the data collapse to a consistent fit that is independent of surface current speed…Although more subtle, [there is a] systematic reduction of the relative wind speeds resulting from wind-driven currents, which act to increase \(C_{DN}\)….”
Wind drift and surface current coupling

“Correct” solutions for surface-current coupling:
Practical - Use surface current equivalent to that used in empirical estimates of drag coefficient.
Theoretical - Use surface current that would exist in the absence of the wind.

Empirical estimates use the best-available near-surface current for a given set of flux and wind observations; not systematic. The “absent-wind” current is not easily determined, even in a model.

Two convenient choices:
Uppermost model grid-level current
Geostrophic surface current
The choice of surface current used for coupling affects the response at first order.

EKE ratio:
- sfc curr cpld/SST cpld
- Thin line: coastal
- Thick line: offshore

EKE ratio:
- sfc curr cpld/SST cpld offshore
- Thin line: sfc current
- Thick line: geostrophic sfc current
Surface current coupling – CCS model

- Wind stress (N m⁻²)
- $|u_s - u_g|$ (m s⁻¹), day=171
- SST (°C)
Surface current coupling – CCS model
Conclusions

1. SST coupling:
   - PBL schemes give range of estimates of coupling strength
   - PBL scheme dependence similar to Perlin et al. (2014) for ARC
   - 10-m wind response 30%-50% weaker than 10-m ENS wind response
   - Dependence also on spatial smoothing
   - Reversal in response at PBL mid-level; log-Ekman PBL model
   - CCS coupling weaker than ARC coupling in model;
     mean wind controls heat flux anomaly magnitudes

2. Surface current coupling:
   - What model “surface current” should be used for coupling?
   - New analytical result for surface wind drift (universality, symmetry)
   - Simulations:
     Offshore decay of EKE enhanced with surface current coupling,
     likely related to systematic damping of mesoscale eddies
     from relative wind effect (e.g., Gaube et al., 2015)
     Measurably different responses for coupling through
     uppermost grid-level and geostrophic surface currents