Use of Satellite Observations to Measure Air-Sea Coupling and to Validate Its Estimates from Numerical Atmospheric Models

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Outline

- Satellite products of mesoscale ocean winds and sea surface temperatures
- Air-sea coupling evidence from satellite products
- Atmospheric modeling simulations in Agulhas Return Current region
- Different PBL parameterizations -> different solutions
- Validating of modeled air-sea coupling using satellite estimates
- Role of vertical turbulent mixing in successful surface wind prediction

Satellite products to study air-sea coupling

 SeaWinds scatterometer onboard QuikSCAT satellite (1999-2009): Multi-year measurements of ocean winds, nearly global daily coverage on a 0.25° grid, product of NASA/Jet Propulsion Laboratory

http://winds.jpl.nasa.gov/missions/quikscat/index.cfm





 NOAA Sea Surface Temperatures, Optimum Interpolation based on AMSR-E and AVHRR satellite products, daily on a 0.25° grid (2002-2011)

http://www.ncdc.noaa.gov/oa/climate/research/sst/oi-daily-information.php

Air-sea interaction: scale dependency

<u>Larger scales</u> > 1000km: Negative correlations are found between the sea surface temperature (SST) and wind speed (Xie, 2004)

=> Atmosphere is driving the ocean (one-way forcing)

<u>Ocean mesoscales</u> <1000 km: Positive correlation has been found between the mesoscale SST variations and near-surface wind speed and surface fluxes (Chelton et al., 2001; O'Neill et al., 2005)

=> Ocean is forcing the atmosphere (possible two-way interaction)

Chelton and Xie, 2010: Coupled ocean-atmosphere interaction at oceanic mesoscales). *Oceanography*, 23. (A review paper) Small et al, 2008: Air-sea interaction over ocean fronts and eddies. *Dyn. of Atm. and Oc.,* 45.

Coupling of SST and wind stress magnitude

High-pass filtered wind stresses (colors) and SST (contours)



SST: Agulhas Return Current

(*From Small et al., 2008*) Fig. 2. Maps of spatially high-pass filtered 2 months (May–June 2003) average wind stress magnitude (Nm⁻², color) and SST (°C, contours, interval 0.5 °C, zero contour omitted). Data from QuikSCAT scatterometer and AMSR-E. (a) North-west Pacific, Kuroshio region, (b) North-west Atlantic, Gulf Stream andNorth Atlantic Current region, (c) South-west Atlantic, Brazil-Malvinas confluence, and (d) Southern Indian Ocean, Agulhas Return Current.

Atmospheric model simulations: WRF and COAMPS

Weather Research and Forecast model -NCAR/NOAA/NCEP

COAMPS model

(atmospheric component) -Naval Research Laboratory

Monthly average of satellite SST estimate (°C) for July 2002, from NOAA OI 0.25° daily SST analysis. Black rectangles outline the location of model simulations domains, outer and nested domains having 75km and 25km grid box spacing, respectively. There are 50 vertical levels in each of the model grids, stretching from the ground to about 18km; 22 levels lie in the lowest 1000m.

Atmospheric model simulations: WRF and COAMPS

The models are initialized and forced with global NCEP FNL Operational Global Analysis data on 1.0°x1.0° grid at 6-h intervals, the product from the Global Data Assimilation System (GDAS) and NCEP Global Forecast System (GFS) model.

experiment name	PBL type scheme	PBL scheme reference	sfc. flux scheme (sf_sfclay_physics)	
WRF_GBM (*)	1.5 order closure	Grenier and Bretherton (2001), Bretherton et al. (2004)	MM5 Similarity (1)	
WRF_MYJ	1.5 order closure	Janjic (1994, 2001)	Eta Similarity (2)	
WRF_MYJ_SFCLAY	1.5 order closure	Janjic (1994, 2001)	MM5 Similarity (1)	
WRF_MYNN2	1.5 order closure	Nakanishi and Niino (2006)	MM5 Similarity (1)	
WRF_CAMUW	1.5 order closure	Brethernon and Park (2009)	MM5 Similarity (1)	
COAMPS_ipbl=1	1.5 order closure	Mellor and Yamada (1982), Yamada (1983)	Louis (1979), COARE-2.6 (water)	
COAMPS_ipbl=2	1.5 order closure	Mellor and Yamada (1982), Yamada (1983)	Louis (1979), COARE-2.6 (water)	
WRF YSU	non-local <i>-K</i>	Hong, Noh and Dudhia (2006)	MM5 Similarity (1)	
WRF GFS	non-local <i>-K</i>	Hong and Pan (1996)	NCEP GFS (3)	

(*) – GBM: Grenier-Bretherton-McCaa PBL scheme, implemented in WRFv3.3 (local), WRFv3.5 (public)

PBL parameterization and turbulent vertical mixing schemes

The momentum equation for the u-component of horizontal flow: $\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - v \frac{\partial u}{\partial y} - w \frac{\partial u}{\partial z} - \frac{1}{\rho} \frac{\partial P}{\partial x} + vf - \underbrace{\partial (u'w')}_{\partial z} \quad \text{Subgrid scale vertical turbulent flux to be parameterized!!!!}$ flux \propto to local gradient $u'w' = -K_M \frac{\partial \overline{u}}{\partial z} \longrightarrow -\frac{\partial (u'w')}{\partial z} = \frac{\partial}{\partial z} \left(K_M \frac{\partial \overline{u}}{\partial z} \right), \quad -\frac{\partial (u'w')}{\partial z} = \frac{\partial}{\partial z} \left(K_M \frac{\partial \overline{u}}{\partial z} - \gamma_c \right),$ Eddy/turbulent mixing coefficient $C_{M} = -K_M \frac{\partial \overline{u}}{\partial z} \longrightarrow -\frac{\partial (u'w')}{\partial z} = \frac{\partial}{\partial z} \left(K_M \frac{\partial \overline{u}}{\partial z} \right), \quad -\frac{\partial (u'w')}{\partial z} = \frac{\partial}{\partial z} \left(K_M \frac{\partial \overline{u}}{\partial z} - \gamma_c \right),$

1.5-order turbulent closure schemes: all level ~2.5 by Mellor and Yamada (1974, 1982) classification

 $K_{M} = l \cdot q \cdot S_{M}$ $q = \sqrt{\left(u^{\prime 2} + v^{\prime 2} + w^{\prime 2}\right)} \quad \qquad \text{Second-order moment!!!}$

Non-local-*K* schemes: often based on Troen and Mahrt (1986)

$$K_{M} = k w_{s} z \left(1 - \frac{z}{h} \right)^{h}$$

boundary layer height

SST from NOAA IO 0.250 satellite-base data product: daily for July 2002

Surface winds and sea level pressure: July 2002

Monthly-average near-surface wind response

$$U_{10mN} = \frac{u_*}{k} \left(\ln \frac{10}{z_0} \right)$$

July 2002 average of 10-m ENS wind perturbations (color), and satellite NOAA AMSR-E/ Reynolds OI SST perturbations (contours, interval 1°C, zero contour omitted, negative dashed). Perturbations result from high-pass filtering, which removes the larger-scale filtering involved signal; loess smoother with 30° longitude and 10° latitude. Wind perturbations are computed for left) (top QuikSCAT satellite wind product (version 4), smoothed with 1.25° x 1.25° loess filter; (other panels) models (WRF v3.3 or COAMPS v4) as indicated, turbulent with various mixing schemes.

Air-sea coupling metric: coupling coefficients

Coupling coefficients between ENS 10-m wind perturbations and SST perturbations fields. Coupling coefficients are estimated as a linear regression slope (red line, marked s values in each panel) of bin-averaged quantities (black dots); shaded gray areas show plus/minus standard deviation for each bin. Dashed blue lines indicate bin population (right blue y-axis). Estimates include range of SST perturbations of approximately -3°C +3°C (bins from to containing >50 data points).

Coupling of SST- and wind stress derivatives

(From Hashizume et al., 2002; courtesy of D. Chelton, CEOAS/OSU)

Schematic illustration of the divergence and curl of the wind and wind stress fields that result from spatial variations of the SST field. Near a meandering SST front (the heavy black line), surface winds are lower over cool water and higher over warm water, shown qualitatively by the lengths of the vectors. Acceleration where winds blow across the SST front generates divergence (green area). Lateral variations where winds blow parallel to the SST front generate curl (red area). The divergence and curl perturbations are proportional to the downwind and crosswind components of the SST gradient, respectively.

Coupling of SST- and wind/wind stress derivatives from QuikSCAT

wind stress curl – crosswind SST gradient

wind stress divergence - downwind SST gradient

ENS wind - crosswind SST gradient

ENS wind divergence – downwind SST gradient

Coupling coefficients summary for

QuikSCAT and models

Database	ENS wind	vorticity - CWSST	wind div DWSST	wind stress	w.s.curl- CWSST	w.s.div DWSST
QuikSCAT v4	0.42	0.39	0.60	0.022	2.20	3.04
WRF_GBM	0.40	0.38	0.74	0.024	2.35	3.82
WRF_MYJ	0.31	0.28	0.57	0.017	1.56	2.82
WRF_MYJ_SFCLAY	0.34	0.30	0.61	0.019	1.79	3.10
WRF_MYNN2	0.56	0.66	1.05	0.035	3.97	6.00
WRF_CAMUW	0.53	0.53	1.03	0.033	3.54	5.66
WRF_GFS	0.23	0.30	0.38	0.014	1.67	2.10
WRF_YSU	0.35	0.29	0.61	0.021	1.87	3.19
COAMPS_ipbl=1	0.36	0.40	0.68	0.016	1.83	2.78
COAMPS_ipbl=2	0.38	0.42	0.82	0.017	1.84	3.19

Eddy mixing coefficients and coupling coefficients

Correlation coefficient: 0.75

Conclusions

- Coupling coefficient for QuikSCAT ENS winds and NOAA OI SST in Agulhas Return Current Region for July 2002 results in 0.42 m s⁻¹ °C⁻¹, and is consistent with earlier estimates for that area
- Turbulent mixing / PBL parameterizations in atmospheric models play an important role in successful prediction of surface wind response to mesoscale SST changes
- WRF simulations with the newly implemented Grenier-Bretherton-McCaa PBL scheme agrees best with QuikSCAT estimates of coupling coefficients, yielding 0.40 m s⁻¹ °C⁻¹
- The strength of ENS wind coupling coefficient is found to correlate with the heightaverage eddy mixing coefficient (eddy viscosity) estimated by the PBL scheme
- Model experiments that agree better with QuikSCAT satellite observations of surface winds are likely more reliable to study vertical structure of winds

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