Submesoscale Current Effects on Waves

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BACKGROUND:

Ocean surface waves, in particular wave breaking, play an important role in modulating the exchange of energy, momentum, and mass across the air-sea interface. Wave breaking and related air-sea fluxes have been traditionally parameterized as a function of wind speed resulting in large uncertainties. Here we present the results of a modeling study with a recently developed wave-breaking model by Romero (2019) characterizing the modulation of breaking due wave-current interactions at very high resolutions O(100 m).

METHODS

1. The spectral model WaveWatchIII was implemented with a regional configuration in Southern California with horizontal resolutions of 270 m (L2) and 100 m (L3) (Dauhajre et al. 2019) .
2. WaveWatchIII was forced with realistic winds from the Weather Forecast and Research (WRF) model and surface currents from the Regional Ocean Modeling System (ROMS)
3. Current effects on waves (WEC) are analyzed comparing solutions forced by wind and currents to those only forced by winds.
4. WaveWatchIII solves the wave action conservation equation according to

$$\frac{\partial N(\boldsymbol{k})}{\partial t} + \frac{\partial}{\partial \boldsymbol{x}} \cdot \dot{\boldsymbol{x}} N(\boldsymbol{k}) + \frac{\partial}{\partial \theta}\dot{\theta} N(\boldsymbol{k}) + \frac{\partial}{\partial k}\dot{k} N(\boldsymbol{k}) = \frac{S_{in}+S_{nl}+S_{ds}}{\sigma}, \quad (1)$$

$$\dot{\boldsymbol{x}} = (\boldsymbol{c}_g + \boldsymbol{u}), \quad (2)$$

$$\dot{\theta} = -\frac{1}{k}\frac{\partial \sigma}{\partial h}\frac{\partial h}{\partial m} - \boldsymbol{k}\cdot\frac{\partial \boldsymbol{u}}{\partial m}, \quad (3)$$

$$\dot{k} = -\frac{\partial \sigma}{\partial h}\frac{\partial h}{\partial s} - \boldsymbol{k}\cdot\frac{\partial \boldsymbol{u}}{\partial s}, \quad (4)$$

where $N(\boldsymbol{k}) = F(\boldsymbol{k})/\sigma$ is the wave action, $F(\boldsymbol{k})$ is the spectrum, $\sigma = (gk\tanh kh)^{1/2}$ is the frequency, h is the water depth, and $\boldsymbol{u}$ is the surface current, taken as the current from ROMS closest to the surface (≈-1 m). The RHS terms are the wind input nonlinear energy fluxes and dissipation.

RESULTS

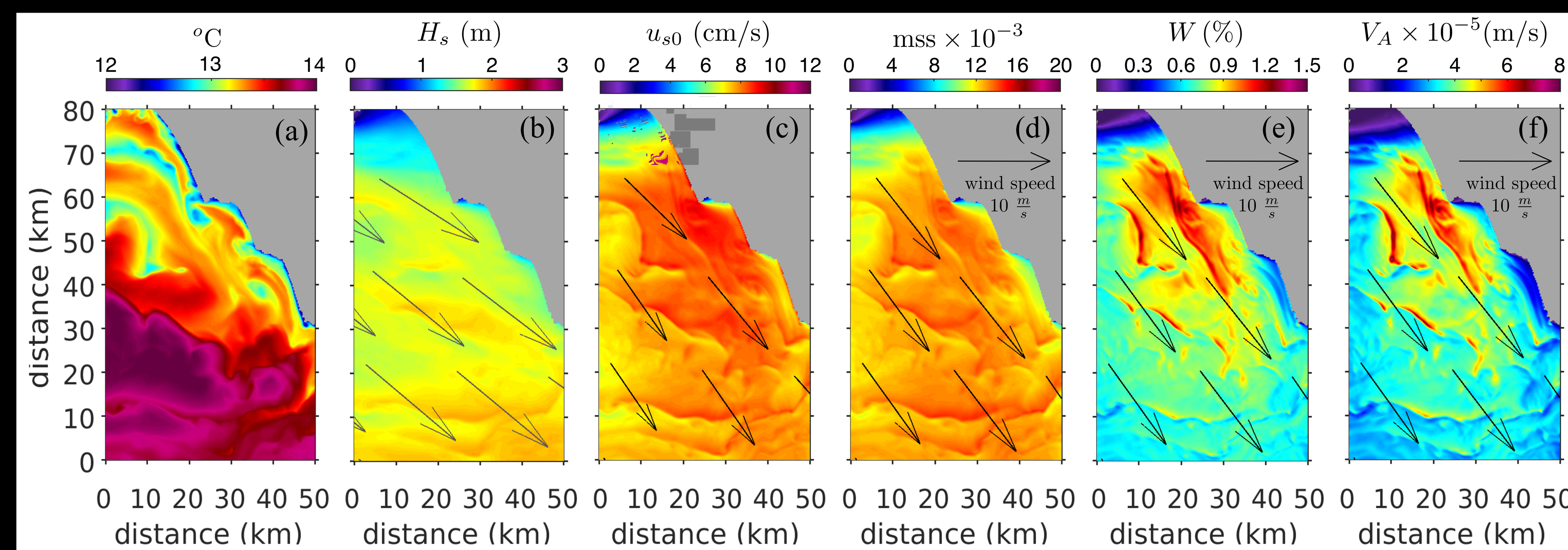
- Submesoscale currents strongly modulate surface waves, particularly wave breaking and related air-sea fluxes.
- Current effects on waves (CEW) are larger for the wave-breaking variables and weakest for the significant wave height.
- Wave breaking model differences due to CEW give statistical distributions positively skewed independent of model resolution.
- CEW decreases with increasing wind speed in part because the current gradients also decrease as the wind speed increases.

References

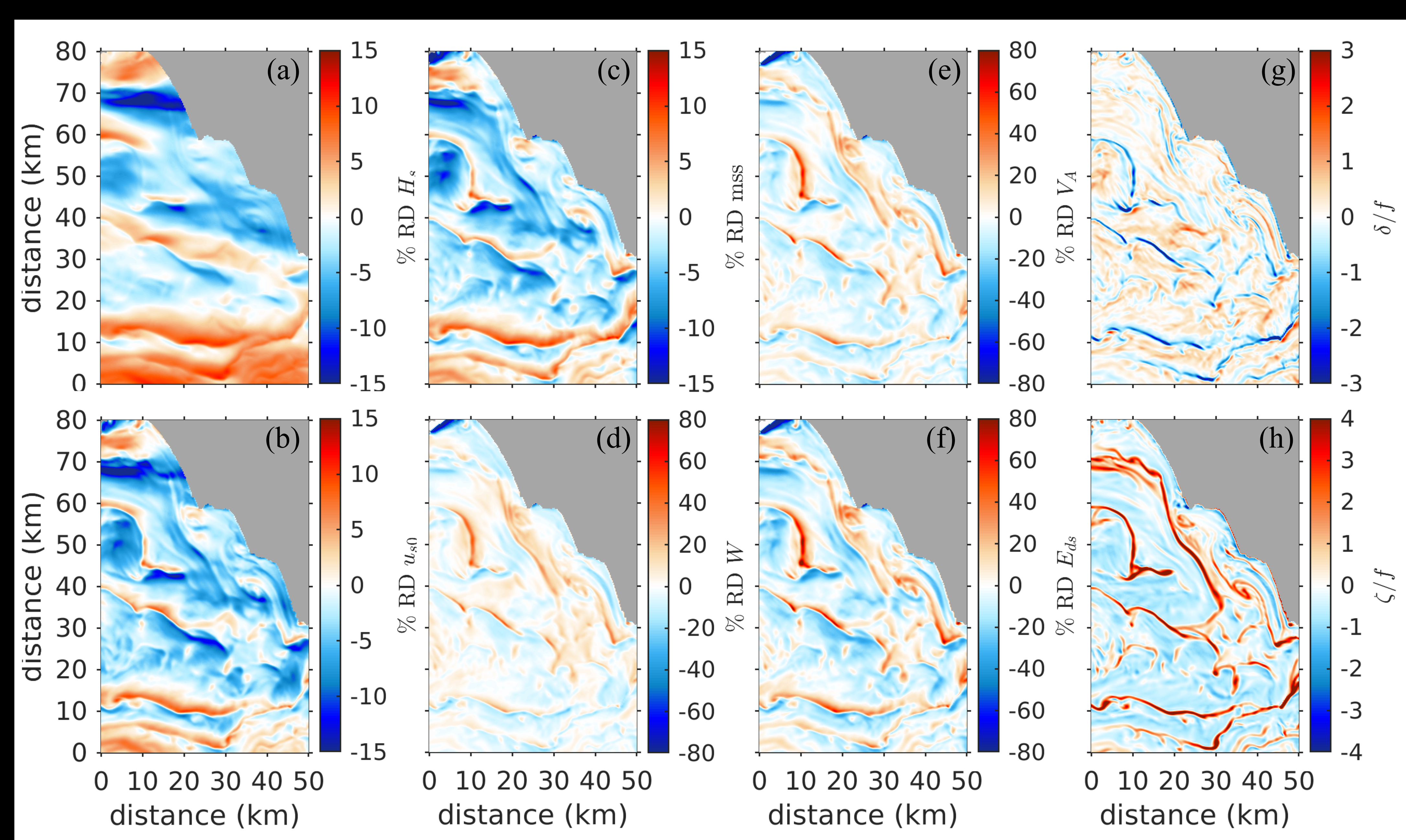
Dauhajre, D.P., McWilliams, J.C., Renault, L., 2019. Nearshore Lagrangian Connectivity: Submesoscale Influence and Resolution Sensitivity. J. Geophys. Res. Ocean. 2019JC014943.

Romero, L., 2019. Distribution of Surface Wave Breaking Fronts. Geophys. Res. Lett. 46, 10463–10474.

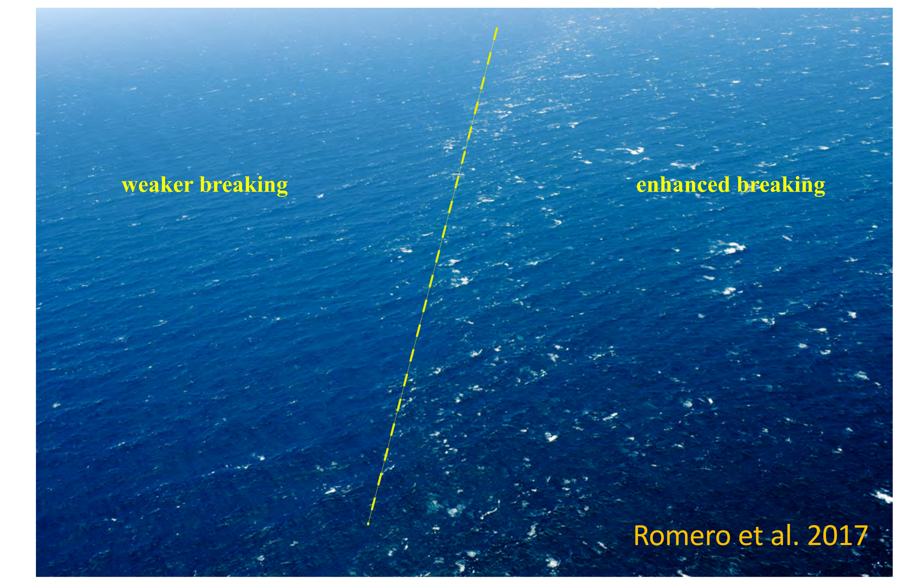
Submesoscale currents (1 km or smaller) strongly modulate wave breaking and related air-sea fluxes.



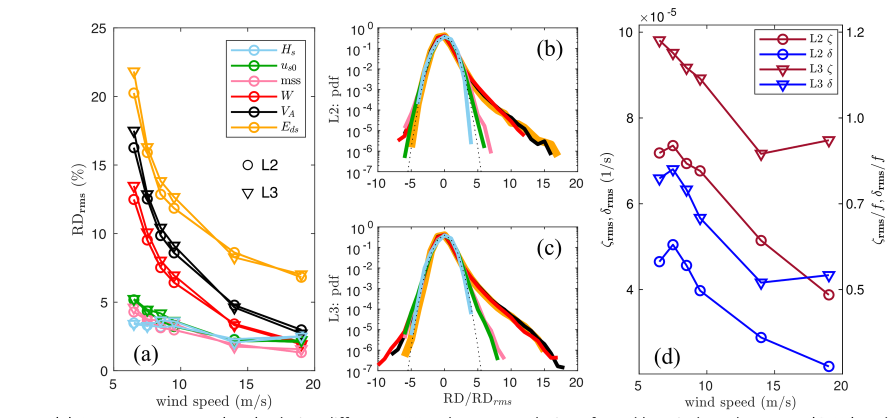
Snapshots model solutions zooming over the Santa Maria Basin north of Point Conception on 12/30/2006 00:00 (UTC) under light wind forcing after the passage of the strong winter storm shown in Figure 4. (a) Sea surface temperature, (b) Significant wave height H_s and peak wave direction, (c) surface Stokes drift u_{s0} , (d) mean square slope mss, (e) whitecap coverage W, and (f) air-entrainment rate V_A. Vectors were subsampled at 20 km spacings. Wave solutions were forced by both wind and currents (L2-CEW)



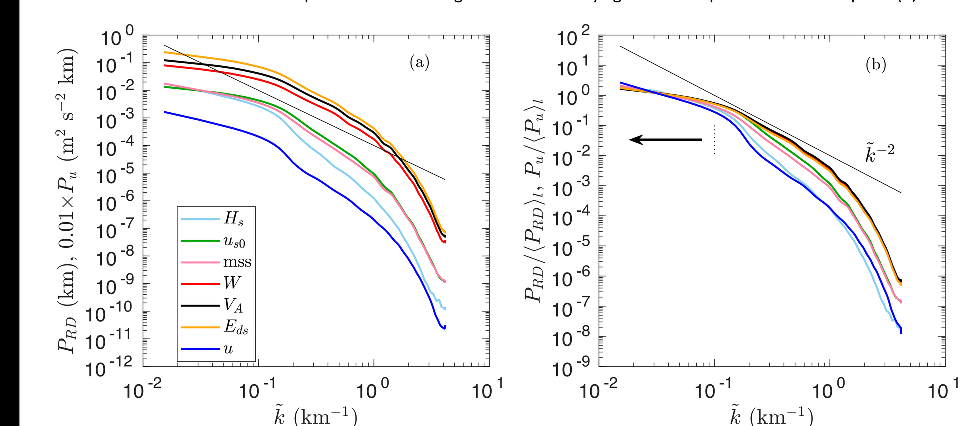
Relative difference RD (%) between solutions forced by winds and currents (L2-CEW) and wind-only (L2-WND) for (a) H_s, (b) u_{s0} , (c) mss, (d) W, (e) V_A, and (f) the energy dissipation due to breaking E_{ds} zooming over an area outside of the Santa Barbara Channel north of Point Conception, within the Santa Maria Basin. The surface current divergence and vorticity normalized by the Coriolis frequency are shown in (g) and (h), respectively.



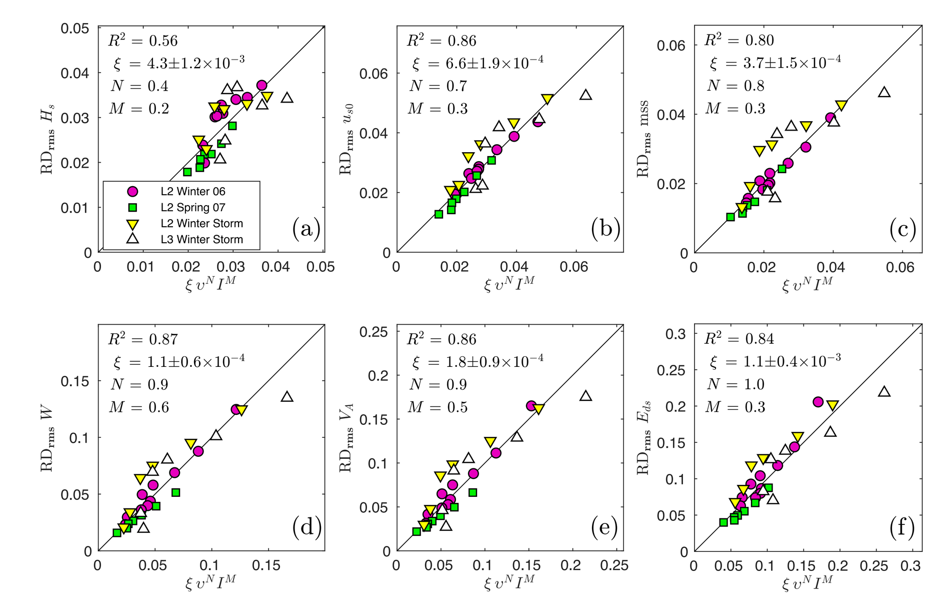
Area of enhanced breaking due to wave–current interactions. Photo taken looking north off the coast of Bodega Bay, California, during the High Resolution Air-Sea Interaction Experiment (Romero et al. 2017).



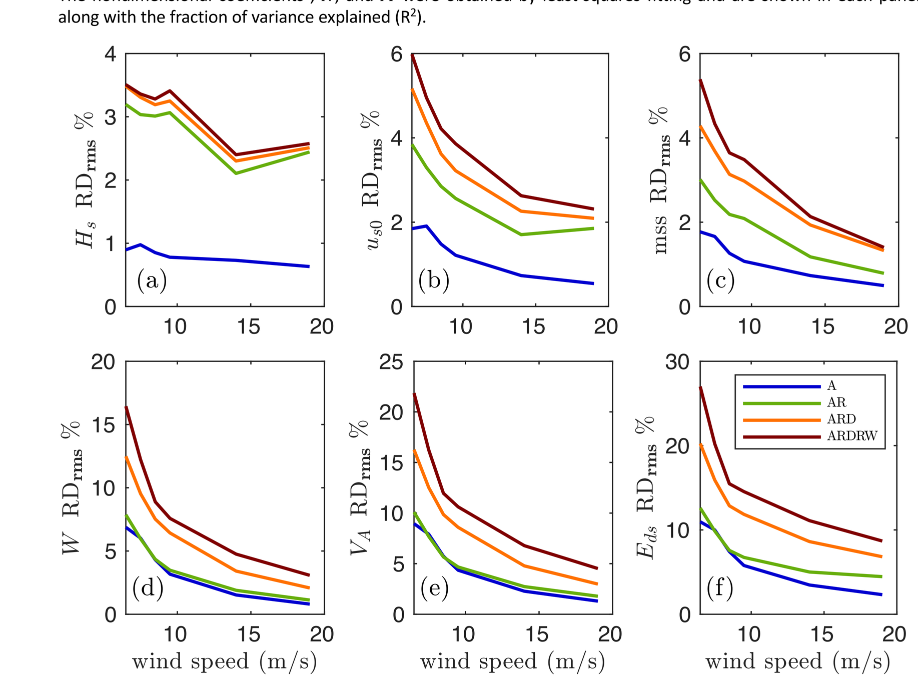
(a) Root-mean-square (rms) relative difference $\mathrm{RD_{rms}}$ between solutions forced by winds and currents (CEW) and wind-only (WND) showing H_s, u_{s0} , mss, W, V_A, and E_{ds}, color-coded as indicated in the legend. The L2 (270 m) and L3 (100 m) solutions are shown with circles and triangles, respectively. The corresponding probability density functions (pdf's) are shown in panels (b) and (c), for L2 and L3, respectively. The black dotted lines is the Gaussian distribution. The root-mean-square values of divergence and vorticity against wind speed are shown in panel (d).



(a) Wavenumber spectra of relative differences (RD) between CEW and WND L3 solutions for H_s, u_{s0} , mss, W, V_A, and E_{ds}, color-coded as indicated in the legend. The variable $\tilde{k}$ denotes the wavenumber of the spectra shown here to differentiate from that of the wave spectrum. For reference, the corresponding spectrum of the surface current speed is shown in blue scaled by a factor of 0.01. (b) Spectra are normalized by the linear spectrum average for $\tilde{k}$ < 0.1 km^{-1} or scales greater than 10 km as indicated by the black arrow, see also definition in equation (12).



Root-mean-square relative difference against the non-dimensional scaling $\xi v^N I^M$, where $v = \left(\frac{g\,T_{0,-1}}{2\pi\,u_*}\right)^2$ and $v = (\delta_{rms}^2 + \delta_{rms}^2)^{1/2}\bar{T}_{0,-1}$, $\bar{T}_{0,-1}$ is the spectrally weighted wave period, and u_* is the air-side friction velocity. The nondimensional coefficients , N, and M were obtained by least-squares fitting and are shown in each panel along with the fraction of variance explained (R^2).



Root-mean-square relative differences between L2 wave solutions forced by winds and currents (CEW) and wind-only (WND). The physics used for each CEW solution are indicated in the legend and labeled as: advection (A), refraction (R), direct forcing by the current gradients (D) and relative winds (RW).

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