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## The spacing of streaks in wind waves from low to high wind

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Quasi-streamwise vortices within aqueous shear layer beneath wind waves are found to contribute significantly to the scalar transfer across the air-water interface. These streamwise vortices manifest themselves by inducing distinct elongated high-speed streaks on the interface. The density of these streaks, which can be quantified by the transverse spacing of streaks, thus characterizes the interfacial scalar transfer contributed by the quasi-streamwise vortices. Thermal imageries of laboratory wind waves and flow fields obtained from numerical simulations of turbulent shear flows bounded by stress-driven flat boundary and wavy surface are utilized to study the characteristics of streak spacings and their dependence on wind speed. Consistent with previous studies, analyses of the thermal imageries of laboratory wind waves confirm that the streak spacings conform closely to a lognormal distribution, and the mean streak spacing  $d$  decreases as the wind speed increases. Revisiting the nondimensional mean spacing scaled by the viscous length,  $d^+ = du^*/\nu$ , where  $u^*$  is the shear velocity of water and  $\nu$  is the kinematic viscosity of water, however, reveals the different interpretations from the previous studies. For low to immediate wind-speed range,  $u^* < 0.5$  cm/s, the nondimensional mean spacing does not follow the scaling of  $d^+ \approx 100$  observed in the turbulent wall layer; the scaled mean spacing  $d^+ < 100$ . This is also observed in numerical simulation of turbulent shear flow bounded by a stress-driven flat surface. For immediate wind-speed range,  $0.5$  cm/s  $< u^* < 1.2$  cm/s, within which surface waves become significant, the nondimensional mean streak spacings derived from the thermal imageries of wind waves remain to be less than the universal value of 100. The scaled mean streak spacing of simulated turbulent shear layer next to a stress-driven plane boundary, however, increases with the wind speed and approaches the value of 100 at this immediate wind-speed range. Imposing surface waves on the simulated turbulent shear flow significantly reduces the nondimensional streak spacing as observed on the wind-wave surfaces. Such reduction of streak spacings in finite-amplitude wind waves can be attributed to the additional wave stress arising in the oscillatory boundary layer, and the turning and stretching of turbulent vortices by the Lagrangian drift of progressive waves. At high wind speeds,  $u^* > 1.2$  cm/s, despite the occurrence of wave breaking, the scaled mean spacing approaches the universal value of 100 observed in the turbulent wall layer. This work was supported by the Taiwan Ministry of Science and Technology (MOST 107-2611-M-002-014-MY3).

