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Characteristics and formation mechanism of coherent vortical structures in high shear surface layer

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The surface layer under high wind condition is characterized by elongated flow structure which manifests itself by forming streaks of bubbles and droplets on the surface. Despite intermittent disruption by breaking waves, the persistent and structural features of these surface streaks suggest the existence of underlying coherent vortices to form surface streaks and self-sustaining mechanism of the vortices. To elucidate the coherent vortical structures and their formation mechanism, high-resolution numerical simulation of turbulent flow subject to high shear was conducted. The flow is driven by imposing a shear stress (surface friction velocity on water side = 1.5 cm/s) on the boundary to mimic the surface layer. For comparison, computations were also conducted for the surface layer with weaker shear rates (surface friction velocity = 0.5 and 1 cm/s). To identify the vortical structures, an indicator of swirling strength derived from local velocity gradient tensor is adopted. By employing the variable-interval space-averaging technique, the vortical structures responsible for various flow processes and surface signatures can be extracted. The simulated shear flow reveals two distinct surface signatures: elongated high-speed streaks arranged with somewhat equal cross-spacing and localized low-speed spots appearing intermittently. Two types of vortical structures responsible for these surface signatures are identified: forward horseshoe vortices (head heading downstream) associated with upwelling motion and surface divergence; and quasi-streamwise vortices. Most quasi-streamwise vortices flank the high-speed streaks as staggered, counter-rotating arrays. Such a vortical structure supports the regenerating mechanism that the pre-existing parent vortices interact with the sheared surface and induce offspring vortices. Surface layers with different shear rates exhibit similar nondimensional streak spacing in viscous scale; the streamwise extend, however, increases with shear rate indicating prolonged surface streaks under high wind condition.
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