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Vorticity Generation in Non-Breaking Free-Propagating Surface Waves

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It has been a prevalent notion that the flow beneath a non-breaking, free-propagating surface wave is essentially irrotational. Recent laboratory measurements (Savelyev et al., 2012) and numerical simulations (Tsai et al., 2015) however observed elongated velocity-converging streaks on the wavy surface suggesting the formation of streamwise vortices underneath. There is no imposed surface stress in the numerical simulations but the results confirm the theoretical analysis of Longuet-Higgins (1953) that an Eulerian mean shear with a magnitude comparable to that of Lagrangian Stokes drift occurs at the edge of the surface boundary layer in the otherwise irrotational oscillatory wavy flow. The formation of streamwise vortices is therefore explained to be induced by the Craik-Leibovich instability which arises from the interaction between the Lagrangian Stokes drift and the Eulerian mean shear. A linear instability analysis of the wave-averaged Craik-Leibovich equation is then conducted. The spanwise wavelength of the least stable disturbance is found to be close to the spacing between predominant counter-rotating vortex pairs, thus confirms the observed streamwise vortices underneath non-breaking free-propagating surface waves are excited by Craik-Leibovich instability.