Langmuir Turbulence Observed Under Wind Misaligned With Waves

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Langmuir turbulence (LT), generated through interaction between wind-driven sheared flow and surface waves, is considered as one major ingredient in the ocean surface mixing (e.g., Belcher et al. 2012). Because the ocean surface mixing has large impacts in sea surface temperature (SST), characteristic features of the LT need to be quantified for better understanding of the Earth climate system. Many previous numerical experiments (e.g., Skyllingstad and Denbo 1995, McWilliams et al. 1997) simulated the LT in simplified model ocean, and contrasted the LT with shear-driven turbulence (ST) to highlight the effects of the wave-flow interaction. These simulations showed that the LT homogenise horizontal Eulerian velocity in the vertical, leaving negligibly small vertical shear of the Eulerian velocity. Turbulent kinetic energy (TKE) of the LT is produced by Stokes production, a product between vertical shear of the Stokes drift velocity and horizontal turbulent stress. This is in marked contrast to the ST in which TKE is produced by shear production, a production between vertical shear of the Eulerian mean flow and horizontal turbulent stress. Resultant turbulent velocity scale of the LT is $(U_*^2 U^S)^{2/3}$ rather than U_* the scale of the ST, where U_* is the friction velocity and U_S is Stokes drift velocity. Although these features of the LT were well quantified in numerical experiments, they are not well identified in the actual ocean (e.g., D'Asaro 2001). To fill gaps between the numerical and the field experiment, we conducted a field experiment around a marine observation tower in a shallow sea off the southern coast of Japan in early winter in 2014 and 2015. During the experiment, winds were sometimes intense (> 10 m/s) and were generally northwesterly while surface waves, propagated from the west, exceeded 1.5 m in significant wave height. Upward- and horizontally-looking Acoustic Doppler current profilers (ADCPs) used in this experiment successfully captured coherent structures (roll structures) similar to Langmuir cells (LCs) in horizontal and vertical velocity field. Orientation of the roll was generally between wind and wave-propagation direction. Turbulent velocity scale was found to be proportional to $(U_*^2 U_S)^{1/3}$, indicating that observed turbulence was the LT. The production terms (Stokes-, shear- and buoyancy production) and the dissipation term estimated from the upward-looking ADCP with the variance method (Lohrmann et al. 1990) and the spectral method (McMillan et al. 2016) showed however that the shear production was as large as the Stokes production term in some conditions. Misalignment between wind and waves seems responsible for this apparently curious results, as this feature was found in the numerical simulation of VanRoekel et al. (2012) who simulated the LT under wind misaligned with waves. Orientation of observed LCs was in good agreement with the simulated orientation. These results indicate that misalignment between wind and waves may change source of TKE of the LT, while it does not alter turbulent velocity scale significantly.

Keywords: Langmuir Turbulence, Misaligned wind with waves, Turbulent kinetic energy analysis