EGU22-7495
https://doi.org/10.5194/egusphere-egu22-7495
EGU General Assembly 2022
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On the wave boundary layer above wind waves: influence of surfactants

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This study aims to investigate the wave boundary layer and the turbulent airflow above wind waves on slick-free and slick-covered water surfaces. To realize this, we carried out laboratory measurements of the airflow in a wind-wave tank, where we deployed three surfactants of different visco-elastic properties, each at five wind speeds ranging from 4 ms^{-1} to 8 ms^{-1}. For measurements over slick-free water surfaces, we chose wind speeds, at which we observed the same peak wave frequencies as in the presence of the surfactants. We measured high-resolution single-point profiles of the horizontal and vertical velocity components at different heights above the water surface using a Laser-Doppler-Velocimeter (LDV), wave heights using a wire gauge, and wave slopes using a laser slope gauge. Both wave field parameters were recorded simultaneously with the airflow measurements to investigate the influences of the small-scale wave field on the wave boundary layer. In the airflow turbulence spectra, we found a clear maximum corresponding to the dominant wave frequencies reflecting the influence of the waves on the airflow. However, depending on wind speed and the surfactants' damping behaviour, the maximum differs in both its strength and its height above the wavy surface, the latter being interpreted as the wave boundary layer height. The LDV achieved mean data rates exceeding 2 kHz; hence, it resolved the small-scale turbulence, which manifests in the high-frequency part of the turbulence spectra. For the slick-free cases, we observed a linear decrease in turbulence with increasing height above the surface, and increasing turbulence with increasing friction velocity u□, which depends on the wind speed and wind-wave interactions. However, we did not find clear trends at any wind speed when the water surface was covered by a surfactant. Here, the turbulence increases with increasing height above the water surface for higher friction velocities. Thus, the surfactants dampen not only the waves, but they also reduce the turbulence in the airflow directly above the waves, within the wave boundary layer.