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Structure of the airflow above surface waves

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Weather, climate and upper ocean patterns are controlled by the exchanges of momentum, heat, mass, and energy across the ocean surface. These fluxes are, in turn, influenced by the small-scale physics at the wavy air-sea interface. We present laboratory measurements of the fine-scale airflow structure above waves, achieved in over 15 different wind-wave conditions, with wave ages Cp/u* ranging from 1.4 to 66.7 (where Cp is the peak phase speed of the waves, and u* the air friction velocity). The experiments were performed in the large (42-m long) wind-wave-current tank at University of Delaware's Air-Sea Interaction laboratory (USA). A combined Particle Image Velocimetry and Laser Induced Fluorescence system was specifically developed for this study, and provided two-dimensional airflow velocity measurement as low as 100 um above the air-water interface.
Starting at very low wind speeds (U10∼2m/s), we directly observe coherent turbulent structures within the buffer and logarithmic layers of the airflow above the air-water interface, whereby low horizontal velocity air is ejected away from the surface, and higher velocity fluid is swept downward. Wave phase coherent quadrant analysis shows that such turbulent momentum flux events are wave-phase dependent. Airflow separation events are directly observed over young wind waves (Cp/u*<3.7) and counted using measured vorticity and surface viscous stress criteria. Detached high spanwise vorticity layers cause intense wave-coherent turbulence downwind of wave crests, as shown by wave-phase averaging of turbulent momentum fluxes. Mean wave-coherent airflow motions and fluxes also show strong phase-locked patterns, including a sheltering effect, upwind of wave crests over old mechanically generated swells (Cp/u*=31.7), and downwind of crests over young wind waves (Cp/u*=3.7). Over slightly older wind waves (Cp/u* = 6.5), the measured wave-induced airflow perturbations are qualitatively consistent with linear critical layer theory.