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Spatial development of the wind-driven water surface flow

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The water velocity field induced by wind and waves beneath an air-water interface is investigated experimentally versus fetch in the large Marseille-Luminy wind wave tank. Measurements of the vertical velocity profiles inside the subsurface shear layer were performed by a three-component Nortek acoustic Doppler velocimeter. The surface drift current was also derived from visualizations of small floating drifters recorded by a video camera looking vertically from above the water surface. Surface wave height and slopes were determined simultaneously by means of capacitance gauges and a single-point laser slope system located in the immediate vicinity of the profiler. Observations were made at steady low to moderate wind speeds and various fetches ranging between 1 and 15 meters.
This study first corroborates that the thin subsurface water boundary layer forced by wind at the leading edge of the water sheet is laminar. The surface drift current velocity indeed increases gradually with fetch, following a 1/3 power law characteristic of an accelerated flat-plate laminar boundary layer. The laminar-turbulent transition manifests itself by a sudden decrease in the water surface flow velocity and a rapid deepening of the boundary layer due to the development of large-scale longitudinal vortices. Further downstream, when characteristic capillary-gravity wind waves develop at the surface, the water flow velocity increases again rapidly within a sublayer of typically 4 mm depth. This phenomenon is explained by the occurrence of an intense momentum flux from waves to the mean flow due to the dissipation of parasitic capillaries generated ahead of the dominant wave crests. This phenomenon also sustains significant small-scale turbulent motions within the whole boundary layer. However, when gravity-capillary waves of length longer than 10 cm then grow at the water surface, the mean flow velocity field decreases drastically over the whole boundary layer thickness. At the same time, long-lived three-dimensional coherent structures which present strong similarities with the so-called Langmuir circulations start to grow. The main features of the wind-induced water surface flow observed at these different stages of development will be compared with previous observations and the results of numerical simulations as described by Tsai et al. (2005, 2009).