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The effect of foam on waves and the aerodynamic roughness of the water surface at high winds

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Air-sea coupling at extreme winds is of special interest now in connection with the problem of explanation of the sea surface drag saturation at the wind speed exceeding 30 m/s. The idea on saturation (and even reduction) of the coefficient of aerodynamic resistance of the sea surface at hurricane wind speed first suggested in [1] on the basis of theoretical analysis of sensitivity of maximum wind speed in a hurricane to the ratio of the enthalpy and momentum exchange coefficients was then confirmed by a number of field (e.g.[2]) and laboratory [3] experiments, which showed that the sea surface drag coefficient was significantly reduced in comparison with the parameterization obtained at moderate to strong wind conditions.

The theoretical explanations of the effect of the sea surface drag reduction exploit either peculiarities of the air flow over breaking waves (e.g.[4,5]) or the effect of sea drops and spray on the wind-wave momentum exchange (e.g. [6,7]). Recently an alternative hypothesis was suggested in [8], where the surface drag reduction in hurricanes was explained by the influence of foam covering sea surface on its aerodynamic roughness.

This paper describes a series of laboratory experiments in Thermostratified Wind-Wave Tank (TSWiWaT) of IAP directed to investigation of the foam impact on the short-wave part of the surface waves and the momentum exchange in the atmospheric boundary layer at high winds in the range of equivalent 10-m wind speed from 12 to 38 m/s. A special foam generator was designed for these experiments. The air flow parameters were retrieved from measurements of the velocity profiles. The frequency-wavenumber spectra of surface waves were retrieved from the measurements of water surface elevation by the array 3-channel wave gauge. Foam coverage of water surface was controlled by video filming of the water surface.

The results of measurements were compared with predictions of the quasi-linear model of atmospheric boundary layer over the waved water surface. For the case of water surface covered with foam, good agreement was obtained between the predictions of the model with the roughness parameter correlated with the size of the foam bubbles and the experimental data. This confirms the non-separated character of the air flow around waves in the case of enhanced surface roughness.

It was shown that the presence of foam reduces the heights and mean square slopes of waves for all wind speeds. At wind speeds below 20-22 m / s foam presence increases the drag coefficient, while at wind speeds above 22-25 m / s, drag coefficient slightly decreases in the presence of the foam. The dependence of water surface drag coefficient in the presence of a foam on the wind velocity is determined by the balance between the small-scale surface roughness increase and decrease of wave form-drag compared to the case of water free of foam.

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