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On effect of sea-spray and foam to the aerodynamic resistance of the water surface at high winds

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Air-sea coupling at extreme winds is of special interest for explanation of the sea surface drag saturation (and even reduction) at the wind speed exceeding 30 m/s confirmed by a number of field and laboratory experiments. Here, we propose an explanation for the peaking dependence of the surface drag coefficient on the wind speed by the combined effect of two phenomena typical for high wind conditions: spume droplets torn from the crest of waves by wind and foam on the water surface.

The starting points for this study were two laboratory experiments. The first one was designed for investigation of the spray generation mechanisms at high winds. During this experiment video-filming of the air-water interface by the high-speed digital and subsequent statistical analysis showed, that the dominant mechanism of generation of the spume droplets at strong and hurricane winds is the bag breakup fragmentation of the air-sea interface. Basing on these data we constructed the spray generation function (SGF) for the bag-breakup mechanism. Using the scaling by the wind-sea Reynolds number, we suggested the fetch dependent SGF valid both for laboratory and field conditions. Then we estimated the contribution of the bag-breakup mechanism to the air-sea momentum flux due to: 1) "bags" as obstacles before fragmentation; 2) acceleration of drops by the wind in the course of their production; and 3) stable stratification of the marine atmospheric boundary layer due to levitating droplets.

The second experiment was 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. The analysis of the data showed, that the surface drag coefficient correlated with the foam coverage fraction and the m.s.s. of surface wave field, while at a certain wind speed, the m.s.s. decreases with increase of the foam coverage fraction, i.e. foam suppresses short waves. Basing on these results, we suggested the simple model for the eddy viscosity coefficient taking into account the effect of foam at the aerodynamic roughness of the surface and parameterized suppression of waves by foam. Comparison showed, that the results of measurements were in good agreement with the predictions of the quasi-linear model of atmospheric boundary layer over the waved water surface with this eddy viscosity coefficient.

The coupled model taking into account the contribution of the bag-breakup and foam effects to the air-sea momentum flux for parameters corresponding to field conditions yields the realistic peaking dependence of the surface drag coefficient on the 10-m wind speed. This non-monotonous dependence is explained by 1) decreases the surface form drag due to suppress of waves by foam; 2) competing effects of increase of number of spray and bags with the wind speed and decrease of sizes of droplets and bags and the consequent contributions to momentum exchange from individual objects.

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