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The synergetic effect of foam at the water surface and spray in the marine atmospheric boundary layer on air-sea fluxes 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. The experiments were performed at two laboratory facilities: the high speed wind-wave tank of the Institute of Applied Physics (Nizhny Novgorod) and the circular wind wave channel Aeolotron of the University of Heidelberg. 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.

The second experiments were carried out in a wind-wave flume in which foam can be artificially produced at the water surface. Tests were conducted under high wind-speed conditions where equivalent 10-m wind speed ranged 12–38 m/s, with measurements made of the airflow parameters, the frequency-wavenumber spectra of the surface waves, the foam coverage of the water surface, and the distribution of the foam bubbles. Analysis of the resulting data indicates that the surface drag coefficient correlates with the fraction of foam coverage and the mean square slope (MSS) of the water surface, and that, at a certain wind speed, the MSS decreases with an increase in the fraction of foam coverage. Based on these results, we suggest a simple model for eddy viscosity in the turbulent boundary layer over a fractionally foam-covered wave surface. The measurements in a laboratory environment are shown to be in good agreement with the predictions of a quasi-linear model of the atmospheric boundary layer over a waved water surface that adopts this eddy viscosity. Adaptation of the proposed model to field conditions is discussed, and the synergetic effect of foam at the water surface and spray in the marine atmospheric boundary layer on ocean surface resistance at high winds is estimated so as to be able to explain the observed peaking dependence of the surface drag coefficient on the 10-m wind speed. Boosting the exchange processes by giant droplets can provide the pronounced increase in the air-sea thermal energy flux crucial for the observed fast intensification of hurricanes.

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