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# Laboratory modeling of air-sea interaction under severe wind conditions

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Wind-wave interaction at extreme wind speed 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 was first suggested by Emanuel (1995) 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. Both field (Powell, Vickery, Reinhold, 2003, French et al, 2007, Black, et al, 2007) and laboratory (Donelan et al, 2004) experiments confirmed that at hurricane wind speed the sea surface drag coefficient is significantly reduced in comparison with the parameterization obtained at moderate to strong wind conditions.
Two groups of possible theoretical mechanisms for explanation of the effect of the sea surface drag reduction can be specified. In the first group of models developed by Kudryavtsev & Makin (2007) and Kukulka,Hara Belcher (2007), the sea surface drag reduction is explained by peculiarities of the air flow over breaking waves. Another approach more appropriate for the conditions of developed sea exploits the effect of sea drops and sprays on the wind-wave momentum exchange (Andreas, 2004; Makin, 2005; Kudryavtsev, 2006).
The main objective of this work is investigation of factors determining momentum exchange under high wind speeds basing on the laboratory experiment in a well controlled environment. The experiments were carried out in the Thermo-Stratified WInd-WAve Tank (TSWIWAT) of the Institute of Applied Physics. The parameters of the facility are as follows: airflow 0 - 25 m/s (equivalent 10-m neutral wind speed U10 up to 60 m/s), dimensions 10m x 0.4m x 0.7 m, temperature stratification of the water layer. Simultaneous measurements of the airflow velocity profiles and wind waves were carried out in the wide range of wind velocities. Airflow velocity profile was measured by WindSonic ultrasonic wind sensor. The water elevation was measured by the three-channel wave-gauge. Top and side views of the water surface were fixed by CCD-camera.
Wind friction velocity and surface drag coefficients were retrieved from the measurements by the profile method. Obtained values are in good agreement with the data of measurements by Donelan et al (2004). The directional frequency-wave-number spectra of surface waves were retrieved by the wavelet directional method (Donelan et al, 1996). The obtained dependencies of parameters of the wind waves indicate existing of two regimes of the waves with the critical wind speed Ucr about 30 m/s. For U10<Ucr the peak wave period and wavelength, significant wave height and peak wave slope are monotonically increasing with the wind speed, the surface drag coefficient increases simultaneously. For U10>Ucr the dependencies of peak wave period, peak wavelength, significant wave height on the wind speed tend to saturation, in the same time the peak wave slope has the maximum at approximately Ucr and then decreases with the tendency to saturation. The surface drag also tends to saturation for U10>Ucr similarly to (Donelan et al, 2004). Video filming indicates onset of wave breaking with white-capping and spray generation at wind speeds approximately equal to Ucr.
We compared the obtained experimental dependencies with the predictions of the quasi-linear model of the turbulent boundary layer over the waved water surface (Reutov&Troitskaya, 1995). Comparing shows that theoretical predictions give low estimates for the measured drag coefficient and wave fields. Taking into account momentum flux associated with the spray generation yields theoretical estimations in good agreement with the experimental data.
Basing on the experimental data a possible physical mechanism of the drag is suggested. Tearing of the wave crests at severe wind conditions leads to the effective smoothing (decreasing wave slopes) of the water surface, which in turn reduces the aerodynamic roughness of the water surface. Quantitative agreement of the experimental

data and theoretical estimations od the surface drag occurs if spray and drop momentum flux is taken into account.
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