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Experimental investigation of effect of surface gravity waves and spray on heat and momentum flux at strong wind conditions

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The most important characteristics that determine the interaction between atmosphere and ocean are fluxes of momentum, heat and moisture. For their parameterization the dimensionless exchange coefficients (the surface drag coefficient C_D and the heat transfer coefficient or the Stanton number C_T) are used. Numerous field and laboratory experiments show that C_D increases with increasing wind speed at moderate and strong wind, and as it was shows recently C_D decreases at hurricane wind speed. Waves are known to increase the sea surface resistance due to enhanced form drag, the sea spray is considered as a possible mechanism of the “drag reduction” at hurricane conditions. The dependence of heat transfer coefficient C_D on the wind speed is not so certain and the role of the mechanism associated with the wave disturbances in the mass transfer is not completely understood. Observations and laboratory data show that this dependence is weaker than for the C_D, and there are differences in the character of the dependence in different data sets. The purpose of this paper is investigation of the effect of surface waves on the turbulent exchange of momentum and heat within the laboratory experiment, when wind and wave parameters are maintained and controlled. The effect of spray on turbulent exchange at strong winds is also estimated.

A series of experiments to study the processes of turbulent exchange of momentum and heat in a stably stratified temperature turbulent boundary layer air flow over waved water surface were carried out at the Wind - wave stratified flume of IAP RAS, the peculiarity of this experiment was the option to change the surface wave parameters regardless of the speed of the wind flow in the channel. For this purpose a polyethylene net with the variable depth (0.25 mm thick and a cell of 1.6 mm $\times$ 1.6mm) has been stretched along the channel. The waves were absent when the net was located at the level of the undisturbed water surface, and had maximum amplitude at the maximum depth of the net (33cm). To create a stable temperature stratification of the wind, the air entering the flume was heated to 30-40 ^{o}C. The water temperature was maintained about 15 degrees. The air flow velocity in the flume corresponded to the 10-m wind speed from 10 to 35 m/s. Turbulent fluxes of heat and momentum and roughness parameters were retrieved from the velocity and temperature profiles measured at the distance 6.5 m from the inlet of the flume and subsequent data processing exploiting the self-similarity of the temperature and velocity profiles. In a result surface drag and heat exchange coefficients and roughness parameters were obtained. Wind wave spectra and integral parameters (significant wave height, mean square slope) were retrieved from measurements by 3-channel array wave gauge by coherent spectral data processing. To estimate the amount of spray in the air flow, a spray marker was introduced using the effect of a sharp decline in film anemometer readings in contact with a droplet.

Dependences of the exchange coefficients on the wind speed, wave parameters and the spray marker were obtained. It is shown that the exchange coefficients increase with the wind speed and wave height. It was found, that the sharp increase of the drag and heat exchange coefficients at wind speeds exceeded 25 m/s was accompanied by the emergence and increasing concentration of the spray in the air flow over water. The correlation coefficient between the drag coefficient and the spray marker was about 0.9.

Using high-speed video revealed the dominant mechanism for the generation of spray at strong winds. It is shown that it is associated with the development of a special type of instability of the air-water interface, which is known as "bag-breakup instability" in the theory of fragmentation of liquids. The hypothesis is suggested, that the observed increase of surface drag and heat exchange can be attributed to the development of this type of instability.

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