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# Bag-breakup control of surface drag in hurricanes

Yuliya Troitskaya (1,2), Sergej Zilitinkevich (2,3,4), Alexander Kandaurov (1,2), Olga Ermakova (1), Dmitry Kozlov (1,2), Daniil Sergeev (1,2)

(1) Institute of Applied Physics, Nonlinear Oscillations and waves, Nizhny Novgorod, Russian Federation (yuliya@hydro.appl.sci-nnov.ru), (2) Nizhny Novgorod State University, Russia, (3) Department of Physics, University of Helsinki, Finland, (4) Finnish Meteorological Institute, Helsinki, Finland

Air-sea interaction at extreme winds is of special interest now in connection with the problem of the sea surface drag reduction at the wind speed exceeding 30-35 m/s. This phenomenon predicted by Emanuel (1995) and confirmed by a number of field (e.g., Powell, et al, 2003) and laboratory (Donelan et al, 2004) experiments still waits its physical explanation. Several papers attributed the drag reduction to spume droplets - spray turning off the crests of breaking waves (e.g., Kudryavtsev, Makin, 2011, Bao, et al, 2011). The fluxes associated with the spray are determined by the rate of droplet production at the surface quantified by the sea spray generation function (SSGF), defined as the number of spray particles of radius r produced from the unit area of water surface in unit time. However, the mechanism of spume droplets' formation is unknown and empirical estimates of SSGF varied over six orders of magnitude; therefore, the production rate of large sea spray droplets is not adequately described and there are significant uncertainties in estimations of exchange processes in hurricanes. Herewith, it is unknown what is air-sea interface and how water is fragmented to spray at hurricane wind.
Using high-speed video, we observed mechanisms of production of spume droplets at strong winds by high-speed video filming, investigated statistics and compared their efficiency. Experiments showed, that the generation of the spume droplets near the wave crest is caused by the following events: bursting of submerged bubbles, generation and breakup of "projections" and "bag breakup". Statistical analysis of results of these experiments showed that the main mechanism of spray-generation is attributed to "bag-breakup mechanism", namely, inflating and consequent blowing of short-lived, sail-like pieces of the water-surface film. Using high-speed video, we show that at hurricane winds the main mechanism of spray production is attributed to "bag-breakup", namely, inflating and consequent breaking of short-lived, sail-like pieces of the water-surface film - "bags". On the base of general principles of statistical physics (model of a canonical ensemble) we developed statistics of the "bag-breakup" events: their number and statistical distribution of geometrical parameters depending on wind speed.
Basing on the developed statistics, we estimated the surface stress caused by bags as the average sum of stresses caused by individual bags depending on their eometrical parameters. The resulting stress is subjected to counteracting impacts of the increasing wind speed: the increasing number of bags, and their decreasing sizes and life times and the balance yields a peaking dependence of the bag resistance on the wind speed: the share of bag-stress peaks at U10 [U+F0BB] 35 m/s and then reduces. Peaking of surface stress associated with the "bag-breakup" explains seemingly paradoxical non-monotonous wind-dependence of surface drag coefficient peaking at winds about 35 m/s.
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