Whitecap coverage measurements in laboratory modeling of wind-wave interaction

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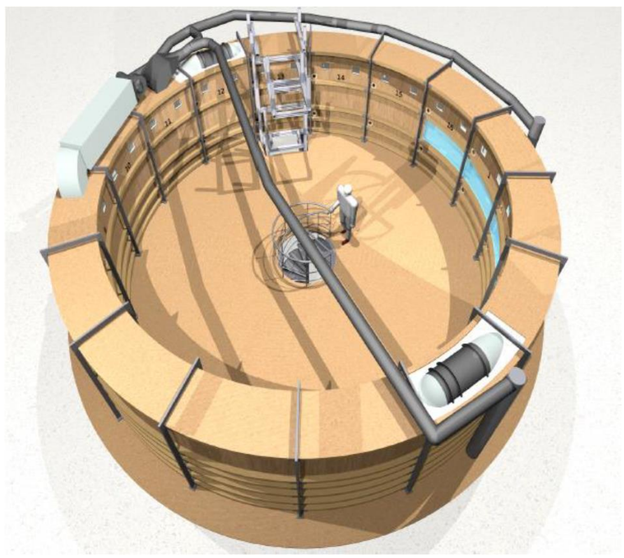
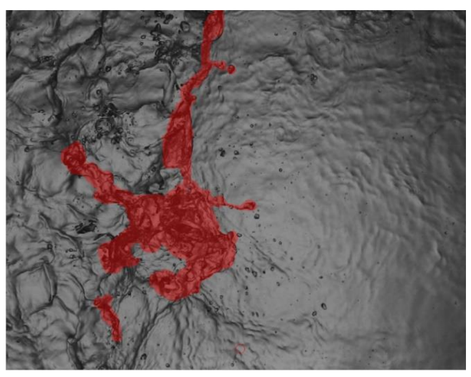
Experiments on modeling the interaction of the atmospheric air flow with the surface of the hydrosphere in the boundary layer were performed on a unique laboratory faculty Heidelberg Small-Scale Air- Sea Interaction Facility:

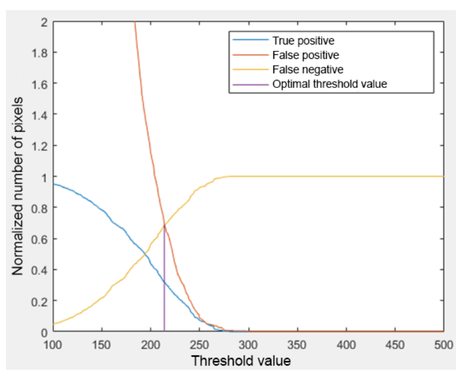
- 60 cm width, 2.4 m height, circumference of 27.3m at the inner wall
- Water depth during experiments 1.0 m, volume 18.0 m³
- Air space volume 24 m³
- Wind is generated by two axial fans mounted into the ceiling
- Annular wind-wave facility, wind speeds up to u_{ref} = 10.5 m/s (U_{10} = 16 m/s)

High-speed video records (up to 8000 fps) were made in the vertical direction (from top to bottom) in a shadowgraph configuration with backlight located under the channel. On the annular channel, regimes with an abrupt start of wind under an unperturbed surface condition were implemented, including the case of butanol presence in water simulating salinity. At the same time, the wave parameters varying depending on the time elapsed after the wind was turned on, made it possible to study the characteristics of the generation of spray at various effective fetches.



General view and principal diagram of the Aeolotron

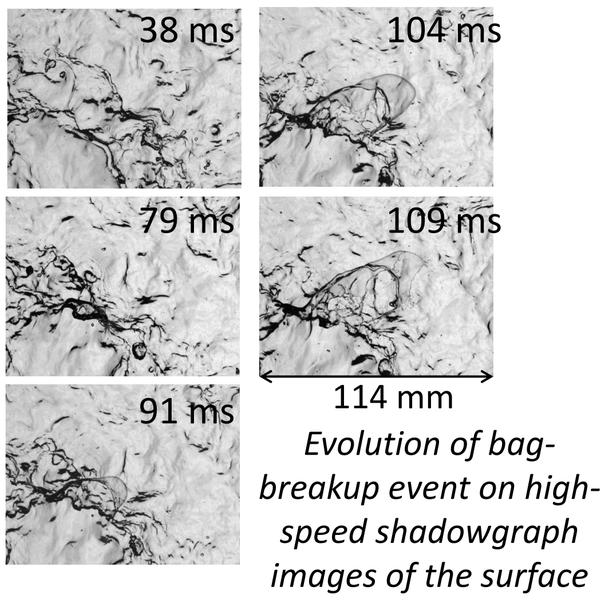




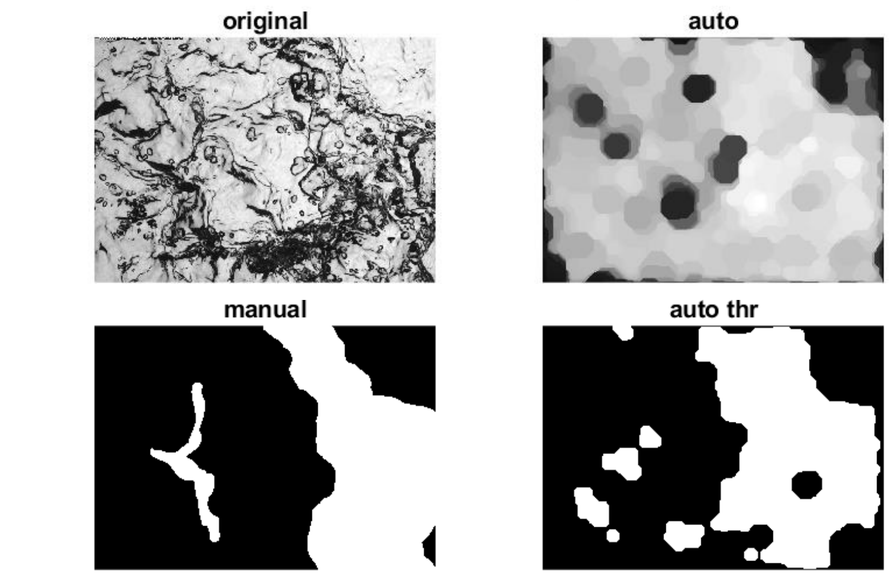
Manual marking of the wave breaking area on single frame from shadowgraph recordings of surface by a high-speed camera: the area occupied by the breaking crests of the wind waves is marked in red (left). Adaptive threshold algorithm (right): dependency of number of corresponding pixels from the selected threshold. The threshold at which the number of false positive and false negative pixels coincides is considered optimal.

Number of bag-breakup events

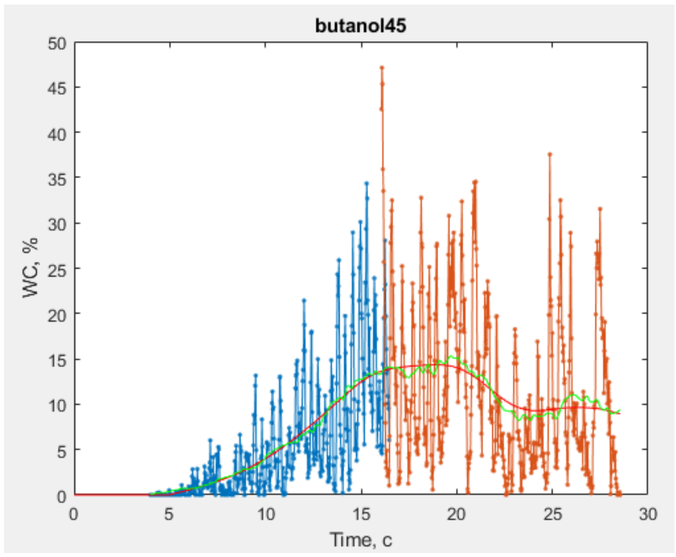
As a result of semi-automatic processing of image sequences using specially developed software that allows marking the moment and position of the bag-breakup formation on the videos, the dependences of the frequency of occurrence of these phenomena per unit surface area versus time after turning on the wind were obtained similar to [Troitskaya et al. (Sci. Rep. 2017)]



Evolution of bag-breakup event on high-speed shadowgraph images of the surface

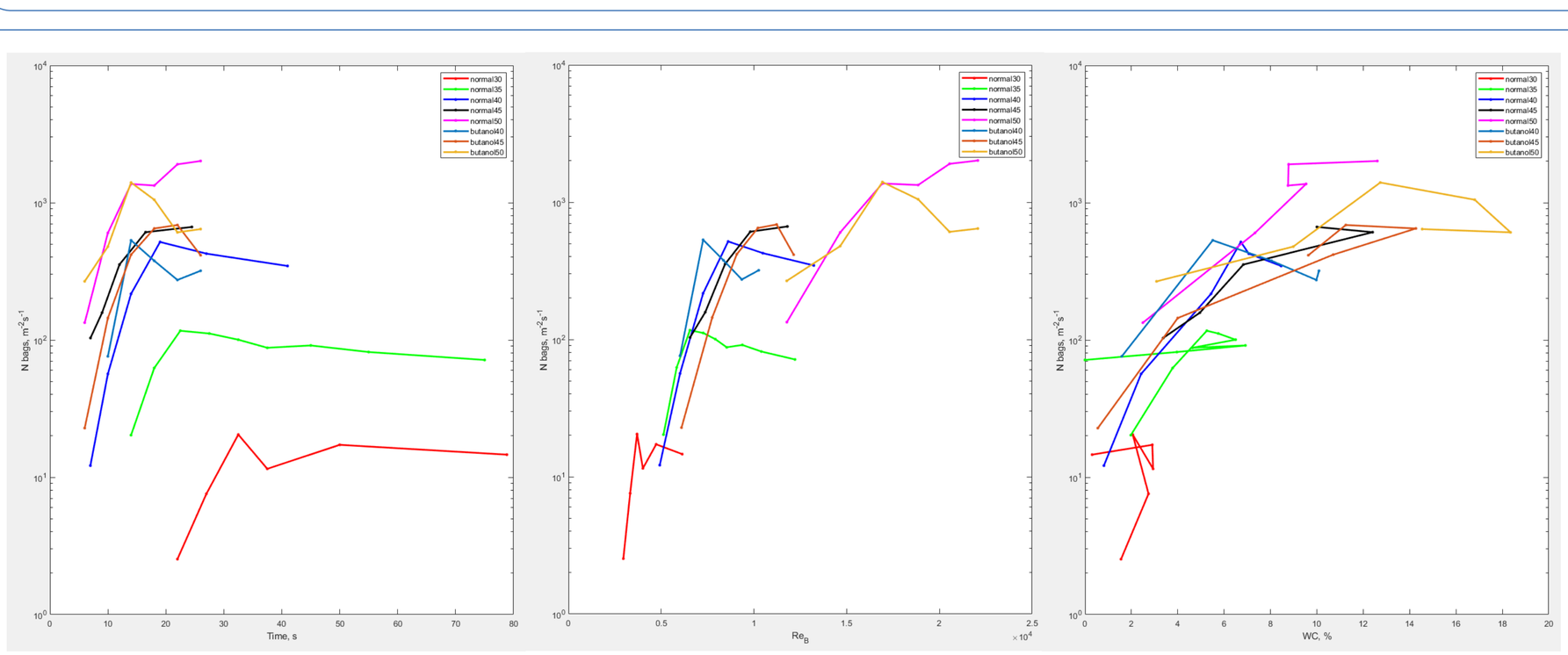


Whitecapping detection algorithm results for single frame: the original image from a high-speed camera (original), the result of preliminary image processing (auto), the result of applying the selected threshold (auto thr), manually marked areas of whitecapping on the image (manual).



An example of obtained dependency of the part of the surface covered by whitecapping on time from wind start for fan frequency 45 Hz and water with butanol. Dotted lines – momentary values for different records. Red and green line – smoothing spline and running average, respectively.

The values of the whitecap coverage area were obtained from the same shadowgraph images, using the developed software for automatic detection of areas of wave breaking. In this case, automatic image processing was performed using morphological analysis in combination with manual processing of part of the frames for tweaking the algorithm parameters: for each mode (water characteristics and wind speed), manual processing of several frames was performed, based on the results of which automatic algorithm parameters were selected to ensure that the resulting whitecap coverage corresponded.



The obtained dependences of the number of bag-breakup events on time (left), on the windsea Reynolds number[Zhao et al. (2006)] (middle) and on the part of the surface covered by whitecapping (right) for different fan frequencies and the chemical composition of water.

Results

The statistics of occurrence of events leading to the spray generation and the dependences of the whitecap coverage on time after turning on the wind were obtained for the same set of high-speed surface images for each regime: fan frequencies and chemical composition of water. Dependencies for all records collapsed to one universal dependency of number of fragmentation events per unit area on the whitecapping area. For investigated conditions the dependency on the whitecapping coverage area appeared to be more universal than the dependence on the windsea Reynolds number.

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