Laboratory simulation of the floating ice influence on the dynamic of the ocean-atmosphere boundary layer

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Abstract. Presented work concerned on the investigation of the ice cover influence on the wind – wave interaction in the marine atmospheric boundary layer. Unique laboratory experiments on the modeling of influence of pancake type of forming floe ice were carried out on the ring wind-wave facility AEOLOTRON university of Heidelberg. The round rubber pucks were used as artificial ice floes. Experiments were carried out for wide range of wind – wave states and artificial ice concentration. Simultaneous measurements of surface elevation, air flow parameters, and artificial floe ice coverage was carried out. For the case of the ice presence, the evolution of the surface demonstrated threshold behavior. The obtained threshold of the excitation of long waves (the length is much greater than the average size of the ice elements and the distance between them), depended on the wind rate and ice concentration.

1 Introduction

In the last decade, the development of the Arctic zone of the world's oceans has become increasingly important in terms of offshore mining (primarily oil and gas), as well as maritime transport (the northern sea route). Just for the polar regions that the greatest difference is noted between the results of forecasting models of the meteorological conditions and wave state with observational data. The most noticeable difference is detected in the regions of the near-marginal ice zone [1]. Therefore, numerical models are being developed that use parametric dependences of momentum, heat, and mass fluxes as boundary conditions on the sea surface, taking into account the influence of ice cover. For example, in the current version of the WAVEWATCH III model it is possible to take into account the influence of ice by connecting parameterizations describing the attenuation of waves under its action (IC) (see [2]), and for modeling atmospheric marine boundary layer in polar conditions, a modification of the atmospheric circulation model was developed WRF-ARW: Polar-WRF (see [3]). The parameterizations of atmosphere – sea surface interaction used in these models are based mainly on empirical data, the quality of which ultimately affects the quality of the forecast.

Detailed in situ investigations of the effect of the ice influence on the processes of wind-wave interaction are very difficult, especially for the forming and floating types of the ice, including pancake (this type of ice is very common and studied thoroughly, see, for example, [4, 5]). A good alternative here is carrying out laboratory experiments. Previously, only studies of the influence of floating ice on the evolution of the mechanically induced waves (by wavemaker) were performed i.e., experiments were carried out on straight flumes of limited fetches (see [6 - 9]). In the works [6, 7] grease ice was investigated, and in the work [8] large scale floes from 0.5 to 6 m. Both experiments were carried out on the special ice tanks. In the work [9] artificial floes were used. The most advanced research in this area concerned with the modeling of ice breaking processes by waves under various conditions [10].

However, basing on these results there is no possibility taking in to account the floating ice influence on the transfer between atmosphere and ocean. First of all, it concerns a surface roughness and momentum fluxes, i.e., in the present models there were no options to modify drag coefficient according parameters of the floating ice covering (concentration, typical sizes etc.). Nowadays, only for areas of solid ice (or at least coarse ice) a difference in the turbulent wind stress from the clean water conditions can be taken in to account. For the areas covered by floating ice the drag coefficient is assumed to be close for the clean water surface. That is why it is not taking in to account in the boundary conditions in atmospheric models and in the wind induced sources in wave models.

The main problems here concerned with carrying out simultaneous in situ measurements in the system wind-ice-waves and providing laboratory modeling of these processes in the laboratory conditions both.

2. Experiment and measurements

This paper presents preliminary results of the laboratory experiments carried out for wind-wave interaction with

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modeling of pancake ice on the AELOTRON ring wind-wave flume of the University of Heidelberg (see Fig. 1). This facility with inner diameter of 10 m, air flow cross section of 0.6 × 1.4 m, the depth of the water is 1 m. The maximum allowed equivalent wind speeds U_{10} (approximated to the 10-m height according logarithmic law) is 17 m/s. The typical pancake ice floes have a round form with typical width and thickness up to 1 m and 15 cm correspondingly. For the first time, the interaction of the wind with the water surface in the presence of artificial ice elements was simulated, which were rubber round pucks (see Fig 2) with a diameter of 7 cm and a thickness of 1 cm with a density of about 0.8 kg/m^3. It was impossible to use contact wire wavegauges under the conditions of solid elements of artificial ice permanently presented on the water surface. Therefore, measurements of the elevation of the rough surface were performed using a laser wavegauge with a frequency of up to 100 Hz. At the same time, in the time records, the intervals corresponding to the passage through the laser beam of the wave gauge were filtered and approximated. The part of surface covered with artificial ice were measured simultaneously with water elevation. A special system with shadow imaging of the water surface covered with pucks was used. The image of the top view with under water LED illumination was taken by camera which was processed with special algorithms, to detect area covered by pucks.

The measurements were carried out on the clean water and at three concentrations of artificial ice: maximal, 2/3 of the maximal, 1/3 of the maximal. At the maximum concentration, artificial ice elements covered approximately half of the water surface in the flume. The measurements were carried out for the fan frequency from 16 to 28 Hz, which corresponded to the range of equivalent wind speeds U_{10} from 7 to 16 m/s. The procedure was as follows: at first, at the minimum allowable air flow rate (fan frequency 6 Hz), uniform seeding with artificial ice was performed. Then the wind rate was increased sharply to the desired value.

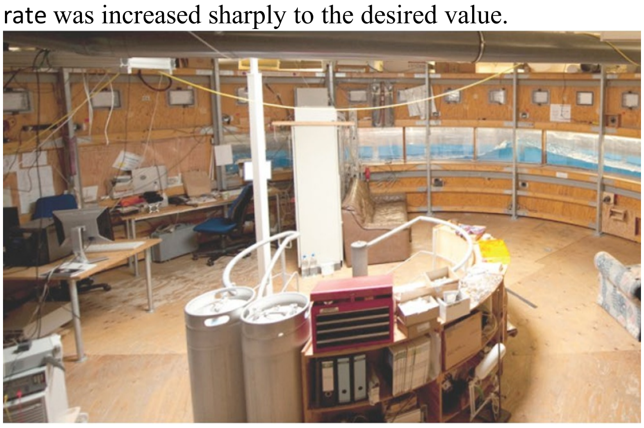

Fig. 1. Overall view of the ring wind-wave AEOLOTRON facility.

Fig. 2. View inside the flume on the water surface covered by artificial pancake ice.

2. Results

For the whole range of allowed wind speeds a monotonic evolution to a stationary state of wavy surface was observed (the higher the wind rate, the more the time of evolution, from 1 to 6 minutes and longer waves were observed) on the clean water. In contrast to this for the case of the ice presence, the evolution of the surface had threshold behavior. The obtained threshold of the excitation of long waves (the length is much greater than the average size of the ice elements and the distance between them), depended on the wind speed and ice concentration.

At all ice concentrations for low wind rates, the development of long waves was not observed for an arbitrarily long wait. When the value of the set wind rate exceeded the threshold value, at first the general wave pattern was similar for light wind conditions, however, after a certain time, long waves spontaneously developed and the situation approached clear water conditions (the wave parameters turned out to be close). The difference between these two regimes could is very well illustrated on the Fig. 2. It very well seen great difference with step from 4.7 to 5 m/s wind rate in the flume only.

On the Fig. 3 the dependence of the significant wave height on the wind speed is demonstrated. The higher the density, the higher the wind speed threshold was. At the same time, the waiting time was sometimes calculated in tens of minutes (maximum one hour), and therefore, the threshold level was determined approximately (for the maximum ice concentration - U_{10} between 11 and 13 m/s, for the intermediate between 10 and 12 m/s, for the minimum between 7 and 9 m/s.

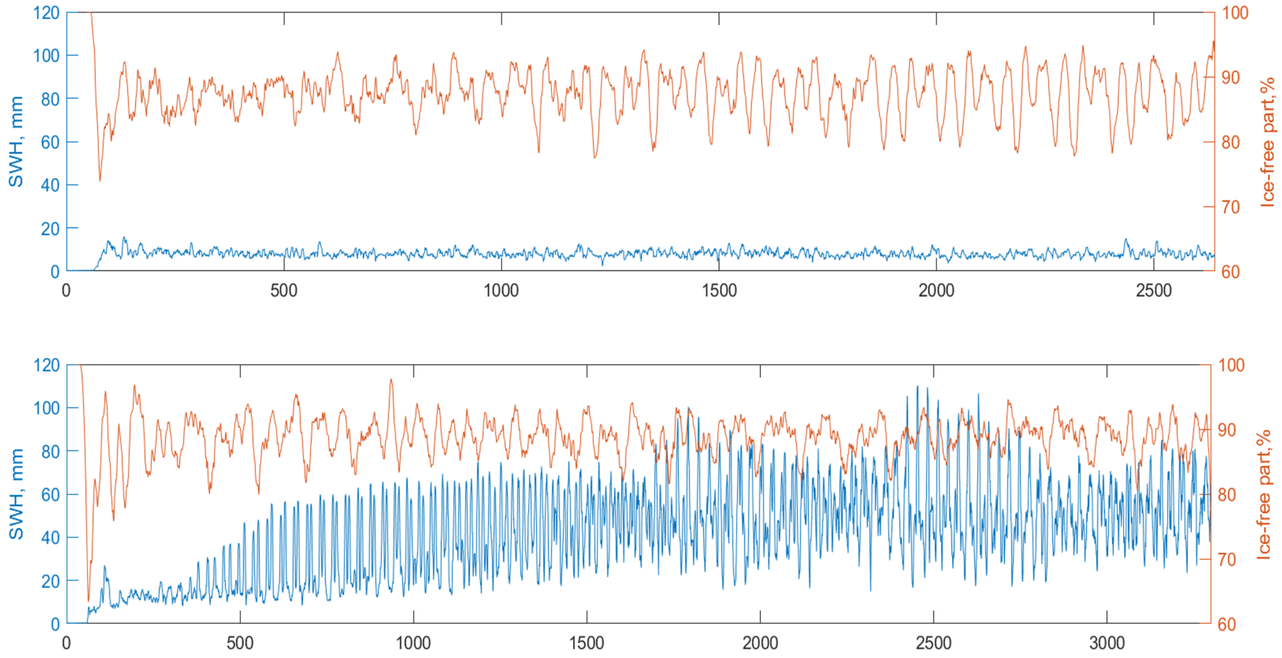

Fig. 2. Time dependencies for the same ice coverage (2/3 of full load) for wind speeds below (top) and over (bottom) the threshold (frequency of rotation of the fans in the flume 21 vs 22 Hz). The significant wave height (blue) and local percent of ice-free surface (orange). Significant wave height was determined for 5 sec time interval.

A hypothesis of the that some kind of transition between the mode of drift movement of ice disks on the surface and small ripples, to the mode of generation and development of long waves became possible when at some time place and time areas of clean water, the dimensions of which strongly exceeds the sizes of ice floes could be offered. The higher the density, the higher the threshold for wind speed. Its, could be concluded that, the threshold behavior should be taken in to account in the parametrization of wind source for the wave models and parameters of surface roughness in the atmospheric models.

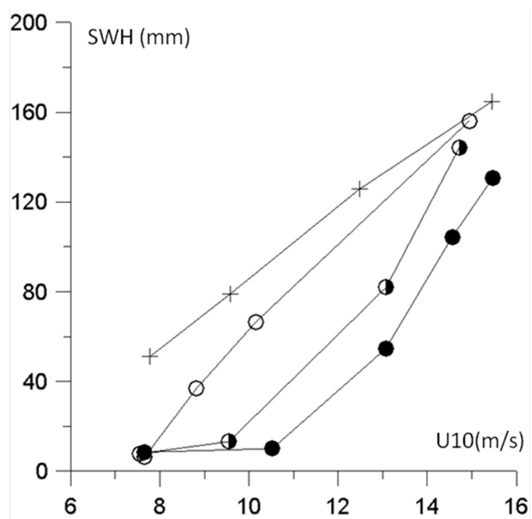

Fig. 4. Side view of the geometry of the simulation area.

4. Conclusion

An approach of the modeling of the hydrodynamic of the marine atmospheric boundary layer for the case of floating ice presence in the laboratory conditions was presented in experimental investigations carried out on the ring wind-wave facility. Simultaneous measurements of the air flow and surface parameters for different conditions of artificial ice concentrations allowed us to demonstrate threshold behavior scenarios of the wind-wave interaction for the first time.

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