Two Algorithms for the Generation of Natural Ice Floe Fields

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Introduction

Climate change is rapidly transforming the Arctic into a navigable ocean, drawing considerable attention from several industries and a corresponding increase in ship traffic. Along with increased maritime operations in the Arctic has come an interest in better understanding the effects of sea ice on the performance of ships.

One of the most common ice conditions in the region is known as pancake ice. This ice condition consists of flat, mostly round ice floes floating on the sea surface. This is similar to ice conditions previously studied in the Antarctic [1,2].

A particular challenge in carrying out simulations of this environment is generating natural ice-floe distributions for computational models. In many of the existing computational models, the initial size and location of each floe must be prescribed. In the work of Sun and Shen [3], Janssen et al. [4] and Huang et al. [5], ice floes are set to be of a uniform size and the distance between all ice floes is constant, as shown in Figure 1.

The motivation for developing floe-size-distribution (FSD) algorithms is to model ice floes in a computational model where floe size and location can follow natural conditions observed in the polar regions. There are two principal features of floe size distribution: (a) ice floes are a mixture of different sizes, and (b) the locations of ice floes should be randomly distributed.

The distribution of floe size probability is observed to follow a log-normal function, an example is shown in Figure 2. For this purpose, two ice generators (I & II) have been developed based on MATLAB, and they are able to generate a natural ice-floe map within a domain. There are two constraints for this problem: the first one is to avoid overlapping between ice floes, and the other is to assure that the whole body of every floe lays inside the domain boundary.

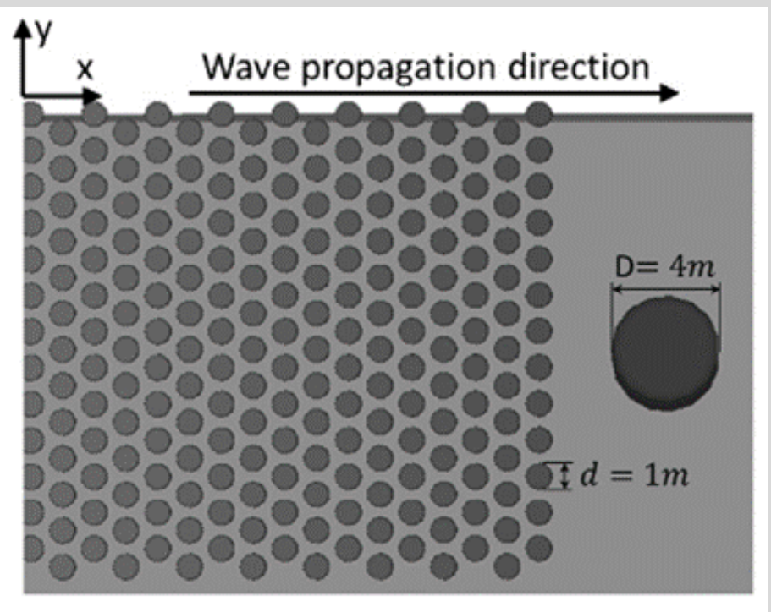

Figure 1 - Regular pancake-ice field used by Sun and Shen [3]

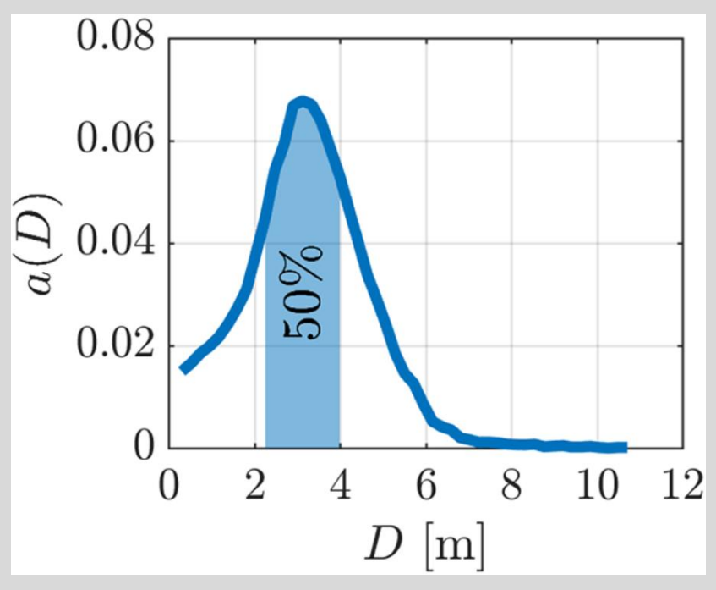

Figure 2 - FSD (floe diameter against probability), measured by Alberello [2].

Method

Two methods were explored for generating pancake ice floe fields. The first of these, Ice Generator (I), uses a method of generating a field of pancake ice floes matching an input floe size distribution, identifying overlapping areas, and then moving the ice piece to open water in the immediate vicinity of the piece under consideration. It is able to quickly create distributions up to 60% ice concentration but displays poor performance for higher concentrations.

To overcome this limitation, sea ice generator (II) was developed using a genetic algorithm to search for ice floe distributions fitting a pre-defined floe diameter probability distribution.

Generator (II) uses a penalty function to reduce overlapping between ice floes, where a higher penalty value corresponds to a higher overlapping area. The target penalty factor is set to be zero in this study, which corresponds to no overlapping. If ice herding and rafting is to be modelled, this penalty factor can be increased to allow for the overlapping seen in these conditions.

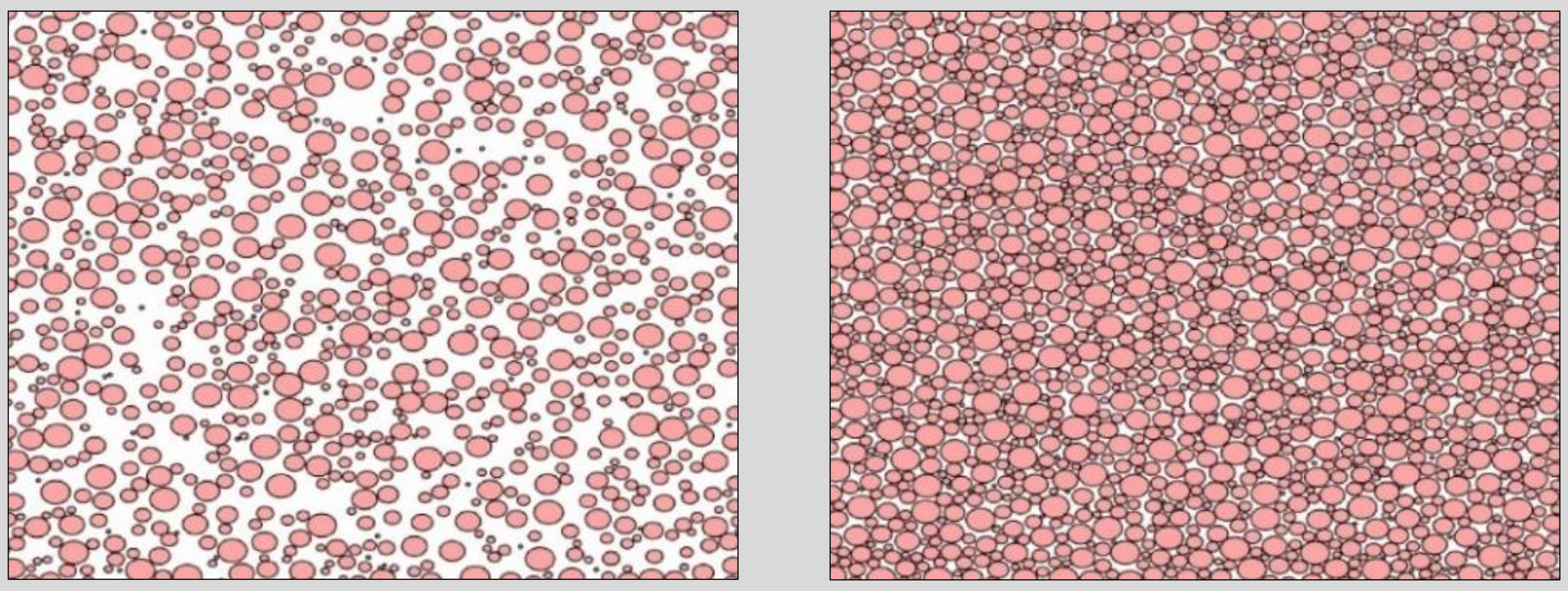

Figure 3 - Ice-floe fields obtained by Generator (I), C = 40% (left side), and by Generator (II), C = 70% (right side).

Results

The output from both algorithms is a matrix listing the *x-y* coordinates of every ice piece and the corresponding floe size, while *z* coordinate is always aligned to the buoyancy-gravity equilibration of each floe.

Ice Generator (I) is efficient at generating ice floe distributions up to an ice concentration of 60%. Above this, the algorithm slows considerably due to difficulty in finding empty areas to move the floes to. Ice Generator (II) is slower compared to (I) up to ice concentrations of 60%. Above this, it outperforms the more simple algorithm.

Figure 3 shows two samples of sea ice distributions obtained by algorithms (I) and (II) respectively, where the ice floe shape was set to be circular. However, both generators are capable of modelling other ice shapes, the limitation of this being that all ice pieces in the model need to be of the same shape. Furthermore, the distribution law does not need to follow Figure 2; it can be easily changed according to any field measurements or aerial observations, such as [2,6].

Future work

- Extend the algorithm to work with shapes which more closely follow recently observed Artic conditions.
- Couple Ice Generators (I) and (II) to work in a hybrid mode so as to speed up the process of generating ice floe distributions with concentrations above 60%.
- Use the hybrid algorithm and random shapes of ice pieces to achieve ice concentrations of up to a theoretical maximum of ~90%; determine the upper limit: the maximum ice floe concentration the hybrid algorithm can achieve.
- Use satellite images to reproduce actual, observed ice conditions that can be validated against on-board ship data.

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