Modeling fracture and fragmentation of sea ice by means of a discrete-element bonded-particle model

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ABSTRACT

Sea ice, permanently or seasonally covering large areas of polar and subpolar oceans, is commonly modeled as a continuum, with various versions of the viscous-plastic rheology. This approach, relatively efficient computationally, gives satisfactory results at large spatial and temporal scales, but has important limitations regarding reliable reproduction of certain physical processes, including fracture and fragmentation of ice, or dependence of its mechanical strength and other properties on the floe size. However, only few attempts to directly account for the granular nature of sea ice have been made (see [1,2] and references there), many of them based on simplifying, unrealistic assumptions.

The discrete-element sea ice model used in this work describes the motion and interactions of two types, or classes, of objects: ‘particles’ (disk-shaped sea-ice blocks moving within a two-dimensional space representing the sea surface) and ‘bonds’ (representing new, usually thinner ice filling cracks, leads and other open spaces between thicker ice blocks). There are two essentially independent mechanisms of interactions between neighboring particles. The first requires that the particles are in direct contact with each other (nonlinear Hertzian contact model, taking into account polydispersity). The second requires that the particles are connected with an elastic bond. Crucially, whereas forces are transmitted in both cases, bonds are also able to transmit momentum; they also have certain tensile strength. Numerically, the model is based on the LAMMPS (Large-scale Atomic/Molecular Massively Parallel Simulator) and LIGGGHTS (LAMMPS Improved for General Granular and Granular Heat Transfer Simulations) libraries. It consists of a toolbox that enables calculation of external forces acting on the ice (wind, ocean currents, etc.) and sea-ice-specific interactions between the particles and bonds. The model is an extension of earlier, simpler LAMMPS-based versions [3,4].

This work presents two different examples of the application of the model to sea ice deformation and fragmentation. The first case concentrates on the response of a compact ice cover, constrained by surrounding land (situation typical, e.g., for the central Arctic in winter), to a strong-wind event. Characteristic for this type of response are localized, narrow deformation zones with power-law distribution of deformation rates [5]. The second case demonstrates sea ice fragmentation due to surface waves, which is the dominating mechanism of ice breaking in regions close to the ice edge. It is related to flexural stresses resulting from the curvature of the sea surface.

Both examples illustrate processes that are poorly or not at all reproduced in continuum sea ice models, but are crucial for sea ice dynamics in the respective ice zones. Although the model has been designed to represent sea ice, the results provide a new insight into the behaviour of other polydisperse granular materials.

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