Emergence of tidewater and ice shelf calving dynamics using a granular model of ice

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Ice sheets and glaciers have traditionally been modeled as thin films of non-Newtonian fluids. This approximation is, however, incompatible with the extensive fracturing of ice that precedes and is occasionally part of the iceberg calving process. In this study, the explosive disintegration of ice shelves and rapid retreat and even advance of tidewater glaciers is explained by instead assuming that glacier ice is heavily fractured to the extent that it behaves in a manner that is more akin to a granular material than a continuous fluid. The conceptual granular ice model thus approximates the ice as a large number of discrete spheres or blocks of ice that interact through friction, damped elastic collisions and elastic bonds. The spectrum of intact to completely disarticulated ice is accommodated by allow bonds connecting adjacent blocks of ice to break. This model is shown to reproduce many of the observed features of calving including (i) the detachment of tabular bergs from ice tongues, (i) explosive disintegration of ice shelves and; (iii) smaller more frequent ice thickness sized bergs that detach from tidewater glaciers. The distinction between modes of calving is controlled by the fraction of bonds broken, ice thickness and near terminus water depth. However, it is shown that if the ice is already heavily fractured, the factor limiting retreat is the transport and export of ice away from the terminus rather than fracturing of the ice. It is possible that analogous continuum granular models can also formulated based on plasticity theory. This would return ice dynamics full circle to a version of the discarded plastic rheology glaciologists once favored.