Anatomy of the Marine Ice Cliff Instability

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Ice sheets grounded on retrograde beds are susceptible to disintegration through a process called the marine ice sheet instability. This instability results from the dynamic thinning of ice near the grounding zone separating floating from grounded portions of the ice sheet. Recently, a new instability called the marine ice cliff instability has been proposed. Unlike the marine ice sheet instability, the marine ice cliff instability is controlled by the brittle failure of ice and thus has the potential to result in much more rapid ice sheet collapse. Here we explore the interplay between ductile and brittle processes using a model where ice obeys the usual power-law creep rheology of intact ice up to a yield strength. Above the yield strength, we introduce a separate, much weaker rheology, that incorporates quasi-brittle failure along faults and fractures. We first tested the model by applying it to study the formation of localized rifts in shear zones of idealized ice shelves. These experiments show that wide rifts localize along the shear margins and portions of the ice shelf where the stress in the ice exceeds the yield strength. These rifts decrease the buttressing capacity of the ice shelves, but can also extend to become the detachment boundary of icebergs. Next, application of the model to idealized glaciers shows that for grounded glaciers, failure localizes near the terminus in "serac" type slumping events followed by buoyant calving of the submerged portion of the glacier. The combination of further failure and ductile flow cause the glacier to thin towards buoyancy resulting in a floating ice tongue consisting of yielded ice—similar to what is currently observed at Jakobshavn Glacier in Greenland. Overall, this simple approach to combining flow and failure yields insight into modes of failure including the marine-ice-cliff instability and rifting of ice shelves.