Evolution of basal crevasses links ice shelf stability to ocean forcing

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Basal melting and iceberg calving are the primary mechanisms responsible for transferring mass from the ice shelves to the ocean. Although the connection between basal melting and ocean forcing is clear, the effect of ocean forcing on iceberg calving remains more controversial with conflicting hypothesis about whether a warming ocean will increase or decrease iceberg production. Previous theories of iceberg calving have often relied on various flavors of fracture mechanics, assuming that iceberg calving is a brittle process. Here I use a perturbation analysis to show that the strain weakening nature of ice allows initially narrow basal crevasses with width much smaller than the ice thickness to seed a visco-plastic instability that gives rise to locally enhanced ductile deformation and ice shelf thinning over length scales that are comparable to the ice thickness. This process, called plastic necking, widens basal crevasses and allows crevasses to penetrate an increasing fraction of the ice thickness as they advect downstream. This instability, however, is weak and progresses slowly, allowing enhanced melting or accretion of marine ice within basal crevasses to have a strong influence on crevasse geometry. Despite large uncertainty in ice-ocean interaction on the scale of individual crevasses, this model is able to explain the difference between the quasi-steady short (<15 km long) Erebus Glacier Tongue and much longer (>80 km long) Drygalski Ice Tongue. Moreover, application of the model to the four largest Antarctic ice shelves predicts that deep crevasses form downstream of the grounding line that correspond to locations of fractures visible in satellite imagery. However, accumulation of marine ice within basal crevasses can substantially decrease crevasse penetration heights, increasing ice shelf stability, providing a strong link between iceberg calving and ocean-forcing. Moreover, the plastic necking instability amplifies any perturbation to the ice shelf thickness (with appropriate wavelength) allowing perturbations due to, for example, melt channels, to seed the necking instability.