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Sensitivity of calving rates to plume melting at an idealised tidewater glacier

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The ongoing retreat of many tidewater glaciers has been attributed to the increased submarine melting of calving fronts in response to warming oceans and increased meltwater runoff. The mechanisms through which submarine melting affects the stability of tidewater glaciers remain poorly understood however. In particular, the existence of a 'calving amplifier effect', in which submarine melting leads to a further increase in ice loss through calving, remains uncertain. Numerical modelling experiments have shown that this effect may occur when a glacier calving front is undercut due to vertical variation in the rate of submarine melting. There has however been relatively little investigation of the impact on calving, and thus total mass loss, of lateral variation in melting across the calving front.

Here, we use a three-dimensional, full-Stokes glacier calving model implemented in Elmer/Ice to examine the response of an idealised tidewater glacier to spatially variable submarine melting. The model uses a crevasse-depth calving criterion that triggers calving when surface and basal crevasses penetrate the full thickness of the glacier. We subject the model glacier to spatially discrete areas of submarine melting representing the zones of intense localised melting that occur at tidewater glaciers where the input of subglacial runoff drives vigorous plumes adjacent to the calving front. We find that submarine melting may have both a positive and a negative impact on the calving rate, depending on a range of variables including the intensity of the melting, the extent of the calving front subject to melting, and location of these zones of intense melting along the calving front. In particular, we find that the greatest positive impact on calving occurs when submarine melting is applied close to the ice margins rather than in the centre of the glacier. This occurs because as the melting incises notches into the calving front, it disrupts the natural compressive stress-arch that provides support to the centre of the glacier, isolating it from the stabilising influence of the fjord walls and thus triggering calving until a new stable geometry is formed. It is thus possible that through this calving amplifier effect, small areas of intense plume-driven melting could trigger enhanced calving and retreat even at large and fast-flowing glaciers at which the average submarine melt rate remains below the glacier velocity.