Towards Process-based Models of Marine Ice-cliff instability

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The finite strength of ice places a limit on ice cliff height above sea level (freeboard) (Hanson and Hooke, 2003; Bassis and Walker, 2012). When this height is exceeded, ice cliff failure can occur. This calving mechanism is currently hypothetical, but could become widespread if deep calving cliffs are exposed on marine ice sheets following the disintegration of fringing ice shelves. Runaway ice-cliff failure or the *Marine Ice-cliff Instability* (MICI) could lead to much more rapid ice loss of the West Antarctic Ice Sheet than the well-established Marine Ice-Sheet Instability (MISI) processes (Pollard et al., 2015; DeConto and Pollard, 2016). It is relatively straightforward to define height thresholds for ice-cliff failure based on field or laboratory measurements of the yield strength of ice, but methods for rates of ice loss remain rudimentary. The current generation of models employs simple rate functions tuned to match observed or prescribed calving rates. Because of the potentially great importance of MICI for future sea-level rise, there is an urgent need for well-founded models of ice cliff instability to enable reliable predictions of ice loss under different forcings.

In this talk, we present preliminary results of investigations into marine ice cliff instability using the Helsinki Discrete Element Model (HiDEM) and Elmer/Ice. We find that the large longitudinal stress gradients at tall ice fronts trigger complex mixed-mode dynamic behaviors, including brittle failure, viscous deformation, and enhanced viscous flow along shear zones. Crucially, brittle and viscous processes are complexly linked: the rate and pattern of fracture development depends on the rheology and stress history of the glacier. Furthermore, fractures influence the larger scale flow of ice tens of ice thicknesses away from the calving front. This creates considerable challenges for modelling, because approaches that rely on alternating between elastic and viscous models (e.g. Vallot et al., 2018) yield results that depend on time-step size. We shall address this problem using a fully visco-elastic version of HiDEM (in development) to explore how interactions between brittle and viscous processes control rates of ice flow and ice-front retreat where the ice-cliff stability threshold is exceeded. The ultimate aim is to use insights from process-based models to develop parameterizations of MICI for regional-scale predictive models.