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# New insights into glacier calving and environmental sensitivity from a combined continuum & discrete 3D modelling approach

Joe Todd (1), Doug Benn (1), Tom Cowton (1), Jan Åstrom (2), and Thomas Zwinger (2)

(1) University of St Andrews, School of Geography & Sustainable Development, St Andrews, United Kingdom, (2) CSC - IT Center for Science, Espoo, Finland

The dynamic response of calving glaciers to warming climate is one of the greatest uncertainties in predictions of future sea level rise. A growing body of observational evidence suggests that the calving glaciers which drain the Greenland and Antarctic ice sheets are highly sensitive to environmental forcing, but the current generation of glacier models is unable to adequately resolve this critical interaction between ice sheets and climate. We present results from a new approach combining the continuum model Elmer/Ice and the discrete element/particle model HiDEM, applied to Store Glacier, a large calving glacier in West Greenland. We use Elmer/Ice to investigate the dynamic/stress response to both submarine melting and ice mélange buttressing of the calving front, and use HiDEM to investigate fracture propagation and calving for specific geometries. We implement a new approach to investigating ice mélange; by allowing the glacier to calve repeatedly into the fjord, we effectively 'build' a mélange from previously calved icebergs.

Our results indicate that lateral support from valley walls plays a critical role in the stability of the calving front; a persistent compressive stress arch exists just behind the current terminus position, transmitting resistive stress from sidewalls to centreline. Furthermore, we find that minimal mélange buttressing applied near the lateral margins is sufficient to advance this compressive arch, allowing the terminus to advance in winter. With respect to submarine melting, we find that a modest melt undercut (60m) can promote calving at an otherwise stable terminus position. Our HiDEM simulations for Store Glacier closely match the calving style observed in satellite imagery; the ability to accurately resolve calving at the event scale is a major step forward in our understanding of calving processes. By comparing stress patterns in Elmer/Ice with fracture patterns in HiDEM, we seek to formulate improved calving laws which can be implemented in ice-sheet scale continuum models.