Damage Mechanics Approach to Modeling Crevasse Propagation and Iceberg Calving

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Iceberg calving is a natural process that occurs when a combination of surface and basal crevasses (fractures) propagates through the entire thickness of the ice shelf or glacier, eventually leading to formation of icebergs. Calving from all Antarctic ice shelves accounts for about 50% of the mass loss from the whole Antarctic ice sheet with the other 50% mass loss attributed to oceanic erosion including basal melting. Modeling the fracture mechanics of calving and parametrizing calving laws in numerical ice sheet models is important to reliably predict future dynamical responses of the Antarctic ice sheet in relation to warmer climates and oceans, which could lead to significant contributions to sea level rise in the next one to two centuries. However, the state-of-the-art ice sheet models either use empirical or heuristic calving laws that do not capture all types of calving behavior. In this context, the widely-accepted hypothesis is that crevasse propagation and calving is dominated by the opening of cracks due to tensile stress. Therefore, researchers have recently attempted to parametrize stress-based calving laws into numerical ice sheet models using linear elastic fracture mechanics and/or continuum damage mechanics. The advantage of the damage mechanics approach over the fracture mechanics approach is that it can simulate crevasse formation and propagation by accounting for viscous creep damage and hydrofracture mechanisms in a thermodynamically consistent and computationally efficient manner.

This talk will present a continuum damage mechanics approach to modeling water-filled surface and basal crevasse propagation in conjunction with the incompressible full Stokes formulation for creeping ice sheet flow. The damage model is calibrated to describe the gradual creep fracture process observed in laboratory tests on polycrystalline ice. The damage mechanics approach is used to investigate the conditions enabling full-depth penetration of dry and water-filled surface and basal crevasses in idealized rectangular grounded marine-terminating glaciers. Specifically, the upper limits on crevasse penetration depth is studied in relation to ice thickness, ice rheology, water depth in surface crevasses and seawater depth at the ice terminus. The model results are compared with those from existing theoretical approaches based on the Nye zero stress and fracture mechanics models. The main finding of our study on surface crevasse propagation is that the damage mechanics approach is consistent with the fracture mechanics approach when the seawater depth at ice terminus is low, but it is inconsistent when the seawater depth at the ice terminus is high (i.e., near floatation). Our results also suggest that the propagation of basal crevasses is sensitive to initial crevasse size and ice rheology. Our ongoing work is focused on investigating crevasse propagation in floating ice tongues and integrating damage mechanics models into higher-order Stokes formulations in the Community Ice Sheet Model (CISM).

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