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Sliding with cavity formation: finite-element model of the generalized Stokes flow equations with free surface

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Sliding velocity is the least predictable component of glacier velocity, and meaningful treatment of sliding is one of the biggest challenges in modeling wet-based ice masses. Field observations indicate that sliding velocity varies in relation to changes in subglacial water pressure or subglacial water storage arising from opening and closing of subglacial water cavities in the lee of bedrock obstacles. Here, we present a numerical model of sliding with cavity formation based on the solution of the generalized (non-Newtonian rheology) Stokes equations with a free surface representing the roof of the cavity. This non-linear system of equations is solved with the finite element method using a penalty formulation. No assumptions are made about cavity shape or sliding rule. Sliding velocity is determined from the balance of forces between driving stress and resisting stress arising from ice flow over obstacles. Sliding speed is computed as a function of water pressure in the cavity, and results are compared to existing field data from alpine glaciers. This formulation improves on prior works by obtaining the precise velocity and pressure field distributions in ice without ad hoc manual adjustment of cavity position.