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An updated-Lagrangian damage mechanics formulation for modeling the creeping flow and fracture of ice sheets

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Abstract

An updated-Lagrangian formulation is developed to model the incompressible Stokes (creeping) flow and fracture of ice sheets using both explicit-integral and implicit-gradient nonlocal damage approaches. The governing equations of incompressible nonlinearly viscous Stokes flow assuming the plane strain approximation are discretized using high-order mixed finite elements over the current reference domain. The discretized nonlinear system is solved using a Picard iteration scheme, and a mesh update method is employed to obtain the updated reference domain at every time step. Fracture (crevasse) initiation and propagation is modeled using a scalar (isotropic) damage variable, and damage control or element removal strategies are implemented to avoid numerical accuracy and convergence issues arising from fully damaged finite elements near the crevasse tip. The formulation is implemented in the open-source finite element software FEniCS, and the relevant numerical algorithms are detailed. Numerical verification and benchmark studies based on manufactured nonlinear Stokes solutions and constant velocity and gravity-driven creep flow experiments are conducted to establish the viability of the formulation. We demonstrate that crevasse propagation rates obtained from nonlinear Stokes and Maxwell viscoelastic models are in good agreement over short time scales (days), so it is reasonable to neglect the elastic effects and employ the Stokes model to simulate iceberg calving. Furthermore, we demonstrate that over long time scales (months) the updated-Lagrangian Stokes formulation is more physically accurate than the total Lagrangian Maxwell viscoelastic formulation because the former accounts for the domain geometry changes. To conclude, the merit of

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