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Modelling the kinematic evolution of valley-scale folding in surge-type glaciers using Elmer/Ice

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Glacier surges produce iconic valley-scale folds which encode a history of polyphase deformation resulting from switches between quiescent and surging flow. The folding is passive, resulting from disturbances to ice foliation during surging flow, and subsequently altered during quiescent flow. We investigate the kinematic evolution of these kilometre-scale folds, using Elmer/Ice, by modelling folds through multiple surge cycles using idealized synthetic glacier confluence configurations, and identifying how differences in glacier flow regimes imprint themselves onto three-dimensional fold geometry. The surge and quiescent phases are simulated by changing the basal conditions of one of the tributaries, and matching the scale of velocity variations observed in temperate glacier surges. We determine fold geometry using a particle tracking algorithm applied to the modelled velocity fields, where, mimicking a medial moraine, vertically-spaced particles are injected at the flow unit confluence and advected downglacier. Using structural analysis of the model outputs, we present an archetype of kinematic evolution that describes the transition from cylindrical, vertically plunging, gentle folds emplaced during the surge phase, to complex, non-cylindrical, depth-varying folds following multiple cycles of surging and quiescent flow. The initial fold geometry is controlled by longitudinal and lateral shear stress regimes during surging, while fold evolution is governed primarily by lateral shearing after emplacement. We examine the sensitivity of fold geometry to valley geometry, glacier dynamics, and mass balance. Finally, we illustrate the potential of our approach to reconstruct more complex fold geometries as observed in nature, by applying it to a large surge-type glacier in the St. Elias Mountains of Northern Canada.