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Modelling the coupling of flood discharge and glacier flow during jökulhlaups

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In Nye's (1976) theory of jökulhlaups, lake water drains through a subglacial channel whose size evolves to govern the outburst hydrograph. His theory ignores the impact of the flood on glacier motion that could arise from a dependence of basal sliding on subglacial water pressure. Such coupling between flood and ice-flow dynamics is worthy of study because ice-motion events of various kinds have been observed before or during jökulhlaups in real systems, and because water exchange between the channel and a distributed subglacial drainage system can affect flood initiation and the flood hydrograph. Here we develop a mathematical model that couples these components (channel thermo-mechanical evolution, lake continuity, distributed cavity drainage, basal sliding and channel-cavity water transfer) along a subglacial flood path. Numerical solution of the model equations reveals that a reverse hydraulic gradient near the lake and spatial variability in channel discharge allows a migrating subglacial water divide to form near the lake between floods. This allows the model to reach repeating limit cycles, simulating multiple flood cycles. The channel injects water into and draws water from the cavities at different stages of the flood cycle, modulating the cavity water pressure and the basal sliding. At flood initiation, a wave of high sliding velocity propagates down-glacier due to the arrival of the water divide at the lake and the high lake level. This is followed by deceleration as the channel begins to remove more water from the cavities resulting in ice velocities that are lower than between floods. This begins near the time of peak channel discharge and is due to the enlargement of the channel and the reduction in lake level during the flood. Experiments demonstrate that the flood peak discharge and initiation threshold both depend on the background water supply to the cavities, and that the velocity wave manifests itself differently in glacier and ice-sheet settings. We present simulations of jökulhlaups from several systems: Gornersee, Switzerland; Grimsvötn, Iceland; and Hidden Creek Lake, Alaska. We find that the model captures key aspects of the hydrological and dynamical changes in these systems when the cavity water supply is assumed to be low. We also simulate jökulhlaups from Merzbacher Lake, Kyrgyzstan, to predict its observable glacier-flow response. Our modelling extends recent interest in the interactions between ice flow and subglacial hydrology by studying the extreme discharge scenario of jökulhlaups from marginal or subglacial lakes.