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A spatially distributed model for routing meltwater to the ice bed through moulins and during lake drainage events

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Seasonal influx of surface-generated meltwater to the subglacial hydrological system can enhance ice surface velocities through basal lubrication and changes in effective pressure at the bed (Iken & Bindschadler, 1986). Recent studies of outlet glaciers on the Greenland Ice Sheet show that ice surface velocities respond directly to periods of increased surface meltwater production (Bartholomew et al, 2010; Shepherd et al, 2009), suggesting that meltwater is transmitted efficiently from the supraglacial to the subglacial hydrological systems. Ice surface uplift and changes in horizontal velocity have also been observed coincident with lake drainage events (Das et al, 2008). The fractures, or moulins, through which meltwater is routed to the bed are able to propagate through the full ice thickness due to the meltwater influx being sufficient to offset closure of the fracture due to the lithostatic stress of the ice. Here we describe a spatially distributed model for predicting where and when surface-originating crevasses propagate to the bed of the ice in an area of south-west Greenland encompassing the Russell and Leverett catchments.

The modelling routine generates surface melt from simple meteorological data using a degree-day approach, and routes the meltwater across the ice surface using a digital elevation model-based single flow direction algorithm. The surface tensile stress regime, derived from ice surface velocities following the Von Mises failure criteria, determines the location of initial surface fractures based on the tensile strength of the ice. Where routed meltwater intersects a surface crevasse, a model for propagation of water-filled fractures is applied (Van der Veen, 2007). Running the model at a daily time-step allows for prediction of both the location and timing of moulin formation, and for quantification of meltwater delivery to the bed. By allowing for longer periods (days to weeks) of supraglacial melt storage, we simulate supraglacial lake filling. Different lake drainage criteria are explored within the modelling routine, initiating propagation of fractures beneath lakes. The meltwater contained within lakes is delivered to the bed when the fracture depth equals the ice thickness. Inclusion of lake formation and drainage within the model allows for delivery of melt to the bed at higher elevations than can be accounted for by moulins alone. Results suggest both that density of surface-to-bed connections would increase and the area containing these connections would expand upglacier under the scenario of enhanced surface melt, due to the controlling influence of meltwater filling rates on crevasse propagation depths. Thus, in a future warming climate, meltwater transfer to the bed will become increasingly significant with penetration of meltwater both at higher elevations and across a wider spatial extent of the ice-bed interface, which may have important implications for ice dynamics.

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