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Modelling debris transport within glaciers by advection in a full-Stokes ice flow model

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As mountain glaciers recede worldwide, an increasing proportion of the remaining glacierized area is expected to become debris covered. The spatio-temporal development of a surface debris cover has profound effects on the glacier behaviour and meltwater generation, yet little is known about how glacier dynamics influence the spatial distribution of an emerging debris cover.

Motivated by this lack of understanding, we present a coupled model to simulate advection and resulting deformation of debris features within glaciers. The finite element model developed in python consists of an advection scheme coupled to a full-Stokes ice flow model, using FEniCS as the numerical framework. We show results from numerical tests that demonstrate its suitability to model advection-dominated transport of concentration in a divergence-free velocity field. The capabilities of the coupled model are demonstrated by simulating transport of debris features of different initial size, shape and location through modelled velocity fields of representative mountain glaciers.

The results indicate that deformation of initial debris inputs, as a consequence of being transported through the glacier, plays an important role in determining the location and rate of debris emergence at the glacier surface. The presented work lays the foundation for comprehensive simulations of realistic patterns of debris cover, their spatial and temporal variability and the timescales over which debris covers can form.