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Preliminary modelling of subglacial erosion using dual-morphology subglacial hydrology and process-based erosion laws

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Glacial erosion is often referred to as the most efficient erosion process on earth. However, it has recently been shown that extensive glaciation could shield pre-existing topography. Although the main mechanisms of glacial erosion have been identified, their drivers and efficiency remain unclear. In this study, we consider the three main processes by which glaciers carve the landscape: (1) quarrying (or plucking) (2) abrasion, and (3) through the subglacial fluvial system. Quarrying and abrasion are directly dependent on glacier sliding speed, while quarrying and subglacial fluvial erosion are a function of the basal water pressure and state of the subglacial hydraulic system. Therefore, subglacial hydrology has a potentially large, yet poorly understood effect on glacial erosion. We adopt a numerical modelling approach to further understand this problem examining the driving processes on annual to sub-seasonal timescales.

Using a two-dimensional higher-order model of ice flow, coupled to a dual-morphology subglacial hydrology model with a Coulomb friction law for sliding, we obtain patterns of sliding and water pressure over one year. The two subglacial morphologies that we incorporate are: (1) a distributed drainage system, characterized by water pressure increase with water inflow and (2) a channelized drainage system in which, at equilibrium, water pressure decreases with enhanced water inflow. Sliding and water pressure patterns are then used to calculate instantaneous rates of abrasion and quarrying.

This model enables us to evaluate the effect of the melt-season on erosion. Overall, the incorporation of subglacial hydrology leads to abrasion and sliding maxima where water inflow is high, lower than the Equilibrium Line Altitude (ELA). Then, introducing channels through a dual-morphology drainage system, we find a migration of about 20% upglacier of the sliding and abrasion maxima over the melt-season, whilst these maxima are spatially stagnant with a distributed drainage system alone. Quarrying rates correlate with large effective pressures (ice overburden pressure minus water pressure). Interestingly the peak in sliding speed during the melt season seems not to change this pattern, due to the very low effective pressures accompanying enhanced sliding. Our results suggest that a simple scaling of glacial erosion with glacier sliding speed or ice discharge might be inadequate in landscape evolution models.