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# Variations in Glacial Erosion over Multiple Glacial-Interglacial Cycles: A Numerical Modelling Approach

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Mountain topography is constructed through a variety of interacting processes. As one of these processes, glacial erosion plays an important role in the development of landscapes by the formation of distinctive topographic features. Glacial landscape evolution models reproduce many observed features at the orogen scale. Detailed comparisons at the scale of individual valleys holds potential for quantifying the influence of glacial physics in glacial erosion models. Over long timescales (>10,000 yr), glacial erosion has typically been simulated using a modified shallow ice approximation (SIA) approach. In this study, we compare the strengths and weaknesses of shallow ice and high-order, Stokes-flow glacial landscape evolution models. Our emphasis is placed on the patterns and rates of glacial erosion over multiple glacial-interglacial cycles.

We present a comparison of two different numerical models for glacial erosion. For both approaches, a modified version of the ICE Cascade model is used to develop and evolve topography. This model calculates hillslope and fluvial erosion and sediment transport, isostasy, temporally variable orographic precipitation, and a range of glaciological processes: glacial mass balance, snow avalanching, basal ice superfreezing, and basal water buoyancy feedback in large overdeepenings. Within this framework, we compare the predicted ice-flow field and erosion patterns using a modified SIA as well as predictions from a nested, thermally-coupled, Stokes-flow model calculated using COMSOL Multiphysics. Simulations are conducted for a range of amplitudes and periodicity in surface temperature change between glacial and interglacial periods. We investigate these simulations, as well as the effects of each model for various initial topographies and with a temperature-dependent ice rheology.

In general, both models predict visually similar patterns in sliding velocity, and resulting erosion rates, assuming the erosion rate scales with the sliding velocity; however, within different climate scenarios, a few key differences stand out. For one, these results are sensitive to the climate and the ice temperature. In general, for colder climates, the effects of the higher-order model on the erosion rate are less. For warmer climates with more sliding, the higher-order model has a larger impact on the erosion rate and basal shear stress. The instantaneous velocity, and the corresponding erosion rate, can vary by over 50% between the high-order physics model and the modified SIA model. This variation is not independent of the variations in ice covered area and ice thickness, however. As the sliding velocity affects the full flow column of the ice, the ice thickness and extent are also influenced. The higher-order glacial model can lead to variations in total ice-covered area averaging around 5-10%, again with larger differences for warmer ice. Extrapolated over geologic time scales and multiple glaciations these results suggest that consideration of higher-order glacial physics may be necessary, particularly in regions with extensive temperate or polythermal glaciers, when comparing model predictions to observed chronologies of glacial erosion.