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Glacial steady state topography inferred from the Shallow Ice Approximation

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The impact of glacial erosion on the shape and height of mountain landscapes has been a subject of vital scientific discussion since the end of the nineteenth century. While substantial progress has been made in understanding glacial landscape evolution, the feedbacks that emerge from the interaction of tectonic activity and glacial processes remain unclear. Glacial erosion is often believed to impose a purely climatic limit on mountain relief irrelevant of tectonic processes, but a dependence of glacial topography on rock uplift rates has been reported as well. These unresolved discrepancies seem to be owed, at least to a large part, to the analysis of transient landscapes, while constraints on possible end-member scenarios, such as a glacial topographic steady state, are lacking.

In the fluvial realm, the definition of steady state river profiles critically improved the understanding of fluvial landscape evolution. Here we present a steady-state solution for longitudinal profiles along eroding glaciers based on the shallow ice approximation and a glacial erosion law. We analyse different influences on ice thickness, ice surface slope and glacial relief such as a non-linear mass balance over elevation, a dependence of ice temperature on air temperature and thus altitude, and variations of the glacial erosion law. Finally, we report the fundamental controls on such glacier profiles and their scaling relations. We show that, in our theoretical approach, both tectonics and climate influence the shape and height of glacial mountain landscapes. In contrast to a fluvial steady state, the dependence of mass balance on altitude reduces the sensitivity of mountain height to rock uplift rate in the glacial realm. This effect emerges from a feedback between mountain height and mass balance. Higher rock uplift rates increase mountain height in both fluvial and glacial landscapes, but in the latter, the increase is reduced due to a mutual increase in mass balance, and thus ice flux, sliding velocity and erosion, which counteracts the growth of relief. In this way, the dependence of relief on rock uplift rate fundamentally differs between glacial and fluvial landscapes.