Analytical long-profile models of coupled glacier-fluvial systems

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Glaciers are an effective agent of erosion and landscape evolution, capable of driving high rates of erosion and sediment production. Glacial erosion is therefore an important process mediating the effect of climate on erosion rates and tectonics. Further, as a source of sediment, glacial erosion also has implications for the carbon and silicate cycles, with the potential for longterm feedbacks. Understanding the interaction of climate, tectonics, glacial erosion and topography will lead to more insight into how glaciers can impact these processes. Simple, analytical long-profile models of fluvial incision are fundamental in tectonic geomorphology and critical for addressing fluvial analogues of problems such as those posed above. The advantage of these simple long-profile models is that they can be applied when information about forcing and boundary conditions is minimal (e.g. in deep time), and they can aid in the development of intuition about how such systems respond in general to different forcing. While models of glacial erosion have existed for quite some time, they tend to be complicated and computationally expensive. Currently, analytical long-profile models do not exist for glacial systems. At the same time, the patterns of glacial erosion and sediment transport, and how these processes respond to climate is fundamentally different than fluvial systems, and cannot be addressed properly with purely fluvial models.

Building on previous work, we introduce several simplifications to make the equations for coupled glacier-fluvial long-profile models easier to use and show that these simplifications have minimal effect on the steady state solution. We then use these new equations to develop an analytical solution for glacier-fluvial long-profiles at erosional steady state. The solution provides glacier geometry, including length and slope, ice thickness, and overall orogen relief for a given uplift rate, rock erodibility, profile length and climatic conditions. To explore the effect of glaciation on the balance between climate, erosion and orogen geometry, we integrate this solution into a critical wedge orogen theory. We find that the total orogen relief should be closely tied to the equilibrium line altitude (ELA), in line with the glacial buzzsaw theory. In addition, our theory predicts that the geometry and average uplift rate of glaciated critical wedge orogens respond more sensitively to changes in climate than those dominated by fluvial erosion. We suggest that the lowered ELA during glacial maxima over the last few million years could have triggered narrowing of critical orogens, with an associated increase in uplift rates within the active orogen core.