Physically-based modelling of ice cliff melt on a debris-covered glacier, Nepalese Himalayas

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Supraglacial ice cliffs can be found on debris-covered glaciers worldwide and provide the only direct atmosphere-ice interface on the tongues of these glaciers. A complex interplay between cliff surfaces with low albedo and surrounding debris slopes emitting a large longwave radiation flux causes very high melt rates, which are likely to account for a significant portion of total glacier mass loss. The actual mechanisms causing their ablation and dynamics however are little understood, and the magnitude of their ablation, mass losses and total contribution to glacier mass balance and catchment runoff has rarely been quantified.
Here, we simulate the ablation of selected ice cliffs using a new physically-based model of cliff backwasting, based on observations obtained from high-resolution aerial and terrestrial images, Structure from Motion and data from automatic weather stations on two glaciers in the Nepalese Himalaya. We show that backwasting leads to a variety of evolution typologies, with cliffs that maintain a constant, self-similar geometry, cliffs that grow laterally and cliffs that disappear through slope shallowing and debris melt-out. The presence of a pond appears to be the key control for cliffs to survive, while east and west facing cliffs grow because of higher radiation receipts. We also quantify their total volume losses over the melt season, and show that this is very high indeed over the glacier.
This work sheds light on mechanisms of cliff melt by quantifying them for the first time with a dynamic, physically-based model and a novel ground control dataset, and provides a tool that can be used for quantification of total mass losses from these features. We show the complexity of the processes, discuss knowledge gaps and point to the need of including cliffs energy, mass and water fluxes into glacio-hydrological models of catchment hydrology applied to Himalayan catchments.