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Characteristics and interannual changes of ice cliffs on the debris-covered glaciers of HMA

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Ice cliffs have been shown to be key contributors to the mass balance of debris-covered glaciers in High Mountain Asia. They are zones of enhanced energy inputs and contribute to glacier melt 3 to 15 times more than the surrounding debris, with backwasting rates of up to 10 cm/day. Field observations have shown that these features can evolve quickly, extending by 50% of their area or being entirely reburied by debris within the course of one monsoon season, while others remain stable over several years. They can also appear suddenly via abrupt events such as englacial conduit collapse, crevasse opening or slope destabilization by supraglacial streams or ponds. These mechanisms and evolution patterns have never been quantified nor even observed at the scale of a glacier, mainly because very few repeat datasets of appropriate temporal resolution exist.

Here we combine one existing and new multi-temporal datasets of cliff outlines derived manually or semi-automatically, from debris-covered glaciers in four regions of HMA with varying topography, debris-cover and climatic regimes. We use a tracking algorithm to automatically detect the evolution of these features over several years, focusing on their formation rates and the evolution of their shapes and sizes obtained from high resolution digital elevation models. Surface velocity maps, debris thickness measurements and outlines of ponds and the main supraglacial streams are used to relate the evolution patterns to glacier dynamics and supraglacial hydrology.

We follow and analyze the inter-annual evolution of more than one thousand cliffs along with the nearby ponds. These results allow us to propose a classification of ice cliffs based on the mechanisms governing their genesis and evolution. Finally, we use this classification to map and quantify the different genesis mechanisms dominant at each of the four sites. By considering the evolution of each cliff independently, this study bridges the gap between large-scale statistical studies of cliff populations and detailed field observations focusing on a few features of specific glaciers. In addition to improving our general understanding of ice-cliff evolution, this study provides the first consistent and regional dataset of cliff characteristics, changes and patterns to support modeling of ice cliffs at a large scale.