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Heterogeneous response of debris-covered and debris-free glaciers to climate change in Langtang Himal determined by geodetic mass balance measurements

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Himalayan glaciers show a heteorogenous response to climate change. Most of them are losing mass at rates similar to glaciers elsewhere, but satellite remote sensing studies have suggested that heavily debris-covered glaciers with stagnant low-gradient termini are receeding less than debris-free glaciers or have even stable fronts. It is well known that debris thickness above a critical value of few cm reduces ablation. However, recent studies based on remote sensing have provided evidence that the present-day lowering rates of debris-covered glacier areas in high mountain Asia might be similar to those of debris-free areas even within the same altitudinal range. It was surmised this could be due to enhanced melt from exposed ice cliffs, supraglacial lakes and reduced ice flux.

In this study we derive glacier volume changes in the upper Langtang catchment in Nepal for different periods between November 1974 and October 2015. Eight different high resolution DEMs, all extracted from stereo or tri-stereo satellite imagery (Hexagon KH-9, Cartosat-1, ALOS-PRISM, SPOT6/7, WorldView2/3), allow gaining detailed insights in spatial and temporal changes in glacier elevation change patterns. With the resulting 30 m resolution dataset of glacier elevation change rates we address three main points. First, we assess for each of the seven glaciers in the sample (five debris covered and two debris free glaciers) if overall thinning has accelerated in recent years. Second, we determine if spatial thinning patterns have changed over time. To explain differences in spatial patterns we use glacier surface velocities measured by cross-correlation feature tracking and analyze glacier surface characteristics. Third, we investigate if there are major differences between the response of debris-covered and debris-free glaciers in the sample.

We show that the debris-covered tongues exhibit a spatially heterogeneous response to climate change. In the upper reaches of debris-covered tongues thinning mostly accelerated in recent years, while the nearly stagnant areas near the terminus show constant or decreasing thinning rates. The highest thinning rates and the strongest increase in thinning rates can be associated to areas with a large presence of supraglacial cliffs and lakes. However, the mean thinning rates per altitudinal band of such areas of maximal thinning are still 20-40% lower than thinning rates of debris-free glacier area at the same elevation. A strong melt reducing effect of supraglacial debris seems therefore indisputable. The mass balance of all glaciers during all studied periods is negative (on average 2006-2015: -0.60$\pm$0.34 m/a), but while for some glaciers the mean annual mass loss between 2006 and 2015 doubled with respect to to the period 1974-2006, for others we do not identify accelerated mass loss. The response of debris-free glaciers seems to strongly depend on glacier hypsometry: almost balanced mass budgets in recent years can be associated to high accumulation area ratios, although thinning of debris-free glacier area below the equilibrium line altitude is accelerating rapidly. We conclude that trends of glacier mass loss rates in this part of the Himalaya cannot be generalized, neither for debris-covered nor for debris-free glaciers.