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Quantifying 3D ice cliff evolution with multi-temporal point clouds on the debris-covered Khumbu Glacier, Nepal

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Observations of ice cliff retreat on debris-covered glaciers have until recently focused on point ablation stake measurements, which may not be representative of the melt rates across a heterogeneous cliff face. Here we present the first fully 3D assessment of spatio-temporal ice cliff evolution on Khumbu Glacier in the Everest region of Nepal. During three field campaigns (Nov 2015, May 2016, Oct 2016), nine ice cliffs were surveyed to enable 3D point cloud generation following a Structure-from-Motion with Multi-View Stereo (SfM-MVS) workflow. Multi-temporal point clouds were differenced using the M3C2 algorithm in Cloud Compare to calculate statistically significant 3D topographic change.

Four out of nine cliffs persisted over the study, whereas five became buried under a layer of debris. The spatio-temporal evolution of ice cliffs was found to be dependent upon cliff-scale characteristics (e.g. height and aspect) and their topographic context (e.g. presence of a supraglacial pond and the back slope of the cliff). Thermal undercutting by a supraglacial pond maintained the cliff angle during retreat, which delayed burial by debris. The back slope of an ice cliff also determined its potential longevity, with a low back slope promoting continued retreat and a high back slope promoting burial under debris. Retreat rates Oct-2015 to May-2016 ranged from 0.46 – 1.50 cm d-1 (mean of 0.8 cm d-1) compared to 0.74 - 5.18 cm d-1 (mean of 2.5 cm d-1) during May-2016 to Oct-2016.

Within a year, cliff retreat exceeded 8 m in several instances. Additionally, new cliffs formed and supraglacial ponds both expanded and drained. Quantifying these glacier surface dynamics therefore requires annual to sub-annual resolution assessments. These data will be used towards the parameterisation of ice cliff retreat into dynamic glacier models, which is essential to forecast the rates of glacier mass loss and subsequent effect on river discharge.