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Processes driving rapid morphological changes observed on the Khumbu Glacier, Nepal

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The response of many Himalayan glaciers to climatic change is complicated by the presence of a supraglacial debris cover, which leads to a suite of processes controlling mass loss that are not commonly found where glaciers are debris-free. Here, we present a range of field, surface topographic and ice-dynamical observations acquired from Khumbu Glacier in Nepal, to describe and quantify these processes in fine spatial and temporal resolution.

Like many other debris-covered glaciers in the Himalaya, the debris-covered tongue of the Khumbu Glacier is heavily in recession. For at least two decades, the lower ablation area has been stagnant as surface lowering in the mid-ablation zone has led to ever decreasing driving stresses. Contemporary velocity data derived from TerraSAR-X imagery confirms that the active-inactive ice boundary can now be found 5 km from the glacier terminus and that the maximum velocity, immediately below the icefall, is around 70 m per year. These data show that in this upper part of the ablation zone, the glacier velocity has not changed during the last 20 years, suggesting that at least above the icefall the glacier remains healthy.

Across the stagnant debris-covered tongue there have been marked surface morphological changes. Mapping from 2004 shows relatively few surface ponds, a homogeneous debris-covered surface, and a small area towards the terminus supporting soil formation and low vegetation. Mapping from field observations in 2014 shows an abundance of surface meltwater, a more heterogeneous surface texture associated with many exposed ice cliffs, and a long (3 km) zone of stable terrain where soils are developing and, in places, low scrub can be found. Most dramatically, a string of surface ponds occupying the true-left lowermost 2 km of ice have expanded and coalesced, suggesting the glacier has crossed a threshold leading towards large glacial lake development.

Two fine-resolution DEMs derived from Structure-from-Motion in spring 2014 and autumn 2015 elucidate the processes driving mass loss across the debris-covered area. Recession is greatest around surface meltwater ponds and in the upper part of the ablation area where debris cover is thinnest. Comparison with an historic DEM from 1984 shows the evolution of the glacier surface topography, which has become increasingly irregular because of the development of surface ponds and associated ice cliffs. These observations suggest a continuous cycle of relief inversion drives surface lowering across large areas of the debris-covered surface, and we propose a conceptual model to illustrate this cycle that is applicable to all receding debris-covered glaciers in the region.