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Variations in debris distribution and thickness on Himalayan debris-covered glaciers

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Many Himalayan glaciers are characterised by extensive supraglacial debris coverage; in Nepal 33% of glaciers exhibit a continuous layer of debris covering their ablation areas. The presence of such a debris layer modulates a glacier's response to climatic change. However, the impact of this modulation is poorly constrained due to inadequate quantification of the impact of supraglacial debris on glacier surface energy balance. Few data exist to describe spatial and temporal variations in parameters such as debris thickness, albedo and surface roughness in energy balance calculations. Consequently, improved understanding of how debris affects Himalayan glacier ablation requires the assessment of surface energy balance model sensitivity to spatial and temporal variability in these parameters.

Measurements of debris thickness, surface temperature, reflectance and roughness were collected across Khumbu Glacier during the pre- and post-monsoon seasons of 2014 and 2015. The extent of the spatial variation in each of these parameters are currently being incorporated into a point-based glacier surface energy balance model (CMB-RES, Collier et al., 2014, The Cryosphere), applied on a pixel-by-pixel basis to the glacier surface, to ascertain the sensitivity of glacier surface energy balance and ablation values to these debris parameters. A time series of debris thickness maps have been produced for Khumbu Glacier over a 15-year period (2000–2015) using Mihalcea et al.'s (2008, Cold Reg. Sci. Technol.) method, which utilised multi-temporal ASTER thermal imagery and our in situ debris surface temperature and thickness measurements. Change detection between these maps allowed the identification of variations in debris thickness that could be compared to discrete measurements, glacier surface velocity and morphology of the debris-covered area.

Debris thickness was found to vary spatially between 0.1 and 4 metres within each debris thickness map, and temporally on the order of 1 to 2 m. Temporal variability was a result of differential surface lowering, spatial variability in glacier surface velocities and intermittent input of debris to the glacier surface through mass movement. Most debris thickening is seen in initially thin areas of debris (< 0.4 m) or within $\sim$1 km of the glacier terminus. Surface energy balance modelling is currently underway to determine the effect of these variations in debris thickness, and other parameters mentioned previously. Future work will be to calculate debris transport flux on the surface of Khumbu Glacier using the time series of debris thickness maps. Debris flux and refined energy balance calculations will then be incorporated into a 3-D ice flow model to determine the response of Khumbu Glacier to debris transport and climatic changes.