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Characterizing aerodynamic roughness length (z0) for a debris-covered glacier: aerodynamic inversion and SfM-derived microtopographic approaches

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Aerodynamic surface roughness is an essential parameter in surface energy balance studies. While actual measurements on bare ice glaciers are rare, a wide range of literature values exist for ice and snow surfaces. There are very few values suggested for debris covered glaciers and actual measurements are even scarcer – studies instead optimize z0 or use a reference value. The increased use of photogrammetry on glaciers provides an opportunity to characterize the range of z0 values meaningful for debris-covered glaciers.

We apply Agisoft's Structure-from-Motion process chain to produce high resolution DEMs for five 1m x 1m plots (1mm resolution) with differing grain-size distributions, as well as a large ∼180m x ∼180m depression (5cm) on Lirung Glacier in the Nepalese Himalayas. For each plot, we calculate z0 according to transect-based microtopographic parameterisations. We compare individual-transect z0 estimates based on profile position and direction, and develop a grid version of the algorithms aggregating height data from all bidirectional transects. This grid approach is applied to our larger DEM to characterize the variability of z0 across the study site for each algorithm.

For the plot DEMs, z0 estimated by any algorithm varies by an order of magnitude based on transect position. Although the algorithms reproduce the same variability among transects and plots, z0 estimates vary by an order of magnitude between algorithms. For any algorithm, however, we find minimal difference between cross- and down-glacier profile directions. At the basin scale, results from different algorithms are strongly correlated and results are more closely clustered with the exception of the Rounce (2015) algorithm, while any algorithm's values range by two orders of magnitude across the study depression. The Rounce algorithm consistently produced the highest z0 values, while the Lettau (1969) and Munro (1989) methods produced the lowest values, and use of the Nield (2013) regression-fits based on topographic metrics produced intermediate values.

A tower of wind and temperature sensors was installed in the depression in October 2014. Using an iterative method to derive friction velocity and temperature scale, we derive the Monin-Obukov length and subsequently surface roughness values for each data pair (Garratt 1992, Hogstrom 1988, Brock 2006). Values range from 0.01 to 0.2 m over the observation period for this single location.

Clearly, the surface of debris-covered glaciers is extremely variable spatially and temporally, so what should be used in models? Our results suggest z0 varies between 0.004 m (smooth cobbles) to 0.5m (large boulders), and that 0.015m is a reasonable central value for Lirung Glacier. As the grain-size distributions closely reproduce the distribution of obstacle sizes determined by the zero-up-crossing method, and d80 preserves the plot ranking of z0 magnitudes, it may be possible to develop a representative z0 lookup table based on grain sizes, which would provide a straightforward method to roughly vary z0 across the debris surface for energy-balance modelling applications.