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Estimating the aerodynamic roughness of debris covered glacier ice

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Aerodynamic roughness length (z0), the height above the ground surface at which the extrapolated horizontal wind velocity profile drops to zero, is one of the most poorly parameterised elements of the glacier surface energy balance equation. Microtopographic methods for estimating z0 are becoming increasingly well used, but are rarely validated against independent measures and are yet to be comprehensively analysed for scale or data resolution dependency. Here, we present the results of a field investigation conducted on the debris covered Khumbu Glacier during the post-monsoon season of 2015. We focus on two sites. The first is characterised by gravels and cobbles supported by a fine sandy matrix. The second comprises cobbles and boulders separated by voids. Vertical profiles of wind speed measured over both sites enable us to derive measurements of aerodynamic roughness that reflect their observed surface characteristics (0.0184 m vs 0.0243 m). z0 at the second site also varied through time following snowfall (0.0055 m) and during its subsequent melt (0.0129 m), showing the importance of fine resolution topography for near-surface airflow. We conducted Structure from Motion Multi-View Stereo (SfM-MVS) surveys across each patch and calculated z0 using three microtopographic methods. The fully three-dimensional cloud-based approach is shown to be most stable across different scales and these z0 values are most correct in relative order when compared to the wind tower data. Popular profile-based methods perform less well providing highly variable values across different scales and when using data of differing resolution.