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A new type of Østrem curve: insights from distributed ablation over the dirty ice areas of debris-covered glaciers

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Dirty ice areas of patchy and discontinuous debris typically occur above the limit of continuous supraglacial debris cover, and are important both as regions of high melt rates and as the locus of the identified increase in debris cover. Dirty ice ablation is spatially highly variable, and debris thicknesses straddle the effective thickness threshold separating enhanced and reduced ablation. The melt response is therefore very sensitive to small changes in debris thickness and extent in this zone. Despite this no previous study has sought to directly quantify ablation dynamics over an area of dirty ice. This may be due to the unsuitability of traditional point ablation stakes which cannot capture the likely spatial variation in ablation. The Østrem curve which relates debris thickness to ablation has been well-established by plot based field experiments, although only recently have models been able to replicate the peak of the curve. However, modelling has suggested that a similar peak in ablation can be achieved by altering the percentage debris cover, although as yet this has not been substantiated with field measurements. Indeed, the existence of very thin, uniform debris layers is questionable, and a discontinuous debris cover is much more likely.

We present a novel approach to determine distributed ablation, based on photogrammetric processing of repeat UAV (Unmanned Aerial Vehicle) imagery, involving correcting the second digital elevation model for the horizontal glacier velocity field, downslope ice movement and the emergence velocity. A high-resolution (approx. 0.04 m x 0.04 m) spatially continuous ablation map was created for a one-month period over a 2.7 ha dirty-ice area on Miage Glacier (Italy). It provides unique insights into ablation beneath continuous and discontinuous debris. We identify several processes that affect surface melt at the local scale, including melt foci along sub-debris drainage routes, stream enlargement, and sliding of large clasts. We are able to quantify the ablation for a given percentage debris cover and identify the peak in ablation associated with moderate percentage covers. Evolution of the debris is investigated by detecting change in percentage debris cover between images. Methods are also developed to link ground-truthed data on debris albedo and clast depth to the UAV imagery, allowing spatial extrapolation of these variables in preparation for future modelling.