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Monitoring the debris cover evolution combining remote sensing and photogrammetric techniques

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Debris cover evolution has been seen to expand in recent years with the increase of rockfalls from the surrounding slopes and of englacial melt-out material caused by a warming climate. Little is known however about the magnitude of the changes in debris and very few models exist which explain or parameterise its evolution. A prerequisite to understand past changes in debris cover extension is the availability of methods to reconstruct accurately debris area. This is important also for the application of numerical melt and mass balance models.

In this paper, we present a comparison of approaches to map debris cover extension and monitor its evolution over Haut Glacier d'Arolla, a small valley glacier in the Swiss Alps, which has patches of rocky debris covering about 10% of its area. Debris thickness ranges from few centimetres to few tens of centimetres and debris concentrates on three main areas, mainly on the glacier tongue. We use three different techniques, from remote sensing to photogrammetric methods, to reconstruct the 2001 and 2010 debris cover extent. The first approach is a semi-automatic debris mapping method that uses Landsat and ASTER images together with a Digital Elevation Model (DEM) to do a classification based on band ratio, slope values and a final manual correction. The second methodology is based on the information from georeferenced terrestrial photos of the glacier. The low reflectivity of the images is combined with the definition of the glacier extension and allows the identification of the glacier area covered by rock. The third technique is based on the inversion of a distributed energy balance model forced by meteorological data and surface temperature provided from ASTER thermal images. This technique not only allows the debris cover mapping but provide also debris thickness maps, key variable for debris energy balance and temperature index model. All three techniques are validated against the debris extent mapped during the 2010 summer .

The results show that all methods are able to map correctly the 2010 debris extent on the glacier. A clear debris cover evolution over the last decade can be identified using the remote sensing and photogrammetric approach. The main limitation of the remote sensing method is that it requires contemporary DEMs to the image, and the lack of these leads to a misclassification of the debris accumulated along the glacier margin. The inversion of the EB on the other side requires knowledge of debris effective conductivity and surface roughness. Uncertainties and limitations are found in the areas in which the debris cover does not form a continuous mantel, but is interrupted by bare ice exposed patches.