Automated debris-covered glacier mapping – development for and application to Afghanistan

Jamal Abdul Nasser Shokory and Stuart Lane
University of Lausanne, Institute of Earth Surface Dynamics, Faculty of Geosciences and Environment, Lausanne, Switzerland (jamal.shokory@unil.ch)

Over the past two decades, several semi-automated approaches for identifying debris covered ice have been proposed but challenges remain. Manual delineation of debris-covered glaciers has been recognized as an accurate method but is labor- and time-intensive for large regions. Geomorphological mapping in complex mountain environments is recognized as difficult and the accuracy of the associated maps is also highly dependent on the expertise of the mapper and their visual interpretation. Other methods seek to move beyond just optical or DEM-assisted classification to make use of the fact that there may be thermal differences in the temperature between debris-covered ice and the temperature of the surrounding non ice-cored zones, making it possible to identify debris-covered ice. Of course, with very thick debris cover, the signal of ice temperature will disappear, but this method may allow identification of zones that are ice cored that would otherwise be classed as non-glacier using other methods. In this study, we take advantage of thermal differences and near infrared measurements for both thin- and thick debris-covered ice that allows automated mapping of remote regions like Afghanistan. However, for debris-covered ice mapping, previous studies observed that using single thermal band misclassified the clean ice as debris-covered ice in transitional zones where clean ice and debris-covered ice meet, due to the coarser spatial resolution of available data (90 – 120 m). Therefore, this study investigated several Landsat 8 spectral bands with better spatial resolution to find correlation over debris-covered ice and to merge it with the thermal band. In a systematic test of all bands over the specific debris-covered ice, we determined that panchromatic band has significant reflectance on clean ice and debris-covered ice, from higher to lower value. Then, a new normalized index was developed accordingly, which increased the spatial resolution and improved the result. The Normalized Supraglacial Debris Index (NSDI) (eq. 1), has been tested for Afghanistan glaciers and validated through a fieldwork campaign on a specific glacier. For the test glacier, the method had 96% overall accuracy and a Kappa coefficient of 0.87.

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\text{Normalized Supraglacial Debris – Covered ice Index (1) (NSDI)} = \frac{\text{FAN} - \text{TIR}}{\text{FAN} + \text{TIR}} \quad [1]
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In addition we also tested the threshold values of NSDI based on the region of interest (ROI), and the ROI was selected up on five glaciers where the detailed map were available. During the process of mapping debris-covered ice using [1], we found several zones of likely debris-covered ice were not being detected with the threshold value neither with any near range. Then we
performed a reflectance test up on each single band of Landsat 8 by classifying band value into equal classes of histograms, and found that SWIR has better reflectance in range of 6,230-7,160 values for the region where the debris-covered ice was missing. In addition the green band (B3) also had lower reflectance. Thus, in combination of both SWIR and Green bands we developed second index separately (eq. 2).

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\text{Normalized Supraglacier Debris - Covered ice Index (2) (NSDI2)} = \frac{\text{SWIR}}{\text{Green}} [2]
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In conclusion, the two newly developed indexes were abled to correctly map the debris covered ice with two different debris characteristics.