Geophysical Research Abstracts
Vol. 18, EGU2016-250, 2016
EGU General Assembly 2016

Multi-temporal high resolution monitoring of debris-covered glaciers using unmanned aerial vehicles

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Debris-covered glaciers in the Himalayas are relatively unstudied due to the difficulties in fieldwork caused by the inaccessible terrain and the presence of debris layers, which complicate in situ measurements. To overcome these difficulties an unmanned aerial vehicle (UAV) has been deployed multiple times over two debris covered glaciers in the Langtang catchment, located in the Nepalese Himalayas. Using differential GPS measurements and the Structure for Motion algorithm the UAV imagery was processed into accurate high-resolution digital elevation models and orthomosaics for both pre- and post-monsoon periods. These data were successfully used to estimate seasonal surface flow and mass wasting by using cross-correlation feature tracking and DEM differencing techniques. The results reveal large heterogeneity in mass loss and surface flow over the glacier surfaces, which are primarily caused by the presence of surface features such as ice cliffs and supra-glacial lakes. Accordingly, we systematically analyze those features using an object-based approach and relate their characteristics to the observed dynamics. We show that ice cliffs and supra-glacial lakes are contributing to a significant portion of the melt water of debris covered glaciers and we conclude that UAVs have great potential in understanding the key surface processes that remain largely undetected by using satellite remote sensing.