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Detection of surface elevation changes using an unmanned aerial vehicle on the debris-free Storbreen glacier in Norway

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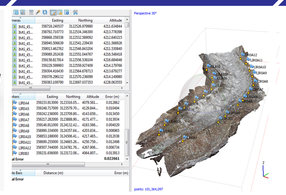
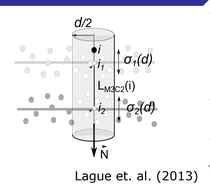
Deployment of unmanned aerial vehicles (UAVs) in combination with image processing using the Structure from Motion (SfM) algorithm has been proven to be valuable for contrast-rich debris-covered glaciers in the Himalaya. In this study an UAV is used on the debris-free Storbreen glacier in Norway to examine whether it is feasible to derive an accurate DEM for the snow cover accumulation area and the debris-free ice of the glacier. We compare the UAV results with a LIDAR based DEM and aerial photo from 2009 to quantify spatial changes in the surface mass balance and terminus retreat.

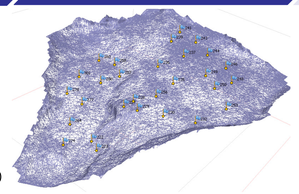
Methodology

Measure ground control points using dGPS → Survey the glacier using eBee UAV → Process images using SfM to create dense 3D point cloud → Cloud to cloud comparison using M3C2 algorithm → DEM extraction and orthomosaic generation → Error estimation (Ongoing)





Lague et. al. (2013)



Study area

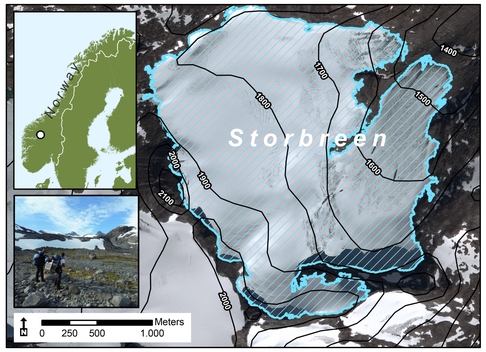


Figure: Location of the study area, the Storbreen Glacier in Jotunheimen, Norway. The glacier has retreated considerably over the last century and now has a remaining surface area of about 5 km^2.

Survey overview

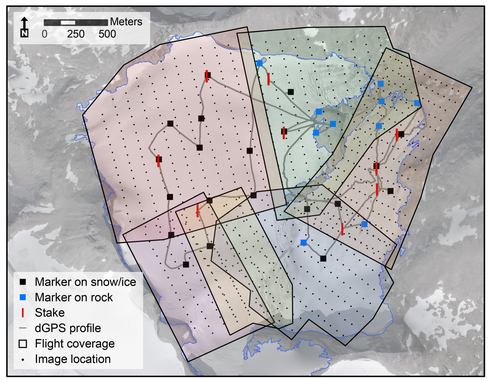
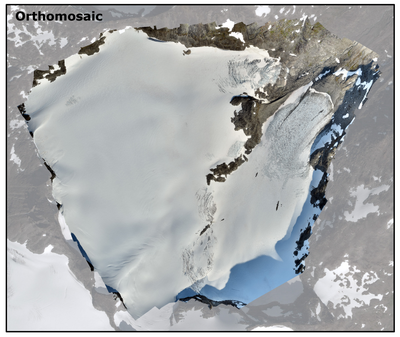


Figure: Overview of the ground control and UAV surveys that were performed on 8 and 9 September 2015. Using the eBee, a total of 7 flights were performed in which the UAV took 915 overlapping images.

Results



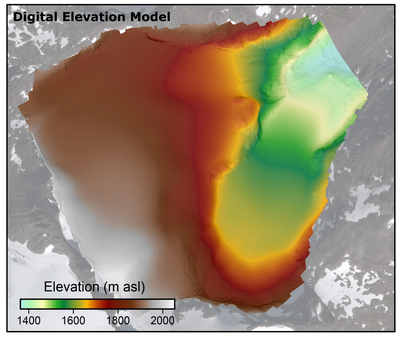


Figure: The output products of the SfM processing of the UAV imagery. An orthorectified image mosaic (orthomosaic) and digital elevation model with 25 cm resolution.

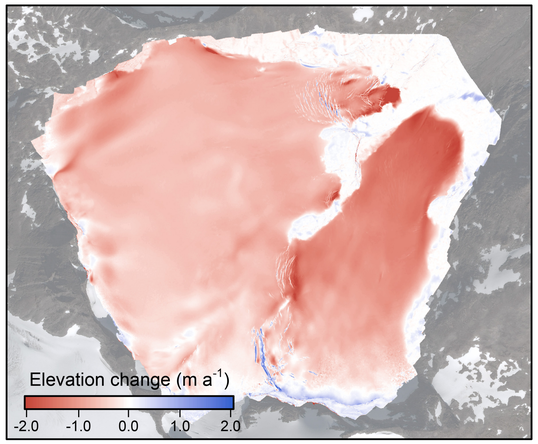
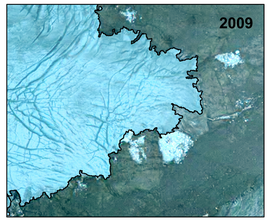


Figure: Elevation change between 2009 and 2015 for Storbreen determined using cloud to cloud comparison.



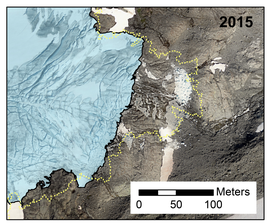


Figure: Retreat of the northern terminus between 2009 and 2015 of 11571 m^2.

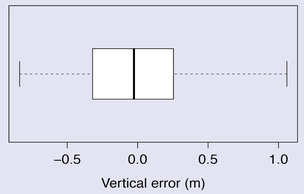


Figure: Boxplot of the difference in z between the elevation model and the ground control points.

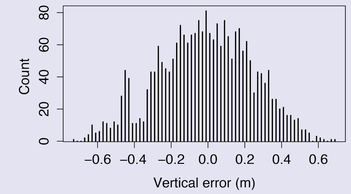


Figure: Boxplot of the difference in z between the elevation model and ~2500 independent points from the dGPS profile

Conclusions

- UAVs are valuable for surveys of snow-covered and clean ice glaciers and can provide accurate elevation models and image mosaics
- The accuracy of the output product is lower when compared to contrast-rich debris-covered glaciers, but considerably higher than spaceborne products.
- UAVs may be used to determine terminus retreat, which is especially valuable for areas that are difficult to access.
- Storbreen exhibits a spatially heterogeneous elevation change over 2009–2015 of about 0.75 m a^{-1} for the upper part and 0.8–1.8 m a^{-1} for the lower part.

P.D.A. Kraaijenbrink, L.M. Andreassen, W.W. Immerzeel (2016), *Recent surface elevation changes based on UAV, LIDAR and field observations of the Storbreen glacier.* The Cryosphere (in prep).