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Monitoring of two rapidly changing glacier tongues in the Swiss Alps by new drone data and historical documents

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Glaciers are considered among the most sensitive indicators of climate change. One of the most visually compelling examples of recent climate change is the retreat of glaciers in mountain regions, and knowledge about the past evolution of glacier fluctuations has been proven to be crucial for studying past decadal to century-scale climate variability. In this presentation, we evaluate the potential of a light fixed-wing UAV (unmanned aerial vehicle; drone) designed for surveying and remote sensing purposes, for monitoring glacier changes. We focus on the frontal zones of two well-known glaciers in the Swiss Alps: Unterer Grindelwaldgletscher in the Bernese Oberland, and Findelengletscher near Zermatt, Valais.

We used a professional mapping drone (eBee by senseFly) to cover both frontal areas of the glaciers in the summer/autumn of 2014. We used a Canon IXUS 125HS RGB camera on-board the drone to collect overlapping nadir images for both study sites. For Unterer Grindelwaldgletscher (Findelengletscher), 187 (421) images were taken for a surveyed area of 3.2 km^2 (2.9 km^2) resulting in digital surface models and orthophotos with a very high spatial resolution of 0.16 m (0.11 m). The high number of images collected per area resulted in accurate elevation models and no detectable systematic horizontal shifts.

Analysis of these images reveal in great detail the typical processes and features known for down-wasting and rapidly disintegrating Alpine glacier tongues: formation of (pro-)glacial lakes, dead ice, thermokarst phenomena, collapse of lateral moraines, and a complex interplay between many of those processes. Typically glacio-fluvial, gravitational, and periglacial processes occur in close vicinity and on different temporal scales (continuous, sporadic).

We compare both glacier landscapes and address the important processes identified to be responsible for the glacier change at both sites. Finally, to set the observed geomorphological processes and the rapid glacier change into a long-term context, we compare the recent findings with available observation data (*in situ* measurements) and historical documents of a high quality, such as the original plane-table sheets (prepared for the Swiss Dufour map) surveyed by W. Jacky for the area of Unterer Grindelwaldgletscher in 1860/61, and by A. Bétemps for Findelengletscher in 1859.

To complement our findings we show pictorial documents, such as early photographs, captured in the mid-19th century and part of a newly discovered collection of photographs for Unterer Grindelwaldgletscher, which depict both glaciers' splendor during the last Little Ice Age advance. Vertical ice loss since the Little Ice Age amounts to about 350 m for the tongue of Unterer Grindelwaldgletscher, and 150 m for Findelengletscher.