

# Monitoring of two rapidly changing glacier tongues in the Swiss Alps by new drone data and historical documents

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## Summary

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.

We used a professional mapping drone (eBee by senseFly) to cover both frontal areas of Unterer Grindelwaldgletscher and Findelengletscher (Swiss Alps) 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<sup>2</sup> (2.9 km<sup>2</sup>) 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).

## Unterer Grindelwaldgletscher

Unterer Grindelwaldgletscher (Bernese Alps, 46°35' N, 8°04' E) is a valley glacier 8.2 km long and covering 17.8 km<sup>2</sup> (data from 2012). It became the historically best-documented Swiss valley glacier thanks to its accessible low ice front position. A wealth of high quality depictions by top artists, e.g. Caspar Wolf (1735–1783) and Samuel Birmann (1793–1847), have allowed the reconstruction of the Little Ice Age (LIA) glacier fluctuations in a uniquely precise way.



Unterer Grindelwaldgletscher, the last three advances of the LIA (all cut-outs of documents, photos by H. J. Zumbühl):

Left: C. Wolf, 1777: the advancing ice front (oil on canvas, Kunstmuseum Bern)

Middle: S. Birmann, 9.9.1826: the "Schweif" in the valley bottom (pencil/watercolour, Kunstmuseum Basel)

Right: Bisson brothers in the summer/autumn of 1855/56: impressive ice tongue (photograph, Alpine Club Library London)

## Findelengletscher

Findelengletscher is a temperate valley glacier located in the Valais, Swiss Alps (46°00' N, 7°52' E), close to the village of Zermatt. With its area of more than 13 km<sup>2</sup> and a length of about 6.7 km (2010), it is one of the larger valley-type glaciers in the Alps. Since its LIA maximum extent in c. 1850, when it was 10.4 km long and 19.96 km<sup>2</sup> in area, the glacier has retreated, interrupted by three shorter time periods of glacier re-advance (in the 1890s, 1920s, and 1980s).

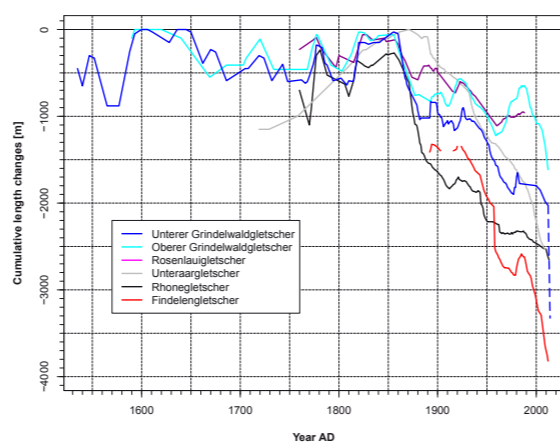


Albert Lugardon (1827–1909): "Le lac vert (Glacier de Findelen)", with Strahlhorn and Rimpfischhorn (oil painting, private collection)



Frontal area of the former Unterer Grindelwaldgletscher with Challi and "Schlossfelsplatte" (right), Stieregg (left), Zäsenberg and "Heisse Platte" (behind, middle); with dead ice, moraines, debris flows (due to permafrost degradation at Mettenberg), rock slips.

Photocomposite of a remotely controlled light drone from 4 October 2014.



Reconstructed and measured frontal variations of selected western and central Alpine glaciers (data: Zumbühl, Nussbaumer, Swiss Glacier Monitoring Network)

Since the end of the LIA the former Unterer Grindelwaldgletscher (1855/56: 10.7 km long) has lost 35–45% of its length. More recently, from 2004 to 2014, the changes in the landscape are accelerating, particularly with dramatic melting since 2007:

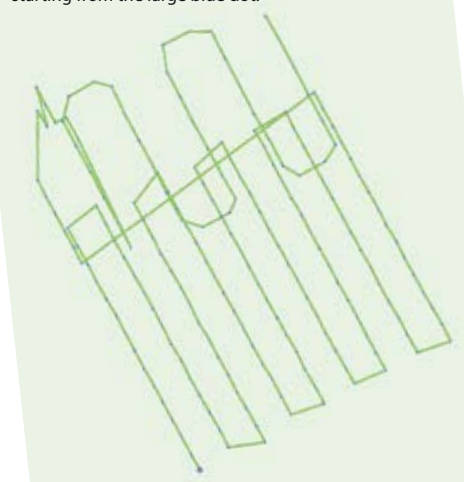
- The former ice tongue disintegrates in a chaotic mass of moraines, ice dams and dead ice (vertical ice loss since the LIA up to 370 m). The dead ice is 1200 m long and ends at 1325 m a.s.l.
- Depending on the season one or two potentially high-risk glacier lakes of different size formed. This required the construction of a costly tunnel (flood-outbreaks) of controversial use.
- Below the Eiger east side (Challi), the "Schlossfelsplatte" was, over a longer time, disintegrated in several rock slides (summer 2008 and 2009).
- The huge moraine-debris-cone of the Stieregg, an Alpine pasture, was strongly changed in its dimensions by erosion and debris flows, hence the slopes became steeper and were sliding down; the Stieregg hut had to be given up.

In 2014 there was no former Unterer Grindelwaldgletscher but only two parts, the Fieschergletscher (6.9 km long) and the Ischmeer (approx. 6.0 km long) remain.

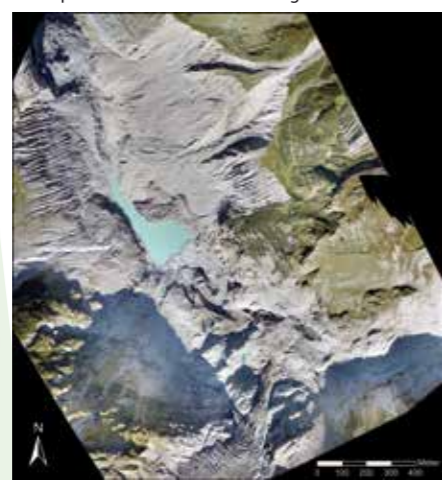


Frontal area of Findelengletscher, obtained from a drone flight on 4 August 2014.

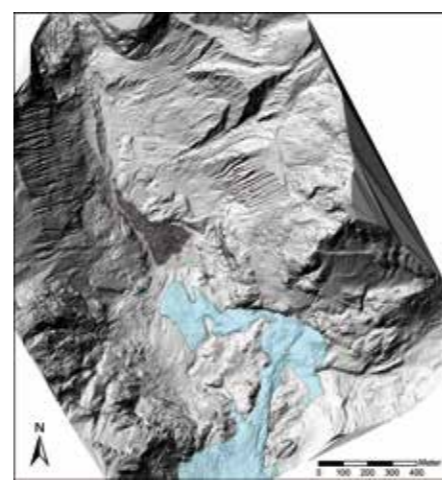
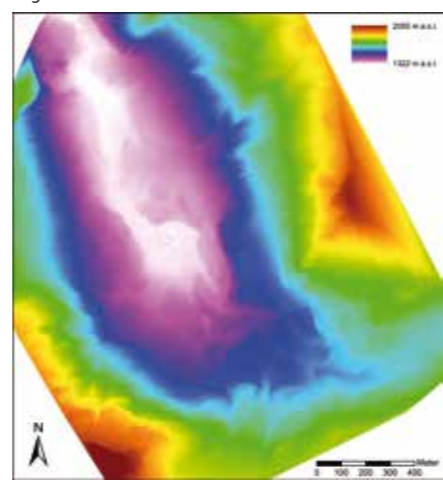
Top view of the initial image positions. The green line follows the position of the images in time starting from the large blue dot.



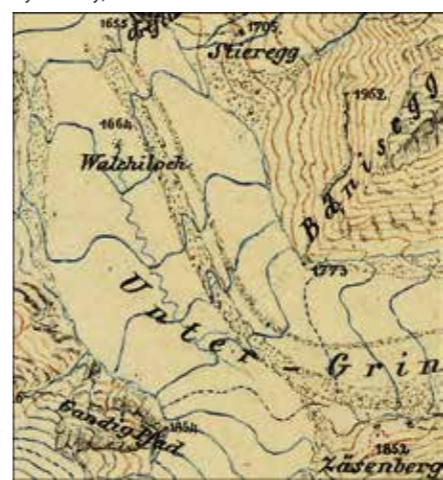
Orthophoto of Unterer Grindelwaldgletscher



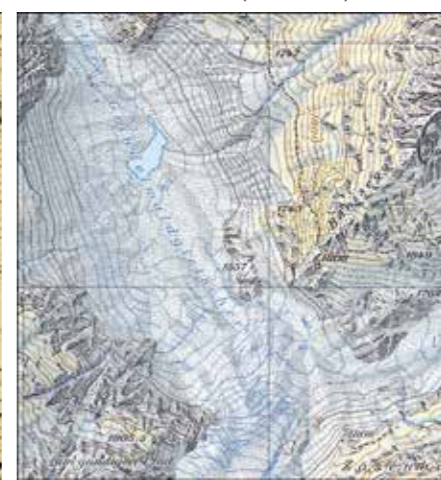
Digital elevation model



Original plane-table sheet ("Messtischblatt" by W. Jacky) from 1860/61



Schweizerische Landeskarte (2006 edition)



Calculated thickness changes 1860/61–2014

