

Name of research institute or organization:

**VAW, ETH Zurich**

Title of project:

Glacier outburst floods, a study of the processes controlling the drainage of glacier dammed lakes

Project leader and team:

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Project description:

Glacier outburst floods (jökulhlaups) are caused by the sudden drainage of glacier-dammed lakes. During such an event, the discharge can increase by more than one order of magnitude within a short time period (hours to days). Jökulhlaups pose a significant hazard potential and have caused substantial damage in the past in the Alps and elsewhere. The assessment and prevention of hazards related to jökulhlaups requires a reliable prediction of the timing, duration and magnitude of the outburst floods. Despite much progress, several aspects of recent field observations were unexpected and highlight the need to improve existing theories. In particular, the rapid rise of discharge during some jökulhlaups indicate that during the start of the drainage different physical processes may be important. This study addresses some important open questions of the subglacial drainage process in a combined field and numerical modeling project. In particular, we propose to study the drainage of the Gornersee located at the confluence of Gorner- and Grenzletscher (Valais).

Gornersee is particularly well suited for this study. Hydrographs from the proglacial river Gornera were recorded since 1967, giving information on the time of the onset, duration and peak discharge of the floods occurring every summer. In the past, glacier floods from Gornersee caused damage in Zermatt and Täsch. Thus, a detailed study of this ice-dammed lake and its drainage is not only of interest for basic glaciology but also for practical reasons. In the past, theory and numerical models of water flow in ice-walled conduits advanced substantially. In addition, techniques to observe glacier dynamics and its short term variations became available. For these reasons, it became possible and timely to produce a comprehensive set of data on glacier floods and to interpret them realistically.

### **Glacier flow perturbation during the Gornersee lake outbursts**

#### **1) Measuring the surface motion of Gornergletscher during the lake drainage 2008 with a portable radar interferometer**

Our observations on several annual drainages of Gornersee (2004-2008) show that the glacier flow pattern is strongly influenced by the lake outburst event. Vice versa, the disturbances in the flow field of Gornergletscher provide information on the lake drainage itself and on the modulation of the glacier flow by the distribution and pressure of water in the subglacial drainage system.

Since 2004, repeated surveys on the movement of markers (aluminium stakes) by using either differential GPS or an automated total station were conducted on the tongue of Gornergletscher. The survey area extends from the immediate lake vicinity up to 2.5 km downstream of the lake. The results have shown changes in the glacier surface elevation of about 20 cm occurring during the Gornersee drainage. Generally, the glacier surface rises during the drainage event and then drops at the drainage termination. However, the magnitude of the uplift is spatially and temporally not uniform across the glacier. The surface uplift may be caused by subglacial water storage as the pressurized water locally detaches the glacier ice from its substrate, or by vertical straining due to horizontal flow speed differences which locally thickens the ice. In either case, we conjecture that internal and basal stress conditions are strongly influenced on short time scales (hours to a few days).

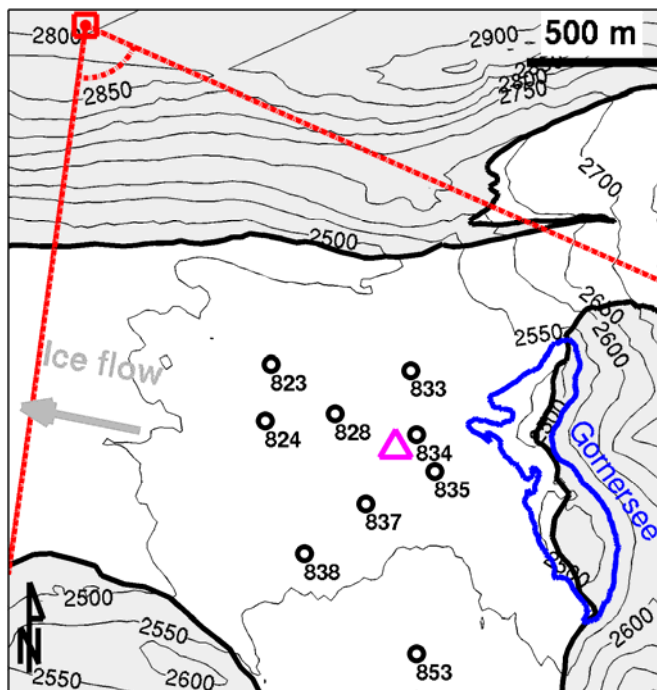


Figure 1: Overview of Gornergletscher (black outline is the ice margin) and Gornersee (blue outline). The radar device location (red square) and the scan azimuth sector (red, dash-dotted) are indicated. Black circles are stake marker locations and the triangle (magenta) is the site of vertical borehole length measurements.

During the lake outburst event in June 2008, we deployed a portable real aperture radar interferometer developed by Gamma Remote Sensing AG (Bern) to investigate the surface ice motion of Gornergletscher downglacier of Gornersee (Figure 1). The aim of the radar was to determine a continuous spatial distribution of the surface uplift of Gornergletscher during the lake drainage event. The Gamma Terrestrial Interferometric Radar (GTIR) operates at high frequency (17.2 GHz). Information on the displacement of targets (in this case the glacier surface) can be extracted from the integration of the interferometric phase difference signals of one or more successively acquired radar images, provided that the images show good coherence.

The device was able to scan a large area of Gornergletscher (Figure 1). The displacement maps inferred from two interferograms of two different 5 hour intervals during the Gornersee drainage show the obvious changes and spatial variations in the displacement of the glacier surface (Figure 2). The GTIR-derived displacements are a projection of both horizontal ice flow and surface elevation changes onto the line of sight direction of the radar. Upstream of the markers 813/814, the look direction of the radar is about normal to the main ice flow. In the case of the results of map 5 (Figure 2, right), the negative displacement observed by the radar at that location indicates that the glacier surface lowered and moved away (towards the glacier center) relative to the radar site. This lateral movement is confirmed by the stake measurements. In the central confluence of Gornergletscher, we measured the vertical strain in boreholes drilled to the glacier bed during the lake drainage (Figure 1). The results did not show any significant length changes throughout the entire ice thickness, this suggests that the observed surface lowering is caused by the release of subglacially stored water towards the lake drainage termination.

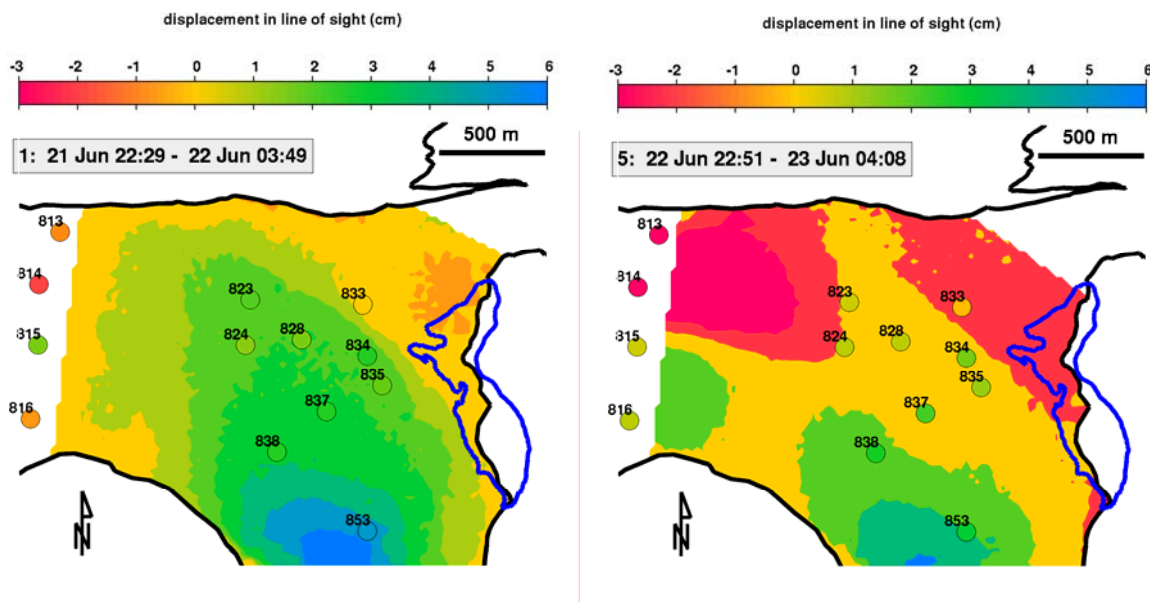


Figure 2: Two displacement maps inferred from the GTIR. The displacement is in line of sight of the radar, positive displacement is towards the radar, negative is away from the radar. Map 1 (left) is during the early stages of the lake drainage and map 5 (right) was obtained at the termination of the drainage. The colored and labeled circles indicate in-situ stake displacements projected onto the respective line of sight direction of the radar. Gornersee is indicated by the blue outline.

However, due to the intriguing observation of sideways movements and other flow anomalies, possible changes in the strain regime of Gornergletscher during the lake drainage must be considered nonetheless.

The sudden drop of the lake water level provokes a rapid release of the water pressure load on the ice dam and the large amount of lake water entering the subglacial environment changes the basal conditions quickly. Our observations are the response of the glacier ice to these rapidly changing boundary conditions.

## 2) Rheological description for ice under rapidly changing stress conditions

Treating the response of glacier ice to rapidly changing stress conditions needs a more complex constitutive model than the generally used pure viscous power-law rheology, which is not designed for such a small timescale (< 10 days). A constitutive description of ice as an elastic second order viscous material has therefore been established based on existing literature. The constitutive model relates the stress tensor to strain, strain rates and strain accelerations. The relation describes primary and secondary creep of ice as well as elastic deformation, all on the aforementioned timescale. A set of appropriate numerical experiments will be used to test for the significance of elastic and higher-order viscous effects. By this approach, we intend to interpret our ice flow observations and to contribute to a better understanding of the drainage initiation process.

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### Key words:

Jökulhlaup, glacier outburst floods

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### Internet data bases:

[http://www.vaw.ethz.ch/research/glaciology/glacier\\_hydraulics/gz\\_outburst\\_glacierdammed\\_lake/](http://www.vaw.ethz.ch/research/glaciology/glacier_hydraulics/gz_outburst_glacierdammed_lake/)

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### Collaborating partners/networks:

Dr. Shin Sugiyama, Hokkaido University, Japan

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### Scientific publications and public outreach 2008:

#### **Refereed journal articles**

Walter F., Deichmann N. and Funk M., 2008, Basal icequakes during changing subglacial water pressures beneath Gornergletscher, Switzerland; *Journal of Glaciology*, **54**(186), 511-521

Bauder A., Funk M., Huss M., Riesen P. And Sugiyama S., 2008, Triggering and drainage mechanisms of the 2004 glacier-dammed lake outburst in Gornergletscher, Switzerland; *Journal of Geophysical Research*, Vol **113**, F04019

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