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Long-term monitoring of climate-sensitive cirques in the Hohe Tauern range

Ingo Hartmeyer[1], Markus Keuschnig[1], Ludwig Fegerl[2], Gerald Valentin[2], Kay Helfricht[3], Jan-Christoph Otto[4]

[1]GEORESEARCH Forschungsgesellschaft mbH, Wals
[2]Landesgeologischer Dienst Salzburg, Salzburg
[3]Institut für Interdisziplinäre Gebirgsforschung, Österreichische Akademie der Wissenschaften, Innsbruck
[4]Universität Salzburg, Fachbereich für Geographie und Geologie, Salzburg

Abstract

Quantitative monitoring data from high-alpine glacial cirques is extremely scarce. To reduce this gap, three long-term monitoring programs were established in the Hohe Tauern range: at the Kitzsteinhorn, at the Oedenwinkel, and at the Sattelkar. The selected sites differ in size, glaciation and lithology and are therefore addressed with different monitoring approaches. Research questions focus on glacial thinning, rockfall patterns and debris flow activity. For each monitoring site, the investigated processes are of direct relevance for nearby tourism, transport, or hydropower infrastructure.

Keywords

Glacial Cirques, Rockfall, Glacier Retreat, Debris Flows, Climate Change

Introduction

By scouring their beds and sapping their headwalls glaciers produce cirques, which belong to the most emblematic high-alpine landscape elements (Benn & Evans 2010, Sanders et al. 2012). Glacial cirques potentially react sensitively to climatic changes such as rising temperatures or an increase in the proportion of liquid precipitation (Scherler 2014). However, due to the lack of robust, long-term data, further assessment of the climate-sensitivity of high-alpine cirques and their role as a risk factor to lower lying catchment sections is subject to considerable uncertainty. For this reason, long-term programs to monitor changes of surface, subsurface, and atmospheric conditions have been started within this decade for three selected sites located north of the Hohe Tauern main ridge. Namely, these are (a) the Kitzsteinhorn, (b) the Oedenwinkel, and (c) the Sattelkar (see Fig. 1a, Fig. 1b). The three selected locations cover areas in and immediately around distinct glacial cirques and are situated in an altitudinal range between 2.100 and 3.450 m asl. The consequences of recent climate warming have had considerable, multifaceted impacts on critical infrastructure situated in direct proximity to the investigated cirques (transport, tourism, hydroelectricity). In this contribution, the three sites, related research questions, and some preliminary results are described in more detail.

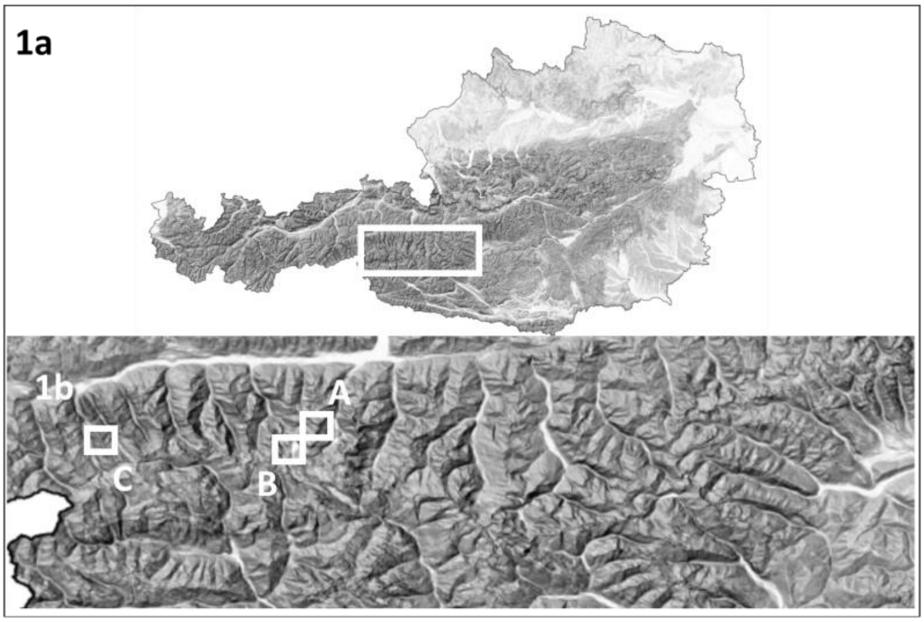

Figure: 1a: Location of the Hohe Tauern Range. Figure: 1b: Location of the three monitored cirques: (A) Schmiedingerkar (Kitzsteinhorn), (B) Oedenwinkelkar, (C) Sattelkar. Copyright GEORESEARCH.

Monitoring Site I: Kitzsteinhorn

The Kitzsteinhorn site covers the Schmiedingerkees cirque, which mainly consists of calcareous mica-schist. Pronounced glacial thinning in recent years caused a significant increase in rockfall activity from fresh bedrock surfaces, which has affected the local tourism infrastructure (up to 1 Mio. visitors per year). To reduce the scientific gap between laboratory evidences on rock **sample** scale and field observations on rock **mass** scale, an extensive Open Air Lab (OpAL) was established in 2010. Since then, the monitoring was constantly expanded and has now become one of the best instrumented long-term monitoring site for permafrost and mass movements in the Alps (please refer to contribution of KEUSCHNIG and HARTMEYER in this volume for more details on the Kitzsteinhorn monitoring).

Local cirque walls are investigated within an extensive terrestrial laserscanning (TLS) campaign since 2011, which revealed the striking impact of glacial thinning on adjacent headwalls: around 80 % of the detected rockfall volume was triggered from areas located less than 20 m above the current surface of the Schmiedingerkees glacier. Overall, more than 400 rockfall release zones were identified, the total rockfall volume exceeded 2.400 m^3. To investigate poorly understood frost weathering and rockfall preconditioning in cirque walls, the project **GlacierRocks** (funded by the ÖAW – Austrian Academy of Sciences) will establish the worldwide first research site for long-term monitoring of stability-relevant processes inside a randkluft system. First components of the innovative randkluft monitoring have been installed in 2017 and will include permanent microseismic arrays, borehole temperature measurements in bedrock and glacier ice, and microclimatic recordings.

Monitoring Site II: Oedenwinkelkar

The Oedenwinkelkar extends from approximately 2.400 to 3.450 m asl. and is composed predominantly of granitic gneiss bedrock. The cirque is occupied by the Oedenwinkelkees glacier, which covers a total area of 1.8 km^2. The particularly pronounced debris cover in the ablation zone of the Oedenwinkelkees glacier is indicative of intense rockfall activity in the steep headwalls of the cirque. Continued glacial thinning is expected to cause increased rockfall occurrence in freshly exposed rockwall sections. Climate change induced modifications of the sediment transport regime directly affect the Tauernmoossee, a hydropower reservoir located immediately downstream of the glacier's proglacial area.

To study interactions between the Oedenwinkelkees glacier and its cirque walls, the project **CirqueMonHT** (funded by ArgeAlp – Arbeitsgemeinschaft Alpenländer) will establish an extensive environmental monitoring at the Oedenwinkel. Stability relevant temperature changes in bedrock surfaces exposed by recent glacier retreat will be monitored in various measurement transects. To monitor bedrock stresses, joint aperture changes will be recorded in selected locations. High-precision remote sensing techniques, such as laserscanning and UAV-based photogrammetry, will be used to localize and quantify rockfall release zones. Ice temperature and ice velocity measurements will be employed to analyze glacial ablation dynamics, enabling an accurate estimation of future glacier behavior close to the headwall. The meso-climate within the cirque will be recorded by several weather stations, allowing to assess the significant influence of topographic shading effects and local wind conditions.

The consequences of climate change usually become apparent only after long response times. Thus, a comprehensive understanding of increased rockfall activity in freshly exposed headwall sections requires monitoring periods of sufficient length. **CirqueMonHT** therefore explicitly strives towards a long-term monitoring of relevant processes at decadal scale and towards the integration of existing glaciological and hydrological datasets.

Monitoring Site III: Sattelkar

The Sattelkar site consists of a west-facing cirque made up of granitic gneiss bedrock. It is located in the Obersulzbach catchment, covering an elevation between approximately 2.100 and 2.700 m asl. The unglacierized slopes below the headwall are overcast with thick layers of post-glacial rockfall deposits, which contributed to the formation of a rock glacier. Since 2003, increased creep/slide rates have been observed in the deposits/rock glacier. In recent years heavy rainfall events repeatedly caused catastrophic debris flow activity from the Sattelkar. The triggered debris flows exceeded the cirque threshold, subsequent torrent activity endangered human lives and caused massive damage to transport infrastructure (railways, roads) in the Obersulzbach valley, as well as further downstream, in the main valley of the Salzach. To detect potentially hazardous future changes and to additionally infer information on the climate-sensitivity of the neighboring cirques (Ofenkar, Mitterkar, Steinkar), an extensive remote sensing and ground temperature monitoring campaign was started in 2015.

Conclusions & Outlook

Despite focusing on different processes, such as rockfall preconditioning, glacial thinning dynamics, and debris flow activity, all three programs investigate how sensitively different high-alpine cirques respond to recent climatic changes. The destabilization of cirque walls and the remobilization of material deposited in cirques does not only affect local infrastructure, it can also have negative short- to long-term cascading effects on lower lying catchment areas. However, the intensity and temporal behaviour of the responses is widely unknown, emphasizing the relevance of robust, long-term monitoring data from these harsh and inaccessible environments.

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Contact

Ingo Hartmeyer, Markus Keuschnig
ingo.hartmeyer@georesearch.at; markus.keuschnig@georesearch.at
GEORESEARCH Forschungsgesellschaft mbH
Hölzlstraße 5
5071 Wals
Austria

Ludwig Fegerl
ludwig.fegerl@salzburg.gv.at
Landesgeologischer Dienst Salzburg
Michael-Pacher-Straße 36
5020 Salzburg
Austria

Kay Helfricht
kay.helfricht@oeaw.ac.at
Institut für Interdisziplinäre Gebirgsforschung
Österreichische Akademie der Wissenschaften
Technikerstraße 21a
6020 Innsbruck
Austria

Jan-Christoph Otto
jan-christoph.otto@sbg.ac.at
Universität Salzburg
Fachbereich für Geographie und Geologie
Hellbrunner Straße 34
5020 Salzburg
Austria