Annals of Glaciology

Rapid formation and drainage of a new glacial lake in the Monte Rosa Massif, Swiss Alps, as observed on Sentinel-2 imagery

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Communication

Cite this article: Pandey A, Kropáček J (2023). Rapid formation and drainage of a new glacial lake in the Monte Rosa Massif, Swiss Alps, as observed on Sentinel-2 imagery. *Annals of Glaciology* **64**(92), 156–158. https://doi.org/10.1017/aog.2023.19

Received: 28 February 2023
Accepted: 7 March 2023
First published online: 14 April 2023

Keywords:
Climate change; jökulhlaups (GLOFs); remote sensing

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Introduction

Due to glacier retreat, glacial lakes are appearing and growing in volume in high mountain areas of the world. Outburst floods from these glacial lakes represent a serious threat to downstream settlements (Taylor and others, 2023). The timely identification of newly appearing glacial lakes is therefore needed. During routine satellite data evaluation, we identified a newly formed lake on the Swiss side of Monte Rosa, the second highest mountain in the Alps. The lake formed on the western part of the mountain at the margin of Gornergletscher and Grenzgletscher in spring 2022 (Fig. 1). The entire glacier system covers an area of 56 km^2 (RGI) and its central flowline is 12 km long. According to a long history of glaciological investigations, the mass balance of the Gornergletscher system remained constant between the 1930s and the early 1980s. Since this time, a negative surface mass balance, resulting from the increase in the average yearly temperature, has resulted in a dramatic decline of the Gornergletscher system (Huss and others, 2012).

Evolution of the lake

To analyse the evolution of this lake, we used atmospherically corrected satellite images from Sentinel-2 (Fig. 1) (Huss and others, 2012; Taylor and others, 2023). The new lake formed in a basin between the Grenzgletscher and its detached tributary, the Gornergletscher, at ~2590 m a.s.l. This is a typical process which can lead to the formation of glacier-marginal lakes (Bigelow and others, 2020). The lake was located along the marginal moraine of Grenzgletscher and was likely not in direct contact with the glacier. It had an elongated shape with a length of ~1.13 km and grew to a maximum extent of 0.098 km^2. Using the empirical formula for volume–area scaling by Huggel and others (2002), we provide a rough estimate of 1.7×10^6 m^3 for the maximum lake volume.

The lake appeared after an exceptionally mild and dry winter. Lake formation coincided with heavy precipitation event connected to a low-pressure system moving from the south of France on 23 April. Initially, the lake developed as a group of multiple, distinct ponds, visible on satellite imagery from 26 April (Fig. 2). Satellite images document the coalescence of these ponds and steady growth of the lake over the following 23 days, until 19 May (Fig. 3). At the beginning, the lake was mainly fed by clean water from snowmelt. From 29 April, sediment-rich inflow from the northeast resulted in a turbid area in the western part of the lake. The exact timing of lake drainage is unclear, but on 21 May, the lake extent was already reduced, and the lake was divided into two ponds. These ponds remained stable until 24 May and the basin was drained completely on 26 May.

Discussion

As the recurrence of this lake cannot be ruled out, its formation, drainage mechanism and the changing morphology of its basin should be studied in detail. The high frequency of Sentinel-2 data acquisitions allowed us to document the evolution of the lake through time at a high temporal resolution. A more accurate estimation of the timing of lake formation and the drainage was, however, hindered by cloudiness. For a realistic hazard assessment, a reliable volume estimation based on a detailed recent DEM would be needed. Based on the satellite imagery, we can only say that the basin features several deeper parts in which the lake formation was initiated. The drainage mechanism of the new lake remains unknown. As there is no evidence of supraglacial drainage in satellite data, the lake either drained along the margin of Grenzgletscher or through a sub- or englacial pathway. It should be noted that the drainage mechanisms of well-studied events are not always completely understood (Bauder and others, 2008).

The new lake was located close to the past glacial lake Gornersee, which has been well documented (Fig. 1). Gornersee was an ice marginal lake which periodically appeared at the confluence of Gornergletscher and Grenzgletscher prior to 2011. The lake drained mainly sub-glacially which led to an uplift of the glacier surface and to changes in glacier flow

https://doi.org/10.1017/aog.2023.19 Published online by Cambridge University Press

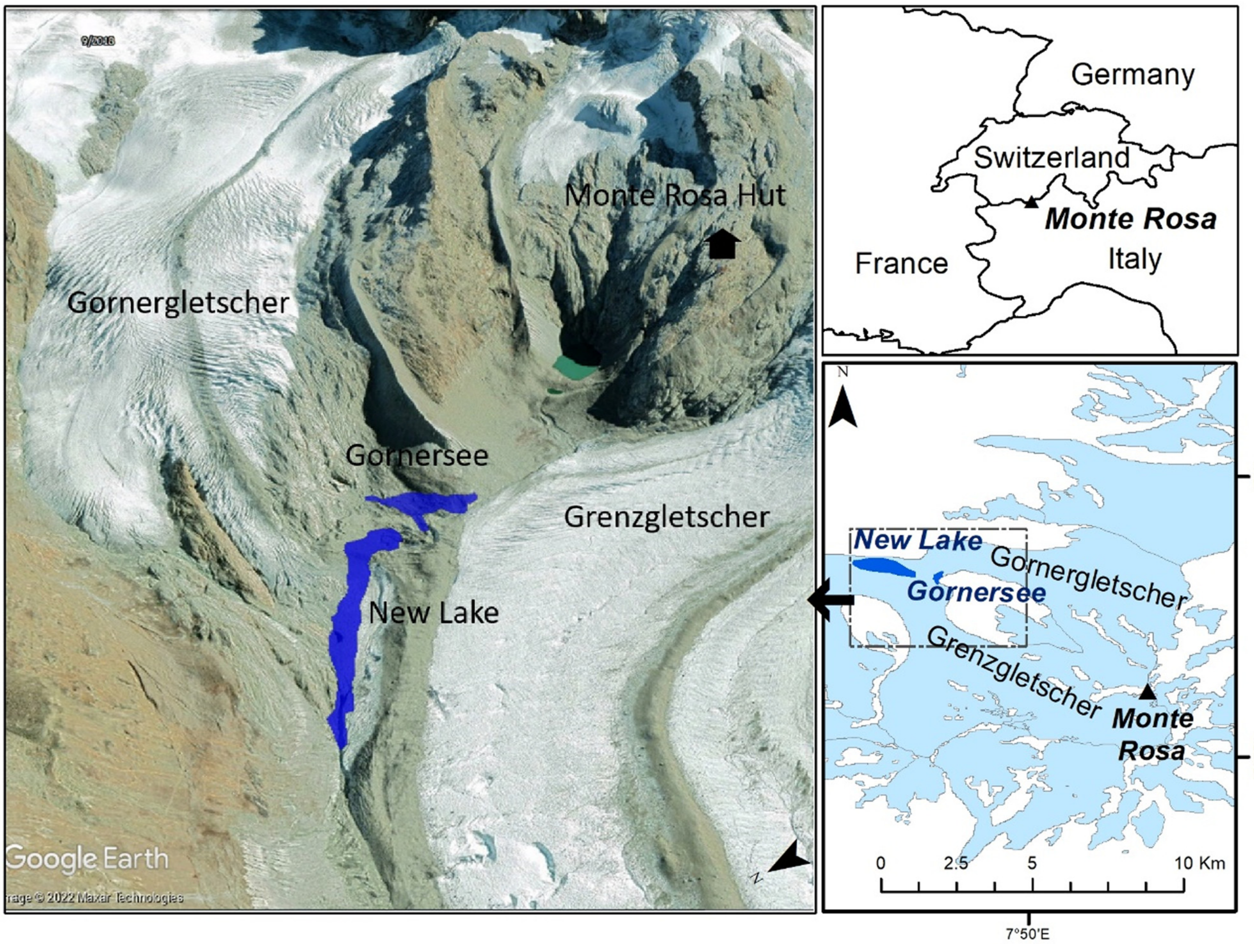

Fig. 1. Google Earth image shows the study area with Gornersee and surrounding areas of the western declivity of the Monte Rosa massif.

(Riesen and others, 2010). The new lake shares at least part of its drainage basin with the former Gornersee whose volume oscillated in range from $1–5 \times 10^6$ m^3 (Huss and others, 2007). In terms of volume, the lake is comparable with the former Gornersee. In terms of drainage timing, the new lake drained much earlier as Gornersee drained between June and August with a shift towards an earlier drainage since 1950s while there was no trend in drainage volume (Huss and others, 2007).

No damage by the drainage of the new lake was reported by local and regional media. Still, a monitoring of the lake basin is recommended as an increase in volume cannot be excluded in

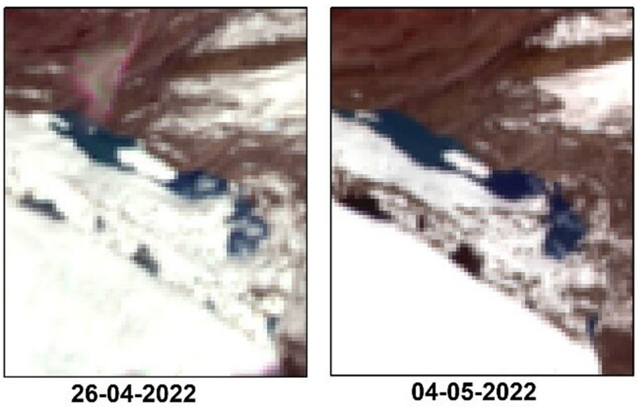

Fig. 2. Evolution of the lake near Grenzgletscher on false colour composite (FCC) images using bands 8, 4 and 3 of Sentinel-2 satellite data.

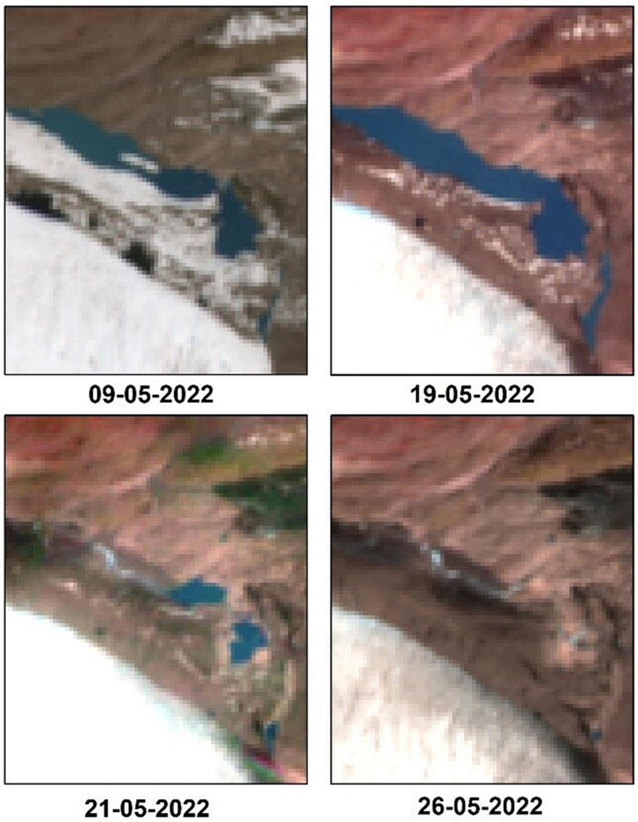

Fig. 2. Continued.

https://doi.org/10.1017/aog.2023.19 Published online by Cambridge University Press

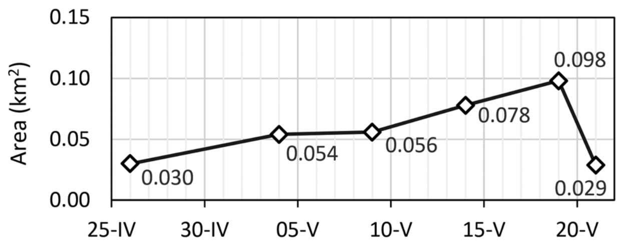

Fig. 3. Growth and drainage of the new lake near Grenzgletscher in April and May 2022 as documented by changes in area derived from satellite images.

the case of the reoccurrence of the new lake. There are several interesting examples of recurrent floods from glacier-marginal lakes in the Alps which necessitated technical measures for reduction of their hazard potential. One prominent example is the Märjelensee, which was a large glacier-marginal lake at the Grosser Aletschgletscher and with a lake volume of $\sim 1 \times 10^6\ m^3$. A series of devastating outburst floods throughout the 19th century made this lake the focus of intensive research. These drainage events lasted between 3 and 7 days (Du Riche Preller, 1896) and were mainly routed through an englacial drainage network, although in some years supraglacial drainage occurred (Schweizer, 1957). To mitigate the risk associated with these floods, a tunnel to control the lake level was constructed in 1895. However, the down-wasting of Grosser Aletschgletscher meant that the lake level eventually sank below the elevation of the tunnel inflow, making the tunnel obsolete.

A more recent threat is represented by the recurrent drainage of the glacier-marginal lake Faverges at Plaine Morte Glacier in the Swiss Alps, which has drained annually since 2011. In summer 2018, the lake grew to a volume greater than $2 \times 10^6\ m^3$ and drained within 24 h on 27 July 2018, causing damage in the downstream village of Lenk (Ogier and others, 2021). As a flood prevention measure, a 800 m long channel combined with a short tunnel, draining the lake across the glacier towards west, was constructed in the spring 2019. The channel became blocked by snow during the following winter requiring further technical measures.

Concluding remarks

We have documented the formation and drainage of a new lake in a thoroughly studied glacier system in the Swiss Alps. Remote-sensing data allowed us to document the lake evolution, still a detailed field investigation is needed for a better understanding of its inflow pattern and drainage mechanism which could indicate the possibility of its recurrence. The fast appearance followed by sudden drainage highlights a potential threat that should be considered in other similar glaciated valleys in the Alps.

Acknowledgements. We acknowledge Copernicus Open Access Hub for providing open data for this work. This work was carried out in the framework of the 4EU Project 'Multidisciplinary approaches to estimate evolution of glacial and periglacial areas in the Alps under climate change conditions.'

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