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Spatial distribution and temporal development of high-mountain lakes in western Austria

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Glacierized high-mountain environments are characterized by active morphodynamics, favouring the rapid appearance and disappearance of lakes. On the one hand, such lakes indicate high-mountain environmental changes such as the retreat of glaciers. On the other hand, they are sometimes susceptible to sudden drainage, leading to glacial lake outburst floods (GLOFs) putting the downstream population at risk. Whilst high-mountain lakes have been intensively studied in the Himalayas, the Pamir, the Andes or the Western Alps, this is not the case for the Eastern Alps. A particular research gap, which is attacked with the present work, concerns the western part of Austria.

We consider a study area of approx. 6,140 km^2, covering the central Alps over most of the province of Tyrol and part of the province of Salzburg. All lakes $\geq$250 m^2 located higher than 2000 m asl are mapped from high-resolution Google Earth imagery and orthophotos. The lakes are organized into seven classes: (i) ice-dammed; near-glacial (ii) moraine-dammed and (iii) bedrock-dammed; (iv) moraine-dammed and (v) bedrock-dammed distant to the recent glaciers; (vi) landslide-dammed; (vii) anthropogenic. The temporal development of selected lakes is investigated in detail, using aerial photographs dating back to the 1950s.

1045 lakes are identified in the study area. Only eight lakes are ice-dammed (i). One third of all lakes is located in the immediate vicinity of recent glacier tongues, half of them impounded by moraine (ii), half of them by bedrock (iii). Two thirds of all lakes are impounded by features (either moraines or bedrock) shaped by LIA or Pleistocenic glaciers at some distance to the present glacier tongues (iv and v). Only one landslide-dammed lake (vi) is identified in the study area, whilst 21 lakes are of anthropogenic origin (vii). 72% of all lakes are found at 2250–2750 m asl whilst less than 2% are found above 3000 m asl. The ratio of rock-dammed lakes increases with increasing elevation at the cost of moraine-dammed lakes.

Multi-temporal analysis of selected near-glacial lakes reveals cases where lakes have appeared as proglacial lakes, but lost contact to the glacier within few decades or even years, or have even been decoupled from the glacial water supply. This goes hand in hand with rapid changes of lake shape and size, with merging or separating of lakes, and with the disappearance of short-lived lakes or lake systems.

Consequently, we distinguish three stages of lake development: (a) a pro-glacial, (b) a periglacial and (c) a non-glacial stage. The dynamics – and also the susceptibility of a lake to sudden drainage – decrease substantially from (a) to (c). Lakes in the stages (a) and (b) are less prominent in our study area, compared to other glacierized high-mountain regions, leading us to the conclusion that (1) the current threat to the population by GLOFs is lower but (2) the future development of emerging lakes has to be monitored carefully.