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A multi-level strategy for anticipating future glacier lake formation and associated hazard potentials

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Due to the expected atmospheric warming, mountain glaciers will retreat, potentially collapse or even vanish completely during the 21st century. When overdeepened parts of the glacier bed are exposed in the course of glacier retreat, glacier lakes can form. Such lakes have a potential for hydropower production, which is an important source of renewable energy. Furthermore they are important elements in the perception of high-mountain landscapes and they can compensate the loss of landscape attractiveness from glacier shrinkage to a certain degree. However, glacier lakes are also a potential source of serious flood and debris flow hazards, especially in densely populated mountain ranges. Thus, methods for early detection of sites with potential lake formation are important for early planning and development of protection concepts. In this contribution we present a multi-scale approach to detect sites with potential future lake formation on four different levels of detail. The methods are developed, tested and – as far as possible – verified in the Swiss Alps; but they can be applied to mountain regions all over the world.

On a first level, potential overdeepenings are estimated by selecting flat parts (slope $< 5°$) of the current glacier surface based on a digital elevation model (DEM) and digital glacier outlines. The same input data are used on the second level for a manual detection of overdeepenings, which are expected at locations where the following three criteria apply: (a) A distinct increase of the glacier surface slope in down-glacier direction; (b) an enlarged width followed by a narrow glacier part; and (c) regions with compressive flow (no crevasses) followed by extending flow (heavily crevassed). On the third level, more sophisticated approaches to model the glacier bed topography are applied to get more quantitative information on potential future lakes. Based on the results of this level, scenarios of future lake outbursts can be modeled with simple flow routing models. Finally, for potentially critical or dangerous situations, on-site geophysical measurements such as ground penetrating radar applied on different sections of a glacier can be performed on the fourth level to investigate the overdeepenings in more detail.

These methods are verified based on historical data from the Trift glacier in the Bernese Alps, where a lake formed in front of the glacier since the 1990s up to the present. Potential future lake scenarios are presented for two regions in the Swiss Alps and the outburst potential of such future lakes is investigated for the Bernina region.

The proposed method is an important step towards early detection of new potential flood hazards related to rapid glacier retreat. At the same time, it can form a basis for an integrative risk and benefit management relating to new glacier lakes.