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Predicting future glacial lakes in Austria – preliminary results

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Summary

Glacier retreat is one of the most apparent consequences of temperature rise in the 20th and 21st century in the European Alps. In Austria, more than 260 new lakes have formed in glacier forefields since the Little Ice Age (Buckel et al., submitted). A similar signal is reported from many mountain areas of the world (Carrivick & Quincey, 2014; Gardelle et al., 2011; Zhang et al., 2015). Glacial lakes can constitute an important environmental and socio-economic impact on high mountain systems including water resource management, sediment delivery, natural hazards, energy production and tourism. Their development significantly modifies the landscape configuration and visual appearance of high mountain areas. Some proglacial lakes have attracted public attention due to disastrous hazard events like outburst floods or increasing hazard potential and risk downstream (ICIMOD, 2011). Increasing public awareness of climate change and related hazards, as well as scientific interest from landscape evolution studies, has put glacial lakes in the spotlight of current high mountain research (Carrivick & Tweed, 2013; Haeberli et al., 2016). Knowledge on the location, number and extent of future lakes can be used to assess potential impacts on the high mountain geo-ecosystems and upland-lowland interactions. This information is significant to appraise threads and potentials provided by the new lakes for society.

The recent developments of regional ice thickness models (Farinotti et al., 2017) in combination with high resolution glacier surface data enables to produce models of the future ice free topography below current glaciers by subtracting modelled ice thickness from glacier surface. Analyzing these potential glacier bed surfaces reveals overdeepened bedrock depressions that represent potential locations for future lakes.

In order to predict the formation of glacial lakes within the ice covered terrain in the Austrian Alps we apply different ice thickness models using high resolution terrain data and available glacier outlines. The results are compared and validated with glacier thickness data from geophysical surveying. Additionally, we run the models on three different glacier extents provided by the Austrian Glacier Inventories from 1969, 1997 and 2006 (Fischer et al., 2015). We present preliminary results of the first model runs here which are compared to existing glacial lakes and geophysical data on ice thickness. First results show a significant mismatch between the models and reality. The applicability of ice thickness models for the detection of future lakes therefore needs critical consideration.

Methods

We applied two different ice thickness models to Austrian glaciers at different extents. Initial ice thickness distribution was developed according to the ice thickness estimation method (ITEM) of Huss & Farinotti (2012). This physically based method requires an estimate of the surface mass balance gradients to calculate ice volume flux along the glacier. Using an integrated form of the flow law for ice, glacier thickness is calculated including the spatial variability in the basal shear stress distribution with respect to valley shape and inclination of the glacier surface. The second model developed by Frey et al. (2014) is a modification of the GLABTOP approach first published by Linsbauer et al. (2012). GLABTOP and GLABTOP2 use the shallow ice approximation method which derives ice thickness from the basal shear stress distribution underneath the glacier. The latter is derived using an empirical relation between shear stress and elevation range of the glacier proposed by Haeberli and Hölzle (1995). The methods computes ice thickness from shear stress, glacier surface slope, gravitational acceleration and a shape factor. Ice gradient is the main control on ice thickness in this model. In GLABTOP2 ice thickness is quantified for random cells and subsequently extrapolated. The resulting model of ice thickness delivers the topography of bedrock underneath the glaciers that contain the targeted depressions likely forming new glacial lakes.

Both models use digital elevation data and glacier outlines. Glacier outlines were produced by LAMBRECHT & KUHN (2007) and FISCHER et al. (2015) documenting the shape and size of glaciers at 1969, 1998 and 2006 . Digital elevation models (DEM) of 10 m resolution exist for all glacier extents derived from aerial imagery from the corresponding years. Subglacial depressions have been generated by simple subtraction of ice thickness from the ice surface DEM.

Results

The models produce around 200 depressions underneath the existing glaciers in Austria. Both models produce depressions at similar locations (Fig. 1). Glabtop2 tends to produce larger objects and more depressions at similar locations in all three model runs. A total area of 8.7 and 12.2 km² of subglacial depressions is modelled by Huss&Farinotti and Glabtop2, respectively.

Evaluation of the ice thickness models is performed using field data on ice thickness delivered from ground penetration radar measurements. A first comparison reveals that both models overestimate the ice thickness thus producing lower bedrock surfaces potentially leading to more and deeper depressions.

Comparing modelled depressions using the 1969 glacier extent with existing lakes reveals a poor location match (< 25 %). GLABTOP2 and Huss and Farinotti produce significantly more depressions (96% and 43%, respectively) than existing lakes. However, around 90% of modelled depressions are located in flat terrain (< 5°) indicating possible locations of filled-up depressions within the glacier forefields.

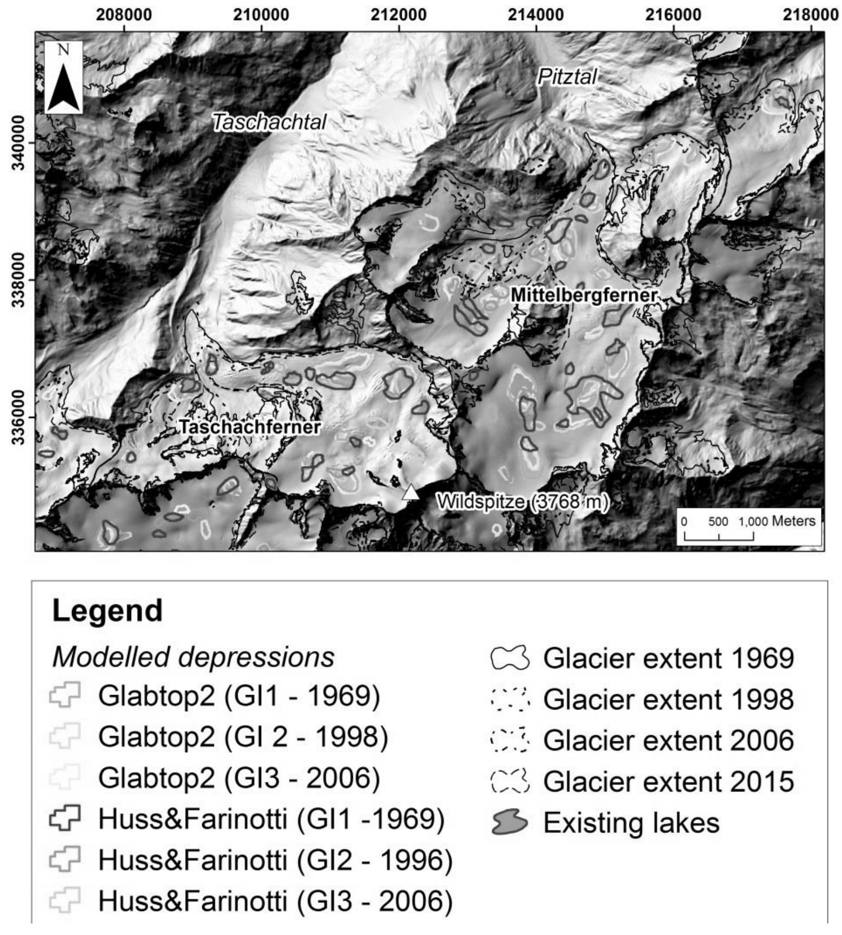

Figure 1: Locations of modelled depressions in the Taschachtal/Pitztal area (Tirol).

Conclusion

The models generated potential subglacial depressions in a similar pattern. First comparison however shows that the results need to be considered carefully and critically discussed. Various impacts on the modelling performances will be analyzed and discussed in a next step including geomorphologic controls for example due to glacial sediment deposition, glaciological controls and impacts due to model principles such as the application of a single shear stress value for an entire glacier.

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