Leibnitzkopf Rock Glacier (Austrian Alps): Detection of a Fast Moving Rock Glacier and Subsequent Measurement of its Flow Velocity

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Introduction

Kinematics of rock glaciers

Rock glaciers are striking features of mountain permafrost. Knowing the kinematic state of a rock glacier is of great importance in several aspects: (1) it enables the classification into active/inactive rock glaciers, (2) it supports rheological modeling, (3) it contributes to climate change research, and (4) it makes hazard risk assessment possible. The kinematic state of a rock glacier or, in general, of any slope of the Earth's surface can be determined by various observation and measurement techniques, e.g., field investigations, geotechnical measurements, optical/radar spaceborne, airborne or terrestrial remote sensing, and geodetic measurements based on tacheometry or global positioning systems, for example GPS. Information about spatio-temporal change needed in the above applications can be obtained through proper (long-term) monitoring.

Objectives

This paper describes a simple method for detection and quantification of fast moving rock glaciers using high-resolution orthoimages of at least two different epochs provided by the geobrowsers Google Maps and Microsoft Bing Maps. A practical test was carried out for the western part of the Schober Mountains in the Austrian Alps and provided the basis for subsequent photogrammetric and geodetic measurements. The techniques applied and results obtained are also presented in this paper.

Image-based identification of fast moving rock glaciers

Study area

The eastern part of the Schober Mountains (46°58' N, 12°58' N) has been the focus of detailed rock glacier studies conducted by the universities of Graz and Innsbruck for at least two decades. Research in the western part has remained scarce [*Buchenauer 1990*] and has only recently been resumed with a main focus on fast moving rock glaciers.

Screening a large area for fast moving rock glaciers

Google Maps and Microsoft Bing Maps (formerly Microsoft Virtual Earth) were used for planning purposes. Both geobrowsers provide high resolution orthoimages (orthophotos) covering the area of interest (approx. 120 km²), but from different sources and acquisition dates. The latter fact was successfully utilized in identifying fast moving rock glaciers. Both geobrowsers were opened side-by-side and corresponding areas showing potential active rock glacier candidates were adjusted vertically. Possible geometric differences (disparities) of the orthoimages presented were detected directly through stereo fusion with the naked eye. Earth terrain movements (motion parallaxes) approximately parallel to the eye base will be observed as a virtual 3D landscape. Areas without any geometric differences show up as horizontal planes. Active rock glaciers with a main flow direction different to EW or WE can be tested in the same way as outlined before, but image data must be rotated appropriately in a digital or analog manner. Screenshots were made of all suspicious rock glaciers detected for further quantitative analysis. A total of 5 rock glaciers with large motion parallaxes were found (see Table 1).

Map projection, image scale, and acquisition date

The well-known Mercator map projection is used in both geobrowsers. Ground sampling distance (GSD) for the screenshots of the different zoom levels was determined using the respective scale bars. The zoom levels of both geobrowsers were identical: GSD 20 cm, 40 cm, 80 cm, etc. The recovery of the acquisition dates is difficult because Google and Microsoft provide only scarce information on the image data. In the present case, however, the copyright information given in the geobrowsers allowed the authors to retrieve the original image data source and the respective acquisition dates (see Table 1). In a later stage of the project this original image data (aerial photographs) was ordered for reasons of comparison.

Table 1. Orthophotos covering Leibnitzkopf rock glacier.

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http://maps.google.com/	http://www.bing.com/maps/
Date: 18 September, 2002	21 September, 2006
GSD: 20 cm, 40 cm, 80 cm	
Source: Province of Tyrol	BEV, Vienna

* Leibnitzkopf rock glacier (46°55'51" N, 12°42'43" E)

Precise change detection and metric quantification

Image matching

Precise co-registration of all available data sets (5 rock glaciers, different coverages according to GSD selected) was carried out using a Matlab-based toolbox. Corresponding points were measured applying area-based image matching techniques with sub-pixel precision. The normalized cross-correlation coefficient was selected as a similarity measure. A consistency check was performed by back matching (left to right, and back from right to left).

Computation of displacement vectors and flow velocity

Since the screenshots refer to local image coordinate systems, offset coordinates must be computed from stable points in the surroundings of the rock glaciers. The two frames are subsequently co-registered to a common coordinate system to enable geometric deformation analysis. In order to compute flow velocities (rate of change) metric displacements must be scaled by the time span, which in our example is 4 years. Figure 1 shows the result obtained for Leibnitzkopf rock glacier (see also Table 1). If the acquisition dates of the two frames to be compared are not known, we can only obtain relative values of change. Information about the geometric quality of the geobrowser orthophotos and our own subsequent co-registration can be deduced from the residual vectors of the stable points. The 40 cm image data of Leibnitzkopf rock glacier was co-registered with a precision of ±0.31 pixel in x and ±0.41 pixel in y-direction, which allows the computation of respective velocities with a precision of ±5.1 cm/year. The maximum flow velocity is 136.9 cm/year. Results for two other rock glaciers have already been published in Kaufmann [*2010*]. The high geometric quality of the results obtained has been confirmed by a comparative photogrammetric evaluation of the original image data (see next section).

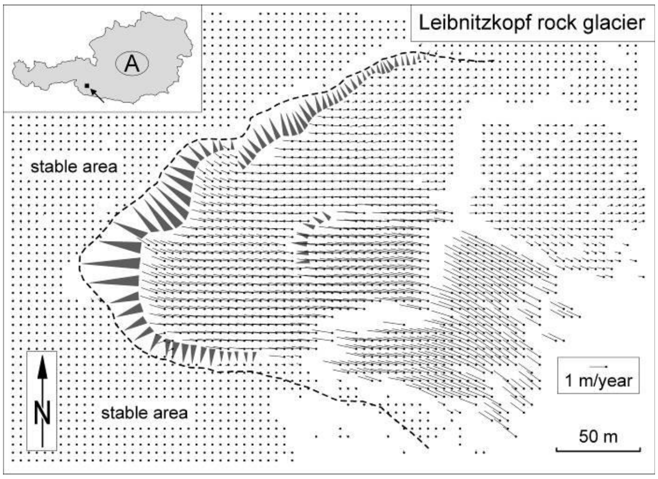

Figure 1. Displacement vectors of Leibnitzkopf rock glacier derived from image data of Google Maps (epoch 2002) and Microsoft Bing Maps (epoch 2006).

Rigorous photogrammetric measurement of the flow velocity field

Photogrammetric change detection

In order to facilitate the accuracy analysis of the simple method presented and to extend the 2D deformation analysis to 3D the original aerial photographs (stereopairs and stereotriplets) covering all 5 rock glaciers were ordered from the respective owners (Table 1). We furthermore augmented the time-series by image data from another epoch (2009), which was also provided by the Province of Tyrol. The photogrammetric processing chain followed the procedure outlined in Kaufmann & Ladstädter [*2003*]. The image matching of the quasi-orthophotos, however, was carried out with the Matlab-based toolbox mentioned earlier. Results are available for three rock glaciers, i.e., Leibnitzkopf, Ganot, and Tschadinhorn.

Analysis of Leibnitzkopf rock glacier

The analysis of the photogrammetric result (precision of velocities: ±2.9 cm/year at 25 cm GSD) with the simple geobrowser-based one (precision: ±5.1 cm/year for 40 cm GSD, ±4.2 cm/year for 20 cm GSD) confirmed the expected high quality of the latter. Independently, direct co-registration of orthophotos from the two different datasets showed that the geobrowser orthophotos are of very high geometric quality, irrespective of water marking and obvious data compression. This comparison confirmed once again that the geobrowsers use a Mercator map projection. It was also found that the scale of the geobrowser images was 2% smaller than the reference Gauss-Krüger map coordinate system. Furthermore, the mean flow velocity of 2006-2009 has increased slightly by approx. 5% compared to 2002-2006.

Low-cost GPS-based measurement of displacement vectors

A GPS-based observation network consisting of 19 stabilized points (4 of which are stable) was installed at Leibnitzkopf rock glacier in 2010. The measurement equipment (GPS module ASHTECH AC-12, data logger, Leica AS05 geodetic antenna, adapter) is low cost and also lightweight. A Virtual Reference Station (VRS) was used. Planimetric accuracy is ±1-2 cm, height accuracy is lower, i.e. ±7 cm. The measurements 2010-2011 revealed a strong increase in flow velocity by approx. 90%. The maximum flow velocity measured is 2.57 m/year.

Conclusions and outlook

Global climate change will have significant impact on rock glacier kinematics. The methods outlined in this paper have great potential to support permafrost and rock glacier research with high-quality numerical data on morphodynamics at relatively low cost.

References

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