MONITORING OF ACTIVE ROCK GLACIERS BY MEANS OF DIGITAL PHOTOGRAMMETRY

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ABSTRACT:

Rock glaciers are striking periglacial landforms, which can be found in many cold mountain areas on earth. Rock glaciers are composed of rocks and ice, and must not be confused with debris-covered glaciers. These ice/rock mixtures are slowly creeping downhill by force of gravity. Due to the physical properties of ice the creep process of active rock glaciers is mostly steady-state with annual creep/flow velocities in the cm to m range. Cumulative deformation causes a lava-like surface topography with furrows and ridges. In 1999 the International Permafrost Association (IPA) and the International Commission on Snow and Ice (ICSI) established a Task Force on "Rock Glacier Dynamics and Permafrost Creep" in order to better understand the complex dynamics of creeping permafrost and, especially, to study the influence of thermal conditions, e.g. global warming, on rock glaciers. In this paper we introduce our in-house developed software package ADVM (Automatic Displacement Vector Measurement) with which surface flow velocities and surface height change of rock glaciers can be measured semi-automatically by means of digital photogrammetric methods applied to digitized multi-temporal aerial photographs. The ADMV software has been tested within the framework of two case studies which comprised the spatio-temporal analysis of the dynamic behavior of three active rock glaciers in the Austrian Alps, i.e., the Inneres and Aeusseres Hochebenkar rock glaciers in the Oetztal Alps and the Hinteres Langtalkar rock glacier located in the Schober group, Hohe Tauern range. Multi-year aerial photographs taken in the years between 1953 and 1999 were evaluated. Some results of both case studies are presented numerically and graphically.

1. INTRODUCTION

Rock glaciers are creep phenomena of alpine/mountain permafrost and consist of a mixture of rocks (debris) and ice (Barsch, 1996). The upper layer (= active layer) is only composed of rocks, its voids are not filled with ice. From a bird's eye view rock glaciers display a viscous flow-like landform with often prominent furrows and ridges. Typically, the front slope of intact rock glaciers is straight and steep. Rock glaciers may be lobate or tongue-shaped, their age is estimated at several thousands of years. Active rock glaciers are creeping downhill by force of gravity. The annual flow velocities are in the range of centimeters to meters. This movement causes surface deformation, in the process creating a topography as described above. In general, the rate of change of the flow velocity and of the rock glacier thickness is strongly influenced by climatic parameters, i.e., the mean annual air temperature and precipitation. In the past two decades rock glaciers have been studied intensively in order to support theories on climatic change, and especially to give proof of recent climatic warming (Haeberli, 2000).

In 1999 IPA and ICSI established a Task Force on "Rock Glacier Dynamics and Permafrost Creep" under the leadership of W. Haeberli (Geography Department, University of Zurich, Switzerland). One of its working groups addresses the geometry and kinematics of rock glaciers. A report on the state-of-the-art of measurement techniques, i.e. geodesy, photogrammetry, laser scanning, satellite-based differential SAR interferometry, is to be prepared and will be presented at the 8th International Permafrost Conference, Zurich, Switzerland, in July 2003.

2. METHOD

A review of the various aerial photogrammetric measurement techniques, i.e. (1) manual or analogue, point-by-point measurements, (2) direct analogue comparison of repeated images, (3) computer-based, point-by-point, measurements, (4) computer-based simultaneous comparison, and (5) fully digital deformation measurement, is given in Kääb & Vollmer (2000). They were one of the first to set up a digital photogrammetric workflow for area-wide mapping and monitoring of permafrost geometry, thickness changes and surface creep based on multi-temporal digital orthophotos. Their software system is called CIAS and is programmed in IDL. Digital point transfer is solved using the normalized cross-correlation function (cp. Kääb & Vollmer, 2000).

We are now presenting a quite similar approach to that of Kääb and Vollmer, but our solution is more rigorous and higher accuracies in the 3-D displacement vectors can therefore be obtained. A detailed outline of the proposed method is given in Kaufmann & Ladstädter (2002). The core of our digital photogrammetric workflow is the ADVM (Automatic Displacement Vector Measurement) software, which is written in Visual C++ for PC.

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The concept of the ADVM software is based on the automatic measurement of 3-D displacement/flow vectors of prominent features of the rock glacier surface, i.e. rocks and boulders, in aerial photographs taken in two different time periods (see Fig. 1). In order to cope with differing photo scales and flight line geometries we propose the use of quasi-orthophotos (cp. Baltsavias, 1996 and Schenk et al., 1990) for digital image matching. Preliminary disparity maps between the orthophotos are computed using the normalized cross-correlation function. Based on this information of approximate locations of homologous points, high-precision image matching is then only carried out at points which had been selected using the Förstner interest operator, applying the least-squares matching algorithm. As a result, precise 3-D displacement/flow vectors can be computed and the given preliminary digital terrain model(s) can be improved as well (see also Kaufmann & Plösch, 2000).

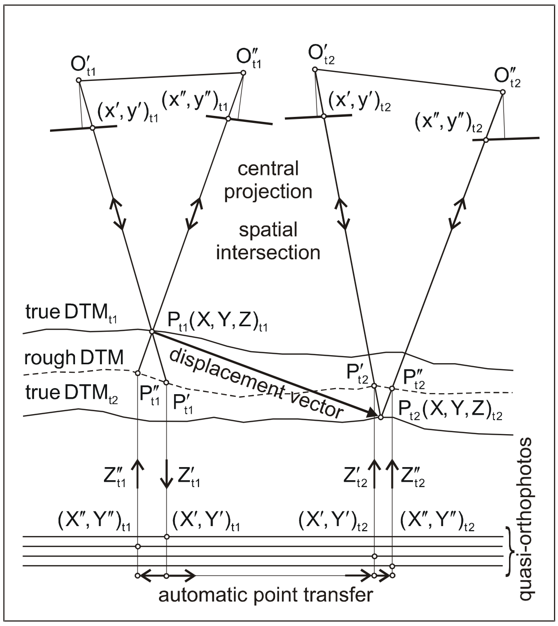

Figure 1. Concept of the computation of 3-D displacement/flow vectors using quasi-orthophotos

3. CASE STUDIES

We have tested the potential of our proposed method within the framework of two case studies which comprised the spatio-temporal analysis of the dynamic behavior of three active rock glaciers in the Austrian Alps, i.e. the Inneres and Aeusseres Hochebenkar rock glaciers (46°49' N, 11°00' E) in the Oetztal Alps and the Hinteres Langtalkar rock glacier (46°59' N, 12°46' E) located in the Hohe Tauern National Park. See Fig. 2.

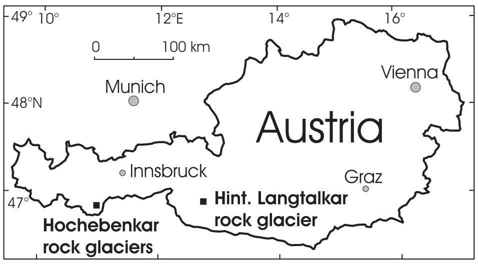

Figure 2. Location map

3.1 Hochebenkar rock glaciers

Both rock glaciers have been the focus of intensive research work since many decades (e.g. Pillewizer, 1957; Vietoris, 1972; Haeberli & Patzelt, 1982). Multi-year aerial photographs taken in the years between 1953 and 1999 were obtained from the Austrian Federal Office of Metrology and Surveying, Vienna. Image scale of the 8 data takes vary between 1:12,300 and 1:38,500. All photographs were scanned using the UltraScan 5000 of Vexcel Imaging Austria. In this paper we present two examples of the results obtained, which refer to the computation of mean annual horizontal flow/creep velocities. Aeusseres Hochebenkar rock glacier is shown for two different years, i.e. 1981 and 1990, in Figs. 3, 4. Note the light snow cover of 1990 and, especially, the topographic changes which took place at the snout of the rock glacier. Fig. 5 presents the horizontal displacement vectors obtained. Stable, non-moving points around the creeping rock glacier were used to compensate for possible systematic errors and to validate the accuracy achieved in planimetry and height. Fig. 6 is deduced from Fig. 5 and reveals very nicely the spatial distribution of the creep velocity for the time period 1981-1990.

An equivalent velocity map is also shown for the adjacent Inneres Hochebenkar rock glacier, but for the time period 1953-1969 (cp. Figs. 7, 8). This rock glacier is quite interesting, since two active regions (max. flow velocities of up to 55.1 cm a^{-1}) are separated from each other by a rather inactive zone. For more details see Kaufmann & Ladstädter (2002). Virtual flyovers and a computer animation showing the results obtained can be downloaded from http://www.cis.TUGraz.at/photo/viktor.kaufmann/animations.html or http://video.tu-graz.ac.at/tugbroadcast/.

3.2 Hinteres Langtalkar rock glacier

This rock glacier (Lieb, 1987) is also very interesting from a morphodynamic point of view, since a slide occurred at its snout between 1992 and 1997 (the exact date is unknown). Compare Figs. 9, 10. Significantly extended flow causes high longitudinal strain rates of up to 17.0×10^{-3} a^{-1}. Such a zone of large extended flow can be seen in the orographic right side of the rock glacier (see Fig. 11). Geomorphological indicators of this process are transversal trenches, which can be observed in the orthophotos of Figs. 9, 10. In comparing Figs. 11, 12 it is obvious that the creep velocity has increased significantly after the slide.

4. CONCLUSIONS

With the present case studies we could demonstrate that the proposed method of deformation measurement in time series of digitized aerial photographs applied to rock glaciers provides highly accurate 3-D displacement vectors, which facilitate the computation of area-wide velocity fields and digital terrain models. Our digital photogrammetric workflow has been semi-automatic up to now, since optimum processing parameters, e.g. window size for image matching, have to be found iteratively with user interaction and also the detection of blunders and systematic offsets require an experienced operator. Further developments of the ADVM software will address these issues.

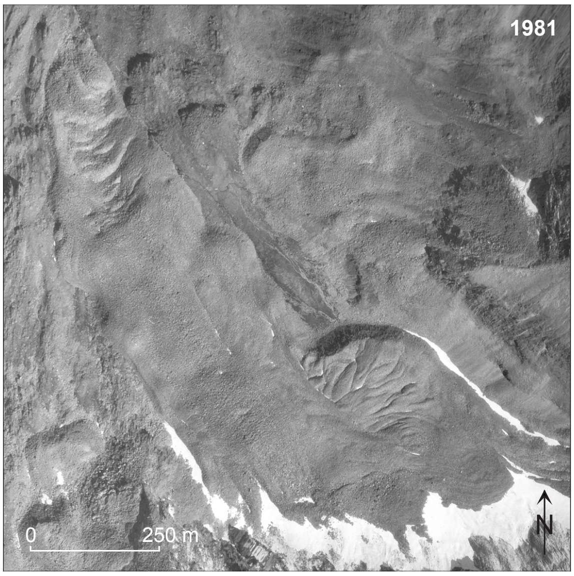

Figure 3. Aeusseres Hochebenkar rock glacier (7.9.1981)

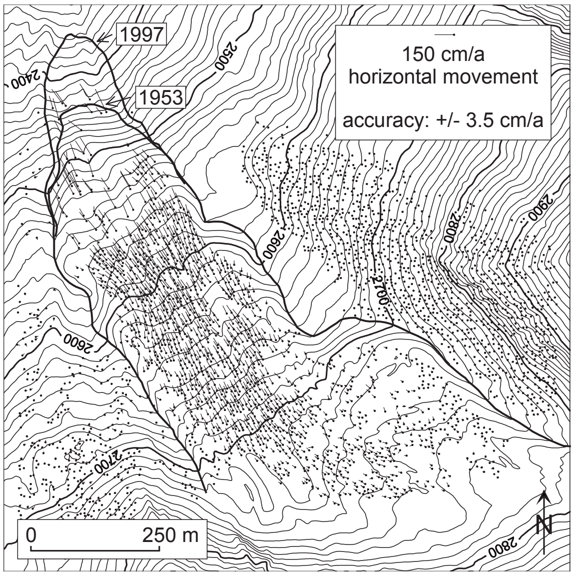

Figure 5. Displacement vectors for the time period 1981-1990

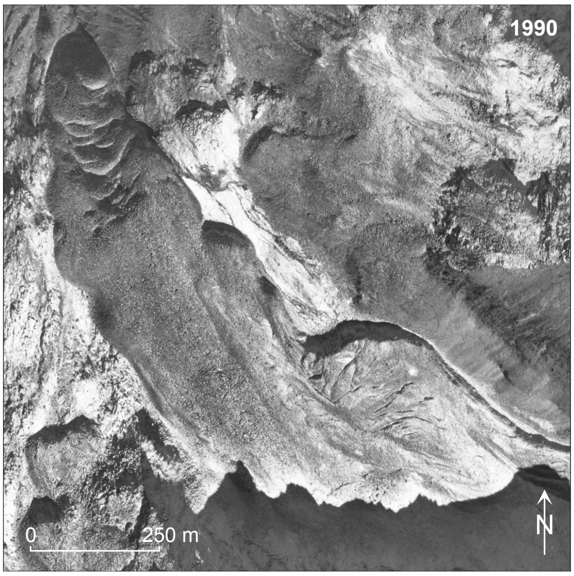

Figure 4. Aeusseres Hochebenkar rock glacier (10.10.1990)

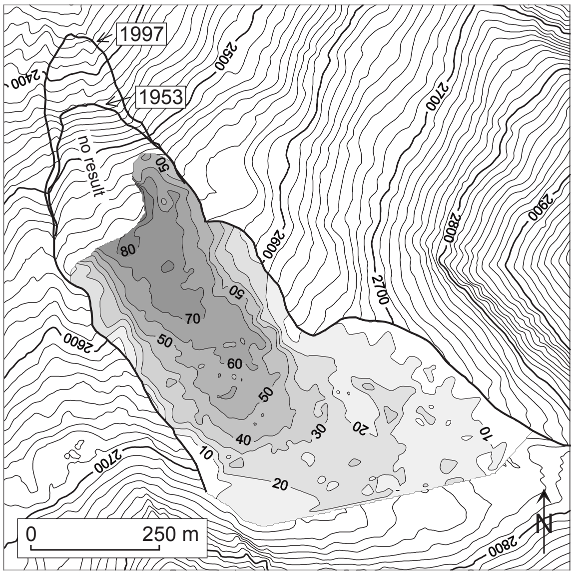

Figure 6. Mean annual horizontal creep velocity (cm a^{-1}) at Aeusseres Hochebenkar rock gl. for the time period 1981-1990

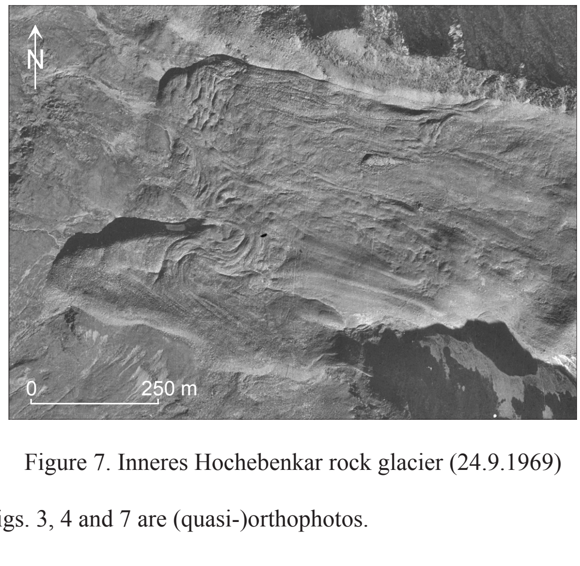

Figure 7. Inneres Hochebenkar rock glacier (24.9.1969)

Figs. 3, 4 and 7 are (quasi-)orthophotos.

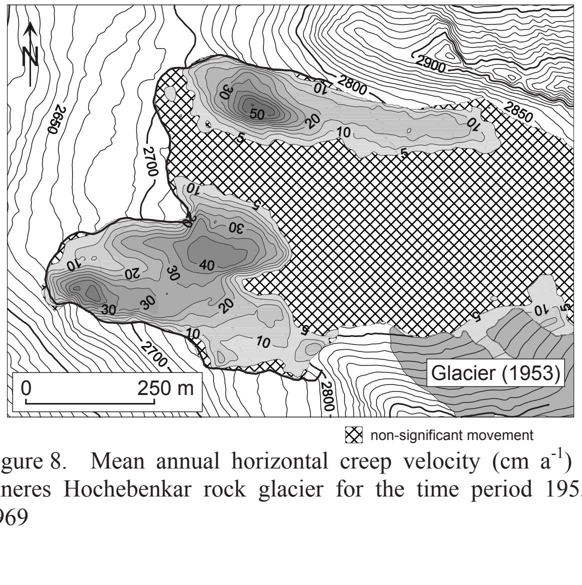

Figure 8. Mean annual horizontal creep velocity (cm a^{-1}) at Inneres Hochebenkar rock glacier for the time period 1953-1969

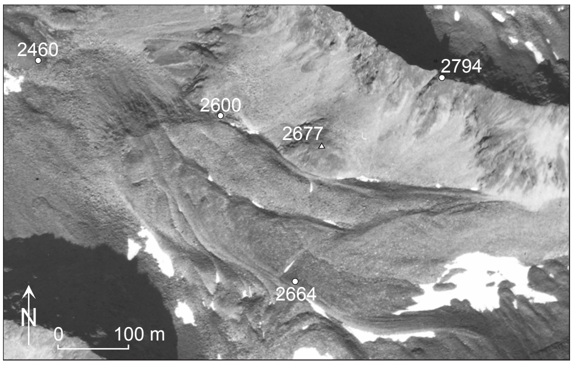

Figure 9. Hinteres Langtalkar rock glacier (4.9.1991)

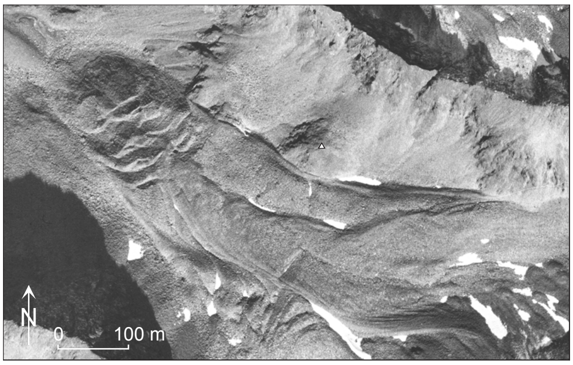

Figure 10. Hinteres Langtalkar rock glacier (24.9.1997)

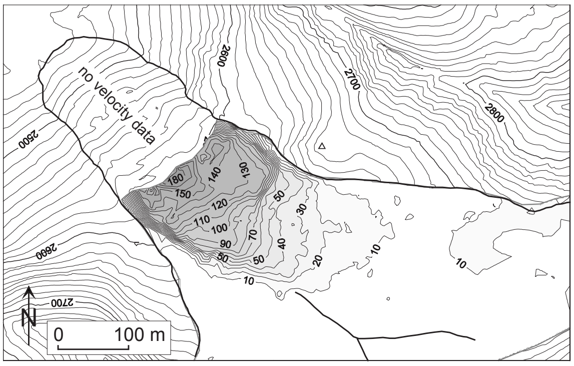

Figure 11. Mean annual horizontal creep velocity (cm a^{-1}) at Hinteres Langtalkar rock glacier for the time period 1991-1997

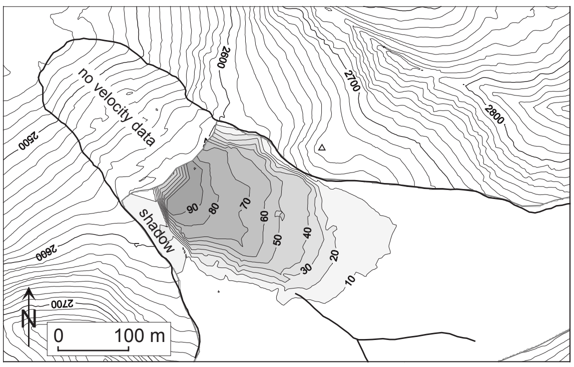

Figure 12. Mean annual horizontal creep velocity (cm a^{-1}) at Hinteres Langtalkar rock glacier for the time period 1969-1991

Figs. 9, 10 are (quasi-)orthophotos.

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