Studying the movement of the Outer Hochebenkar rock glacier (Ötztal Alps, Austria)
Aerial vs. ground-based photogrammetric methods

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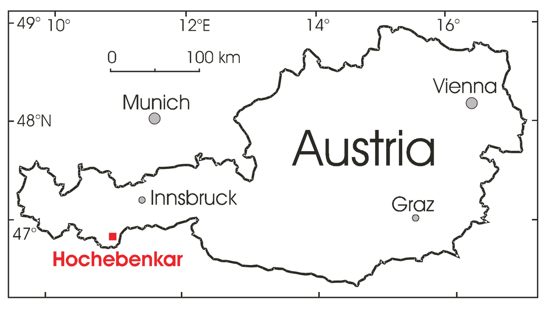
Abstract:

Photogrammetric methods can be used to derive metric information of surface deformation and flow velocity of periglacial phenomena, e.g. permafrost creep. In this case study, the potential of ground-based (terrestrial) photogrammetry for monitoring mountain slopes of local extent (typically 10^2 - 10^3 m) has been investigated. We selected the Outer Hochebenkar rock glacier since it has been subject to intensive research for many decades. Stereo pairs have been taken in three terrestrial surveys in 1986, 1999 and 2003. Four different camera systems (analog/digital) have been used in total, including a phototheodolite build in 1961 and a modern Nikon D100 digital still camera. For the combined evaluation of the multi-temporal image data, an automated digital photogrammetric workflow has been applied. Image matching allows to derive high quality terrain models for each epoch. Using images of different epochs, points can be tracked as they move on the rock glacier surface. Results from this digital photogrammetric measurements have been compared with geodetic and also aerial photogrammetric surveys.

1. Introduction



The Outer (German: Äußeres) Hochebenkar rock glacier (46°50'N, 11°01'E) is located in the Ötztal Alps, Austria close to the village of Obergurgl. It is a tongue-shaped rock glacier, about 1 km in length and 42 ha in size. The rooting zone is located at about 2800 m a.s.l. and its snout reaches down to about 2360 m a.s.l. This rock glacier is characterized by a comparatively high flow velocity of several m/a and periodically changing flow rates. Below 2580 m, which marks the end of the steady-state creeping zone, the snout has moved into very steep terrain. In this area landslides have occurred due to the specific topographic situation. The Outer Hochebenkar rock glacier is well known for its long record of velocity measurements. Early ground-based photogrammetric surveys were performed by W. Pillewizer starting in 1938. Geodetic measurements were started in 1951 by L. Vietoris and have been continued from 1972 until the present by H. Schneider from the University of Innsbruck.

2. Camera equipment of the terrestrial surveys

Phototheodolite
Photheo 19/1318
13 x 18 cm glass plates

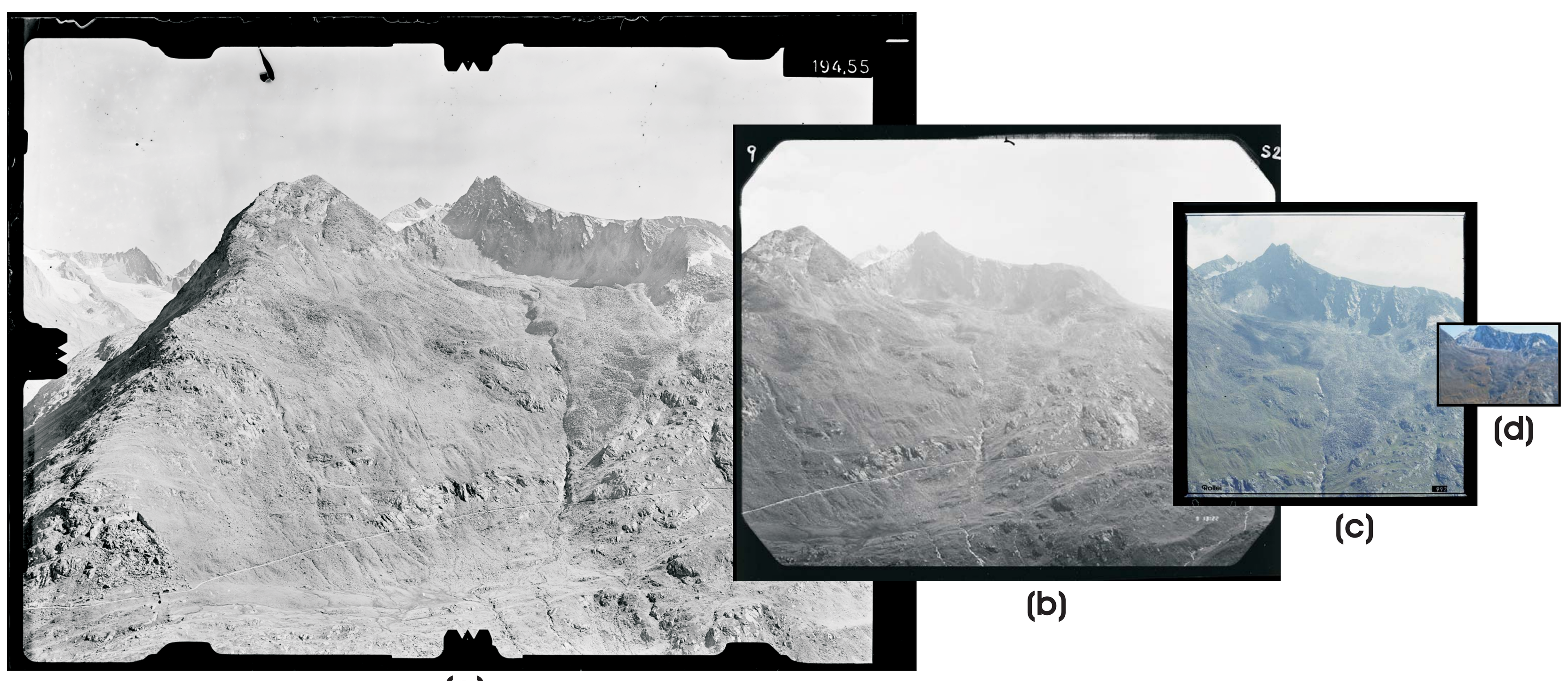
Metric camera
Linhof Metrika
9 x 12 cm film
150 mm - lens

Réseau camera
Rolleiflex 6006 metric
6 x 6 cm film
150 mm lens

Digital camera (SLR)
Nikon D100
6 MPixel CCD sensor
50 mm - lens

The camera systems used in the terrestrial surveys represent four quite different camera types. While Photheo 19/1318 and Linhof Metrika are both metric cameras, Rolleiflex 6006 and Nikon D100 are semi-metric and non-metric cameras, respectively. Photheo 19/1318 uses glass plates (which are no longer available), the other two (analog) cameras are based on roll film (large/medium format). Nikon D100 digital camera on the other hand is a low cost consumer camera equipped with a 6MPixel CCD and a 1GByte Microdrive.

3. Image format, scale and resolution



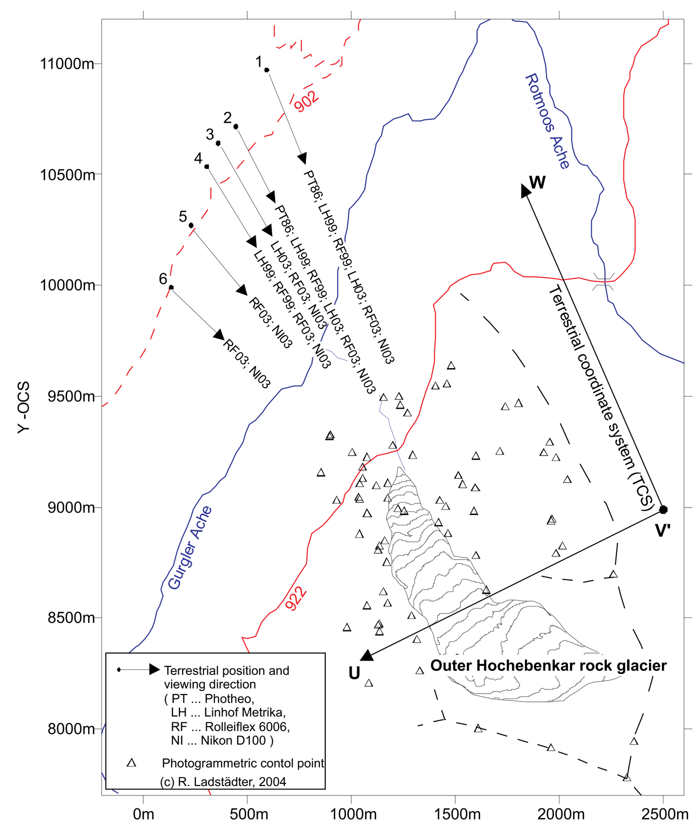
(a) (b) (c) (d)

All analog images were digitized using the UltraScan 5000 (Vexcel Imaging Austria). A scan resolution of 10 μm was used for all images. The size of the resulting image scans and the digital image data obtained from the Nikon D100 camera is given in Table 1. Image scale, given for a mean object distance of 1800 m, varies for each camera system according to the focal length. Geometric resolution in object space is computed by multiplying the pixel size with the mean image scale. This gives a theoretical value (denoted as "*GSD_v*"), which only holds for a vertical plane normal to the viewing direction located in the mean object distance. To calculate the GSD in the ground plane, an image pixel has to be mapped onto the surface of the rock glacier and furtheron be projected into the ground plane. This value is given in the last column of the table.

Camera	Mean scale	Image size [pixel]	GSD_v	GSD_h
Photheo 19/1318	1 : 9500	18000 x 13000	9.5 cm	19 cm
Linhof Metrika	1 : 12000	12000 x 9000	12 cm	24 cm
Rolleiflex 6006	1 : 12000	6000 x 6000	12 cm	24 cm
Nikon D100	1 : 36000	3008 x 2000	28 cm	56 cm

4. Terrestrial photogrammetric setup

The figure to the right shows the six different camera positions used in the terrestrial surveys of 1986, 1999 and 2003. They are located on the opposite slope between 2450 m and 2600 m a.s.l. They can easily be reached from the hiking trail leading from the village of Obergurgl to the Ramol hut (3005 m a.s.l.). The baseline between points 1 and 2 was installed in 1986 and is about 300 m long. This baseline was extended by a third point (nr. 4) in 1999, forming a second baseline of 225 m length. Points 3,5 and 6 were added in the 2003 survey. (Unsignaled) control points have been derived from aerial photographs, oriented in the Austrian Gauss-Krüger reference frame. A local, terrestrial coordinate system (TCS) has been defined as shown in the right figure. The TCS was used for the orientation of the terrestrial photographs, which allowed us to use standard photogrammetric software for image orientation and orthophoto production in the following steps.



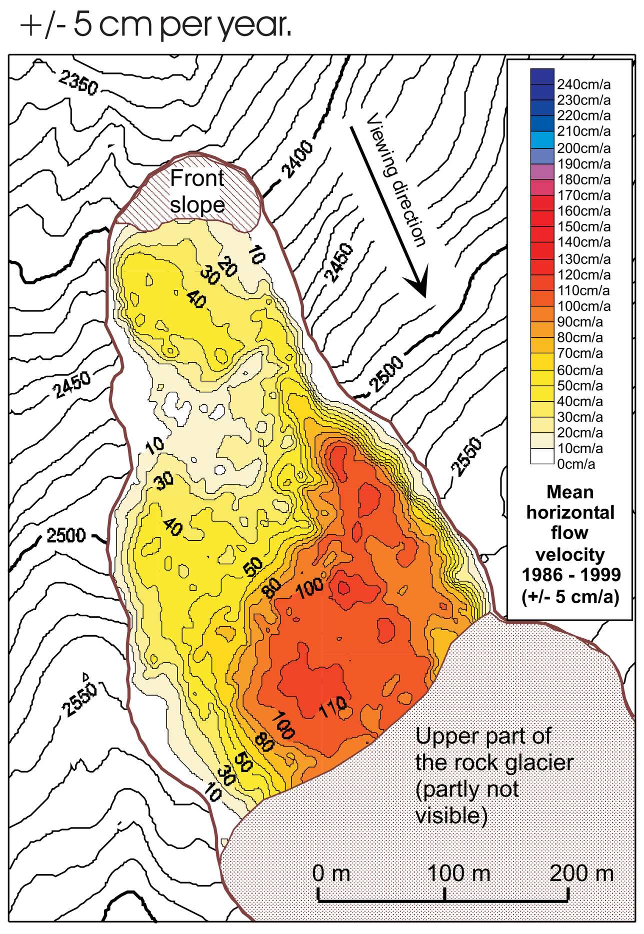
5. Digital-photogrammetric evaluation

The result of the image orientation/triangulation in the terrestrial coordinate system is given for all cameras and epochs. To get rid of perspective distortions, all images have been rectified using a rough digital terrain model (DTM). The resulting "pseudo" ortho images have the same geometric resolution and can be matched with high accuracy. A very robust "Multi-Photo-Constrained-Matching" algorithm (MPCM) is used for automated digital point transfer. Points can be matched simultaneously in multiple images of different epochs, which allows for direct determination of dense 3D vector fields. These flow vector fields are describing the surface deformation with high spatial resolution. The measured 3D point clouds also allows to derive a new DTM for each epoch, which can be compared inorder to derive surface height changes.

Model	#Images	R.M.S.- U [m]	R.M.S.-V [m]	R.M.S.-W [m]
Photheo/1986	2	0.28 (< 0.9)*	0.15 (< 0.4)	0.42 (< 1.3)
Linhof M./1999	3	0.72 (< 1.5)	0.37 (< 0.9)	0.82 (< 2.3)
Rolleiflex/1999	3	0.35 (< 0.8)	0.23 (< 0.7)	1.05 (< 2.7)
Linhof M./2003	3	0.37 (< 2.0)	0.20 (< 0.7)	0.80 (< 2.4)
Rolleiflex/2003	4	0.69 (< 1.5)	0.34 (< 0.7)	1.40 (< 3.9)
NikonD100/2003	6	0.40 (< 1.0)	0.25 (< 0.6)	0.87 (< 1.9)

6. Results

The figure on the right side shows the extracted flow vectors for the time period 1986 - 1999, derived from the stereopairs of two different camera systems (Photheo/Linhof M.). Note that the 3D vectors measured in the terrestrial coordinate system have been transformed into the Austrian Gauss-Krüger reference system for visualization. Parts of the rock glacier are not visible from the camera positions because of the surface topography (furrows and ridges). In the upper, distant part of the rock glacier the viewing direction becomes more and more surface parallel, which also prevents successfull measurements. In these areas the density of the flow vector field is reduced or there is no data at all. In the surrounding stable areas, the extracted vectors should be zero. This can be used to eliminate any existing bias in the orientation of the two epochs considered. The final accuracy for a single flow vector is +/- 60 cm (mean value, depending on the distance from the camera). Considering the time interval of 13 years, the mean flow velocity can be derived with an accuracy of +/- 5 cm per year.



On the left side the mean annual horizontal flow velocity is shown in a color coded thematic map. Flow velocity was interpolated from the measured 3D flow vectors. The maximum flow velocity (~120cm/a) is measured at the orographic right side of the rock glacier at the lower end of the steady-state creeping zone. For the time period 1999-2003 (not shown here) flow velocities up to 230cm/a can be measured in this area. This means, that the movement of the Outer Hochebenkar rock glacier has accelerated during the last few years. At the orographic left side however, a rather inactive zone can be identified during all epochs. All of these results are in very good accordance with measurements derived from aerial photographs but also with geodetic measurements of the University of Innsbruck (B.&H. Schneider).

6. Conclusions

This case study showed that the ground-based photogrammetric approach can be a valuable and inexpensive supplement to aerial photogrammetric surveys of rock glaciers. Terrestrial surveys are restricted to comparatively small areas (such as the rock glacier snout) and will best work in rather steep terrain. Photographs of different camera systems (analog/digital) can easily be combined in a digital photogrammetric workflow which has been adapted from the aerial to the terrestrial case. The resolution of the 6 MPixel Nikon D100 consumer camera is not sufficient for larger object distances as used in this study (>1km). With the large image format and scale of the Photheo 19/1318 and Linhof Metrica cameras however, detailed photogrammetric studies of the rock glacier surface were possible.

(EUCOP 2005, Potsdam)