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Mapping of the 3D Surface Motion Field of Doesen Rock Glacier (Ankogel Group, Austria) and its Spatio-Temporal Change (1954-1998) by Means of Digital Photogrammetry

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Abstract

Doesen rock glacier (46°59'N, 13°17'E, altitude range 2339-2650 m, width 150-300 m, length 1000 m) is located in the Ankogel group of the Hohe Tauern range in Austria. The rock glacier has been the subject of multi-disciplinary research work since 1994. For example, the kinematics of Doesen rock glacier has been studied by means of geodetic surveys and remote sensing techniques, i.e., photogrammetry and satellite-based differential SAR interferometry.

The 3D motion field of Doesen rock glacier was photogrammetrically obtained from multi-temporal aerial photographs from various epochs between 1954 and 1998. This heterogeneous set of photographs was evaluated twice, (1) by means of visual tracking of prominent surface particles (boulders) in the 3D stereomodels and (2) by applying automatic image matching techniques. The latter method, however, was not successful from a practical point of view, since the photogrammetric scanner used for digitizing the aerial photographs introduced geometric errors in the scans which could not be eliminated during the evaluation process.

The present paper describes a second attempt to apply the same algorithms (ADVM software) to the newly digitized aerial photographs, this time using an UltraScan 5000 photogrammetric scanner of Vexcel Imaging Austria. We will briefly outline our approach of measuring 3D displacement vectors, and the practical work and the results obtained will be presented. A comparison of the results of the two photogrammetric evaluation processes, i.e., manual mapping and image matching, is given.

KEY WORDS: Permafrost, rock glacier, long-term monitoring, flow velocity, digital photogrammetry, image matching, Doesen rock glacier, Hohe Tauern range, Austria

1. Introduction

Permafrost creep and rock glacier dynamics have become promising research topics during the past 10 years (Haeberli et al. 2006). On-going research in this field is highly interdisciplinary. It is not only aimed at a better understanding of mountain permafrost and rock glaciers per se but also at obtaining a clearer picture of atmospheric warming of the earth's high mountain environment. In recent years planetary permafrost has been studied in more detail. For example, scientists have mapped flow/creep phenomena on planet Mars that resemble rock glaciers on earth. It is assumed that these features of distinct surface deformation are due to ancient (maybe also recent) subsurface ice (Marchant and Head 2003).

Doesen rock glacier (46°59'12"N, 13°17'08"E) is located at the end of Doesen valley, which belongs to the Ankogel group of the Hohe Tauern range, Austria (see Fig. 1). It stretches from Mallnitzer Scharte (2674 m) in westerly direction towards the lower Doesen lake (2269 m) (see Fig. 2). The tongue-shaped rock glacier covers an area of approximately 25 hectares and is one of the largest active rock glaciers in the Eastern Austrian Alps (Lieb 1996 and 1998). Multi-disciplinary research work on Doesen rock glacier started in 1994 and, amongst other topics, focused on the documentation of the creep process. The spatio-temporal evolution of the flow field of Doesen rock glacier was determined for the time period 1954-2005 using various observation techniques as outlined in the review paper by Kaufmann et al. (2006). Figure 11 of that paper summarizes the change in the mean annual surface flow/creep velocity at Doesen rock glacier for the period 1954-2005. Data obtained by means of photogrammetry were based on classical stereo compilation, with the exception of 1993-1997, where the movement of the rock glacier was quantified by means of digital photogrammetry and automatic procedures.

In this paper we intend to re-compute the surface motion field of Doesen rock glacier for selected time periods using automatic digital photogrammetric techniques and we will thus be able to quantify the accuracy of the results previously obtained by interactive mapping. It will be shown that Figure 11 of Kaufmann et al. (2006) remains valid.

Chapter 2 briefly describes the possibilities of how to retrieve surface motion fields by means of manual/interactive stereo compilation using analog photographs. Two examples of previous studies are presented for purposes of comparison. The mapping of motion fields from dig-

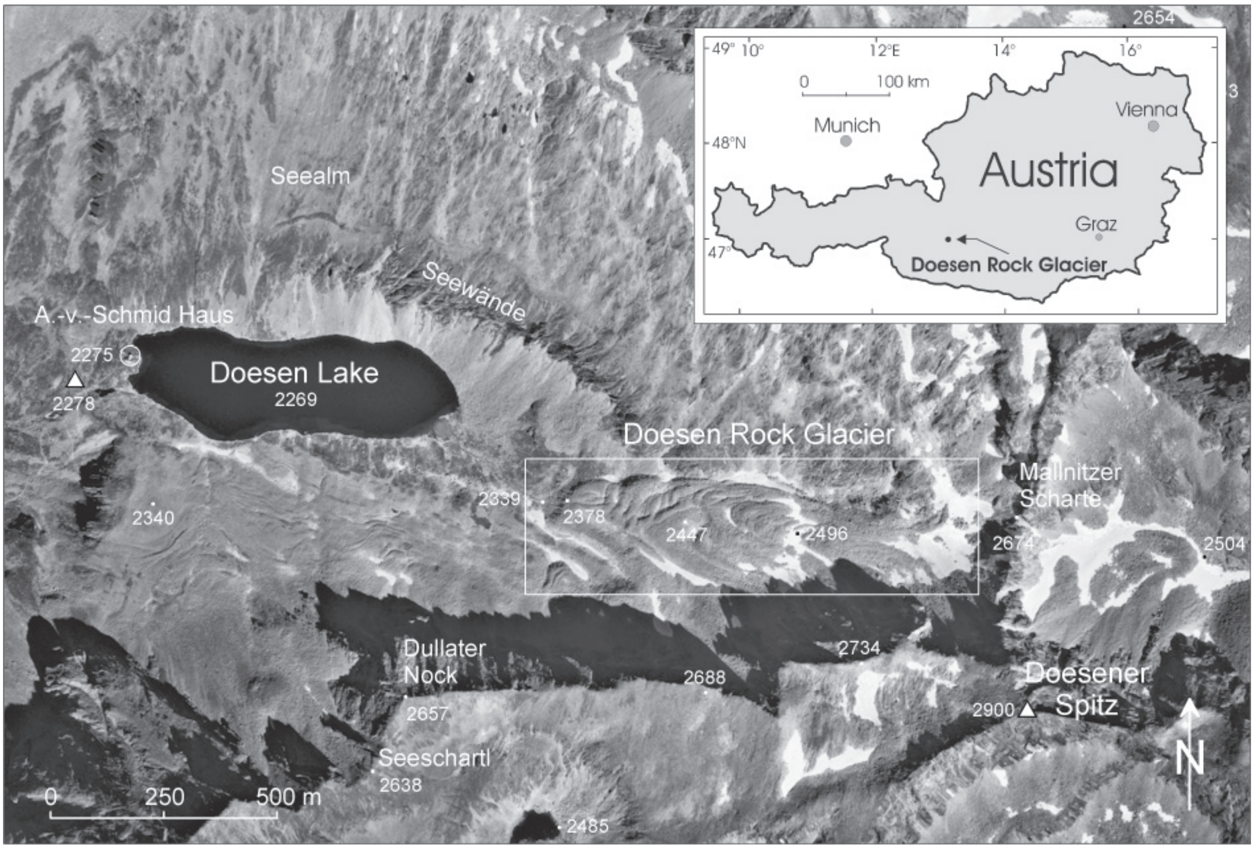


Figure 1: Orthophoto of 1 September 1997 showing the inner Doesen Valley with Doesen rock glacier. A white rectangle indicates the study area. The aerial photograph was taken by Bildflug Fischer.

ital (digitized) aerial photographs is outlined in chapter 3, which also includes a brief description of the in-house developed software ADVM (Automatic Displacement Vector Measurement). Practical results are presented in chapter 4. Finally, chapter 5 is dedicated to the comparison of the corresponding data sets, the discussion of results and conclusions.

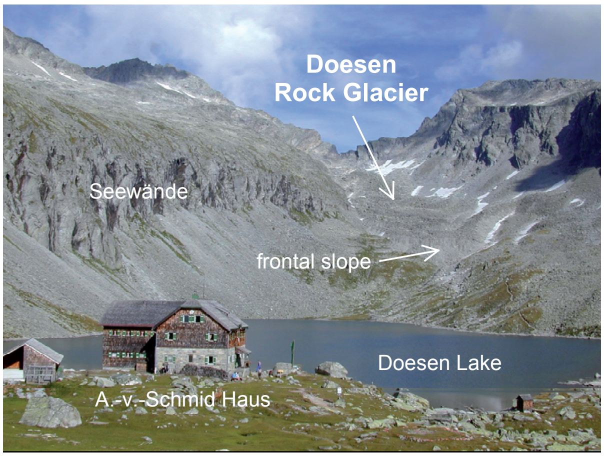


Figure 2: Terrestrial view of Doesen rock glacier of 23 August 2004. Photo taken in easterly direction.

2. Motion fields from analog aerial photographs

The task is to determine 3D displacement vectors of rock glacier surface points of at least two epochs by means of particle tracking in analog aerial photographs. One epoch is taken as a reference, and the surface change of the second epoch is determined in respect to the first one. Displacement (flow/creep) rates can be derived based on the known time span between the two epochs. The task described relates to the problem of deformation measurement, which is a typical problem of engineering geodesy.

In general, the positioning of corresponding 3D object points of different epochs can be done either in (1) independent stereomodels without stereoscopic point transfer between photographs of different acquisition dates (cp. Messerli and Zurbuchen 1968) or (2) utilizing the concept of aerotriangulation with stereoscopic point measurement (cp. Kääb et al. 1997). Moving object points must be computed separately since the photogrammetric line intersection constraint is no longer valid. From a practical point of view the second method is much more convenient, since point transfer between photographs of different epochs is done directly by means of stereoscopic vision, which makes this method more time-efficient, less error-prone and more robust than the first one.

In the early phase of our study appropriate software for the second method was not yet available for our Kern DSR-1 analytical plotter. Moreover, the large scale differences and strongly varying viewing geometries of the aerial photographs involved (see Tab. 1) would have made it very difficult to succeed with the second method. Over 600 prominent individual rocks (boulders) evenly distributed over the rock glacier surface were selected for change detection. The locations of these points were marked on enlarged photographic prints and sketches were drawn for each point for later precise point identification. Details on the photogrammetric work flow and results obtained are given in Kaufmann (1996, 1997 and 1998) and in Kaufmann and Heiland (1998). For purposes of comparison, two thematic maps showing the mean annual horizontal flow/creep velocity for the time periods 1954-1975 and 1975-1993 are presented in this paper (see Fig. 3 and 4).

3. Motion fields from digitized (digital) aerial photographs

In the 1990s digital photogrammetry started to supersede analytical photogrammetry. While analytical stereoplotters work with analog photographs, digital photogrammetric workstations (DPW) are based on dig-

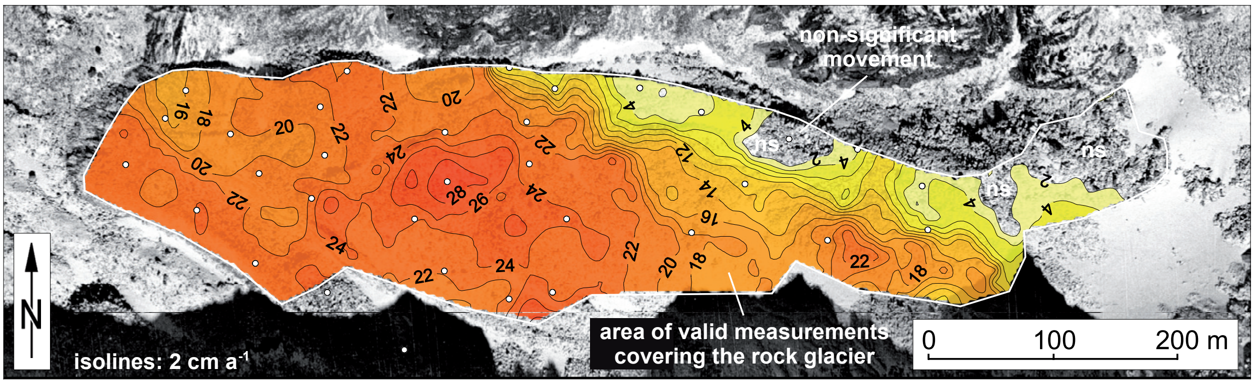


Figure 3: Mean annual horizontal flow/creep velocity (cm a^{-1}) of Doesen rock glacier for the time period 1954-1975. The result shown was derived by means of classical stereo compilation. For purposes of comparison the 34 geodetic observations points (cp. KAUFMANN et al. 2006) are shown as white dots. Orthophoto from 1954 (undated).

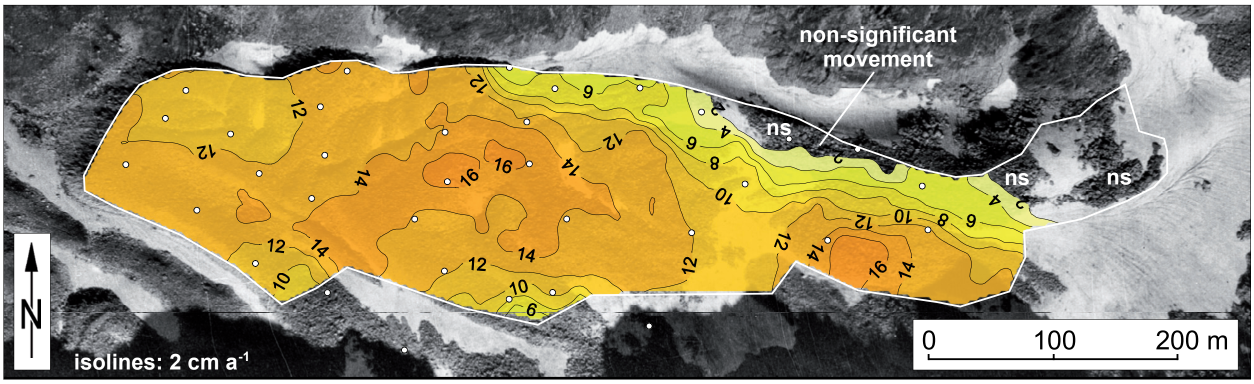
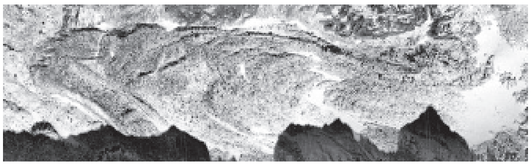
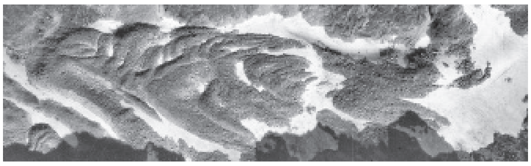


Figure 4: Mean annual horizontal flow/creep velocity (cm a^{-1}) of Doesen rock glacier for the time period 1975-1993. The result shown was derived by means of classical stereo compilation. For purposes of comparison the 34 geodetic observations points are shown as white dots. Orthophoto from 17 September 1975.

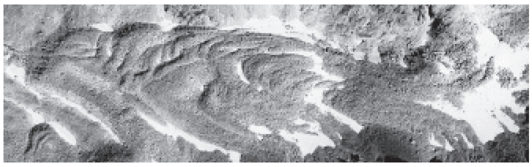


1954

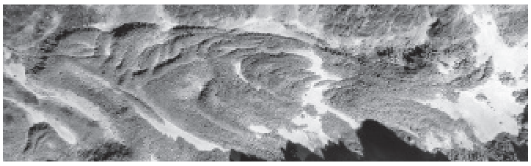
1969



1975



1993



1997

1998

date	image scale	focal length	flying height	type of film
1954	1 : 16,300	210 mm	5930 m	black-and-white
1969	1 : 29,700	153 mm	7040 m	black-and-white
17.9.1975	1 : 19,800	153 mm	5520 m	black-and-white
15.8.1983	1 : 46,400	153 mm	9580 m	black-and-white
15.8.1993	1 : 11,300	215 mm	4930 m	color infrared
1.9.1997	1 : 14,000	152 mm	4640 m	black-and-white
10.9.1998	1 : 33,400	153 mm	7600 m	black-and-white

+date of acquisition unknown
++acquisition between 29.9. and 12.10.
Aerial photographs acquired by the Austrian Federal Office of Metrology and Surveying, Vienna, and by Bildflug Fischer, Graz, Austria.

Table 1.: Aerial photographs used in the study.

ital image data. This means that available analog images, e.g. aerial photographs, must be digitized before processing, or primary data acquisition has to be digital from the beginning. The fully digital processing chain can benefit from automation based on algorithms from various disciplines of computer science, such as computer vision, digital image processing and pattern recognition. Heipke (1995) gives a good overview of the functionality and potential of DPWs.

It should be mentioned that commercial DPWs are suitable for basic photogrammetric tasks only, e.g., phototriangulation, computation of digital terrain models, orthorectification. Special tasks, e.g. deformation measurements based on multi-temporal image data, normally require additional dedicated software. Referring to the mapping of 3D motion fields of rock glaciers – this also applies to debris-covered glaciers, landslides and other mass movements – we list three possible solutions:

- The most basic solution follows method (1) of chapter 2 but using a DPW. This simple solution offers no automation in terms of computer-based measurement of points to be tracked over different epochs.
- The second solution utilizes the full potential of digital image matching provided by a DPW. This procedure corresponds to method (2) of chapter 2 and achieves very high accuracy. Due to the procedural complexity, however, the number of measurements will be limited and a trained operator is needed. Automation is hardly possible.
- Basic photogrammetric tasks, as already indicated previously, are carried out on a DPW. The automatic measurement of 3D (2D) displacement vectors is accomplished using additional software outside the DPW, as developed, for example, by university institutes. The programs available are still of an experimental type. They include not only an automatic measurement tool but also some limited functionality of deformation analysis, including detection of gross errors, elimination of systematic errors, and accuracy analysis.

Fully digital deformation measurements based on the third concept can be carried out, for example, with CIAS (Correlation Image Analysis) developed at the Department of Geography, University of Zurich, or ADVM (Automatic Displacement Vector Measurement) developed at the authors' institute. For details on CIAS see Kääb and Vollmer (2000). Additional examples of practical applications of CIAS are given in Kääb (2005).

The basic concept of the ADVM software is described in Kaufmann and Landstätter (2004). This software is designed to achieve the highest possible accuracy in point measurement but is still robust enough to handle aerial photographs taken with different cameras at different scales from different positions and different viewing angles. To achieve this goal the matching process is not done in the original (perspective) image data but in pre-rectified image parts limited to the project area (the rock glacier). The core module of ADVM is based on multi-photo constrained matching adapted to the orthoimage geometry. The algorithm developed takes advantage of the geometrically more similar image content of the pre-rectified images (cf. Tab. 1) without introducing any systematic errors to the calculated displacement vectors, even if the digital terrain models used are only rough representations of the terrain surface. The simultaneous matching and reconstruction process of the object points in two or more epochs allow to introduce additional flow constraints, e.g. flow in steepest slope direction. These additional constraints are considered to make the multi-temporal point transfer even more robust.

In a first attempt, aerial photographs of Tab. 1 were scanned using a RM-1 photogrammetric scanner of Wehrli & Associates Inc. and subsequently processed on an Intergraph DPW. After running ADVM software and analyzing the 3D deformation vector fields obtained we found out that systematic (cyclic) errors were present due to mechanical deficiencies of the scanner used (Ladstädter 1999). The following chapter describes the second attempt of scanning and subsequent fully digital processing.

4. Results

All aerial photographs were scanned a second time with 10μm pixel size using the UltraScan 5000 photogrammetric scanner of Vexcel Imaging Austria. Photogrammetric orientation was carried out on a digital photogrammetric workstation ISSK of Z/I Imaging. Only one stereomodel per epoch was considered. Absolute orientation of the stereomodels was done using an inventory of 75 stable landmarks. Digital terrain models were available for the epochs 1954, 1975, 1993, and 1997. Ground sampling distance (GSD) of the orthophotos was selected at 50 cm for the small-scale and 20 or 25 cm for the large-scale photos. Motion fields of the following time periods were computed using ADVM: 1954-1975, 1975-1993, 1969-1975, 1969-1998,

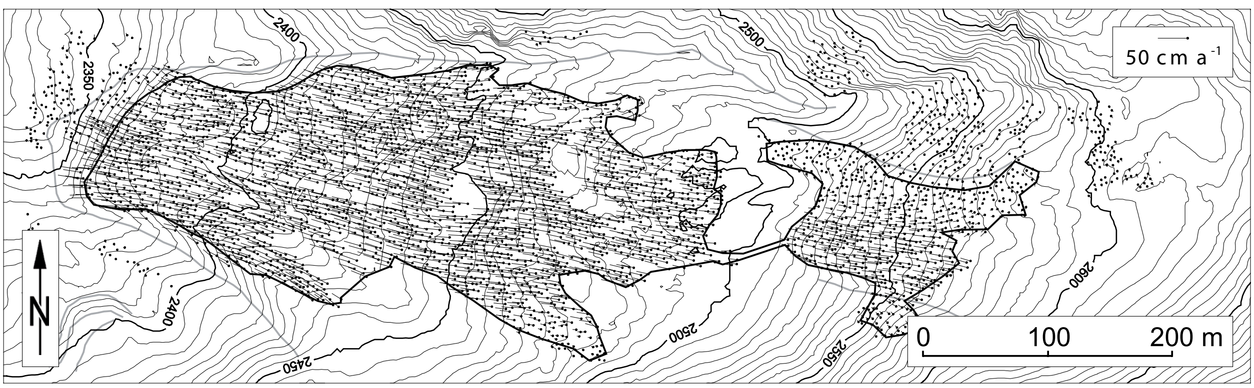


Figure 5: Horizontal displacement vectors derived from large-scale aerial photographs 1954 and 1975 using image matching techniques (ADVM software). 3359 vectors were computed. The accuracy achieved in vector length is ±1.8 cm a^{-1}.

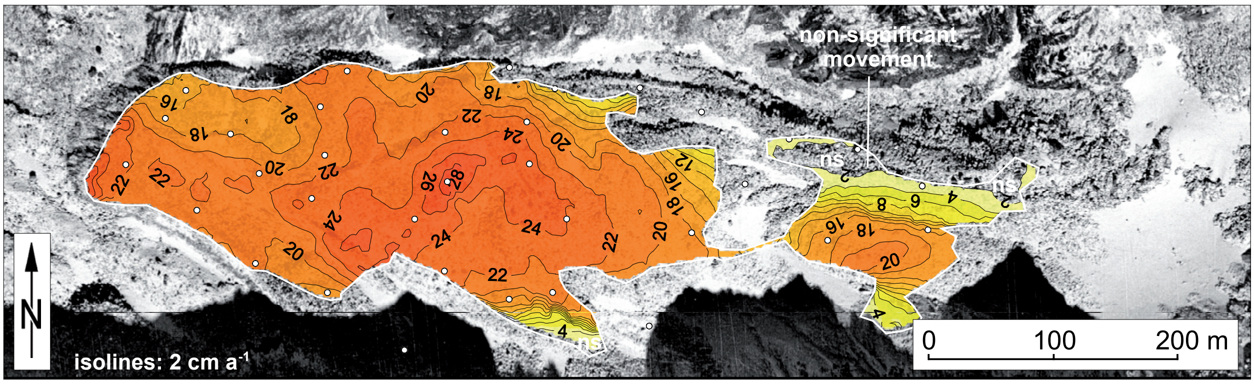


Figure 6: Mean annual horizontal flow/creep velocity (cm a^{-1}) of Doesen rock glacier for the time period 1954-1975. The result shown was derived from measurements shown in Fig. 5. Orthophoto from 1954 (undated). Compare with Fig. 3.

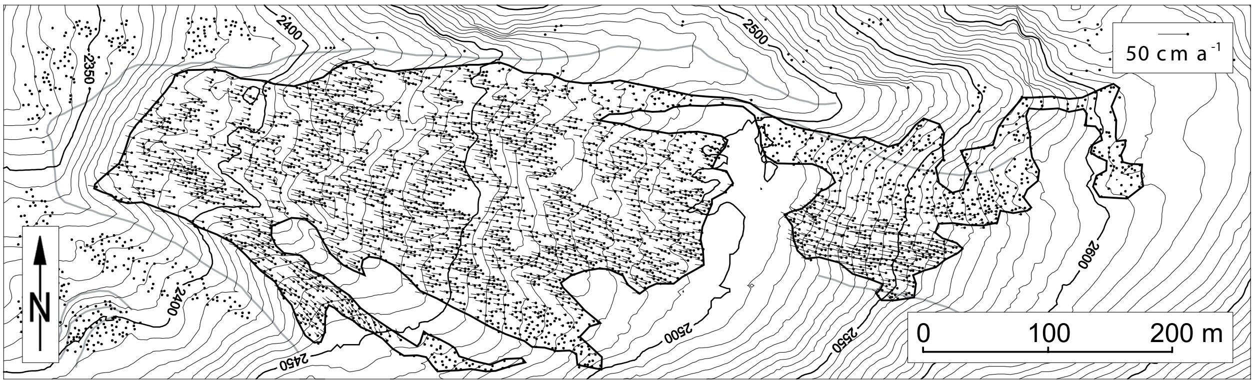


Figure 7: Horizontal displacement vectors derived from large-scale aerial photographs 1975 and 1993 using image matching techniques (ADVM software). 3408 vectors were computed. The accuracy achieved in vector length is ±0.7 cm a^{-1}.

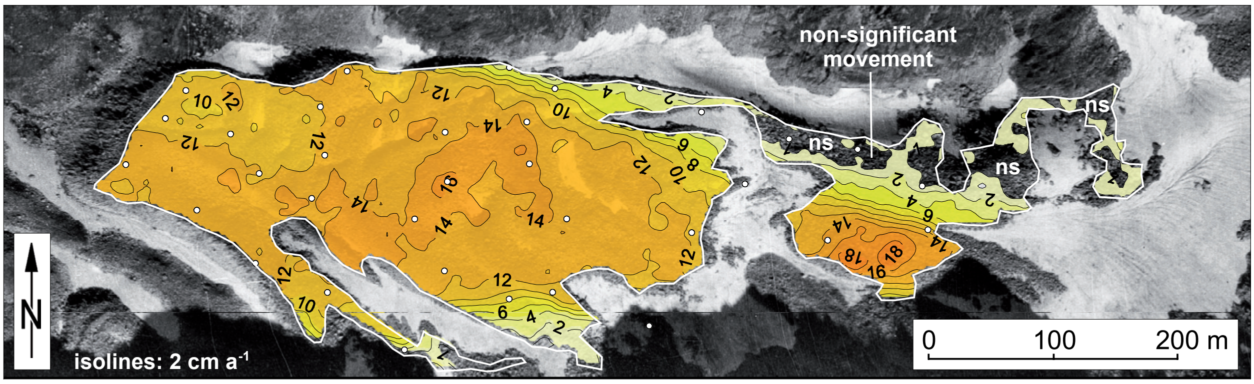


Figure 8: Mean annual horizontal flow/creep velocity (cm a^{-1}) of Doesen rock glacier for the time period 1975-1993. The result shown was derived from measurements shown in Fig. 7. Orthophoto from 17 September 1975. Compare with Fig. 4.

and 1993-1997. The result of the time period 1993-1997 has already been published in Kaufmann et al. (2006). First we assumed that the automatic point transfer from the 1954 image data to the 1975 data would fail due to fresh snow cover of the study area in 1954. We finally succeeded, however, with a sufficiently large matching window, i.e. 55 × 55 in size. In this paper we present the motion fields of Doesen rock glacier obtained for the time periods 1954-1975, 1975-1993 and 1969-1998 (see Figs. 5-10).

5. Discussion

The accuracy of the 3D displacement vectors obtained was estimated from stable (non-moving) surface points in the surroundings of the rock glacier. Root mean square errors of the computed horizontal movement amount to ±1.8 cm a^{-1} (1954-1975), ±0.7 cm a^{-1} (1975-1993), ±4.8 cm a^{-1} (1969-1975), and ±1.2 cm a^{-1} (1969-1998). The numbers presented here are of the same order of magnitude as ob-

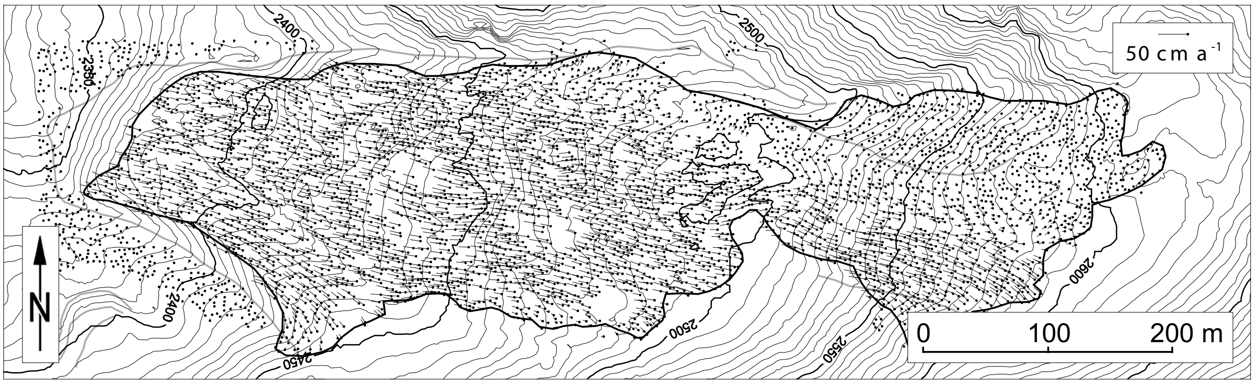


Figure 9: Horizontal displacement vectors derived from small-scale aerial photographs 1969 and 1998 using image matching techniques (ADVM software). 4335 vectors were computed. The accuracy achieved in vector length is ±1.2 cm a^{-1}.

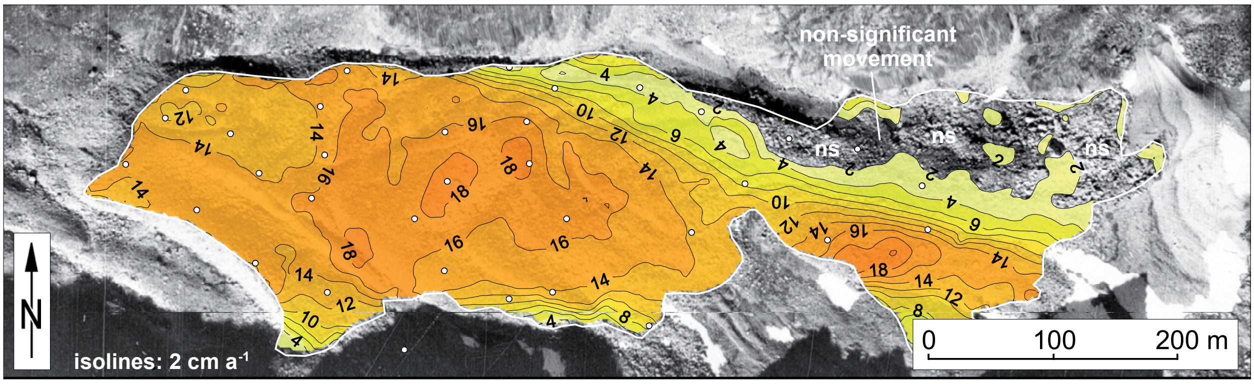


Figure 10: Mean annual horizontal flow/creep velocity (cm a^{-1}) of Doesen rock glacier for the time period 1969-1998. The result shown was derived from measurements shown in Fig. 9. Orthophoto from 1969 (acquisition between 29 September and 12 October).

tained by manual/interactive mapping (derived from the statistics of absolute orientation). In general, the accuracy of each individual 3D displacement vector depends very much on the geometric and radiometric similarity of the phototextures involved. Scratches on the photographic film, cast shadow, perennial snow patches, artifacts of orthorectification and also differential parallaxes within patches to be matched decrease accuracy, or even cause mismatches (gross errors). Gross errors were detected by visual inspection and removed manually from the data set.

time period	difference of the averaged mean annual horizontal movement (cm a^{-1})	standard deviation (cm a^{-1})
1954-1975	0.5	±1.3
1975-1993	0.4	±0.8
1969-1975	-1.6	±3.6
1969-1998	no manual/interactive mapping of 1998 data	
1993-1997	-0.1	±1.7

Table 2: Differences of the mean annual horizontal movement obtained from manual/interactive and fully digital change detection measurements.

Table 2 gives a comparison between the results obtained by manual/interactive and fully digital mapping. The numbers given refer to an area of approximately 19 hectares covering the central part of the rock glacier, which is comparable to the extension of the area considered in Fig. 11 of Kaufmann et al. (2006).

From Tab. 2 we can deduce that the averaged values of annual horizontal movement do not differ significantly between the two results (manual/interactive vs. fully digital). Compare Fig. 3 with Fig. 6, and Fig. 4 with Fig. 7. This implies that Fig. 11 of Kaufmann et al. (2006) is still valid taking the new results into account.

From a statistical point of view we have not found any significant difference between the results compared. However, looking at the individual measurement we can state that the inner and outer reliability (cf. Kraus 1997) is much higher in the fully digital approach than in the approach without digital point transfer. This is simply due to the very large number of measurements which can only be achieved using the automatic measuring concept. This also implies that the thousands or even ten-thousands of measured points better reveal the flow/creep pattern of the rock glacier.

6. Acknowledgments

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