Viktor Kaufmann

Morphometric Documentation and Computer-Based Visualization of Slope Deformation and Slope Creep of the Blaubach Landslide (Salzburg, Austria)

Abstract

This paper describes a project (2001 - 2002), which has been initiated and partially financed by the Oberpinzgau regional branch of the Austrian Forest Engineering Service of Torrent and Avalanche Control. The Institute of Geodesy of the Graz University of Technology was asked to provide basic information about the past 50 years of spatio-temporal development and the present state of the dynamic behavior of the very active Blaubach landslide.

1 Introduction

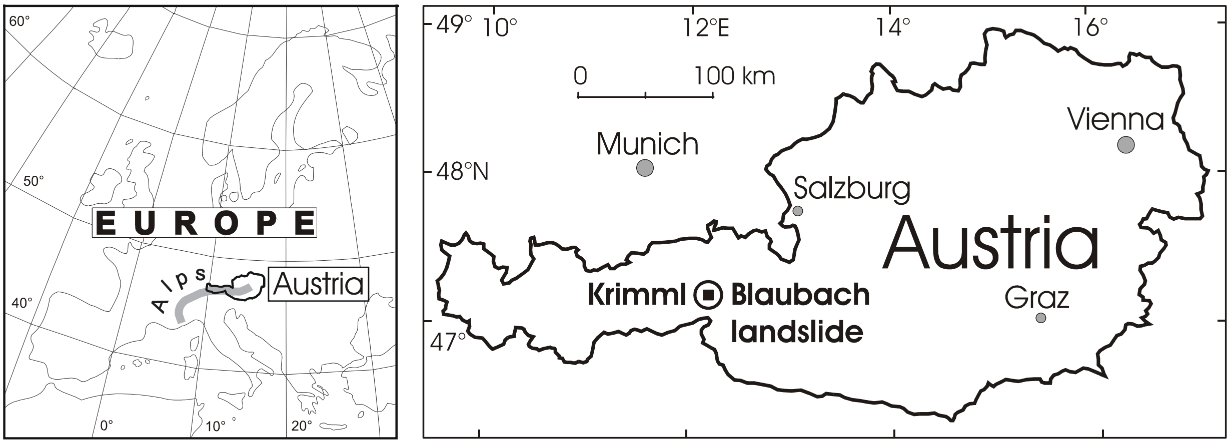

Fig 1: Location map.

The Blaubach landslide (geographical position 12°08' E, 47°13' N, see Fig. 1; altitude range 1500 m – 2000 m; area 0.23 km², length 750 m) is located in the headwaters of the Blaubach torrent and comprises two creeping morphological units, which merge downslope forming a Y- shaped terrain unit (see Fig. 2).

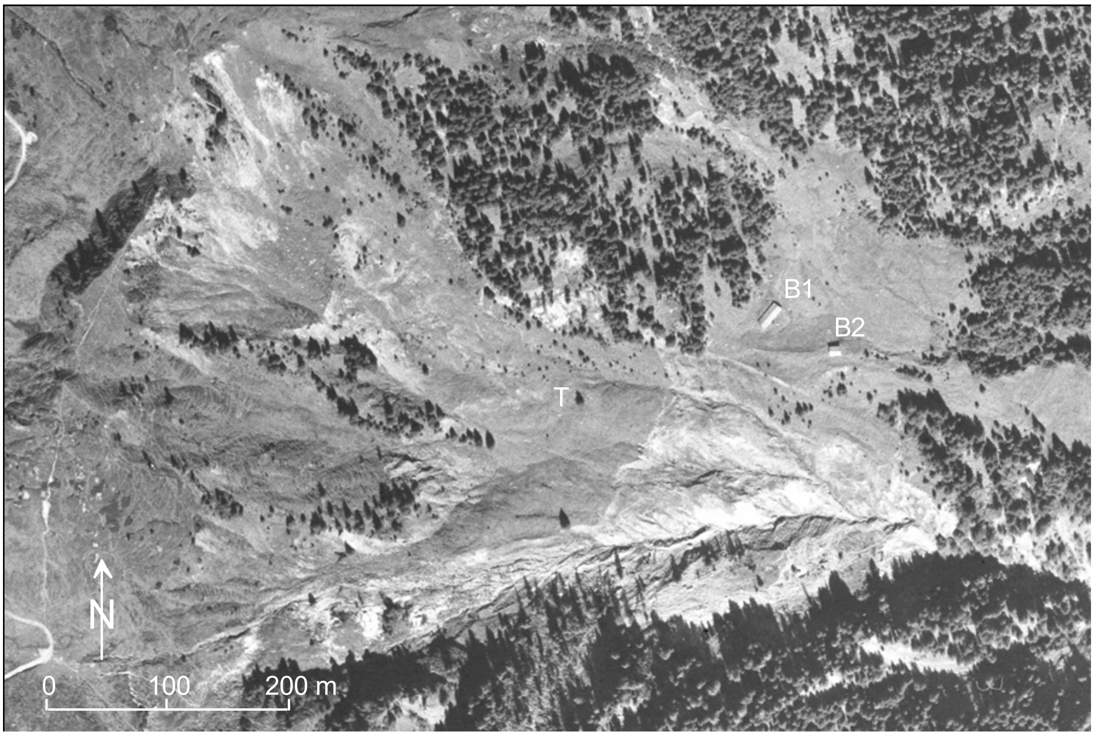

Fig 2: Orthophoto (September 13,1999) showing the Blaubach landslide (Aerial photograph © BEV-2001, Vienna, No. 40708/01).

The lower part of this unit is characterized by retrogressive erosion and large mass wasting. Soil, boulders and debris are transported by run-off waters through a narrow channel into the Blaubach gorge (see Fig. 3). No forest cover, as can be seen in the surroundings of the landslide zone, has been able to develop due to the obvious high creep velocity and surface mass movements, mostly rotational landslides. Only a few trees are growing on the prevailing Alpine meadows, which are used intensively for sheep grazing. Swamps can be found in many locations. The landslide is structurally aligned along a prominent geological fault. The substrate is mainly composed of graphitic phyllites, strongly weathered schists and other tectonically fractured rocks (see ZOBL 2001). After heavy rainfall the water of the Blaubach torrent is usually of a bluish color because of its sediment load, which also explains the torrent's name (German blau = blue). Mudflows triggered by such rainfalls are a potential hazard for the inhabitants of the village of Krimml and may also damage construction works, e.g. Gerlos Alpenstrasse (scenic road) and a reservoir belonging to a hydroelectric power plant. Protective measures such as retaining walls have already been built along the Blaubach torrent.

In the upper part of the torrent additional retaining structures and also debris-sorting dams are to be finished soon (see Fig. 4). Draining and afforestation of the landslide area is in the planning stage. Despite the fact that investigations have been carried out on the present landslide over a period of many years no quantitative information, e.g. on creep velocity or volumetric change, is available for authorities, planners and decision makers.

Fig 3: The lower part (foot) of the Blaubach landslide is characterized by large mass wasting. Note person (within white circle) for scale. Photograph taken July 4, 2001.

Fig 4: Retaining walls and debris-sorting dams are built along Blaubach torrent as a protective measure. Photograph taken October 23, 2000.

2 Description of the Project

The aim of the project stated above was reached by means of photogrammetric (Section 2.1) and geodetic (Section 2.2) measuring methods. Multi-temporal aerial photographs (1953 – 1999) were used to area-wide map slope deformation and related creep velocity, whereas a geodetic network was set up to determine the current (2001) three-dimensional displacement vectors of selected points of the mass movement. Furthermore, great emphasis was laid on the computer-based visualization (Section 2.3) of the results obtained in order to best convey the information content to the recipient.

In the following all three tasks are outlined briefly. For more details see KAUFMANN et al. 2002.

2.1 Photogrammetric Measurements

Aerial photographs of 11 different data acquisition periods between 1953 and 1999 were acquired from the Austrian Federal Office of Surveying and Mapping, Vienna (Table 1).

date	Z_0 (m)	ΔH (m)	c (mm)	image scale	film type	frame size
13.9.1999	6853	5103	152.700	1:33.400	B/W	23 × 23 cm
2.9.1997	5246	3496	214.760	1:16.300	CIR	23 × 23 cm
11.10.1991	7149	5399	152.600	1:35.400	B/W	23 × 23 cm
21.7.1989	3734	1984	213.910	1:9.300	CIR	23 × 23 cm
23.8.1987	4731	2981	213.910	1:13.900	CIR	23 × 23 cm
22.7.1983	8737	6987	152.580	1:45.800	B/W	23 × 23 cm
14.9.1977	7008	5258	152.040	1:34.600	B/W	23 × 23 cm
6.9.1973	4576	2826	210.440	1:13.400	B/W	18 × 18 cm
9.10.1969	7027	5277	152.670	1:34.600	B/W	23 × 23 cm
14.9.1962	4881	3131	210.420	1:14.900	B/W	18 × 18 cm
5.8.1953	4991	3241	210.110	1:15.400	B/W	18 × 18 cm

Table 1: Aerial photographs used in the project.
Annotations: Z_0 = flying height above m.s.l., ΔH = flying height above ground, c = focal length, B/W = black-and-white film emulsion, CIR = colour-infrared film emulsion.

Image scales vary between 1:9,300 and 1:45,800. In order to support methodological questions the evaluation of the multi-temporal photographs was carried out using the analytical plotter DSR-1 of Kern and the digital photogrammetric workstation ISSK of Z/I Imaging. High-quality image scans were made available through Vexcel Imaging Austria, Graz, using the UltraScan5000 (GRUBER & LEBERL 2001). High-resolution digital terrain models with a grid spacing of 1 meter were obtained for all periods, thus facilitating the computation of the changes in surface height and volume of the landslide in the course of the past 46 years. Maximum changes in surface height due to surface deformation were measured at +10.0 m and –15.0 m, respectively. The volumetric changes in the 1990s suggest a mean annual sediment load of 12,000 m³/year as an input to the Blaubach torrent. The results obtained clearly show the course of vertical slope deformation and, especially, the increase of mass wasting in the southern branch of the landslide and also in the badland-type areas at the foot of the mass movement during the last decade. ADVM software, originally developed at the Institute of Geodesy for monitoring debris-covered glaciers and rock glaciers, was used to automatically derive three-dimensional displacement vectors based on image matching techniques (cp. Fig. 5). An average of 39,900 displacement vectors were obtained for all calculated time periods (see Fig. 6, compare with CUNIETTI et al. 1984). Numerical (mean annual horizontal creep velocities) and graphical (flow/creep velocity fields) representations of the results obtained show that the landslide was active throughout the observed time span, with maximum creep velocities of up to 1.6-1.8 m/year for the time period 1953-1962. For 1991-1999 a maximum creep velocity of 1.3 m/year was measured, whereas the terrain above the main scarp of the retrogressive erosion zone moved downslope at a rate of 1.1 m/year in horizontal direction (see Fig. 7). Despite changes in long-term creep velocity due to sudden surface landslides and annually changing creep velocities, the creep velocities observed are quite uniform (secondary creep) over time. Shear zones (moving/non-moving) can be clearly identified at the outer margins of the landslide. The results of the digital photogrammetric evaluation were checked by means of conventional photogrammetric measurements through an operator tracking individual trees riding on top of the mass movement. For example, a horizontal movement of 53.9 m was measured for a single tree (position T in Fig. 2) for the time period 1953-1999. Significant movements of two buildings (positions B1 and B2 in Fig. 2) situated directly outside the main sliding area were also detected, with annual horizontal displacements amounting to 4.2 cm.

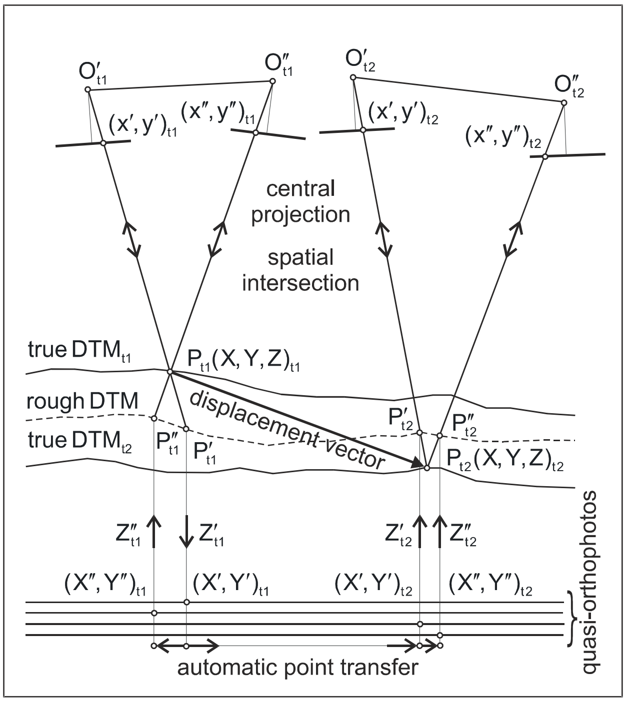

Fig 5: Basis concept of the automatic measurement of 3D displacement vectors in digital multi-temporal photographs. Detailed explanations of this concept are given in KAUFMANN & LADSTÄDTER 2002.

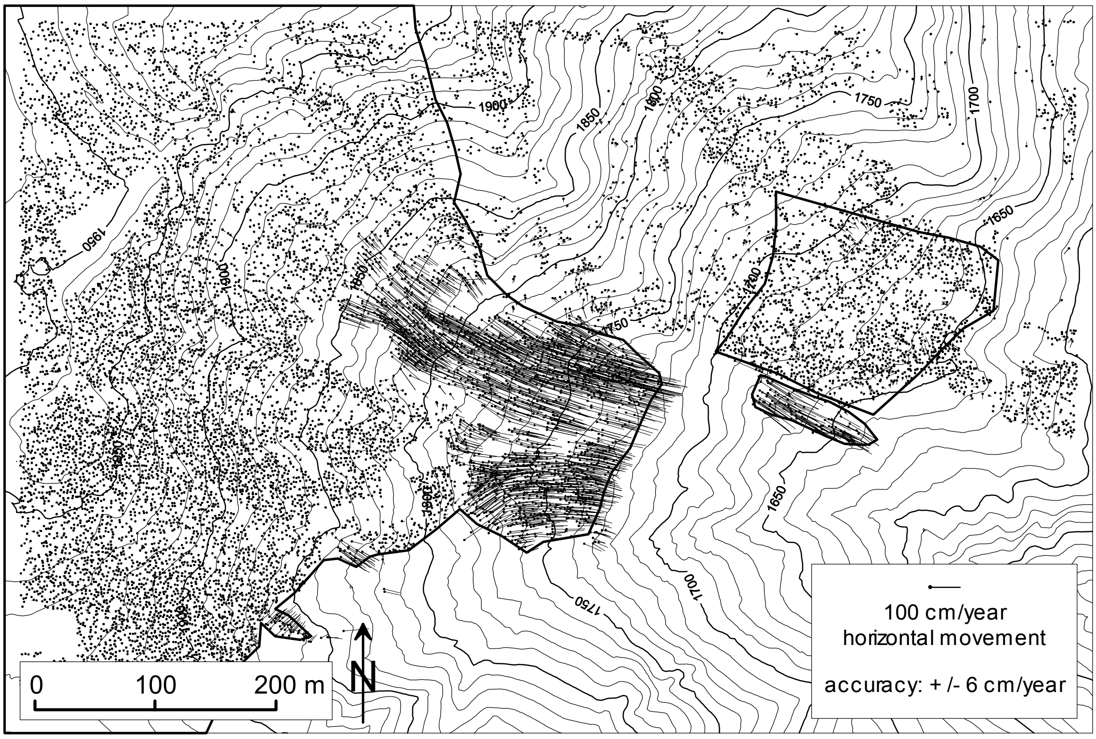

Fig 6: Flow vector field (displacement vectors) at Blaubach landslide for the time period 1991-1999. Three selected areas for further analysis are outlined.

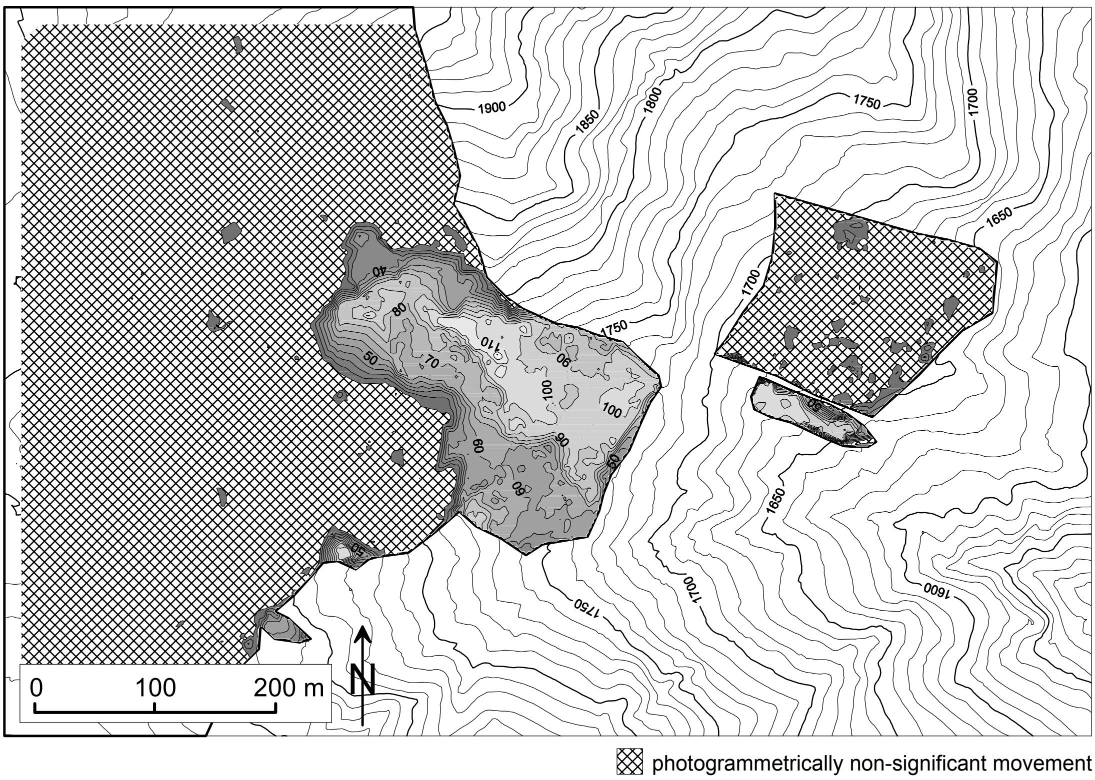

Fig 7: Mean annual horizontal flow/creep velocity at Blaubach landslide for the time period 1991-1999. Numbering of isotachs is given in cm/year.

2.2 Geodetic Measurements

A geodetic observation network consisting of several non-moving reference points outside the moving terrain and 41 observation points evenly distributed inside the landslide area was set up for high-precision deformation measurements in June 2001. Due to the very soft substrate of the landslide all observation points were stabilized with 1.5 m long iron rods. The absolute orientation of the network was derived from differential GPS (Global Positioning System) measurements.

However, all observation points were measured using an electronic theodolite (Total Station). Two surveys of the network were carried out in 2001, i.e. in July and October. Maximum horizontal displacements of up to 23 cm were obtained (see Fig. 8).

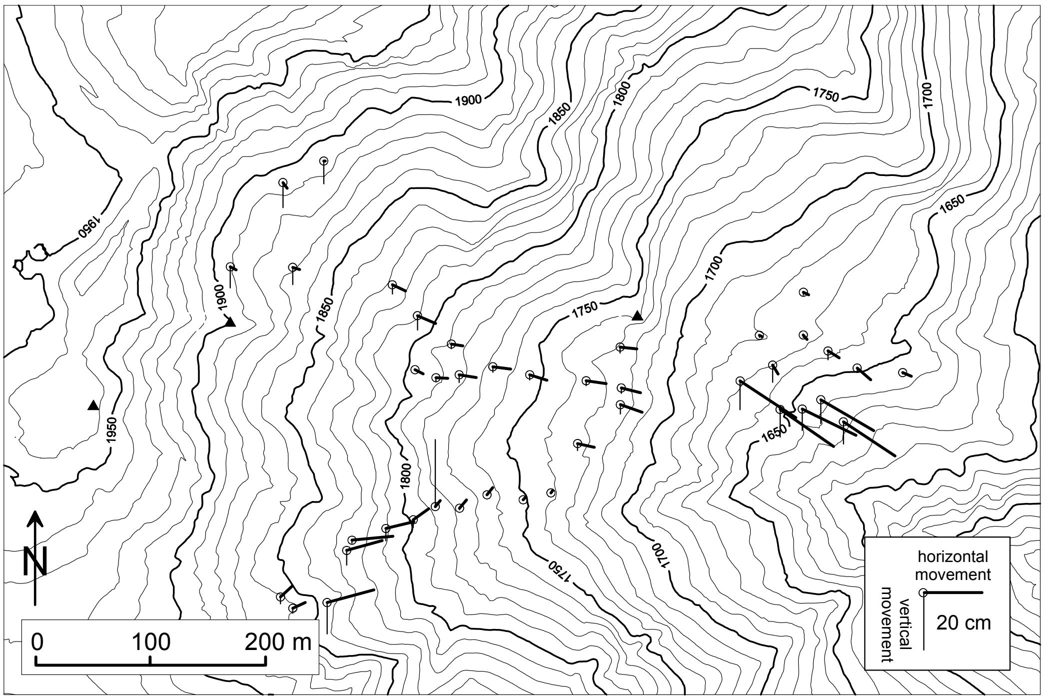

Fig 7: Mean annual horizontal flow/creep velocity at Blaubach landslide for the time period 1991-1999. Numbering of isotachs is given in cm/year.

However, after scaling these data to annual values, the extrapolated creep velocities were four times smaller than anticipated from the photogrammetric measurements. It is assumed that seasonally changing precipitation caused the observed short-time change of activity of the landslide. In order to prove this statement the geodetic measurements will be repeated in July 2002, or even better, more frequently throughout the year (cp. HARTINGER 2001).

2.3 Visualization and Animation

Orthophoto maps of all available periods were prepared at scales 1:5,000 and 1:2,500. A large set of thematic maps showing the results of the photogrammetric and geodetic measurements was produced. Computer animation was introduced to visualize the three-dimensional landscape of the study area and its dynamic, time-dependant change of surface geometry and texture. The rather slow long-time changes of the surface topography and the respective creep phenomenon were made clearly visible employing various animation techniques. As a result a video film entitled "Panta Rhei" is now available. Please see also http://www.cis.TUGraz.at/photo/viktor.kaufmann/animations.html.

3 Conclusions and Outlook

Slope deformation and creep velocity of the Blaubach landslide could be measured successfully with high spatial and temporal resolution. Especially digital photogrammetry, i.e. automatic image matching, offers a great potential in monitoring dynamic processes of the earth's surface at a regional scale. However, the proposed method cannot be applied to landslide areas with forest cover. Furthermore, shadows and lack of good photo texture may hamper high-precision results. In recent years airborne laser scanning (ASL) has become a powerful remote sensing method for obtaining high-resolution digital terrain models. Thus, this technique is highly suitable for detecting changes in surface height, all the more the area of interest is wooded. In case of high risk of a slope failure a continuous deformation monitoring system, e.g. using GPS, has to be installed. Such kind of early warning system could alert decision makers in case of unexpected acceleration of the slope movement.

It is hoped that the obtained results of the present project will facilitate further conservation measures at the Blaubach landslide, i.e. draining and afforestation.

Acknowledgments

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