Glacier monitoring by means of terrestrial photogrammetry: A case study in the Hohe Tauern National Park

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Abstract: The mapping of glacier fluctuations is an important task of environmental research. Several methods of glacier mapping on a local, regional and global scale are available. From a historical point of view, terrestrial photogrammetry was the first powerful tool in obtaining reliable metric information about glaciers in mountainous landscapes. Today, however, terrestrial photogrammetry is only applied occasionally in glacier studies, if at all. In this poster we seek to show that the availability of low-cost high resolution digital (consumer) cameras opens up new perspectives in glacier monitoring. Since digital photogrammetric software is readily available for 3D data capture, we conclude that there is a good chance of a revival of classical terrestrial photogrammetry in the digital domain. The potential of a fully digital approach using a low-cost digital consumer camera has been investigated in a case study. The main task of the study was to obtain parameters quantifying the retreat of the Goessnitzkees glacier from ground-based photographs taken at three different time periods (1988, 1997, 2003).

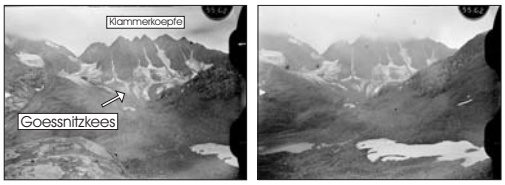
1. Introduction

Goessnitzkees (12°45' E, 46°58' N) is a small debris-covered cirque glacier located in the Schober group of the Hohe Tauern range, Austrian Alps. The glacier covered an area of some 0.75 km² in 1997. In 1982 Goessnitzkees was included into the network of annual glacier measurements of the Austrian Alpine Club (ÖAV). Since 1982 until now all annual measurements (mid-September) on Goessnitzkees have been carried out by members of the Institute of Geography and Regional Science of the University of Graz (UNI Graz) From 1996 to 1998 a glacier study under the leadership of G.K. Lieb (Institute of Geography and Regional Science, UNI Graz) was carried out in order to reconstruct the glacier history of Goessnitzkees from 1850 (maximum extent of glaciation) until 1997. In 1996 the former Institute of Geodesy of the Graz University of Technology selected Goessnitzkees as a test site for high-mountain studies. A three-dimensional geodetic network was installed for this purpose, comprising also some reference points of the previously described annual measurements for ÖAV.

2. Data acquisition

2.1 TAL - Glacial stage 1988

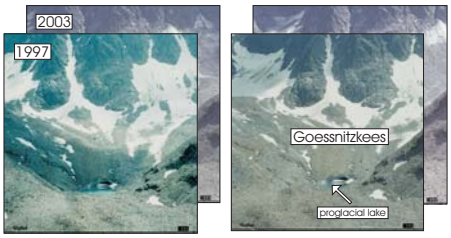
Zeiss TAL phototheodolite
principal distance: 55.62 mm
glas plates: 6.5 cm x 9 cm



Photography: R. Kostka and V. Kaufmann, August 7, 1988

2.2 Rolleiflex 6006 - Glacial stages 1997 and 2003

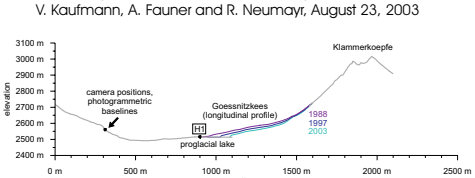
Réseau camera Rolleiflex 6006
principal distance: 151.608 mm
format: 6 cm x 6 cm (roll film)



Photography: V. Kaufmann et al., August 11, 1997;
V. Kaufmann, A. Fauner and R. Neumayr, August 23, 2003

Remarks concerning 2.1 and 2.2:

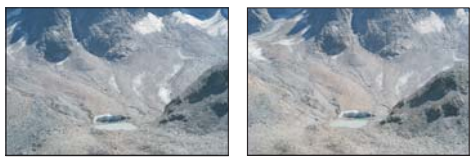
- Scanning with UltraScan 5000 (Vexcel Imaging Austria) at 10 um
- Masking of réseau crosses
- Geometric and radiometric pre-processing (e.g. correction of film shrinkage, film unflatness and chromatic aberration)
- TAL: appr. 8000 x 6000 pixel
- Rolleiflex: 6001 x 6001 pixel



Terrestrial photogrammetric disposition

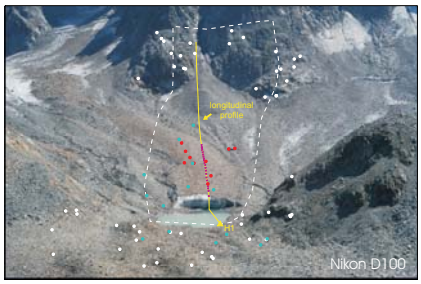
2.3 Nikon D100 - Glacial stage 2003

Digital camera Nikon D100
principal distance: 51.579 mm
CCD array: 3008 x 2000 pixel



Photography: V. Kaufmann, A. Fauner and R. Neumayr, August 23, 2003

3. Geodetic measurements 1997 and 2003



Since 1996 annual glacier measurements have been carried out every year (mid-August) until the present time:

(1) terminus of the glacier
(2) shoreline of the proglacial lake
(3) velocity markers
(4) longitudinal profile (azimuth 154.5 gon)

1997: R. Wack
2003: P. Raffold

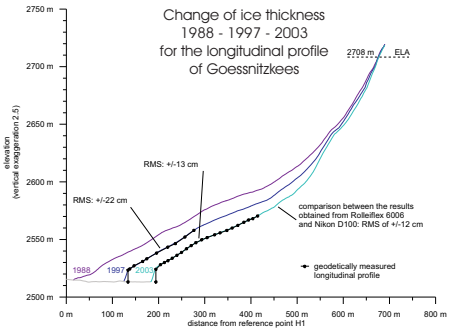
- geodetic reference point H1
- photogrammetric control point (N)
- photogrammetrically determined tie point (T)
- geodetically measured profile point
- additional point for velocity measurement
- longitudinal profile
- photogrammetric mapping area

4. Photogrammetric evaluation

Photogrammetric orientation of all image data was carried out using an ImageStation SSK of Z/I Imaging. The Rolleiflex 6006 stereo model of 2003 was selected as a reference model for subsequent absolute orientation of the other stereo models. The absolute orientation of this reference model was performed using the photogrammetric control points (N) measured geodetically at the same time of data collection. Some 55 tie points (T) were selected in areas of the deglaciated forefield of Goessnitzkees and in the steep back walls of the cirque glacier.

5. Results

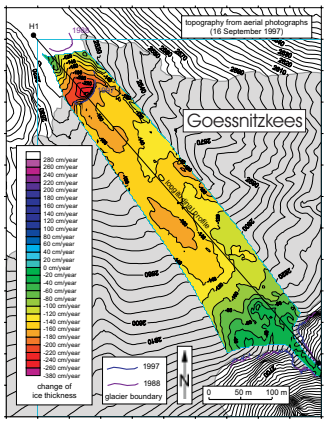
Digital elevation models (DEMs) were obtained for all four stereo pairs through manual measurement of a regular grid of surface points with a sampling distance of 5 m. Furthermore, linear features, e.g., the outline of the glacier terminus, other glacier boundaries, shoreline of the proglacial lake, breakline and drainage lines, were compiled. These data were also considered in the computation of the DEMs. The accuracy of the DEMS was checked independently by means of the geodetic measurements. Numerical values quantifying the glacier retreat were obtained from the 3-dimensional data showing the amount of change of ice thickness and the horizontal recession of the terminus (cp. Table). Various graphs and thematic maps were produced for visualization purposes (see Figures below).



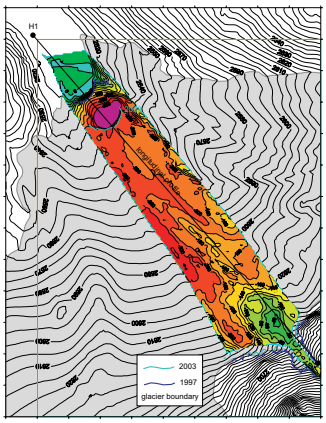
Change of ice thickness [2530 - 2560 m]:
1988 - 1997: -13.6 m (= -1.51 m/a)
1997 - 2003: -12.2 m (= -2.03 m/a)
1988 - 2003: - 25.1 m (= -1.67 m/a)

Glacier length change:
1988 - 1997: -85.2 m (= -9.47 m/a)
1997 - 2003: -61.5 m (= -10.26 m/a)
1988 - 2003: -144.9 m (= -9.66 m/a)

Ablation gradient [100 m]: 0.969 m w.e.
Mean flow velocity: 30 - 60 cm/a



Terrestrial photogrammetric documentation
of change of ice thickness 1988 - 1997



Terrestrial photogrammetric documentation
of change of ice thickness 1997 - 2003

6. Discussion

The usefulness of low-cost SLR digital consumer cameras for terrestrial photogrammetric glacier surveys was demonstrated. In respect to Goessnitzkees we conclude that the annual change of ice thickness can probably be computed with an accuracy of 20 cm using the Nikon D100 digital camera. Assuming a mean annual surface lowering of about 2 m, a relative measurement error not worse than 10 % can be expected. In summary, it can be said that terrestrial photogrammetry, as described in this poster, can be applied successfully in long-term monitoring projects for small glaciers or selected areas of a glacier, e.g. outline of the terminus, if a sufficient number of stable points is available in the vicinity of the area of interest.

(Kaprun, September 15-17, 2005)