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Investigations on the Retreat of two small cirque glaciers (Goessntizkees and Hornkees) in the Austrian Alps, Europe

Abstract

The aim of the study is to show the variations in area, altitude and volume of two neighbouring glaciers since the Little Ice Age advance. The respective glaciers are situated in the Schober group (Hohe Tauern range, Central Alps) between 2500 and 3100 m a.s.l. The reconstruction of the maximum extent in 1850 was possible due to well-preserved moraines, while the other stages were derived from old maps (1873, 1929) and aerial photographs (1954, 1969, 1974, 1983, 1992 and 1997).

As a result digital maps and high-resolution digital terrain models of all these glacial stages were obtained and numerically evaluated in respect to glacier-characteristic geomorphometric parameters. Furthermore, an orthophoto map at 1:10,000 scale was produced in order to show the present glaciation of 1997.

Summarizing the results it can be said that the two glaciers have lost 52 % (Goessnitzkees) and 61 % (Hornkees) of their area since 1850, the decrease in volume was 77.5 x 10^6 m³ and 38.2 x 10^6 m³, respectively. These values as well as some other data on changes in area and volume according to elevational intervals correspond quite well with results from other glaciers of the Central Alps.

1 Purpose and concept of the study

The respective investigations were carried out within the framework of a research project funded by the Hohe Tauern National Park, in which the two glaciers are situated. The aim of the project was to reconstruct glacial stages since the last maximum of the Little Ice Age advance in about 1850 in order to visualize the changes that took place in this period. Furthermore, the single stages (chapter 3) were numerically evaluated with special regard to the parameters area and volume, both for the total glaciers as presented in this paper and for elevational intervals. In this way the deglaciation is documented in detail and can thus serve as a basis for regional comparisons (chapter 6) and further investigations, e.g. mass balance modelling.

The two glaciers are situated in very remote places keeping away tourist masses as well as scientists. Information on this area is quite scarce. Hence, the orthophoto map enclosed in this paper for the first time shows the glaciers and their surroundings at a scale suitable for glaciological, geomorphological and geoecological work. Furthermore, the glaciers represent a special type of topographic position characterized by high rock faces surrounding the glaciers and a larger contribution to snow accumulation by avalanches than is the case on most glaciers of the nearby mountain groups.

2 Geographical setting of the glaciers

The two glaciers are located in a mountain group (Schober group) which is situated in the S of the main crest of the Hohe Tauern range and of the Eastern Alps, about 12 km SSE to Großglockner (3798 m), the highest summit of Austria. The precise position as well as some basic information on geology, climate and geoecology of the area are indicated on the enclosed map. Due to the rough topography of the Schober group (steep rock faces, narrow crests, lack of flat surfaces at high elevations) the mean size of the glaciers amounts to only 0.18 km² (data for 1969 taken from the Austrian glacier inventory), making Goessnitzkees ("Kees" is the local name for glacier) the largest glacier of this mountain group. The general exposure of the glaciers is NW with high crests and mountain tops to the S in both cases (Grosser Hornkopf, 3250 m). The lower end of Goessnitzkees was situated at 2465 m in 1850 and at 2515 m in 1997, whereas the same values for Hornkees are 2406 m and 2600 m, respectively.

Both glaciers have well-developed lateral moraines accumulated in the course of different advances in the Holocene period, which also includes the Little Ice Age advances with the last maximum in about 1850. At least in two places these lateral moraines are perennially frozen and supersaturated in ice showing permafrost creep phenomena. The character of the forefields (i.e. the area that has become ice-free since 1850) is quite different at the two glaciers. The forefield of Hornkees is steep and also extends over a rock terrace with a big alluvial fan at its foot. In contrast, the forefield of Goessnitzkees is situated on a flat cirque floor (this is why the glacier end has risen only 50 m since 1850), which allowed two proglacial lakes to develop. The surface substrate in both forefields is dominated by coarse boulders, which cover also great parts of the glaciers themselves and originate from the rock faces in the S.

3 Reconstruction of the stages and preparation of maps

As mentioned in chapter 2 the Little Ice Age moraines are well preserved and allow the shape of the glaciers at their maximum extent to be drawn quite exactly. In contrast, the reconstruction of the surface topographies had to be done hypothetically with the help of longitudinal transects, because there are no old maps or other historical sources giving detailed information (for this reason it is also unknown whether the maximum extent has been reached exactly in 1850 or some years earlier or later, cf. LANG & LIEB 1993). Therefore a slight inaccuracy in the data derived from the "1850 stage" must be taken into consideration. To a certain extent this is also true for the reconstructions of the stages 1873 and 1929, which both have been elaborated on the basis of old maps. The older one is of course even less reliable and had to be widely corrected in order to adapt the topography to the modern terrain model. All the other stages were directly mapped from aerial photographs and thus can be mutually compared without problems, with the exception of the already mentioned fact that the lower part of Goessnitzkees, especially in the younger stages, is widely covered with debris making the delimitation of the ice difficult in some places.

Aerial photographs of several time periods between 1954 and 1997 were obtained from the aerial photograph archive of the Austrian Federal Office of Metrology and Surveying, Vienna. Additionally, in 1997 an aerial survey was carried out over the area of interest by a private company. This heterogeneous set of photographs shown in Table 1 was mapped into a common co-ordinate system (Austrian Gauss-Krueger map projection) by means of aerotriangulation (cf. KERSTEN & MEISTER 1993). Since ground control is based mainly on natural detailed points the achieved absolute mapping accuracy is reduced to a certain extent. But this is not too critical, as long as the glacier maps of the various stages are based on the same control (cf. KONECNY 1964). Detailed photogrammetric evaluation of contour lines, break lines, ridge lines, drainage lines, spot heights, snow patches, glacier borders and other thematic features has been done for both glaciers at 1:5,000 scale using the analytical plotter DSR-1 of Kern. The previously mentioned reconstructions of the oldest glacier stages were digitised and subsequently analysed together with the photogrammetrically derived data using the Geographical Information System (GIS) IDRISI of Clark University. As a result 9 digital vector data sets comprising consistent planimetric and height information of the glaciated areas and its neighbouring non-glaciated areas are available. Due to the limited coverage of Hornkees with overlapping photographs of 1992 three-dimensional mapping for that year was possible only for the lower end of the glacier tongue.

In order to study the volumetric changes of both glaciers, high-resolution digital terrain models (DTMs) with a grid spacing of 2.5 m were derived using the software “Terrain Modeler” of Intergraph (cp. REINHARD & RENTSCH 1986). Since the selected GIS is raster-based, the areal extent of the glaciers, which is given by polygons, was also converted to raster-based layers (masks) with the same resolution as specified before. The results of the numerical analysis of the glacier variations are given in chapter 5. A more thorough analysis, as has been shown by FINSTERWALDER 1953 and HOFMANN 1958, will be included in future work. The glacier variations in area and volume were not only expressed numerically but were also visualized by means of thematic maps applying various cartographic methods. Figure 1, e.g., clearly illustrates the retreat of the Goessnitz- and Hornkees during the last 147 years (1850-1997).

Table 1. Aerial photographs used in the mapping of glacial stages.

date of acquisition	number of photographs	focal length [mm]	image scale	film type
September 9, 1954	8	210.230	1:12,600-1:17,100	BW
October 10, 1969	3	152.670	1:25,000-1:31,200	BW
September 5, 1974	11	210.440	1:6,900-1:11,400	BW
July 23, 1983	3	213.790	1:27,800-1:32,300	CIR
September 18, 1992	4	214.760	1:11,400-1:15,800	CIR
September 1, 1997	3	152.383	1:15,600-1.21,900	BW
September 16, 1997	2	152.700	1:28,300-1:34,500	BW

Annotations: The frame size of the photographs of 1954 is 18 cm by 18 cm, otherwise 23 cm by 23 cm. For 1992 there is no full stereoscopic coverage of the Hornkees. The photographs of September 16, 1997 were only used for orthophoto production (cf. chapter 4).

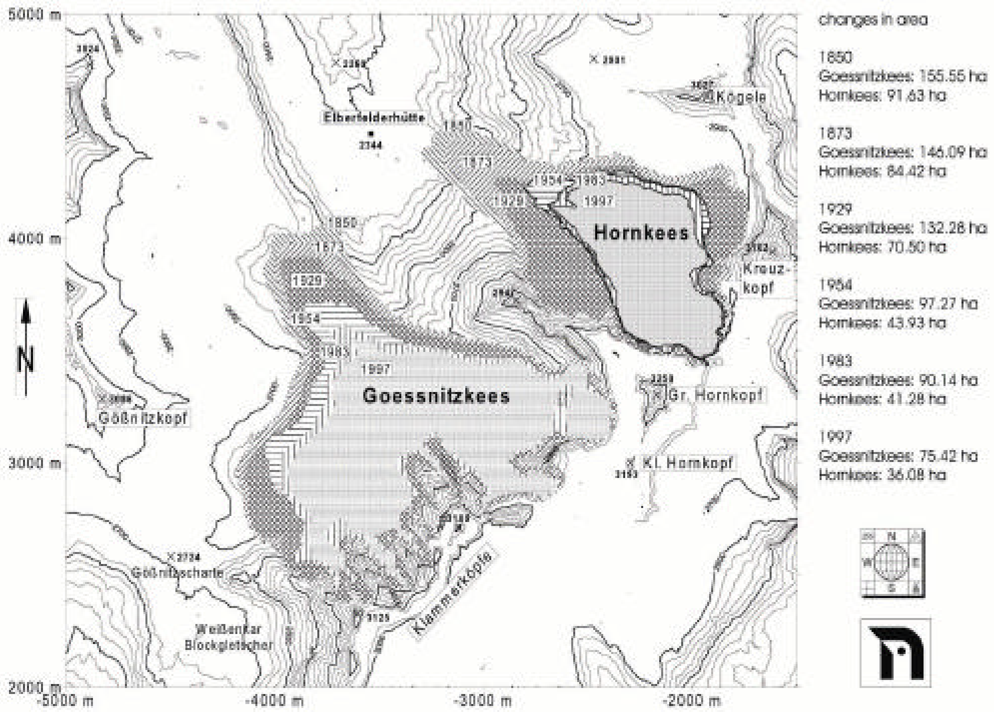

Figure 1: Thematic map at 1:20,000 scale showing the changes in area of Goessnitz and Homkees since 1850.

Orthophoto map 1:10,000

One of the key issues of the present study was to publish an orthophoto map at 1:10,000 scale showing the present glaciation. The layout of the map was designed as a black-and-white combined image-line map (prototype in KAUFMANN 1996). A printed version of the map with the title “Goessnitz- and Hornkees, Schober group - Orthophoto map 1:10,000” is attached to this volume. The area visible in the map comprises the end of the Goessnitz valley in the Schober group, where both glaciers are located. The map covers a total area of 10.5 km². The aerial photographs of September 1, 1997 were used to photogrammetrically extract the topographic information required for map production, e.g., contour lines, spot heights, drainage system, buildings, hiking trails, etc. Due to dark shadows in some north-facing slopes and due to difficulties in three-dimensional viewing of steep slopes some areas could not be mapped using the given stereotriplet. The remaining white spots on the map were completed using the other aerial photographs (1954-1992). Based on these data (260-280 points/hectar) a high-resolution DTM was computed (as indicated in chapter 3) for the whole area in order to facilitate orthophoto generation. Actually, this DTM also served as the geometric reference for the set-up of the DTMs of the individual glacier stages.

Unfortunately, the medium-scale photographs of September 1, 1997, which would have been most suitable for orthophoto production in terms of image scale and resolution, could not be used because of their unfavourable high image contrast. However, at a later stage the appropriate aerial photographs of September 16, 1997 were at our disposal. A single photograph covering the whole area of the map was scanned with a resolution of 12 µm using a Rastermaster RM-1 image scanner of Wehrli. Ortho-rectification of the image content was accomplished using the software “Base Rectifier” of Intergraph, resulting in an orthophoto of 0.625 m spatial resolution (picture element size). Image brightness and contrast of the orthophoto were set to optimal values for printing. This modification of the histogram and an additional image sharpening process were performed under Adobe Photoshop 4.0. The final layout of the orthophoto map was produced with the desktop publishing system CorelDraw 6.0. The orthophoto serves as a background for all other cartographic elements, e.g., 50m-contour lines (black) interpolated from the DTM, spot heights (white), drainage system (black), trails (white), names (white or black) taken from the Austrian topographic 1:50,000 map (sheet 179), buildings and selected geodetic points. Other elements, e.g., technical parameters, scale bar, legend, location maps, a perspective view of the area, a general description of the area in German and English, and logograms, were added in the bottom and right margin of the orthophoto map. Screening was performed with 60 lp/mm using elliptically shaped dots.

Quantification of glacier retreat

In this paper the deglaciation that has taken place since 1850 is shown by the parameters area (Tab. 2) and volume (Tab. 3). In 1997 Goessnitzkees covered only 48 % of the area of 1850, and Hornkees even 39 %. The respective value of the volumetric change cannot be given due to the fact that the present volume of the two glaciers is not known. However, the percental loss of volume may be expected to be even more dramatical than the retreat in area. In order to be able to compare the individual periods, annual values are given in the tables. In spite of the different length of the periods the data clearly show the course of deglaciation with a peak between 1929 and 1954, whereas the climatic conditions were more favourable for the glaciers around 1980, which resulted in a slight volumetric increase.

Tab. 2. Changes in area of Goessnitz- and Hornkees since 1850.

period	Goessnitzkees		Hornkees	
	change in area (ha)	change in area (ha/a)	change in area (ha)	change in area (ha/a)
1850/1873	-9.45	-0.41	-7.21	-0.31
1873/1929	-13.82	-0.25	-13.92	-0.25
1929/1954	-35.01	-1.40	-26.58	-1.06
1954/1969	-4.01	-0.27	-1.70	-0.11
1969/1974	-3.35	-0.67	-0.51	-0.10
1974/1983	+0.24	+0.03	-0.45	-0.05
1983/1992	-11.87	-1.32	.	.
1992/1997	-2.85	-0.57	-5.20 (1983/97)	-0.37 (1983/97)
1850/1997	-80.12	-0.55	-55.57	-0.38

Annotations: The changes in area are given in hectares (ha = 0.01 km²); the annual values were calculated by simple division by the number of years; the evaluation of entire Hornkees for the stage 1992 was not possible (cf. chapter 3).

Tab. 3. Changes in volume of Goessnitz- and Hornkees since 1850.

period	Goessnitzkees		Hornkees	
	volumetric change ($10^6 m^3$)	volumetric change ($10^6 m^3/a$)	volumetric change ($10^6 m^3$)	volumetric change ($10^6 m^3/a$)
1850/1873	-11.98	-0.52	-7.80	-0.34
1873/1929	-17.08	-0.31	-12.63	-0.23
1929/1954	-30.65	-1.23	-12.49	-0.50
1954/1969	-3.09	-0.21	-0.40	-0.03
1969/1974	-2.49	-0.50	-0.36	-0.07
1974/1983	+0.55	+0.06	+0.87	+0.10
1983/1992	-8.83	-0.98	.	.
1992/1997	-3.93	-0.79	-5.35 (1983/97)	-0.38 (1983/97)
1850/1997	-77.50	-0.53	-38.16	-0.26

Annotations: See Table 1.

Comparison with results from other Alpine regions

The situation illustrated by Table 2 and 3 corresponds very well to the glacier history known from neighbouring mountain groups (e.g. BÖHM 1994) or greater parts of the Eastern Alps (e.g. GROSS 1987, LIEB 1993). However, the total decrease in area is slightly higher than in other regions, which is probably due to the small size of the glaciers. Since 1850 two periods of glacier advance have been observed on most glaciers of the Eastern Alps. The first is the “advance of 1920” which resulted in the accumulation of small moraines within the forefields of many glaciers and also of Goessnitzkees. Unfortunately this is not documented by the present study because of the lack of cartographic sources for the period of maximum advance. It can be seen, however, that the annual retreat in the 56-year-period 1873/1929 is below the mean of 1850/1997. In contrast, the second “advance of 1965 to 1980” is clearly visible in the data, although it was comparably moderate, accumulating only a very small moraine ridge in front of Hornkees. The most recent periods (from 1983 onwards) are again characterized - on the two glaciers as well as in the entire Alps - by a marked retreat which will probably continue in the near future.

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