DIGITAL PHOTOGRAMMETRY FOR THE NEW GLACIER INVENTORY OF AUSTRIA

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ABSTRACT

During the summer seasons of the last years since 1996 nearly all Austrian glaciers were covered by aerial images with the aim to create a new glacier inventory of Austria. Its main products are high accurate Digital Elevation Models (DEM), analogue glacier maps and ortho images, both in the scale of 1:10000. The Chair for Photogrammetry and Remote Sensing together with the Commission of Glaciology of the Bavarian Academy of Science, both located in Munich are contractors for the southern part of the Oetztal alps and the Stubai alps containing 166 glaciers. For the project an optimized work-flow had to be established. The experiences and challenges in photogrammetric production with digital systems in high mountain areas covered with glaciers are reported. Typical examples illustrating both the efficiency and problems of the digital work-flow are presented and discussed in the paper.

1 INTRODUCTION

Glacier monitoring is of great importance especially for alpine countries. Glaciers are influencing essential areas of life like water supply, energy production, flood protection and tourism. Additionally, the variation of glaciers is an indicator for local and global climate change. The new glacier inventory of Austria is meant to make an essential contribution to this task. Taking into account, the amount of 925 glaciers, it becomes obvious, that the project is rather challenging in terms of project management, data acquisition, DTM modelling, mapping, and data management. Modern methods of Photogrammetry seem to be very suitable to cope with this project. The Chair of Photogrammetry and Remote Sensing at the Technical University of Munich together with the Commission of Glaciology of the Bavarian Academy of Science carried out a pilot study in the year 1997 to examine state-of-the-art photogrammetric methods for establishing a digital glacier inventory (Würländer, Eder, 1998). Especially the benefit of digital photogrammetric methods like image matching have been investigated and reported within this study. Afterwards this working group successfully applied for the photogrammetric evaluation of some project regions including the largest Austrian glaciers like the southern part of the Oetztal alps and the Stubai alps. The work-flow and methods handling this task together with first experiences are presented in this paper.

2 GLACIER INVENTORY OF AUSTRIA

2.1 The existing glacier inventory of Austria (1969)

The first glacier inventory of Austria (Patzelt, 1980) containing 925 glaciers mainly was established using aerial photographs of the year 1969. Some small glaciers have been analysed using topographic maps in the scales 1:25.000 and 1:50.000. Glacier maps with the content isolines, spot heights, glacier boundaries, snow lines and moraines have been produced with the methods of analogue photogrammetry. These maps in the scales of 1:10.000 to 1:50.000 are the bases of the glacier inventory of 1969.
Glaciological informations like the distribution of the glacier area in different height zones have been determined by graphical methods (Finsterwalder, 1953) and have been introduced into a digital data base for the glacier inventory of 1969.

2.2 The new glacier inventory of Austria

As the status of the existing glacier inventory is more than 25 years old, a new glacier inventory was initiated by Prof. Kuhn, Institute of Meteorlogy and Glacial Geology in Innsbruck. Financed by several authorities of Austria and the federal State of Tyrol this new glacier inventory is established presently under the guidance of Prof. Kuhn, assisted by Dipl.-Ing. R. Würländer in photogrammetric project management.
Since the year 1996 image flights have been carried out by the Division of Aerial Reconnaissance of the Austrian Army to capture up-to-date aerial photographs of all Austrian glaciers. Additionally image flights of other projects shall be used for photogrammetric data capturing. Till now not all glaciers are available within aerial photographs because of the difficult weather conditions in the high alpine regions, but most of the glaciers are contained in images of the years 1997 and 1998. The heterogeneous image material is partly in colour and partly in black&white. The image scale varies from 1:15.000 to 1:35.000. Based on these images photogrammetric capturing of the DEM and the glacier objects is carried out by different photogrammetric companies and research institutes. Basic information for the photogrammetric data capturing like control points or the existing DEM of the alpine regions is delivered by the BEV - Federal Office of Metrology and Surveying in Vienna.
The basic results of the new glacier inventory are digital data (DEM, glacier objects, digital ortho images) and data analysis will be carried out by digital methods. Analogue maps and ortho images will be produced mainly for control purposes.

3 PROJECT MANAGEMENT AND WORK-FLOW

In total, the project of the “Munich group” contains 166 individual glaciers with an aera of 177.5 sqkm covered by glaciers (according to 1969 inventory) and around 430 sqkm to be processed for DGM generation. The duration of the project is about one year. According to the experiences in the pilot study a time schedule has been set up which arranges all necessary tasks of two to three stereomodels per week. Some main conditions have been put into account for the establishment of the project´s work-flow:

- use of automatic processes as much as possible
- partitioning of tasks on different sytems
- use of digital photogrammetric workstation for AAT, DEM generation and DEM verifikation
- use of the analytical plotter for interpretation intensive tasks and line measurement
- pre-interpretation of features to reduce the measurement time on cost intensive devices
- compatibility of data flow between involved systems

The established work-flow is presented in figure 1. The Hard- and Software components used in the project are listed in table 1.

Task	Hardware	Software
automatic aerial triangulation (AAT)	Silicon Graphics Dual Head, Maximum impact	PHODIS-AT
bundelblockadjustment	PC, PIII, 550 Mhz	CLIC
measurement of linear features	Silicon Graphics, Indy Zeiss Planicomp P1	PHOCUS
semi-automatic DEM generation and DEM verfication	Silicon Graphics Dual Head, Maximum impact	PHODIS-TS
DEM generation and products	Unix workstation	HIFI
generation of ortho images	Silicon Graphics Dual Head, Maximum impact	PHODIS-OP

Table 1: Hard – and Software components used in the project

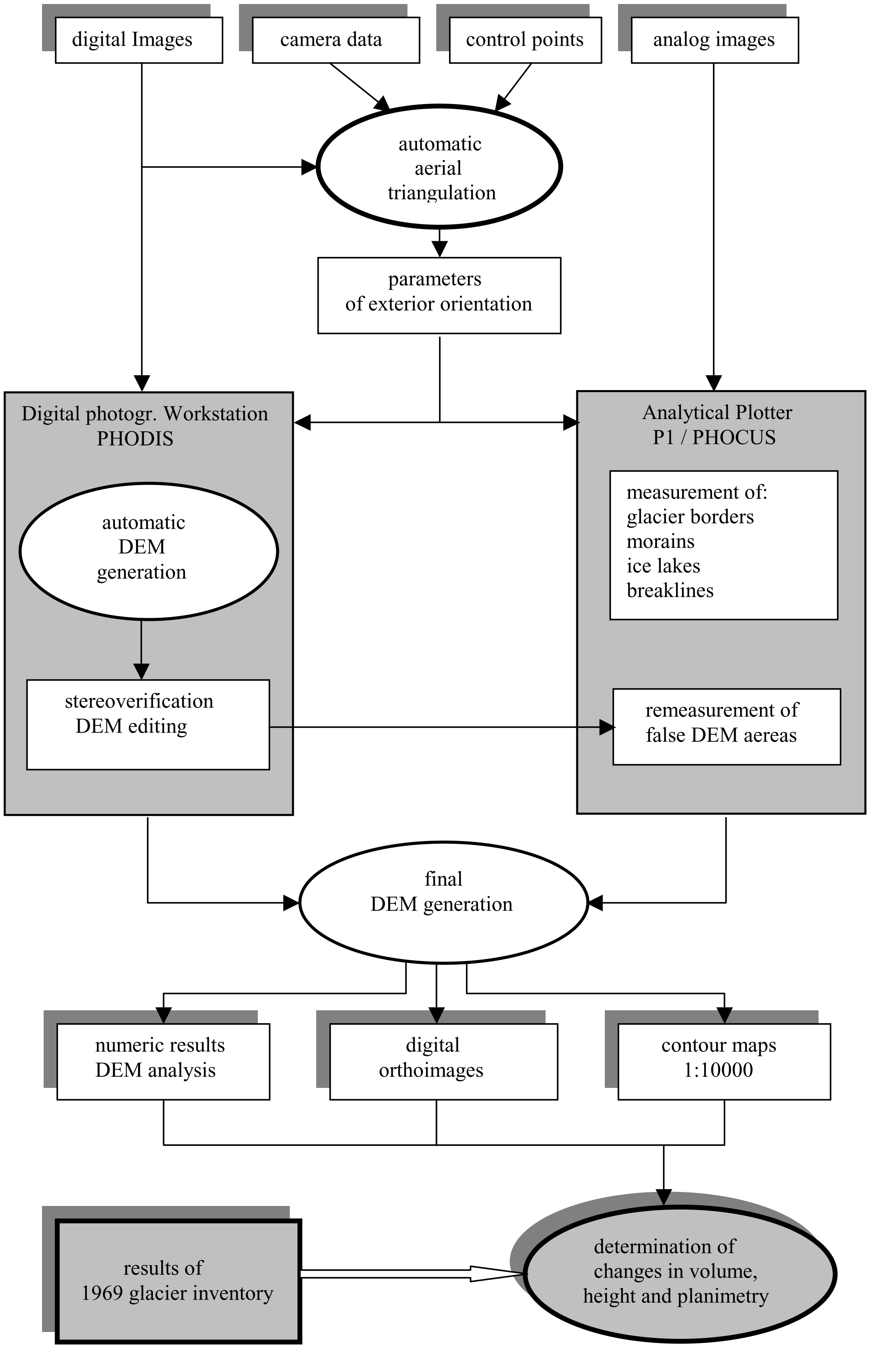


Figure 1. Work-flow for the project

4 PHOTOGRAMMETRIC TASKS

4.1 Image orientation by automatic aerial triangulation

Image orientation can be considered as a key task which is most important both for the accuracy as well as for the workflow of the project. As the state-of-the-art method automatic aerial triangulation (AAT) was applied to the block “Oetztal” which covers an essential part of the project area of the Chair for Photogrammetry and Remote Sensing.
Taking into account the results of the OEEPE/ISPRS test on automatic tie point generation (Heipke, Eder, 1999) and experiences reported of AAT in alpine regions (Kersten et al., 1998) and beeing aware, that especially in snow covered areas with low contrast, automatic tie point generation will run into problems, the automatic tie point measurement was inspected carefully. Additionally the AAT system PHODIS AT gave hints on weak image connections. Figure 2. shows the block configuration with image connections marked, where manuell tie point measurement was required.

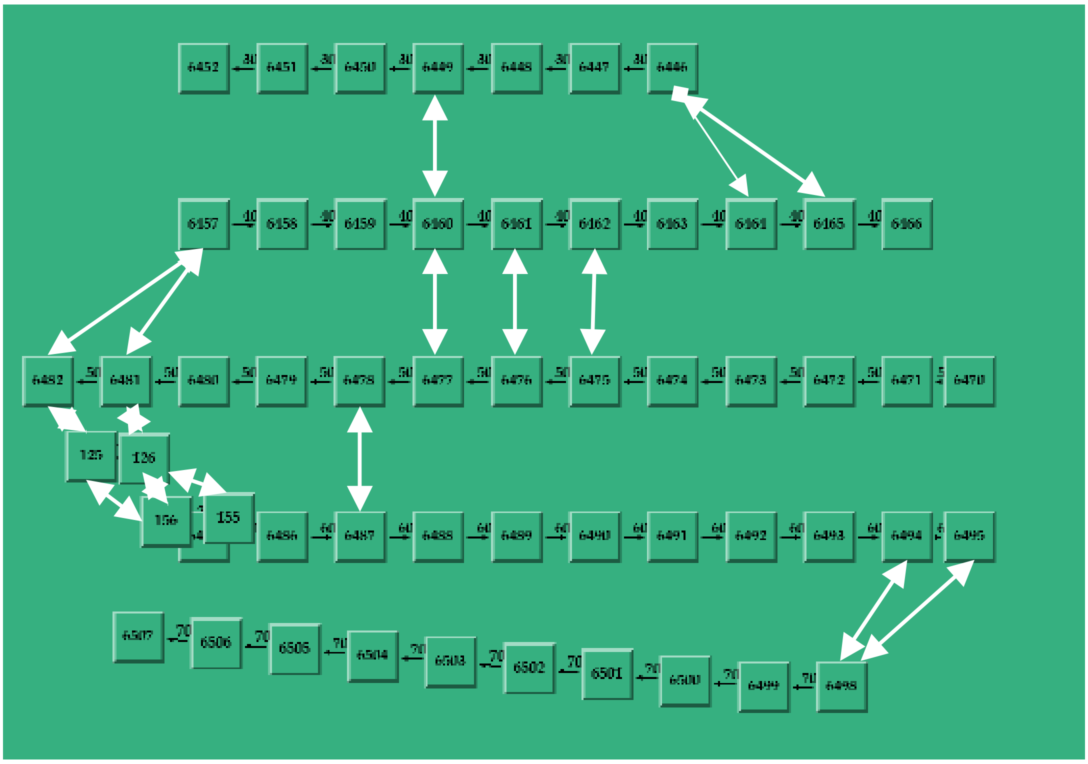
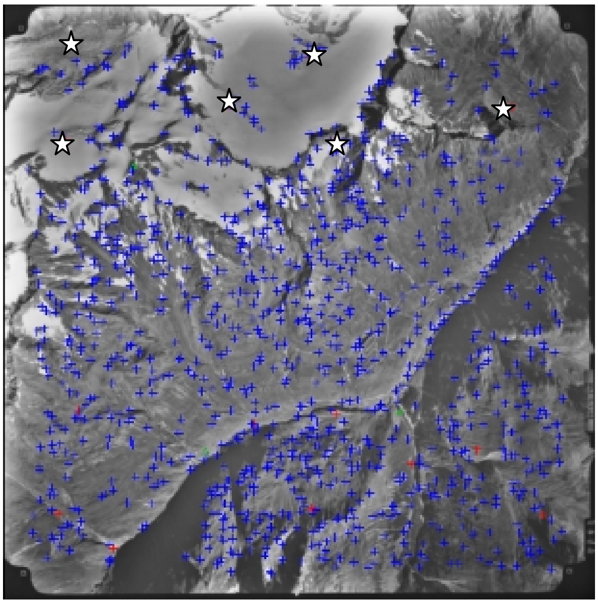


Figure 2 . Block configuration showing image connections improved by manual tie point measurement

In figure 3 the automatic tie point generation with additional manual measurement of a typical image is presented.
The details of the block “oetztal” and the results of the bundle block adjustment can be summarized as follows:

- Image data:
  51 images, black and white, image scale 1:35000, Camera RC10 Uag 15
  4 images, black and white, image scale 1: 25000, Camera RMK 15/23
  scan resolution: 28 Mikrometer
- Block Configuration:
  5 image strips, 60% forward overlap, 30 % side overlap
  4 additional images to complete area coverage
- Ground control points:
  42 full control points, 4 height control points, accuracy : 0.5 Meter.
- Automatic tie point generation:
  generation of about 30000 tie points
  21697 two-ray points, 6463 three-ray points, 395 four-ray points, 51 six-ray points, 2 seven-ray points
- Manual Measurements:
  image coordinates of the ground control points (46 points)
  manual measured tie points to improve image tying (83 tie points)



Results of the bundle block adjustment:

eliminated gross errors: 334 measurements
sigma naught : 6.4 Mikrometer
mean standard deviation of exterior orientation parameters:
$s_{x0} = \pm 0.199$ m, $s_{y0} = \pm 0.259$ m $s_{z0} = \pm 0.162$ m
$s_{\varphi} = \pm 0.0019$ g ,$s_{\omega} = \pm 0.0027$ g, $s_{\kappa} = \pm 0.0008$ g
mean standard deviation of object points:
$s_x = \pm 0.24$m, $s_y = \pm 0.30$m, $s_z = \pm 0.66$m
RMS of residuals at ground control points:
RMSx = ±0.372 m, RMSy = ±0.356 m, RMSz = ±0.338 m

☆ tie point measured manually

Figure 3. A typical image with the resulting automatic and manual tie point measurement

The parameters of exterior orientation were transferred into the digital photogrammetric workstation PHODIS-ST **and** the analytical plotter Planicomp P1. This way it is guaranteed, that exactly the same exterior orientation is used for all measurement tasks as well as the semi-automatic DEM generation.

4.2 Acquisition of glaciological and topographic objects

The acquisition of linear features is one of the most time consuming tasks. Three different groups of data can be distinguished:

§ glaciological elements like glacier borders and moraines
§ topographic elements like break lines
§ additional geometric features like polygons of interest and cut out areas.

border is interpretation and measurement simultaneously on the analytical plotter by an operator who is well experienced in glaciologic interpretation.
According to the experiences made during the pilot phase the most effective way for the acquisition of the glacier Besides the accuracy of interpretation and measurement, the topology is of great importance, since the glacier border of an individual glacier has to be a closed polygon sometimes composed of measurements form different stereo-models. Rocky areas within the glacier have to be measured as cut out areas. The functionality of PHOCUS is well suited for this task.
The acquisition of breaklines for the improvement of DEM generation especially in alpine regions is obvious and has been proved also by the pilot study. Measurement of breaklines in rocky areas needs a trained operator, too. It turned out, that pre-interpretation using a stereo device is very helpful for generalization and reduces the measurement time considerably.
For an optimal set up of the automatic DEM generation it is necessary to determine so called “areas of interest” in advance. For details see chapter 4.3.

4.3 Semi-automatic DEM generation

The DEM can be considered as the central part of the glacier inventory. It serves as the base for the determination of changes in volume and height for the time period from 1969 to 1997. The changes in height have to be determined with an accuracy of ± 0.1 Meter per year. Using error propagation for the 1969 DEM – which has to be generated by digitalization of contour maps – and a period of 27 years the accuracy requirement for the DEM results in ±1.9 m. The pilot study recommended either a grid measurement of 20-30 Meter at an analytical plotter or a semi-automatic DEM generation. The conditions and experiences at the Chair for Photogrammetry and Remote Sensing promoted the semi-automatic method.

In a first step areas have to be determined where automatic DEM Generation should be carried out. Since one and the same area might be depicted in different stereo-models it has to be decided which stereo-model should be used for automatic DEM generation. Figure 4 illustrates the pre-selection of DEM areas schematically.

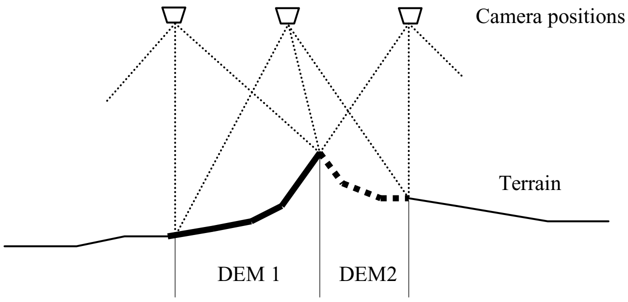


Figure 4. Pre-definition of optimal DEM acquisition areas

The automatic generated DEM (gridsize 20m) is thereafter superimposed in the stereomodel and inspected carefully. In general the automatic process works very well on gravel, rock and ice, problems occur in shadow regions and snow areas, where the DEM points are modified using the editing functions of PHODIS-TS. Areas without texture are selected as non-measureable cut-outs. The time necessary for stereo-verification ranges between one to five hours per stereo-model.
For the final DEM generation (gridsize 15m) all relevant data are transferred into the DEM package HIFI. The glacier borders, morains and lake borders serve together with the recorded breaklines as breaklines for the DEM interpolation, the modified DEM points from PHODIS-TS as reference points.

5 PRODUCTS

The products that have to be delivered are pretended by the project management of the glacier inventory. In Würländer, Kuhn, 2000 the ideas of the repertory and a summarised presentation of these products is given in detail. For instance capturing of temporary snow lines and firn lines is not postulated as this information varies extremely in the years of the photo flights and can be determined later on using the digital ortho images.
The data that have to be delivered are

- the DEM (captured break lines and raster / 15m-grid),
- the glaciological objects (glacier boundaries, moraines, ice lakes),
- contour maps in the scale of 1:10.000 with a height interval of 20m including all glaciological objects and
- ortho images also in the scale of 1:10.000.

The contour map and the ortho images have to be delivered in digital form, too.

As an example, an ortho image from the glacier tongue of the “Rettenbachferner” with a ground resolution of 1 meter is presented in figure 5. The influence of tourism, in this case a glacier skiing region, can be studied in detail.

6 DEM ANALYSIS

The analysis of the glacier surface is the most interesting part of the glacier inventory. This task will be carried out by the central project management using an identical method for all glaciers, developed for the pilot study to the glacier inventory and first explained in Würländer, Eder, 1998. It is in principle a raster method using raster DEM data and a raster mask for each glacier. The results are the maximum, minimum and mean elevation of the glacier, the total area and the area of the glacier for individual height zones (see table 2). In case of additionally captured temporary snow lines and firn lines the proportions of various glacier coverages within each height zone can be reported, too.
The data shown in table 2 for the glacier “Rettenbachferner” are preliminary results as the measurement of the watershed, forming the boundary to neighbouring glaciers, has to be proofed with the interpretation of the glacier inventory of 1969. At least the three lowest height zones – not effected by the interpretation of the watershed – are representative and show a significant reduction of the glacier surface.
Rather more interesting will be the differences in height and volume that can be calculated after digitising the contour map of 1969, carried out by another working group. The program mentioned above is best suited to the glaciological requirements for calculating the difference information between two glacier surfaces of different years. For each height zone the area difference, the mean height difference and the difference in volume can be determined. More information about the method and results is given in Würländer et al, 1999.

	New glacier inventory	Glacier inventory of 1969
Maximum elevation of the glacier	3358 m	3350 m
Minimum elevation of the glacier	2645 m	2610 m
Mean elevation of the glacier	2926 m	2920 m
Total area of the glacier	1.608 sqkm	1.786 sqkm
Area distribution within 100m height zones:		
2600 m – 2700 m	0.117 sqkm	0.167 sqkm
2700 m – 2800 m	0.296 sqkm	0.357 sqkm
2800 m – 2900 m	0.272 sqkm	0.299 sqkm
2900 m – 3000 m	0.358 sqkm	0.385 sqkm
3000 m – 3100 m	0.391 sqkm	0.358 sqkm
3100 m – 3200 m	0.095 sqkm	0.100 sqkm
3200 m – 3300 m	0.064 sqkm	0.094 sqkm
3300 m – 3400 m	0.015 sqkm	0.026 sqkm

Table 2. Preliminary results of the area height analysis of the “Rettenbachferner”

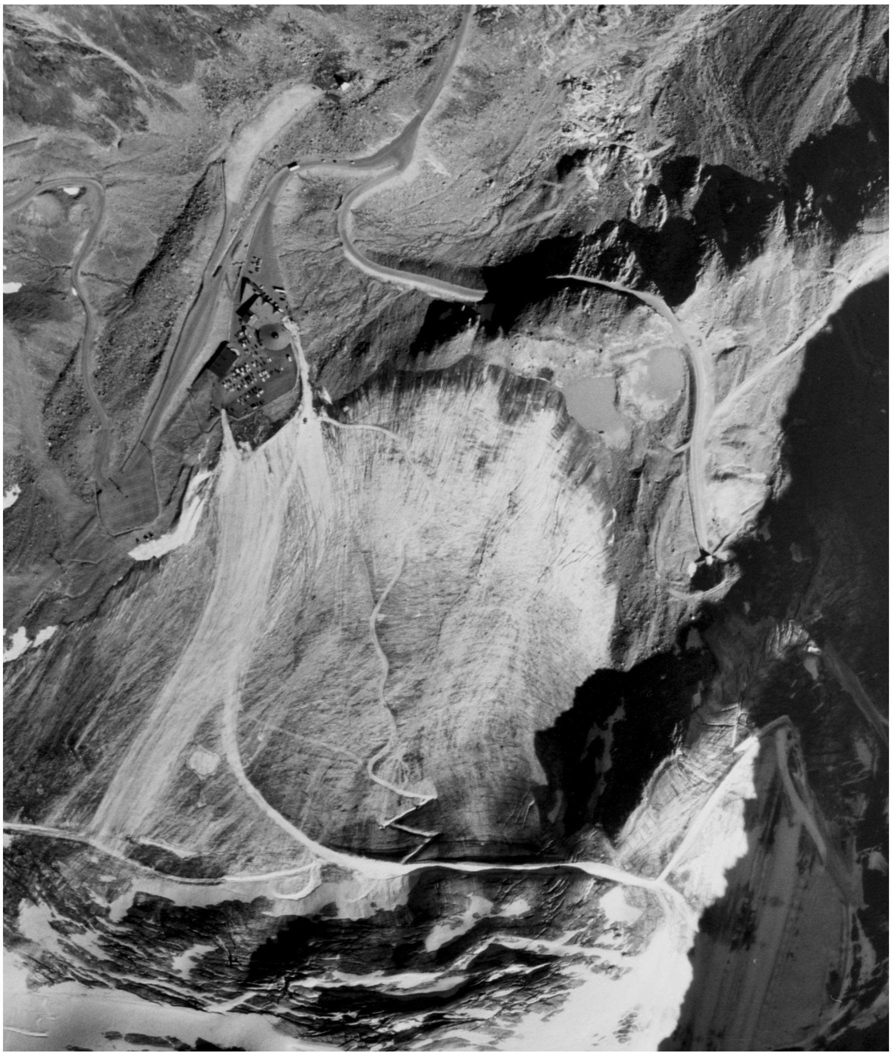


Figure 5. Ortho image of the “Rettenbachferner” showing the impact of tourism

7 CONCLUSION

The establishment of the new glacier inventory of Austria is an interesting and challenging task for modern photogrammetry. In early 2000 the production phase of the project has been started at the Chair for Photogrammetry and Remote Sensing in Cooperation with the Commission of Glaciology of the Bavarian Academy of Science.
An optimised work-flow for the evaluation has been established. It contains the following steps:

- image orientation by automatic aerial triangulation
- acquisition of glaciological and topographic objects
- automatic DEM generation
- stereo-verification and editing of the automatically generated DTM
- final DEM computation
- derivation of DEM products
- generation and output of digital ortho images

First experiences have shown that digital photogrammetry is very feasible to cope with the project. Automatic aerial triangulation works properly, but in areas with less texture manuell tie point measurement is necessary to ensure satisfactory strip connection.
Automatic DEM generation by digital image matching is very efficient and shows good results on gravel, rock and ice, problems occur in shadow regions and snow areas. Verification on a photogrammetric work station is absolutely necessary and rather time consuming.

ACKNOWLEDGEMENT

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