MODERN METHODS OF PHOTOGRAMMETRY IN THE FIELD OF GLACIOLOGY

Hermann Rentsch
Commission for Glaciology of the Bavarian Academy of Sciences
Marstallplatz 8, D-8000 Munich
Fed.Rep. Germany
Commission IV

ABSTRACT
Photogrammetry today is an essential tool for the research of glaciers. The efficiency of photogrammetry for recording the surfaces of glaciers was already recognized at the beginning of this century.
Therefore the development of photogrammetry to modern methods has been passed through by glaciology, too. Besides the classic analog technique, today mainly analytic and even digital methods are applied. These modern applications of the Commission for Glaciology, Bavarian Academy of Science, are presented in the paper.
In future it is planned to establish a Glaciological Information System which allows for the storage, organisation, processing and representation of glaciologic, geodetic, geophysic and meteorologic data.

INTRODUCTION
Photogrammetry is a very useful tool for glacier research. Surfaces of glaciers can be recorded at a defined moment exactly and completely by photogrammetric means. For this task other methods of topographic survey are not able to compete with photogrammetry. As a result documentations of glacier surfaces and their time-dependent variations can be compared with climate and climate changes. Glaciologists are very interested in this problem of nature sciences.
On the other hand research of glaciers is a satisfactory application for photogrammetry. Photogrammetric measurements are used effectively and high mountains with their glaciers have an interesting topography.
A practical example of interdisciplinary work can be found in Munich, two institutions, the Commission for Glaciology of the Bavarian Academy of Sciences and the Chair for Photogrammetry of the Technical University, closely cooperate in research and application of photogrammetry and glaciology, since 1963, when the Commission for Glaciology was founded, a glaciologist - as a permanent guest - works

FIGURE 1: S. Finsterwalder in 1924

at the Chair for Photogrammetry and applies photogrammetric methods in the field of glaciology.
The efficiency of photogrammetry for recording glacier surfaces was already adknowledged in the beginning of this century. 1888/89 S. Finsterwalder /1/ carried out a photogrammetric survey of the total area of Vernagtferner and Guslarferner in the Oetztal Alps/Austria by means of so-called plane table photogrammetry /2/. The result was an exact topographic map of scale 1:10 000. He thus founded the photogrammetric research of glaciers /3/.
Since about 1910 terrestrial photogrammetry was widely used in glaciology. This method is suitable for a survey of high mountains. At the present time there still are applications, especially on exploring expeditions /4/,/5/. Aerial photogrammetry, compared with the other mentioned methods, offer the most extensive applications, for the glaciology too.

MODERN METHODS OF PHOTOGRAMMETRY

In this paper methods based on elextronic data processing are called modern methods. The applications of the Commission for Glaciology are descriped in the following.
With the development of computer assisted and controlled methods, aerotriangulation was applied more in photogrammetry and became the state of the art.
Ground control points necessary for the evaluation of stereopairs are determinated by means of block adjustment /6/,/7/,/8/. Block adjustment gives exact results for any photogrammetric single point determinations. A effective example is the derivation of ice flow on glacier surfaces from the positions of distinct points of different epochs.
The development of digital measuring and recording techniques allowed for the description of the terrain by regular Digital Terrain Models (DTMs).
At the Commission for Glaciology, DTMs have above all been used in two projects

- for the determination of areas of the Vernagtferner influenced by the shading effect of neighbouring montains /9/. For a square grid the elevations of the grid points were interpolated graphically from an existing contour map.
- for a projective transformation of a DTM into an amateur photo of the Vernagtferner /10/. For this purpose, contour lines were digitized from an up-to-date map and the DTM heights were interpolated digitally.

The recording of the terrain by DTM became faster and more effective when analytical stereo plotters could be used for the photo data aquisition.

- Data were recorded directly from photogrammetric stereo measurements.
- Orientation of stereopairs could be carried out computer controlled and thus much faster.

Analytical processing allows for evaluations of amateur photos as well as photograms. The data of the interiour orientation can be taken into consideration. Therefore the measurement of image coordinates becomes much more accurate. In the summer 1987 such a camera, a LINHOF Aero Technika, was used for the recording of the Vernagtferner. According to a suggestion of O. Kölbl /11/ oblique photographs of the whole glacier were taken through an open window of a small aeroplan. From this an orthophoto map, scale 1:10 000, will be derived.

Today the analytical method of DTM data acquisition is mainly used. Manual and automatic digitization is applied for measurements in old maps, surveying by tachymetry only for special tasks /12/.
For about ten years the analytical plotter ZEISS Planicomp C-100 is available at the Chair of Photogrammetry.
Measured quantities are
- single points and geomorphical characteristics of the glacier and its environment like break lines or skeleton lines as primary data of a DTM,
- borders between different covers like rock, moraine, ice, snow, water,
- distinct points for the calculation of ice movement and of strain rates.

From the primary data various DTMs can be generated with the program package HIFI /13/, developed at the Chair for Photogrammetry. The Commission for Glaciology applies a regular DTM as unitary reference system. Therefore data of different epochs refer to identical grid points. They can be compared easily, to determine changes in volumne and elevation on the glacier surface /14/. These are parameters of the mass balance of glacier /15/, important features in glacier studies. For the calculation of changes in volume and elevation the primary data can be used without interpolation, when the elevations of the points for the regular DTM are be measured directly. The application of DTMs makes the activities of the glaciology more flexible. This is shown by further products derived from DTMs:
- profiles for the production of orthophotos,
- mapping of contour lines of optimal interval, extension and scale,
- calculation of slope models and slope lines,
- computation of profiles of the glacier surface in any directions,
- intersection of the DTM with orientated bundle rays,
- perspective views of the DTM.

Recently the Commission for Glaciology applied the combination of DTM and digital image processing, to produce attractive graphic representations such as perspectivs and digital orthophotos. This new possibilities /16/ will be demonstrated with a practical example.
In future it is planned to establish a glaciological information system. DTMs and other glaciological relevant data will be aquired, stored, processed and represented simultaneously. For this project aero photographs of Antarctica will be processed using photogrammetric stereo measurements. Additionally, geodetic measurements and data from digitization of existing maps can be integrated in this system as well as informations from glaciology, geophysics and meteorology.

PRACTICAL EXAMPLE VAUGHAN-LEWIS-ICEFALL

The Vaughan-Lewis-Icefall is part of the Juneau-Icefield covering territories of Alaska/USA and British Columbia/Canada. The Vaughan Lewis Glacier comes from the huge, flat icefield. The ice is forced through stepp rock formations and forms wave-ogives below the icefall with 150 m wave length and 15 m height. W. Welsch /17/ has chosen this icefall for photogrammetric measurements on example for a model of ice movement. In summer 1981 he started the measurements, using terrestrial photogrammetry. Since 1982 the Commission for Glaciology takes part in this pro-

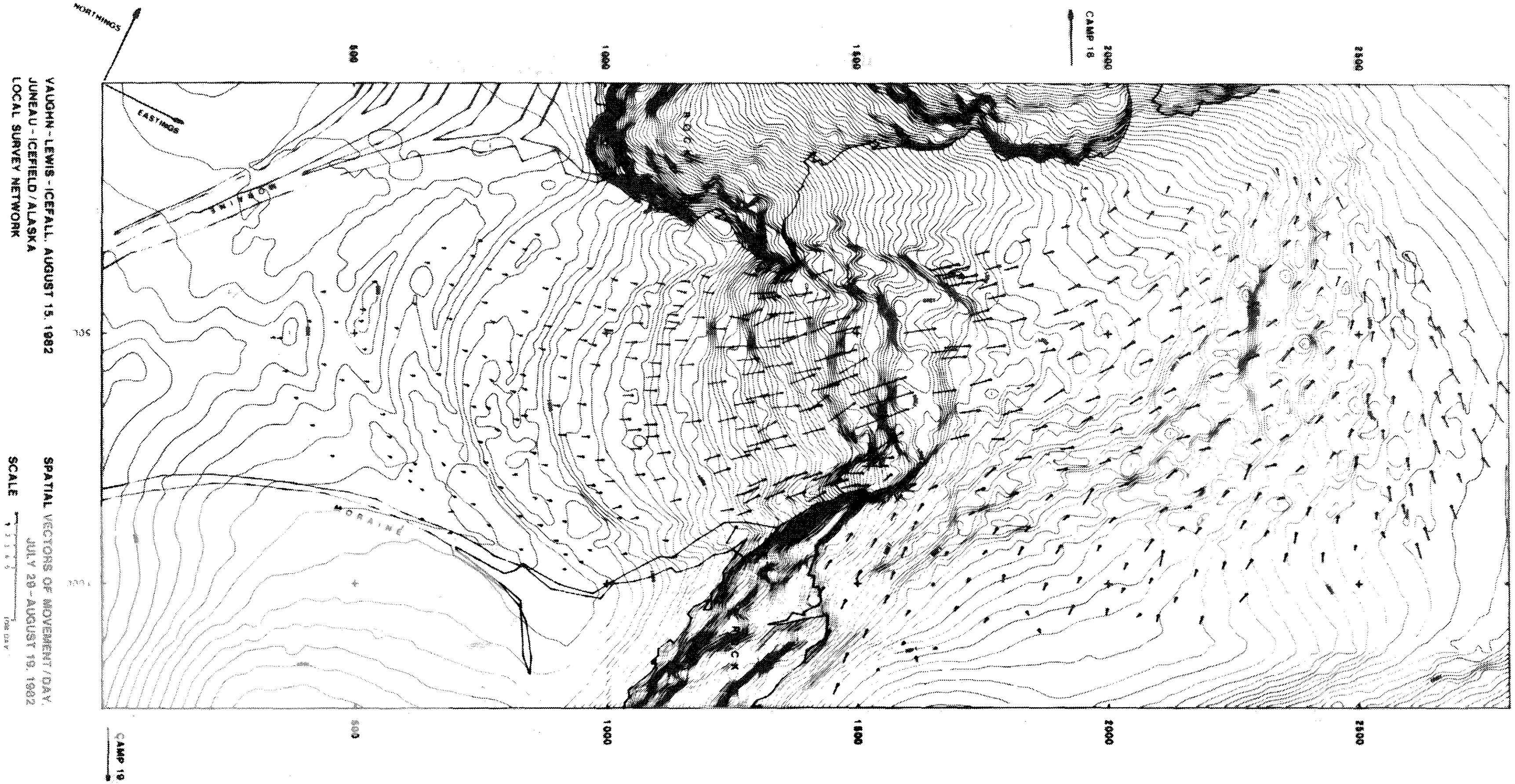

FIGURE 2: VAUGHAN-LEWIS-ICEFALL. Contour lines, derived from the 20m-DTM superimposed with movement vectors

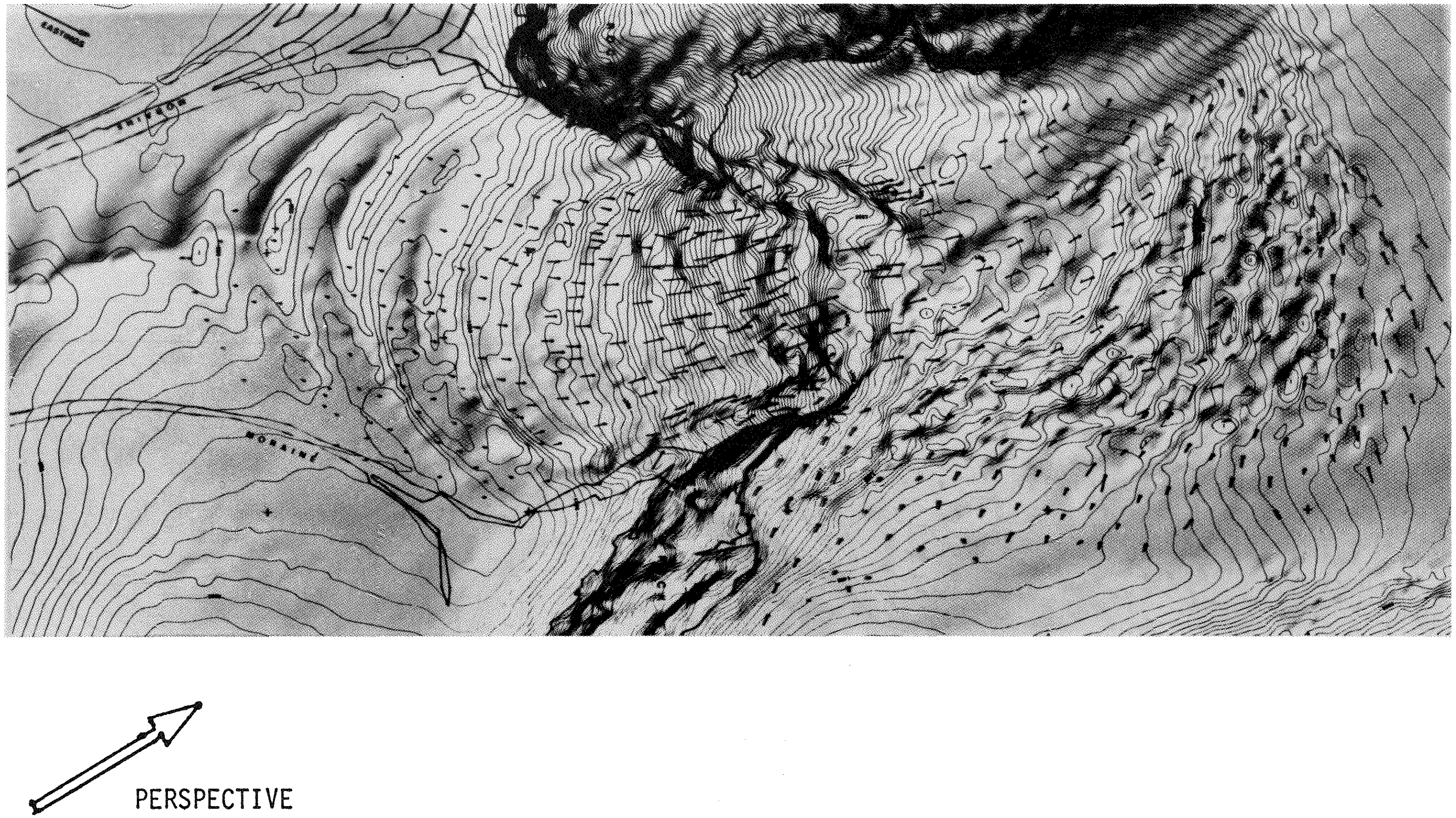

FIGURE 3: VAUGHAN-LEWIS-ICEFALL. Contour lines and movement vectors superimposed with a synthetic orthophoto.

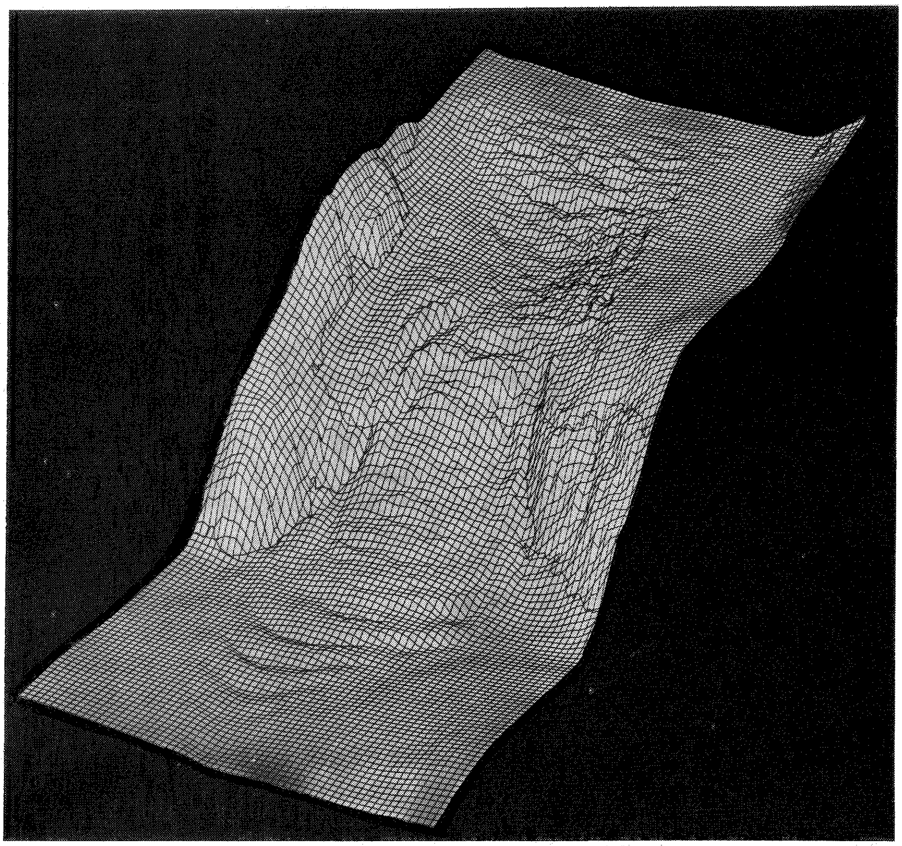

FIGURE 4: VAUGHAN-LEWIS-ICEFALL. Perspective view, wire frame model.

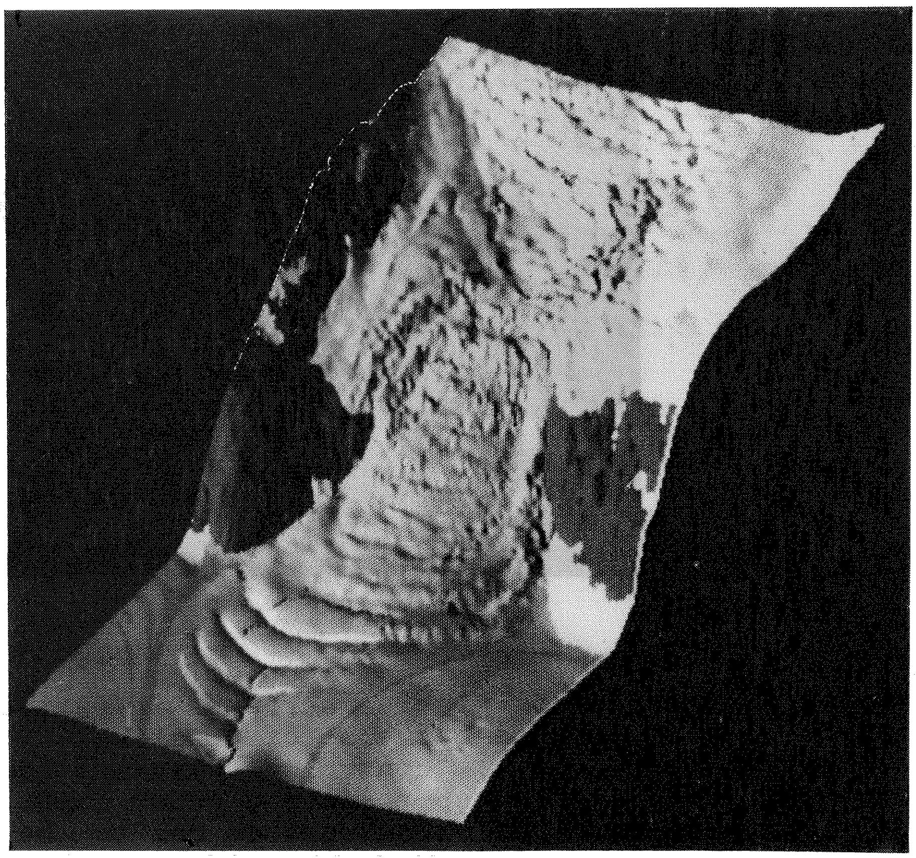

FIGURE 5: Perspective view of the icefall, relief and terrain cover

ject. In the same year between Juli 29th and August 19th the icefall was recorded three times by terrestrial photogrammetry. A contour map and rates of movement, shown in Fig. 2 were derived from the material. Contour plotting was done with the Planicomp C-100. Simultaneously, the intersection of the contour lines (5 m-intervall) with a regular 20 m-grid were recorded. Additionally, borders of terrain covers were measured. From measured heigh information a 10 m-DTM (in the steep parts of the glacier a 5 m-DTM) was generated using the HIFI program package (figure 4 gives a perspective view of a 20 m-DTM as a wire frame model). On order to accent the spectacular geomorphology the DTM was combined with digital image processing.
The following steps were performed:

- the mesh size was reduced to 2.5 m by bilinear interpolation (without taking into account breake line information etc.),
- a relief or synthetic orthophoto (see figure 3) was derived applying an illumination model to the DTM,
- the relief was superimposed with terrain cover information. The result is a coloured synthetic orthophoto,
- perspective views where computed, see figure 5,
- stereo pairs of these perspectives to further visualize the information were derived. The azimut difference for the stereo pairs was chosen to 5 gon.

K. Eder, Technical University, carried out all the computation in relation with the HIFI program package. The digital image processing of the icefall was done in cooperation with the Industrieanlagen-Betriebsgesellschaft (IABG), Munich by C. Heipke, IABG. Special thanks to both of them for their share of work.

FIGURE 6: Destroyed houses in Aschbach / Ötztal in 1987

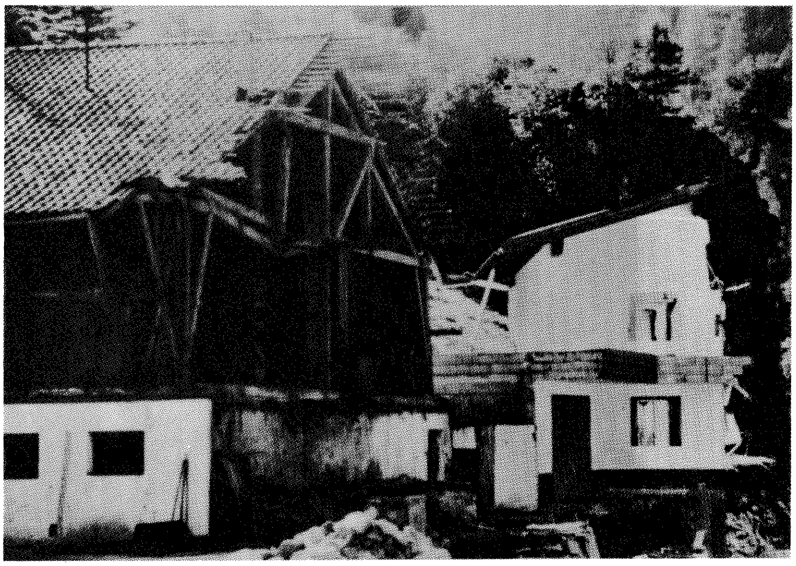

Photo G. Hirtlreiter

FINAL REMARKS
Monitoring of glaciers and of glacier surfaces in particular is not only interesting to science but also of practical relevance such as catastrophy predivtion, control of glaciers as fresh water reservoirs, production of up-to-date glacier maps. In this conjunction, the prediction of catastrophies has to be considered as extraordinary significant. Surges of glaciers have caused serious catastrophies in the past because of ice drops, ice avalanches and the eruption of dammed up water. In case of

heavy warm rain falls in conection with a rapid increase of melt water the danger of floods becomes acute. That catastrophy happened in August 1987 in the Austrian Oetztal.
The Oetztaler Ache which drainages a large glacier area became a large torrent and caused devastating damages at the villages along the valley, see figure 6. This catastrophy shows the importance of a solid observation of the glaciers.

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