EXPERIENCES WITH THE NEW HYDRO-METEOROLOGICAL STATION "VERNAGTBACH"

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Introduction

In the study of the climate-glacier relationship it has long been debated whether measurements taken on the glacier are to be preferred over measurements taken at stations beyond the glacier. Lang (1968) found air temperature measurements taken outside the range of Aletsch glacier, for example, to be more useful for discharge calculation purposes than on-glacier measurements using the temperature-index method. In order to ensure continuous meteorological measurements on alpine valley glaciers, great efforts must be invested in the maintenance of these monitoring stations due to the quickly changing surface properties and harsh weather conditions, whereas off-glacier stations can be operated more reliably. The contribution aims to show that the continuous operation of an off-glacier base station and short-term process-oriented studies on the glacier can complement each other in an optimal way for gaining a better understanding of the climate-glacier system.

Figure 1: Gauging station "Vernagtbach" at 2640 m a.s.l. with the wooden walls to protect the station from high flows, with the climate station on the right. (Photo taken 30 September 2003 by L. Braun).

Background

The “Pegelstation Vernagtbach” hydro-meteorological station, situated at 2640 m a.s.l. in the Ötztal Alps (Austria), ~1.5 km downstream from the glacier terminus of Vernagtferner, was constructed in the fall of 1973, and hydro-meteorological data have been recorded there since then as part of a long-term glacier monitoring programme of the Bavarian Academy of Sciences (Figure 1).

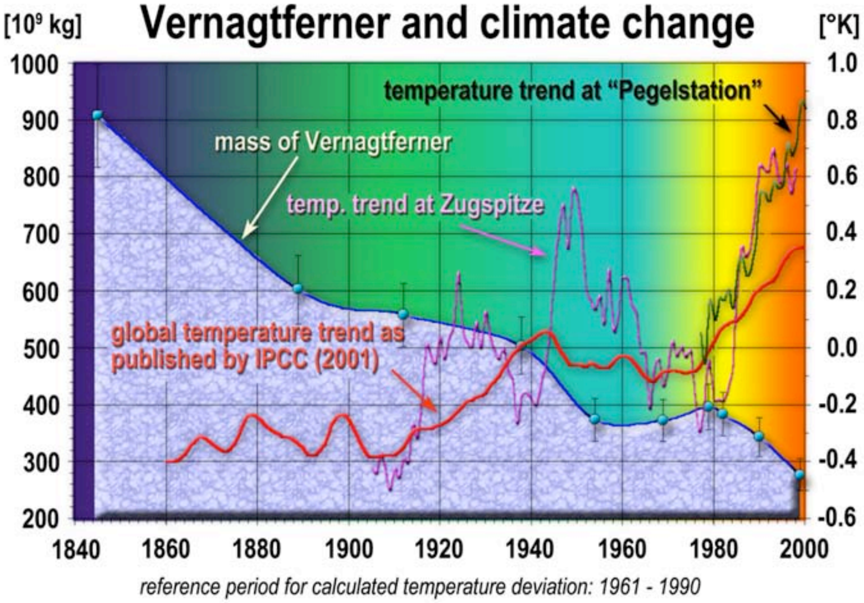

Figure 2: The shrinking of Vernagtferner ice mass since the middle of the 19th century and the increase in air temperature averaged over the northern hemisphere (IPCC, 2001), at the summit of Zugspitze (2962 m a.s.l.) and at the Vernagtbach gauging station (2640 m).

Direct measurements of annual glacier mass balance have been made since 1964 (Reinwarth and Escher-Vetter, 1999), and geodetic surveys of this glacier date back to 1889, when the first accurate map of an entire glacier was derived based on terrestrial photogrammetry. Based on these surveys and hydro-meteorological measurements, the reduction of glacier mass since the middle of the 19th century can be shown in a unique way (Figure 2). For comparison purposes, curves of air temperature change smoothed by a 9-year running mean are shown for the northern hemisphere, for the mountain summit station on Zugspitze (2962 m a.s.l.), and at the Vernagtbach gauging station. It can be shown that the temperature increase in the last 30 years at the Vernagtbach gauging station is nearly the same as over a span of 100 years at Zugspitze. Based on the continuous measurements of runoff, precipitation and glacier mass balance at the Vernagtferner, the individual terms of the water balance of the catchment (11.4 km^2, 75% glaciated in 2002) are known for positive, balanced and strongly negative mass balance years (Figure 3).

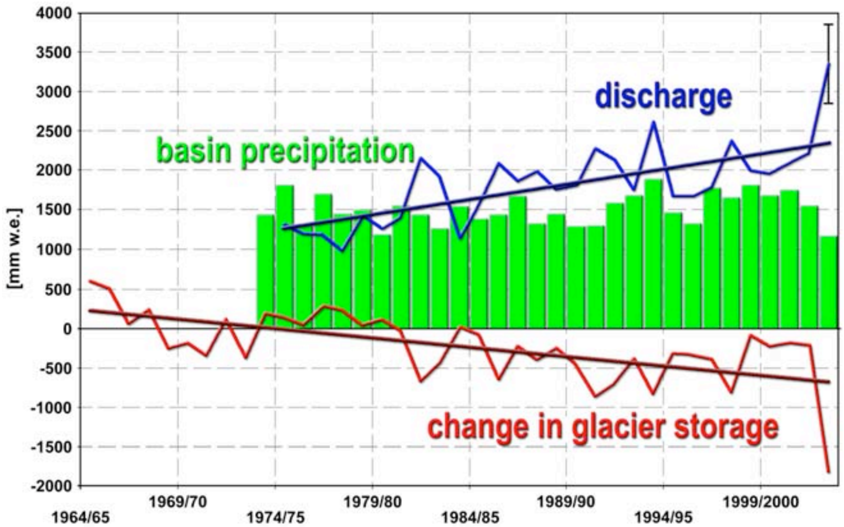

Figure 3: Selected terms of the water balance of the Vernagtferner drainage basin; mean evaporation (1974-1985) determined as residual is 170 mm/yr (Moser et al., 1986).

Measurement strategy for the investigation of the climate-glacier interaction

Because of the prominent site of the Vernagtbach climate station in the valley bottom within the range of the katabatic downflow of air from the glaciated area (more than 85% of the time over a year, the wind is directed from the glacier; during melt conditions as much as 100%), the meteorological variables measured there are strongly affected by the energy exchange processes on the glacier surface. For this reason the measurements are not comparable with "regular" climate stations situated away from the mountains. For example, temperature and humidity contain less information about the free atmosphere, but more about the cooling and evaporation/condensation processes in the shallow air layer situated over the snow- and ice-covered areas. This effect depends on the distance between the station and the glacier snout, and on glacier length. Therefore, the effect diminishes with ongoing glacier retreat, which may be the reason why observed temperature changes at stations in the high mountains show a larger increase than the global mean values reported by IPCC (2001) as given in Figure 2.

To quantify the effect of meteorological variable modification at the off-glacier station in contrast to the undisturbed atmosphere, one needs to know the corresponding true values obtained by in-situ measurements directly on the glacier. Such measurements performed on Vernagtferner show a strong and general relationship between melt rates and the differences in temperature measured at both sites (Weber, 2004). This fact is in good agreement with the concept of the air temperature index method commonly used in conceptual glacier mass balance models. To determine the coefficients of such a relationship it is essential to perform sophisticated direct measurements of the components of the surface energy balance as listed in Table 1 as micrometeorological stations (Figure 4 and Figure 5). Only measurements of this kind are able to deliver melt rates at a satisfactory temporal resolution better than several hours. Once this function is known, hourly melt rates can be estimated with acceptable accuracy at simple on-glacier ablation stations (Table 1) where only (ventilated!) air temperature measurements approximately 2 m above the ice surface are needed (Figure 7). For validating the results, direct cumulative ablation measurements by sonic range sensors, ablation stakes or other methods are useful. All further required data such as tilt-sensitive global radiation or total runoff can be obtained at the off-glacier base station.

Figure 4: Measurement of energy balance components with the HyMEX-Station using Eddy-Correlation-method and a 9-m-profile-tower on Vernagtferner August 2000 at 2995 m a.s.l. At the left side the required mobile power station and two tents to shelter the data acquisition computers. (Panoramic Photo taken by M. Weber)

Table 1: Hydro-meteorological measurement scheme in the Vernagtferner basin.

Station	Variables measured	Type of measurement	Type of information
Permanent off-glacier gauging station Vernagtbach (2640 m a.s.l.)	Discharge, air temperature, relative humidity, precipitation, wind speed and direction, short-wave rad. balance, net all-wave rad. balance, snow depth	Continuous	Continuous background information on glacier discharge and climate, influenced by the glacier's Katabatic wind zone
Summit station Schwarzkögele (3070 m a.s.l.)	Air temperature, relative humidity, wind speed and direction, short-wave incoming radiation; Daily photographs of the surface conditions of Vernagtferner (melting of the winter snow cover)	Continuous	Background information on climate outside the Katabatic wind layer
On-glacier micrometeorological experiment stations	Direct measurements of all components of the surface energy balance to obtain ablation rates at high temporal resolution	A few days during strong melt	Detailed insight into the ice melt processes, especially on the structure of turbulence and radiation balance
On-glacier ablation stations	Ice surface lowering (sonic range sensor) and ventilated air temperature	Continuous over ablation season	Point-information on the course of ablation and air temperature at various points on the glacier

Parallel to the continuous hydro-meterological measurements taken at the gauging station (2640 m a.s.l.) situated some 200 m lower than the glacier tongue, an additional automatic weather station is in continuous operation on Schwarzkögele (Figure 6), an easily accessible mountain summit with an elevation of 3070 m a.s.l., which corresponds quite well with the equilibrium line altitude of Vernagtferner under balanced conditions (3080 m). From this daily photographs are taken of the glacier area to document the melt out of the glacier surface and thus the temporary snow line.

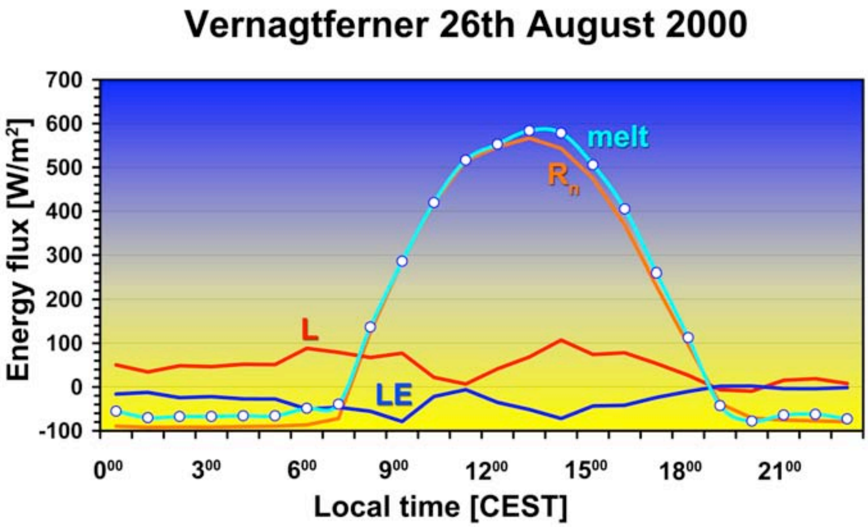

Figure 5: Results of hourly averages of the measured components of the surface energy balance and the available melt energy during the field experiment HyMEX 2000. (Rn: net radiation, L: sensible heat flux, LE: latent heat flux).

Long-term operation of the off-glacier base station

Comprehensive long-term observations over decades are needed in order to detect evidence of climate change in the past and in the future. Due to the "long memory" of the processes involved, it is necessary to provide information over a period long enough to explain the current evolution of glaciers in the glacier-climate relationship. Therefore, the data series need to be continuous and homogeneous. These requirements are not easy to fulfil, even for stations off the glaciers. As can be shown using the example of the Vernagtbach gauging station major revisions were necessary in order to adapt to changes in discharge conditions, measurement techniques and available funding.

In October 1995 and July 2000 the measurement channel of the gauging station had to be rebuilt to adapt flow capacity to increased daily flood peaks (Figure 1; Reinwarth and Braun, 1998). The diurnal variations of glacier discharge had increased over the years due to strong glacier mass losses since 1980 and the thinning of the firn areas (Figure 3). These structural adaptations were absolutely essential to protect the gauging stations against flood damage, in particular when strong melt was combined with intense rainfall.

Figure 6: Automatic summit station “Schwarzkögele”. (Photo taken in 2000 by T. Naeser).

Figure 7: “On-glacier” ablation station, equipped with a sonic range sensor and a ventilated shielded Pt100-thermometer. (Photo taken in 2003 by M. Siebers).

In November 2001 the meteorological instruments and data loggers were completely replaced by a modern Campbell system and run in parallel with the former data acquisition in operation since 1984. Included among the new devices are ventilated air temperature sensors, a Belfort precipitation gauge (measurement of hourly precipitation), and a sonic range sensor of snow height. SMS messages with selected data are sent to Munich daily, which facilitate quality control and the checking of current climatological conditions at the gauging station. Furthermore the data are instantly made available via the world-wide web under the addresses www.glaciology.de and www.glaziologie.de. The power supply for the whole station is derived from solar panels, including the ventilation of sensors and the transmission of the data to Munich.

Conclusions

The monitoring concept as realized in the Vernagtferner basin offers the unique option to conduct investigations of glacier evolution. The conventional geodetic and direct glaciological determinations of glacier mass balance can be validated additionally by the hydrological method based on the determination of the water balance components. With this scheme of investigation there is no disadvantage to installing the permanent base station off-glacier because hydro-meterological data can be obtained more reliably, accurately and completely over extended periods than is the case for on-glacier stations.

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