Technical comments on the data records from the Vernagtbach station for the period 1970 to 2001

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1) Introduction

The hydrological and meteorological program at the Vernagtbach station (Fig. 1 shows the meteorological instruments, Fig. 2 the runoff channel) was started in 1974. The data records between 1974 and 1986 formed the experimental basis for the research project A1 'Runoff in and from glaciers' as part of the special research program SFB 81 'Runoff in channels' ('Abfluss in Gerinnen'), hosted by the Technical University Munich and funded by the German Research Foundation. The project comprised hydrological, meteorological and glaciological research in the Vernagtferner basin (Oetztal Alps, Austria, 2635 m a.s.l. to 3633 m a.s.l., 81 % glacierized by the Vernagtferner in 1986). Its main research purpose was the complete modeling of the runoff processes of a glacier with a physical approach. Therefore, an energy balance model was developed to determine the melt water production at the glacier surface (Escher-Vetter, 1980); with a hydrological model the storage and the outflow of the water from different parts of the glacier with different hydraulic properties were analyzed (Baker et al., 1982, Oerter et al., 1981). The records from the Vernagtbach station were partly used as input for the melt water production model, partly to validate the model output. The complete model was run for the ablation periods of the years 1978 to 1985 (Moser et al., Part I and II, 1986).

After the end of the special research program the Commission for Glaciology of the Bavarian Academy of Sciences in Munich (since 2010: Commission for Geodesy and Glaciology, Section Glaciology) continued to run the station until this very day (summer 2013) , and as a result, long series of several climate parameters are now available from this high alpine site.

The basic quantities recorded at the Vernagtbach station since 1974 comprise 1) total discharge from the basin (Q), based on water stage records; 2) water temperature (Temp), 3) precipitation (Precip), 4) air temperature (TTT), 5) air humidity (RH), 6) air pressure (PoPoPoPo), 7) global radiation (SWD), 8) reflected short-wave radiation (SWU), 9) long-wave radiation from the air (LWD), 10) long-wave radiation from the ground (LWU), both determined as the difference between all-wave and shortwave radiation components, 11) wind speed (ff) and 12) wind direction (dd). (Abbreviations in brackets give the respective names in the Pangaea data files). Precipitation records already started in 1970. Daily sums or averages of discharge, precipitation, air temperature and global radiation were already published in

Moser et al., Part II (1986). Compared to that early publication, the data which are now presented in the Pangaea database have been partly corrected, supplemented and revised.

The station has no permanent observers, but is visited periodically, typically once a month between May and October and only once or twice between November and April. This leads to two types of restrictions, which have to be considered when using these records, i.e. limitations due to the type of the recording devices and due to unnoticed failures of the instruments.

Fig. 1: Meteorological site of the Vernagtbach station; from left to right: Fuess precipitation gauge with wind shield, radiation instruments, Belfort precipitation gauge, Gertsch tipping bucket, solar panel and hair hygrometer, Thiess anemometer, Wölfle anemometer, Stevenson screen with air temperature and BTW long-term thermo- and hygrograph inside. The photograph was taken by Markus Weber in October 1984.

Fig.2: Hydrological part of the Vernagtbach station; from left to right: Stevenson screen and Wölfle anemometer (the same as in Fig.1), wind generator for power supply, gauging station Vernagtbach. The photograph was taken by Hans Oerter in September 1979.

2) General remarks on the recording devices

Limitations of the recording devices were induced primarily by two factors: lack of power supply and/or early expiration of paper charts and tapes. Power supply for instruments as well as loggers was implemented partly by dry cells and partly by accumulators which were recharged by a wind generator for the first years, afterwards by solar panels. Until 1978, all data were recorded on paper charts (Ottschreiber for water stage, Schenkschreiber for all temperatures, humidity and radiation components, Wölfle anemometer for wind velocity and direction, Fuess and Belfort paper charts for precipitation, Thiess barograph for air pressure, Bureau Technique Wintgens (BTW) long-term thermo- and hygrograph). From 1979 until 1985 the records were partly on paper charts, partly on a tape recorder (Microdata M 1600 L), i.e. already in digital form. With the exception of the BTW and the precipitation gauge, these recording devices could only be run during summer. In 1984 the solid state storage device Modas 84 replaced the M1600 L, and only then, most of the – now nearly completely digitally available - records became gradually available for the whole year. Additional information on loggers and instruments for the early period is provided by Moser et al. (1986), pp.42 to 45.

3) Special information on the individual parameters

3.1 Discharge

Missing records caused by disruptions in the measuring channel were completed by modeled daily mean values for the following periods:

06.07. – 12.07. **1974** 27.08. – 15.09. **1987**

19.06. – 25.09. **1994** 01.10. – 31. 10. **1995**

For the winter months (November to April), the discharge series has to be supplemented by the constant amounts which are given in Table 1.The monthly means for the summer months are also displayed in this Table.

Table 1: Monthly averages of discharge in m³/s as recorded at the Vernagtbach station for the period 1974 to 2001

Year	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1974	0.025	0.019	0.019	0.020	0.056	0.284	1.049	2.037	0.973	0.100	0.040	0.035
1975	0.025	0.019	0.019	0.020	0.115	0.443	1.789	2.006	1.064	0.404	0.060	0.035
1976	0.025	0.019	0.019	0.020	0.129	0.917	2.514	0.743	0.321	0.148	0.050	0.035
1977	0.025	0.019	0.019	0.020	0.150	0.800	1.751	1.126	0.958	0.213	0.060	0.035
1978	0.025	0.019	0.019	0.020	0.028	0.504	0.999	1.633	0.663	0.190	0.050	0.035
1979	0.025	0.019	0.019	0.020	0.197	0.868	1.580	1.925	1.254	0.285	0.040	0.035
1980	0.025	0.019	0.019	0.020	0.063	0.382	0.643	2.679	1.198	0.283	0.055	0.035
1981	0.025	0.019	0.019	0.020	0.119	0.927	1.519	2.068	0.964	0.192	0.055	0.035
1982	0.025	0.019	0.019	0.020	0.156	1.099	3.068	2.550	2.054	0.187	0.055	0.035
1983	0.025	0.019	0.019	0.020	0.056	0.648	3.503	2.236	1.441	0.441	0.060	0.035
1984	0.025	0.019	0.019	0.020	0.064	0.357	1.455	1.638	0.743	0.118	0.050	0.035
1985	0.025	0.019	0.019	0.020	0.117	0.399	2.394	2.242	1.357	1.028	0.070	0.035
1986	0.025	0.019	0.019	0.020	0.374	1.102	1.909	3.202	1.233	1.231	0.075	0.035
1987	0.025	0.019	0.019	0.020	0.037	0.285	2.500	2.013	1.793	0.125	0.050	0.035
1988	0.025	0.019	0.019	0.020	0.255	0.517	2.898	3.438	1.134	0.436	0.060	0.035
1989	0.025	0.019	0.019	0.020	0.183	0.559	2.569	2.744	0.875	0.177	0.050	0.035
1990	0.025	0.019	0.019	0.020	0.296	0.751	2.687	3.145	0.586	0.322	0.055	0.035
1991	0.025	0.019	0.019	0.020	0.023	1.074	2.878	3.170	2.189	0.165	0.050	0.035
1992	0.025	0.019	0.019	0.020	0.289	0.799	2.407	4.048	1.266	0.126	0.050	0.035
1993	0.025	0.019	0.019	0.020	0.366	1.087	2.006	3.235	0.551	0.144	0.050	0.035
1994	0.025	0.019	0.019	0.020	0.241	1.220	4.150	3.970	1.360	0.315	0.050	0.035
1995	0.025	0.019	0.019	0.020	0.188	0.449	3.402	2.475	0.181	0.340	0.050	0.035
1996	0.025	0.019	0.019	0.020	0.241	1.644	2.055	2.446	0.276	0.144	0.050	0.035
1997	0.025	0.019	0.019	0.020	0.189	0.993	1.190	2.923	2.126	0.474	0.050	0.035
1998	0.025	0.019	0.019	0.020	0.207	1.468	2.804	4.061	1.012	0.051	0.050	0.035
1999	0.025	0.019	0.019	0.020	0.291	0.942	2.566	2.933	1.688	0.173	0.050	0.035
2000	0.025	0.019	0.019	0.020	0.548	1.921	1.647	2.758	0.957	0.189	0.050	0.035
2001	0.025	0.019	0.019	0.020	0.436	0.888	2.574	3.576	0.305	0.191	0.050	0.035

3.2 Water temperature

The water temperature Pt-100 sensor is installed within the stream, but during periods of low water stage, its position may lie outside the water. This can result in too low (below zero °C) or too high (above 6 °C) values.

3.3 Precipitation

This quantity is most likely the most difficult one to record under the given conditions. And this statement only refers to the point measurement, not to the areal distribution of precipitation! In recognition of this fact, major efforts were made to provide a rather homogeneous record of hourly intensities of precipitation. To this purpose, three precipitation instruments were run at the site of the gauging station Vernagtbach during the last decades. Table 1 provides selected specifications for the three tools. All the devices are positioned within a circle of approx. 40 m diameter (c.f. Fig. 1). None of the precipitation device is heated. Thus, snowfall in the tipping bucket is mainly recorded after the snow has melted, i.e. later than the actual event. During winter, the devices can become snow- covered from time to time, but it is hard to tell, when this was the case.

Table 1: Data availability and specifications of the three precipitation instruments at the gauging station Vernagtbach

Device	Available data	Recording tool	Temporal resolution	Amplitudinal resolution
Fuess weighing gauge	1970 - 1995 Mainly in summer	Paper chart, hand-wound mechanical clock unit	1 day = 2.7 cm	1mm precipitation = 2 mm on chart
Belfort weighing gauge	1975 – 2001 All year round (on principle)	Paper chart, battery-driven clock unit	1 day = 0.81 cm	1 mm precipitation = 1 mm on chart
Gertsch tipping bucket (unheated)	1990 – 2001 Only in summer	Digitally recorded (Modas logger)	Logger time step: 1 h	1 mm precipitation = 10 impulses

In order to get the longest record available, the precipitation series of any year was put together by combining the records of the different devices. In doing this, the device with the higher temporal resolution was preferred to that of a lower one. Therefore, Fuess was preferred to Belfort until 1990; from 1990 to 2001, Gertsch was preferred to Fuess. If none of the three devices at the “Pegelstation” had analyzable precipitation records for a longer time, records from the Belfort gauge “Schwarzkögele” were used if available. This device is positioned below the summit of Schwarzkögele in 2980 m a.s.l.; the linear distance to the climate station Vernagtbach is 1.5 km. These records were used in January/February 1994 and between January and April 1996. Nevertheless, for several years no complete annual record could be sampled.

The accuracy of the temporal allocation of the Fuess and Belfort records depends on the frequency of time marks on the registration and the number of rotations between changing the chart. Fig. 3 and 4 show two Belfort records from the years 1994 and 1997, respectively. The 1994 record can be dated and evaluated rather easily, whereas the 1997/98 record displays some (not all! e.g. wind effects) of the possible problems.

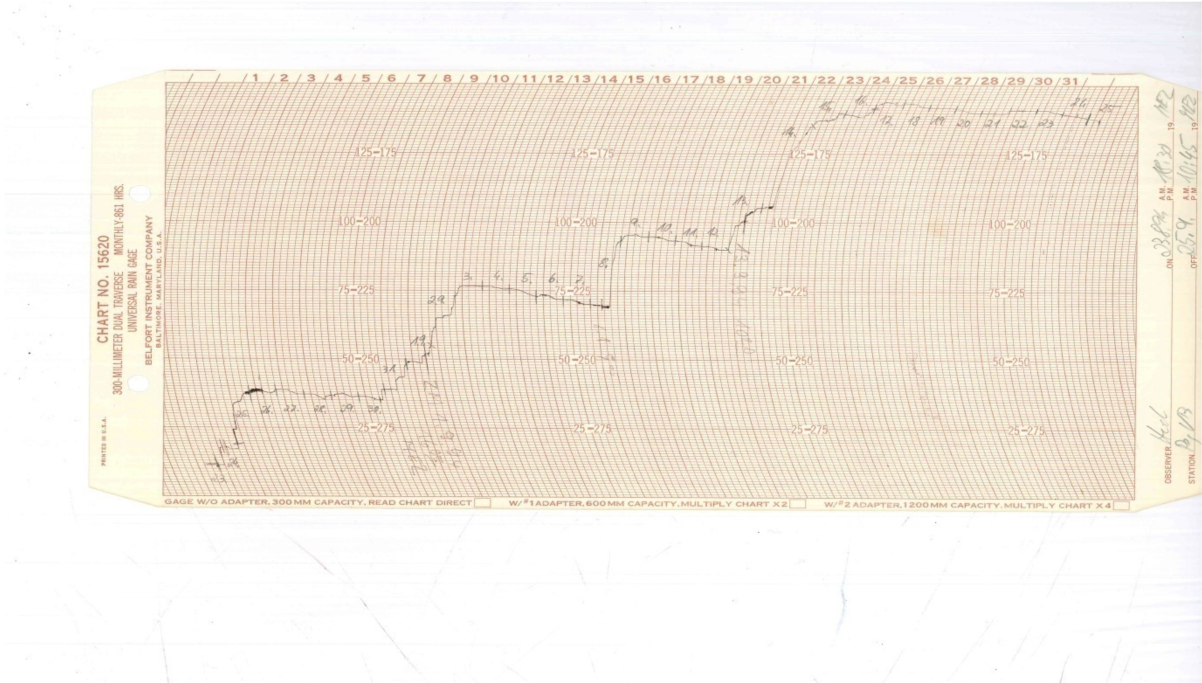

Fig.3: Belfort precipitation chart, gauging station Vernagtbach, 23 August to 25 September 1994

The hourly sums of precipitation from the paper charts were analyzed as follows: precipitation sums smaller than 0.1 mm were assigned to one hour within the precipitation interval, larger sums were evenly distributed over the total length of the interval. Just to give an example: precipitation started on July, 1, 14^h and ended on July, 2, 8^h with a total amount of 5 mm. The hourly average then is 5 mm / 18 h = 0.28 mm/h. The method described here sometimes results in extremely small hourly intensities, caused by precipitation amounts of 1 or 2 mm within several hours. Whereas the hourly intensities seem to be unrealistically small, the total amount of the individual event is nevertheless rather reliable.

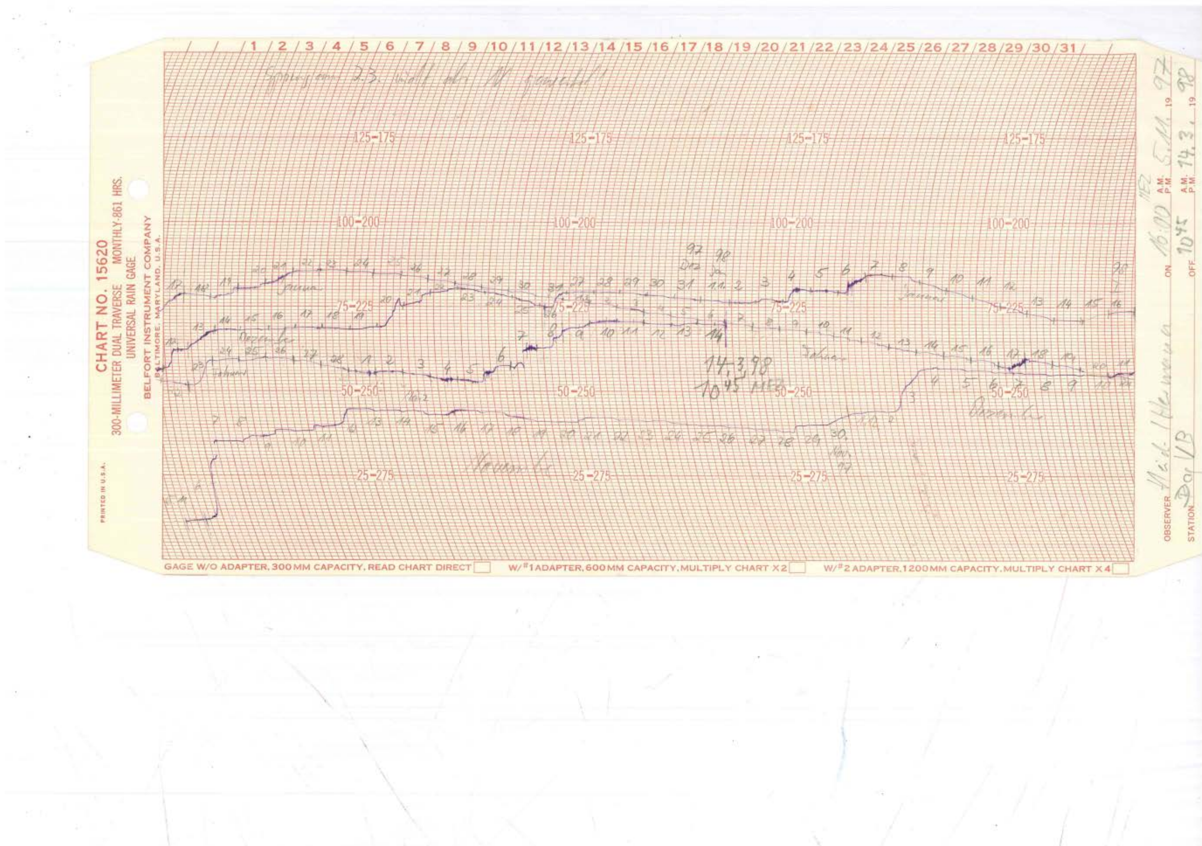

Fig.4: Belfort precipitation chart, gauging station Vernagtbach, 5 November 1997 to 14 March 1998

Tables 2 and 3 show which time spans of the annual series were taken from the different devices, and for which periods daily photographs of the catchment are available.

Table 2: Periods of precipitation records from the Belfort and Fuess precipitation devices used in the annual series, and of daily photographs (c.f. text); for the years 1970 to 1975, the periods without records are not specified. The dates specify the first and the last day of the periods used, the format is dd.mm.

	Belfort	Fuess	No records	Photographs
1970	--	10.09. – 30.10.		--
1971	--	30.04. – 18.10.		--
1972	--	26.07. – 30.09.		--
1973	--	12.10. – 01.12.		--
1974	--	15.03. – 14.06. 20.07. – 28.10. 25.11. – 31.12.		--
1975	11.11. – 31.12.	13.03. – 26.03. 01.05. – 01.06. 08.06. – 14.06. 19.07. – 23.07. 25.07. – 10.11.		--

1976	01.01.– 04.02. 17.02. – 21.05. 14.09. – 28.09. 24.11. – 31.12.	22.05. – 13.09. 29.09. – 24.11.	05.02. – 16.02.	03.08. – 25.09.
1977	01.01.– 10.03. 20.05. – 23.05. 30.05. – 06.06. 19.06. - 21.06. 04.11. – 09.12.	03.05. – 19.05. 24.05. – 29.05. 07.06. – 19.06. 22.06. – 19.08. 19.08. – 03.11.	10.03. – 03.05. 19.08. 10.12. – 31.12.	--
1978	08.03. – 28.05. 10.11. – 31.12.	29.05. – 09.11.	01.01. – 08.03.	10.07. – 15.10.
1979	01.01.– 13.03. 08.11. – 26.12.	26.05. – 18.06. 22.06. – 07.11.	14.03. – 26.05. 18.06. – 22.06. 27.12. – 31.12.	24.05. – 09.10.
1980	18.10. – 27.10. 05.11.	07.05. – 17.10. 28.10. – 04.11.	01.01. – 06.05. 06.11. – 31.12.	08.05. – 07.07. 26.07. – 28.08. 17.09 – 01.11.
1981	08.03. – 21.03. 29.07. – 08.08. 09.10. – 24.11.	24.04. – 28.07. 09.08. – 08.10.	01.01. – 07.03. 22.03. – 23.04. 25.11. – 31.12.	02.05. – 07.06. 17.06. – 18.10.
1982	27.10. – 20.12.	30.04. – 26.10.	01.01. – 29.04. 21.12. – 31.12.	18.05. – 26.10.

1983	12.03. – 06.05. 04.09. – 22.09.	07.05. – 03.09. 23.09. – 03.11.	01.01. – 11.03. 04.11. – 31.12.	04.05. – 21.09.
1984	23.03. – 02.05. 16.09. – 10.10. 07.11. – 31.12.	03.05. – 15.09. 11.10. – 06.11.	01.01. – 22.03.	05.05 – 10.06. 05.07. – 28.09.
1985	01.01.– 18.04. 29.04. – 22.05. 06.11. – 31.12.	23.05. – 05.11.	19.04. – 28.04.	21.05. – 03.11.
1986	01.01.– 16.01. 01.11. – 25.12.	29.04. – 31.10.	17.01. – 28.04. 26.12. – 31.12.	22.05. – 23.07. 25.07. 27.07. – 11.08. 22.08. – 22.10.
1987	11.03. - 24.06. 11.07. - 31.12.	25.06. - 10.07.	01.01. - 10.03.	25.07. – 18.09.
1988	01.01. - 24.02. 02.06. - 31.07. 27.10. - 31.12.	02.05. - 1.06. 01.08. - 26.10.	25.02. - 01.05.	04.05. – 04.07. 17.07. – 25.10.
1989	01.01. - 31.12.	--	--	18.05. – 22.06. 02.07. – 03.08. 25.08. – 20.10.

Table 3: Periods of precipitation records from the Belfort, Fuess and Gertsch precipitation devices used in the annual series; last column: periods with daily photographs (c.f. Table 2)

	Belfort	**Fuess**	**Gertsch**	**No records/ Remarks**	**Photographs**
1990	01.01. - 24.06. 09.07. - 11.09. 17.10. - 31.12.	--	25. 06. - 08.07. 12. 09. - 16.10.	--	09.05. – 22.06. 24.08. – 26.09.
1991	01.01. - 31.05. 17.10. - 31.12.	--	01. 06. - 16.10.	--	24.05. – 30.07. 28.08. – 01.10.

1992	01.01. - 04.04. 13.05. - 12.06. 01.10. – 09.10. 21.10. - 31.12.	24.07. - 31.07.	13.06. - 23.07. 31.07. – 30.09. 10.10. – 20.10.	05.04. - 12.05.	11.05. – 11.06. 10.07. – 03.08. 13.08. – 22.10.
1993	01.01. - 04.05. 26.09. - 05.10. 19.10. - 25.10. 20.11. - 31.12.	--	05.05. - 25.09. 06.10. - 18.10. 26.10. - 19.11.	--	05.05. – 11.06. 30.06. – 08.09.
1994	01.01. – 05.05. 04.06. - 07.06. 01.07. - 07.07. 05.11. - 31.12.	06.05. - 03.06. 08.06. - 30.06. 08.07. - 15.07.	16.07. - 04.11.	SK: 29.01. - 12.02.	04.05. – 22.05. 30.05. – 02.06. 06.07. – 30.10.
1995	01.01. - 04.05. 01.11. - 31.12.	--	05.05. - 31.10.		03.05. – 06.06. 17.07. – 17.08.
1996	01.01. – 30.04. 13.09. – 14.09. 01.10. – 31.12.	--	01.05. – 12.09. 15.09. – 30.09.	SK: 20.01. - 31.01. 08.02. - 14.02. 01.04. - 30.04	27.04. – 02.07. 11.07. – 13.09. 19.09. - 24.10.
1997	01.01. – 03.06. 10.10. – 16.10. 01.11. – 31.12.	--	04.06. – 09.10. 17.10. – 31.10.		*29.04. – 30.06.*[1] 01.07. – 26.07. *28.07. – 28.09.* 30.09. - 04.11.
1998	01.01. – 08.05. 10.06. – 13.06. 06.10. – 31.12.	--	09.05. – 09.06. 14.06. – 05.10.		07.05. – 15.05. *17.05. – 02.06.* 04.06. – 02.07. *04.07. – 08.07.* 10.07. – 31.07. *02.08. - 04.08.* 06.08. – 06.11.
1999	01.01. – 26.05. 31.10. – 31.12.	--	27.05. – 30.10.		29.04. – 29.06. *25.07. – 02.08.* 04.08. – 05.09. 07.09. 09.09. – 30.10.

[1] For all periods of the years 1997 to 1999 which are written in italics, photographs were made only every second day.

					01.11. – 25.11.
2000	01.01. – 04.05. 01.10. – 31.12.	--	05.05. – 30.09.		05.05. – 08.06. 17.06. – 27.10.
2001	01.01. – 30.04. 11.10. – 30.11. 01.12. – 31.12. [2]	--	01.05. – 10.10.		29.04. – 02.06. 09.06. – 17.10.

Several controls were made to check the validity of the records. 1) If available, parallel records of the different devices at the Vernagtbach site were quantitatively compared to recognize major evaluation errors. 2) To control the temporal allocation of precipitation events for the Vernagtbach site (2640 m a.s.l.), records from this site and that of the climate station in Vent (1890 m a.s.l., distance to climate station Vernagtbach approx. 6.5 km) were used. To this purpose, a comparison was made whether heavy precipitation events or longer periods of days without precipitation occur simultaneously at the Vernagtbach and the Vent station – a pattern which is rather likely. For the few periods with major temporal discrepancies, the manned Vent station series was taken as time-reference. 3) The temporal allocation of the Gertsch records, i.e. of the original data from the tipping bucket published here may provide a wrong pattern in case of snowfall, as already mentioned. In many cases however the daily sums of precipitation from the tipping bucket and the weighing gauge are rather similar, implying that snowfalls are melted and recorded mainly on the same day. To provide some information on the precipitation type, the last column of Tables 2 and 3, respectively show the periods, where daily photographs of the glacier and part of its forefield are available. This series started in 1976 and continued until 2010 with one photograph per day. In the files 'Vernagtferner_photographs_year', the day where an analogue photo is available shows the comment 'fresh snow', if the photograph shows that snowfall has occurred within the last twenty-four hours in the major part of the basin. It is mainly on the basis of these data sets that the development of the relationship between snowfall and rain amounts since the 1970ies was analyzed in Escher-Vetter and Siebers (2007).

3.4 Air Temperature

Air temperature was measured with a PT-100 resistance thermometer from the beginning of the records. Due to power supply limitations, no ventilation could be installed. The sensor is mounted within the Stevenson screen, which can be filled with snow in winter due to wind drift. Parallel registrations of a thermometer within a so-called 'Baumbach-Hütte' were run in the 1970ies, but only rarely used to complete the time series. For the winter periods, the records from the BTW instrument were taken.

3.5 Relative humidity of the air

Over the whole period, air humidity was recorded with hair hygrometers, as psychrometers cannot be used in this high alpine automatic weather station. Until 1984, humidity was

[2] From December, 1, the digital records of the new Belfort weighing gauge are used.

recorded during winter on the BTW paper chart device within the Stevenson screen. Afterwards, data were taken from a hair hygrometer on a mast (c.f. Fig. 1). During winter, this device was put in a black plastic bag in order to shield the hairs from drifting snow (as freezing of the snow can result in a rupture of the strings). Some holes in the plastic allowed for a small exchange of air, but the data are nevertheless corrupted by occasional sunny spells, heating the device inside the bag. As far as it can be reconstructed from various field books, the following table gives the periods with undisturbed data.

Table 4: Periods with undisturbed records of relative humidity

Year	Undisturbed records
1986	03.05. – 12.11.
1987	12.05. – 06.11.
1988	04.05. – 25.10.
1989	18.05. – 25.10.
1990	09.05. – 20.10.
1991	24.05. – 26.10.
1992	12.05. – 21.10.
1993	04.05. – 20.11.
1994	04.05. – 09.11.
1995	04.05. – 15.11.
1996	28.04. – 05.11.
1997	30.04. – 05.11.
1998	07.05. – 20.11.
1999	29.04. – 27.11.

3.6 Radiation components

From 1976 to 1984, Moll-Gorczynski and Schenk pyranometers, afterwards Eppley devices were used to measure shortwave incoming (SWD) and outgoing radiation (SWU). Total radiation (LWD and LWU) was measured with a Schulze-type pyrradiometer of the Schenk Company. Due to power supply limitations, no ventilation was installed for the radiation instruments at any time. The soft (‘Lupolen’) cups of the all-wave radiation device were shielded with a cap in winter to prevent damage from snow, so long-wave radiation components are not available for the winter months.

The radiation devices can deviate from the horizontal alignment and the deviation can even be different for the short-wave and the all-wave components, thus affecting the calculated long-wave radiation. The upper cup of the short-wave radiation device can be covered with snow, so recorded global radiation is smaller than reflected radiation. These error sources could only be corrected/removed during the routine visits at the station.

No numerical zero point compensation was made for shortwave components, leading to small negative or positive values during the night. As different users apply differing procedures for this purpose, we leave any corrections of this kind to the individual user.

Problems with global radiation recordings are visible in 1988 (until end of August) and in 1989 starting from July, 22. For both years however, the reflex radiation records seem to be realistic, therefore, both parameters are included in the data set. In the Bachelor thesis of Mause (2013), some methods are described to correct these erroneous data sets; he also mentions possibilities to scope with snow covered upper cups of the devices.

3.7 Wind velocity and wind direction

The cups of the anemometer can be afflicted by ice accretion, resulting in too low wind speed data. This applies both for the Wölfle device and the later used cup anemometers.

3.8 Air pressure

The device was mounted within the gauging station, so no problems were observed in the records of the analogue paper chart (until 1977) and the digital data afterwards.

3.9 Calibration of the devices and recording tools

Calibrations of the instruments were performed in various ways. The recording tools were calibrated several times within their lifetime, mainly by applying constant voltage sources in the appropriate range. As far as possible, sensors were calibrated individually, partly in the lab (Pt-100 thermometers), partly in the field (discharge, radiation, precipitation).

4) Outlook

Although it was not intended from the start to study the Vernagtferner data with respect to climate change and in spite of all the problems mentioned above, records of long duration for many parameters have been obtained for this high alpine site in the meanwhile. For discharge, data series are available for all years since 1974. Precipitation, wind, air temperature, humidity and pressure also have long continuous records, whereas water temperature and the long-wave components of radiation are somewhat poorly represented even in summer. On a whole, however, the records from 1970 to 2001 published in the Pangaea data base form a substantial part of the total glaciological, hydrological and meteorological investigations in the Vernagtferner basin.

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