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The use of automatic station data for continuing the long time series (1864 to 2008) of foehn in Altdorf

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Abstract

This paper is dedicated to Gian Gensler*, former Chief Meteorologist of MeteoSwiss, who passed away on April 13, 2013 at the age of 92.*

In Altdorf, in the Uri part of the Reuss Valley, foehn observations have been recorded from 1864 until 2008 at a station whose position was changed only marginally during this time. Hence, with 145 years, this is the longest time series of foehn events in the Alpine massif.

Based on the three main parameters temperature, humidity, and wind, the occurrence of foehn was originally subjectively determined at the so-called climate observation times in the morning, at noon, and in the evening. These triple observations were concentrated in monthly sums for each of the observation times. At the end of 2008, these observations were discontinued.

Climatologists regret the ending of the classical observations as a serious loss for future analyses. In response to this, a method was developed by which triple observations can be extracted from newly available objective parameters. The aim is to allow a seamless continuation of the classical long time series.

Today, in the time of automatic observation networks, special procedures allow the identification of foehn in 10-minute intervals; this new data series is called foehn index. This paper describes how triple observations can be extracted from foehn indices.

Starting in 1955, foehn hours were determined manually from station recordings. From 1981 to 2008, foehn hours as well as the "classical" foehn observations at the three observation times were computed from automated foehn indices. In addition, a regression analysis shows the possibilities for transforming either the original observations to foehn hours or vice versa.

Keywords: Foehn, climatology, Altdorf, time series, discontinuity

1 Altdorf and its long time series

This paper describes the methods by which foehn data were and are collected at Altdorf, Switzerland; it neither discusses foehn theory nor its climatology.

Altdorf is situated in the Reuss Valley, i.e., in the so-called Gotthard cross section (see Fig. 1). It is not known why Altdorf became a foehn observation station. There are indications that the Capuchin monastery made weather observations long before the Swiss Government decided to set up a permanent observation network in 1864. Altdorf had burnt down three times almost completely during foehn storms, hence, there was a strong and respectful interest in this scary wind.

Foehn observations were made uninterruptedly, very reliably, and as consistently as possible over more than 140 years; notably for over 84 years by members of the same family. Based on the three main parameters temperature, humidity, and wind, the occurrence of foehn was originally subjectively determined in the morning, at noon, and in the evening at the so-called climate observation times ("Klimatermine" in German; henceforth,

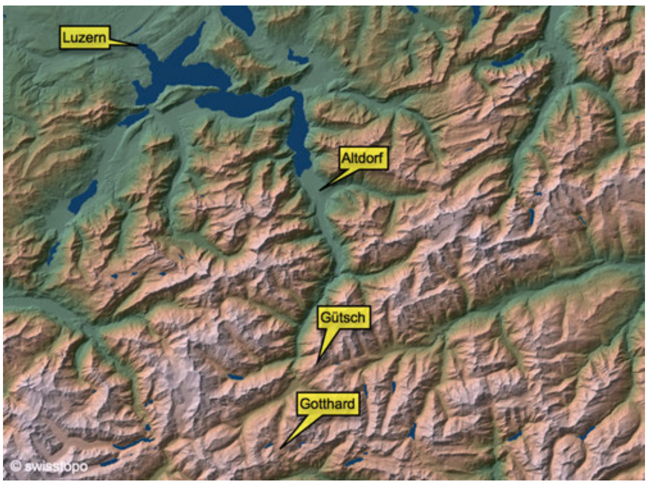

Figure 1: Topography of the upper Reuss Valley with the foehn station Altdorf, the ridge station Gütsch, and the Gotthard Pass.

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these observations will be called "triple observations"). The observations were then concentrated in monthly sums for each of the observation times. At the end of 2008, these triple observations were discontinued.

Foehn data from Altdorf were investigated with respect to foehn theories by Walter (1938) and in an attempt to improve foehn forecasting by Widmer (1966); for a general overview of foehn phenomena and foehn forecasting, see Richner and Hächler (2012). Comparative climatological analyses were carried out by Picard et al. (1968) and by Waibel (1984).

Similar studies were conducted at another key station for foehn research, namely at Innsbruck. For that station, regular foehn observations started in 1870. According to Seibert (1985) and Ortner (2010), this time series unfortunately exhibits serious inhomogeneities; consequently, Ortner restricted his climatological analysis of foehn in Innsbruck to the period 1948 to 2008.

Climatologists regret the ending of the classical observations in Altdorf as a serious loss for future analyses; for their studies, it is important to have time series of sufficient length without shifts and breaks. Since climate change has become an important focus, the quality of climatological time series has received significant attention (Aguilar et al., 2003). For the foehn time series of Altdorf, possibilities were requested for transforming new data in such a way that it can be amended to the discontinued time series of different character.

The automated method for the foehn indices applies basically the same criteria that were used when making triple observations (Dürr, 2008). Similar objective processes were developed in Austria: Vergeiner (2004) determines foehn based on station data, while Plavcan (2013) devised a statistical approach.

This paper presents a method by which triple observations can be extracted from new, objective foehn indices derived from automatic station data, with the aim to seamlessly continue the classical, long time series. Thanks to the fact that there is a 28 years long overlap with automatic observation data at the end of the classical time series of foehn observations, it is possible to construct a transformation algorithm allowing the continuation of the classical time series.

Another foehn time series for Altdorf was begun in 1955, when foehn hours were extracted manually from station recordings. Also for this series, an automated process is described by which hour data can be derived from foehn indices. Finally, a regression analysis shows the possibilities for transforming either the classical, original triple observations to foehn hours or vice versa.

During the course of time, the foehn station Altdorf was relocated eight times, in six cases by less than one kilometer. For the exact locations, see Gutermann et al. (2012). There is no indication that any of these dislocations has caused a break in the time series. As will be shown (Fig. 5), the variability of the data is anyhow considerable, hence, a break due to moving the observation site would have to be quite large in order to become relevant.

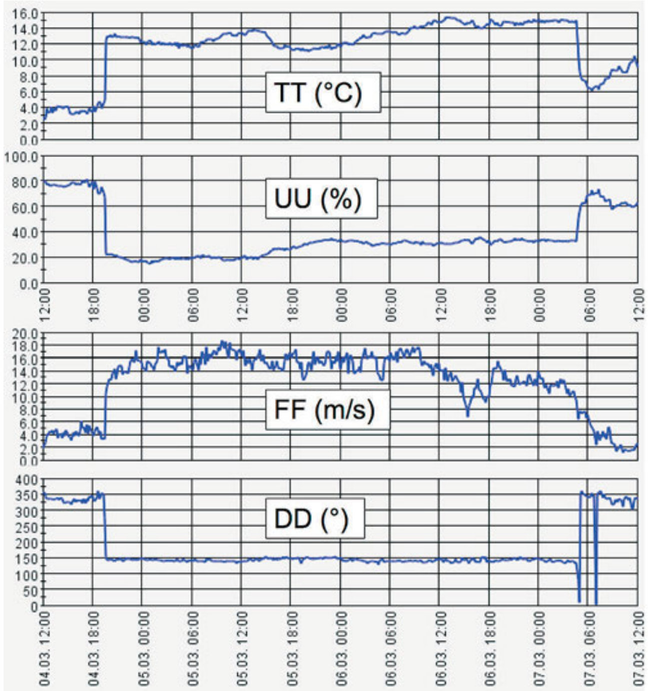

Figure 2: A typical foehn event at Altdorf: the frames show temperature (TT), humidity (UU), wind speed (FF) and wind direction (DD) for the period March 4, 2013, 1200 UTC to March 7, 2013, 1200 UTC. Temperature and relative humidity are instantaneous values at 10-minute intervals, wind data are 10-minute scalar means. Note that both onset and breakdown of foehn can in most cases be determined clearly and unambiguously.

2 Criteria for foehn and data sources

During the 145-year period discussed here, "foehn/no foehn" observations were – as mentioned – made three times daily. Until 1970 the times were 06:30, 12:30 and 20:30 UTC, beginning in 1971, the evening time was shifted to 17:45 UTC because the climate observation times were moved to earlier times in general. The detailed criteria for foehn used in the 19th and early 20th century are not known. Later, numerical values were introduced (e.g. the exact sector for wind direction, or the temperature change relative to the previous day) and adjusted to coincide with subjective criteria. "Increased temperature", "low relative humidity", and "high windspeed (direction SE/S) with significant gusts" were always mandatory for a positive foehn observation. Starting on 1961, a wind within 90° to 240° at the station Gütsch (situated on the Alpine ridge 2282 m asl, see Fig. 1) became an additional requirement.

Table 1 shows the criteria for "foehn/no foehn" as further described in Gutermann et al. (2012). By varying the values for the different criteria, their effect on the number of triple observations was tested. Fact is, that differences are extremely small, i.e., in the one percent range. Foehn in Altdorf is a very prominent and clearly observable feature; for an example, see Fig. 2.

The "manual" determination of "foehn/no foehn" was discontinued for operational reasons in 2008. On

Table 1: Criteria for “foehn/no foehn” at the station Altdorf for automated and manual determination.

	“automated”	*“manual”*
Gütsch (GUE) wind direction	90°…240°	90°…240° *)
Altdorf (ALT) wind direction	60°…240°	90°…240°
wind velocity ALT vector averaged over 10′	$\geq 3.7\,\mathrm{m/s}$	–
wind gust (3-sec mean)	$\geq 6.2\,\mathrm{m/s}$	$> 5\,\mathrm{m/s}$
temperature	–	positive change $> 2\,\mathrm{K}$ relative same time on previous day
difference in potential temperature ALT minus GUE	$\geq -4\,\mathrm{K}$	–
relative humidity **)	$\leq 54\,\%$	negative change to $< 50\,\%$

*) criterion not used before 1961
**) most of the time $< 40\,\%$, however, with dimmerföhn significantly higher; the automated procedure cannot identify dimmerföhn with a relative humidity above 54 %. (According to WMO glossary, dimmerföhn is a “rare form of foehn where a pressure difference of 12 mb or more exists between the S and N sides of the Alps”. This definition is not generally accepted, the main characteristic of dimmerföhn is cloudiness and high humidity directly in the lee of the mountain barrier irrespective of pressure difference.)

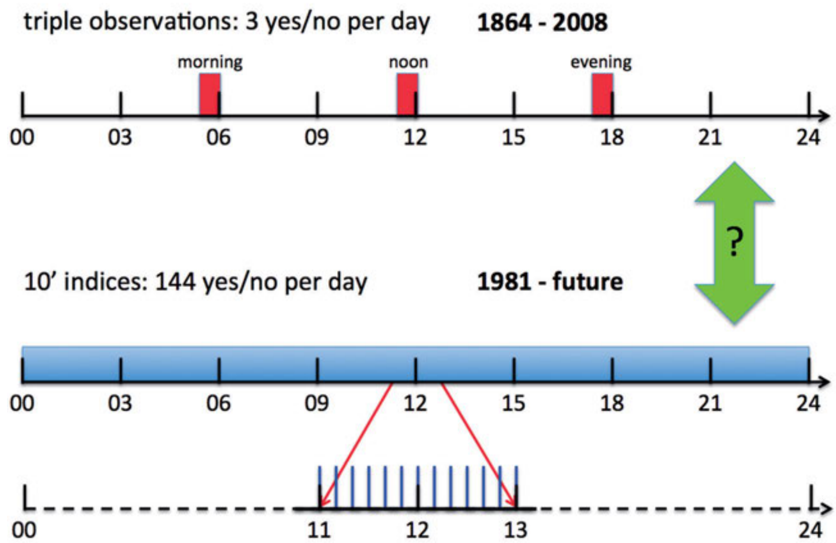

Figure 3: Diagram showing the characteristics of the classical time series of foehn triple observations (red, upper time line) and that with the automated and objective 10-minute indices (blue, lower time line).

the other hand, highly resolved foehn data became available when Dürr (2008) devised an objective, automated method for extracting “foehn/no foehn” data from automatic station data. While the new series of these so-called foehn indices (available at 10-minute intervals) offers new possibilities for foehn studies, it is *per se* not suitable for continuing climatological analyses based on the time series before 2008. Consequently, methods were sought by which triple observations can be extracted from the automatically determined foehn indices.

The station Altdorf provides automatic station data at 10-minute intervals since June 1981. Consequently, foehn indices could be computed in retrospect, offering the possibility to compare the classical time series of triple observations with the new series of foehn indices over a period of almost 28 years (Fig. 3).

3 Using foehn indices for continuing the classical time series

The basic principle of the automated extraction of triple observations from foehn indices is as follows:

Step 1: Select a time window around the time for the triple observations, i.e., for “morning”, “noon”, and “evening”, respectively.
Step 2: Count the number of positive 10-minute foehn indices within this time window.
Step 3: If the number of positive indices exceeds a certain threshold, set the classical foehn observation for the corresponding time to “foehn”.

Table 2: Mean differences of the yearly sums between observations extracted from 10-minute foehn indices and manually determined foehn observations in the morning. Columns are labeled with the length *wl* of the window (one to seven 10-minute intervals), rows are labeled with the number *pi* of required positive indices for a foehn observation. The numbers in the cells represent the difference "extracted" minus "actually observed", the absolute minima for each window length are shaded. Tables for other observation times have an analog structure.

wl / *pi*	1	2	3	4	5	6	7
1	0.29	0.62	1.02	1.34	1.63	1.70	2.03
2		−0.33	0.22	0.51	0.91	1.16	1.38
3			−0.58	−0.18	0.07	0.47	0.65
4				−0.94	−0.33	**0.04**	0.29
5					−1.12	−0.73	−0.33
6						−1.27	−0.83
7							−1.31

In order to continue the classical time series homogenously, the optimal combination of the length of the time window *wl* and number of positive indices *pi* had to be determined. The almost 28-year-long overlap of the two series represents a comfortable basis for statistical analyses. In a first step, the total number over the comparison period (331 months) of foehn observations derived from the indices was compared to the actual number of triple observations in the original, classical time series; the window length *wl* was varied from 1 to 7, the number of positive indices *pi* from 1 to the window length.

The analyses were carried out both with monthly and with yearly sums; for both cases, the results were very similar. The differences for the yearly sums are listed in Table 2 (for the year 1981, in which data could be compared only over 7 months, the 7-months period was extrapolated to one year). Several combinations of window length *wl* and number of positive indices *pi* produce practically zero difference between the sums of manually determined foehn observations and of those extracted from 10-minute foehn indices.

Since an agreement in the sum of the observations does not necessarily mean a good correlation, also the correlation coefficients for all combinations of window length and number of necessary positive indices were computed, this separately for each year (i.e., 28 comparisons) and for each month (i.e., 331 comparisons). These correlation coefficients are all > 0.994 and depend very little on the different combinations *wl*-*pi*, i.e., the method is statistically quite robust.

wl-*pi* combinations with a longer window length *wl* yield a slightly higher correlation coefficient than those with a shorter window length. The reason for this can be seen in the broader statistical basis: The longer the window length (and the higher the number of required positive indices), the smaller the chance that an isolated positive index leads erroneously to a positive triple observation.

As Table 2 shows, the combination $wl = 6$ and $pi = 4$ is optimal, i.e., if within a window of six 10-minute intervals a minimum of four foehn indices are positive, the foehn observation for the term is positive. The time window with the six intervals is chosen such that three intervals are before the times 05:40 UTC for "morning", 11:40 UTC for "noon", and 17:40 UTC for the "evening" parameter. In the mean, the manual method produced 58.4 foehn observations per year, while the extraction method with these parameters yielded 57.2 (the yearly mean difference is larger than twelve times the monthly mean difference because of the substantial inter-annual variation of foehn frequency).

Although there are several combinations of window length and required positive indices producing minimal differences, the selection of the optimal *wl*-*pi* combination is quite crucial (Table 2). On the other hand, the exact position of the window around the nominal observation time ("morning", "noon", "evening") is uncritical. Tests have shown that shifts up to ±30 minutes do not alter the correlation quality.

Fig. 4 gives a visual impression of the difference in the yearly sums between the original, classical time series of foehn observations and the observations extracted from the 10-minute indices as just described. Table 3 lists some statistical characteristics of and between the two time series.

4 Computation of foehn hours

For some analyses it is of interest to know the number of foehn hours within a certain period (Schütz and Steinhauser, 1954; Waibel, 1984). For the years 1955 to 2008, foehn hours for Altdorf were recorded manually on the basis of mechanical recordings of wind and temperature: for every foehn incident, the time between onset and break-down was determined and rounded to the nearest hour (Gensler and Wolfensberger, 1955), breaks of less than 30 minutes were ignored.

4.1 Foehn hours from foehn indices

For the years 1981 to 2008, these manually retrieved foehn hours were compared with those based on the automatically determined 10-minute indices. If at least three of the six 10-minute intervals exhibited a positive foehn index, said hour was labeled as being an hour with foehn. Table 4 shows verification percentages between the hours with/without foehn based on foehn indices and the "foehn/no foehn" hours determined manually. The hit rate computed from Table 4 amounts to 0.955, the false alarm rate to 0.00376.

Between 1981 and 2008, the total time with foehn was also determined by summing the 10-minute intervals with positive indices; these amount to 13060 h 20′. The manually determined foehn hours sum up to 13028 h,

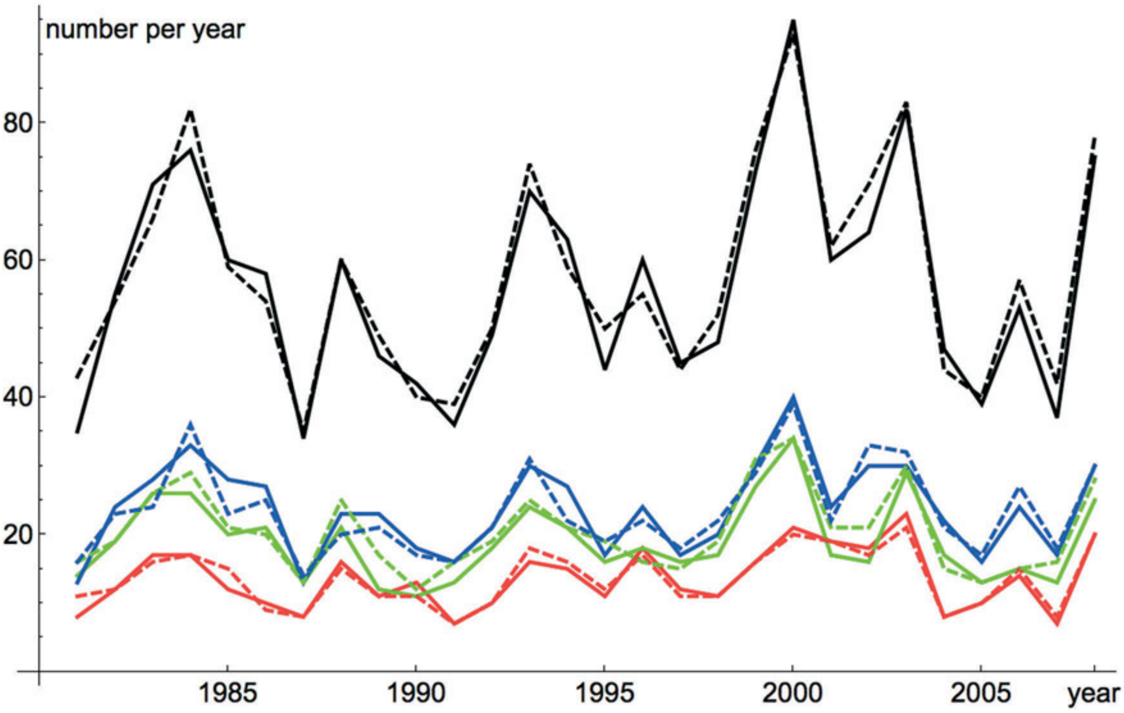

Figure 4: Yearly sums of foehn observations, manually determined (dashed lines) and extracted from 10-minute indices (solid lines) using the method described in the text. Depicted are the sums for morning (red), noon (green), and evening (blue) observations, as well as the daily total (black). The series covers the period 1981 to 2008. Because 10-minute indices are available only since June 1981, the yearly sums for 1981 were extrapolated from 7 to 12 month.

Table 3: Comparison of manually determined foehn observations with observations that were derived from 10-minute foehn indices for monthly and yearly sums, yearly sums are also listed for the individual observation times "morning", "noon", and "evening". Again, data for 1981 were adjusted.

	monthly sums	*yearly sums*	*yearly sums morning only*	*yearly sums noon only*	*yearly sums evening only*
mean and standard deviation over 331 monthly sums, or 28 yearly sums, respectively; **manually**	4.79 ± 5.01	58.4 ± 15.3	13.8 ± 4.2	20.7 ± 5.9	23.9 ± 6.4
mean and standard deviation over 331 monthly sums, or 28 yearly sums, respectively; **derived** from automatically determined foehn indices	4.69 ± 5.01	57.2 ± 15.6	13.8 ± 4.5	19.3 ± 5.8	24.1 ± 6.5
mean and standard deviation of difference manually−derived	0.10 ± 1.0	1.23 ± 3.7	0.04 ± 1.2	1.5 ± 2.0	-0.25 ± 2.3
r.m.s. differences	1.0	3.8	1.2	2.4	2.3
correlation coefficient	0.98	0.99	0.99	0.99	0.99
max. positive deviation of derived observations	+4	+5	+2	+2	+5
max. negative deviation of derived observations	−4	−8	−3	−5	−3

Table 4: Verification table for "foehn/no foehn" classification by automatic indices and manual classification. The table covers the actual comparison period June 1, 1981 to Dec 31, 2008, i.e., 10076 days or 241824 hours, this last number corresponding to 100 %.

	indices: "no foehn"	indices: "foehn"	total
manually: "no foehn"	94.25 %	0.36 %	94.61 %
manually: "foehn"	0.24 %	5.15 %	5.39 %
total	94.50 %	5.50 %	100 %

i.e., the sums differ by 33 h 20′ or 0.26 percent. Hence, if a need for foehn duration analysis arises, it can be accomplished with little effort from 10-minute indices with the additional advantage that onset and break-down can be defined more accurately, namely to the nearest 10 minutes instead of the nearest full hour.

4.2 Converting triple observations to foehn hours

Foehn hours can also be derived from triple observations, as there is again a comfortable overlap of 54 years (1955 to 2008) of the time series for foehn hours and for triple observations. Both series were obtained – albeit from the same basic data – by independent methods. It seems logical to correlate the number of triple observations with the number of foehn hours for different combinations and sums, such as individual months, individual years, and individual observation times (morning, noon, evening). A trial and error analysis using linear and quadratic polynomials showed that the most reasonable transformation – characterized by minimal differences in sums – consists in simply determining the factor between the two totals.

During the comparison period 1955 to 2008, a total of 26512 foehn hours and 3265 triple observations were recorded. This means that there are 487 minutes (8.12 hours) per triple observation, a value that comes surprisingly close to the theoretical value of 8.0 hours (because there are three triple observations per 24 hours). The deviation is caused by the fact that the triple observation times are not evenly distributed over the 24 hours, and that foehn frequency is not constant over the day (see Table 2).

The reliability of this transformation can be demonstrated by transforming the time series of the monthly sums of triple observations to the respective hour sums. The thus obtained hour sums were correlated (using a linear regression model) with the actually determined foehn duration. This yielded a correlation coefficient of 0.96 (sample size 648 months), the associated probability of error (p-value) is < 0.1 percent, the standard deviation 0.44 hours.

In order to obtain a feeling for the reliability of the transformation with respect to the diurnal variation, also the monthly sums for the individual observations "morning", "noon", and "evening" were transformed and correlated with the actually observed foehn hours for the periods 00 to 08, 09 to 16, and 17 to 24 UTC. Because the triple observation times are not perfectly centered in the corresponding time period, a reduced correlation coefficient must be expected. However, the results are very similar to those for the monthly sums of all three daily triple observations, at any rate, there is no significant difference in the correlation coefficients. Somewhat surprising is the fact that the standard deviation between the sums over the combined triple observations (0.44 h) is larger than the one for the individual triple observation (for all three about 0.23 h). A possible reason might be the fact that the mean sums differ significantly among the individual triple observations. The time series for the sums of the three individual triple observations "morning", "noon", and "evening" are more homogeneous than their combination, this being again because foehn events do show a diurnal variation.

The time series with the triple observations was transformed into foehn hours using the conversion process described above. Fig. 5 shows the result for the yearly sums. As can be seen, the simulated series of foehn hours exhibits an almost identical variability as the number of triple observations over the entire period. Of course, this result cannot be surprising for the time before 1955. However, after 1954 the independently determined foehn hours are depicted. Consequently, the root-mean-square difference for the time before 1955 is less than 0.5 percent (representing the numerical noise produced by discretization). For the interval 1955 to 2008, however, the r.m.s. difference amounts to 4.7 percent. The mean of the individual differences is, of course, zero since the conversion parameters were derived from these very data.

5 Remarks about time resolution

In principle, from both the classical and the new high-resolution time series, the number of foehn days could be extracted. In some countries, climatologies of the number of the so-called foehn days are being kept, a foehn day being defined as a day on which foehn occurs regardless of its duration (see, e.g., Ortner, 2010). However, in Switzerland, climatological analyses were never based on foehn days, and no such time series exist.

The main aim is to homogenously continue the original series of triple observations with the one-month resolution. Nevertheless, with triple observations extracted from the 10-minute indices, foehn duration can be determined to the nearest 10 minutes as compared to 60 minutes in the classical foehn hour time series.

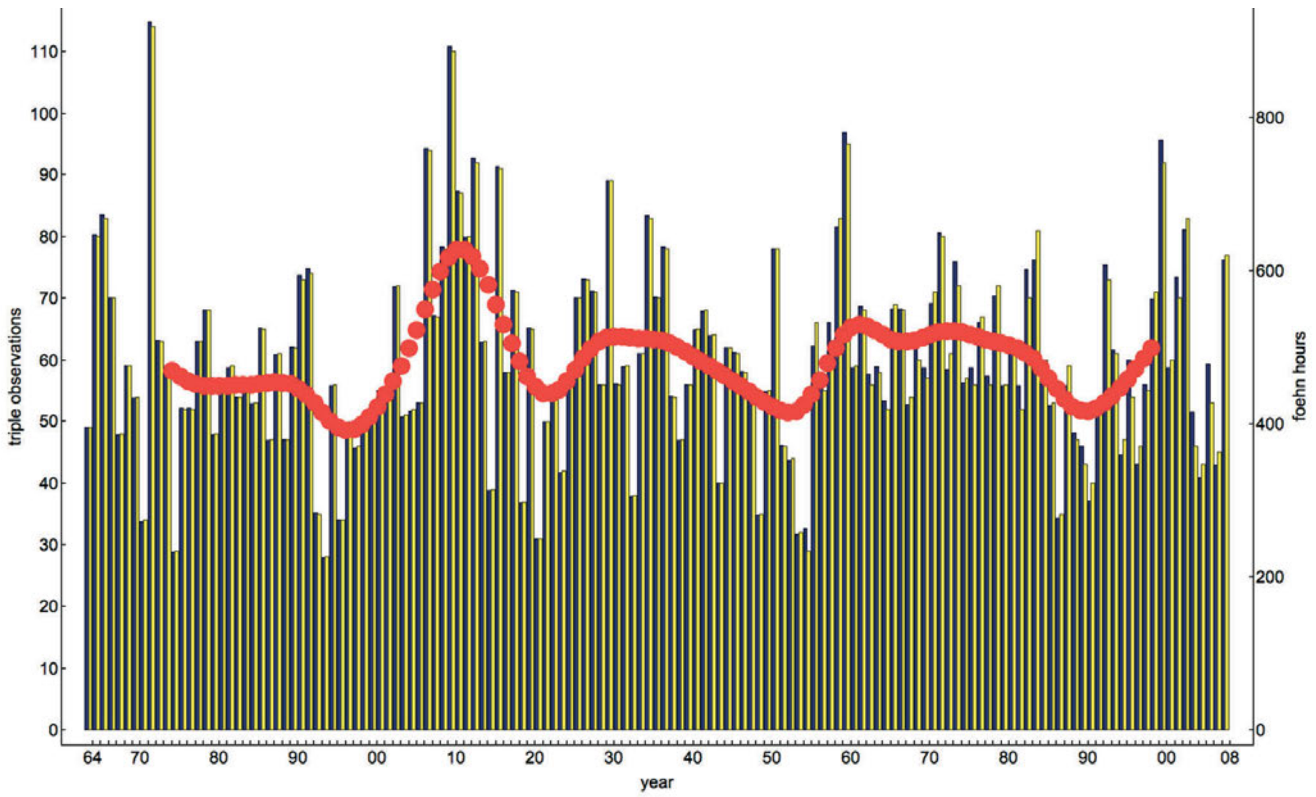

Figure 5: Comparison of yearly sums of the triple observations (black, scale left) with the yearly sums of foehn hours (yellow, scale right) for the period 1864 to 2008. Before 1955, foehn hours are computed from triple observations, for 1955 to 2008, they were determined manually from station recordings. The red line represents the mean values of the original, manual triple observations filtered by a moving Gaussian lowpass filter with a length of 20 years.

The high resolution of foehn events can be quite helpful for case studies. For climatological investigations, high-resolution foehn indices guarantee that the extracted triple observations are now based on quantitative and more homogeneous criteria than this was the case in the past. Of course, if e.g., a climatological change in foehn frequency should be investigated, one has to rely on the long, classical time series of the triple observations. (Even in this quite long series, no trend is discernible, the year-to-year variability being quite high; see Fig. 5.)

6 Conclusion

The comparisons demonstrate that the unique, long, and precious time series that started in 1864 can be continued, this despite the fact that the manual observations are no longer available. The continuation relies on the availability of the so-called foehn index, a parameter that is operationally determined at 10-minute intervals. If within the hour corresponding to the former time of the triple observations "morning", "noon", and "evening" at least four positive foehn indices are present, foehn is assumed for the corresponding observation time.

Also the much shorter time series started in 1955 and listing for every hour whether foehn was present or not, can be continued: If at least three of the six indices within the hour are positive, foehn is assumed to be present.

Foehn duration can be derived back to 1864 by converting the triple observations to foehn hours. As the statistical analysis shows, one positive triple observation corresponds to 8.12 h of foehn. Triple observations are available only as monthly sum, consequently, also foehn duration will be monthly totals.

These conversions were shown to allow a homogeneous continuation irrespective of very different observation methods. Whether one prefers to analyze triple observations or foehn hours is irrelevant. Thus, the nightmare of any climatologist – a discontinuity in a time series – can effectively be prevented.

At the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss), the automated extraction of 10-minute foehn indices for Altdorf (in fact for about 15 other Alpine stations as well) has been implemented as near-real-time operational process. At the end of each month, triple observations und foehn hours are subsequently derived using the methods described.

A detailed climatological analysis of foehn occurrence in the period 1864 to 2013, i.e., 150 years, is being prepared as separate publication.

Acknowledgments

The numerous observers who worked at the climate station Altdorf accomplished the basic work for this paper. They all watched and measured over years the weather and noted reliably its development three times a day. The members of the Nager family deserve a special mentioning: they observed for over 85 years! Unknown employees of the Swiss Army Storage Facility continued the work of the Nager family for another 41 years. We are also grateful for the hourly foehn analyses initiated by Gian Gensler and Hermann Wolfensberger. We thank also for support received from the Federal Office for Meteorology and Climatology (MeteoSwiss), and from the Alpine Research Group Foehn Rhine Valley/Lake Constance (AGF). Finally, we are grateful to two anonymous reviewers for their helpful suggestions for improvements of this text.

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