STATISTICAL ANALYSIS OF FOEHN IN ALTDORF, SWITZERLAND

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Abstract: Since 1864, the occurrence of foehn in Altdorf is being monitored. Altdorf lies in the Reuss Valley. The line Leventina (the valley south of the Alps) and the Reuss Valley are the only valley combination in the Alpine region which is straight, almost perpendicular, and has only a single ridge. The time series of foehn occurrence is analyzed with respect to diurnal and seasonal variation of foehn as well as with respect to the year-to-year variations. While the yearly and seasonal variations are clearly caused by the corresponding variations in synoptic patterns, diurnal variations are believed to be caused by the interaction of local phenomena such as mountain-valley wind systems with the foehn flow.

Keywords: *ICAM, mountain meteorology, local wind systems, foehn, climatology, statistics*

1. THE DATA

1.1. The time series

Since 1864, an observing station for monitoring foehn is in operation in Altdorf, Switzerland. Although there are continuous recordings of some parameters since 1955, the analysis presented here deals - for reasons of homogeneity - only with the so-called climatological observations. These are made three times a day, namely in the morning, around noon, and in the evening; they consist of a simple foehn/no-foehn information. Recently, the exact times for such climatological observations have been changed several times, however, these slight changes are not expected to have any significant influence on the results of the statistical data analysis. Tab. 1 lists the exact observing times for the different periods.

Table 1: Exact observation times for foehn at the station Altdorf. Since 1979, UTC is the binding reference time.

period	local time			UTC		
	morning	noon	evening	morning	noon	evening
Jan 1, 1864 to Dec 31, 1970	0730	1330	2130	0630	1230	2030
Jan 1, 1971 to Dec 31, 1978	0645	1245	1845	0545	1145	1745
since Jan 1, 1979	0640/0740	1240/1340	1840/1940	**0540**	**1140**	**1740**

Consequently, for each day maximum of three foehn occurrences are possible. The analysis presented is based on monthly data, i.e., on the number of foehn observations in the morning, at noon, and in the evening of each month since 1864.

1.2. The foehn criteria

At each observation time, the classification foehn or no-foehn is based on wind direction and speed, humidity, and temperature. Nowadays, criteria for the automated classification are: wind direction between 60 and 240 degrees, wind speed (averaged over 10 minutes) greater than 3.7 m/s, gusts greater than 6.2 m/s, and relative humidity less than 54 percent. In addition, wind direction at Gütsch (a mountain-top station at 2287 m asl, about 25 km south of Altdorf) must be within 90 to 240 degrees, and the difference in potential temperature between Altdorf and Gütsch must be greater than - 4 Kelvin. Earlier, the criteria were, of course, much more subjective. However, tests have shown that the difference between subjective and objective classification are extremely small. While not true for all other stations, foehn in Altdorf is a prominent and rather distinct meteorological phenomenon!

1.3. Location of the observing station

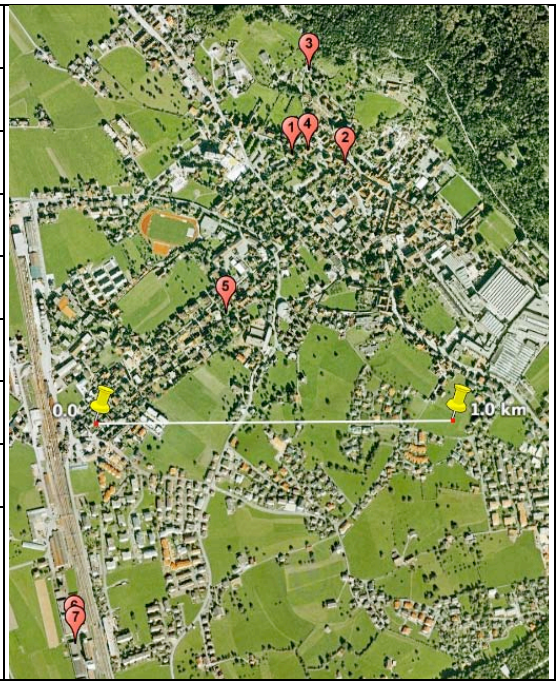
The foehn station Altdorf was moved six times since the beginning of the observations on October 1, 1863. The first five locations were quite close to each other, they are contained within a circle with less than

400 m radius. However, the locations six and seven resulted from a move of more than 1 km from the last station, also they are significantly closer to the central axis of the Reuss Valley. All locations were between 445 and 480 m asl. In the time series, no apparent discontinuities can be found. Parallel observations at old and new location were only made for the just mentioned major move (see section 2.1.).

Table 2: Locations of the foehn station Altdorf since 1863

period	number	location (Swiss coordinates)	elevation (m asl)
Oct 1, 1863 to Dec 31, 1872	1	691570/193100	452.5
Jan 1, 1873 to Apr 30, 1882	2	691700/193080	455
May 1, 1882 to Oct 31, 1892	3	691620/193350	480.2
Nov 1, 1892 to Apr 30, 1901	4	691600/193100	451
May 1, 1901 to Sep 30, 1958	5	691400/192650	456.3
Jan 1, 1955 to May 7, 1978	6	691000/191750	449
May 8, 1978 to present	7	690960/191700	449

Note: The numbers on the map correspond to the numbers in the station list above. The white line delimited by the yellow pins represents the distance of 1 km. North is at top as usual.



2. THE DATA ANALYSIS

2.1. The trend analysis

For the trend analysis of the time series, yearly values of foehn occurrence were calculated by simply summing up number of observations during the year. As Fig. 1 shows, the year-to-year variation is rather large, and no general trend can be recognized.

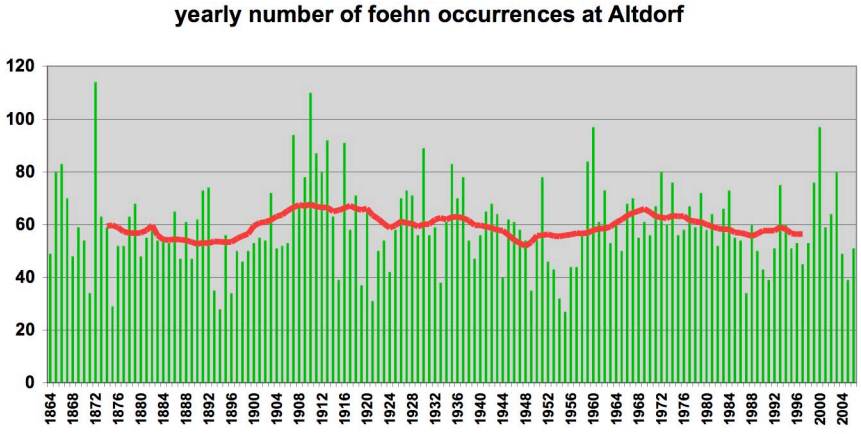


Figure 1: Year-to-year variation of foehn occurrence at the station Altdorf. The heavy line represents the 20-year running mean.

An attempt has been made to estimate a possible effect of the dislocation of the station in 1955. From Jan 1, 1955 to Sep 30, 1957, the stations at locations 5 and 6 were run in parallel. For the time series shown in Fig. 1, data from the new station, i.e., station 6 was used.

A comparison of the long-term mean before and after the dislocation was made. In addition, also the mean occurrences as observed at the two locations were compared directly. The figures are listed in Tab. 3.

Table 3: Mean absolute and relative differences between different station locations

period	mean	n	abs. difference	rel. difference
1864 - 1954	59.4 ± 16.8	101	0.3	99.5 %
1955 - 2006	59.7 ± 14.1	52		100 %
1955 - 57 location 5	42.1 ± 11.0	4	10.2	80.4 %
1955 - 57 location 6	52.3 ± 16.0	4		100 %

While there is no significant difference in the mean of the two long time series, the two stations operated in parallel exhibit rather different means. Nevertheless, statistically speaking, none of the means differs significantly; in the case of the parallel stations, the computed error probability is 33 percent. Still, the result for the stations operated in parallel is somewhat surprising. For the two long time series, the means include all the different meteorological situations that can occur. However, in the short parallel operation, both stations observe - separated by about 1 km - the same foehn case. Consequently, it must be assumed that the local variability of foehn on a scale of about 1 km is about as large as the meteorological variability over a long period. At any rate, a correction of foehn occurrence data for the new station does **not** seem appropriate.

A trend analysis for the entire period 1864 to 2006 does not yield any significant trend. If only data since the sixties is included, a linear regression yields a decrease of foehn occurrence by 0.17 observations per year (the yearly value still being the sum of the three daily observations). Because of the great variability, no conclusions about any actual change should be based on this result. As can easily been seen in Fig. 1, there were several even longer segments exhibiting similar trends.

2.2. Seasonal and diurnal variation of foehn occurrence

The seasonal and diurnal variation of foehn occurrence was extracted from the entire period 1864 to 2006. The left frame of Fig. 2 shows the mean seasonal variation of foehn. The well-known peaks in spring and autumn are very pronounced. The right frame depicts for each month the relative frequencies of foehn in percent occurring at the three observation times (100 percent corresponds to the mean total number of occurrences per month, as shown in the left frame).

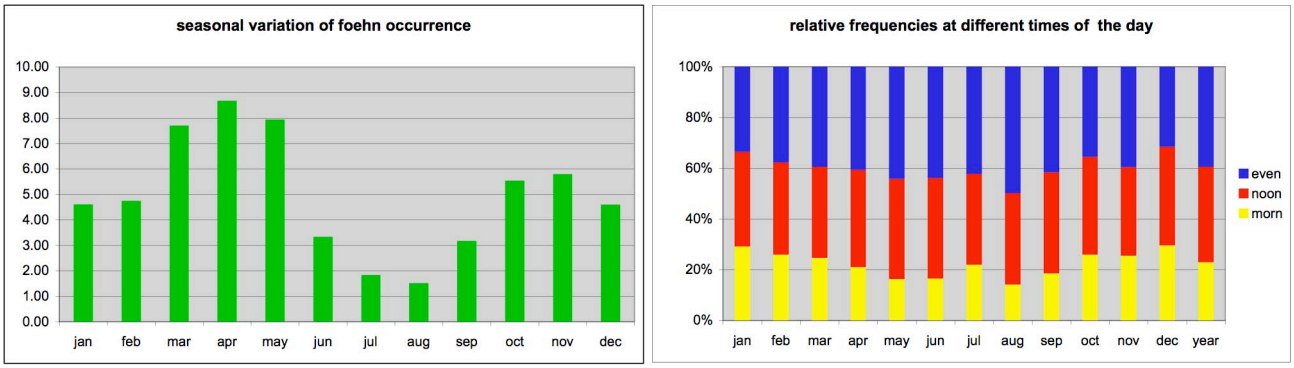


Figure 2: Seasonal variation of total foehn occurrences per month (left) and relative frequencies of occurrence at the three observing times.

While it has been noted long ago that the prevailing, season-dependent meteorological situation controls the seasonal variation of foehn occurrence (left frame), the variations of the relative frequencies at the different times of the day (right frame) are not fully understood yet. It is assumed that the interaction of foehn with local wind systems is the cause.

2.3. Comparison with other foehn stations

The map in Fig. 3 compares the mean number of foehn occurrences per year at different stations. Fig. 4. shows that the seasonal variation at each station is very much alike and, thus, independent of both the total number of occurrences and the local topography. The pronounced relative minimum in April and - to a lesser degree - in November are most likely caused by the overall synoptic situations in the period investigated. Again, this feature is clearly discernible at practically all stations, independent of the total foehn frequencies.

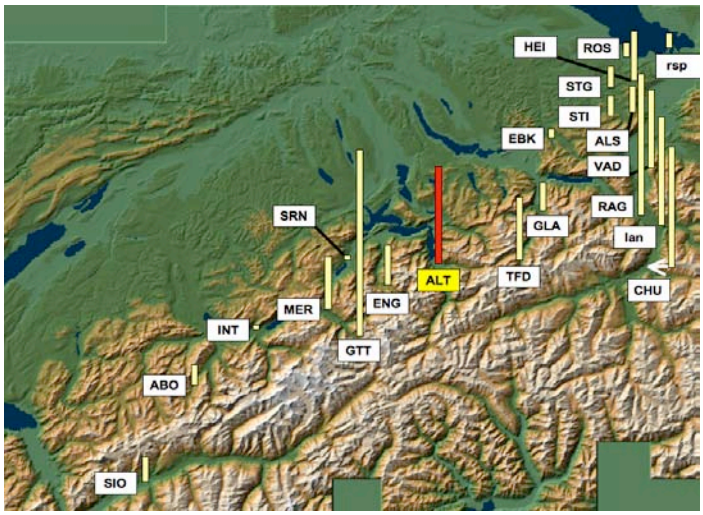


Figure 3: Comparison of the yearly foehn occurrence at different stations. Values represent the mean yearly sum for the period 1973 to 1982 (two stations for a slightly shorter period). The value for Altdorf (ALT) for this period is 62.2, this number being the sum of positive observations three times a day as described above.

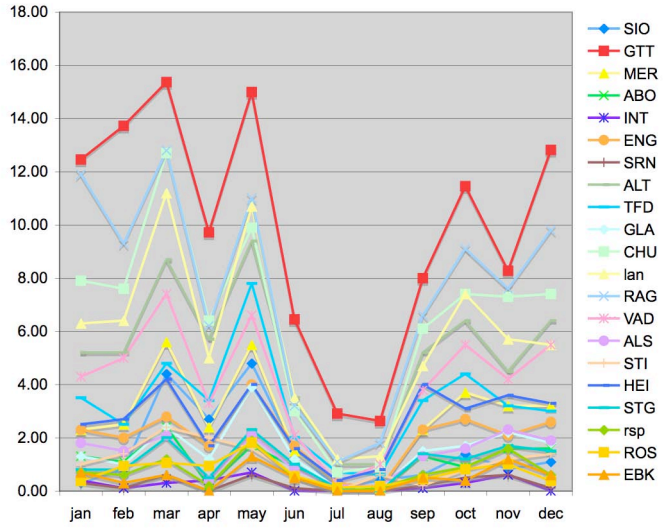


Figure 4: Seasonal variation of foehn occurrence for 21 stations. Data is for the period 1973 to 1982 (two stations for a slightly shorter period). Note the relative minima in April and November.

Fig. 5 presents the relative frequency at the different observation times for the different stations. The topography around a particular station supports the above-mentioned hypothesis that the diurnal variation of foehn is controlled by local wind systems superimposed on the foehn flow. Future work will have to concentrate on this issue.

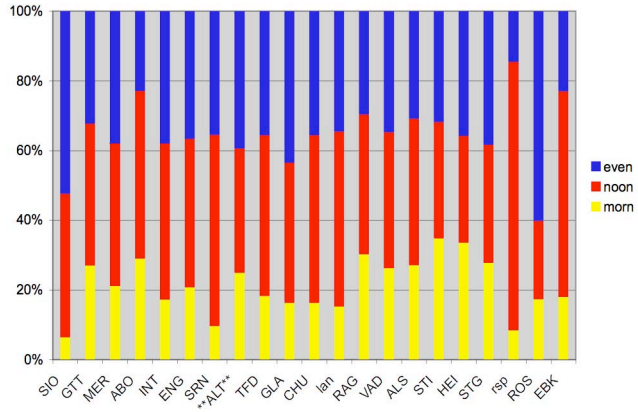


Figure 5: Relative frequencies of foehn occurrence at the three observation times. Data is for 1973 to 1982 (two stations for a slightly shorter period); 100 percent correspond to the sums depicted on the map in Fig. 3 for each station.

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