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CORRECTION OF MEASURED PRECIPITATION IN THE ALPS USING THE WATER EQUIVALENT OF NEW SNOW

(Submitted by Boris Sevruk)

Summary and purpose of document

This document provides a paper published in Nordic Hydrology, which presents an analysis carried out at the testsite of Weissfluhjoch, which is one of the SPICE testsite.

ACTION PROPOSED

The Meeting is invited to take this information into consideration for the analysis of the SPICE data, as appropriate.

Appendix: B. Sevruk: Correction of Measured Precipitation in the Alps Using the Water Equivalent of New Snow, Nordic Hydrology, 1983, 49-58

Nordic Hydrology, 1983, 49-58

Correction of Measured Precipitation in the Alps Using the Water Equivalent of New Snow

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The Hellmann heated siphon pluviograph with wind shield shows 56 % less winter precipitation than measured on a snow board at an altitude of 2,540 m a.s.l. For the Swiss heated tipping bucket gauge and the storage gauge precipitation was 31 % less. A relationship between the deficit and wind speed was only found for the storage gauge. The effect of the parameter of snowfall structure, defined as the portion of snowfall on days with temperature lower than -8°C, is small. The results can be used to make a preliminary adjustment of precipitation sums at Alpine gauge sites where wind speeds and temperature can be assessed.

Introduction

The general equation for a correction of the systematic error in precipitation measurement is as follows

$$P_K = k(P_g + \sum \Delta P_i) \qquad (1)$$

where P_K is the corrected or "true" amount of precipitation, k is the conversion factor to account for the systematic error, caused by deformation of the wind field above the gauge orifice, P_g is the measured amount of precipitation in the commonly used gauge elevated above the ground and $\Sigma\Delta P_i$ are corrections for wetting and evaporation losses, splashing or blowing and drifting snow. For solid precipitation, P_K can be considered to be equal to the water equivalent of new snow w_n measured on the ground within the same dates of observation. Because of drifting snow, loss from melting snow, evaporation and condensation processes, all of which are usually out of control, this approach can neither be regarded as perfect nor generally applicable (Sevruk 1982). However, it is the best available reference quantity in standard networks. It has been used to estimate k in Finland (Korhonen 1926, 1944, Solantie 1974, Tammelin 1982) and in Canada (Goodison 1978).

In general, k depends not only on wind speed but also on the structure of precipitation. Korhonen (1926, 1944) used the air temperature T_p during snowfall, as a parameter of the structure of snow. This was approved on a wide basis in the USSR. Tammelin (1982) showed that the air temperature affects k for the Wild gauge only in the range of $T_p < -10°C$.

The other components of systematic error in snowfall measurement using standard precipitation gauge (referred as ΔP_i in Eq. (1), have been investigated in the USSR (summarized in Sevruk 1982). Losses due to evaporation seem to be important mainly for heated precipitation gauges and depend on the heating system. The total loss due to heating was less than 6 % for the U.S. Weather Bureau tipping bucket (T-B) gauge (Davis and Tincher 1970) and 3.4 % for the Swiss T-B gauge (hereafter Pluv. II) (Joss and Gutermann 1980). However, in both cases mentioned above, the deficiency in the measured precipitation of heated gauges relative to the comparison standard gauges amounted to 8-9 %. No reasonable explanation for the residual difference was presented in either paper. Joss and Gutermann (1980) attributed it to the calibration error, but Førland (1981) showed that the deficiency of 15 % for Pluv. II in Oslo depends on air temperature, humidity, wind speed and precipitation intensity. For Siap and Plumatic heated (T-B) gauges the respective deficiency was 27 and 47 % (Førland 1981) and for the French gauge it was 30 % (David 1969). The losses due to convective currents above the orifice of heated gauges are to be expected mainly for light snowfall during low air temperatures. This effect has been simulated using confetti by Davis and Tincher (1970). They showed that the trajectories of falling confetti did not significantly change due to such currents. More important is the blowing out, but, as yet, this effect was not investigated. The wetting losses can amount to 2-3 % in the Swiss Alps and to 20 % in the regions of sparce precipitation.

In this paper the effect of wind speed on the monthly values of k for heated precipitation gauges and the storage gauge under extreme Alpine winter conditions will be discussed.

Experimental Site

The experimental plot is situated at Weissfluhjoch near Davos in Switzerland, at an altitude of 2,540 m a.s.l. It is open and the wind field seems to be homogeneous (Föhn 1976). w_n is measured each morning on a snow board (0.5 × 0.5 m) using a snow sampler with an orifice area of 1,000 cm^2. The location of the snow board was carefully selected to prevent drifting snow. Nearby there is a meteorological screen, a Swiss storage gauge (3 m above ground) with the Nipher-Billwiller wind shield, the same type as used at 130 gauge sites in Switzerland, and two heated recording gages with wind shield of the Alter-type. One recording gauge is of the Hellmann siphon type (Pluv. I) elevated at 3-5 m above the snow cover (depending on the snow depth) and another one is a tipping bucket gauge (Joss-Tognini, Lamprecht) which can be moved vertically, so that the orifice level is permanently elevated 1.5 m above the snow cover (Pluv. II). The latter gauge, but non-shielded, is used at 58 Swiss automatic meteorological stations, at a fixed height of 1.5 m above ground. All three Weissfluhjoch precipitation gauges have an orifice area of 200 cm^2. An anemometer, 5 m above the ground, is located at a distance of 600 m from the gauges, on a small peak (2,693 m a.s.l.). The air temperature and the wind speed are measured 3 times per day. The observations are published annually (Jahresberichte 1973-78). Some analysis of data has been done by Martinec (1974) and Föhn (1976). According to Martinec and Rango (1981) evaporation, condensation and melting of snow are negligible at Weissfluhjoch. The range of the mean air temperature on days with snowfall taken over a month in the winter season from November to April is between -5.7 and -11.5°C. On average, there is less than one day with snowfall in a month with the maximum air temperature greater than 0°C.

Methods

The monthly and seasonal amount of precipitation P_g from precipitation gauges for a 5-year period from November to April 1973/74-1977/78 was compared with the corresponding sum for the water equivalent of new snow w_n, on the snow board. The latter divided by P_g was defined as the conversion factor k. Its values for each gauge were related:

1) to the average wind speed u_p on days with snowfall for a particular month
2) to the average wind speed $\bar{u}_p$ weighted according to P_g and
3) to the parameter of snowfall structure, defined as the portion N_s of the snowfall on days with the mean air temperature T_p less than -8°C. N_s was computed for Pluv. I.

To account for the possible effect of drifting snow, the days with $k \leqslant 1.0$ were excluded from the analysis of the monthly data from Pluv. I. Such k^* values were related to the same factors as above.

A further parameter Q_u was also introduced into the relationship, where Q_u is the increase in the percentage wind-caused loss per one unit of the wind speed, i.e. per 1.0 m s^{-1}

$$Q_u = 100(k-1)u_p^{-1} \tag{2}$$

The pairs of monthly values of Q_u and N_s were plotted. In addition, N_s was plotted against the monthly air temperature T_p on days with snowfall, with the aim of indirectly estimating N_s. The monthly air temperature T_3 (3 observations per day) was used to estimate T_p. The same procedure was applied for the estimation of the monthly wind speed u_p on days with snowfall. Moreover u_p was computed using the parameter L ($L = u_p \times u_3^{-1}$) derived empirically by Bogdanova (1969). L depends on the number of days with snowfall and varies from 1.26 to 1.08 for 6-10 days, and more than 20 days, respectivelly.

For practical reasons linear fitting was considered. Only the measured values of the wind speed at a height of 6 m above ground were used in the analysis. For symbols see Table 1.

Results

The results of comparison are summarized in Table 1. As can be seen from the Table Pluv. I shows, on average, 56 % less snow than the snow board (in % P_g of Pluv. I). For both Pluv. II and the storage gauge the deficit is roughly 31 %. The monthly k-values vary considerably for each gauge as well as between the gauges. The variations of k for the whole winter season from November to April are much smaller. The differences between these values of k for Pluv. II and the storage gauge are negligible.

The range of monthly values of N_s is from 14 to 100. The largest values usually occur in the coldest month February ($T_3 = -8.2$°C, $T_p = -9.7$°C and $\bar{N}_s = 70$) and the smallest values are to be expected in November or April ($T_3 = -6.0$°C, $T_p = -7 \div -8$°C and $\bar{N}_s = 50$).

Figs. 1 and 2 show that there is no relationship between wind speed, k and k^*, respectively for actual monthly values from both heated gauges, Pluv. I and Pluv. II, (Figs. 1a, b, 2a), but there is a reasonably well defined linear relationship for

Table 1 – Data from Weissfluhjoch (2,540 m a.s.l.)

Legend:

k	conversion factor (w_n/P_g)	T_p	T_3 on days with snowfall
N_s	portion of snow on days with low temperature (< −8°C)	u_3	wind speed at a height of 6 m above ground (3 observations per day)
P_g	amount of precipitation in Pluviograph I	u_p	u_3 on days with snowfall
		$\bar{u}_p$	u_p weighted according to P_g
T_3	air temperature (3 observations per day)	w_n	water equivalent of new snow.

Table 1 – Data from Weissfluhjoch (2,540 m a.s.l.)

Year	Month	w_n (mm)	P_g (mm)	T_3 (°C)	u_3 (m.s^{-1})	T_p (°C)	u_p (m.s^{-1})	$\bar{u}_p$ (m.s^{-1})	N_s (%P_g)	k Pluv.I	k Pluv.II	k Stor gauge
1973	Nov.	215.9	191.9	- 5.4	5.1	-10.4	6.3	8.1	20	1.120	-	1.327
	Dec.	253.4	199.7	- 8.8	6.0	-10.5	-6.2	9.9	14	1.269	1.969	-
1974	Jan.	120.8	88.5	- 5.6	5.0	- 5.7	5.8	9.5	37	1.365	1.175	1.571
	Febr.	132.8	55.5	- 9.2	5.2	- 9.9	5.2	7.2	87	2.393	1.985	1.602
	March	40.6	66.3	- 6.6	3.5	- 8.7	3.5	3.6	31	0.825	1.357	0.891
	April	69.6	31.5	- 5.9	3.9	- 7.8	3.9	4.0	62	2.210	1.875	1.014
		832.2	633.4	- 6.9	4.8	- 8.8	5.2	8.1	30	1.310	1.479	1.472
1974	Nov.	160.4	117.1	- 6.4	5.3	- 8.4	5.9	7.4	97	1.370	1.179	1.379
	Dec.	270.2	136.9	- 6.8	7.3	- 7.5	7.8	12.1	70	1.973	1.259	1.531
1975	Jan.	143.4	91.8	- 5.6	4.6	- 7.0	5.0	9.2	48	1.562	1.434	1.084
	Febr.	25.0	11.0	- 7.2	2.4	- 8.7	2.7	2.2	82	2.273	1.471	1.136
	March	102.4	73.5	- 9.1	3.1	-10.7	3.1	3.2	78	1.625	1.391	1.175
	April	112.0	62.0	- 5.4	3.7	- 7.4	4.4	6.3	57	1.806	-	-
		813.4	498.4	- 6.8	4.4	- 8.3	4.8	8.4	71	1.630	1.342	1.326
1975	Nov.	108.4	65.2	- 5.4	3.8	- 7.0	4.9	5.6	37	1.663	1.252	1.168
	Dec.	61.0	35.1	- 5.4	3.2	- 8.2	5.3	3.0	95	1.738	1.667	1.154
1976	Jan.	174.3	97.3	-10.2	5.5	-11.2	5.7	6.7	53	1.791	1.359	1.289
	Febr.	24.0	11.9	- 7.0	3.0	-10.7	3.6	3.6	100	2.017	1.500	1.333
	March	48.6	23.2	- 8.8	3.1	- 9.8	2.8	2.9	66	2.095	1.231	1.297
	April	51.9	37.4	- 5.2	2.9	- 6.3	3.0	4.4	22	1.388	0.813	0.897
		468.2	270.1	- 7.0	3.6	- 8.9	4.2	5.2	54	1.730	1.226	1.778
1976	Nov.	107.1	58.8	- 6.4	4.9	- 7.9	5.7	5.5	26	1.821	-	-
	Dec.	176.1	124.7	- 9.7	4.9	-11.5	5.4	7.1	88	1.412	2.012	2.437
1977	Jan.	116.5	70.5	- 9.2	4.5	-11.3	4.4	3.8	96	1.652	1.603	1.219
	Febr.	179.8	154.3	- 8.4	4.3	- 8.4	4.0	3.8	40	1.317	1.333	1.316
	March	127.5	58.9	- 4.3	5.0	- 6.8	5.7	5.8	15	2.165	1.407	1.376
	April	196.6	92.0	- 5.8	5.0	- 6.9	5.5	7.8	54	2.137	1.037	1.138
		903.6	559.2	- 7.3	4.8	- 8.8	5.1	5.6	56	1.620	1.392	1.383
1977	Nov.	146.0	93.3	- 6.9	4.6	- 9.7	5.7	4.5	68	1.565	-	-
	Dec.	109.5	57.7	- 5.2	3.7	- 8.0	5.5	8.2	53	1.898	1.164	1.753
1978	Jan.	143.2	101.1	- 9.7	4.7	-10.9	4.5	5.7	80	1.416	1.204	0.805
	Febr.	146.5	113.7	- 9.7	4.3	-10.8	4.2	4.4	39	1.288	1.281	1.168
	March	262.9	146.3	- 7.8	6.1	- 8.9	6.4	7.7	71	1.797	1.227	1.587
	April	73.4	39.8	- 6.6	2.2	- 7.2	2.3	2.7	54	1.844	1.630	1.056
		881.5	551.9	- 7.6	4.3	- 9.2	4.8	5.1	62	1.600	1.260	1.263
		3916.0	2513.0	- 7.1	4.3	- 8.8	4.8	6.0	55	1.558	1.324	1.305

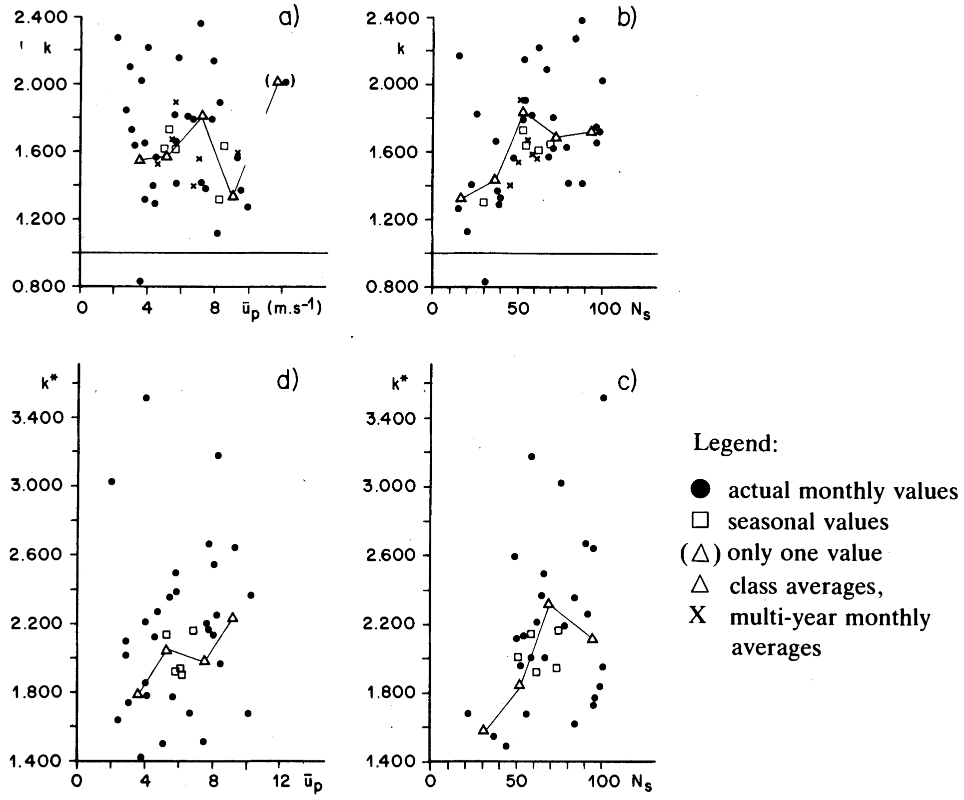

Fig. 1. Conversion factors k and k^* as a function of the weighted wind speed $\bar{u}_p$ (a,d) and the portion N_s of snowfall on days with the air temperature $T_p < -8°C$ (b,c) *Pluviograph I.* Weissfluhjoch/Davos, November-April 1973/74-1977/78.

the storage gauge, with a correlation coefficient of $r = 0.6$ (Fig. 2b). In contrast a weak relationship exists between k and the parameter N_s but only for heated gauges (Figs. 1b and 2d, $r_{\mathrm{I}} \doteq 0.35$, $r_{\mathrm{II}} = 0.45$). No significant differences in the relationship were found if the average wind on days with snowfall is used instead of weighted averages or if the Q_u values are related to N_s.

The linear regression lines for wind speeds, (Figs. 1 and 2) do not go through the origin. This is partly due to the wind speed values used in the analysis. These are measured at exposed peak, 600 m away and values are not reduced to the level of the gauge orifices.

There is an indirect way of estimating N_s using the monthly data for the air temperature T_3. A rule of thumb is: $N_s = 8T_3$. However, the relationship between the above factors is approximative ($r = 0.4$) and it is better to use daily data T_p to estimate N_s.

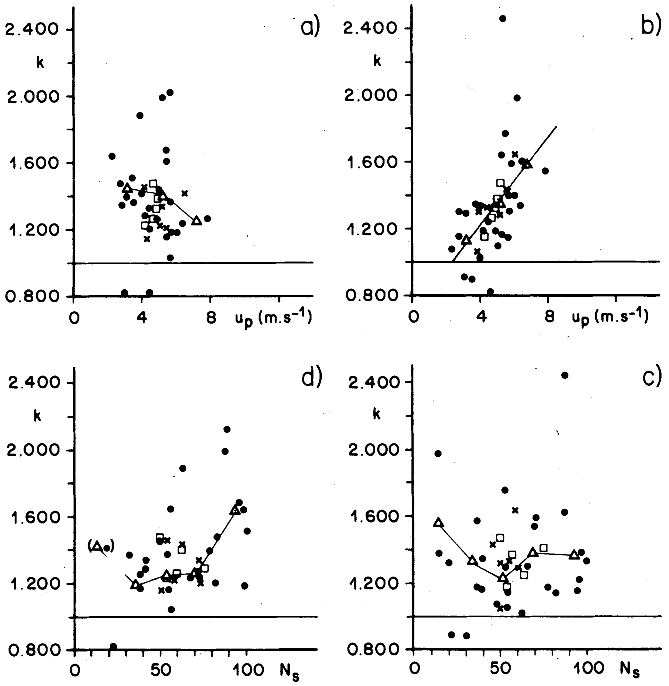

Fig. 2. Conversion factor k as a function of the wind speed u_p and the portion N_s of snowfall on days with air temperature $T_p < -8$°C (d,c). *Pluviograph II* (a,d) and the *storage gauge* (b,c). Legend see Fig. 1.

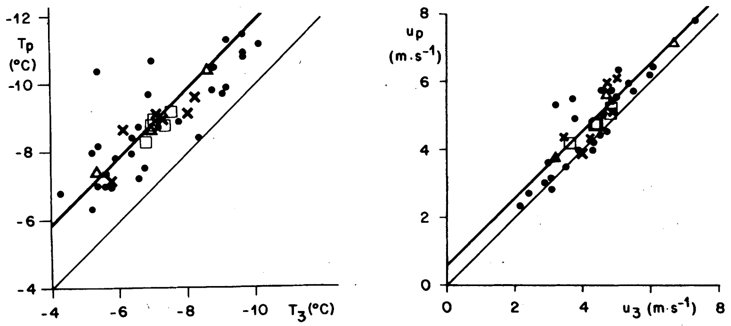

Fig. 3. Relationship between monthly means (index 3) and mean monthly values on days with snowfall (index p). Left: air temperature. Right: wind speed. Weissfluhjoch-/Davos, November-April 1973/74-1977/78. Legend see Fig. 1.

Table 2 – Comparison of monthly means of wind speed during snowfall at Weissfluhjoch estimated by different methods (November-April 1973-78)

Number of days with snowfall	Number of months	u_3	u_p	u'_p	$\bar{u}_p$	L Bogdanova	L^* Weissfluhjoch
6-10	3	2.9	3.9	3.7	3.0	1.26	1.36
11-15	4	4.3	5.3	5.4	7.7	1.25	1.23
16-20	15	4.4	4.7	5.2	7.5	1.18	1.07
> 20	8	5.0	5.1	5.4	5.6	1.08	1.02
Average		4.2	4.8	4.9	6.0		
Percentage difference to u_3			14	17	43	$^*L = u_p \times u_3^{-1}$	

Legend:

u_3 mean monthly wind speed (3 observations per day)

u_p monthly wind speed on days with snowfall

u'_p monthly wind speed on days with snowfall ($u'_p = u_3 \times L$)

$\bar{u}_p$ u_p weighted according to the amount of precipitation P_g

The monthly averages of air temperature T_p and wind speed u_p on days with snowfall are fairly well correlated with the corresponding monthly means T_3 and u_3, respectively (Fig. 3): monthly means are smaller by 24 % for the air temperature and by 14 % for wind speed.

An agreement exists between the wind speed estimates using the factor L and the monthly averages on days with snowfall (Table 2).

Discussion

The different average values of the conversion factor k for three types of gauges are due to differences in construction and heating systems of gauges and in orifice levels above the surface. Further it must be kept in the mind that k values for the storage gauge and for heated gauges are not the same. For the former k is identical with the losses due to wind field deformation above the gauge orifice as defined in Eq. (1) and consequently, k is related to wind speed. This is not valid for heated gauges where k is identical with the total losses relative to the water equivalent of new snow, i.e. the losses due to wind, evaporation, convection currents and blowing out and thus k is rather related to the portion N_s of snowfall on days with low temperatures. The explanation is that the snowfall during such days consists mainly of smaller snow particles which are more affected by the heating and blowing out than snowfall on warmer days. Thus an interesting fact emerges from the analysis, showing that the parameter N_s, which has to be consi-

Table 3 – Correction ΔP_g for the percentage systematic error in the winter precipitation measurement in the Alps.

Swiss storage gauge with wind shield					Swiss tipping bucket gauge with wind shield					
u_3	2	4	6	8	N_s	20	40	60	80	100
ΔP_g	10	35	60	85	ΔP_g	20	30	40	50	60

Legend:

u_3 wind speed 6-12 m above ground, exposed site near the gauge
N_s portion of snow on days with low temperature (< -8°C)

dered as a subjective compromise to reflect the variability of the structure of monthly precipitation, can be rather used to determine the total loss of heated gauges than to assess the effect of precipitation structure on k.

There is no direct evidence of the effect of drifting snow on k. It seems that if such an effect exists it is small or the increase and decrease of water equivalent of new snow due to drifting snow compensates for the longer time period. In any case there is practially no improvement in the relationship to u_p and N_s for Pluv. I if k^* is introduced instead of k for months and there is only a small improvement for class averages. On the other hand the relationship between k and u_p for the storage gauge ($r = 0.6$) is in accordance with similar relationships from the literature (Sevruk 1982, Tammelin 1982).

The effects of evaporation, condensation and melting of snow are small. The water equivalent of snow cover measured at the end of the winter season (May 1) averages only 4 % less than the total of water equivalents of new snow w_n.

Thus in spite of no other data being available at present, the results from Weissfluhjoch can be used to make some preliminary adjustment, according to Table 3, to monthly precipitation sums of high altitude regions (2,000 – 3,000 m a.s.l.) at gauge sites where, as yet, only storage gauges are used.

Conclusions

Considerable systematic losses in winter precipitation measurements in the Alps, using heated and storage gauges, show that corrections of precipitation data are a necessity. For storage gauges the losses are related to wind speed measured near the gauge site. For heated gauges the losses are more complex due to heating and blowing out of snow. They can be roughly assessed from the portion of snowfall on days with the temperature less than −8°C. However, more investigations into this problem are necessary.

Acknowledgement

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