INTERCOMPARISON MEASUREMENTS OF RECORDING PRECIPITATION GAUGES IN SLOVAKIA

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Abstract

In order to check the accuracy and reliability of a new electronic weighing recording precipitation gauge with a very fine resolution of 0.001 mm, 99 precipitation measurements of liquid, mixed and solid precipitation were compared with the standard manually operated gauge and the heated tipping-bucket gauge. The results show that there are differences in the total amount and duration of precipitation as measured using these three types of gauges. The tipping-bucket gauge shows losses in the case of solid precipitation. In contrast, it overestimates the precipitation amounts in the case of long-duration precipitation events with moderate intensities, which is due to the repeated wetting of the buckets. After each emptying of the bucket a small amount of water remains in the bucket and is added by the following filling of the bucket to the precipitation. The more sensitive electronic weighing system can give some false records due to external influences like wind gusts.

INTRODUCTION

In connection with the development of a new flood-warning system in the Slovak Republic the Slovak Hydrometeorological Institute (SHMI) is going to expand its network of automatic precipitation gauges to 250 in the next few years. The first 90 gauges have already been installed during the last year. Each gauge uses an electronic weighing system TRWS of domestic production, developed by MPS System Ltd. in Bratislava. The resolution is 0.001 mm per minute. This new type of gauge has been preferred to tipping-bucket gauges, which are considered to be not very reliable (Sevruk, 2002). They need recalibration each year, show considerable losses in high intensity rains (Adami and Da Deppo, 1985) and due to heating in the winter season (Zweifel and Sevruk, 2002), the buckets do not empty completely and consequently, and the tips do not correspond to the specified amount. Moreover they suffer from frequent clogging due to bird droppings and leaves falling into the gauge. The purchase price is low, but the operational cost tends to be high. The electronic weighing systems also show some specific errors such as a temperature dependence of measured values or software errors in filtering out the effects of wind shocks, vibrations and sudden changes etc. (Sevruk and Chvíla, 2005). These errors can result in false precipitation records.

Differences in the measurements of precipitation gauges of different design and measuring systems arise mainly due to the different magnitude of systematic errors, particularly wind induced losses, wetting and evaporation losses. The systematic errors can be minimized using appropriate corrections (Sevruk, 1982; 2005; Nespor and Sevruk 1999); the effect of random errors can be eliminated through the checking of precipitation records and the installation of gauges in situ (Sevruk, 1984). All other types of errors need additional investigations. If this is not done, the precipitation time series show inhomogeneities and hydrological computations are inaccurate. The wind-induced error of electronic weighing gauges was analyzed by Chvíla et al. (2002; 2005).

The aim of this intercomparison was to check the operational reliability and the accuracy of the new gauge, particularly the wetting and evaporation effects. Because the wind-shocks during strong winds can produce false precipitation records by the weighing gauges, this phenomenon was also investigated. It is also of interest to know how the very high resolution of 0.001 mm of the new gauges is going to expand our knowledge of the temporal precipitation distribution, particularly the precipitation amount and duration. Precipitation amounts of less than 0.1 mm and their duration, which cannot be measured using standard gauges and common tipping-bucket gauges could be important factors in the climatological, agrometeorological and hydrological applications and scientific investigations.

METHODS

The intercomparison measurements took place at the Bratislava-Koliba meteorological station, which is located at the headquarters of SHMI, during a three months period with liquid and solid precipitation. All gauges, the recording weighing TRWS (WG), the recording heated tipping-bucket PAAR AP23 (TBG) and the manual standard gauge Metra (SG) have more or less the same catching area of 500 cm^2 with deviations of 0.2% for the PAAR AP23 and 0.1% for the Metra and TRWS. The Metra gauge has a thin orifice rim and the two recording gauges have thick orifice rims. The elevation height of the orifice rim was 1 m above the ground, which is standard in Slovakia. The resolution of standard and tipping-bucket gauges is 0.1 mm per minute. The standard gauge provided measuremets three times per day.

Figure 1. The experimental polygon of precipitation gauges at the Bratislava-Koliba meteorological station.

In addition, the precipitation detector Vaisala DRD11 was also used to check the duration of precipitation measurements and, in relation to the wind speed, to separate and eliminate false precipitation records. The wind measuring instrument was elevated 10 m above the ground. The phenomena observations from SYNOP messages were used to separate between liquid, mixed and solid precipitation.

In the first step the total amounts of liquid, mixed and solid precipitation from the three gauges over the three month period were compared and differences between the precipitation events analyzed. The precipitation events were separated from each other by at least a 10-minute precipitation-free period. This analysis has been based on the records of the more reliable weighing gauge. Non-registered precipitation events were evaluated separately.

In order to check the effects of wetting of buckets of the tipping-bucket gauge, the precipitation events were subdivided according to their duration into six sub-groups as follows: from 1 to 5 minutes; 6–15 minutes; 16–30 minutes; 31–60 minutes; 61–100 minutes and finally 101 and more minutes. In addition a special group was identified for events during which the weighing gauge does not register the precipitation as compared to the tipping-bucket. The differences in total amount between both recording gauges were computed and their dependency on the total amount, which corresponds to the number of tips was analyzed.

RESULTS AND DISCUSSION

The results of the comparison of the total precipitation amounts measured by all three gauges are presented in *Table 1*. They show differences in precipitation amounts between the standard precipitation gauge Metra and the two recording gauges of 5%. This difference, which amounts to 4 mm, occurred in two days and can be attributed to the error made by the observer. (Metra showed 15.8 mm on one day and recording gauges 12.5 mm. On another day Metra showed 2.1 mm and recording gauges 1.1 mm.) No other explanations of such a substantial error were on hand. With the exception of these two days, the differences in precipitation amounts between the Metra and the two recording gauges were small and varied from positive to negative values. The different thickness of the gauge orifice rim can affect the wind field deformation above the gauge (Sevruk et al., 1989) and contribute to the observed differences through wind-induced losses. However these differences depend on wind speed and we estimate them to be generally small. In addition they are negative or positive between two types of gauges.

Between the weighing and tipping-bucket gauges, which have the same thickness of orifice rim, there are no significant differences in total amounts. Greater differences are obtained only in the case of mixed and solid precipitation, when the weighing gauge, WG, records more precipitation than the tipping-bucket gauge, TBG, which seems to be affected by the losses due to heating. However, the number of days with mixed or solid precipitation over the examined period was low therefore related results are not very representative.

Table 1. The total amount of liquid, mixed and solid precipitation measured using the standard conventional gauge Metra (SG), the weighing gauge TRWS (WG) and the tipping-bucket gauge PAAR (TBG). Bratislava, Slovakia, October-December 2004.

Precipitation form	Number of days with precipitation	Total amount of precipitation in [mm]		
		SG	WG	TBG
liquid	23	52.6	51.384	52.0
mixed	4	37.1	34.121	33.7
solid	1	0.2	0.449	0.2
Total	28	89.9	85.954	85.9

The comparison of precipitation events is presented in *Table 2*. It shows significant differences in the duration of the precipitation events. In the case of liquid precipitation, the TBG did not register roughly 50% of all events, particularly very small ones under 0.1 mm. In the total it makes 1.67 mm with a duration of nearly 1000 minutes. In the case of solid precipitation the proportion of non-registered events by the TBG is exceptional great (6 out of 8). This is primarily caused by the higher resolution of the WG. The tipping-bucket mechanism is not able to detect the low intensity precipitation events like the drizzle or very light rain even if its total amount is larger than the gauge resolution of 0.1 mm. This is well demonstrated in the right graph of the cumulative sums in *Figure 2*. It may be due to the greater wetting losses of the gauge collector and the buckets of the TBG as compared with the WG. For the latter gauge the wetting of the collector is partly weighted and included in the amount of precipitation. Only the wetting of the orifice rim is not weighted and in this way, it contributes mostly to the wetting losses.

The start of recording solid precipitation by the TBG is also considerably delayed in relation to the WG. This is primarily due to the smaller resolution and partly to the evaporation losses of the heated catching area of the TBG. The higher wind speeds during the events with solid precipitation could also affect the magnitude of differences in measurements between the gauges due to the different wind-induced losses.

During the examined period there are 11 events with the records of the WG unrelated to the precipitation. All of them occurred during windy periods (see *Table 2*). In 7 events the wind gusts exceeded 15 m s^{-1}, which is twice the average wind speed. The force of wind shocks affects the precipitation gauge collector, which is placed directly on the weighing mechanism. Its total load can vary due to the shocks and in this way it can affect the registration, which can record some very small amounts of “precipitation” near the resolution value of 0.001 mm.

Table 2. The total amount, duration, average wind-speed and the average delay in the start of recording precipitation events, sub-divided according to the precipitation form and the not-registered events by the tipping-bucket gauge, TBG. Bratislava, Slovakia, October-December 2004.

Precipitation form	Number of events	Total amount WG	Total amount TBG	Duration WG	Duration TBG	Wind speed average	Delay* in beginning
		[mm]	[mm]	[min]	[min]	[m s^{-1}]	[min]
All precipitation events							
liquid	84	52.836	52.6	3930	1732	3.2	16
mixed	7	31.199	31.6	1372	1122	3.0	25
solid	8	1.909	1.7	327	162	3.8	26
Total	99	85.944	85.9	5629	3016	3.3	22
no precipitation**	11	0.041	0.1	34	1	6.8	-
Precipitation events not registered by TBG							
liquid	44	1.670	0	949	0	3.0	-
mixed	2	0.121	0	50	0	3.2	-
solid	6	0.243	0	91	0	4.1	-
Total	52	2.034	0	1090	0	3.4	-
no precipitation**	10	0.041	0	34	0	7.2	-

* average value **precipitation registered by the gauge when no precipitation occurred

Figure 2 shows the records of liquid precipitation by WG and TBG for two different events. The left graph shows the delay in the start of recording the precipitation smaller than 0.1 mm by the TBG as compared to the WG, which is due to the different resolution of both gauges, and practically no delay at the 0.1 mm value. The TBG shows 0.05 mm precipitation less than the WG at the end of the time period. The right graph demonstrates differences in the recording of very light rain in the first 60 minutes and the following rain of higher intensity in the last 45 minutes of the record. The first part of the rainfall event was not recorded by the TBG and the second part was recorded with some delay. The difference in precipitation amount at the end of time period is 0.1 mm.

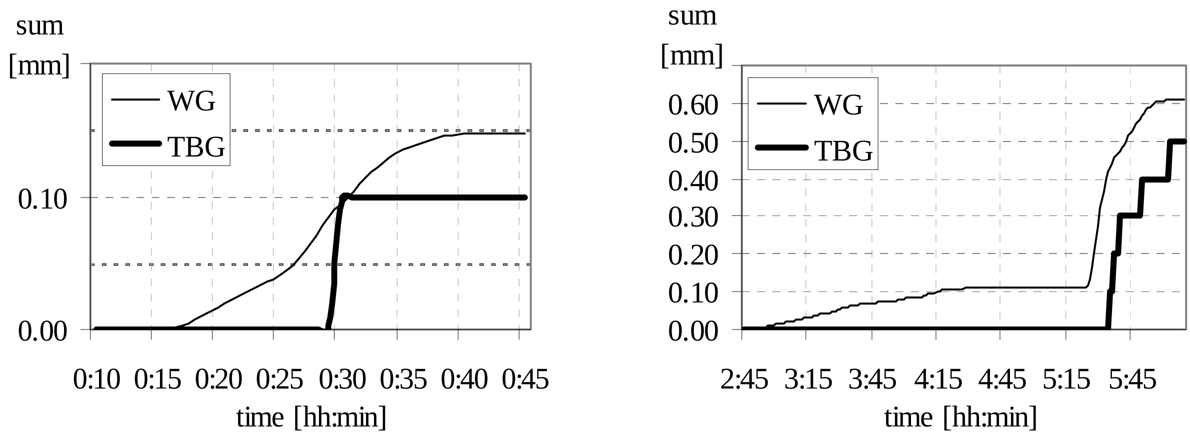

Figure 2. The cumulative sums of precipitation recorded by the weighing (WG) and tipping-bucket (TBG) precipitation gauges in two different time periods. Bratislava, 2004.

Table 3. Differences in the total amount of precipitation measured using the weighing gauge (WG) and the tipping-bucket gauge (TBG) for different forms of precipitation, sub-divided according to the duration of precipitation events into six classes and one class of precipitation events not recorded by WG.

Duration of events by WG	Number of events	Total amount		Differences in total amount WG-TBG		Average number of tips	Average duration of events		Wind speed average
		WG	TBG	absolute	relative		WG	TBG	
[min]	[-]	[mm]	[mm]	[mm]	[% TBG]	[-]	[min]	[min]	[m s^{-1}]
Liquid precipitation									
no record by WG	3	0	0.3	-0.300	-100	1	0	1	3.6
1-5	17	0.123	0.0	0.123	100	-	3	0	3.7
6-15	17	1.168	0.9	0.268	29.8	0.5	10	1	2.7
16-30	13	1.085	0.9	0.185	20.6	0.7	21	1	2.5
31-60	13	4.206	3.3	0.906	27.4	2.5	44	13	2.8
61-100	8	2.775	2.3	0.475	20.7	2.9	71	13	2.4
101 and more	13	43.479	44.9	-1.421	-3.2	34.5	177	110	3.6
Mixed and solid precipitation									
1-5	1	0.001	0	0.001	100	-	1	0	4.1
6-15	4	0.084	0	0.084	100	-	9	0	2.6
16-30	2	0.331	0.2	0.131	65.5	1	23	4	5.1
31-60	4	1.634	1.8	-0.166	-9.2	4.5	43	20	3.1
61-100	0	0	0	0	0	-	0	0	0
101 and more	4	31.058	31.3	-0.242	-0.7	78.3	361	299	3.4

Table 3 confirms that in the case of precipitation events with longer duration and moderate intensities, the total amount of precipitation recorded by the TBG is slightly larger than that recorded by the WG. It is also evident, that the form of precipitation plays no role in this phenomenon at all. It agrees well with the theory of wetting of buckets. A very small part of precipitation always rests in the buckets, so the tips do not correspond to 0.1 mm amounts but count already slightly smaller amounts of precipitation as the 0.1 mm value, which explains the overestimation of the total amount. Because the wetting of buckets is very small, the number of tips should reach a certain critical value to cumulate enough water, which could be registered by the

resolution of 0.1 mm. Consequently, the number of tips greater than the critical value relates to the overestimation and to the amount of precipitation since these two variables are proportional. In calibrations curves presented by Adami and Da Deppo (1985; see also Sevruk, 2004) the overestimation is evident between precipitation intensities of less than 50 mm h^{-1}. It increases toward smaller intensities up to 4%.

The fitted line in *Figure 3* shows that the critical value corresponds to about 15 tips, when the TBG starts to record more precipitation in total than the WG. In *Table 3*, it is shown that at an average number of tips of 34.5 per event, the TBG shows already 3.2% more liquid precipitation than the WG. In contrast, the WG shows up to 30% more liquid precipitation if the average number of tips per event is less than 3. For the mixed and solid precipitation such a relationship is not so clearly evident.

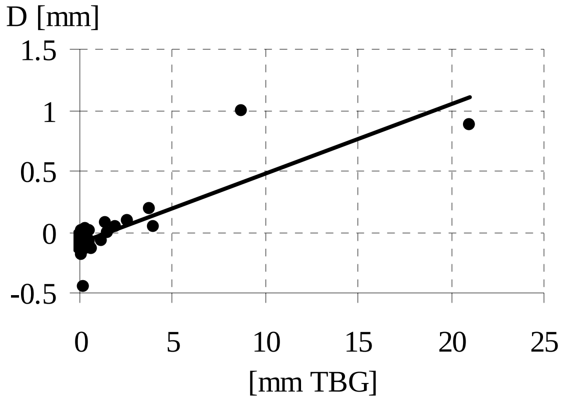

Figure 3. Relation between the total amount of precipitation measured using the tipping-bucket gauge (TBG) and the absolute difference, D, in precipitation values between the weighing gauge and the tipping-bucket gauge (TBG).

CONCLUSIONS

The electronic weighing principle with a very high resolution of 0.001 mm is more accurate to measure the precipitation amount and duration than the heated tipping-bucket gauge, especially in the cases of low intensity precipitation. Measurements using the recording tipping-bucket gauge are affected by evaporation and wetting. Heating losses can be considerable during the winter season. In contrast, the sensitive weighing gauge can also produce the erroneous recordings. To ensure the reliability of the gauge, it is important to use appropriate software to eliminate false records. The manual gauges are subject to observational errors and all types of precipitation gauges are subject to systematic and random errors.

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