Reply to Nominated Referee #1

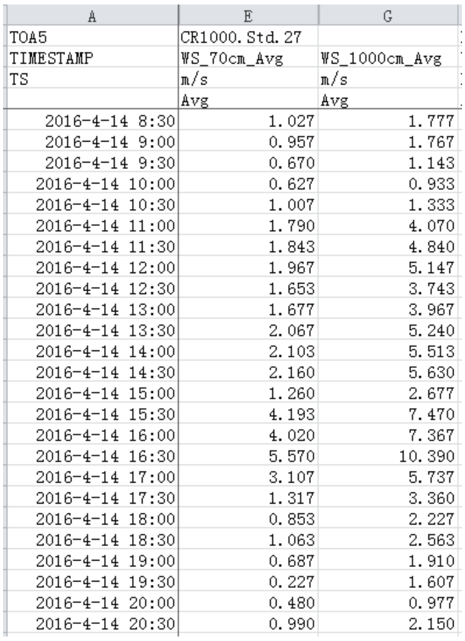
We thank Dr. Kochendorfer for the comments; below we give the reply to the comments.

Specific comments:

1) Wind speeds were relatively low at the testbed during the measurement period (a maximum of 2 m s^{-1}, from Fig. 7), and there were only a few solid precipitation events (I count only 11 in Fig. 7c). The authors need either a longer measurement period like Chen et al. (2015), or a more thorough justification of the general applicability and usefulness of the proposed correction.

Because the purpose of the adjustments derived in the manuscript is presumably to correct gauge measurements at other sites, the adjustments must be representative of the wide range of meteorological conditions that such monitoring sites may be exposed to. Such adjustments are most significant for solid precipitation occurring in high wind speeds. For example, neglecting differences in the wind speed measurement height, Chen et al. (2015) noted at this same site, "the wind speed showed no significant effect…below 3.5 m s^{-1}". In the manuscript under review, Fig. 2 shows that the $TRwS_{SA}$ measurements did not typically underestimate the "true" amount of precipitation, and were in fact fairly comparable to the DFIR-shielded manual gauge used as a reference. This is what one would expect given the range of conditions that the site was subject to. The problem with this is that corrections derived from such measurements will not be applicable to windy monitoring sites that are subject to solid precipitation events, where such corrections are actually most significant and necessary. The measurements presented in the manuscript could be used to test some of the transfer functions available in the WMO-SPICE Special Issue and elsewhere, but they do not comprehend a wide enough range of meteorological conditions for the derivation of valid and useful transfer functions.

Reply:



A	E	G
TOA5	CR1000.Std.27	
TIMESTAMP	WS_70cm_Avg	WS_1000cm_Avg
TS	m/s	m/s
	Avg	Avg
2016-4-14 8:30	1.027	1.777
2016-4-14 9:00	0.957	1.767
2016-4-14 9:30	0.670	1.143
2016-4-14 10:00	0.627	0.933
2016-4-14 10:30	1.007	1.333
2016-4-14 11:00	1.790	4.070
2016-4-14 11:30	1.843	4.840
2016-4-14 12:00	1.967	5.147
2016-4-14 12:30	1.653	3.743
2016-4-14 13:00	1.677	3.967
2016-4-14 13:30	2.067	5.240
2016-4-14 14:00	2.103	5.513
2016-4-14 14:30	2.160	5.630
2016-4-14 15:00	1.260	2.677
2016-4-14 15:30	4.193	7.470
2016-4-14 16:00	4.020	7.367
2016-4-14 16:30	5.570	10.390
2016-4-14 17:00	3.107	5.737
2016-4-14 17:30	1.317	3.360
2016-4-14 18:00	0.853	2.227
2016-4-14 18:30	1.063	2.563
2016-4-14 19:00	0.687	1.910
2016-4-14 19:30	0.227	1.607
2016-4-14 20:00	0.480	0.977
2016-4-14 20:30	0.990	2.150

Figure 1: An example of the wind speed at this site.

In fact, the wind speeds at this site were not all low (e.g., Figure 1). However, because most half-hour wind speeds were low, the average wind speeds (especially at gauge height) during precipitation were relatively low. It really seems difficult to derive a general transfer function which can be applied in a wide range of meteorological conditions from these data. Given this, the constructive suggestion made by Dr. Kochendorfer that the measurements presented in this study could be used to test some of the transfer function available in the WMO-SPICE Special Issue and elsewhere will be a good alternative. Additionally, the less solid precipitation events during the experiment are really a problem for the analysis work. We consider updating the experimental data to make up the deficiency as far as possible.

Specific comments:

2) The separation of specific and systematic/aerodynamic errors merits further examination. Based on the use of equations 1-3, two assumptions are made: 1) The single-Alter shielded CSPG is itself free from specific errors and 2) The aerodynamic error for the single-Alter shielded TRwS and CSPG are identical. While the second assumption may (or may not) be valid, the first assumption is also problematic. Comparisons of identical precipitation gauges with identical shielding show that differences between like measurements in such a field site are significant. All precipitation gauge comparisons are subject to errors due to causes such as general measurement uncertainty and the spatial variability of precipitation. Such errors are not aerodynamic, but the methodology presented in the manuscript defines all differences between the two CSPG gauges as aerodynamic; there is no specific error term in Eq. 3, which indicates that the CSPG is completely free from specific errors. A more defensible and direct way to estimate such specific errors would be to install a DFIR shielded TRwS and compare it to the DFIR-shielded CSPG, or to simply use low wind speed or rainfall measurements, where the effects of shielding and wind are negligible.

In general I don't understand the advantages of estimating specific and systematic errors with the indirect approach described in the manuscript. Both correctable and uncorrectable errors could be examined directly by creating a transfer function, and then quantifying the remaining uncertainty in either the transfer function or the corrected measurements.

Reply:

We agree with Dr. Kochendorfer that all precipitation gauges are subject to errors due to causes such as general measurement uncertainty and the spatial variability of precipitation. The general measurement uncertainty for manual method is difficult to be determined and quantified, and we also do not know the magnitude of the random errors at this site at present. Whereas, since the observer is well trained and all gauges were installed not far away to each other, these errors can be relative small compared to errors like from aerodynamic effect and software problem (especially for automatic gauges). In this case, they can be ignored. As Dr. Kochendorfer commented, we did not discuss the errors of CSPG measurements comprehensively in the methodology, and we will clarify it in the revised manuscript. Related experiment about the random errors will be carried out at this site in the near future.

In addition, what we need to explain again is that the specific errors in this manuscript mainly refer to errors caused by weighing system problem of TRwS204. As suggested above, a more defensible and direct way to estimate such specific errors can be to install a DFIR-shielded TRwS and compare it to the DFIR-shielded CSPG. In fact, we have installed $TRwS_{DFIR}$ at this site in the summer of last year. So far, there are only half a year's data which can not be used in analysis. After full consideration, we consider to use low wind speed (lower than 1 m s^{-1}) measurements to compute specific errors as suggested by Dr. Kochendorfer.

For the opinion from Dr. Kochendorfer that “In general I don’t understand the advantages of estimating specific and systematic errors with the indirect approach described in the manuscript”, I will explain from the following several aspects. Firstly, it really does not need to estimate the specific errors for weighing gauge if DFIR shielded TRwS was chosen as reference. The transfer function can be established since the undercacth is mainly caused by systematic errors. However, we mainly want to test the performance of TRwS and correct its precipitation measurements in this study. In order to achieve these goals, we need a reference which should be more representative of the real precipitation. Compared to the weighing precipitation gauges, manual measuring gauges tend to measure more precipitation when under the same configuration both in previous work (Sevruk and Chvíla, 2005) and in our work. Hence, the corrected $CSPG_{DFIR}$ measurements were regarded as “true” precipitation in this study. Once the reference has been decided, the specific errors should be discussed because they are mainly caused by the two kinds of measurement methods. Secondly, analysis of specific errors and systematic errors can help to understand the error sources comprehensively, and achieve more clearly and better correction.

Technical corrections:

Pg. 1 ln. 17. It would be revealing to discuss the root mean square or the mean of the absolute values of specific errors in addition to the average.

Reply:

We agree with Dr. Kochendorfer that “It would be revealing to discuss the root mean square or the mean of the absolute values of specific errors in addition to the average”. Hence, we will consider this suggestion in our revised manuscript.

Pg. 3 ln. 20-25. Please describe these measurements in more detail. Exactly how were the 12 hr TRwS measurements estimated from the 30-min measurements? Were there different outputs available for this gauge? For example, was the change in the absolute depth calculated or were the average 30-min intensities used? Was any smoothing or averaging performed? What type of anti-freeze and oil were used, and how was the heater configured? How were the CSPG measurements taken, by weight or by measuring stick for example? Was solid precipitation melted before being measured manually? How were the meteorological measurements recorded (heights, sensors, etc.)?

Reply:

The TRwS is a weighing rain gauge without funnel produced by the company MPS from Slovakia. It is able to indicate the liquid as well as the solid precipitation with a resolution of 0.001 mm and an accuracy of 0.1%. Exactly, we calculated daily (24-h) measurements. The 24-h TRwS measurements were estimated from 30-min measurements through cumulative calculation. TRwS has two outputs:①Pulse output corresponds to the value of increment of precipitation; ② Opto-isolated (optional) serial output RS 485 or SDI12 standard. We used the change in the absolute depth to calculate the result. Additionally, we do not have to do any smoothing. The anti-freeze we used is ethylene glycol anti-freeze, and we did not enable heating options because the heating ring of the gauge is quite energy consuming. For the CSPG, precipitation was measured by volume for rain and sleet events, while the funnel and glass bottle were removed from the CSPG and precipitation was weighed under a windproof box for snow events (Chen et al., 2015). Solid precipitation did not melt before measured manually. We used CR1000 datalogger (from Campbell Scientific, Inc.) to record the meteorological measurements. Wind speeds at gauge height were measured by WS200-UMB Wind Sensor (from G. Lufft Mess- und Regeltechnik GmbH).

Pg. 4 ln. 10. Change 'corrected' to 'subject to'.

Reply:

Okay. We will change it in the revised manuscript.

Pg. 4 ln. 22. "The catch ratio which served as the function of environmental…" needs to be rewritten.

Reply:

We rewrite this sentence as "The catch ratio which can be expressed as a function of environmental variables was also used during analysis, especially of the wind speed at the gauge height of the orifice".

Pg. 4 ln. 30-31. Manual methods are also subject to specific errors.

Reply:

We agree with Dr. Kochendorfer that "manual methods are also subject to specific errors". In fact, the specific errors in this study mainly refer to the gauge problem for automatic weighing gauges. Nevertheless, we did not correctly interpret this view in this manuscript, and we will rewrite it in the revised manuscript.

Pg. 5 ln. 5-7. I don't know much about the TRwS, but most weighing gauges output the total depth, allowing for small changes in the total depth to be calculated over longer time periods. This issue may be due to shortcomings in the way that the gauge measurements were logged and processed, although the stated 0.001 mm resolution seems quite good. Does this resolution translate to 0.001 mm/30-min?

Reply:

In the study of Sevruk and Chvíla (2005), they used different weights (0.5 g, 1 g, and 4 g) to investigate the relationship between simulated precipitation amounts (0.025 mm, 0.05 mm and 0.2 mm)and different measuring intervals (1 min,2 min, 3 min, 5 min, and 10 min) for TRwS in Bohunice and Liesek. Results show that lighter simulated precipitation was more likely to be less measured over longer measurement intervals in Liesek.

Of course, this issue may also be due to shortcomings in the way that gauge measurements were logged and processed as Dr. Kochendorfer put. According to MPS-system official website introduction (http://www.mps-system.sk/pdf/Projektarbeit_final_report.pdf), the measurements can be sent to a server through a GPRS (General Packet Radio Service). The transmission of data will encounter problem if the strength of the GPRS signal is not sufficient, and some data will be lost if the strength of the GPRS signal is not sufficient during a long time.

Additionally, we did not translate this resolution to 0.001 mm/30-min.

Pg. 5 ln. 24-25. Please clarify, "Even though the losses were less for snowfall events, their measurement ratio was minimal throughout the experiment".

Reply:

For sleet and snowfall measurements, the losses are 5.8 mm and 7.6 mm which are significantly less than rainfall measurements (116.2 mm) during the experiment. Since the measurement ratio is expressed as the value of TRwS_{SA} measurements / ”true” precipitation, the less losses will produce higher measurement ratio if “true” precipitation for all precipitation types were equal. However, the total “true” precipitation for snowfall events are 41.6 mm which is significantly less than rainfall events (901.2 mm) and sleet events (105.7 mm). As calculated, the total measurement ratio for snowfall events is minimal. Since Dr. Kochendorfer put this question, we realized that maybe this sentence is not on the expression of concise. We will rewrite it in the revised manuscript.

Pg. 5 ln. 29. How were the corrected $\text{CSPG}_{\text{DFIR}}$ measurements “proven” to be true in rainfall? Was it using the pit gauges?

Reply:

Yes, we have compared precipitation measured by $\text{CSPG}_{\text{DFIR}}$ and CSPG_{PIT} for rainfall events during experiment before choosing $\text{CSPG}_{\text{DFIR}}$ as a reference gauge. As shown below, $\text{CSPG}_{\text{DFIR}}$ performed well and it can be chosen for a reference gauge also for rainfall events in this field, neglecting the measurement uncertainty and random errors.

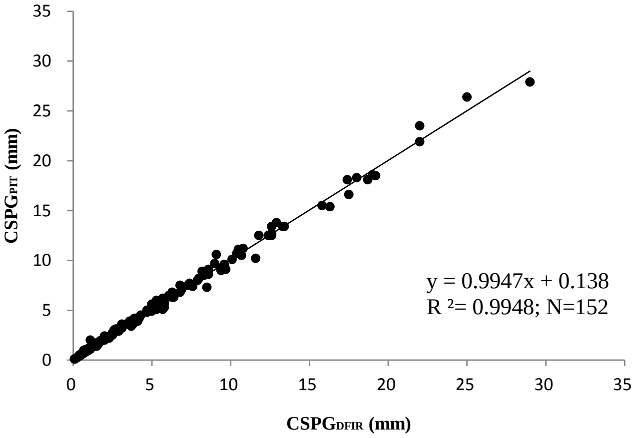


Figure 2: Precipitation measured by $\text{CSPG}_{\text{DFIR}}$ vs. CSPG_{PIT} for rainfall events during experiment.

Pg. 6 ln. 2. Clarify by rewriting, “with a mean difference within this range of 0.5 mm”.

Reply:

We change “with a mean difference of 0.5 mm” to “with a mean absolute difference of 0.5 mm within this range”.

Pg. 6 ln. 20-22. Clarify how these sums were estimated. Were actual totals of the specific errors used, rather than totals of the absolute values of the specific errors? If the mean specific errors were actually significant, this indicates that there is a systematic bias between the two single-Alter gauges, and that it might be more effective to derive the TRwS_{SA} adjustment by comparing it directly to the $\text{CSPG}_{\text{DFIR}}$.

Reply:

Yes, the losses caused respectively by specific errors and systematic errors were the actual totals of specific errors and systematic errors. Here, we think using totals of the absolute values of the specific errors or systematic errors may be not very appropriate. Fig.3 mainly analyzes the losses of $TRwS_{SA}$ from the two contributions, and the totals of the absolute values can not explain this. We consider applying the mean of the absolute values in analysis (Pg.7 ln.3-3 and Pg.7 ln.27-28) as suggested by Dr. Kochendorfer.

We investigate the precipitation difference between $CSPG_{SA}$ and $TRwS_{SA}$ for mean wind speed at gauge height during precipitation lower than 1 m s^{-1}. As calculated, the mean of the absolute values of the difference is 0.78 mm, 0.89 mm and 0.40 mm for rain, sleet and snow, respectively. Since wind speed below 1 m s^{-1} is relative low, the systematic bias induced by wind can be regarded as small.

Pg. 6 ln. 31. Clarify how the $TRwS_{SA}$ and $CSPG_{SA}$ CR were the same. Were the CR based on systematic differences, rather than measurements?

Reply:

Neglecting the different wind profile caused by these two different gauge orifice rim, gauge catchments should be the same for $TRwS_{SA}$ and $CSPG_{SA}$ because the same wind shields were used. CR refers to the value of gauge catchment / ”true” precipitation. Hence, in this case, CR of $TRwS_{SA}$ and $CSPG_{SA}$ were regarded as the same. CRs were based on corrected $CSPG_{SA}$ measurements since we think that CR of $TRwS_{SA}$ and $CSPG_{SA}$ were the same. However, we realize that this assumption may not be valid because the systematic difference caused by the different wind profile can not be ignored for windy condition. Given this, applying and testing existing transfer functions can be a better choice. In this way, however, we may discuss MR (measurement ratio) instead of CR (catch ratio) because we don’t know the actual catchment of $TRwS_{SA}$.

Pg. 8 ln 8. The range is not a good estimate of average errors, especially considering that there were many more measurements available at low wind speeds. Examine this statement more carefully, and try to support it by quantifying the errors (or scatter) at different wind speeds.

Reply:

Okay. After examining this statement by quantifying the scatter at different wind speeds, this statement is proved to be not rigorous. Therefore, we decide to delete this statement.

Pg. 9 ln 12. Light precipitation over longer intervals may be easier to quantify using the gauge depth, rather than the precipitation intensity.

Reply:

The statement that “Light precipitation coupled with longer measuring intervals has been proven to affect $TRwS_{SA}$ significantly” may be not sound. Although very small precipitation (eg., 0.001 mm) can be missing measured due to the not translated resolution, the total precipitation may be roughly the same. We have recognized that longer intervals may do not have much effect on the result since using the gauge depth. As mentioned above, it may be caused by the reason that the strength of the GPRS signal is not sufficient during a long time.

Finally, thanks again for Dr. Kochendorfer’s comments, which are valuable in proving the quality of our manuscript.

Reference:

Chen, R., Liu, J., Kang, E., Yang, Y., Han, C., Liu, Z., Song, Y., Qing, W., and Zhu P.: Precipitation measurement intercomparison in the Qilian Mountains, north-eastern Tibetan Plateau, The Cryosphere, 9, 1995–2008, doi: 10.5194/tc-9-1995-2015, 2015.

Léonard Murisier: High resolution precipitation intensity: measurement and analysis, projektarbeit_final_report, http://www.mps-system.sk/pdf/Projektarbeit_final_report.pdf.

Sevruk, B., and Chvíla, B.: Error sources of precipitation measurements using electronic weight systems, Atmos. Res., 77, 39–47, doi:10.1016/j.atmosres.2004.10.026, 2005.