Reply to Nominated Referee #2

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

General comments:

The presented concept of separation into systematic and instrument-specific errors (*2.2 Data Analysis and 3.3 specific errors of* $TRwS_{SA}$) is a different approach and might be interesting.

The derivation of the concept, however, is not convincing and is based on assumptions which are not further proofed. Generally, the rather small data set and very limited meteorological conditions at the site would make it difficult to evaluate another aspect of possible gauge errors in a representative way.

Instead of just stating that the wind-induced errors for $TRwS_{SA}$ and $CSPG_{SA}$ are the same, I suggest that you first present and compare data for both instruments and then eventually discuss this idea further based on the presented data and analysis.

Wind speeds during the two year measurement period reached maximal 2 m/s, which makes the evaluation of a wind dependent error very difficult and the derivation of an own set of wind dependent transfer functions does not make sense (*3.3 systematic errors of* $TRwS_{SA}$) as they won't be valid for other meteorological conditions or sites. Instead, I recommend to use your valuable data set of not yet in detail tested gauges and wind shield configurations to test existing transfer functions.

Please be aware that it is not meaningful to conclude on the effect of the single Alter wind shield (*4 conclusions*) for the light wind speeds you experienced during your measurement period.

Reply:

We agree with Dr. Wolff that it would be better to first present and compare data for both instruments and then eventually discuss this idea further based on the presented data and analysis. Since the wind profile for TRwS204 and CSPG can be a little different, it really seems like an immature method for distinguishing between systematic errors and instrumental specific errors of automatic gauge in this manuscript. Furthermore, the fact that relative small data set and limited meteorological conditions at this site also makes the matter worse. It will be more appropriate to discuss this idea at last.

Additionally, the limited meteorological conditions may make the result of derivation of meteorological variables dependent transfer function site-specific and data-specific. We agree with Dr. Wolff that using the measurements to test existing transfer functions rather than deriving a new one.

The authors compare 30-min precipitation data of an automatic gauge with 12 or 24 hour data of a manual gauge. It remains unclear how the 12/24 hour data for the automated gauge are derived and which data product of the automated gauge is used. Beside calculated precipitation accumulations for the chosen measurement interval (here 30 min), the TRwS 204 also provides the raw bucket content. I assume that you summed up the precipitation totals of each individual 30 min period to determine the precipitation measured during the 12 h or 24 hour period? If my assumption is correct, then you divide already low daily precipitation totals as measured from the manual gauge to the 30 min periods measured by the TRwS204 (*3.1 Total losses of* $TRwS_{SA}$). Most of those 30-min totals may be lower than the detection threshold from the gauge, thus resulting in a lower precipitation total. For those kind of comparisons, it would be more fair to either increase the measurement period of the TRwS 204 (if possible) or to use the change in the bucket content instead. The TRwS204 is a collecting gauge and over a longer period the accumulation would add up eventually, so that the accumulation is measurable.

The repeated statement of the absolute difference in precipitation measurements for different precipitation types is misguiding as it does not take into account the very different amounts measured for each precipitation type.

Reply:

Yes, the 24-h TRwS measurements were calculated cumulatively from 30-min measurements. We used the change in the absolute depth to calculate the result. For the raw bucket content, do you mean the raw weight? For TRwS204, it provides the total weight. I' m sorry I' m not quite sure about the meaning of the sentence "If my assumption is correct, then you divide already low daily precipitation totals as measured from the manual gauge to the 30 min periods measured by the TRwS204".

Since the depth resolution of TRwS204 is 0.001 mm, even if most of those 30-min totals may be lower than the detection threshold from the gauge, less than 9.6 mm (0.001 *48*200 = 9.6) will be missing measured by TRwS204 for 200 precipitation events (days). As recommended by Dr. Wolff, increasing the measurement period of the TRwS204 or using the change in the bucket content would be more fair to achieve this comparison. Now, it seems impossible to increase the measurement interval period of the TRwS204 during the experiment. Additionally, do you mean the change in the total weight in stating "the change in the bucket content"?

Finally, as commended by Dr. Wolff, we are aware of that "the absolute difference in precipitation measurements for different precipitation types" is not an appropriate way of expressing data. We will pay attention to this detail in the revised manuscript.

Specific comments:

1 Introduction

Page 2, lines 25-26: I think you don't want to imply that only automatic gauges tend to underestimate precipitation in the presence of wind. The placement of **in contrast to** needs to be changed to make that clear.

Reply:

Yes, we don't want to imply that only automatic gauges tend to underestimate precipitation in the presence of wind. We will change this sentence to "However, **compared to** manual precipitation gauges, automatically measured gauges not only ……"

2.1 Site and Data Sources

Page 3, lines 9-10: How did you determine values for annual total precipitation and annual mean air temperature? From the two years of data or any other period? Which period? Why are you using the term approximately?

Reply:

In fact, the source of annual total precipitation is from Zongxing Li et al. (2015). So I used the term **approximately**. I am so sorry that I missed this reference. I will add up it in the revised manuscript. For the annual mean air temperature, the two years (from August 2014 to August 2016) data was used. Here, I misused the term **approximately** to express that 0.7 ℃ is an approximate value. In fact, it is a matter about the number of decimal places. Hence, the term

approximately in “and the annual mean air temperature (from August 2014 to August 2016) was **approximately** 0.7 ℃” should be deleted.

Page 3, line 17: Please give a source for the stated resolution of the TRwS, I assume you took that from the provider’s manual or other documentation.

Reply:

The source for the stated resolution of the TRwS204 was from http://www.mps-system.sk/pdf/TRWS204_504_205_405_LC_1v03.pdf.

Page 3, lines 17-19: Please state that the sensor comes with an in-built software which filters the data for vibration and evaporation.

Reply:

I am sorry that we have no idea of the in-built software which filters the data for vibration and evaporation.

Page 3, line 25: Could you please describe the filtering process and the manual quality control in some details?

Reply:

Okay. Firstly, we removed the 30-min precipitation data for corresponding humidity less than 50%. Secondly, we went on to remove the 30-min precipitation data for corresponding sunshine duration equal to 0.5 h. For the above two steps, we reserved the continuous 30-min precipitation data.

Page 3, lines 25-26: Are the half-hour values averages or just aggregated values?

Reply:

The half-hour air temperature, relative humidity, and wind speed values are averages. As questioned by Dr. Wolff, this sentence may be not rigorous, and it can be more accurate by rewritten as “The half-hour **average** air temperature, relative humidity, and wind speed…… ”.

Page 3, section 2.1: It would be great, if you could add the following information:

- Which parameters are you recording form the TRwS?
- Map of the location of the site
- Layout of the site with instrument set up, also for anxcillary measurements like temperature, wind, humidity, ...
- Instrument types of anxcillary measurements or citation of a more detailed description of the site
- height of the gauge inside the DFIR

Reply:

We agree to Dr. Wolff the above recommendations.

One minute intensity and total sum of precipitation (weight and depth) were recording from the TRwS. For the map of the location of the site, layout of the site with instrument set up and a more detailed description of the site, we will supplement this content in the revised manuscript. The gauge inside the DFIR at this site is a CSPG (height = 70 cm); and the gauge inside the DFAR is a TRwS204 (height = 54 cm).

Page 3, section 2.1.: I think the information on the new automated gauge (given in section 3.3.) in a double fence can also be stated here for a complete description of the site.

Reply:

We agree with Dr. Wolff, and we will give a complete description of the site including introduction to DFAR and other gauges in the revised manuscript.

2.2 Data Analysis

Page 4, Equation 2: Please check the first line of the equation. According to Allerup et al. (1997), the corrected precipitation is P=R*measured* + Σ(Δ*Rerrors*)=k(P*measured* + Σ(Δ*Rerrors*) where R, is refering to a **reference gauge** while P is refering to the gauge under test.

Reply:

We agree with the content commented by Dr. Wolff. According to Allerup et al. (1997), the correction algorithms in our manuscript would be

$P = P_{DFIR} + \Delta P_w + \Delta P_t$

$P = k(P_{CSPG} + \Delta P_w + \Delta P_t)$

$P = k(P_{TRwS} + \Delta P_s)$,

where P is the "true" precipitation, P_{DFIR} is the $CSPG_{DFIR}$-measured precipitation, P_{CSPG} is the $CSPG_{SA}$-measured precipitation, P_{TRwS} is the $TRwS_{SA}$-measured precipitation, ΔP_w is the wetting loss of CSPG, and ΔP_t is the trace precipitation of CSPG, ΔP_s is the specific errors of $TRwS_{SA}$, and *k* is the aerodynamic correction factor.

The equations

$P = P_{TRwS} + \Delta P_s + \Delta P_a$

$P = P_{CSPG} + \Delta P_w + \Delta P_t + \Delta P_a$

where ΔP_a is the aerodynamic loss for single Alter shielded gauges, is introduced primarily to calculate the specific errors of $TRwS_{SA}$. They are a little different from general correction model in the work by Allerup et al. (1997), through which we attempt to quantify the aerodynamic losses.

Page 4, Lines 15-16: For your analysis you make the assumption that the systematic errors of the $CSPG_{SA}$ and the $TRwS_{SA}$ are the same. While it is an interesting idea to separate the errors in instrument-specific and systematic error, I find that you have at this point of the manuscript to little substance to introduce this step and it seems rather artificial and complicated. I suggest that you first present and compare data for both instruments and then discuss this idea based on the analysed data.

Reply:

We agree with Dr. Wolff. We did briefly describe the separation method, but made it look complicated. We will consider carefully the suggestion made by Dr. Wolff.

Page 4, line 25: Earlier you introduce that manual measurements are performed twice a day (Page 3, line 23). Here you refer to daily precipitation. Are you using 12 or 24 h periods? In case of 24 h-periods (= daily) which of the two daily measurements are you using?

Reply:

Yes, we used 24 h periods. As stated in page 3 line 23, manual measurements were performed twice a day at 08:00 and 20:00 (Beijing time). We used these two measurements in one day to calculate the manual measurements of the day.

3.1 Total Losses TRwS$_{SA}$

Table 1 and related text in the section: For completeness, please add the measurements of CSPG$_{SA}$ in the table and discuss those. As discussed under general comments, I think the comparison of precipitation totals based on separate 30-minperiods with totals for 12 or 24 h periods introduce an additional (non-real) bias for the automated gauge. It is possible for the TRwS to measure the total accumulation over the longer interval, thus also the TRwS may be able to register those small amounts of precipitation.

Reply:

We will consider the suggestion made by Dr. Wolff that "For completeness, please add the measurements of CSPG$_{SA}$ in the table and discuss those". Additionally, we agree with the comment made by Dr. Wolff that "the comparison of precipitation totals based on separate 30-min-periods with totals for 24 h periods introduce an additional (non-real) bias for the automatic gauge". It may cause the fact that the small amounts of precipitation were failed to be recorded. However, this undercatch would be small (less than 0.048 mm/24 h).

Further, 10 out of 207 events are less than 5%. That means, in more than 95% of the cases, the TRwS$_{SA}$ detected precipitation measured by the reference. I find that is a very important and positive result which should be mentioned. I find it doubtful to conclude on remaining instrument issues caused by temperature effects and inaccurate measurement of small amounts of precipitation from 10 single cases.

Reply:

We agree with Dr. Wolff that the fact that TRwS$_{SA}$ detected precipitation measured by the reference in more than 95% of the cases is a very important and positive result. It should be mentioned while we overlooked this point. We will state it in the revised manuscript. Additionally, we did somewhat hurriedly came to the conclusion that "Given that the measuring interval was set to 30 min, these events can be explained by the combined effect of the light precipitation and longer measuring intervals" which need to be given further consideration. This issue may also be due to shortcomings in the way that gauge measurements were logged and processed. 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.

Page 5, line 9: Isn't the definition of trace that the amount of precipitation can't be measured? Thus, the fact that the manual methods did not measure the trace is redundant and not a special fact which needs to be explained by the complex microtopography of the area.

Reply:

Yes, the definition of trace is that the amount of precipitation can't be measured. Here, we are mainly trying to explain the situation that the TRwS also failed to measure the 12 events of trace precipitation reported by the observer. Since the depth resolution of TRwS is 0.001 mm, it is expected to have the ability to record trace precipitation which usually can not be measured by manual method with a resolution of 0.1 mm.

Page 5, line 18: To my knowledge are winds up to 3 m/s called light. The term moderate is used for winds higher than 5.5 m/s. That is important, because for light winds the expected wind-induced undercatch is very small.

Reply:

We agree with Dr. Wolff that the term “moderate” is inappropriate here. It should be replaced by the term “light” more accurately. We are sorry to have failed to consider these words carefully.

Page 5, line 19: The different precipitation types occured in very different numbers (both number of events and amount of precipitation) and the comparison of absolute values is not giving the right impression on where you noticed large and small deviations. From the numbers in table 2, I calculate that the reference measured on average 2 mm snow, 3 mm sleet and 7 mm of rain per event. Your stated average undercath of 0.4 mm for snow, 0.2 mm for sleet and 0.8 mm for rain relates to 20% undercath for snow and approx. 10% undercatch for rain and sleet. I find those kind of numbers better comparable with results from other studies.

Reply:

We agree with Dr. Wolff, and we are aware of this problem. We will pay attention to the way of expressing data in the revised manuscript.

Page 5, line 20-22: The sentence "**This result was unexpected ...**" belongs into conclusions and should be discussed there.

Reply:

OK, we will consider this suggestion in our revised manuscript.

Table 2 and related text in the section: For completeness, please add the measurements of $CSPG_{SA}$ in the table and discuss those.

Reply:

OK, we will add the measurements of $CSPG_{SA}$ in Table 2 and discuss those as suggested by Dr. Wolff.

3.2 Linear Correlation of $TRwS_{SA}$ Measurements and "True" Precipitation

Figure 2: I wonder if it is possible to combine those plots into one, using different colors for the different precipitation type, thus giving a more comparable impression of the scatter plots. For completenes, please add a similar plot(s) for the measurements of $CSPG_{SA}$. I find it questionable to calculate new regression lines, as especially for sleet and snow the low number of points make it difficult to reach statistically significance. Why not calculate the standard deviation and the standard error?

Reply:

Yes, we can combine those plots into one, using different colors or the different precipitation type. Since it could achieve a better comparison, we will redraw a new one. Moreover, a similar plot for the measurements of $CSPG_{SA}$ will be added as suggested by Dr. Wolff.

In addition, there can be some problems for calculating new regression lines when the precipitation events are fewer. Although this situation may be improved by extending the experiment period, we will also try to calculate and analyze the standard deviation and the standard error.

Page 6, lines 9-10: Instead of stating that half of the measured events were overestimated, I recommend to state that the deviations seems to be randomly distributed around the 1-1-line and both over- and underestimate, or generally that a larger scatter was observed. The calculation of standard deviation would help to set this in relation to rain and snow. The different scales of the panels in figure 2 makes it difficult to see which deviations are actually "larger" and "smaller".

Reply:

We agree with Dr. Wolff that it will be better to state that the deviation seems to be randomly distributed around the 1-1 line and both over-and underestimate rather than state that half of the measured events were overestimated. We will adopt the suggestion made by Dr. Wolff. Additionally, the different scales of the panels in Figure 2 did make it difficult to see which deviations are actually “larger” and “smaller”. As recommended by Dr. Wolff, it will give a more comparison impression of the scatter plots when combine plots in Figure 2 into one.

3.4 Systematic Errors of $TRwS_{SA}$

Page 7, line29: The Alter shield has also in other studies shown good effect for reducing wind-induced undercatch for light wind speeds.

Reply:

We agree with Dr. Wolff that the Alter shield has also shown good effect for reducing wind-induced undercatch for light wind speeds. This sentence may be described as not too rigorous and we will reconsider it.

Pages 8-9: I don’t understand why you try to generate new transfer functions with you data set instead of applying existing (with advantage from different authors) transfer functions and discuss if they work. As you don’t have data with gentle, moderate or strong wind speeds, it will be difficult to develop new representing transfer functions depending on wind speed.

Reply:

We agree with Dr. Wolff that it will be better to apply and test the existing transfer functions given the current precipitation data and limited meteorological conditions. We will adopt this suggestion in the revised manuscript.

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

Reference:

Allerup, P., Madsen, H., and Vejen, F.: A comprehensive model for correcting point precipitation, Hydrol. Res., 28, 1–20, 1997.

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

Zongxing Li, Yan Gao, Yamin Wang, Yanhui Pan, Jianguo Li, Aifang Chen, Tingting Wang, Chuntan Han, Yaoxuan Song, Theakstone W.H.: Can monsoon moisture arrive in the Qilian Mountains in summer, Quatern. Int., 358, 113–125, 2015.