Response to K. Helfricht

General comments

The paper "Errors and adjustments for single-Alter shielded and unshielded weighing gauge precipitation measurements from WMO-spice" by John Kochendorfer et al. is published as a part of the HESS special issue presenting results of the recent WMO initiative evaluating the catch efficiency from different gauge types. The paper contributes to the present efforts of adjustments of precipitation undercatch for a wide range of applications in climatology and hydrology as well as real-time corrections for nowcast and short-term forecast applications. On the basis of well measured data from eight locations including lowland and mountain stations it presents transfer functions which can be used to adjust 30 minute precipitation gauge data for undercatch in scientific studies and in operational services. The paper is well structured and concisely written. It presents the literature on this subject comprehensively. The paper is worth publishing in HESS with a few minor corrections.

Authors' response: Thank you.

Specific comments

(1) The authors used aggregated 30 minute precipitation data to develop the transfer functions. However, the authors should discuss if the presented transfer functions are also valid adjusting precipitation data of higher or lower time intervals, e.g. 10 minute, hourly or daily. Deviations can be expected caused by different mean wind speeds. This may be achieved by calculating adjusted precipitation for the sub-daily time intervals and comparing the daily aggregated values.

Authors' response: Deviations caused by different mean wind speeds are indeed possible for longer time periods. The validity of the transfer functions derived from 30-min measurements when applied to longer time periods (12 h and 24 h) has been addressed in the revised manuscript and the response to Fortin. The approach used was to create 12 and 24 h precipitation datasets, apply the 30-min derived transfer functions, and also derive and apply 12 and 24 h derived transfer functions. Because the reference amount of precipitation is known and has been measured in these different time intervals, it is not necessary to take the suggested step of summing up from shorter intervals to longer intervals in order to evaluate the effects of varying time interval, although this is a good suggestion. Accumulation periods shorter than 30 min have not been evaluated. One of the challenges in evaluating different time periods is that datasets derived for different time periods following the WMO-SPICE event selection criteria were independent of each other. For example the sum of all of the 30-min event accumulations in a day will not necessarily be equal to the corresponding 24 h accumulation. This is due to the fact that not all 30-min periods may meet the criteria for inclusion in the 24 h event dataset. Application of a transfer function to periods that do not meet these event criteria is perfectly valid, but such an analysis is beyond the scope of this manuscript. In addition, the approach taken with the 12 and 24 h periods, whereby the presented transfer functions were compared to transfer functions derived specifically for the 12 and 24 h periods, may not work well on time periods shorter than 30 min, as the amount of measurable solid precipitation will in many cases be approaching the noise level of the gauge.

(2) The authors present the complexity of errors at mountain stations. Especially the Weissfluhjoch station showed individual deviations at high precipitation – high wind speed events. Using a lower maximum wind speed thresholds results in smaller errors at this station. It will be advantageous if the authors present at least an advice on how to quality control data of mountain stations for such anomalies from the presented transfer functions without having a DFAR reference.

Authors' response: Unfortunately, without a DFAR or some other type of well-shielded reference, it is not possible to know how appropriate the presented transfer functions are for a given site. This issue was addressed in the Discussion (pg. 16. Ln. 1-10 in the originally-submitted manuscript). Here is an excerpt, "However, because one mountainous site was overcorrected (Weissfluhjoch), and the other two were undercorrected (Formigal and Haukeliseter), it is not possible to recommend general modifications to the transfer functions for use in mountainous sites." The advantage of the multi-site transfer functions and the multi-site evaluations in the present manuscript is that at least the uncertainty can now be estimated. The authors recommend using the transfer functions as presented, acknowledging the known uncertainties. This sentence has been added to the conclusions, "These results indicate that the transfer functions developed and presented here should be evaluated at new testbeds in the mountains and complex terrain, and also in other areas subject to high winds and unusual precipitation."

(3) Since no transfer function for adjusting liquid precipitation is presented, please consider to add "for mixed and solid precipitation" to the paper title.

Authors' response: The title has been changed to, "Analysis of single-Alter shielded and unshielded measurements of mixed and solid precipitation from WMO-SPICE". In an effort to make the title more concise, other words were removed.

Minor Comments

P3 Line 11ff: Please add the time interval of the data analysed.

Authors' response: This time period of the measurements is described in detail in the Methods section, but the phrase, "spanning two winter seasons from 2013-2015" has been added.

P3 Line 16: The last sentence may be shifted to the conclusion section.

Authors' response: The sentence has been moved to the first paragraph of the Conclusion.

P4 Line 21 and 23: Please present the expected min/max/range values for the 1 minute values.

Authors' response: This text refers to all of the WMO-SPICE measurements, including air temperature, wind speed, wind direction, and others, and as such includes many different min/max values. This has been clarified by changing the text from, “A range check, to identify and remove points with values outside of the maximum and minimum expected values for each sensor”, to “A range check, to identify and remove values that were outside of the manufacturer-specified output range for each sensor”.

P5 Line 23: Please refer to the number of events given in Tab. 1 and 2.

Authors’ response: Table 1 and 2 do not include all of the SEDS measurements, as they were subject to further quality assurance and threshold tests as described in the section titled, “Filtering of precipitation events”. Because of this it would be inaccurate to reference them here.

P7 Line 1: Add the information of time interval for aggregation of 30 min.

Authors’ response: Thank you! This is especially important now that the manuscript includes analysis of other time periods. The text has been changed accordingly.

P8 Line 12: The 30 minute minimum thresholds of SLEDS are quite low. Disaggregating these values to 60 % of 30 minutes results in precipitation rates of a minimum of 0.001 to 0.002mm/minute. How do these values correspond to the nominal accuracy of the precipitation gauge?

Authors’ response: It is indeed true that the precipitation rate of the SLEDS is quite low. However weighing gauges output the total weight of accumulated water, so in theory extremely low-rate precipitation can be measured accurately if the time period is extended, allowing the gauge to accumulate a measurable change in weight. This is part of the reason accumulation periods shorter than 30 min were not evaluated, as snowfall is frequently associated with low precipitation rates. Based on the manufacturers specifications, the 600 mm Geonor T200B accuracy is 0.6 mm (0.1% full scale), and its sensitivity is 0.05 mm. The output from this gauge is a frequency however, so in practice the resolution is higher than 0.1 mm if it the output is averaged or summed over a longer time period. The Pluvio^2 stated accuracy is 0.1 mm, and its resolution is 0.01 mm. In practice the accuracy of these gauges were fairly similar, and were both typically less than 0.1 mm, as can be seen from Figure 9 in the original manuscript (Figure 10 in the revised manuscript).

P9 Line 16ff: Is it the maximum threshold of the 30 min average wind speed or is it the maximum wind speed in the 30 min interval. Please clarify.

Authors’ response: This is an excellent question! We have clarified in the manuscript that the threshold was applied to the mean 30-min wind speed. To further clarify, the threshold is now referred to as the “wind speed threshold”, rather than the “maximum wind speed” throughout the text.

P11 Line 25ff: The higher catch efficiency might also be caused by increased wind influence and thus undercatch at the DFAR. Please discuss.

Authors' response: Thank you, this is indeed possible. This has been added to the manuscript, "Heterogeneous winds and/or significant mean vertical wind speeds may also have caused the DFAR to underestimate precipitation in high winds."

P12 Line 15: Please define "other sites".

Authors' response: A list of the other sites has been added in parentheses, "(CARE, Sodankylä, Caribou Creek, Marshall, and Bratt's Lake)".

P12 Line 18: Replace "alpine measurements" by "measurements at mountain sites"

Authors' response: "Alpine" has been replaced by "mountainous" throughout the text.

P15 Line 29: (here and throughout the text) Are the same stations meant with "alpine" and "mountain" sites? If so, please consider to use only one of the two.

Authors' response: "Alpine" has been replaced by "mountainous" throughout the text.

Figures: Figure 2 and 6: To show the temperature dependence of Eq.3 please present additional calculations for at least one warmer and one colder temperature level (e.g. -2 and -10◦C).

Authors' response: Due to the relative insensitivity of the transfer functions to temperature below -2 °C, the addition of these other cold temperatures do not add much value, and they detract from the main point of these figures. Figure B1 is included below as an example.

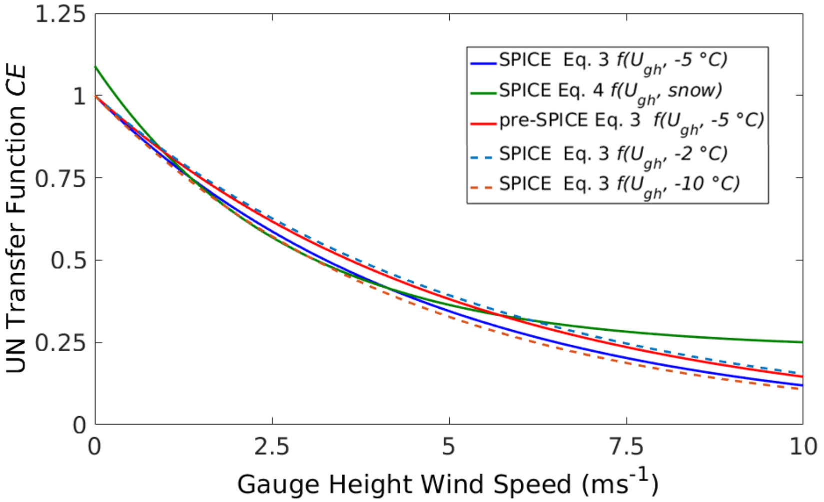

Figure B1. Transfer functions describing the unshielded (UN) catch efficiency (*CE*) as a function of the gauge height wind speed (U_{gh}). The Eq. 3 results were produced by modelling *CE* with respect to wind speed at T_{air} = -5 °C, and both the Kochendorfer et

al. (2016) pre-SPICE (red line) and the current results (blue line) are shown. In addition, the Eq. 3 function is shown at T_{air} = -2 °C and T_{air} = -10 °C (dashed lines). The Eq. 4 snow (T_{air} < -2 °C) results (green line) are also shown.