<u>Response to V. Fortin.</u>

This is a much needed paper that addresses a very important problem in meteorology, climatology and hydrology: dealing with gauge undercatch from all-weather gauges in operations around the world. The paper is well written and nicely builds upon the published literature on the subject. It makes use of a unique dataset carefully gathered during the SPICE project. I strongly recommend its publication. I however do have a few comments that I would like to see addressed before the paper is published in HESS.

My most important comment is that the results may not be readily applicable, because of the authors' decision to derive transfer functions that require 30 minute data. Sub-hourly data is not easily accessed in real-time, and can be very difficult if not impossible to obtain for archived data. Even hourly data is hard to obtain. And when it is accessible, it is often not quality controlled at this frequency. The authors are strongly encouraged to discuss how their method could be applied to data that is only available at lower frequencies (hourly, three-hourly, six-hourly, twelve-hourly and daily).

Authors' response: Fortin raises an important issue here regarding the relationship between the time period over which a precipitation measurement is recorded and the resultant catch efficiencies. This topic was the subject of much discussion and analysis among the authors of this manuscript and the other participants in WMO-SPICE, but this work was admittedly not originally reflected in the present manuscript. 30-min data were used to derive the transfer functions because this period is short enough to allow for representative wind speed and air temperature measurements while simultaneously being long enough to allow for significant and measurable solid precipitation to accumulate, but this does not mean that the transfer functions can only be applied to 30-min measurements. To address this, additional analysis has been performed on 12 and 24 h precipitation measurements. 12 and 24 h precipitation accumulations were created, and the 30-min transfer functions were applied to them. For the sake of comparison, transfer functions specific to the 12 and 24 h accumulations were also created and applied to the appropriate measurements. This analysis is described in the new Methods Section 2.2.6, an additional paragraph in Methods Section 2.2.9, the new Results Section 3.7, and an additional paragraph in the Conclusions. These changes are documented in the track-changes version of the revised manuscript, which has been provided along with our responses to the reviews. Four new figures have also been created describing the 12 and 24 h precipitation measurement errors (Figures A1 – A4), demonstrating that the transfer functions derived from the 30 min measurements are appropriate for these longer time periods. However, for the sake of brevity only the figures describing the unshielded measurements (Figures A1 and A3) are included in the revised manuscript.

The authors acknowledge that significant uncertainty remains after bias correction on the precipitation amount, even if the method does a reasonable job of controlling the bias. The authors should ideally communicate this uncertainty by publishing, together with the transfer function, an estimate of the standard error of the catch efficiency, as was done for example by Fortin et al. (2008), Hydrol. Proc.

Authors' response: This is indeed a good point. The uncertainty has now been calculated for all of the transfer functions (Table A1 below) and a summary of the results has been added to the manuscript (Section 3.3). These results show that the uncertainty is approximately 0.2 for all of the functions tested. Other testing performed in a separate manuscript submitted to HESS in April 2017 (which has not yet been published for discussion) show that the uncertainty of the transfer function is also fairly insensitive to the wind speed.

Using the method proposed in this paper by the authors, I hope that bias-corrected precipitation data can soon be used in an optimal manner by land-surface data assimilation systems in cold regions. Such systems are routinely used to initialize land-surface, meteorological and hydrological forecasting systems. However, in a data assimilation system it is crucial to accurately estimate the standard error of the observations. Information on the standard error of the catch efficiency is obviously crucial for this purpose. This is why I strongly recommend that the authors propose an estimate for the standard error of the catch efficiency together with the transfer functions.

Authors' response: We agree. See the response to the comment above.

Minor comments: Equation (2) The equation is incorrect. Wind speed is proportional, not approximately equal to log[(z − d)/z0]. It should be mentioned that this equation assumes neutral stability conditions.

Authors' response: Thank you! The ≈ symbol has been replaced with a proportional symbol, and the assumption of neutral stability has been noted in the revised manuscript.

Section 2.2.6 The authors need to better justify lumping together data from the Pluvio and Geonor gauges

Authors' response: Fortin brings up an important point here. Section 2.1 (pg. 4, ln. 9 -13) does include some justification for combining the Pluvio and Geonor gauge data, but further justification has been added to this section of the revised manuscript. The CARE site had both unshielded and single-Alter shielded Pluvio^2 and Geonor gauges. In response to this comment, these paired measurements were compared more closely. Fig A5 shows the results of the comparison between the unshielded gauge measurements. 389 single-Alter shielded Pluvio^2 and Geonor measurements were also compared, resulting in a slope of 1.01, offset of -0.002, and a RMSE of 0.085 mm (not shown); fewer single-Alter shielded measurements were available for comparison with each other due to the proximity of the DFIR to the single-Alter shielded Geonor gauge at the CARE testbed. In addition, Eq. 4 type solid precipitation transfer functions were created independently for each of the two types of single-Alter shielded gauges and also for the two unshielded gauges at CARE (e.g. Fig. A6), and no significant differences were found between the wind-speed responses of the different gauge types. Fig. A5 and a summary of these comparisons have been added to the first Methods Section of the revised manuscript. Fig. A6 required some additional analysis to create (the version included here is in fact somewhat preliminary), requiring accompanying explanation and methods, and is arguably not important enough or central enough to the main point of the manuscript to merit its addition.

Figures

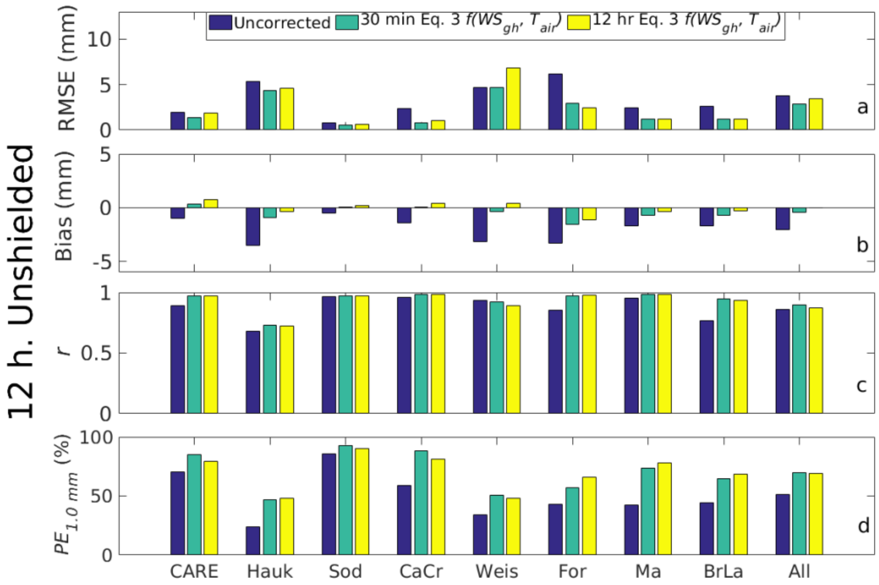


Figure A1. Error statistics for 12 h unshielded precipitation measurements that are uncorrected (blue), corrected using the 30-min derived transfer functions (green), and corrected using the 12 h derived transfer functions (yellow) are compared.

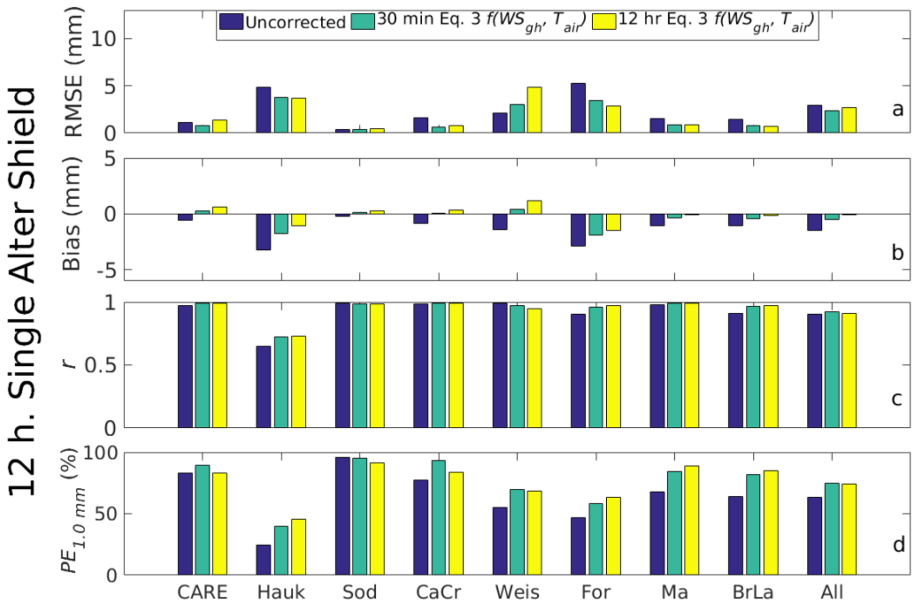
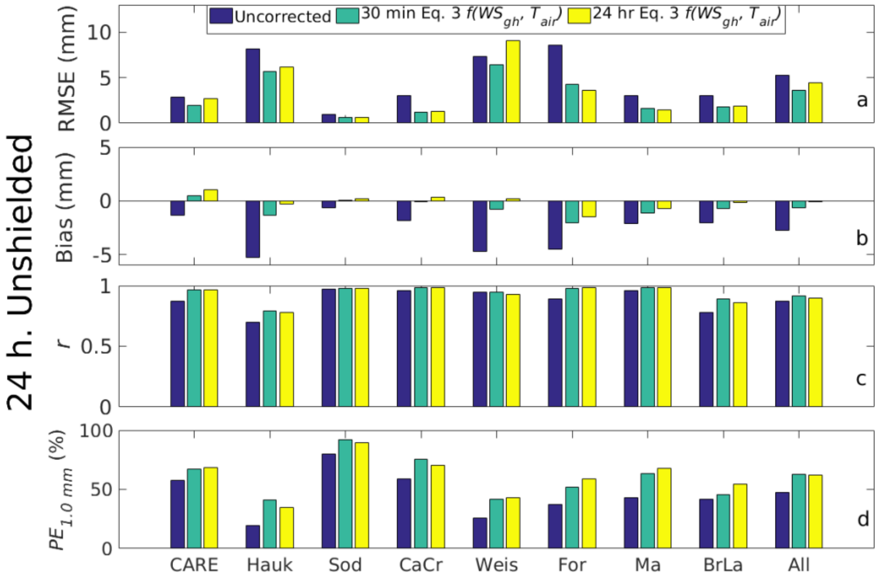


Figure A2. Error statistics for 12 h single-Alter shielded precipitation measurements that are uncorrected (blue), corrected using the 30-min derived transfer functions (green), and corrected using the 12 h derived transfer functions (yellow) are compared.



5 **Figure A3. Error statistics for 24 h unshielded precipitation measurements that are uncorrected (blue), corrected using the 30-min derived transfer functions (green), and corrected using the 12 h derived transfer functions (yellow) are compared.**

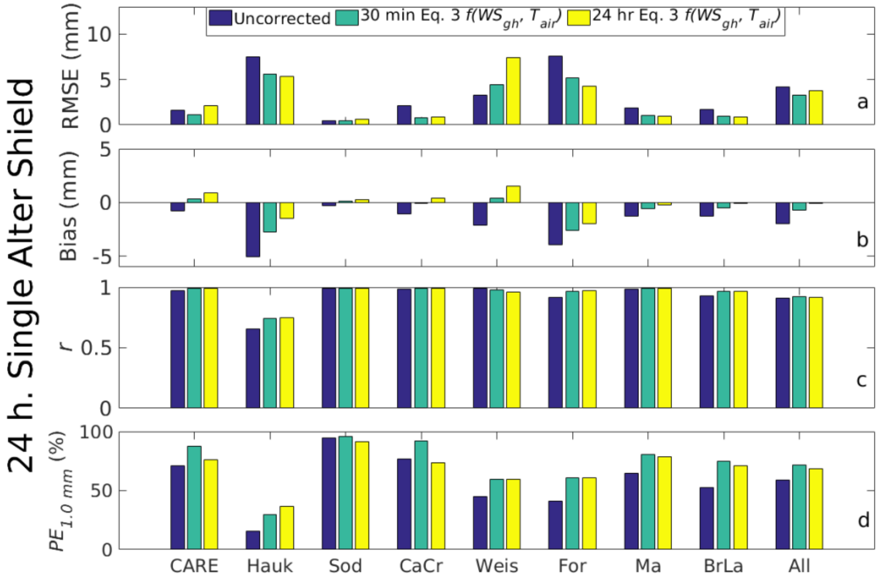


Figure A4. Error statistics for 24 h single-Alter shielded precipitation measurements that are uncorrected (blue), corrected using the 30-min derived transfer functions (green), and corrected using the 12 h derived transfer functions (yellow) are compared.

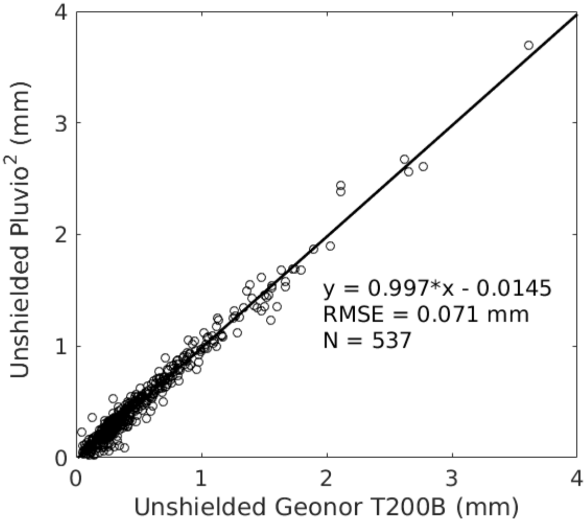


Figure A5. Comparison of unshielded Pluvio^2 and Geonor gauges at the CARE testbed during WMO-SPICE.

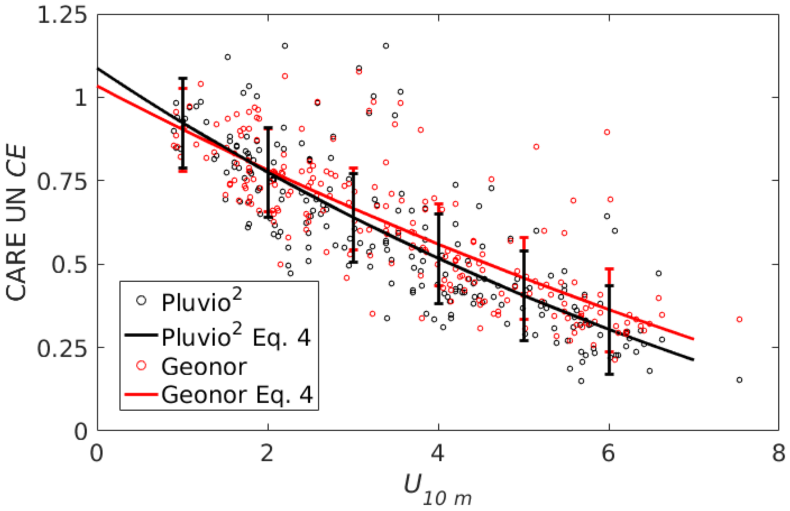


Figure A6. Catch efficiency (*CE*) measurements from unshielded Pluvio^2 (black circles) and Geonor (red circles) solid precipitation (T_{air} < -2 °C) measurements at the CARE testbed during WMO-SPICE. Eq. 4 has been fit to each measurement type (solid lines). Errors were estimated using the RMSE of the *CE* transfer functions, which were 0.13 for the Pluvio^2 and 0.12 for the Geonor.

Tables

Configuration	**Transfer function**	**Wind speed**	***CE* RMSE**
Unshielded	Eq. 3	Gauge height	0.18
Unshielded	Eq. 4, mixed	Gauge height	0.20
Unshielded	Eq. 4, snow	Gauge height	0.19
Unshielded	Eq. 3	10 m	0.18
Unshielded	Eq. 4, mixed	10 m	0.21
Unshielded	Eq. 4, snow	10 m	0.19
Single Alter	Eq. 3	Gauge height	0.18
Single Alter	Eq. 4, mixed	Gauge height	0.19
Single Alter	Eq. 4, snow	Gauge height	0.19
Single Alter	Eq. 3	10 m	0.18
Single Alter	Eq. 4, mixed	10 m	0.19
Single Alter	Eq. 4, snow	10 m	0.19

Table A1. Transfer function uncertainty, expressed as the RMSE of the function used to describe catch efficiency (*CE*).