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Interactive comment on "Evaporation from weighing precipitation gauges: impacts on automated gauge measurements and quality assurance methods" *by* R. D. Leeper and J. Kochendorfer

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The authors would like to thank each of the reviewers for their efforts in reviewing our manuscript entitled "Evaporation from Weighing Precipitation Gauges: Impacts on Automated Gauge Measurements and Quality Assurance Methods". Reviewer comments and suggestions have culminated in a manuscript that is now more inclusive and thorough with the addition of algorithm descriptions and a more complete explanation of diurnal depth variations over dry periods. They also led to the correction of figure 5

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(previously 4) that originally displayed the incorrect column of data for the Geonor-NonEvap gauge, improving the manuscript further. These modifications have strengthened a manuscript that investigates the importance of quality control techniques on precipitation measurements that should appeal to both QC development and data user communities, resulting in what we hope will be a useful and well-cited manuscript. Provided below are author responses (italicized) and when necessary manuscript revisions (in purple) to each reviewer comment.

P 12852: line 17-20: Abstract: Please add here the names of the two important methods used later extensively in the analysis: pairwise and weighted average method.

The algorithm names have been incorporated into the abstract.

In general, the pairwise method that utilized a longer time series to smooth out sensor noise was more sensitive to gauge evaporation (-4.6% bias with respect to control) than the weighted-average method that calculated depth change over a smaller window (< +1% bias).

P 12852: line 3: "lower" not clear what you mean.

The sentence has been modified with "lower" removed.

Evaporation from a precipitation gauge can cause errors in the amount of measured precipitation.

P 12853: line 28: In the WMO, 2008 document the precipitation bias is given in percent, not in absolute difference. In Table 1, only the difference is provided. The precipitation events are often treated differently based on the intensity. Perhaps further conclusion could be provided using percent error due to evaporation per event.

Reporting percent differences for the relatively small (< 1 mm) individual precipitation events captured over this study period would be miss leading, resulting in very large or NA percent differences. For instance, the pairwise algorithm for event 9 had reported precipitation from the Geonor-Evap gauge, but none from the control. In these cases,

"NA" would be reported. In other scenarios, differences as small as 0.1 mm can result in percent differences greater than 25%; see events 2, 9, 10, 24, 27, and 29 for the wAvg method. Moreover, the mean of event percent differences would not match the study period percent difference of for the pairwise (4.6%) or wAvg (< 1%) algorithms. Differences as small as 0.1 mm can be caused by other factors such as sensor noise or the natural spatial variability of precipitation even over short distances. Over time, such factors would average out and therefore it may be more appropriate to report percent differences over the entire study period rather than on an event time scale. In addition, other studies investigating the impacts of gauge evaporation biases on precipitation measurements generally report a mean difference over larger periods of time (annually-in Golubev et al. (2009)) or do not report percent error for event below some lower limit as in Duchon and Essenburg (2001). For these reasons the authors have opted not to include percent differences per event.

P 12854: line 13: replace "Addition" with "Additional"

This has been revised based upon comment from reviewer 1's second introduction comment with the word "Addition" removed.

P 12855: line 11: Similarity of the Tretyakov and Geonor gauges is a subjective statement, it is more important to describe the characteristics of the gauges.

This sentence was removed during the rewrite of this paragraph as suggested by reviewer 1 methodological comments 1 and 2. The design of the Geonor gauge is now better described.

P 12855: line 21: For the transparency of the experiment the description of the suppressant (type, quantity and concentration) should also be added. Related to the gauge description, I could not find weather it is heated or non-heated gauge; the type of shield applied on the actual two Geonor T-200B gauges.

The text has been changed to include these details. See response to reviewer 2 com-

ment 4 regarding the antifreeze/oil mixture.

The campaign consisted of two identical Geonor T-200B gauges surrounded by double-Alter shields that are collocated within 10 meters as shown in Fig. 2.

The CRN Geonor gauges also have inlet heaters installed on them to prevent orifice capping caused by snow and ice; however, these heaters are only operated at freezing temperatures and were never activated during this study.

Methodology: The applied terminology of "evap" gauges is confusing to me as well (similarly to Referee #2). The term used as noun (evaporation) or as the gauge descriptionshould be separated. I like better the terminology suggested by Ref#1: Geonor-Evap and Geonor-NonEvap for the gauge type description.

This new reference system has been adopted throughout the manuscript.

Additionally, there are four different time-series discussed here: 1) Geonor_Evap_pairwise; 2) Geonor_Evap_wAvg; 3) Geonor_NonEvap_pairwise; 4) Geonor_NonEvap_wAvg. To avoid any misunderstanding, I suggest spelling out at each of the occurrences.

A list of the four series has been worked into the first sentence of the last methodology section paragraph.

To evaluate QA performance, gauge data from the collocated Geonor-Evap and Geonor-NonEvap gauges were processed through two QA systems for precipitation and compared, resulting in a total of four series: Geonor-Evap_wAvg, Geonor-Evap_pairwise, Geonor-NonEvap_wAvg, and Geonor-NonEvap_pairwise.

P 12856: line 14: Further details are required in the description of USCRN QA system regarding "aggregated" one-minute gauge depth to 5 minutes.

As noted in our response to reviewer 1 comment 1a. This is really just a simple sub-sampling and the text has been modified to make this clearer.

P 12856: line 16-27: Two types of quality assurance (QA) algorithms were applied on the raw data from the experiment, namely the pairwise and the weighted average wAvg method. The definitions of the equations are missing from the paper, only referring to another submitted (accepted?) paper. Since the difference from these two methods is an important finding of the present discussion paper, detailed and precise description of the equations should be added here.

The authors are currently awaiting reviewer responses to the revised submitted manuscript. As such, descriptions of both QA methods have been added in the creation of an additional section focused on the QA method description. This section immediately follows the manuscript's introduction. With that said, there is no single equation that describes the process, which is made up of a series of steps and described in this new section. See response to reviewer 1 comment 1b.

P 12857 line 23-24: The average hourly loss and the associated range should be defined better, the meaning is not clear in the context. Also, the same precision should be used on the base and interval.

The range represents the standard deviation, which was included to provide the readers some context to the distribution of data about the mean. The interval has been removed and replaced with an additional figure (figure 4) showing box plots of depth variations for both gauges. This new figure not only shows the distribution of data about the mean, but also helpful in distinguishing variations in gauge depth over dry periods due to sensor noise and gauge evaporation.

P 12858 line 7: "regardless of wind speed" – based on figure 4d, this statement is not true.

This sentence was written based on the fact that losses in gauge depth of 0.5 mmhr-1 or more were observed over the entire wind speed range; 0 to 8 ms-1. In other words, losses in gauge depth occurred at very low (< 1ms-1) and moderate (>6 ms-1) wind speeds. There is indeed a weak positive correlation between evaporation rate and

wind speed (R2 = 0.13), however as the relationship between wind speed and VPD is equally significant (R2 = 0.14), it may not be that important. See our response to reviewer 1 comment 2 as well.

P 12858 line 9: false precipitation due to "condensation buildup" – need to be studied and explained further.

The algorithms handle false precipitation scenarios (due to condensation buildup, synchronized sensor noise, animal infestations, or other possible sources) by using a collocated precipitation detector that determines if precipitation is falling, independently confirming the presence precipitation. In these scenarios, this test will throw out false precipitation due to condensation. This test is included in both algorithms and is documented in the algorithm descriptions.

P 12858 line 15: Figure 5 – the minimum reached at 19 not 18

Thank you. The minimum depth change did actually occur at 18:00. The figure labels did not appear on the graph correctly. Specifically hour 0 was improperly labeled 1. Figure five (now 6) has been corrected.

P 12858 line 17: albeit = even though

Sentence has been reworded as shown below.

A diurnal signal was also detected from the Geonor-NonEvap gauge due to sensor noise, which had a much smaller amplitude and dissimilar periodicity (timing of peak and trough) compared to the Geonor-Evap gauge.

P 12858 line 13-22: In this resolution all the consideration regarding the results is not necessary true before the actual processing algorithm and signal noise is not well defined. The analysis of the magnitude of possible errors would add to the credibility of the conclusions.

A comprehensive analysis of all possible gauge errors is beyond the scope of this study.

However, the comparison of identical Geonor gauges over dry periods was done not only to analyze evaporative losses from the Geonor, but also provide some insight into the magnitude of sensor noise over the study period. Assuming depth changes over dry periods is due to all possible errors (there should be no change in gauge depth), the Geonor-NonEvap gauge should provide some measure of error due to sensor noise. Likewise, variations in gauge depth over the dry period from the Geonor-Evap gauge should give some measure of errors due to sensor noise and gauge evaporation.

To quantify these variations further, root mean squared error (RMSE) was calculated for both gauges over the dry period using the same assumption; that changes in gauge depth are caused by errors the over dry periods. RMSE values computed over dry hours (no precipitation) were 0.16 and 0.04 mm for the Geonor-Evap and Geonor-NonEvap gauges respectively. It is interesting to note that the RMSE values from the Geonor-Evap gauge is larger than variations due to other sources of noise besides evaporation from the Geonor-NonEvap gauge. In addition, afternoon (13:00-19:00 local time) hourly losses in gauge depth of 0.2 mm hr-1 or greater from the Geonor-Evap gauge exceeded the RMSE value for this gauge, suggesting that losses in gauge depth due to evaporation were larger than the uncertainty of the gauge due to sensor noise. RMSE results were presented in the results section of the manuscript as noted below.

In addition, the Geonor-NonEvap gauge has a smaller root mean squared error (RMSE) of 0.04 mm than the Geonor-Evap gauge (0.16 mm), assuming any change in gauge depth over dry periods is considered an error. The mean reductions in depth from the Geonor-NonEvap gauge were of similar magnitude to the NWS standard 8" gauge reported in the Golubev et al. (1992) study. The larger variations in depth change from the Geonor-Evap gauge suggest that the gauge evaporation signal is larger than sensor noise and causes a negative bias in depth change. Given average losses and RMSE values were below the accuracy of the instrument (0.1 mm), depth changes over the dry period from the Geonor-NonEvap gauge were considered negligible.

P 12859 lines 3-4: It is actually Evap – NonEvap in Table 1, please correct. Also, the sign of difference is not consistent in case of pairwise algorithm either.

This sentence is referring to figure 6 not table 1, which was calculated as Geonor-NonEvap minus Geonor-Evap. However, for consistency sake figure 6 (now 7) was recreated to remain consistent with table 1 and as such the sentence has been revised as suggested.

P 12859 lines 10-18: some details of the missing QA pairwise and wAvg descriptions are included here (the use of reference depth), even more highlighting the need for the accurate description of the algorithms earlier in the methodology section!

As noted previously, algorithm descriptions have been included in the manuscript; see section 2 of the revised manuscript.

P 12861 lines 11-14: The conclusion that "suppressants and evaporative adjustments : : : may not be required" is too strong, cannot be concluded from this field extremely limited experiment (one location, 3 summer months, 29 rain events). This sentence should be modified by adding the circumstances under the experiment were performed.

Thank you. This concluding remark has been modified. See comment #5 from reviewer #1 above.

In addition, this does not suggest that evaporative suppressants are unnecessary year round. In a network like the USCRN that is designed to measure solid precipitation, evaporation suppressants must still be used during the winter to suppress the evaporation of antifreeze chemicals necessary to measure the liquid equivalent of frozen hydrometeors.

Table 1: It is a very important part of the paper. Additionally to the "Event Id", the Event duration would also be useful for full understanding. Also, would it be possible to add another digit – increase the precision from 0.1mm to 0.01mm? It is particularly important in the difference series, where several identical values are found. Some of

the results later in the paper are anyhow defined in higher precision. This would provide a consistency through the paper.

Determining the duration of an event is not trivial. Each gauge and algorithm provide a different perspective on each event's duration. For instance, the pairwise method for the Geonor-Evap gauge may have an event duration that differs from the wAvg approach for this same gauge. Recall from figure 7, the two algorithms can have different precipitation initiation and duration times. One could provide an event duration determined from the length of the event window from which all gauges and algorithms reported precipitation. However, this duration would not accurately reflect the period of time precipitation fell and therefore cannot be used to evaluate precipitation intensity. Equally as confusing would be a reported duration for each combination of gauge and algorithm, which really isn't the focus of the study. For these reasons, duration was excluded from the table so readers would not inadvertently misinterpret this information.

As for resolution, the algorithms only report precipitation to the nearest tenth of a millimeter. The higher resolution of data over the dry period section is used because the gauge reports depths up to the nearest 100th of a millimeter. The reduction in precision was done to limit false precipitation. For consistency throughout the manuscript, the precision of the dry results section was reduced to the coarser 10th of a millimeter resolution.

Table 1 and Figure 6 are seemed to be the mirror of each other (-3 in Table 1 and +3 in Figure 6: : :. Can it be change to be consistent?

Thank you. The figure has been changed to match Table 1. See our response to your "P 12859 lines 3-4" comment as well.

Figure 3-5: Title should contain the reference to the type of events it includes (definition of dry condition – or all?)

The captions for figure 3 (now 4) and 5 (now 6) will be updated to make this clearer

âĂć Figure 3 (now 4) shows all data. âĂć As indicated in Figure 4 (now 5) caption, this is only dry period data âĂć Figure 5 (now 6) is dry period data only

Figure 3-5: The terminology "wire-noise" first appears in the conclusion and the "wire" in figure titles. Please add the definition, its meaning to the description part.

The wires refer to the actual load sensors that use a vibrating wire to monitor gauge depth. The initial paragraph of the methodology section was modified to include how the load sensors operate and describe the wire, which should make this terminology clearer. See response to reviewer 1's second methodology comment.

Figure 6: Since this figure contains only results from evap gauges, different choice of colors would be better compared to Figure 5 where both type of gauges were present.

Thank you. The figure has been updated as suggested. See our response to the reviewer 2 final technical comment as well.

Interactive comment on Atmos. Meas. Tech. Discuss., 7, 12851, 2014.

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