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Atmospheric Measurement Techniques
Discussions

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

R. D. Leeper and J. Kochendorfer

ronald.leeper@noaa.gov

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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

(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.

1. In the Introduction, you describe the different networks (USCRN and COOP), and mention that gauge type affect evaporation rate. You need to better describe which gauges are used in which network and how the measurements are done (manual, automatic, time resolution), since this is relevant when you compare the behavior and impact of the evaporation (lines 15-24, p. 12852, lines 5-7, p. 12854).

Additional information regarding gauge type, level of shielding, and operational mode (automated versus manual) has been incorporated into the introduction to provide additional details about a referenced comparison study between USCRN and COOP. The additional information was provided in two locations. The first was introduced in respect to the Golubev et al. (1992) study (1) and the during the USCRN and COOP comparison discussion (2)

Golubev et al. (1992) Golubev et al. (1992) noted the automated non-funnel capped Tretyakov gauge had evaporation rates (1.15 mm day-1) six times greater than the manual funnel-capped standard 8" gauge (0.19 mm day -1) used at Cooperative Observer (COOP) stations.

USCRN and COOP Comparison study by Leeper et al. (2015a) However, recent research comparing USCRN with COOP stations indicate gauge evaporation can bias observations even when taken frequently at a sub-hourly rate (Leeper et al. 2015a). The USCRN monitors precipitation at a 5-minute frequency from a well shielded automated funnel-less gauge where as COOP stations operate a manual funnel-capped gauge that is checked daily. Despite COOP stations monitoring precipitation from an unshielded gauge, USCRN observations of precipitation (daily aggregated sum of sub-hourly data) were slightly less than COOP by 1.5% (Leeper et al. 2015a).

2. You pretend that USCRN observations are slightly lower than the COOP ones, even though the USCRN gauges are shielded and the COOP gauges are not (lines 7-9, p. 12854). Please explain what "slightly" is, especially whether these differences are significant in regard to gauges specifications, and if this is a general behavior on all sites.

The sentence has been modified as noted above to include the average difference between the two networks at all compared stations, which was 1.5%. These differences are larger than gauge uncertainty and is a larger factor at stations reporting more rain than frozen hydrometeors that are more sensitive to surface wind bias. The manuscript documenting these network differences (Leeper et al. 2015a) has been accepted in the Journal of Atmospheric and Oceanic Technology.

Network differences were not as large for northern located station pairs that had a greater percentage of frozen hydrometeors, which are more sensitive to surface wind and where gauge shielding has a more dominant impact of catch efficiency (Leeper et al. 2015a)

3. Then you point out that this behavior (see point 2) was shown to be the opposite in previous studies, where results matched with what we actually would expect (line 9, p. 12854). Here again, please provide some numbers (differences shielded vs unshielded) from the past studies (the references you choose to mention). Please specify whether they concern the same gauge type.

The studies that I referenced used a variety of different gauges with few including the Geonor and COOP standard 8" gauge. Listing each type of gauge used in those studies have been omitted for brevity, but the sentence was modified to reflect that the Geonor gauge was not commonly included in these studies.

Overall, these results are contrary to other studies that found unshielded gauges tended to report 4 to 11% less precipitation for liquid hydrometeors (Golubev et al. 1992, and Duchon and Essenburg 2001), although neither included the Geonor gauge used at USCRN stations.

4. In the Methodology, you describe the set-up of the experiment. You need to give more information on the suppressant used (type), including quantity and quantity of water that was poured in the bucket at the beginning of the experiment.

At the test bed in Marshall, CO, the added mixture to the Geonor-NonEvap gauge included both antifreeze (60% methanol and 40% glycol) and 300 ml of oil (automatic transmission fluid).

The Geonor-Evap gauge was compared the control gauge Geonor-NonEvap, which had an evaporative suppressant mixture of antifreeze (60% methanol and 40% glycol) and 300 ml of automatic transmission fluid added to limit gauge evaporation.

5. Ancillary measurement (lines 5-7, p. 12856): please provide location (compared to the gauges) and measurement height for temperature and wind.

This is a good point. The ancillary measurements of temperature, wetness, dew point temperature and wind speed, which were used to compute VPD were all measured at a height of 1.5 meters above the ground. The temperature and disdrometer measurements were taken from the nearest tower (within 10 meters of both gauges), wind speed and dewpoint measurements were taken from a separate towers located $\sim$ 37m and 65 m from the test gauges. The manuscript has been modified appropriately.

…were also monitored throughout the study period from a height of 1.5 meters. The sensors that monitor these variables were located on separate towers near the study gauges with temperature, humidity, and wind speed measurements taken approximately 10, 37, and 67 meters away respectively

6. Description of the two QA methods used in this study (lines 12 ff, p. 12856) is

quite lacunar or confusing (e.g. line 16, p. 12856: "The initial QA methodology uses a pairwise approach to combine redundant observations of depth change and will be referred to as pairwise") and not easy to understand for a person who is not familiar with these methods. As this represent the core of the paper, more information should be given on algorithms (description) and current use by other institutes, met services, operational networks.

A paragraph describing each of the two QA methods have been included in the manuscript in a new section between the Introduction and Methodology sections. See author responses to reviewer 1 comment 1b. While there are other institutions currently considering our QA approaches, none have completely adopted our approach at present.

7. Dry conditions description (3.2): You compare the average losses from the two gauges, and give a sort of range for this value (e.g. 0.122 _ 0.07 for the evap gauge). What does this range represent? Standard deviation? Uncertainty? How did you come to these numbers, and what is the conclusion (significant)?

The number range (removed from current version) showed the standard deviation of hourly depth change over all dry periods. The intent was to show how the data were distributed about the reported means. In this context, the authors replaced the standard deviation values with box plots of depth change for the two respective gauges. The figure clearly shows the distribution of the data and adds value to the manuscript discussion.

8. Investigation of the correlation between weather conditions and evaporation (lines 5-10, p. 12858). Did you investigate the combined effect of wind and temperature, and in particular events with low wind speed and high temperature? This is a typical condition for high gauge evaporation (bucket heating).

We did not investigate the combined effect of wind and temperature on evaporation; however, we did look at the combined effect of wind speed and vapor pressure deficit

(VDP), which is a function of both temperature and humidity, and is more directly related to evaporation than air temperature. See author response to reviewer 1 comment 2 about how the inclusion of wind speed in a linear model did not improve the model's goodness of fit.

9. The statement "The largest average increase (0.03mm/h) and decrease (0.04mm/h) over the diurnal scale from the control (nonEvap) gauge were considered negligible" (lines 18-19, p. 12858) needs to be completed: what is the cause for these variations? Instrument sensitivity? Atmospheric conditions (e.g. wind)? Is it a common signal for this gauge type? Moreover, the increase at 06:00LT in both gauges needs also some explanation: why is the positive signal not of the same magnitude for both gauges if it is condensation coming from the air humidity?

Diurnal variations in gauge depth are possible with the load sensors used in this gauge. For instance, changes in temperature can affect the length of the load sensor wire, resulting in a change in vibration frequency and corresponding gauge depth. These variations (plus or minus 0.05 mm/h) are common to the Geonor gauge, which are discussed in Duchon (2008). As for the increase at 05:00 LT, both gauges experienced about the same amount of positive depth change (+0.03 mm). The Geonor-Evap gauge appears to change more only in contrast to the typically more negative depth changes it experiences throughout the rest of the day due to an evaporation signal. However, during the early morning hours the evaporation signal is likely reduced such that sensor noise is the dominate source of depth variations, which from the Geonor-NonEvap gauge tends to consist of both negative and positive depth changes near zero. This likely explains the late evening and early morning rise in mean depth change from the Geonor-Evap gauge. The inclusion of possible noise sources was added in the proceeding paragraph with a discussion of newly added figure 4.

Variations in depth from the Geonor-NonEvap gauge are likely the result of sensor noise caused by temperature and wind speed variations described by Duchon (2008).

However, it is interesting to note that the Geonor-Evap and Geonor-NonEvap gauges both experienced small positive depth changes ($\sim$ +0.03 mm) at 05:00 LT. The coincident timing may indicate that on days when condensation buildup occurred (likely not every day) it was observed within the same hour for both gauges even though the mean depth change was below the 0.1 mm accuracy of the gauge.

10. The statement on “near systematic (evap < nonEvap) differences reported from the pairwise method” (line 1, p. 12861) does not correspond to the precipitation event data presented in Table 1, where it is the case for only 13 events out of the 29 listed. This statement needs to be corrected.

The paragraph was reworked to focus on why the wAvg algorithm was less sensitive to gauge evaporation with this particular sentence removed from the manuscript.

Technical Corrections

1. The terminology used to differentiate both gauges is confusing (evap and nonEvap).

A new naming convention was adopted where evap and nonEvap are replaced with Geonor-Evap and Geonor-NonEvap respectively. See response to reviewer 1’s second technical abstract comment.

2. Reference to Sevruk publication are not correctly written (Survek instead of Sevruk) on page 12853 (line 13 and 21).

The references on page 12853 lines 13-21 should refer to Boris Sevruk who has been the lead author on several WMO investigations on precipitation biases between different types of gauges. The incorrect spelling on pg. 12853 ln 11 has been corrected. Thank you.

3. Line 22, page 12853: affect, and not effect

Corrected

4. Line 7, page 12854: Despite COOP gauges were monitoring

Sentence has been revised.

Despite COOP stations monitoring precipitation from an unshielded gauge...

5. Line 13, pahe 12854: Additional, and not addition

This sentence has been modified with “Addition” removed all together. See response to reviewer 1 comment 2.

6. Line 15, page 12854: sensitive, and not sensitivity

Thank you, this has been corrected

Further analysis of the QA system, using synthetic precipitation events of a known precipitation signal revealed the method used to calculate depth change was sensitive to gauge evaporation bias and sensor noise (Leeper et al. 2015b).

7. Line 6, page 12855: true for networks, and not true of networks

Sentence revised

This is particularly true for networks operating gauges with an exposed reservoir and an in sufficient quantity of evaporative suppressant.

8. Line 10, page 12855: equipped with three redundant load sensors

Sentence modified as suggested

To observe precipitation, the USCRN uses the all-weather Geonor T-200B gauge equipped with three redundant load sensors as shown in Fig 1a.

9. Line 6, page 12861: sensitive, and not sensitivity

Word modified as suggested

These combined studies demonstrate that the wAvg approach to calculating precipitation is less sensitive to gauge evaporation than the pairwise algorithm and is a more suitable method to monitor USCRN station precipitation.

10. Figure 2: evap gauge is indicated with red arrow, nonEvap with blue arrow, which is the other way round than in the graphes later on. It should be the same for all figures to avoid confusion.

Thank you. Great point. The color scheme in the figure has been modified as suggested.

11. Figure 6 and 7: the same colors (blue and red) are used to display the two different algorithms. Other colors than for the gauges should be used to avoid confusion.

The colors schemes identifying the two algorithms for figure 6 and 7 have been changed in tandem to where plots showing pairwise and wAvg computed precipitation/depth change are presented in green and purple respectively.

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