J2.8 PRECIPITATION QUALITY ASSURANCE METHODS FOR WEIGHING BUCKET PRECIPITATION GAUGES HAVING THREE REDUNDANT MEASUREMENTS

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1. Introduction

Precipitation is one of the U.S. Climate Reference Network (USCRN) core observations in addition to being one of the more challenging quantities to observe accurately over time (You et al. 2007). As a result, it is essential that comprehensive and well documented quality assurance (QA) methods are applied to observations from calibrated instruments in stable locations (Fiebrich et al. 2010; Shafer et al. 2000). In order to serve a broad community as a high quality climatic data source, the USCRN has conducted extensive gauge and shield configuration testing (Baker et al. 2005). Attention is now being focused on the development of an improved second-generation precipitation QA system for USCRN. The purpose of this report is to provide an overview of USCRN's current precipitation QA methodology, outlining its known weaknesses and presenting improvements to the current strategy.

2. USCRN Quality Assurance Method

Precipitation is calculated within the current USCRN QA strategy (currentQA) by processing changes in gauge depth from three independent measurements (vibrating wires) at sub-hourly increments (5 minutes currently, or 15 minutes early in network history). The calculation of sub-hourly precipitation can be broken down into three stages: 1) range checking the three weighing bucket vibrating wires and independent wetness sensor instrument output; 2) establishing the reference depth with which to compare changes in depth; and 3) calculating precipitation (gauge depth minus reference depth).

3. Current USCRN QA Concerns

Testing of the current USCRN QA strategy against both real observations and artificially generated cases has revealed some potential areas for improving calculated precipitation totals. Potential improvements were identified in calculations made during some precipitation events in the establishment of wire reference depths, in several aspects of the determination of valid wires, and in the final precipitation calculations themselves. While current methods for calculating precipitation totals provide data of high quality, refinements in QC algorithms can better ensure the most accurate precipitation measurements. In some ways, the current approach may be too stringent and eliminate some real precipitation from consideration (Figure 1). In other cases, the current approach may be too sensitive to measurement noise and non-precipitation processes such as evaporation from the weighing bucket (Figure 2).

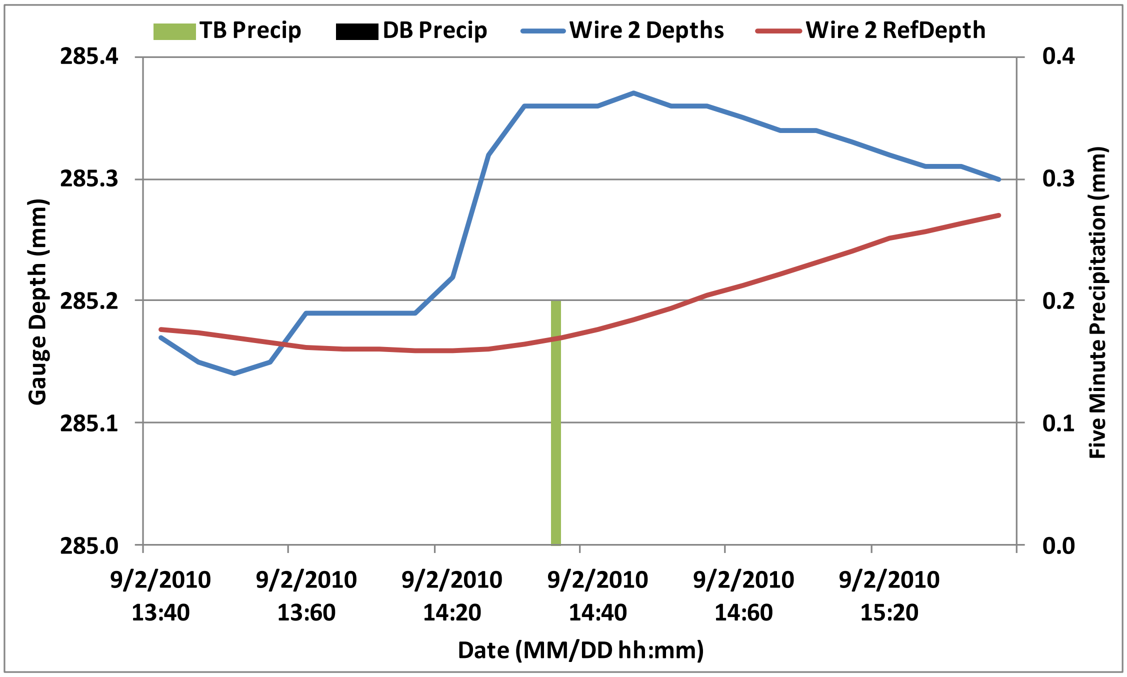

Figure 1. Sioux Falls, SD, record for a light precipitation event that triggered a tipping bucket response (green bar) but did not result in calculated precipitation in the data base from the weighing bucket gauge (no black bar). The actual depth change during the period was over 0.2 mm between the lowest and highest depths of wire 2 (blue), but results between wires did not agree simultaneously, the reference depth started to rise (red), and the small event was missed.

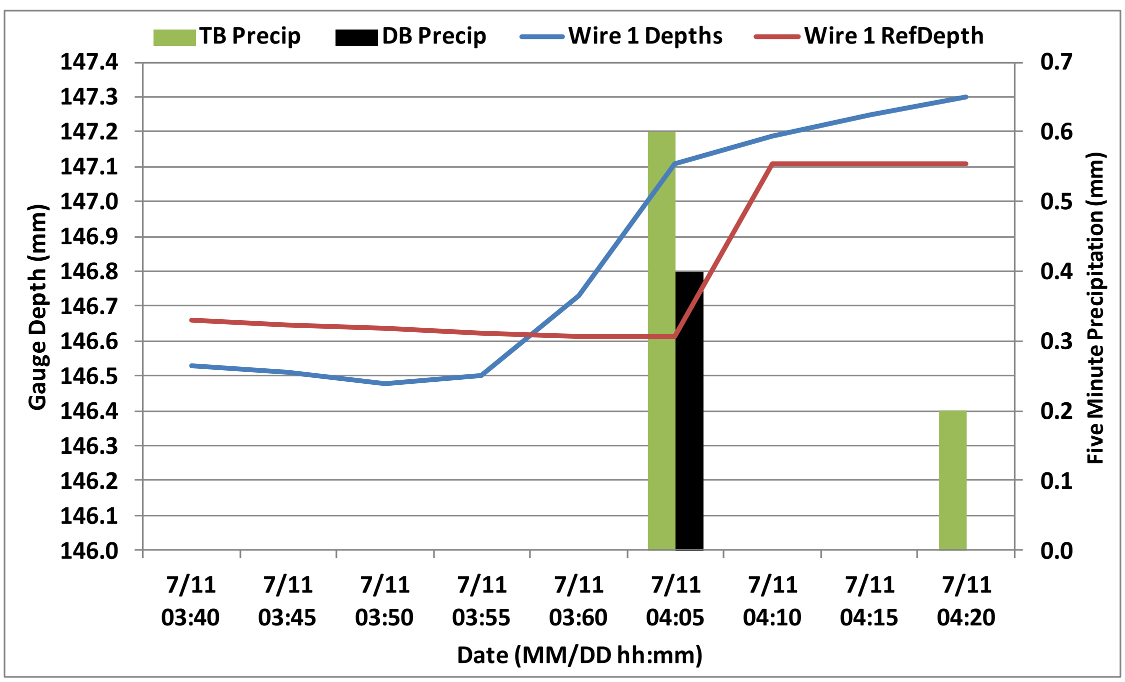

Figure 2. Sioux Falls, SD, record for a light precipitation event that triggered a larger tipping bucket response (green bar) than weighing bucket gauge response (black bar). Evaporation brought the wire 1 depth down (blue) prior to the start of precipitation, while the reference depth (red) stayed higher due to averaging over two hours, resulting in the weighing bucket calculation being 0.4 mm less.

4. Quality Assurance Improvements

Improvements to the current precipitation QA method were considered in two contexts. First, incremental adjustments (incrementQA) were made to the current QA strategy, allowing it to evolve as modifications were identified. Once completed, the incrementQA approach would resemble the original algorithm. Additionally, a second approach, weighted average (weightedAvgQA), was designed to be a computationally efficient method with limited sensitivity to the previously disclosed issues, and capable of meeting USCRN operational demands (precipitation calculated at sub-hour increments to the nearest tenth of a millimeter). A bulleted list summarizing each of these QA procedures are provided below:

Incremental QA 4.1

- Verify the weighing bucket gauge depths over the previous two hours are valid
- Calculate a weighted average reference depth from valid sub-hourly gauge depths with weights assigned based on proximity to current time step (values from time steps close to the present are weighted more than earlier values)
- Calculate wire deltas (wire depth minus reference depth) and delta variance (squared difference from the mean of the three deltas for each sub-hourly period)
- Ensure deltas and average delta variance are in range
- Compare wire deltas and select wires with preference given to the wire with the least amount noise (delta variance)
- Calculate precipitation as a weighted average from healthy wires with weights inversely proportional to delta variance
- Round sub-hourly precipitation to the nearest tenth of a millimeter such that the hourly sum is unchanged.

Weighted Average QA 4.2

- Calculate sub-hourly deltas by simply subtracting the depth during the previous sub-hourly period from the current sub-hourly period (i.e., there is no reference depth)
- Calculate the squared difference from the mean of the three deltas for each sub-hourly period
- Generate weights for each wire that are inversely proportional to its average squared difference from the mean
- Set wire weight to zero if any previous gauge depth is out of range
- Calculate precipitation as a weighted average
- Set negative precipitation to zero
- Set unreasonably large precipitation (25 mm for 5-minute period) and adjacent sub-hourly period to zero
- Take any calculated precipitation when the wetness sensor was dry is set to zero.
- Round sub-hourly precipitation to the nearest tenth of a millimeter in such a way that the hourly total precipitation is preserved.

5. Preliminary QA Comparison Results

For artificial test cases, incrementQA and weightedAvgQA both outperformed the currentQA methodology. For a ten-member ensemble of the standard artificial precipitation event (60.73 mm over 12 hours) with no gauge evaporation or wire noise, currentQA, incrementQA and weightedAvgQA variants were on average within 0.27, 0.19, and 0.03 mm of the artificial precipitation signal respectively (Table 1). In addition, both incrementQA and weightedAvgQA ensemble averages were nearer the precipitation signal than currentQA for each combination of gauge evaporation and wire noise (Table 1). Overall, weightedAvgQA ensemble averages were nearest the precipitation signal than the other QA variants.

Station annual rainfall estimates from incrementQA and weightedAvgQA methods were compared to currentQA (Table 2). For all twelve stations, weightedAvgQA annual accumulated rainfall was consistently greater than currentQA estimates by 0.15 to 7.56%. Most of these additional rainfall gains from weightedAvgQA occurred at the onset of a light precipitation event when currentQA limitations were more pronounced, as shown in Figure 3.However, annually accumulated rainfall comparisons between incrementQA and currentQA were sensitive to station location. For instance, at northern stations such as Quinault, WA, Buffalo, SD, Kingston, RI, and Arco, ID, annual precipitation estimates from incrementQA were typically greater than currentQA. However, the opposite was true for Southern stations, particularly those located in the desert southwest (Monahans, TX, Yuma, AZ, etc) (Table 2). As a percentage, differences between incrementQA and currentQA ranged between -15.53 to 5.18 %.

6. Discussion

Potential enhancements to existing USCRN precipitation QC algorithms have been identified (i.e. reference depth sensitivities, too stringent checks, and frequent rounding). While USCRN precipitation data are of high quality, these issues have prompted the development of USCRN next generation precipitation QA strategies.

Artificial precipitation event tests have shown improvements for both strategies (incrementQA and weightedAvgQA) relative to the currentQA. However, this was not the case for annual precipitation totals. IncrementQA results were sensitive to gauge evaporation, and in some cases significantly under caught compared to currentQA. Performance for weightedAvgQA was much more consistent with respect to currentQA, capturing on average 2.8% more annual precipitation.

To fully assess next generation QA performance, further testing that includes additional artificial cases and network wide comparisons are necessary going forward. With that said, the weightedAvgQA algorithm has proved to be more skillful based on tests performed to date. In light of these findings and additional work needed to correct incrementQA sensitivity to gauge evaporation, additional tests will primarily involve weightedAvgQA.

Table 1. Ten-member ensemble average difference from the standard artificially generated precipitation signal for currentQA, incrementQA, and weightedAvgQA generated with various combinations of gauge evaporation and wire noise levels. Differences are reported in terms of magnitude in mm with color indicating the degree to which the ensemble average diverged from the precipitation signal.

QA Variant	Gauge Evaporation	Wire Noise 000	111	113	133	333
CurrentQA	0.00	0.27	0.22	0.52	0.56	0.52
	0.01	0.17	0.25	0.43	0.48	0.43
	0.02	0.09	0.26	0.44	0.36	0.36
IncrementQA	0.00	0.19	0.10	0.13	0.22	0.40
	0.01	0.09	0.10	0.10	0.18	0.42
	0.02	0.07	0.10	0.17	0.20	0.35
WeightedAvgQA	0.00	0.03	0.07	0.08	0.13	0.23
	0.01	0.03	0.08	0.08	0.12	0.21
	0.02	0.04	0.07	0.09	0.13	0.21

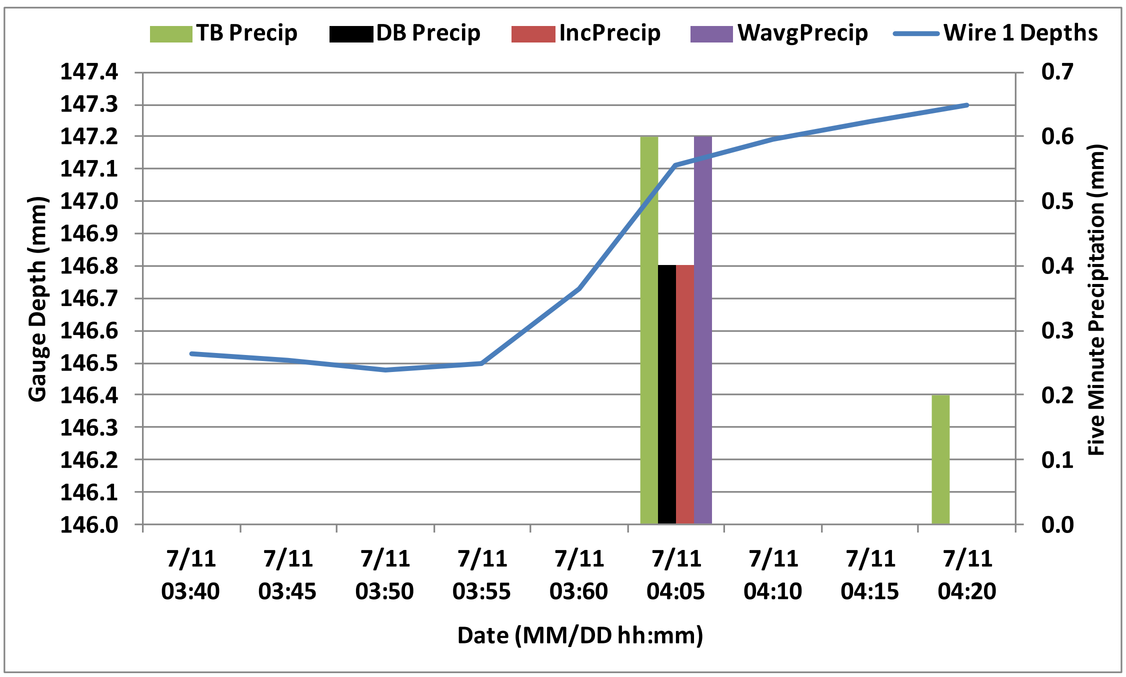

Figure 3. Same as Figure 2 with the inclusion of incrementQA (red bar) and weightedAvgQA (purple bar) precipitation. WeightedAvgQA caught more rainfall at the onset of the precipitation event than both currentQA and incrementQA in line with tipping bucket gauge.

Table 2. Annual accumulated rainfall estimates for currentQA, incrementQA, and weightedAvgQA strategies with percent differences for incrementQA and weightedAvgQA calculated as variantQA minus currentQA for USCRN stations in 2010.

Station	CurrentQA (mm)	IncrementQA (mm)	IncrementQA Difference (%)	WeightedAvgQA (mm)	WeightedAvgQA Difference (%)
Quinault, WA	3663.9	3735.6	1.96	3726.0	1.69
Buffalo, SD	505.5	522.9	3.44	516.9	2.26
Sioux Falls, SD	875.1	893.0	2.05	900.3	2.88
Monahans, TX	333.0	304.9	-8.44	344.6	3.48
Kingston, RI	1457.7	1485.6	1.91	1488.5	2.11
Newton11, GA	931.2	883.9	-5.08	965.2	3.65
Arco, ID	526.7	547.0	3.85	535.2	1.61
Nunn, CO	305.7	302.1	-1.18	307.8	0.69
Merced, CA	330.3	347.4	5.18	355.5	7.63
Titusville, FL	1133.1	1074.7	-5.15	1150.8	1.56
McClellanville, SC	1317.2	1298.0	-1.46	1319.2	0.15
Yuma, AZ	144.9	122.4	-15.53	153.4	5.87
Average	960.4	959.8	-1.54	980.28	2.80

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