A comparison of University of South Alabama Mesonet precipitation sensors.

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Introduction

The University of South Alabama (USA) built its first Mesonet station in January 2005, with the primary focus on hurricane and tropical storm landfall monitoring. Hence, most stations were installed in coastal counties and the line of counties north of the coastal counties. As of February 2010, 21 stations were fully operational with the tower and associated hardware having been installed for the remaining five. These five will be outfitted with instruments by the 2010 hurricane season. The location of all sites is shown in Figure 1. The Mesonet stretches about 325 km in an east-west direction, across three states. The north-south dimension ranges from about 100 km at the western end to about 30 km in southeast Alabama north of the Florida Panhandle. The spacing between stations ranges from 5.4 to 55.6 km with an average of about 30 km. The majority of station hosts are public schools which provide a safe, well-maintained environment with free access to the Internet. All stations are surrounded by a barbed wire fence which has no doubt contributed to the fact that no vandalism has been encountered to date. Schools also offer the opportunity to integrate weather station data with public education. Near real-time, archived, and metadata are available online at http://chiliweb.southalabama.edu/. A picture of a typical station is shown in Figure 2.

Rain gauges

Rainfall is measured by two tipping bucket rain gauges, a Hydrological Services TB3 tipping bucket rain gauge (TB3) and a Texas Electronics TE525 rain gauge (TE), placed in the northwest and northeast corners of the enclosed fence. Both gauges measure 0.254 mm of rainfall per bucket tip. Every minute, the USA Mesonet dataloggers report the number of tips that occurred in the preceding minute, as well as the accumulated rainfall since midnight. The accumulated rainfall since midnight is also recorded even though the accumulation is not actually reset at midnight. The reason for this is that any rain falling during the last minute of a given day (i.e. between 23:59 of that day and 00:00 of the next day) is logged at 00:00 of the next day. Because this rain needs to be accounted for in the preceding 24 hour time period, the rainfall accumulation cannot be reset to zero at 00:00, and is actually reset at 00:01 CST.

The TB3 functions as the primary rain gauge as it includes a siphon tube (to deliver a preset volume of collected water to each bucket reducing under-catchment during heavy rainfall, e.g. Humphrey et al. 1997), a built-in level for more precise positioning, dual reed switches, and a sturdy tipping bucket made of synthetic ceramic coated brass. The TB3 was chosen because its syphon mechanism will provide more accurate rainfall measurements during heavy rainfall events

such as hurricanes and tropical storms. Dual rain gauges are used at USA Mesonet stations in case of damage due to severe weather or outage as a result of accumulated debris or nesting insects. The redundancy also allows for internal consistency checks at each station for quality control (QC) purposes.

Rain gauge comparison

Each USA Mesonet station has two different models of tipping bucket rain gauges: a Hydrological Services TB3/Campbell Scientific CS700 rain gauge and a Texas Electronic TE525-L20 rain gauge or TB3 and TE for short. The TB3 is considered the better quality gauge because of the following attributes not featured on the TE: 1) a syphon that allows the rain to flow at a steady rate to the tipping bucket mechanism regardless of rainfall intensity; 2) a built-in level for precise positioning; 3) sturdy tipping buckets made of synthetic ceramic coated brass instead of plastic; and 4) a finer filtering mechanism. A photograph of both gauges is shown in Figure 3. In the current station design, the gauges are positioned 3.05 m apart from one another. Prior to the summer of 2008, the rain gauges were less than 50 cm apart. Both gauges measure 0.254 mm of rainfall per bucket tip. Every minute, the USA Mesonet dataloggers report the number of tips that occurred in the preceding minute (converted to mm), as well as the accumulated rainfall since midnight. In this document, three rainfall products will be discussed: rain rate (number of tips per minute), rainfall accumulation since midnight (accumulated rainfall since midnight for a given minute), and 24-hour rainfall total (accumulated rainfall at midnight of the following day).

Table 1 lists the frequency (and percentage) of the number of bucket tips per minute, or precipitation rates. Each bucket holds the equivalent of 0.254 mm, so the number of bucket tips per minute can be converted to precipitation rates in mm min^{-1} or mm h^{-1}. Most of the time (99.3 % to 99.4%), the buckets sit idle because rainfall events are relatively rare. These percentages seem high and were verified using data from a nearby COOP site available from NCDC (available online at http://www.ncdc.noaa.gov/oa/ncdc.html) The least amount of missing minutes occurred at Bay Minette (Table 1) so this site was chosen for the verification. The TB3 at the USA Mesonet site at Bay Minette collected a total of 1202.5 mm in 2007 and 1442.25 mm in 2008. In 2007 it had 12 minutes of missing data, while in 2008 it had 11,512 missing minutes. The Bay Minette COOP site collected 1389.38 mm (2007) and 1600.96 mm (2008) with 1 to 9 days missing both years. This amounts to about 10 - 13 % less rainfall collected at the USA Mesonet site. Some of this can be accounted for by the missing minutes of the TB3, however, the COOP site also encountered missing data. The discrepancy may be attributed to the different types of rain gauges used; COOP sites use collection gauges instead of tipping bucket gauges. Tipping bucket gauges are known to under-collect during both very heavy and very light rainfall (e.g. Humphrey et al 1997). However, they offer the advantage of automated collection of rainfall rates per minute, hour, or other time interval.

Low rainfall rates of 15 mm h^{-1} are the most common when it does rain: 74% to 78% of all non-zero observations. As the rainfall rate increases, the likelihood of it occurring, decreases. Occasionally the two gauges recorded different rainfall rates, this was examined more closely using the correlation coefficients between the two types of tipping buckets for the three rainfall products mentioned above (Table 2). The correlation coefficients ranged from 0.868 to 0.9996 indicating a very high degree of agreement between the two gauges. This is no surprise

considering no rainfall was recorded about 99% of the time. After removing observations where no rainfall was recorded by both gauges, the correlation coefficients decreased only slightly (r ranged from 0.787 to 0.999) for all three products. Among the three rainfall products, the rainfall rate showed the lowest degree of agreement (r = 0.777 to 0.809), while the other two products (rainfall accumulation and daily totals) showed about the same level of (almost perfect) agreement (r = 0.999). Table 3 shows the difference in rainfall rates between the two gauges (TE rate - TB3 rate). Around 30% of the time both rain gauges collected the same rainfall rate per minute. Between 67% and 68% of the time the collection rate differed by just one bucket tip per minute. Out of all 1-bucket tip discrepancies, the TB3 more often collected one tip more than the TE. A difference of two tips occurred 1.5% or less of the time, with the TB3 usually collecting more than the TE. A difference of three tips was rare, occurring only seven times overall. In six out of these seven extreme cases, the TB3 recorded more rain than the TE.

The above shows that both rainfall rates and accumulations correlate well (all correlation coefficients are statistically significant at the 5% level). About a third of the time the gauges collect the same amount of rainfall, while the remaining two-thirds of the time they differ by just one tip. Rainfall accumulations show higher correlation coefficients than rainfall rates (number of tips per minute). When adding rainfall rates together, a 1-tip deficiency (TB3 records 1 tip *more* than the TE) one minute can be offset by a 1-tip excess (TB3 records 1 tip *less* than the TE) in a following minute, causing the rainfall accumulations of both gauges to be similar.

As indicated above, there is a high degree of correlation in rainfall collection between the two tipping buckets, with the TB3 recording slightly higher values occasionally. It has been shown that tipping bucket rain gauges suffer from inaccuracies during very low rainfall rates and during very high rainfall rates. Undercatchment during heavy rainfall events (buckets cannot reposition themselves fast enough after a tip to collect all of the rainfall entering the outer funnel) and under-estimation during light drizzle (water evaporates before the bucket gets a chance to tip) are typical errors associated with tipping bucket rain gauges (Humphrey et al.1997). Since the TB3 is equipped with a siphoning mechanism to reduce under-catchment during heavy rainfall events, this gauge is may record higher rainfall rates during heavy rain events. Mean differences in rainfall rates (TE minus TB3) as a function of TB3 rainfall rates are shown in Figure 4. At each station the negative mean differences indicate that larger TB3 rainfall rates occur on average. For small TB3 rainfall rates, smaller differences between the two gauges are observed. A distinct increase (at an increasing rate) in mean rainfall rate differences is seen as the TB3 rainfall rate increases. Table 4 further confirms that the TB3 collects more at high rainfall rates. TB3 rainfall rates in excess of 150 mm h^{-1} and corresponding TE rainfall rates are shown. The TB3 collected more rainfall than the TE for 38 out of the 42 minutes that TB3 rainfall rates in excess of 150 mm h^{-1} were recorded. This was by 1 tip (24 times), 2 tips (11 times), or 3 tips (3 times) and four times the two buckets collected the same number of tips. This analysis provides confidence that the siphoning mechanism is working well in reducing the under-estimation of TB3 rainfall at higher rain rates.

Since the TB3 mostly exceeds the TE in rainfall rate recording, a similar trend is expected in rainfall totals. Figure 5 shows the relative frequency distribution of the difference (TE minus TB3) between the two gauges in midnight precipitation totals. For Agricola the difference ranges from -8.50 to 0.25 mm. At Bay Minette the differences range from -9.5 to 1.0 mm. For Mt. Vernon the range is -5.8 to 1.25 mm, while for Pascagoula the numbers are -8.7 to 0.75 mm. The TB3 recorded smaller midnight totals only between 1.0% and 7.0% of the time. The TB3

recorded more 24-hour rainfall between 72% and 80% of the time, while the two gauges were in agreement between 18.0 and 21.0 % of the time.

Conclusion

In most cases, and especially under high rainfall rate conditions, the Hydrological Servcies TB3 records slightly more rainfall than the Texas Electronics TE525 tipping bucket rain gauge. This provides confidence that the siphoning mechanism is working well in reducing the under-estimation of TB3 rainfall at higher rain rates. While the TB3 tipping bucket rain gauge is a better quality gauge equiped with a syphon that allows the gauge to perform more accurately in heavy rainfall events, the more affordable TE525 only slightly undercollected the TB3 during such events. This can make the TE525 a good choice tipping bucket rain gauge for certain applications and for operations working under a restricted budget.

References

Humphrey, M. D., J. D. Istok, J. Y. Lee, J. A. Hevesi, and A.L. Flint, 1997: A new method for automated dynamic calibration of tipping-bucket rain gauges. *J. Atmos. Oceanic. Technol.*, **14**, 1513 - 1519

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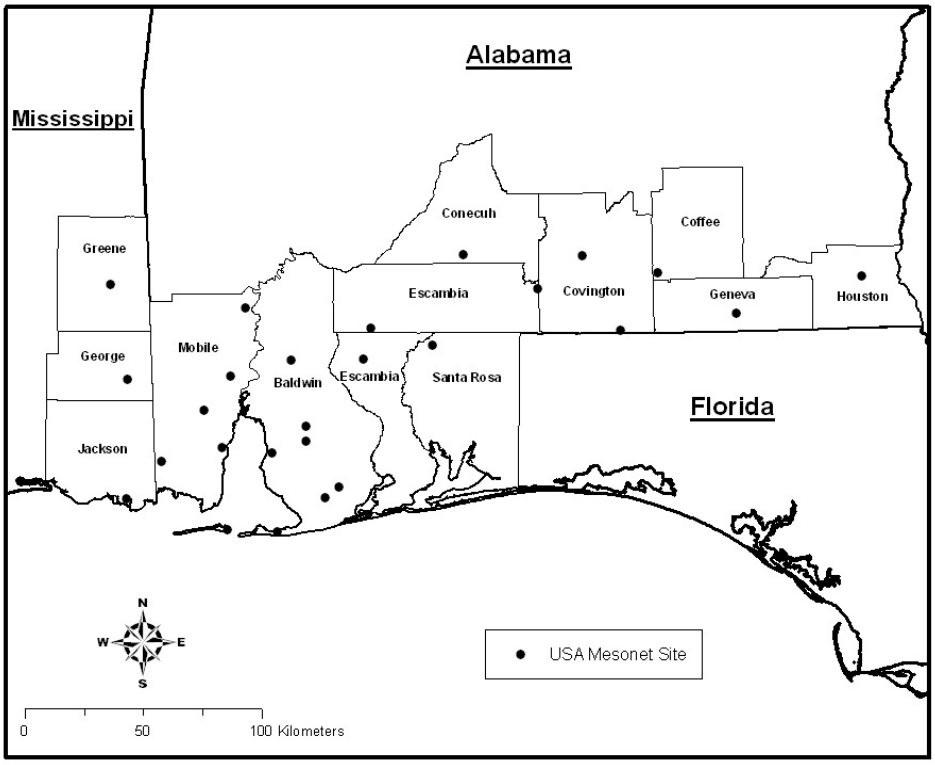

Figure 1: Map depicting all 26 stations of the University of South Alabama Mesonet. State and county names are included, station names are not.

Figure 2: Southward facing photograph of the Loxley station of the University of South Alabama Mesonet. Photograph taken on 13 November 2009 by Ivory Reinert.

a)

b)

Figure 3. University of South Alabama Mesonet tipping bucket rain gauges: a) Hydrological Services TB3 and b) Texas Electronics TE525. Photographs taken at USA Campus site by S. Kimball.

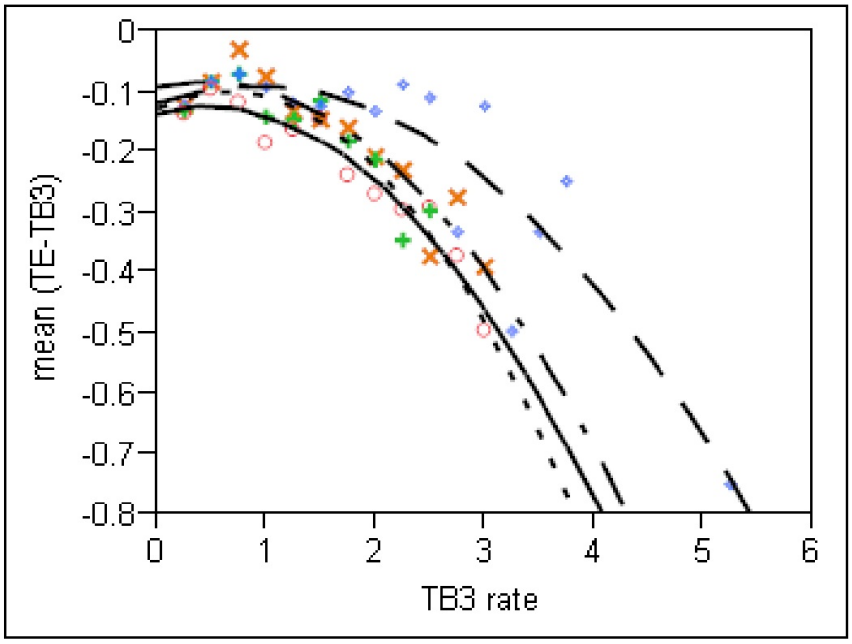

Figure 4: Mean differences in TE-TB3 rainfall rates as a function of TB3 rainfall rate (mm min^{-1}) for Agricola (solid), Bay Minette (dotted), Mt. Vernon (dashed), and Pascagoula (dot-dash) in 2007 and 2008.

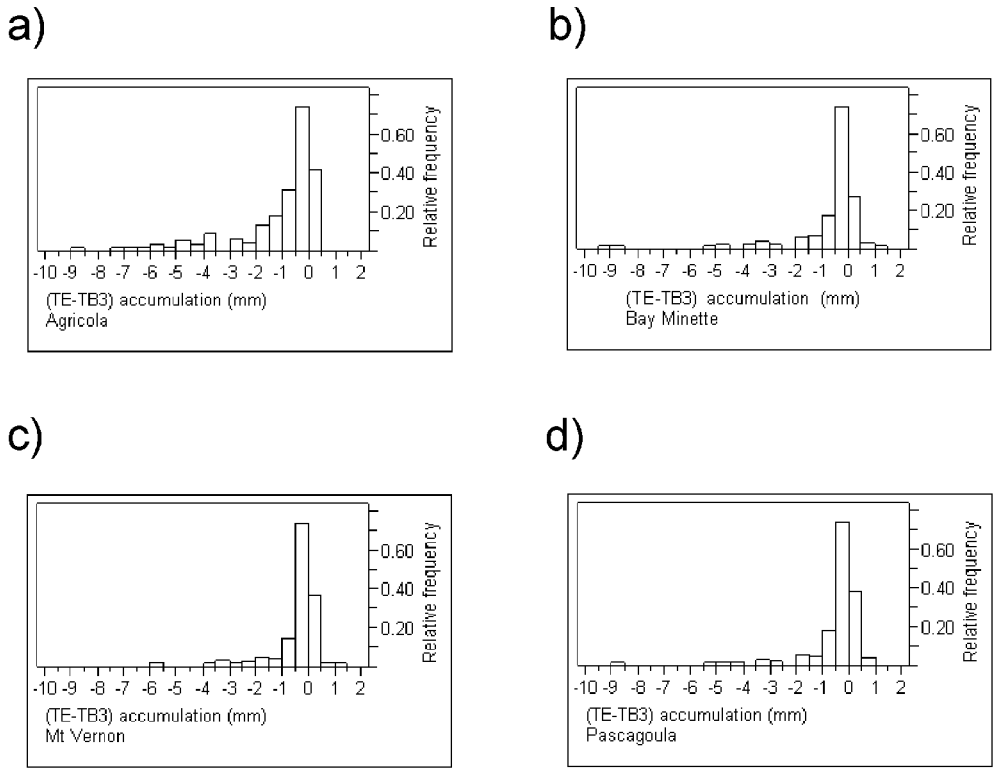

Figure 5: Relative frequency distribution of TE - TB3 precipitation totals at midnight for only those observations (minutes) when at least 1 gauge recorded precipitation for a) Agricola, b) Bay Minette, c) Mt. Vernon, d) Pascagoula in 2007 and 2008.

Table 1: Frequency of rainfall rates recorded by the TB3 (upper number) and TE (lower number) tipping bucket rain gauges in 2007 and 2008. The total number of records is less than the total number of minutes in these two years (525,600 + 527,040 = 1,052,640) due to missing data as a result of communication errors, datalogger outages, and periods when rain gauge calibrations took place. Statistics listed in parentheses are percent of non-zero observations, except for the top row where the statistics in parentheses are the percentages of the total number of available observations, and the bottom row where the statistics in parentheses indicate the number of non-zero observations.

Rainfall Rate mm h^{-1} (mm min^{-1})	**Agricola**	**Bay Minette**	**Mt. Vernon**	**Pascagoula**
0	850,634 (99.30) 850,871 (99.34)	1,034,258 (99.34) 804,908 (99.40)	971,849 (99.34) 949,200 (99.35)	1,017,897 (99.36) 1,012,339 (99.35)
15 (0.25)	4,532 (76.01) 4,401 (77.76)	5,227 (76.22) 3,735 (76.62)	4,839 (74.38) 4,673 (75.68)	4,881 (74.95) 4,788 (75.95)
30 (0.5)	682 (11.44) 619 (10.94)	820 (11.96) 516 (10.58)	846 (13.00) 763 (12.36)	709 (10.89) 662 (10.50)
45 (0.75)	293 (4.91) 279 (4.93)	302 (4.40) 280 (5.74)	360 (5.53) 328 (5.31)	354 (5.44) 333 (5.28)
60 (1)	167 (2.80) 144 (2.54)	187 (2.72) 144 (2.95)	171 (2.63) 169 (2.74)	210 (3.22) 223 (3.54)
75 (1.25)	108 (1.81) 77 (1.36)	132 (1.92) 78 (1.60)	125 (1.92) 103 (1.67)	143 (2.20) 140 (2.22)
90 (1.5)	63 (1.06) 65 (1.15)	65 (0.95) 54 (1.11)	63 (0.97) 56 (0.91)	87 (1.34) 67 (1.06)
105 (1.75)	49 (0.82) 34 (0.60)	50 (0.73) 40 (0.82)	51 (0.78) 37 (0.60)	59 (0.91) 39 (0.62)
120 (2)	25 (0.42) 25 (0.44)	46 (0.67) 17 (0.35)	17 (0.26) 17 (0.28)	29 (0.45) 27 (0.43)
135 (2.25)	27 (0.45) 13 (0.23)	17 (0.25) 5 (0.10)	11 (2.25) 12 (0.19)	13 (0.20) 11 (0.17)
150 (2.5)	12 (0.20) 2 (0.04)	4 (0.06) 3 (0.06)	9 (0.14) 7 (0.11)	10 (0.15) 10 (0.16)
165 (2.75)	2 (0.03) 1 (0.02)	3 (0.04) 0	6 (0.09) 3 (0.05)	10 (0.15) 3 (0.05)

180 (3)	2 (0.06) 0	2 (0.03) 2 (0.04)	2 (0.03) 3 (0.05)	7 (0.11) 1 (0.02)
195 (3.25)	0	2 (0.03) 1 (0.02)	1 (0.02) 2 (0.03)	0
210 (3.50)	0	1 (0.01) 0	3 (0.05) 1 (0.02)	0
225 (3.75)	0	0	1 (0.03) 0	0
240 (4.00)	0	0	0	0
255 (4.25)	0	0	0	0
270 (4.50)	0	0	0 1 (0.03)	0
285 (4.75)	0	0	0	0
300 (5.00)	0	0	0	0
315 (5.25)	0	0	1 (0.03) 0	0
Total and (non-zero) observations	856,596 (5,962) 856,531 (5,660)	1,041,116 (6,858) 809,783 (4,875)	978,355 (6,506) 955,375 (6,175)	1,024,409 (6,512)) 1,018,643 (6,304)

Table 2: Correlation coefficients between TB3 and TE tipping bucket rain gauges for 3 rainfall products at 4 USA Mesonet sites in 2007 and 2008. Rainfall products are rainfall rates recorded every minute, rainfall accumulation since midnight recorded every minute, and 24 hour rainfall accumulation. Correlations in parentheses were calculated excluding observations where both gauges recorded zero rainfall

Station	**Rainfall Rate (mm min^{-1})**	**Rainfall Accumulation (mm)**	**24-hour Rainfall Total (mm)**
Agricola	0.868381 (0.777013)	0.999444 (0.999355)	0.99952 (0.999378)
Bay Minette	0.874186 (0.779324)	0.999428 (0.999249)	0.999382 (0.999199)
Mt. Vernon	0.874674 (0.786815)	0.999657 (0.999431)	0.99963 (0.999564)
Pascagoula	0.887752 (0.809168)	0.999415 (0.999029)	0.999441 (0.999322)

Table 3: Frequencies of TE precipitation rate - TB3 precipitation rates for only those observations (minutes) when at least 1 gauge recorded precipitation, for 2007 and 2008. Statistics in parentheses are percentages.

rain rate difference mm h^{-1} (mm min^{-1})	**Agricola**	**Bay Minette**	**Mt. Vernon**	**Pascagoula**
-45 (-0.75)	3 (0.04)	1 (0.01)	1 (0.01)	1 (0.01)
-30 (-0.50)	123 (1.48)	90 (1.28)	107 (1.22)	79 (0.88)
-15 (-0.25)	3189 (38.41)	2594 (36.88)	3094 (35.20)	3164 (35.34)
0	2447 (29.47)	2124 (30.20)	2714 (30.88)	2870 (32.06)
15 (0.25)	2536 (30.55)	2218 (31.53)	2868 (32.63)	2830 (31.61)
30 (0.5)	4 (0.05)	7 (0.10)	5 (0.06)	8 (0.09)
45 (0.75)	0	0	0	1 (0.02)

Table 4: Number of occurrences of TB3 rainfall rates of 165 mm h^{-1} and higher at Agricola, Bay Minette, Mt. Vernon, and Pascagoula in 2007 and 2008. Numbers in parentheses are corresponding TE rainfall rates.

TB3 Rate (mm/h)	Agricola	Bay Minette	Mt. Vernon	Pascagoula
165	2 (150, 135)	3 (twice 150, once 120)	6 (4 times150, twice 135)	10 (once 165, 7 times 150, twice 135)
180	2 (both 165)	2 (180,150)	2 (180, 165)	7 (180, twice 165, 3 times 150, once 135)
195	N/A	1 (180)	1 (165)	N/A
210	N/A	1 (195)	3 (twice 195, once 180)	N/A
225	N/A	N/A	1 (210)	N/A
315	N/A	N/A	1 (270)	N/A