Optical Rain Gauge and Tipping Bucket Rain Gauge Comparisons at the ARM Climate Research Facility TWP Sites

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1. Introduction

Measurement of rainfall and precipitation is a difficult task even in the best of circumstances. Different types of gauges are used depending on the type of precipitation expected (solid or liquid) and the rate at which it falls. The ARM Program uses two types of precipitation sensors in its surface meteorological systems: the optical rain gauge (ORG) and the tipping bucket rain gauge (TBRG). The ORG was originally chosen for the Tropical Western Pacific (TWP) sites because the tropical rainfall is expected to fall at high rates. Additionally, at the TWP sites, sensors that could become contaminated with or blocked by debris or require routine maintenance were not considered useful. On the islands of Manus and Nauru, the Australian Bureau of Meteorology's (BoM's) Automatic Weather Stations (AWS) were installed near the TWP Surface Meteorology (SMET) systems. The AWS weather stations use TBRGs to measure precipitation as part of the base package.

High data quality is the goal of any long-term monitoring process. One way to determine data quality is to conduct sensor inter-comparisons. Co-location of the TWP SMET and the BoM AWS sites makes them perfect candidates for inter-comparisons. The only hurdles are getting both sets of data to match temporally and receiving the data in a timely manner. It is futile to find problems after they have been corrected by the local observers (e.g., plugged funnel on TBRG) or large periods of useless data have been generated. To bypass these problems, we connected the data logger from the ARM SMET system directly to the BoM AWS TBRG. This allowed real-time access to the data and direct collection of data from the TBRG in ARM's temporal resolution of 60 sec. The TWP sites C1-Manus and C2-Nauru are connected in this manner. TWP site C3-Darwin is too far from the BoM site to connect to the AWS in this manner, so a separate TBRG of the same type used by the AWS was purchased and connected to the SMET system. Table 1 shows the dates when the TBRGs were connected to the SMET systems.

Site	Date Connected
TWP-C1 Manus	Oct 16, 2006
TWP-C2 Nauru	Nov 29, 2006
TWP-C3 Darwin	Sep 26, 2006

Table 1. Dates of tipping bucket rain gauge connection by site.

Rainfall data from the time of installation at each site through September 8, 2007, were used for the inter-comparison of the ORG and TBRG.

2. Methodology

We used 1-min data files from each system. These files contain the ORG 1-min average rainfall rate in mm/hr and the accumulated rainfall amount from the TBRG. The ORG data were converted to mm/min rainfall rates to match the TBRG data. All data that failed QC checks were removed and counted in addition to times when the TBRG measured 0 and the ORG measured values < 0.2 mm. Additionally, data were removed when the TBRG was > 0 but the ORG reported values between 0 and 0.2 mm. We used these values as error cut-off points, because the TBRG resolution is 0.2 mm per tip, but the ORG continually generates a voltage value. Any value >= 85 mV is converted to a rainfall rate by the logger, while values < 85 mV are discarded prior to collection. The equation for the ORG is

$$\text{Rain Rate (mm/hr)} = 25(V^{1.87}) - 0.15 .$$

Use of this formula still leads to very small rain rates when averaged over a 1-min period.
The TBRG data were subtracted from the converted ORG data for each site for each minute and plotted on scatter plots. Daily average differences between the ORG and TBRG were also calculated and plotted on scatter plots. The daily average differences were color-coded according to standard deviation (SD; black < 1, 1 < red < 2, blue > 2). The accumulated departure from the mean for each site was plotted to identify problems with data quality, as reported by Linacre (1992) and Sandstrom et al. (2002). Data outside 5 SD were removed so that outliers did not affect the mean value.

3. Results

We had slightly less than one year of data for each site. Even so, the number of days of rain varied significantly between sites. Table 2 shows the number of days of rain for each site.

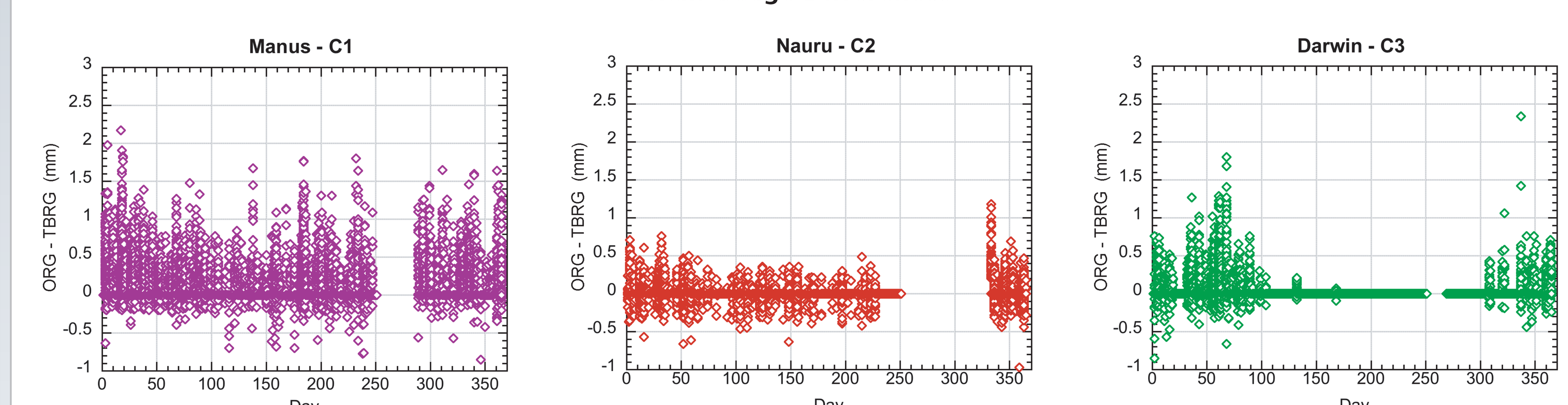
Site	Days of Rain
TWP-C1 Manus	201
TWP-C2 Nauru	108
TWP-C3 Darwin	75

Table 2. Number of days of rain for each TWP site.

The Instruments

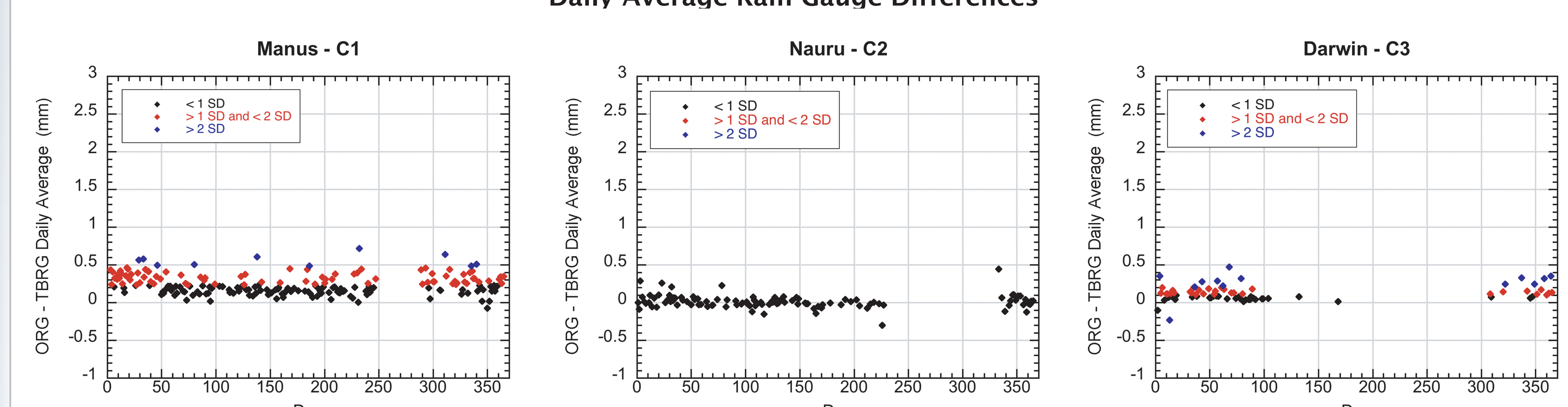
Tipping Bucket Rain Gauge (left)
Optical Rain Gauge (center)
Disdrometer (right) (not used in this study)

Rain Gauge Differences



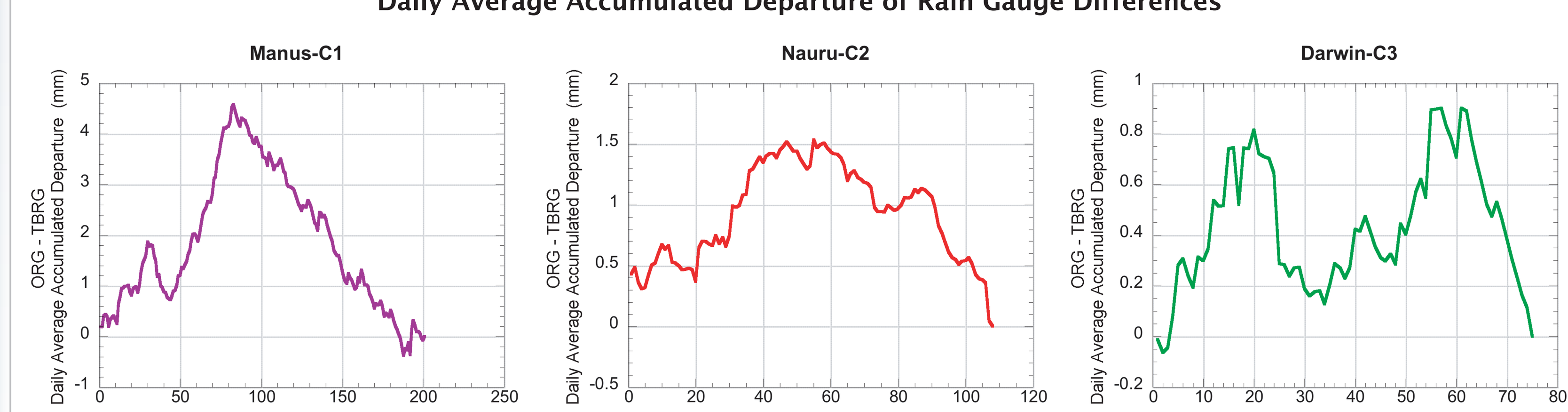
Graph 1 Graph 2 Graph 3

Daily Average Rain Gauge Differences



Graph 4 Graph 5 Graph 6

Daily Average Accumulated Departure of Rain Gauge Differences



Graph 7 Graph 8 Graph 9

References

Linacre, E. (1992). Climate, Data and Resources, Routledge, New York.

Sandstrom, M.A., Lauritsen, R.G., Changnon, D. (2004). "A Central-U.S. Summer Extreme Dew-point Climatology (1949-2000)." Physical Geography, Vol. 25, No. 3, pp. 191-207.

TWP site C1-Manus had twice as many rain days as C2-Nauru and 2.5 times as many as C3-Darwin. Rainfall at C3 is marked by defined wet and dry seasons, as the daily difference plots (Graph 3) clearly indicate. The plots (Graphs 1-3) show that for C1 the differences ranged from -0.5 mm to 2 mm, while C2 and C3 had ranges between -0.5 mm and 1 mm. Sites C1 and C3 have more numerous positive values, while site C2 values are evenly distributed around the zero line. This observation is strengthened by the daily average differences (Table 3).

Site	Daily Avg. Difference
TWP-C1 Manus	+0.24mm
TWP-C2 Nauru	+0.01mm
TWP-C3 Darwin	+0.13mm

Table 3. Daily average differences for each site.

The daily average difference plots (Graphs 4-6) for days with precipitation show good agreement between the TBRG and ORG. Clustering of values outside 1 SD can sometimes signify problems. Site C1 daily average differences (Graph 4) ranged from 0 to 0.5 mm. Clusters of values outside 1 SD are noticeable on days 289-340 and days 1-50 for Manus.

Site C2 daily average differences (Graph 5) ranged from -0.4 to 0.5 mm (Graph 2), but the differences appeared to become smaller over time. The only clusters of values outside 1 SD were before day 70. Site C3 daily average differences (Graph 6) ranged from -0.3 mm to 0.8 mm. Between day 300 and day 65, clusters of values outside 1 SD occurred. After day 105 the remainder of the data set produced 0-mm differences during Darwin's dry season.

The accumulated departures from the mean were plotted linearly. A positive trend represented larger ORG values than TBRG values when compared to the mean. A negative trend represented the inverse. Break points at abrupt slope changes suggest a possible change in sensor behavior. The days in the graphs are not Julian days, but instead the number of the rainfall event (1 = 1st day of rain, etc.). In future work we will convert the scales to dates for easier problem identification.

Accumulated departure for site C1 (Graph 7) showed large break points at days 33, 48, 84, and 190. Accumulated departure for site C2 (Graph 8) showed much more variability, with break points at days 4, 11, 21, 53, and 78. Both sites C1 and C2 showed an overall trend of increasing departures followed by a period of decreasing departures. This suggests that the ORG at both sites was measuring more precipitation than the TBRG, but after about 80 days (day 84 for C1 and day 78 for C2) the TBRG began measuring more precipitation. Accumulated departure for site C3 (Graph 8) is unique in having a bi-modal distribution with break points at 20, 35, 56, and 75. This observation may be related to Darwin's dry season; neither C1 nor C2 has marked a dry season. Further investigation is needed to discover the reasons for changes in the slopes.

Overall, the ORG and TBRG appear to be in good agreement, but calculation of the total underestimation of the TBRG told a different story. The formula

$$\text{(ORG Precip - TBRG Precip)/(ORG Precip)}$$

was used to calculate the rainfall underestimation. Generally, the ORG measured more rainfall than did the TBRG. The TBRG is susceptible to underestimation at high rain rates, particularly during the cumuliform rain that dominates in the tropics. Table 4 shows the underestimation percentage and error by site.

Site	% Underestimate	% Error
C1	45.2%	5.4%
C2	26.2%	11.2%
C3	25.7%	9.6%

Table 4. Underestimation by the TBRG and overall errors.

4. Conclusions and Future Work

Overall, minute and daily average differences suggest that the ORG and TBRG are in good agreement. However, summing all precipitation measured by the sensor for a year to achieve a climate-relevant scale indicates that the error rates are much larger than suggested. The underestimation by the TBRG is expected, as these gauges have trouble keeping up mechanically at high rain rates. Additional data will be analyzed as they are collected. The error percentage results are slightly higher than expected, but a portion of this error is due to the ORG output of very small values for rain rates that are not real. For example, if the ORG reports a voltage above the threshold (85 mV) for 1 sec, the rain rate is reported as .00016 mm/hr. Investigation will continue into further error-checking routines to remove the very small values from the data record. Incorporating the daily average accumulated departures to detect errors as a new plotting method at ARM's Data Quality Office will be pursued.

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