U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-ARM-TR-110

Rain Gauge Instrument Handbook

MJ Bartholomew

January 2016

ARM CLIMATE RESEARCH FACILITY

DOE/SC-ARM-TR-110

Rain Gauge Instrument Handbook

MJ Bartholomew

January 2016

Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement
DIST	disdrometer
DQ	data quality
LED	light-emitting diode
PM	planned maintenance
QME	quality measurement experiment
RMSE	root-mean-square error
VAP	value-added products
VDIS	video disdrometer

Contents

Figures

Tables

1.0 General Overview

To improve the quantitative description of precipitation processes in climate models, the Atmospheric Radiation Measurement (ARM) Climate Research Facility deployed rain gauges located near disdrometers (DISD and VDIS datastreams). This handbook deals specifically with the rain gauges that make the observations for the RAIN datastream. Other precipitation observations are made by the surface meteorology instrument suite (i.e., MET datastream).

2.0 Contacts

Mentor

Mary Jane Bartholomew
Brookhaven National Laboratory
MS 490D
Upton, NY 11973
Phone: 631-344-2444
Fax: 631-344-2060
E-mail: bartholomew@bnl.gov

Instrument Developers

Tipping Buckets
NovaLynx Corp.
Grass Valley, California
www.novalynx.com

Weighing Bucket Rain Gauges
Belfort Instrument Company
727 Wolfe St.
Baltimore, MD 21213
ww.belfortinstrument.com

Deployment Locations and History

Tipping Buckets	*Begin*	*End*
Darwin, ARM TWPC3	February 2006	November 30, 2010
Southern Great Plains, ARMC1	April, 2006	September 9, 2010

Weighing Bucket Rain Gauges	*Begin*	*End*
Darwin, ARMTWPC3	December, 2010	January 2015
Southern Great Plains ARMC1	September, 2010	Ongoing
Manus, ARM TWPC1	December, 2010	January 2015
ENA	December, 2013	Ongoing

Near-Real-Time Data Plots

http://plot.dmf.arm.gov/plotbrowser/

3.0 Data Description and Examples

3.1 Data File Contents

Datastreams

- Where xxx = three letter site designation, n = the site number

Rain Gauges

- XxxrainCn.00 tipping bucket and weighing bucket
- XxxrainCn.b1 tipping bucket and weighing bucket
- XxxrainauxCn.00 tipping bucket only
- XxxraiauxnCn.b1 tipping bucket only

3.2 Primary Variables

The primary variables for the tipping bucket and the weighing bucket rain gauges are listed in Table 1 and Table 2, respectively.

Table 1. Tipping bucket rain gauge variables, RAIN datastream.

Quantity	Variable	Measurement Interval	Unit
Base time in epoch	base_time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset from base_time	time_offset	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset from midnight	time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
North latitude	lat[a]	Constant	degrees
East longitude	lon[a]	Constant	degrees
Altitude	alt[a]	Constant	meters above sea level
Instrument serial number	serial_number	Constant	
Calibration date	calib_date	Constant	
Precipitation	precip_tbrg	1 min	millimeters
Rainfall rate	rain_rate	1 min	millimeters/hr

[a] lat/lon/alt refer to the ground where the instrument is sited, NOT the height of the sensor.

Table 2. New variables for RAIN datastream for weighing bucket gauges.

Quantity	Variable	Measurement Interval	Unit
Base time in epoch	base_time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset from base_time	time_offset	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset form midnight	time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
North latitude	lat[a]	Constant	Degrees
East longitude	lon[a]	Constant	Degrees
Altitude	alt[a]	Constant	Meters above sea level
instrument serial number	serial_number	Constant	
Precipitation amount	precip	1 min	Millimeters
Precipitation rate	precip_rate	1 min	Millimeters/hour
Sensor 1 temperature	temp1	1 min	Degrees C
Sensor 2 temperature	temp 2	1 min	Degrees C
Sensor 3 temperature	temp3	1 min	Degrees C
Sensor weight 1	weight1	1 min	kg
Sensor weight 2	weight2	1 min	kg
Sensor weight 3	weight3	1 min	kg
Sensor 1 frequency	frequency1	1 min	Hz
Sensor 2 frequency	frequency2	1min	Hz
Sensor 3 frequency	frequency3	1 min	Hz
Logger panel temperature	ptemp	1 min	Degrees C
Logger minimum voltage	volt_min	1min	volts
Bucket total weight	total_weight	1min	kg
Bucket total mm of precipitation	total_mm	1 min	Millimeters
Logger scan total	scans_per_minute	1 min	Unitless
Sensor status	stat_latch	1 min	Unitless
Sensor error	error_latch	1 min	Unitless

[a] lat/lon/alt refer to the ground where the instrument is sited, NOT the height of the sensor.

3.3 Expected Uncertainty

Impact disdrometers measure rain drop size over the range of 0.3 to 5.4 mm. The expected uncertainty is 3% of drop diameter for those drops landing on the very center of the sensor. Mainly because the sensitivity of the sensor is somewhat dependent on the location of a drop impact on the sensitive surface of the sensor cone, the pulse amplitudes of drops of equal diameter will form a distribution around the average amplitude. The standard deviation of this distribution, transformed into drop diameters, is approximately ±5% if the drops are distributed evenly over the sensitive surface. The specified accuracy of a drop-size measurement of ±5% of the measured drop diameter means that the average measured diameter of a large number of drops of equal diameter, evenly distributed over the sensitive surface of the sensor will be within 5% of their actual diameter.

Precipitation amounts measured by the tipping bucket gauges and weighing bucket gauges are reported every minute with an uncertainty of 0.01 mm; rain rates have an uncertainty of 0.6 mm/hr.

3.4 Definition of Uncertainty

We define uncertainty as the range of probable maximum deviation of a measured value from the true value within a 95% confidence interval. Given a bias (mean) error *B* and uncorrelated random errors characterized by a variance σ^2, the root-mean-square error (RMSE) is defined as the vector sum of these.

$$RMSE = \left(B^2 + \sigma^2\right)^{1/2}$$

(*B* may be generalized to be the sum of the various contributors to the bias and σ^2 the sum of the variances of the contributors to the random errors). To determine the 95% confidence interval, we use the Student's *t* distribution, $t_{n;0.025} \approx 2$, assuming the RMSE was computed for a reasonably large ensemble. Then, the *uncertainty* is calculated as twice the RMSE.

3.5 Diagnostic Variables

When the rainfall rate is between 1 and 10 mm/hr for several hours, a comparison with the tipping bucket rain gauge is warranted. In such cases, the total rain amounts over the event should agree to within 15%. Otherwise, the best indicators of instrument health and performance are carried out by monitoring the quality control flags discussed in the next section.

3.6 Dimensional Variables

Dimensional variables for the tipping bucket and weighing bucket gauges are given in Table 3 and Table 4, respectively.

Table 3. Tipping bucket dimensional variables.

Quantity	Variable	Measurement Interval	Unit
Base time in epoch	base_time	1 min or 30 min	Seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset from base_time	time_offset	1 min or 30 min	Seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset form midnight	time	1 min or 30 min	Seconds since YYYY-mm-dd XX:XX:XX X:XX
North latitude	lat[a]	Once	Degrees
East longitude	lon[a]	Once	Degrees
Altitude	alt[a]	Once	Meters above sea level

[a] lat/lon/alt refer to the ground where the instrument is sited, NOT the height of the sensor.

Table 4. Weighing bucket dimensional variables.

Quantity	Variable	Measurement Interval	Unit
Base time in epoch	base_time	1 min or 30 min	Seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset from base_time	time_offset	1 min or 30 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
Time offset form midnight	time	1 min or 30 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
North latitude	lat[a]	Once	Degrees
East longitude	lon[a]	Once	Degrees
Altitude	alt[a]	Once	Meters above sea level

[a] lat/lon/alt refer to the ground where the instrument is sited, NOT the height of the sensor.

4.0 Data-Quality Flags

If data are missing for a sample time, a "missing_value" value of -999 is assigned to that field. Data-quality flags for the tipping bucket and weighing bucket rain gauges are provided in Table 5 and Table 6 respectively.

Table 5. Tipping bucket data-quality flags.

Quantity	Variable	Measurement Interval	Minimum	Maximum	Delta
Sample time	qc_time	1 min			
Precipitation total	qc_precip_tbrg	1 min	0	10	N/A
Battery voltage	qc_vbat	60 min	9.6	16	N/A
Battery minimum	qc_batt_min	60 min	9.6	16	
Battery maximum	qc_batt_max	60 min	9.6	None	
Panel temperature	qc_panel_temp	60 min	-25.0	50.0	N/A
Panel temperature minimum	qc_panel_min	60 min	-25.0	50.0	N/A
Panel temperature maximum	qc_panel_max	60 min	-25.0	50.0	N/A

Table 6. New data-quality flags for RAIN datastream (weighing bucket gauges).

Quantity	Variable	Measurement Interval	Minimum	Maximum
Time offset from base_time	qc_time_offset	1 min		
Time offset form midnight	time	1 min	0	86,400
Precipitation amount	qc_precip	1 min	-10	200
Precipitation rate	qc_precip_rate	1 min	-600	1200
Sensor 1 temperature	qc_temp1	1 min	-40	100
Sensor 2 temperature	qc_temp 2	1 min	-40	100
Sensor 3 temperature	qc_temp3	1 min	-40	100
Sensor weight 1	qc_weight1	1 min	0.33	8
Sensor weight 2	qc_weight2	1 min	0.33	8
Sensor weight 3	qc_weight3	1 min	0.33	8
Sensor 1 frequency	qc_frequency1	1 min		
Sensor 2 frequency	qc_frequency2	1 min		
Sensor 3 frequency	qc_frequency3	1 min		
Logger panel temperature	qc_ptemp	1 min	-40	100
Logger minimum voltage	qc_volt_min	1 min	8	20
Bucket total weight	qc_total_weight	1 min	1	8
Bucket total mm of precipitation	qc_total_mm	1 min	-20	200
Logger scan total	qc_scans_per_minute	1 min	16	21
Sensor status	qc_stat_latch	1 min	000	111
Sensor error	qc_error_latch	1 min	0	1

5.0 Data-Quality Health and Status

The following links go to current data-quality health and status results:

- DQ HandS (Data-Quality Health and Status)
- NCVweb for interactive data plotting using.

The tables and graphs shown at these sites contain the techniques used by ARM's data-quality analysts, instrument mentors, and site scientists to monitor and diagnose data-quality.

5.1 Data Reviews by Instrument Mentor

- *QC frequency:* Once or twice a week
- *QC delay:* Three days behind the current day
- *QC type:* DSview plots for instrument operation status, otherwise DQ HandS diagnostic plots
- *Inputs:* None
- *Outputs:* Data-Quality Problem Report and Data-Quality Report as needed
- *Reference:* None.

5.2 Data Assessments by Site Scientists/Data-Quality Office

All Data-Quality Office and most Site Scientist techniques for checking have been incorporated within DQ HandS and can be viewed there.

5.3 Value-Added Products and Quality Measurement Experiments

Many of the scientific needs of the ARM Program are met through the analysis and processing of existing data products into "value-added" products, or VAPs. Despite extensive instrumentation deployed at the ARM sites, there will always be quantities of interest that are either impractical or impossible to measure directly or routinely. Physical models using ARM instrument data as inputs are implemented as VAPs and can help fill some of the unmet measurement needs of the program. Conversely, ARM produces some VAPs, not in order to fill unmet measurement needs, but to improve the quality of existing measurements. In addition, when more than one measurement is available, ARM also produces "best estimate" VAPs. A special class of VAP, called a Quality Measurement Experiment (QME), does not output geophysical parameters of scientific interest. Rather, a QME adds value to the input datastreams by providing for continuous assessment of the quality of the input data based on internal consistency checks, comparisons between independent similar measurements, or comparisons between measurement with modeled results, and so forth. For more information, see VAPs and QMEs web page.

6.0 Instrument Details

6.1 Detailed Description

A detailed discussion of the disdrometer instrumentation and technique can be found in Section 9 of the users handbook. See 260-2500e-manual.pdf for a discussion of the tipping bucket rain gauge. See Belfort AEPG Manual Rev 11162012 for weighing bucket.

6.2 List of Components

The sensors are well described in the links mentioned above. The other components of the system comprise the data acquisition system. Two waterproof enclosure boxes house the electronics used to collect and send the data to the site data management facility. Figure 1 shows the wiring diagram, and Figure 2 and Figure 3 show close-up views of the data acquisition electronics.

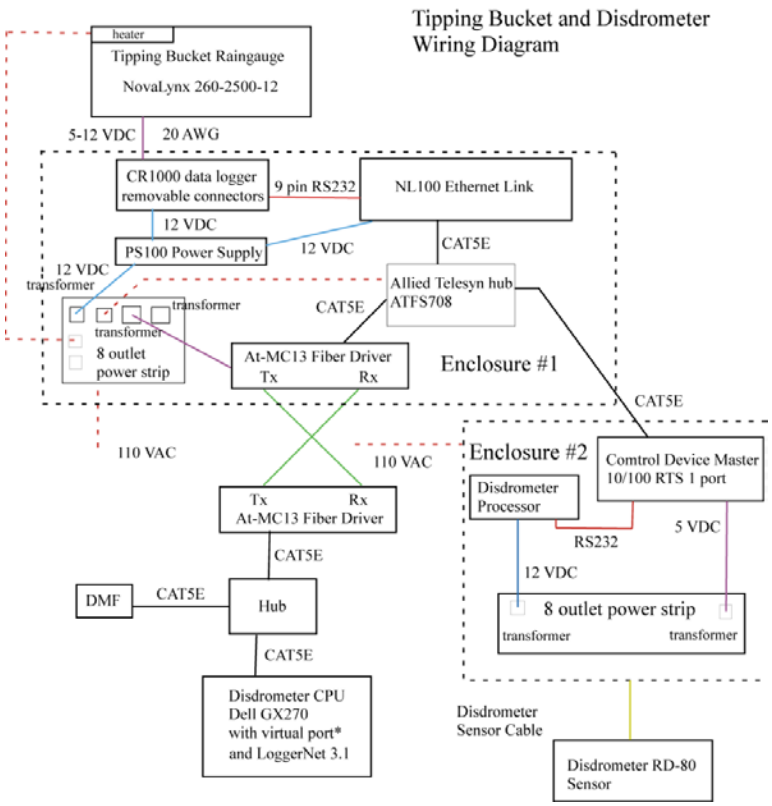

Figure 1. Disdrometer wiring diagram.

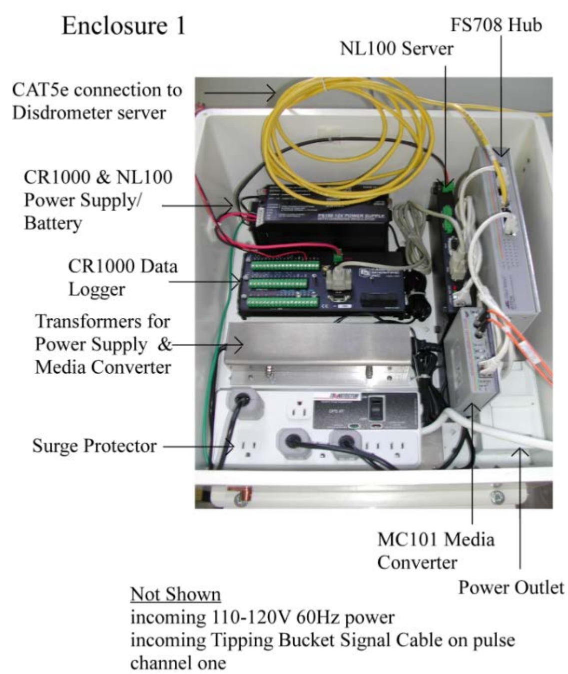

Figure 2. Disdrometer and tipping bucket system enclosure 1.

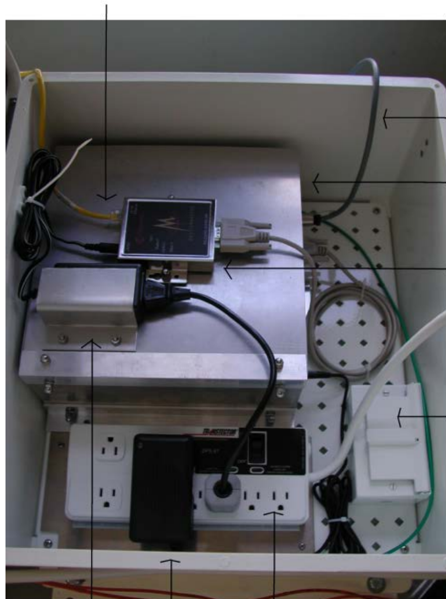

Figure 3. Disdrometer and tipping bucket system enclosure 2.

7.0 Data-Acquisition Cycle

During normal operation, both the disdrometer and the rain gauge make measurements once a minute.

8.0 Processing Received Signals

The manufacturer of the disdrometer provides software for data acquisition, analysis, and inspection. The program is called Disdrodata, and it runs on a personal computer, which in this case is an ARM Core PC, Dell GX620 running Windows XP.

Data acquisition for the tipping bucket rain gauge is carried out with a CR1000 Campbell Scientific data logger.

9.0 Siting Requirements

The site requirements for the rain gauges include a solid footing. A wind screen will be required for an open Southern Great Plains prairie installation and may be needed at the ARM Darwin site as well. Nearby objects should be placed away at a distance least twice their height. If snowfall could occur at the site, the opening of the gauge should be above average snow level.

10.0 Calibration

Tipping bucket gauges should follow the calibration procedures used for the ARM MET system. Currently, a tip test is conducted once every 2 weeks. When ARM's dynamic calibration system is ready, a full calibration should be done once a year.

11.0 User Manuals

- Tipping Bucket Manual - 260-2500e-manual.pdf
- Weighing Bucket Manual - Belfort AEPG Manual Rev 11162012

12.0 Routine Operation and Maintenance

12.1 Frequency

Weekly

12.2 Inspection of Site Ground Near the Instrument

Visually check the grounds around the instrument for hazards such as rodent burrows, settling in buried conduit trenches, and insect nests.

Checklist Response:

- No Problems Noted
- Problem - Enter any applicable comments for this planned maintenance (PM) Activity

12.3 Visual Inspection of Instrument Components

12.3.1 Conduit, Cables, and Connectors

Check that all the conduits on the bottom of the control boxes are secure. Check all conduits from the control boxes to the sensors for damage. Check all sensor wires inside the control box for tightness and damage. Check all the connections at the sensors for damage, water intrusion, and tightness.

Checklist Response:

- No Problems Noted
- Problem - Enter any applicable comments for this PM Activity

12.3.2 Check Status of Light-Emitting Diode (LED) on CR1000 Data Logger

The LED should flash once every second during normal operation.

Checklist Response:

- No Problems Noted

- Problem - Enter any applicable comments for this PM Activity

12.3.3 Check Status of Power LED on Disdrometer Processor

The green LED light on the power switch should be lit.

Checklist Response:

- No Problems Noted
- Problem - Enter any applicable comments for this PM Activity

12.3.4 Check Clock Values Shown on LoggerNet Connect Screen

The station clock should automatically be set to the server clock if times differ by 1 second or more. This automatic check is done once a day by the LoggerNet program. The times should never differ by more than 1 minute.

Checklist Response:

- No Problems Noted
- Problem - Enter any applicable comments for this PM Activity

12.4 Active Maintenance and Testing Procedures

12.4.1 Rain Gauge

Remove the rain gauge funnel and ensure that both the large and small funnels are clear of debris. Check the wiring and connector for tightness and the housing for debris and damage. Inspect all conduits and cables. Re-install the rain gauge funnel.

Checklist Response:

- No Problems Noted
- Problem - Enter any applicable comments for this PM Activity

12.4.2 Rain Gauge Tip Test

1. Set flag 7 to high using the port and flags utility within the LoggerNet program running on the system's computer. and log the time when the flag was set.
2. A red led should now light up on Com port 5 of the CR1000 device in Enclosure 1.
3. Remove the funnel from the top of the rain gauge and manually tip the rain gauge bucket several times to make sure that it is free to move.
4. If desired, the flag_tot variable can be checked. It should be equal the number of manual tips.
5. Check the output of variable rain_mm. It should be equal to # tips × 0.254.
6. Reset flag 7 to low or 0, and log the time that the flag was reset.

Checklist Response:

- No problems noted
- Problem - Enter any applicable comments for this PM Activity

13.0 Software Documentation

Tipping Bucket Rain Gauge

- Data logger script
- File splitting script
- Ingest software

14.0 Supplemental Information

14.1 Formulas Used in Data Processing

$$R = \frac{\pi}{6} \cdot \frac{3.6}{10^3} \cdot \frac{1}{F \cdot t} \cdot \sum_{i=1}^{20} (n_i \cdot D_i^3)$$

$$RA = R \cdot t/3600$$

$$RT = \sum RA$$

$$W = \frac{\pi}{6} \cdot \frac{1}{F \cdot t} \cdot \sum_{i=1}^{20} (\frac{n_i}{v(D_i)} \cdot D_i^3)$$

$$Wg = W/1000$$

$$Z = \frac{1}{F \cdot t} \cdot \sum_{i=1}^{20} (\frac{n_i}{v(D_i)} \cdot D_i^6)$$

$$ZdB = 10 \cdot \log Z$$

$$EK = \frac{\pi}{12} \cdot \frac{1}{F} \cdot \frac{1}{10^6} \cdot \sum_{i=1}^{20} \left(n_i \cdot D_i^3 \cdot v(D_i)^2\right)$$

$$EF = EK \cdot 3600/t$$

Dmax

$$N_0 = \frac{1}{\pi} \cdot \left(\frac{6!}{\pi}\right)^{\frac{4}{3}} \cdot \left(\frac{W}{Z}\right)^{\frac{4}{3}} \cdot W$$

$$\Lambda = \left(\frac{6!}{\pi} \cdot \frac{W}{Z}\right)^{\frac{1}{3}}$$

$$N(D_i) = \frac{n_i}{F \cdot t \cdot v(D_i) \cdot \Delta D_i}$$

14.2 Drop-Size Classes

Drop-Size Class in DISDROD ATA Program	Output Code of Processor RD-80	Lower Threshold of Drop Diameter; mm		Average Diameter of Drops in Class 1 (Di), mm	Fall Velocity of a Drop with Diameter Di (vDi), m/s	Diameter Interval of Drop-Size Class 1 (∆Di); mm
1	1-13	0.313		0.359	1.435	0.092
2	14-23	0.405		0.455	1.862	0.100
3	24-31	0.505		0.551	2.267	0.091
4	32-38	0.596		0.656	2.692	0.119
5	30-44	0.715		0.771	3.154	0.112
6	45-54	0.827		0.913	3.717	0.172
7	55-62	0.999		1.116	4.382	0.233
8	63-69	1.232		1.331	4.986	0.197
9	70-75	1.429		1.506	5.423	0.153
10	76-81	1.582		1.665	5.793	0.166
11	82-87	1.748		1.912	6.315	0.329
12	88-93	2.077		2.259	7.009	0.364
13	94-98	2.441		2.584	7.546	0.286
14	99-103	2.727		2.869	7.903	0.284
15	104-108	3.011		3.198	8.258	0.374
16	109-112	3.385		3.544	8.556	0.319
17	113-117	3.704		3.916	8.784	0.423
18	118-121	4.127		4.350	8.965	0.446
19	122-126	4.573		4.859	9.076	0.572
20	127	5.145		5.373	9.137	0.455

CLIMATE RESEARCH FACILITY

www.arm.gov

U.S. DEPARTMENT OF ENERGY

Office of Science