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Disdrometer and Tipping Bucket Rain Gauge Handbook

MJ Bartholomew

December 2009

ARM
CLIMATE RESEARCH FACILITY

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1.0 General Overview

The Distromet disdrometer model RD-80 and NovaLynx tipping bucket rain gauge model 260-2500E-12 are two devices deployed a few meters apart to measure the character and amount of liquid precipitation. The main purpose of the disdrometer is to measure drop size distribution, which it does over 20 size classes from 0.3 mm to 5.4 mm. The data from both instruments can be used to determine rain rate. The disdrometer results can also be used to infer several properties including drop number density, radar reflectivity, liquid water content, and energy flux. Two coefficients, N_0 and Λ, from an exponential fit between drop diameter and drop number density, are routinely calculated. Data are collected once a minute.

The instruments make completely different kinds of measurements. Rain that falls on the disdrometer sensor moves a plunger on a vertical axis. The disdrometer transforms the plunger motion into electrical impulses whose strength is proportional to drop diameter. The rain gauge is the conventional tipping bucket type. Each tip collects an amount equivalent to 0.01 in. of water, and each tip is counted by a data acquisition system anchored by a Campbell CR1000 data logger.

2.0 Contacts

2.1 Mentor

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

2.2 Instrument Developer

Distromet LTD
Basel, Switzerland
www.distromet.com

NovaLynx Corp.
Grass Valley, CA
www.novalynx.com

3.0 Deployment Locations and History

One system was deployed at the Darwin TWP site in December 2005, and the other was deployed at the SGP central facility early in spring 2006.

4.0 Near-Real-Time Data Plots

This section is not applicable to these instruments.

5.0 Data Description and Examples

5.1 Data File Contents

Data Streams
XxxdisdrometerC1.00
XxxdisdrometerC1.b1
XxxrainC1.00
XxxrainC1.b1
XxxrainauxC1.00
XxxraiauxnC1.b1
Where xxx = three letter site designation.

5.1.1 Primary Variables and Expected Uncertainty

The variables for the disdrometer and tipping bucket rain gauge are listed in Tables 1 and 2.

Primary Variables for Disdrometer and Tipping Bucket Rain Gauge

Table 1. Disdrometer variables, datastream ***************.

Quantity	Variable	Measurement Interval	Unit	Manufacturer Variable Name
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	constant	degrees	
east longitude	lon	constant	degrees	
altitude	alt	constant	meters above sea level	
instrument serial number	serial_number	constant		
calibration date	calib_date	constant		
precipitation	precip_dis	1 min	millimeters	RA rain amount
number of drops	num_drop	1 min	integer	n
verage diameter of drop class	drop_class	1 min	millimeters	D Average diameter of drops in class

Table 1. (cont'd)

Quantity	Variable	Measurement Interval	Unit	Manufacturer Variable Name
rain rate	rain_rate	1 min	millimeters/hr	R Rainfall rate
largest drop	d_max	1 min	millimeters	Dmax Largest drop registered
number density	nd	1 min	$1/(m^3 \cdot m)$	N(D) Number density
fall velocity	fall_vel	constant	m/s	v(D) fall velocity
diameter interval between drop size classes	delta_diam	constants	millimeters	ΔD delta diameter
liquid water content	liq_water	1 min	grams/meter^3	Wg Liquid water content
radar reflectivity	zdb	1 min	dB	ZdB Radar reflectivity factor
energy flux	ef	1 min	joules/(meter^2 · hour)	EF Energy Flux
distribution slope	lambda	1 min	1/millimeter	Λ slope
distribution intercept	n_0	1 min	1/(meters^3 · millimeters)	N_0 intercept

Note: lat/lon/alt refers to the ground where the instrument is sited, NOT the height of the sensor.

Table 2. Tipping bucket rain gauge variables, 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 form midnight	time	1 min	seconds since YYYY-mm-dd XX:XX:XX X:XX
north latitude	lat	constant	degrees
east longitude	lon	constant	degrees
altitude	alt	constant	meters above sea level
calibration date	calib_date	constant	
instrument serial number	serial_number	constant	
precipitation	precip_tbrg	1min	millimeters
rainfall rate	rain_rate	1 min	millimeters/hour

Note: lat/lon/alt refers to the ground where the instrument is sited, NOT the height of the sensor.

Expected Uncertainty

The disdrometer measures rain drop size over the range of 0.3 mm to 5.4 mm once a minute. The expected uncertainty is 3% of drop diameter for those drops landing on the very center of the sensor. Mainly due to the fact that 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. Typical values for the drop size classes, terminal fall velocities, and diameter intervals are listed in Table 3.

Table 3. Drop class specifics.

Average diameter of drops in each class (mm)	Fall velocity of a drop in each class (m/s)	Diameter interval between drop classes (mm)
0.359	0.455	0.551
0.656	0.771	0.913
1.116	1.331	1.506
1.665	1.912	2.259
2.584	2.869	3.198
3.544	3.916	4.350
4.859	5.373	1.435
1.862	2.267	2.692
3.154	3.717	4.382
4.986	5.423	5.793
6.315	7.009	7.546
7.903	8.258	8.556
8.784	8.965	9.076
9.137	0.092	0.100
0.091	0.119	0.112
0.172	0.233	0.197
0.153	0.166	0.329
0.364	0.286	0.284
0.374	0.319	0.423
0.446	0.572	0.455

Precipitation amounts measured by the rain gauge are reported once a minute with an uncertainty of 0.001 mm.

5.1.1.1 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.

5.1.2 Secondary/Underlying Variables

This section is not applicable to these instruments.

5.1.3 Diagnostic Variables

When the rainfall rate is between 1 and 10 mm per hour 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 via monitoring the quality control flags discussed in the next section.

5.1.4 Data Quality Flags

If the data is missing for a sample time, a "missing-value" value of -999 is assigned to that field.

Table 4. Disdrometer data quality variables.

Quantity	Variable	Measurement Interval	Min	Max	Delta
sample time	qc_time	1 min			
precipitation total	qc_precip_dis	1 min	0	10	N/A
number of drops	qc_numdrop	1 min	0	none	N/A
rain rate	qc_rain_rate	1 min	0	none	N/A
d_max		1 min	0	10	
ef		1 min	0	4000	
liq_water		1 min	0	100	

Table 5. Tipping bucket data quality flags.

Quantity	Variable	Measurement Interval	Min	Max	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

5.1.5 Dimension Variables

Table 6. Disdrometer dimension variables.

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	once	degrees
east longitude	lon	once	degrees
altitude	alt	once	meters above sea level

Note: lat/lon/alt refers to the ground where the instrument is sited, NOT the height of the sensor.

Table 7. Tipping bucket dimension 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	once	degrees
east longitude	lon	once	degrees
altitude	alt	once	meters above sea level

Note: lat/lon/alt refers to the ground where the instrument is sited, NOT the height of the sensor.

5.2 Annotated Examples

This section is not applicable to these instruments.

5.3 User Notes and Known Problems

Routine testing of the electronic processor unit of the disdrometer system results in a number of drops (typically a few hundred) occurring in drop class 7 (1 mm), when little or no drops occur in the other classes. Testing takes place once a week, provided it is not raining, and is usually run between 15:00 and 18:00 UTC. These observations should be ignored. Furthermore, wind can cause the sensor to vibrate, resulting in false detection of small drops usually in the 0.3 mm drop class; see figure below.

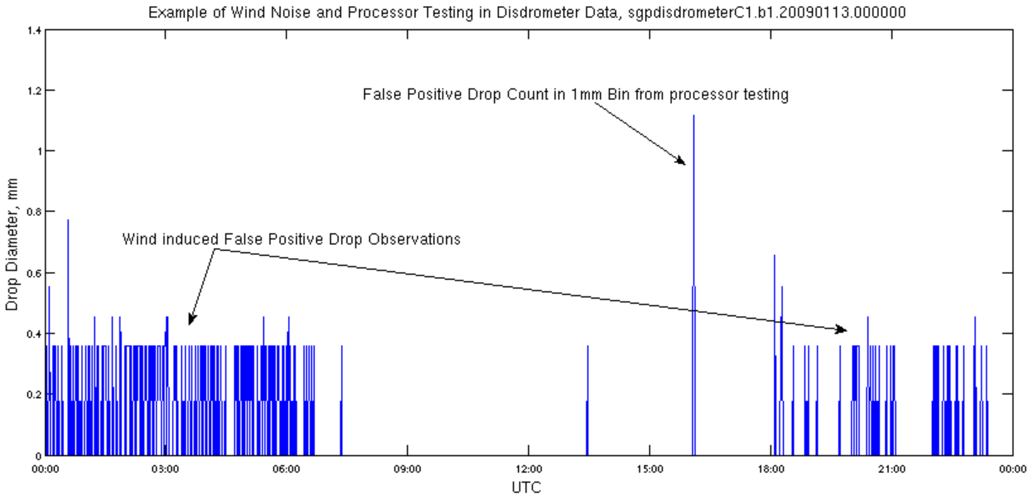


Figure 1. Example of wind noise and processor testing.

5.4 Frequently Asked Questions

This section is not applicable to these instruments.

6.0 Data Quality

6.1 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

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

6.2 Data Reviews by Instrument Mentor

- **QC frequency:** Once or twice a week
- **QC delay:** Three days after the current day
- **QC type:** DSview plots for instrument operation status, otherwise DQ HandS diagnostic plots
- **Inputs:** None
- **Outputs:** DQPR and DQR as needed
- **Reference:** None

6.3 Data Assessments by Site Scientist/Data Quality Office

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

6.4 Value-Added Products and Quality Measurement Experiments

Many of the scientific needs of the ARM Climate Research Facility 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. ARM produces other VAPs 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. 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.

7.0 Instrument Details

7.1 Detailed Description

A detailed discussion of the disdrometer instrumentation and technique can be found in Section 9 of the disdrometer operating instructions. For a copy of the operating instructions, contact the instrument manufacturer, DISTROMET LTD.

The 260-2500 Tipping Bucket Rain Gauge user's manual is available on the manufacturer's website.

7.1.1 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 2 shows the wiring diagram, and Figures 3-4 show close-up views of the data acquisition electronics.

7.1.2 System Configuration and Measurement Methods

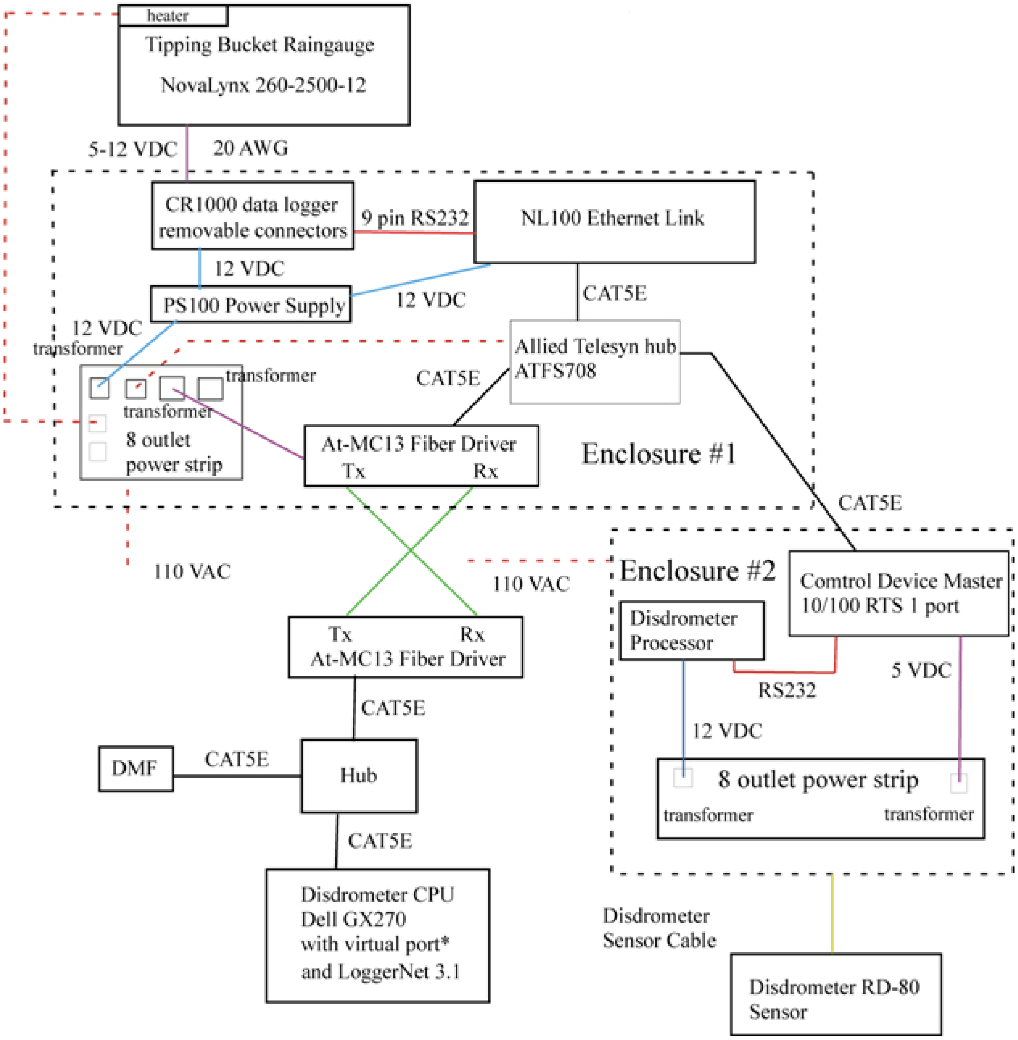
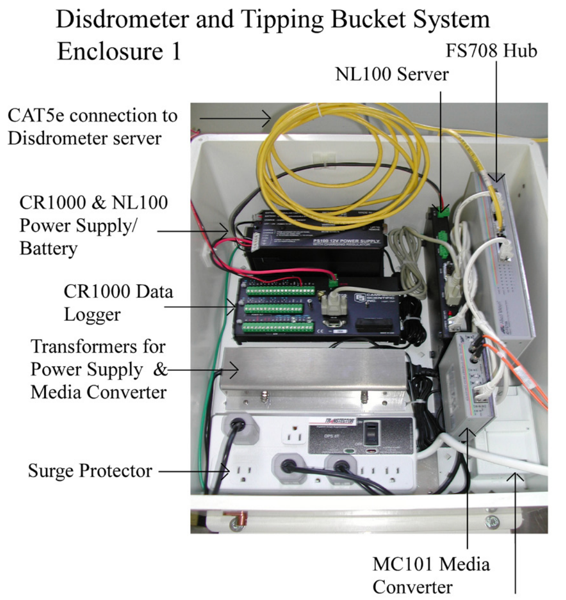
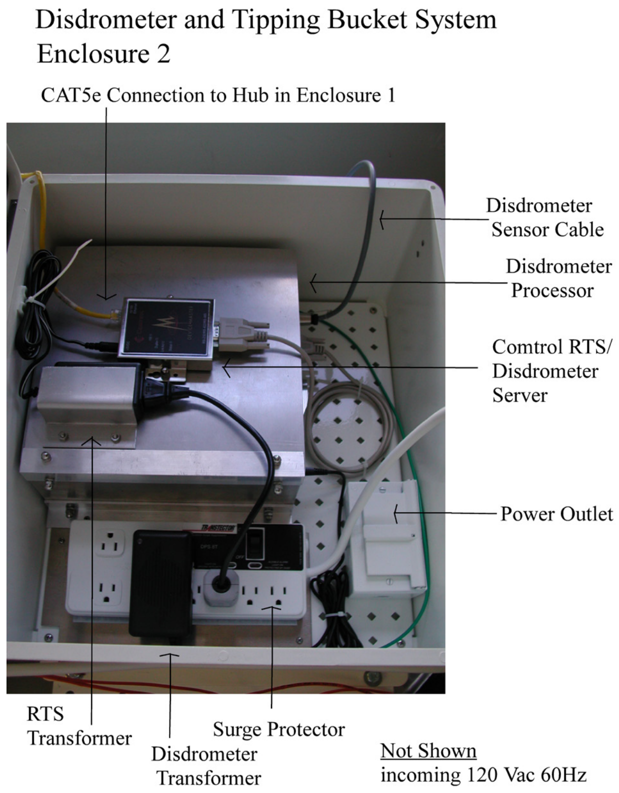


Figure 2. Tipping bucket and disdrometer wiring diagram.



Not Shown
incoming 110-120V 60Hz power
incoming Tipping Bucket Signal Cable on pulse channel one

Figure 3. Disdrometer and tipping bucket system enclosure 1.



Not Shown
incoming 120 Vac 60Hz

Figure 4. Disdrometer and tipping bucket system enclosure 2.

The Data Acquisition Cycle

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

Firmware Overview

Processing Received Signals

The disdrometer's manufacturer provides software for data acquisition, analysis, and inspection. The program is called Disdrodata, and it runs on a personal computer (Figure 3), 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.

Siting Requirements

The disdrometer needs a level firm base and a quiet environment because acoustic noise can be detected by the sensor. Strong winds that produce turbulence at the edges of the sensor are a source of error as well. Mounting the top of the sensor flush with its surroundings minimizes the wind problem. Furthermore, the sensor must not be flooded, and the top of the sensor needs to be free of snow. Lastly, external sources of electromagnetic fields and power surges can interrupt and influence the measurements made by the disdrometer.

The site requirements for the rain gauge include a solid footing and a relatively sheltered area. A wind screen will be required for an open SGP prairie installation and may be needed in Darwin as well. Objects nearby should be at least twice as far away as their height. If snowfall can be expected at the site, the opening of the gauge should be above average snow level.

7.1.3 Specifications

The disdrometer specification can be found in Section 4 of the user's manual.

7.2 Theory of Operation

This section is not applicable to these instruments.

7.3 Calibration

The disdrometer sensor and processor will be sent to Distromet for calibrations once a year. This should be done during the winter at SGP and during the driest time of the year for Darwin.

The tipping bucket gauges should follow the procedures used for the SMOS 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.

7.3.1 Theory

This section is not applicable to these instruments.

7.3.2 Procedures

This section is not applicable to these instruments.

7.3.3 History

Both devices were last calibrated in the fall of 2005.

7.3.4 User Manuals

Disdrometer Manual- Contact the instrument manufacturer

Tipping Bucket Rain Gauge Manual- 260-2500e-manual.pdf

7.3.5 Routine Operation and Maintenance

Frequency: weekly

Inspection of site grounds near the instrument:

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

Checklist response:

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

Visual inspection of instrument components:

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

Check status of LED on CR1000 data logger

LED should flash once every second during normal operation.

Checklist response:

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

Check status of power LED on disdrometer processor

Green LED/power switch should be lit.

Checklist response:

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

Check clock values shown on LoggerNet connect screen:

The station clock should automatically be set to 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

Active maintenance and testing procedures

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

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 Encloser 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 output of variable rain_mm; should be equal to # tips x 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

Disdrometer maintenance

Keep sensor free of leaves and/or other debris.

Disdrometer testing

The disdrometer has an internal circuit for testing the processor and presence of the sensor.

1. Press the test button (no need to hold this down).
2. LED # 4 on processor front panel should light, and the sensor should produce a faint 1000 Hz sound.
3. If LED #4 does not light or a different LED lights, the processor may not be connected properly. Check sensor cable connections and repeat test.

Checklist response:

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

7.3.6 Software Documentation

Disdrometer-

Ingest software

Tipping Bucket Rain Gauge-

Data logger script
File splitting script
Ingest software

7.3.7 Additional Documentation

This section is not applicable to these instruments.

7.4 Glossary

See the ARM Glossary.

7.5 Acronyms

See the ARM Acronyms and Abbreviations.

7.6 Citable References

Joss, J., and A. Waldvogel, 1967: Ein Spektrograph fuer Niederschlagstropfen mit automatischer Auswertung. *Pure Appl. Geophys.,* **68**, 240-246.

Joss, J., and A. Waldvogel, 1969: Raindrop size distribution and sampling size errors. *J. Atmos. Sci.,* **26**, 566-569.

7.7 Formulas Used in Data Processing

The following quantities are calculated for a distribution with a time interval t:
R Rainfall rate (mm/h)
RA Rain amount (mm)
RT Total rain amount since start of measurement (mm)
W Liquid water content (mm3 /m3)
Wg Liquid water content (g/m3)
Z Radar reflectivity factor (mm6 /m3)
ZdB Radar reflectivity factor (dB)
EK Kinetic energy (J/m2)
EF Energy flux (J/(m2 . h)
Dmax Largest drop registered (mm)
N0 (1/[m3.mm])
Λ Slope (1/mm)
N(Di) the number density of drops of the diameter corresponding to size class i
per unit volume, (1/[m3.mm])

Input Data:
ni number of drops measured in drop size class i during time interval t
Di average diameter of the drops in class i mm Appendix 5.1
F size of the sensitive surface of the disdrometer m2
F = 0.005 m2
t time interval for measurement s
t = 60 s (standard value)
v(Di) fall velocity of a drop with diameter Di m/s Appendix 5.1
Ref: **Gunn, R. and G.D. Kinzer, 1949**: The Terminal Velocity of Fall for Droplets in Stagnant Air. *J. Meteor.*, **6**, 243-248.
ΔDi diameter interval of drop size class i mm, see drop size classes below

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

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

$$RT = \sum RA$$

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

$$Wg = W/1000$$

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

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

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

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

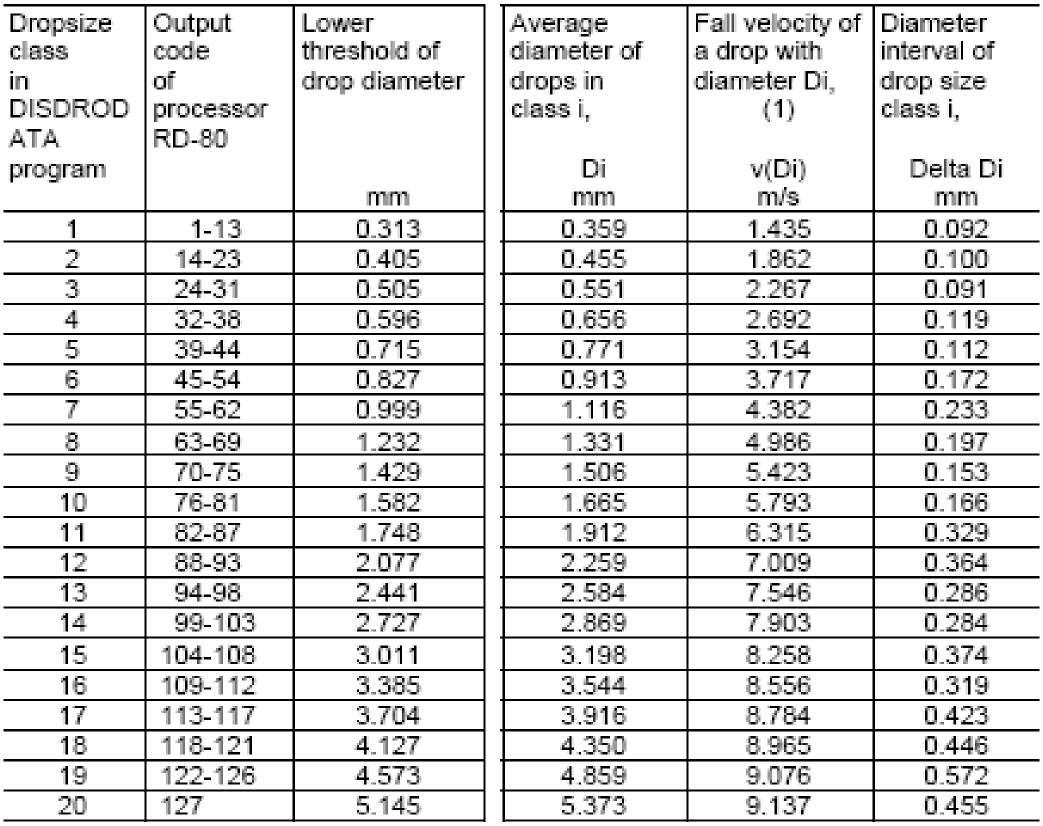
Dmax

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

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

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

Drop Size Classes



Dropsize class in DISDRODATA program	Output code of processor RD-80	Lower threshold of drop diameter mm	Average diameter of drops in class i, Di mm	Fall velocity of a drop with diameter Di, (1) v(Di) m/s	Diameter interval of drop size class i, Delta 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	39-44	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

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