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DOE/SC-ARM-TR-111

Impact Disdrometer Instrument Handbook

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ARM
CLIMATE RESEARCH FACILITY

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Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement Climate Research Facility
DOE	U.S. Department of Energy
LED	light-emitting diode
PM	planned maintenance
QC	quality control
QME	Quality Measurement Experiment
UTC	Coordinated Universal Time
VAP	Value-Added Product
VDIS	video disdrometer

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Tables

1.0 General Overview

To improve the quantitative description of precipitation processes in climate models, the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility has been collecting observations of the drop size spectra of rain events since early in 2006. Impact disdrometers were the initial choice due to their reliability, ease of maintenance, and relatively low cost. Each of the two units deployed was accompanied by a nearby tipping bucket. In 2010, the tipping buckets were replaced by weighing buckets rain gauges. Five video disdrometers were subsequently purchased and are described in ARM's VDIS Handbook.1 As of April 2011, three of the weighing bucket instruments were deployed, one was to travel with the second ARM Mobile Facility, and the fifth was a spare. Two of the video disdrometers were deployed, a third was to be deployed later in the spring of 2011, one was to travel with the second ARM Mobile Facility, and the last was a spare. Detailed descriptions of impact disdrometers and their datastreams are provided in this document.

2.0 Contacts

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Instrument Developers
Impact Disdrometers
Distromet LTD
Basel, Switzerland
www.disdtromet.com

Instrument manual available from manufacturer http://www.distromet.com/5/home

Deployment Locations and History

	Begin	End
Darwin, ARM TWPC3 site	February 2006	Ongoing
Southern Great Plains, SGPC1 site	April 2006	January 2015

Near-Real-Time Data Plots
http://plot.dmf.arm.gov/plotbrowser/

Data Description and Examples
Data File Contents

[1] VDIS is the abbreviation for video disdrometer.

Data Streams
Impact Disdrometers
XxxdisdrometerCn.00
XxxdisdrometerCn.b1

3.0 Primary Variables

The primary variables for the disdrometer and rain gauge datastreams are listed in Table 1.

Table 1. Primary impact disdrometer variables, DISD 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 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		
Calibration date	calib_date	constant		
Precipitation	precip_dis	1 min	millimeters	RA - rain amount
Number of drops	num_drop	1 min	integer	n
Average diameter of drop class	drop_class	1 min	millimeters	D - Average diameter of drops in class
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 reflectiviey	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

Quantity	Variable	Measurement Interval	Unit	Manufacturer Variable Name
Distribution intercept	n_0	1 min	1/(meters^3 millimeters)	N_0 - intercept
[a] lat, lon, and alt refer to the ground where the instrument is sited, NOT the height of the sensor.				

4.0 Expected Uncertainty

The impact disdrometers measure rain drop size over the range of 0.3 mm to 5.4 mm. The expected uncertainty is 3% of drop diameter for those drops landing on the very center of the sensor. Primarily because the sensitivity of the sensor depends somewhat 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 drop size classes, terminal fall velocities, and diameter intervals are listed in Table 2.

Table 2. Drop class specifics for impact disdrometer observations.

Average Drop Diameter 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

5.0 Diagnostic Variables

When the rainfall rate is between 1 and 10 mm/hr for several hours, a comparison between impact disdrometers and rain gauges is warranted. In such cases, the total rain amounts collected 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.

6.0 Data-Quality Flags

If data are missing for a sample time, a "missing_value" value of -999 is assigned to that field. Impact disdrometer data-quality variables are provided in Table 3.

Table 3. Impact disdrometer data-quality variables.

Quantity	Variable	Measurement Interval	Minimum	Maximum	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	

7.0 Dimension Variables

Disdrometer dimension variables are provided in Table 4.

Table 4. 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[a]	once	degrees
east longitude	lon[a]	once	degrees
altitude	alt[a]	once	meters above sea level
Video disdrometer width of bins	bin_width	constant	0.2 mm

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

8.0 User Notes and Known Problems

Routine testing of the electronic processor unit of the impact 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 when 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, which results in false detection of small drops usually in the 0.3-mm drop class (see Figure 1).

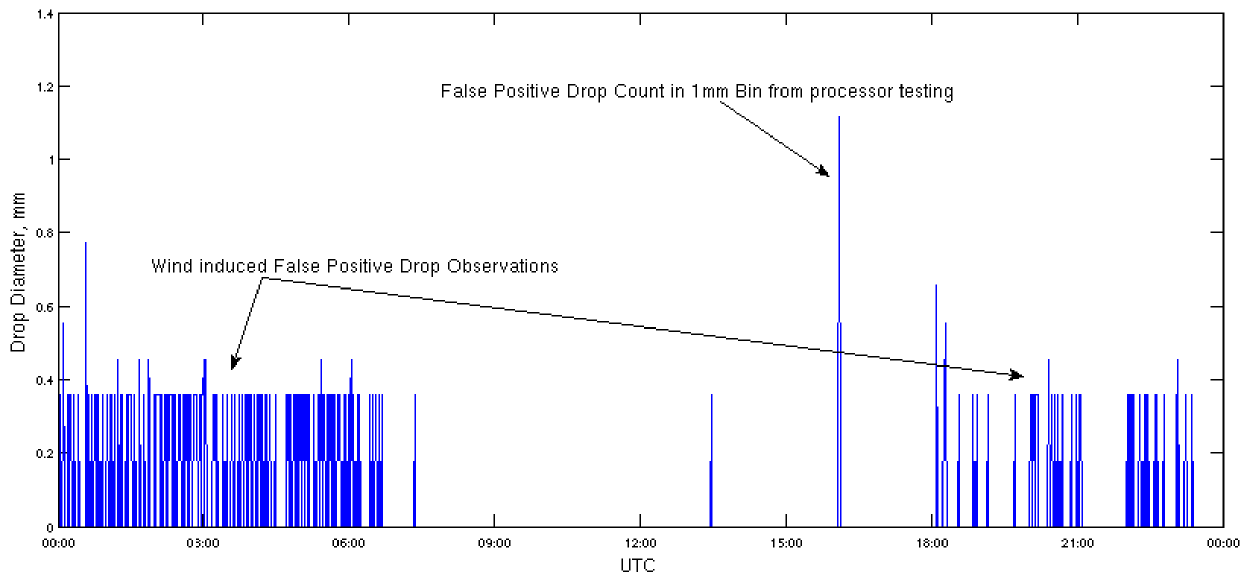

Figure 1. Examples of wind noise and processor testing in disdrometer data.

9.0 Data Quality

9.1 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 using

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.

9.2 Data Reviews by Instrument Mentor

- Quality Control (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.

9.3 Data Assessments by Site Scientist/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.

10.0 Value-Added Procedures and Quality Measurement Experiments

Many of the scientific needs of ARM are met through analysis and processing of existing data products into “value-added” products or VAPs. Despite extensive instrumentation deployed at 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 facility. Conversely, ARM produces some VAPs, not 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.

11.0 Instrument Details

11.1 Detailed Description

A detailed discussion of the disdrometer instrumentation and technique can be found in Section 9 of the user’s handbook (see RD-80 Manual Dec 04.pdf).

11.2 List of Components

The sensors are described well in the links provided above. The other components of the system comprise the data-acquisition system. The impact disdrometer data-acquisition component shares hardware with the rain gauge (either a tipping bucket or weighing bucket). Two waterproof enclosure boxes house the electronics used to collect and send data to the site data management facility. Figure 2 shows the wiring diagram, and Figure 3 and Figure 4 show close-up views of the data-acquisition electronics.

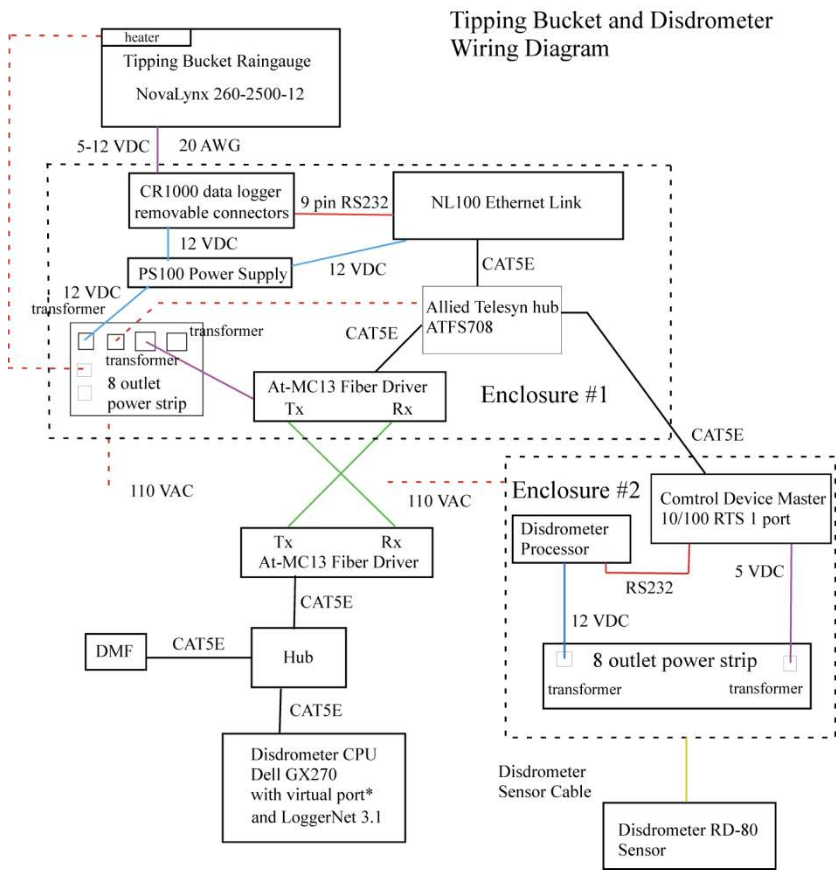

Figure 2. Disdrometer wiring diagram.

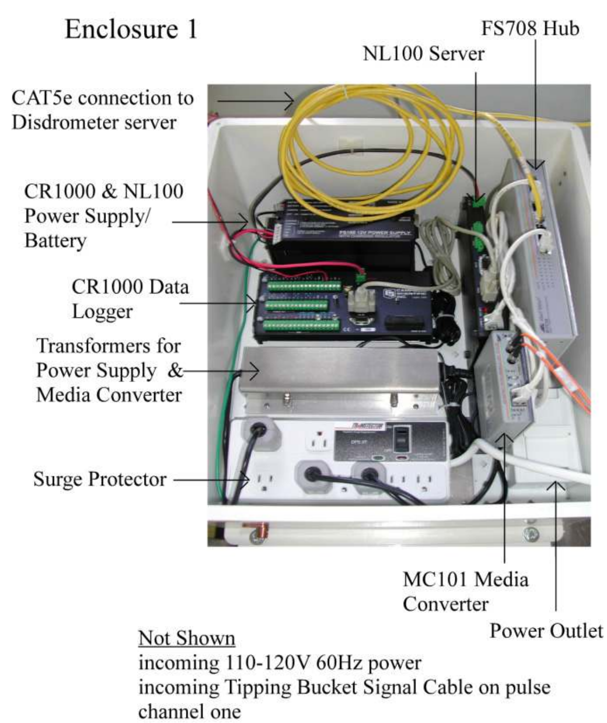

Figure 3. Disdrometer and tipping bucket system enclosure 1.

Figure 4. Disdrometer and tipping bucket system enclosure 2.

12.0 Data-Acquisition Cycle

During normal operation, all disdrometers and rain gauges make periodic 1-minute observations.

13.0 Processing Received Signals

The manufacturer of the disdrometers provided software for data acquisition, analysis, and inspection. In the case of the impact disdrometers, 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. The video disdrometer software is called the Indoor User Terminal software package, and it runs on Windows 7.

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

14.0 Siting Requirements

The impact 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 clear of snow. Lastly, external sources of electromagnetic fields and power surges can interrupt and influence the measurements made by the disdrometer.

15.0 Specifications

The disdrometer specification can be found in Section 4 of the user's manual (see RD-80 Manual Dec 04.pdf).

16.0 Theory of Operation

The sensor transforms the mechanical momentum of an impacting drop into an electric pulse. The amplitude of the pulse is roughly proportional to the mechanical momentum. The sensor consists of a cylindrical metal housing that contains an electromechanical transducer and an amplifier module. The processor contains circuitry to eliminate unwanted signals, resulting mainly from acoustic noise, and produces a 7-bit code at the output for every drop that hits the sensitive surface of the sensor.

17.0 Calibration

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

18.0 User Manuals

Disdrometer Manual - RD-80 Manual Dec 04.pdf.

19.0 Routine Operation and Maintenance

19.1 Frequency

Weekly

19.2 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 planned maintenance (PM) Activity

19.3 Visual Inspection of Instrument Components

19.3.1 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

19.3.2 Check Status of Power Light Emitting Diode on Disdrometer Processor

Green light emitting diode (LED)/power switch should be lit.

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

19.4 Active Maintenance and Testing Procedures

19.4.1 Disdrometer Maintenance

Keep sensor free of leaves and/or other debris.

19.4.2 Disdrometer Testing

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

1. Push 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 10000-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 the test.

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

19.4.3 Software Documentation

Disdrometer - Ingest software

20.0 Citable References

Joss, J and A Waldvogel. 1967. "In spektrograph fuer niederschlagstropfen mit automatischer auswertung." *Pure Applied Geophysics* 68(1): 240-246, doi:10.1007/BF00874898.

Joss, J and A Waldvogel. 1969. "Raindrop size distribution and sampling size errors." *Journal of Atmospheric Science* 26: 566-569, doi:10.1175/1520-0469(1969)026-0566:RSDASS>2.0.CO;2.

21.0 Supplemental Information

Formulas used in data processing:

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

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

$$RT = \sum RA$$

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

$$Wg = W/1000$$

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

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

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

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

Dmax

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

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

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

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 [mm^3/m^3]
- Wg: Liquid water content [g/m^3]
- Z: Radar reflectivity factor [mm^6/m^3]
- ZdB: Radar reflectivity factor [dB]
- EK: Kinetic energy [J/m^2]

- EF: Energy flux [J/(m^{2}h)]
- Dmax Largest drop registered [mm]
- N0: [1/(m^3.mm)]
- Λ: Slope [1/mm]
- N(Di): Number density of drops of the diameter corresponding to size class I per unit volume, [1/(m^3.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
- F size of the sensitive surface of the disdrometer [m^2]

F = 0.005 [m^2]
T: Time interval for measurement [s]
t = 60 s (standard value)
v(Di): Fall velocity of a drop with diameter Di [m/s]
Ref: Gunn, R and GD Kinzer. 1949. "The terminal velocity of fall for water droplets in stagnant air." *Journal of Meteorology* 6: 243-248, doi:10.1175/1520-0469(1949)006<0243:TTVOFF>2.0.CO;2.
ΔDi: Diameter interval of drop size class i [mm]; see drop size classes in the following table.

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 (ΔDi); 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

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