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Radar-disdrometer comparison

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Abstract. A THIES-CLIMA disdrometer has been installed in November 2003 in the vicinity o f the C-band Trappes (near Paris) radar of Météo France. 1-minute data representing the number of particles detected per class diameter and class fall speed have been continuously recorded since then allowing the retrieval of the reflectivity and rain rate at ground level. Also archived are the dominant particle types among 8 different types (rain, snow, graupel). In a first part, the disdrometer performances have been assessed using various precipitating events (rain, snow, hail). The outputs of the particle type identification were compared with two other microphysical sensors (PWD11 and PWD21) and the rain rates were compared to those measured with rain gauges. Overall, the quality of the disdrometer was in agreement with PWD sensors. In a second part, the rain rate and reflectivity measurements were compared to co-located radar measurements for a number of rain events and analysed in terms of calibration biases and fluctuations of the Z-R relationship.

1 Introduction

The purpose of this work is to calibrate a conventional C band radar with a disdrometer. Radar calibration is done at Météo France by injecting in the receiver a signal with a high frequency signal generator. In this case, we control the amplitude and the frequency of injected signal. The results of the calibration are three numbers namely the tuned frequency, the gain and the offset. With that kind of procedure however we only calibrate the receiver and not all the components of the radar. Radar data are also compared to rain gauge measurements on monthly basis but the comparison is rendered difficult by VPR effects and the drop size distribution or DSD fluctuations. With a disdrometer, the input signal is DSD, and we can calibrate the entire radar system. In a first part, we assess a "Laser precipitation monitor" or LPM, a disdrometer of the THIES-CLIMA company. In second part, we explain how to use the disdrometer data to calibrate the Radar.

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2 Presentation of Laser precipitation monitor or LPM

The disdrometer was installed on the same site as the C band radar since September 2003, in Trappes 20 km west of Paris. This LPM consists of a laser beaming and the sensing area is 45 cm^2, the thickness of it is 0.75 mm.The principe of measuring is shown in Fig. 1. The principle of measurement is the occultation of parallel beam of infrared light by falling hydrometeors. As raindrops pass though the beam of ligh they reduce the transmitted signal. The diameter of particle is calculted from the amplitude of the reduction and the fall speed is estimated from the duration of reduced signal. The LPM data consist of the number of particles n_i per class diameter D_i and per class velocity V_i. D_i in 20 categories ranges in size from 0.125 mm to 7.0 mm, and the range of the fall speed of drops range from 0.2 m/s to 10 m/s, the velocity V_i is distributed into 20 size intervals. The diameter is equivolumetric diameter. The Thies software delivers each minute a message giving the type of precipitation (snow, rain, soft hail, hail as well as mixed precipitation), the spectrum distribution of particles 20×20 couples of (D_i,V_i) over the class bining and the intensity of precipitation.

3 Quality of velocity measurements

We utilize two empirical laws of fall speed from Atlas 1973, Atlas and Ulbrich 1984:

$$V(D) = 9.65 - 10.3e^{-0.6D} \quad (1)$$

$$V(D) = 3.866D^{0.67} \quad (2)$$

where $V(D)$ is the fall velocity (m/s) and D is the drop diameter (mm). The first law fits well for diameters range from 0.6 mm to 5.8 mm and the second law is used by diameters

Fig. 1. Explanation of the measuring principle of LPM.

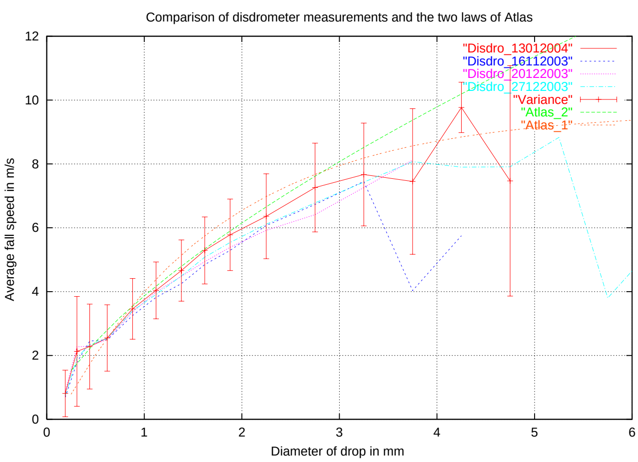

Fig. 2. Comparison Thies with Atlas laws. Plots of speed fall vs diameter.

range between 0.6 mm and 5 mm. Fig. 2 displays the comparison of Atlas's laws and LPM's data. We compare these two laws with disdrometer data of four rainy days during the winter: November 16, December 20 and 27 2003 and January 13 2004. For diameters under 3 mm, the 4 curves from disdrometer data fit with the second law of Atlas. For the larger diameters, the curves of 27 December and 13 January follows the first law, but there are fewer drops (less 15) so is not statically representative.

In the two first classes of diameters, (D <0.375 mm) , we notice some particles with high velocity (V >10.00 m/s, not shown in Fig 2), it doesnot fit with to Roger (1976) law, whose estimate for very lower Reynolds number or particles with diameter D <0.1 mm, the velocity V should have a simple linear relationship with a diameter D:

$$V(D) = 8.5D. \tag{3}$$

where V(D) is the fall velocity (m/s) and D is the drop diameter (mm). So we could remove this 2 first classes of diameter for our study.

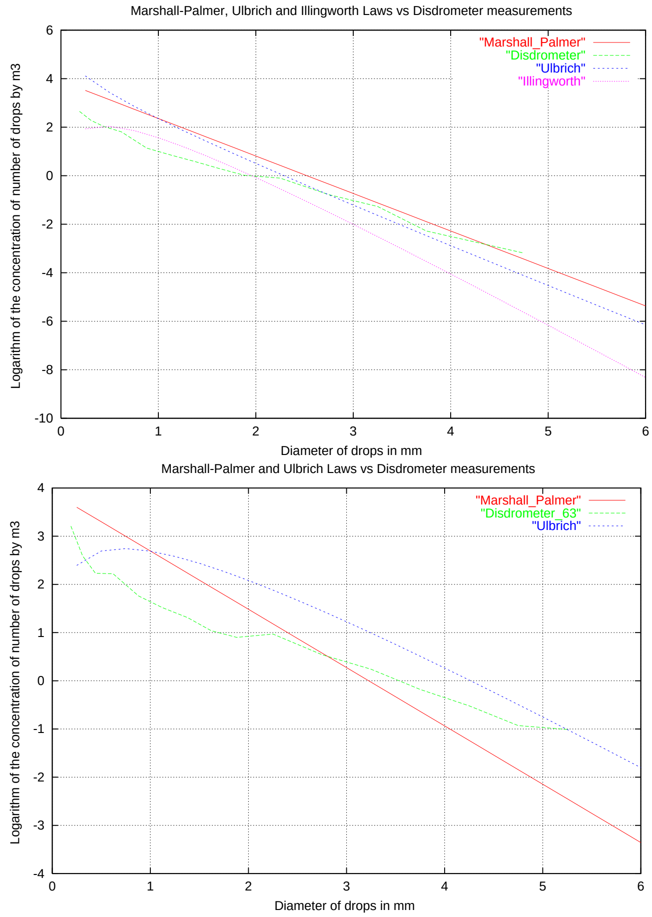

Fig. 3. Distributions for intensity of 1.6 mm/h and 6.3 mm/h.

4 The raindrop size spectra

Since 1948, Marshall Palmer suggested a simple exponential relationship with the concentration of drops by volume and the diameter of the drops and the intensity of the rain.

$$N(D) = N_0 e^{-\gamma D} \tag{4}$$

with

$$\gamma = aR^b. \tag{5}$$

But Ulbrich (1983) and Illingworth and Blackman (1999) suggested more appropriate gamma functions :

$$N(D) = NoD^{\mu} e^{-\gamma D} \tag{6}$$

$$N(D) = cNo * D^{\mu} e^{-(3.67+\mu)D/D_0} \tag{7}$$

We notice, in the case of intensity of 1.6 mm/h, that the distribution from Thies data fits the three gamma functions. But the tilt of the slope is less important with a disdrometer than the other curves. We observe, in the case of 6.3 mm/h, average of intensity during 15 min, the LPM overestimates the concentration of big drops when diameters are over 3 mm.

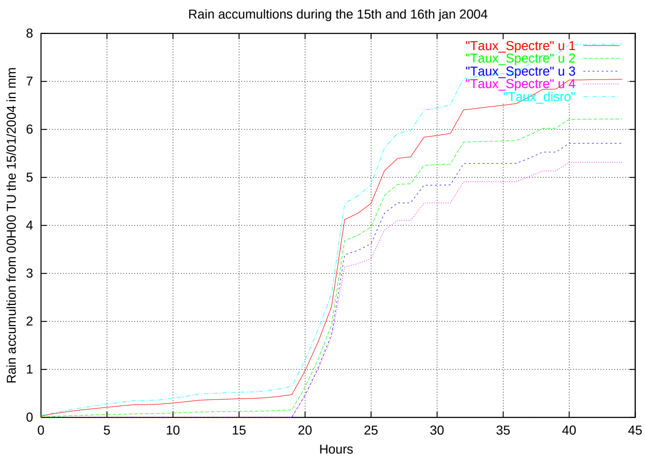

Fig. 4. Contribution of DSD for rain fall accumulation or I. Plots of the evolution of I vs time from disdrometer measurements during 48 h. 5 plots represent 5 I_n rainfall accumulations, where I_0 (the blue plot) is rain fall accumulation from the Thies telegram, and the otherI_n is a rain fall accumulation from the DSD without (n-1)th first classes of diameters.

5 Intensity of precipitation

Every minute the disdrometer delivers a value of intensity of precipitation. The following formula is used by the manufacturer :

$$I = \rho * \pi/6 * \sum_{i=1}^{i=20} D_i^3 N(D_i)\Delta D_i \tag{8}$$

with ρ is the density of hydrometeor. ρ equals 1 for the rain, or a number between 0.05 et 0.4 for the snow.

$$N(D_i)(mm^6 m^{-1}) = n_i/(v(D_i) * S * \tau * \Delta D_i) \tag{9}$$

Where $v(D_i)$ is the fall speed of a drop of diameter D_i, S is the cross section area, τ is sampling time (60 s) and ΔD_i is the width of the ith category.

We have looked at in an event of 15 and 16 Jan 2004, where the referenced rain gauge recorded 5.2 mm during the 48 hours. The rain began to fall in Trappes after 6 pm the 15th, or the disdrometer recorded some precipitations before the rain came, we think that the wind could swing the mast and made some false drop detections in clear weather. The false detections appear in the two first classes of diameters, so it is better not to use it for the calculation of the intensity. We draw in the Fig. 4 , 5 plots represent 5 I_n rainfall accumulations, where I_0 (the first plot) is rain fall accumulation from the Thies message, and the other I_n is a rain fall accumulation from the DSD without (n-1)th first classes of diameters. Without corrected value, the rain fall accumulation recorded by disdrometer was 7.8 mm, with computed accumulation the sum is 7.1 mm, without the first class, the sum is 6.2 mm. To reach the referenced value (i.e. 5.2 mm in 48 h), in that case, we have to remove 3 first classes. We noticed the same overestimated values for several cases. The intensity computed by the Thies software overstimates the real value by more 40.

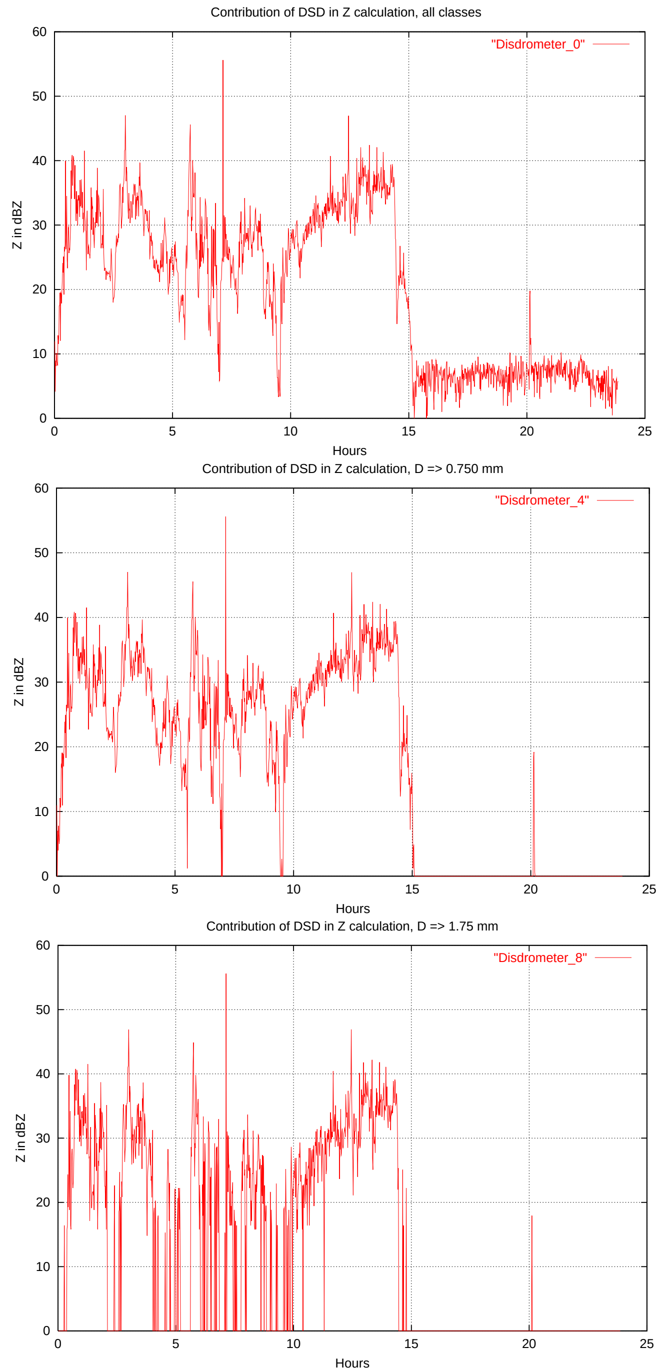

Fig. 5. Contribution of DSD for reflectivity calculation. Plots of the evolution of Z (dBZ) vs time from disdrometer measurements the January 13 2004. The first plot uses all the classes of diameters, the second uses the classes from the 5th category and the third uses classes from 9th category.

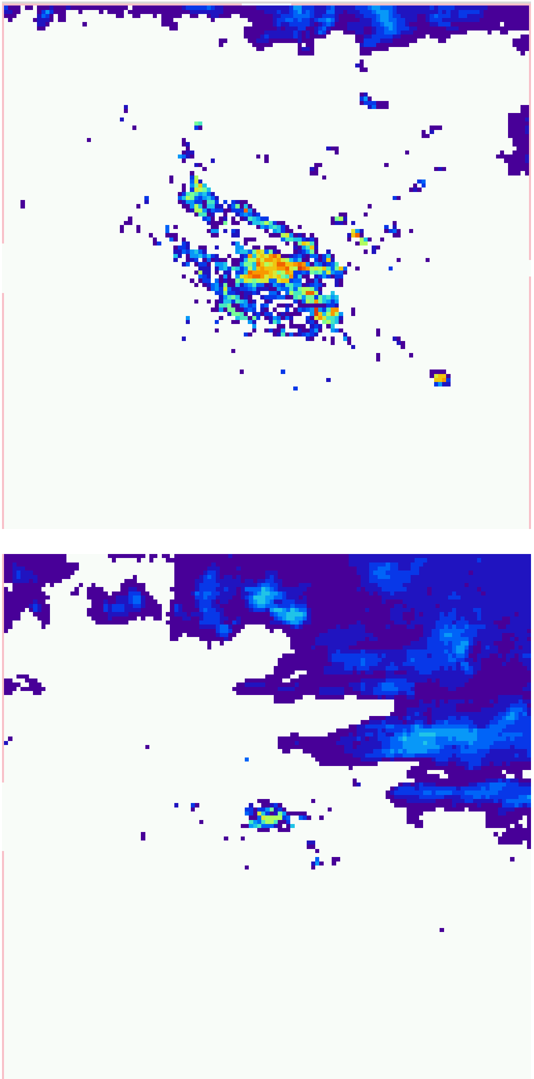

Fig. 6. The two radar images display the ground clutter at the elevation 0.4 and 9.0 degree, this images are from two scans at 6 degrees per second, each picture represents an area of 80 km by 80 km.

6 Reflectivity

The best way to compare radar and disdrometer data is to use the reflectivity. In the case of C band radar, we could use the Rayleigh approximation, so the reflectivity is: $Z = \int_0^\infty N(D) * D^6 * dD$ and the unit is mm^6/m^3. Computation of the reflectivity from disrometer data involves the simple summation over the drop size categories :

$$Z(mm^6m^{-3}) = \sum_{i=1}^{i=20} D_i^6 N(D_i) \Delta D_i \tag{10}$$

Here $N(D_i)$ is the distribution of drop diameters calculated by Eqs. 9.

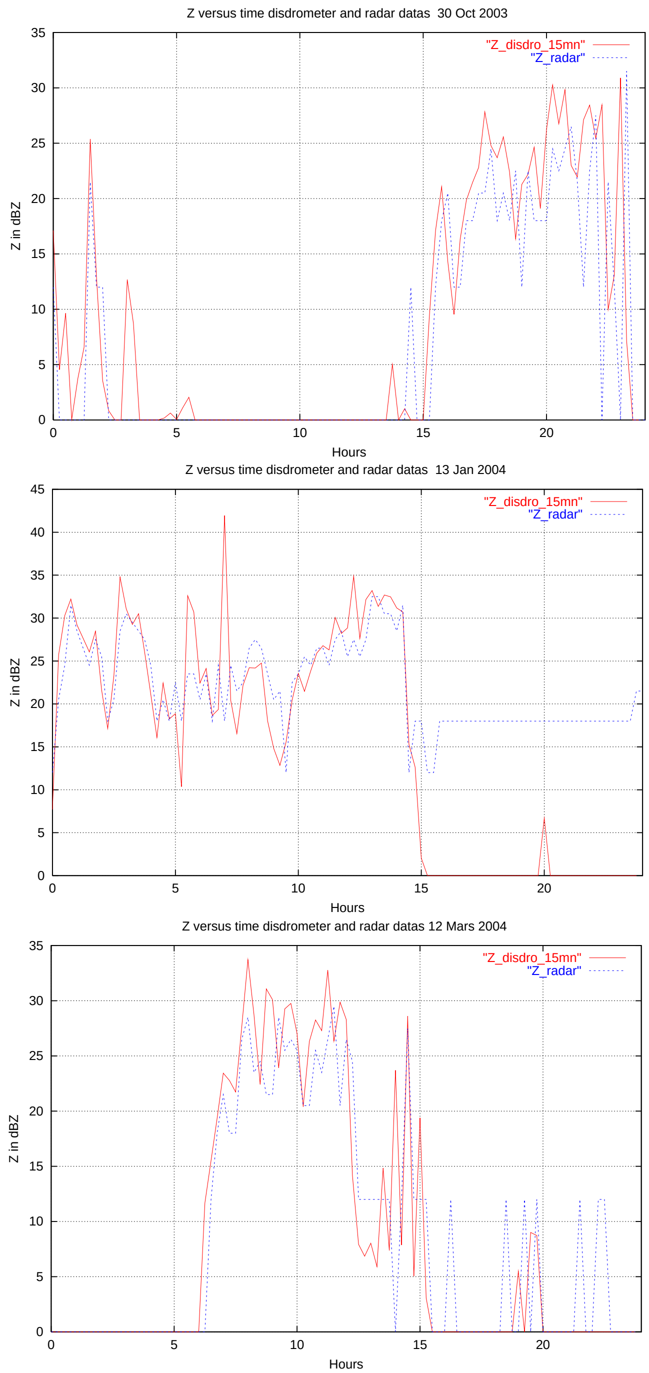

Fig. 7. Plots of Z (dBZ) vs time as found from disdrometer measurement (solid line) and from C Band radar measurements (dash line) for three events of rain over Trappes on 30 Oct 2003, 13 Jan and 12 Mars 2004.

7 Contribution of DSD for reflectivity calculation

In the Sect. 4, we have seen that the two first classes of diameter were noisy and so it is better not to use it for the study. We chose a long event of rain, about 15 h the January 13, 2004, and there are some peaks of reflectivities over 40 dBZ.

Figure 5 displays the evolution of reflectivity during 24 h and there is a value of it every minute. The 3 pictures represent the same event, but for the nth picture (Fig 5) the 1st is on the top and the 3rd is on the bottom), in the calculation of Z_n we don't use the 4(n-1)ith first class of diameters. Here Z_n the reflectivity of the nth picture :

$$Z_n = \sum_{i=4(n-1)+1}^{i=20} D_i^6 N(D_i) \Delta D_i \qquad (11)$$

We notice in the end of the day where there are very low reflectivities, and in comparison of the two first images we conclude that the influence of the four first classrs affect only the reflectivities under 10 dBZ. Hence the noise in the beginnig of the spectrum of diameters doesn't disturb the comparison between radar and disdrometer data. In the other side of the spectrum, we could say that the calculation of Z is very sensitive with N(D) for the bigger diameter $D > 3$ mm.

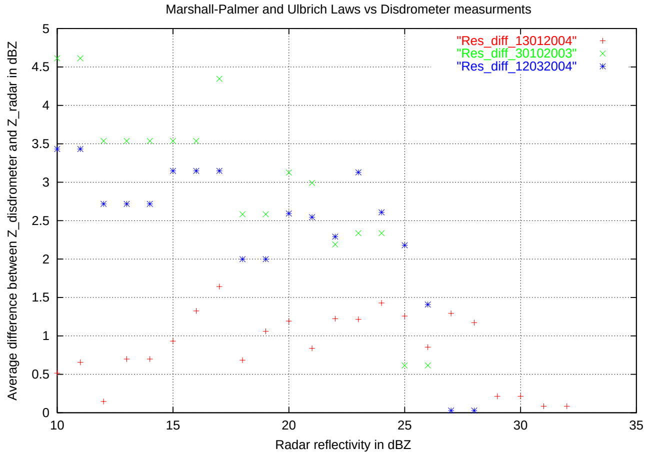

Fig. 8. Plots of $Z_{disdrometer} - Z_{Radar}$ (dBZ) vs Z_{Radar} for three events of rain over Trappes on 30 Oct 2003, 13 Jan and 12 Mars 2004.

8 Calibration

The C band radar scans 8 different elevations in 3 cycles of 5 min with a constant speed rotation at 6 degrees per seconde, the next table sums up the scanned elevations :

	round number			
cycle of 5'	1	2	3	4
1st cycle	9.0	1.5	3.6	0.4
2nd cycle	6.5	1.5	2.4	0.4
3th cycle	4.8	1.5	1.8	0.4

We select the images from the elevation 9 degrees where we found 2 pixels without ground clutter (in Fig. 6) and close to the disdrometer location at 2,3 km. The sampling for this pixels is 15 min versus one minute in the case of LPM. We had to calculate a 15 min reflectivity from disdrometer data, the value is simply the average of quarter of hour, this average was computed in unit mm^6/m^3, then change dBZ unit.

The Fig. 7 displays the evolution of Z of radar and disdrometer for three events of rain over Trappes on 30 Oct 2003, 13 Jan and 12 Mars 2004, we notice for reflectivity over 15 dBZ, the two instruments are well agreement. In case two cases of 30 october 2003 and 12 Mars 2004, more then 80 pourcents $Z_{disdrometer} > Z_{Radar}$ and the mean difference is around 3.5 dB (Mars 2004) and 2.7 dB (Oct 2003) (Fig. 8). In the others events, not shown in this article, the difference are around 3 dB. The variations of Z_{radar} and $Z_{disdrometer}$ are very well related. We only find a case, the 13 Jan 2004, that the difference is very close around 1 dB.

9 Conclusions

A thies clima was installed in September 2003 in Trappes on the same as an operational C band radar. The instrument is easy to install. Comparison with rain gauge reference show that the disdrometer measures too much rain (over 40 pourcents), and it records rain in clear weather. The disdrometer is very sensitive of wind. The comparison with the radar reflectivity reveals a stricking correlation but also a biais that varies from episode to another. Perspective: Further studies are needed of couse but results are promising. Three disdrometers will be deployed around the new Trappes polarimetric radar to evaluate the feasevility of retrieving in real time the Z-R relationship from polarimetric data.

Appendix A Classes of diameter

class	diameter (mm)	width of interval in mm
1	≥ 0.125	0.125
2	≥ 0.250	0.125
3	≥ 0.375	0.125
4	≥ 0.500	0.250
5	≥ 0.750	0.250
6	≥ 1.000	0.250
7	≥ 1.250	0.250
8	≥ 1.500	0.250
9	≥ 1.750	0.250
10	≥ 2.000	0.500
11	≥ 2.500	0.500
12	≥ 3.000	0.500
13	≥ 3.500	0.500
14	≥ 4.000	0.500
15	≥ 4.500	0.500
16	≥ 5.000	0.500
17	≥ 5.500	0.500
18	≥ 6.000	0.500
19	≥ 6.500	0.500
20	≥ 7.000	∞

Appendix B Classes of fall speed

class	fall speed (m/s)	width of interval in m/s
1	$\geq$ 0.000	0.200
2	$\geq$ 0.200	0.200
3	$\geq$ 0.400	0.200
4	$\geq$ 0.600	0.200
5	$\geq$ 0.800	0.200
6	$\geq$ 1.000	0.400
7	$\geq$ 1.400	0.400
8	$\geq$ 1.800	0.400
9	$\geq$ 2.200	0.400
10	$\geq$ 2.600	0.400
11	$\geq$ 3.000	0.400
12	$\geq$ 3.400	0.800
13	$\geq$ 4.200	0.800
14	$\geq$ 5.000	0.800
15	$\geq$ 5.800	0.800
16	$\geq$ 6.600	0.800
17	$\geq$ 7.400	0.800
18	$\geq$ 8.200	0.800
19	$\geq$ 9.000	1.000
20	$\geq$ 10.00	10.000

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