CHARACTERISTICS OF RAINDROP SPECTRUM BASED ON THE SIFT METHOD

FANG, B.[1,2,3] – YANG, W. X.[1,2,4*] – ZHANG, T. N.[3] – LI, Y.[3] – ZHANG, M. J.[3] – WANG, J. X.[1,2,4]

[1]*China Meteorological Administration Xiong'an Atmospheric Boundary Layer Key Laboratory, Xiong'an New Area 071800, China*

[2]*Key Laboratory of Meteorology and Ecological Environment of Hebei Province, Shijiazhuang 050021, China*

[3]*Liaoning Weather Modification Office, Shenyang 110166, China*

[4]*Weather Modification Center of Hebei Province, Shijiazhuang 050021, China*

[*]*Corresponding author*
e-mail: ywx418@163.com; phone: +86-0311-8166-0079

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Abstract. Using the sequential intensity filtering technique (abbreviation is the SIFT method) ,two parameters (rainfall rate R and median diameter D_m) were selected to analyze the drop spectrum data of rainfall in Shenyang from 2020-2021,the results show that: 1. The SIFT method reduces distribution fluctuations and sampling errors by comparing standard deviations SD, mean relative error AFE, standard deviation SDFE of the rainfall rate R, mean diameter D_m, raindrops concentration N_t, radar reflectance factor Z of the measured spectrum with the mean spectrum obtained by the SIFT method. 2. By analyzing the difference between the average spectrum and the SIFT method, the SIFT method has the smallest error of fitting, which shows that the SIFT method can reduce the influence of the sampling error caused by natural rainfall changes on the droplet spectrum fitting, improve the accuracy of the inversion droplet spectrum distribution characteristics.
Keywords: *sampling errors, raindrop size distribution, rainfall rate, median diameter, radar reflectance factor*

Introduction

Raindrop spectrum observation is one of the important contents of cloud and precipitation physical observation, and it has a very important application value in meteorology, hydrology, and related disciplines. Raindrop spectrum refers to the distribution of raindrop size per unit volume, reflecting the mutual constraints between cloud precipitation process, cloud dynamics and microphysics. It is of great significance in further understanding of the physical process of natural precipitation, it is also used to study the mechanism of precipitation, evaluate the cloud and water conditions of artificial precipitation, and test the catalytic effect. The distribution of raindrop spectrum has been studied for nearly 100 years. Marshall (1948, 1953) and Palmer (1948) measured the earliest detailed distribution of the average raindrop spectrum and obtained the M-P distribution. Ulbrich (1983) and Willis (1984) presented an expression for the Gamma distribution. Testud (2001) expressed the distribution form of raindrops spectrum by liquid water content and mean volume diameter. Chen et al. (1998) fitted the M-P distribution and Γ distribution of three types of precipitation clouds by using the data of Shenyang GBPP-100 raindrop disdrometer. Zhou et al. (2001) analyzed the characteristics of surface raindrops in Henan Province. Niu et al. (2002) analyzed the rain

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droplet spectrum and the characteristics of related physical quantities of different precipitation weather systems in Ningxia in summer. Zheng et al. (2007) made a comparative study on the M-P distribution and Gamma distribution of raindrops spectral function. Yang et al. (2010) used SAATP and SIFT methods to process raindrops spectrum data and obtain μ-λ relationship. Li et al. (2010) gave the Γ distribution fit of the droplet spectrum and the change characteristics of parameters over time by using the observation data of Parsivel laser raindrop spectrometer. Liao et al. (2011) analyzed the drop spectrum characteristics of the summer lightning weather system in the Pearl River Delta region of China. Liu (2015) analyzed the overall characteristics of precipitation drop spectrum of cumulus, layered mixed cloud and stratified cloud in Chengdu based on the parameters of microphysical characteristics. Wen et al. (2019) found that the precipitation in East China was mainly convective cloud precipitation in summer, which had significant Marine characteristics. The contribution of stratified cloud precipitation to precipitation in other seasons was similar or even greater than that of convective cloud precipitation. Zhao (2021) studied the droplet spectrum characteristics of precipitation in mountainous and plain areas of Beijing and pointed out that due to the large difference of underlying surface and other factors, the particle size of mountainous droplet spectrum was large and the number concentration was low, the mountainous area was inclined to continental convective droplet spectrum. Suh (2021) analyzed the spectral characteristics of stratified cloud and convective cloud precipitation in different climatic zones around the world and in the southern coastal and inland areas of South Korea. Zeng (2021) used the measured rain drop spectrum to derive the μ-λ relationship and sought a suitable local parametric scheme for Gamma distribution. Zeng (2022) studied the spectral distribution characteristics of the top and bottom of Tianshan Mountain. Seela (2022) used the rain drop spectrum to study the precipitation momentum. Sun (2023) studied the characteristics of different precipitation types and precipitation intensity conditions in Changbai Mountain in China.

There are great fluctuations in the distribution of raindrops spectrum in natural precipitation, as well as the sampling errors in the observation of raindrops spectrum. When processing the raindrops spectrum data, the sampling error should be reduced as far as possible, so that the shape factor μ and slope Λ are less affected by the error. However, the above studies have less considered the sampling error. The SIFT method (Sequential Intensity Filtering Technique, shorter form is SIFT method) is proposed by Lee et al. (2005), that all the observed drop spectrum data are classified according to the two parameters of rainfall rate R and median volume diameter D_0, and the classification average spectrum is obtained, so as to reduce the influence of factors such as drop spectrum distribution fluctuation and sampling error on rainfall inversion in natural precipitation. According to the SIFT method proposed by Lee et al. (2005), the two parameters of rainfall rate R and median diameter D_m (As the raindrop shape is regular during rainfall, D_m replaces the median volume diameter D_0 to reduce the calculate amount) are selected to analyze the drop spectrum data of Shenyang rainfall process from 2020 to 2021. The results show that the SIFT method can reduce the sampling error caused by natural rainfall changes on the raindrops spectrum fitting, can improve the accuracy of the inversion raindrops spectrum distribution characteristics, can correct the precipitation of weather radar observation, can improve the accuracy of radar quantitative estimation precipitation is of great significance.

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Material

In this project, Shenyang spring raindrop spectrum data from 2020 to 2021 obtained by Parsivel laser raindrop spectrometer were selected. There were 39,678 samples in this data. The sampling interval was 1 minute, and each sample was a two-dimensional array of 32×32 in the equivalent volume diameter D (32) and descent velocity V (32), a specific value in the array represents the number of precipitation particles N at a specific scale and velocity state.

The SIFT method and raindrop spectrum processing

As is known from the moment parameters of the drop spectrum:

$$M_n = \int_{D_{min}}^{D_{max}} D^n N(D) dD \qquad \text{(Eq.1)}$$

The M of higher order (large n) is greatly affected by the observation error and natural fluctuation of the raindrop spectrum, but the M of low order (small n) is affected by the observation error of the small drop segment of the raindrop spectrum. In order to reduce the impact of these uncertainties, two intermediate orders of feature parameters-rainfall rate R and median diameter D_m can be selected to analyze the whole data set.

The characteristic parameters R and D_m are indicated as described below:

$$R = \frac{\frac{\pi}{6}\sum_i (n_i D_i^3)}{st} \times 3600$$
$$\int_{D_{min}}^{D_m} N(D) D \, dD = \frac{1}{2}\int_{D_{min}}^{D_{max}} N(D) D dD \qquad \text{(Eq.2)}$$

n_i -- the number of raindrops observed in each gear;
D_i -- the diameter of each gear, unit: mm;
s -- sampling area, $s=54cm^2=0.0054m^2$;
t -- sampling time, unit: s;
R-- the rainfall rate, unit: $mm.h^{-1}$;
D_{min} -- the minimum diameter of raindrops;
D_{max}-- the maximum diameter of raindrops;
D_m -- the median diameter of raindrops, unit: mm;
N (D) -- the spectral density of raindrops, the number of raindrops in unit volume and unit scale interval, unit: $m^{-3}.mm^{-1}$.

In the statistical analysis of the whole data set, in order to make the uniform distribution of the sample number, the rainfall rate R and the median diameter D_m were divided. The specific classification and their measurement range were shown in *Table 1* and *Table 2*. The data set was divided into 48 (163) classes of different rain droplet profiles. Each grid point in the R-D_m plane in *Figure 1(a)* represented a class of droplet spectrum, with the individual droplet spectrum samples at the same grid point having similar R and D_m, and the column length represented the number of observed samples. *Figure 1(b)* and *Figure 1(c)* showed the distribution probability corresponding to the rainfall rate R and the median volume diameter D_m. According to *Table 1*, *Table 2* and *Figure 1*, the median volume diameter corresponding to the droplet spectrum with lower

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rainfall rate R-D_m was also small, while the median volume diameter D_m corresponding to the droplet spectrum with large rainfall rate R was also relatively large.

Table 1. *Rain R and corresponding measurement range (unit: mm.h^{-1})*

Serial number	Classification range	Serial number	Classification range
1	0.07(0～0.14)	9	0.56(0.50～0.62)
2	0.155(0.14～0.17)	10	0.66(0.62～0.7)
3	0.195(0.17～0.22)	11	0.75(0.7～0.8)
4	0.235(0.22～0.25)	12	0.85(0.8～0.9)
5	0.275(0.25～0.3)	13	0.95(0.9～1)
6	0.34(0.3～0.38)	14	1.1(1～1.2)
7	0.415(0.38～0.45)	15	1.3(1.2～1.4)
8	0.475(0.45～0.50)	16	3.2(5～1.4)

Table 2. *The classification of the median diameter D_m and the corresponding measurement range (unit: mm)*

Serial number	Classification range
1	0.406 (0～0.812)
2	0.8745 (0.812～0.937)
3	2.3435 (0.937～3.75)

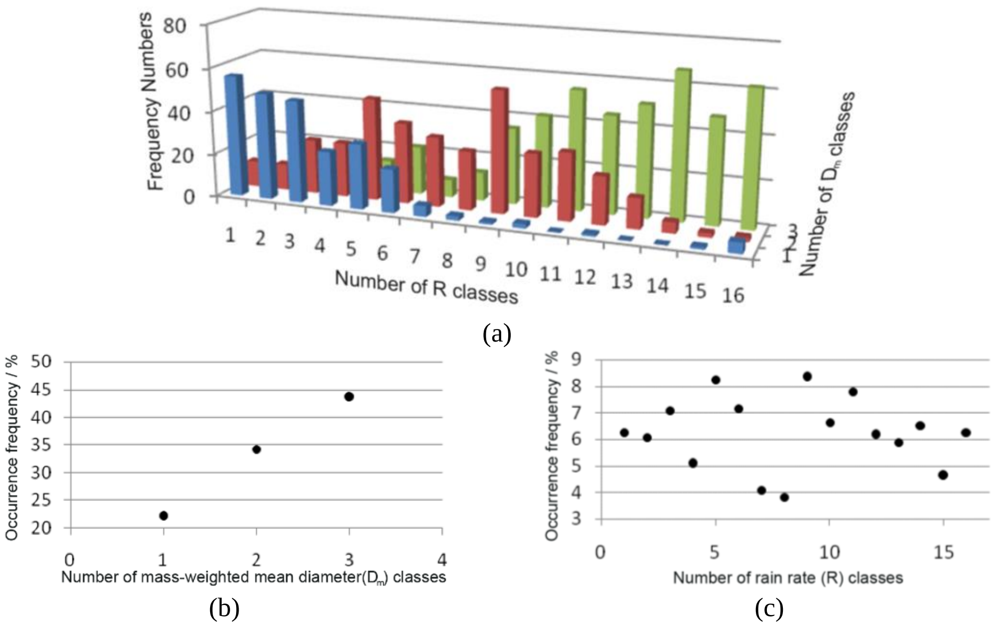

Figure 1. *(a) Frequency of occurrence of raindrop spectrum samples based on rainfall rate R (0-5 mm.h^{-1},16 levels) and median diameter Dm (0-3.75 mm, 3 levels) (b) The distribution probability (%) corresponding to each gear of the rainfall rate R (c)Distribution probability (%) corresponding to each gear of the median diameter*

A new average raindrop spectrum was averaged in the same lattice space. The curves in *Figure 2(a), 2(b)* and *2(c)* represented the mean rain droplet profiles of (R,D_m) = (0.07 mm·h^{-1}, 0.406 mm), (0.275 mm·h^{-1}, 0.8745 mm) and (1.1 mm·h^{-1}, 2.3435 mm) 1, respectively. As can be seen from *Figure 2,* the three new raindrops lines

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after averaging treatment can be better distinguished, and the two lines (0.07 mm h^{-1}, 0.406 mm) and (0.275 mm·h^{-1}, 0.8745 mm) were also different due to the large difference in D_m. Meanwhile, the larger the span of the median diameter D_m, the farther the extension to the large drop end.

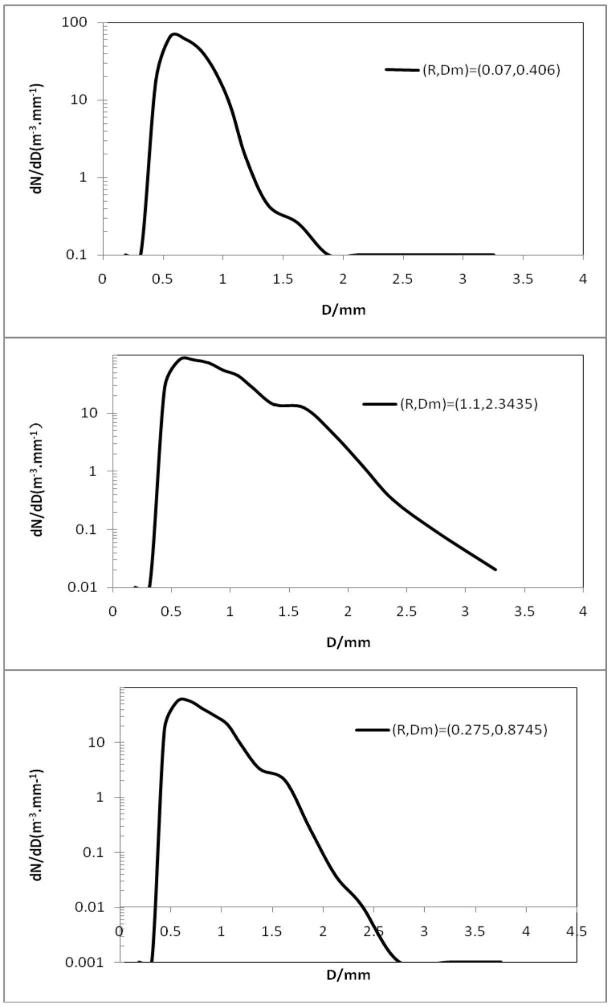

Figure 2. *The average drop spectrum of three categories (a) (R, D_m) = (0.07 mm.h^{-1},0.406 mm) (b) (R, D_m) = (0.275 mm .h^{-1},0.8745 mm) (c) (R, D_m) = (1.1 mm.h^{-1},2.3435 mm)*

Characteristics of raindrop spectrum processed by SIFT method

Below, the difference between the measured spectrum and the mean spectrum will be analyzed by standard deviation SD, mean relative error AFE, standard deviation of the relative error SDFE of the rainfall rate R, median diameter D_m, raindrop number concentration N_t, radar reflectance factor Z, water content M, these parameters were expressed as follows:

$$SD = \left[\left[\frac{1}{k}\sum_i (R_i - R_A)^2\right]\right]^{\frac{1}{2}} \quad \text{(Eq.3)}$$

$$AFE = \frac{1}{k}\sum_i \frac{|R_i - R_A|}{R_A} \quad \text{(Eq.4)}$$

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$$SDFE = \left[\frac{1}{k}\sum_i \left[\frac{|R_i - R_A|}{R_A}\right]^2\right]^{\frac{1}{2}} \quad \text{(Eq.5)}$$

$$Z = \sum_i N(D_i) D_i^6 \quad \text{(Eq.6)}$$

$$M = \frac{\pi}{6} 10^{-3} \rho_w \sum_i N(D_i)\, D_i^3 \quad \text{(Eq.7)}$$

k-- the number of samples;
R_i -- the rainfall rate obtained from the observed data;
R_A -- the rainfall rate of the averaged new raindrop spectrum data.

Switch R to D_m, N_t, Z, or M in *formula (3) to (7)* to calculate the relevant statistics for all variables.

For the class 3 raindrop spectrum samples in *Figure 2*, the standard deviation SD relative to its average spectrum of rainfall rate R was 0.299, 0.289, 1.032 mm·h^{-1}, respectively. The standard deviation SD, mean relative error AFE, standard deviation of the relative error SDFE of median diameter Dm, raindrop number concentration Nt, reflectivity factor Z, and water content M were shown in *Table 3*. *Table 3* showed that the raindrop spectrum distribution fluctuation and sampling error were reduced after treatment with the SIFT method.

Table 3. *Statistics of the 3 sets of rain spectrum data in Figure 2*

		Rainfall rate /R	**Median diameter /D_m**	**The concentration of raindrops-/ Nt**	**Reflectivity factor /Z**	**Moisture content /M**
SD	First group	0.299mm.h^{-1}	0.063mm	7.31m^{-3}	1.560dBz	0.014g.m^{-3}
	Second group	0.289mm.h^{-1}	0.064mm	27.748 m^{-3}	0.684dBz	0.013g.m^{-3}
	Third group	1.032mm.h^{-1}	0.062mm	45.06 m^{-3}	0.742dBz	0.043g.m^{-3}
AFE%	First group	8.67	4.67	5.55	1.93	6.85
	Second group	3.52	3.99	6.57	0.69	3.05
	Third group	3.86	3.48	6.31	0.59	3.84
SDFE%	First group	9.96	5.26	7.30	2.20	7.93
	Second group	4.11	4.60	6.64	0.81	3.50
	Third group	4.48	3.88	9.29	0.70	4.29

Comparison of three raindrop spectra

In order to confirm the practicability of SIFT method, this paper analyzed the sequential average (the whole sample data set was arranged in chronological order, average spectrum for every 50 samples was obtained, finally the Gamma spectrum was used as the fitting spectrum of the original sample), the single observation and SIFT classification method, and compare the difference among the three spectrum. This project randomly selected 10 samples from the original raindrops spectrum samples, and calculated the standard deviation SD, mean relative error AFE, standard deviation SDFE between N (D) and N (D) of Gamma fitted spectrum according to formula (7)~(11). As can be seen from *Table 4*, in the case of single observation, the worst fitting effect was observed, while the fitting error of the SIFT method was much smaller than that of the sequential average and single observation, which showed that the SIFT method was much better than that of the sequential average and the single observation.

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Table 4. *Statistics of raindrop number density N (D) in a randomly selected sample of 10 raindrop spectras*

Random sample	**(R,D_m)**	**(0.34,0.406)**	**(0.56,0.406)**	**(0.85,0.406)**	**(3.2,0.406)**	**(0.275,0.8745)**	**(0.75,0.8745)**	**(1.1,0.8745)**	**(0.34,2.3435)**	**(0.75,2.3435)**	**(1.3,2.3435)**	**ave**
SD/	SIFT	21.2	24.6	9.3	35.7	66.6	43.2	17.8	53.8	62.3	72.7	40.7
$m^{-3}.mm^{-1}$	Order average	56.3	46	24	73.8	144.9	96.2	34.9	102.4	129.3	125.8	83.4
	Single observation	88.5	99.9	39	100.2	170.4	133.9	59.5	182.4	165.1	192.0	123.1
AFE/%	SIFT	5.03	6.81	5.8	6.51	7.47	5.34	5.9	6.75	7.58	7.87	6.51
	Order average	14.25	17.66	18.06	20.89	25.82	27.61	13.21	21.45	19.12	23.81	20.19
	Single observation	30.47	38.96	27.1	36.48	41.37	36.89	29.95	35.63	33.65	40.1	35.06
SDFE%	SIFT	6.55	7.88	7.45	8.42	10.51	8.02	8.14	9.3	10.63	9.98	8.69
	Order average	17.95	20.73	20.41	22.74	29.77	29.03	15.05	22.5	21.45	25.61	22.52
	Single observation	35.35	40.39	31.24	39.82	44.69	38.04	31.33	37.36	35.29	43.18	37.67

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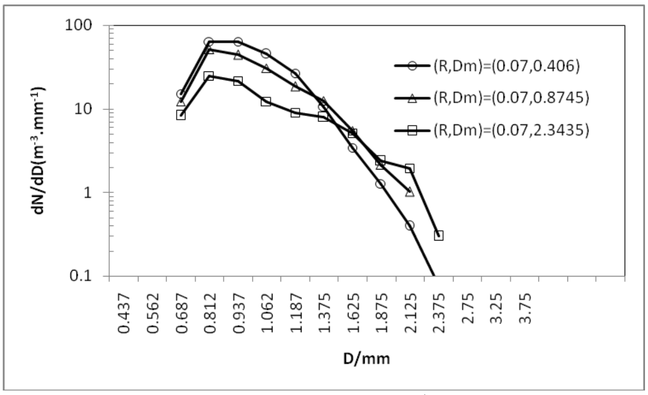
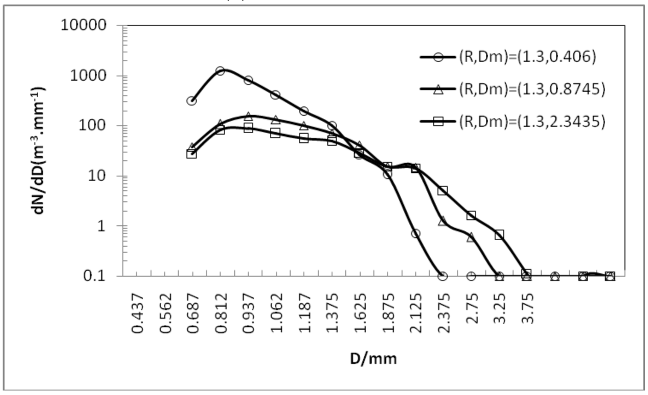
The statistics in *Tables 3* and *4* showed that the mean difference between the droplet spectrum treated by the SIFT method and its original drop sample is small, thus the new raindrop spectrum can characterize the taxonomic average status of the original sample. This indicated that the use of the SIFT method can reduce the effect of sampling error caused by the natural rainfall, the accuracy of its raindrops spectral distribution characteristics was improved. Therefore, applying the SIFT method to treat rain droplet spectral data was effective and feasible.

On the basis of proving the feasibility of the SIFT method, the distribution characteristics of the average raindrop spectrum with the same rainfall rate R different median diameter D_m (*Figure 3*) and different rainfall rate R same median diameter D_m (*Figure 4*) were given. *Figure 3* showed that when the rainfall rate R was the same size, the larger the median volume diameter, the fewer the number of small drops in the average spectrum, and the larger the number of large drops, and the larger the maximum diameter of the raindrops. This indicated that the distribution of raindrop profiles, with the larger median diameter D_m, changed more gently at the same precipitation rate R.



(a) R =0.07 mm·h^{-1}



(b) R =1.3 mm·h^{-1}

Figure 3. *Distribution of rain droplet profiles in multiple groups with the same rainfall rate R and different median diameter D_m*

When D_m was the same and R was different (*Figure 4*), because the median diameter of D_m was equal, the overall change of the droplet distribution was very similar. However, because of the different rainfall rate between different rainfall spectrum, the difference still exists, mainly the curve with large rainfall rate was located above the curve with a slightly smaller rainfall rate, so the arrangement was combined with the same D_m and

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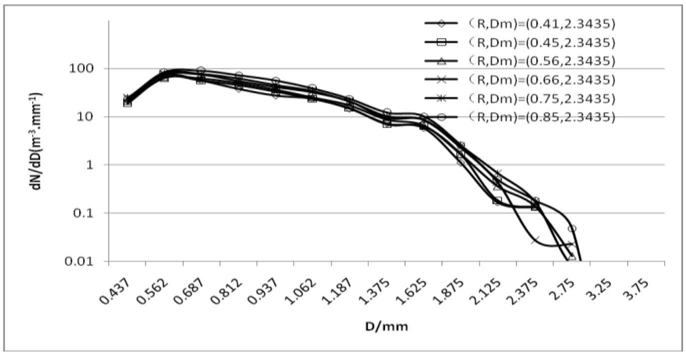
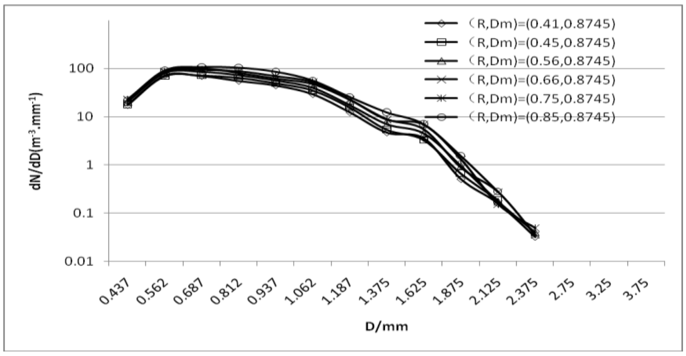
different R rain spectrum, and the parallel distribution law of various new average spectrum was obvious. This pattern of raindrop spectrum distribution in *Figure 3* and *Figure 4* was statistically reasonable and further confirmed the availability of the SIFT method.



(a) D_m =0.8745 mm·h^{-1}



(b) D_m =2.3435 mm·h^{-1}

Figure 4. *Multiple groups with the same median diameter D_m and different rainfall rate R*

Conclusion and discussion

(1) This project used the SIFT method to divide all the raindrop spectrum data in Shenyang from 2020-2021 into 48 (16×3) classes, this classification reflected the basic characteristic that the rainfall rate R was smaller, the median volume diameter D_m was smaller, and the median volume diameter D_m of the rain spectrum was relatively larger, the rainfall rate R was larger.

(2) The SIFT method reduced distribution fluctuations and sampling errors by comparing standard deviations SD, mean relative error AFE, standard deviation SDFE of the rainfall rate R, mean diameter D_m, raindrops concentration N_t, radar reflectance factor Z of the measured spectrum with the mean spectrum obtained by the SIFT method.

(3) This project analyzed the difference among the spectra of the sequential average, the single observation and the SIFT method, found that the fitting effect of the sequential average was the worst, the fitting effect of the single observation was median, however, the fitting error of the SIFT method was smaller than that of the sequential average and the single observation. This showed that the SIFT method fitting the droplet spectrum was better than the sequential average, the single observation.

The results showed that SIFT method classified all raindrops spectrum data according to the two parameters of rainfall rate R and median diameter D_m, and obtained the

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classification average spectrum, which can reduce the influence of raindrop spectrum distribution fluctuation and sampling error on precipitation in natural precipitation. The improvement of the estimation accuracy of raindrops spectrum is of important application value for measuring ground precipitation by Z-I relationship and thus improving the accuracy of measuring rainfall rate. Therefore, applying the SIFT method to treat rain droplet spectral data was effective and feasible.

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