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THE MICRO-FEATURES OF HEAVY RAIN OVER GUANGZHOU IN FLOODS SEASON

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ABSTRACT

In this paper, the raindrop spectral data collected at the Conghua station in Guangzhou area in June 1994 have been analyzed. It is found that the June rainfall causing great floods damage in southern China has the following features: It has long duration, large intensity, raindrop density and scale, with the largest raindrop diameter and rainfall intensity at 6.5 mm and 155.06 mm/hr respectively. On the other hand, according to weather system and rainfall nature, we divided the rainfall into five types and provided a group of Z-I relationships that can be referenced and used in radar quantitative measurement of rainfall.

Key words: raindrop spectra, rainfall intensity, raindrop density, radar quantitative measurement of rainfall.

Ⅰ. INTRODUCTION

In the beginning of 1960's, the raindrop data collected in the South China Mountains Range area were studied in China, from the end of 1970's up to date the microphysical features of rainwater were also observed and studied respectively for the Northeast China Plain, Yangtze River Basin and Northwest China Plateau. In 1980's, the observation and study of raindrop microphysical structures were done for several times over the Guangzhou area in southern China, the variations and distributions of the microphysical features were studied, and a set of the relationships of the radar inflective factors(Z) and rainfall intensity(I) were also accumulated. In June 1994, the heavy rain in southern China resulted in severe flooding damages, in which the staff from the clouds physics office of the institute happened to be in field observation at the Conghua station, and obtained a set of important raindrop spectral data (425 items). In this paper, the synthetical analysis and study have been made, and the features of spectral types and distributions of all parameters discussed.

It is common knowledge that as the time-space distributions of rain are unhomogeneous, large errors of regional measurement of rainfall are resulted for a conventional network of meteorological stations with a density of about 1000 km^2. The errors are, however, smaller using the techniques of radar quantitative measurement. The most popular method applied is the Z-I relationship, the key of which is obtaining the Z-I relationship for all types of precipitation. By comprehensive consideration of synoptic systems and rainfall features, the data set is divided into five types: thundery shower, slight shower, steady rain, mixing rain, typhoon rain, and the Z-I relationships of all types are solved for parameters of reference in radar quantitative measurement of rainfall.

Ⅱ. THE DISPOSAL OF DATA AND CALCULATING METHODS OF RAINDROP SPECTRA

The observation was sited at the Conghua station (23°33′, 113°34′) north of

Guangzhou from 28 May to 20 June, 1994. The traditional color-stain method of fumigating starch-content filter paper with iodine was used to observe the raindrop spectra, and the original data was processed by a picture instrument of the Weather Modification Institute of the Academy of Meteorological Science of China. The data intervals are mainly 1-10 minutes, and the diameter of target raindrops ranges from 0.1 to 6.5 mm, for which the rainfall intensity (I) and radar inflectivity factor (Z) are decided by

$$I = 6\pi\Sigma n_i.(s.t)^{-1}d_i^3 \qquad Z = 10^6 n_i.(s.t)^{-1}d_i^6/V_i, \tag{1}$$

where d_i is the raindrop diameter in unit of mm, n_i is the number of raindrop for the diameter, s the area that is sampled in unit of cm^2, t the exposure time in unit of s, and V_i is the terminal fall velocity of the corresponding diameter in unit of cm/s.

Ⅱ. THE FEATURES OF GROUND RAINDROP SPECTRA

The data stand for the rainfall in the period from 28 May to 20 June, 1994, belonging in the order of appearence to a) the post-front rainfall (of heavy thundery shower, light shower, or steady rain) the end of May through 2 June, b) the typhoon-induced rain from 8 to 9 in June, and c) the frontal rainfall (including the thundery shower, light shower and rain of mixed causes subject to typhoon low-pressure circulation and front). During the period, severe tropical storm 9403 landed on Leizhou Peninsula, moved northerly first, and then easterly, an accompanying rain belt moved with it, passing by the Conghua station and brought more stable rainfall after 10 June. The station was sometimes within the center of the rainbelt and sometimes at the edge of it or entirely out of it. The process of destruction was mainly caused by the rainfall in June, especially in the first and second ten-day periods, which was just covered by our field observation such that the timing of each collection was right to reflect each of the rain as it was. In other words, the observations were truely the mean features of the reality we consider that the data stand for the mean feature of the floods-infiliating rain. The whole month was controlled by weather situation that was favourable for long intervals of rain. (It was marked mostly by thundery and mixing precipitation) The steady rain is defined here as light and mild, similar to that by sheet clouds in northern China with little variation in intensity, which is not the prevailing characteristics of the rain in June 1994.

Based on synoptic system and rainfall features, the rainfall has been divided into five types: thundery shower, light shower, steady rain, mixing rain, and typhoon rain. In this paper the structure features of the raindrop spectra have been analyzed in several aspects, which will be described respectively as follows:

Table 1. Characteristic spectral quantities of raindrop for individual rain patterns.

	Number of observation	N_o (Drop/m^3)	$N_{1d>0.4mm}$ (Drop/m^3)	$N_{2d>1.0mm}$ (Drop/m^3)	D_1 mm	D_2 mm	D_3 mm	I mm/hr	Z mm^6/m^3	W g/m^3	D_{Max} mm	I_{Max} mm/hr
Thundery shower	100	339.88	291.19	169.54	1.25	1.40	1.54	18.58	30565.6	0.75	6.1	155.06
Light shower	95	178.65	156.04	66.55	1.03	1.11	1.19	4.32	9723.5	0.20	6.5	64.69
Steady rain	24	393.34	302.52	127.38	0.95	1.05	1.14	7.19	4769.8	0.35	3.9	38.32
Mixing rain	135	297.69	246.19	106.95	1.02	1.10	1.18	7.69	7774.1	0.35	5.5	63.71
Typhoon rain	53	372.41	372.41	178.94	1.05	1.18	1.29	15.14	21293.7	0.65	5.9	146.33

As one can see in Table 1, N_0 is the raindrop density, N_1 and N_2 are the raindrop density with the diameter larger than 0.4 mm and 1.0 mm respectively, D_1, D_2 and D_3 are the mean, root-mean-square and root-mean-cube diameters respectively, I is the mean rainfall intensity, Z is the radar inflectivity factor, W is the water content, and D_{Max} and I_{Max} are largest raindrop diameter and rainfall intensity respectively. From the table, it is shown that the rainfall intensity and water content are larger, there are more raindrops which are larger than 1.0 mm, for the thundery shower and typhoon rain; the radar inflectivity factor is increasing with rain intensity and raindrop diameter. The set of data is generally featured by relatively larger characteristic values, especially of rainfall intensity.

It is shown that the causes leading to floods damage in southern China are long duration of rain, large raindrop density and raindrop diameter, and higher rainfall intensity. In other words, it is mainly attributed by typhoon rain, thundery shower and mixing rain. The steady rain as defined in this paper is seldom seen due to the fact that the rain of June 1994 was generally violent and rush in great intensity, leaving little chance for homogeneous and light appearence.

From Table 2, except for the steady rain, the other types of rain have the chance to appear in all ranges of frequency. The frequency for each of the rain patterns varies for any given density and the dominant frequency of appearence is less than 500 raindrops/m^3 while the raindrop density is smaller for the light rain, 83% of which being below 300/m^3.

Table 2. Appearence frequency of raindrop density (%).

(Drop) /m^3	0-100	101-300	301-500	501-700	701-1000	>1000
Thundery shower	19	42	20	8	6	5
Light shower	45	38	11	2	3	1
Steady rain	0	35	43	17	4	0
Mixing rain	32	30	21	5	10	2
Typhoon rain	25	26	17	9	9	13

Table 3 shows that of all processes of rain the maximum raindrop diameter is larger than 1.0 mm for the typhoon rain and thundery shower and smaller than 4.0 mm for the steady rain. The peak values are in the range of 2.0-2.9 mm for all types of precipitation. The frequency for the diameter to exceed 4.0 mm in the thundery shower and typhoon rain is greater than other types of rain. It is interesting to note that the light

Table 3. Frequency of diameter for largest raindrops to appear in each sample. (%)

D(mm)	0.1-0.9	1.0-1.9	2.0 2.9	3.0-3.9	4.0-4.9	5.0-5.9	>6.0
Thundery shower	0	15	43	28	12	1	1
Light shower	2	37	52	6	1	1	1
Steady rain	4	17	61	17	0	0	0
Mixing rain	1	28	47	19	4	1	0
Typhoon rain	0	26	47	19	6	2	0

shower has relatively large raindrop diameter in spite of small rain intensity. From Table 1, it is understood that the largest raindrop diameter appears in light shower. Table 4 shows that only thundery shower and typhoon rain have the instantaneous rainfall intensity of larger than 70 mm/hr, and greater frequency of larger rainfall intensity than any other types of rain. On the other hand, the frequency of light shower with lower rainfall intensity is higher and the rainfall intensity of steady rain mainly lies in the range of 3..1-10. 0 mm/hr.

Table 4. Frequency of instantaneous rainfall intensity. (%)

I(mm/hr)	0. 0-0. 1	0. 2-1. 0	1. 1-3. 0	3. 1-10. 0	10. 1-25. 0	25. 0-70. 0	>70. 0
Thundery shower	2	11	24	20	14	25	4
Light shower	9	42	22	20	6	1	0
Steady rain	0	13	8	65	9	4	0
Mixing rain	3	22	30	14	17	8	0
Typhoon rain	4	18	10	40	15	10	6

Ⅳ. THE RELATIONSHIPS OF *Z-I* and *W-I* OF ALL TYPES OF RAIN

As we know, in the radar meteorological equations, the mean receivable power (P_r) is directly in proportion to the inflectivity factor(Z),and following theoretical studies and actual observation,there is a relationship between Z and rainfall intensity I. With the development of electronic techniques,qualitative radar rainfall measurement becomes more and more quantitative. At present the distance between any two rainfall measuring stations is usually dozens of kilometers in contrast to unhomogeneous distributions of rainfall intensity. (The maxima exist even in sheet cloud rainfall, leaving alone the convective cloud rainfall which has large rainfall intensity spatially)Consequently,it is difficult to obtain an accurate amount of rain over a given area from the less representative data of rainfall intensity and rainfall measured at the ground stations insufficiently spaced. The radar, however, can estimate the rainfall intensity across the scanning domain and the rainfall distributions and total rainfall of a certain area, and timely obtain quantitative rain data over large areas.

The radar meteorological equation is usually expressed as:

$$P_r = C\,Z/R^2, \tag{2}$$

where C is radar parameter, which can be used as constant after demarcating each parameter of radar. Therefore, given the relationship of Z-I, the rainfall intensity I can be derived based on the mean echo inflectivity power P_r at a distance R from the radar.

Using the ground raindrop spectral data, the Z-I relationship can be regressed by means of the least square methods:

$$Z = AI^b. \tag{3}$$

the Z-I relationship greatly differs by the region, season, rainfall type, and raindrop spectral form, and even by each process of rain. It is, of course, mainly dependent on the type of raindrop which in turns corresponds to the type of rain. It is necessary to categorize the rain according to the season for a particular region. In this paper, five types of rainfall have been regressed and analysed and the results are shown in Table 5 where r is correlation coefficient and s is the residual variance. From Table 5, it is understood that the relationship between LnZ and LnI is very close for any type of rain by having all of the correlation coefficients of higher than 0.96 and the residual variances of less than 0.28. Table 5 shows that the Z-I relationships vary with the type of rain, indicating that the Z-I relationship for different rain type cannot be substituted with each other. On the other hand, it is found that the Z-I relationship of thundery shower is similar to that of light shower and so is the case of mixing and typhoon rains . It is suggested that the thundery and light showers can be classified into one type, and mixing and typhoon rains into another. It is possible that rainfall types with large difference in characteristics may have consistent Z-I relationships.

Table 5. The Z-I relationships of five rainfall types.

Rain types	Observational times	A	b	r	s
Thundery shower	100	303.44	1.3904	0.9855	0.1858
Light shower	95	306.55	1.2874	0.9637	0.2669
Steady rain	24	146.93	1.5704	0.9944	0.0946
Mixing rain	135	294.52	1.3348	0.9604	0.2790
Typhoon rain	53	288.94	1.3216	0.9723	0.2645

On the other hand, the relationship of water content W with rainfall intensity I is also statistically studied in

$$W = AI^b. \tag{4}$$

Table 6 shows a rational exponential allocation of precipitable water content and rainfall intensity for all of the rain types by having correlation coefficients of higher than 0.99 and residual variances of less than 0.09; the W-I relationship of thundery shower is similar to that of light shower, and so is the case of typhoon amd mixing rains.

Table 6. The W-I relationships of five rainfall types.

Rain types	Observational times	A	b	r	s
Thundery shower	100	0.0578	0.8979	0.9975	0.04903
Light shower	95	0.0583	0.9106	0.9936	0.07737
Steady rain	24	0.0758	0.8049	0.9981	0.02798
Mixing rain	135	0.0608	0.8908	0.9911	0.08633
Typhoon rain	53	0.0601	0.9035	0.9948	0.07676

V. THE MICROPHYSICAL FEATURES OF RAINFALL IN DIFFERENT AREAS

In Table 7, the names in the column of rain systems have been shortened.

Shower A appears in the South China Mountains Range (Rong et at=l. ,1965) and shower B in the Taishan Mountains Range (Rong et al. ,1965). Thundery shower A takes place in the Taishan Mountains Range (Yuan,1965) and thundery shower B in the area of Guangzhou. Sheet cloud rain A is recorded in Ningxia (Wu,1989) and sheet cloud rain B in Jilin (He,1965). Heavy rain A is seen in Anhui (Jiang et al. ,1986). and heavy rain B in Ningxia (Wu,1987). Light shower A and light shower B are reported in the floods periods of Guangzhou (Wu et al. ,1994). Cumulus rain A is witnessed in the Pearl River Delta① and cumulus rain B in the same area②. Front rain A is with quasi-stationary fronts in southern China③ and front rain B with spring fronts in southern China (Wu et al. ,1994). Warm sector rain occurs in quasi-stationary fronts in southern China (Wu et al. ,1994). Steady rain, mixing rain and typhoon rain are in the floods periods of Guangzhou.

Table 7. The raindrop spectral features of different rainfall types in different areas.

Rain systems	Time	N (Drop/m^3)	$\bar{D}$ mm	D_{Max} mm	I mm/hr	Z mm^6/m^3	W/g/m^3
Shower A	May 1962				5.2		
Shower B	Jul.-Aug. 1962				4.0		0.37
Thundery shower A	Jul. 1962	115		7.3	10.6	0.14	
Sheet cloud rain	Jun. 1984	320	0.61	5.2	0.8		0.06
Heavy rain A	Jun. 1983	438	0.90	6.3	9.5		2.19
Sheet cloud rain B	Jul. 1981	544		4.2	5.6		0.29
Heavy rain B	Jun. 1983	563	0.60	4.8	4.6		0.21
Light shower A	Jun. 1984	142	1.10	6.5	3.65	3167	0.17
Cumulus rain A	Jun. 1984	388	1.21	7.4	10.44	24953	0.71
Cumulus rain B	Jun. 1984	366	1.24	7.1	25.47	61680	1.00
Front rain A	Mar.-Apr. 1985	109	1.16	5.2	4.08	4131	0.18
Front rain B	Mar. 1988	246	0.63	3.5	1.38	620	0.08
Warm sector rain	Mar. 1989	154	0.92	7.3	2.86	3415	0.13
Thundery shower B	Jun. 1994	340	1.25	6.1	18.58	30566	0.75
Light shower B	Jun. 1994	179	1.03	6.5	4.32	9724	0.20
Steady rain	Jun. 1994	393	0.95	3.9	7.19	4770	0.35
Mixing rain	Jun. 1994	298	1.02	5.5	7.69	7774	0.35
Typhoon rain	Jun. 1994	372	1.05	5.9	15.14	21293	0.65

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① Chen Weizhao, The Microphysical Analysis of Cumulus Rain of Triangular Islet in ZhuJiang river in Spring. (Xiang) The Soientific and Technological Information, 1988,3:27-32 (In Chinese).

② Gan Chunling, The Raindrop Spectrum Analysis of Several Times Cumulus Heavy Rain Process, (Xiang) The Soientific and Technological Information, 1988, 3:38-42. (In Chinese)

③ Chen Weizhao, The Microphysical Features of Rainfall of Cloud System of a Quasi-Stationary Front in South China, (to be Published). (In Chinese).

Table 7 shows that the changes of the drop density of sheet cloud in northern China are large, but that of the scales and rainfall intensity are small, the drop densities of light shower in Guangzhou are smaller, but the scales are larger. In the rainfall data in June 1994, the largest raindrop diameter stays with light shower. The rainfalls in southern China have the characteristics of large changes in drop density, scale and rain intensity.

Table 8 shows that the coefficient A changes within a large scale, while the exponent B in a relatively small range, and the *Z-I* relationships are much different by rain type and area (regional difference), indicating that it is very necessary to study precipitation in southern China by categorized geographic areas and rainfall types.

Table 8. The *Z-I* ($Z=AI^B$) relationships of different type of rainfalls in different areas.

Rain type	Area	Sampling time	A	B
Steady rain	Ningxia	Jun.-Sept. 1983	205	1.22
	Jilin	May-Jul. 1970/80	245	130
	Beijing	1962, 1963	188	116
	Anhui	Jun.-Aug. 1979	203	1.33
Mixing rain	Ningxia	Jun.-Sept. 1983	301	129
	Beijing	1962, 1963	237	1.46
	Jiangsu	1980	211	112
	Anhui	Jun.-Aug. 1979	262	1.33
Showery rain	Ningxia	Jun.-Sept. 1983	509	1.35
	Beijing	1962, 1963	316	1.78
	Jiangsu	1979	357	1.34
	Anhui	Jun.-Aug. 1979	274	1.64
	Hunan	1977	291	1.54
Light shower		Jun. 1984	345	1.39
Shower		Jun. 1986	264	1.53
Cumulus rain A		Jun. 1984	563	1.33
Cumulus rain B		Jun. 1984	490	1.33
Fontal rain		Mar.-Apr. 1985	339	1.50
Fontal rain		Mar. 1988	270	1.36
Warm sector rain		Mar. 1989	370	1.42
Thundery shower		Jun. 1994	303	1.39
Light shower		Jun. 1994	307	1.29
Steady rain		Jun. 1994	147	1.57
Mixing rain		Jun. 1994	295	1.33
Typhoon rain		Jun. 1994	289	1.32

In Table 8, the light shower and shower are all in the Guangzhou area while the cumulus rain A, B and frontal rain A are referred to Notes ①, ② and ③ in the previous page. Frontal rain B occurs in spring in southern China (Wu et al. , 1994) and the warm sector rain in quasi-stationary fronts in southern China (Wu et al. , 1994). The last five types of rain (shower) in the table are all recorded in the flood period of Guangzhou area.

Ⅵ. CONCLUSION

By the order of appearence and in various intensity, heavy thundery shower, light shower, steady rain, frontal rain caused by circulation of low pressure (typhoon) systems (thundery showers, light shower and mixing rain), occurred in the area of Guangzhou in late May and June 1994. The observation was right in timing in representing characteristics of each process of this so-called "June '94 heavy rain". The set of observational data is divided into five major categoriesz—thundery shower, light shower, steady rain, mixing rain and typhoon rain. The following is what we believe concludes the structural characteristics of the raindrop spectra analysed.

a. The rainfall features leading to severe flood damages in June 1994 include long duration and large intensity.

b. The exponential Z-I and W-I relationships for all types of rain are successful, and the correlation coefficient of LnZ and LnI, LnW and LnI are higher than 0. 96 and 0. 99 respectively. It is found that the Z-I, W-I relationships of thundery and light showers, mixing and typhoon rains are similar respectively, but their characteristic values have large differences.

c. The spectral features and Z-I relationships for different areas and rain types have large differences, indicating that it is necessary to study by classified areas and rain types.

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