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THE SYNTHETIC ANALYSIS OF THE VERY HEAVY RAINSTORMS IN GUANGDONG*

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ABSTRACT: Twelve very heavy rainstorms that caused severe floods in Pearl River drainage basin from 1949 to 1994 are analyzed here. It is found that the rainstorms can be divided into three kinds, and they have different characteristics in circulation and physical quantities. Rainstorms that caused floods in the Xijiang River and Beijiang River usually happen during the first flood season of the year (Apr.-Jun.). They last long, cover large areas and cause severe disasters. There are stable circulation backgrounds and complete frontal precipitation systems, and large stratification instability fields. Rainstorms often cause floods in coastal rivers and small tributaries during the second floods season (Jul.-Sept.). They happen suddenly, last a short time but have strong rainfall intensity. They are always caused by tropical cyclones but show significant instability only in rainstorm fields. The characteristics of rainstorms causing floods in the Dongjiang River or other main tributaries are similar to the two above. That is, they may be connected with fronts or tropical cyclones, and its stability degree is between the preceding two kinds.

Key words: Guangdong; very heavy rainstorms; flood characteristics

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I. INTRODUCTION

Rainstorm is a common disaster in China. Very heavy rainstorms that cause floods often bring great losses to economy and people's lives. So lots of research have been done on the cause of the rainstorms (Tao, 1980; Bao and Wang et al., 1981; Wang, Wu and Wei et al., 1985; Liang, 1990; Zhang, 1990).

Most of these works focused on rainstorms in North China and the middle and lower reaches of the Changjiang River (Zhang, 1980; Collective writers, 1982; Collective writers, 1992), while other system and case research deal with rainstorms in South China in the first flood season (Huang, 1986; Collective writers, 1996). Guangdong has complex topography and is easily affected by middle and lower latitude's circulation. Complex river belts in the Pearl River Delta make it an area that meets floods frequently. But there are less compositive research on rainstorms and floods of this area (Liang, 1993). So we selected some flood-causing rainstorms that brought great disasters here to analyze in an attempt to find out different circulation backgrounds and affecting causes, and have concluded a synthetic image of the very heavy rainstorms in Guangdong.

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II. CHARICTERISTICS OF FLOOD-CAUSING CASES OF RAINSTORMS

1. *Floods and losses*

We selected 12 cases for the analysis. All of them caused great losses in history (Collective writers, 1997) and covered the main tributaries of the Pearl River and some coastal rivers, so we believe they can represent common situation of rainstorms in Guangdong.

(1) Xijiang R. flood in June 1949

The peak and flow of this flood had not been met in Xijiang R. during the prior 50 years. According to the survey, the flow quantity from Wuzhou to Gaoyao was just smaller than that in the great flood in 1915. A total of 393 000 hm^2 of fields were flooded and stricken population reached 3 700 000.

(2) Dongjiang R. flood in June 1959

Taking place around the middle and lower courses of Dongjiang R., it was the largest one for 100 years. 159 000 hm^2 of fields were submerged under water, 76 000 houses were damaged, and 78 persons killed.

(3) Hanjiang R. flood in June 1960

This process lasted shorter than other cases. 102 000 hm^2 of fields aside Hanjiang R. and Rongjiang R. were drowned.

(4) Hanjiang R., Dongjiang R. and Beijiang R. flood in June 1964

Some stations made a record flow quantity in 100 years. Mountain flood and avalanche caused by rainstorm resulted in severe damages.

(5) Dongjiang R. flood in June 1966

The flood covered the entire Dongjiang valley but consequent disaster was confined to the lower reach of the river and its tributaries like Zengjiang and Xizhijiang.

(6) Xijiang R. and Beijiang R. flood in June 1968

This process lasted a long time with high water level and large flow quantity. 127 300 hm^2 of fields were affected, and among them 19 000 hm^2 were in the Pearl River Delta.

(7) Coastal rivers floods in western Guangdong in September 1976

Gaozhou, Huazhou and Maoming were submerged. 72 000 hm^2 of fields were under water surface in Maoming.

(8) Xizhijiang R. flood in September 1979

It is the severest flood in Xizhijiang, one of Dongjiang's tributaries, in 100 years, which is marked with high peaks and large flows. It lasted a short time with sudden changes of the height of water. Dongkeng, Pingshan and Pingtan recorded a historical high.173 300 hm^2 of fields of Huiyang Prefecture were drowned, 136 000 houses were damaged, 620,000 people were injured with 151 dead. The direct economic loss was about 200 000 000 yuan.

(9) The middle and lower courses of Beijiang R. flood in May 1982

The process had such characteristics as high peak, large flow, sudden change of height of water and short life of high water time. 132 000 hm^2 of fields, over 160 000 houses and 2 290 000 people were injured with 493 dead. The direct loss was about 440 000 000 yuan.

(10) Coastal rivers in eastern Guangdong flood in July 1986

It was a flood with historical record of high water in eastern coastal rivers of Guangdong. 653 300 hm^2 of fields and 125 000 houses were damaged. 261 persons were killed. The direct loss was 2 260 000 000 yuan.

(11) Xijiang R. and Beijiang R. flood in June 1994

This was the severest flood since 1949 and the second one in this century. In Guangdong, all the Beijiang River valley was flooded, a large scale region was affected, and the damages

were the greatest since 1949. 1 250 000 hm^2 of fields in Guangdong and Guangxi were injured (in Guangdong it was 260 000 hm^2). 371 persons died (including 145 in Guangdong). As far as Guangdong Province was concerned, the direct loss reached 10 200 000 000 yuan.

(12) Xijiang R. and Beijiang R. flood in July 1994

Just after the flood in June, there was another process in July. In Guangdong, 305 600 hm^2 of crops, 454 500 houses and 9 320 000 people were injured. A total of 109 people died. Direct loss was 6 800 000 000 yuan.

The flood disasters in the two months affected 85 counties in Guangxi. 1 102 towns in Guangdong were damaged. The direct economic loss of the two provinces reached 63 200 000 000 yuan.

Tab.1 shows the basic situations of these cases. We should figure out that comparison

Tab.1 Basic conditions of all rainstorm floods (unit: mm for rainfall; date for time)

Case (yy-mm)	49-06	59-06	60-06	64-06	66-06	68-06	76-09	79-09	82-05	86-07	94-06	94-07
Time	22-30	11-15	6-10	9-15	20-23	21-27	19-23	23-25	9-14	10-14	8-17	17-26
First flood season	*	*	*	*	*	*			*		*	
Second flood season							*	*		*		*
<7 days		*	*		*		*	*	*	*		
≥7 days	*			*		*					*	*
Xijiang R.	*					*					*	*
Beijiang R.	*			*		*			*		*	*
Dongjiang R.		*		*	*							
Hanjiang R.			*	*								
Xizhijiang R.								*				
Eastern coastal area										*		
Western coastal area							*					
Maximum process rainfall	582.9	943.6	924.5	699.4	743.6	1389.1	987	1009.0	824.9	1201.1	1080	716
Lasting time	9	5	5	7	3	24	4	3	6	4	10	8
Maximum daily rainfall	300.0	432.0	399.8	353 1	367 9	385.8	680	400	548.7	728.3	599.0	
Maximun rainfall in 24 hours		448	620.0	398.9	627.0	366.5	731.4	997.5	646.7	786.2	624.2	
Maximum flow/m^3/s	50000	12800	13300	13000	10200	42600	5900	14290	18000	5810	49200	
Height of water	25.55	15.68	76.47	16.95	16.90			51.23	58.74	51.28	84.17	

should not be done among them because of lack of data and the different frequency of meeting flood in different regions. But in most cases the records of flow quantity and height of water were historical peaks.

2. *Rains*

We can see from Tab. 1 that most of the 12 processes happened in the first flood season (April-June). The affected extent included Xijiang R., Beijiang R.and Dongjiang R., as well as some tributaries of the Pearl River such as Hanjiang R. And Xizhijiang R. and coastal rivers in eastern and western Guangdong. Xijiang R. and Beijiang R. always converged floods. When a flood happened around Dongjiang R., it had a smaller affecting scale. Most cases lasted a short time (within a week).

(1) Case 49-06

It happened mainly in Xijiang R. in Guangxi. It rained for 9 days and rains for the last 4 days mainly caused the flood. The maximum amount of total rainfall from 22^{nd} to 30^{th} was over 500 mm. The maximum daily rainfall was 300.0 mm at 28^{th} at Yongfu (see Tab. 1).

(2) Case 59-06

With a large-scale coverage and high intensity, it was only in southeast part of Guangdong that accumulated rainfall above 400 mm. Rainfall center moved with date, and it was especially the rainfall between 11^{th} to 13^{th} that had caused the flood on Dongjiang R.

(3) Case 60-06

The rainstorm region included the entire eastern Guangdong. But high amount of rainfall was only on a small scale. It rained mainly on 8^{th} and 9^{th}.

(4) Case 64-06

It is a long and wide-covered rainstorm. It lasted for 7days but rains fell down mainly from 12^{th} to 14^{th}, and from 14^{th} to 15^{th} in the east part.

(5) Case 66-06

It is a wide-covered rainstorm with strong intensity. It lasted for only a short time but with heavy intensity. Main rain days were from 20^{th} to 22^{nd}, especially on 21^{st} and 22^{nd}.

(6) Case 68-06

For Xijiang R., it rained mainly in Guangxi from 21^{st} to 27^{th}, especially from 23^{rd} to 25^{th}. For Beijiang R., this was an all-drainage-covered rainstorm. In fact, this flood was resulted from long and wide-distributed rainfall rather than short and strong rainstorms.

(7) Case 76-09

This was a short but wide-covered rainstorm. The maximum center moved from east to west with date from 19^{th} to 22^{nd}.

(8) Case 79-09

It is a typical short-lived rainstorm. The rainstorm region included south and southeast part of Guangdong, and the center shifted from Huiyang to Shanwei. Daily rainfall reached more than 400 mm. At Duozhu, the maximum rainfall in 24 h was 670.3 mm, the maximum for 3 d was 910.2 mm. It was 4.7 times of mean monthly precipitation in September and 46.6% of mean annual precipitation.

(9) Case 82-05

It is a rainstorm that covered wide scale and the rain concentrated on 11^{th} and 12^{th}, especially on 12^{th}.

(10) Case 86-07

This process affected the east and southeast part of Guangdong and was with high amount (see Tab. 1).

(11) Case 94-06

The long period and wide covering rainstorm could be divided into two periods: From 8th to 11th when the daily amount was between 100 mm and 200 mm; From 12th to 17th it rose to 200 mm to 300 mm. In this case there was no significant rainfall centers. The flood was caused by long period and large-scale precipitation.

(12) Case 94-07

For the Xijiang R., the precipitation was mainly in Guangxi and the amount was less than that of Case 94-06. But for Beijiang R. the situation was severer. At Zhukeng on Beijiang R. a remark of 716 mm was recorded during this process.

Generally speaking, from the analysis above we can sum up some characteristics of the very heavy rainstorms that caused floods in Guangdong:

- Rainstorms often happen in spring and summer, especially in June;
- Rainstorms that can cause floods have such basic features as strong intensity, long duration and wide influence scale. The maximum daily rainfall surpasses 300 mm. The maximum rainfall of 24 h often reaches over 600 mm. And the rainfall amount of one process is usually between 800 mm to above 1000 mm.
- Rainstorms causing floods can happen in all tributaries of the Pearl River and coastal rivers. It will be more frequent in Xijiang R. and Beijiang R. For Xijiang R., floods often begin at its upper course in Guangxi. And for Beijiang R. floods always cover the whole valley.

3. *Types of cases*

After the preliminary analysis above, we can find that there are two kinds of rainstorms (see Tab. 2): Type A represents those lasting long , covering widely and evenly; type B represents those lasting for shorter periods and covering smaller areas but with strong intensity like 400 mm or even 600 mm in one or two days. We can make further efforts to divide them into three kinds:

Tab. 2 Kinds of rainstorms

	Type A					Type B						
Characteristics	1. Lasting long 2. Covering widely 3. With scattered centers 4. Small amount of daily rainfall					1. Lasting shortly 2. Covering narrowly 3. With high concentrated centers 4. Large amount of daily rainfall						
Case	49.6	94.6	68.6	94.7	64.6	59.6	66.6	82.5	60.6	76.9	79.9	86.7
Time	F	F	F	S	F	F	F	F	F	S	S	S
Area	X, B	X, B	X, B	X, B	H,D,B	D	D	B	H	W	XI	E
System	front	front	front	TS	front	front	front	front	front TC	TC	TC	TC

F: the first flood season; S: the second flood season; X: Xijiang R.; B: Beijiang R.; D: Dongjiang R.; H: Hanjiang R.; XI: Xizhijiang R.; W: western coastal rivers; E: eastern coastal rivers; TS: tropical system; TC: tropical cyclone.

(1) Rainstorms related to front systems in the first flood season

It is the most common kind in Xijiang R. and Beijiang R. valleys, and they often cause serious floods by usually raining for a long time in a large area. The amount is large and it rains evenly, sometimes with more than one center. They often happen around the upper and middle courses of the river in the first flood season as a result of frontal systems.

(2) Rainstorms related to tropical cyclones in the second flood season

Being more common in coastal rivers and some small tributaries of Pearl River, this kind of rainstorms is usually caused by tropical cyclones and has the characteristics of short duration and high intensity. They often cover a small area and the rainfall center is near where the cyclone lands. In some cases it rained just before the cyclone landed, and the center moved as the cyclone track moved. Though this kind of rainstorms affects a relatively smaller region, it can result in great disaster in a short time.

(3) Rainstorms related to the two systems

Rainstorms in Dongjiang R. and other main tributaries of the Pearl River are not so easily to be put into the two kinds above. This kind often happens in the first flood season. It can affect a larger scale than the second kind, but it also has intensity as strong as the second one. Being not so frequent as the first kind, it can also bring serious disasters. It may be caused by frontal systems or tropical cyclones and even sometimes by both of them.

III. ANALYSIS OF RAINSTORMS CAUSES

According to the analyses of weather background and physical quantities, we can see different causes for the three kinds of rainstorms.

1. *Rainstorms related to frontal systems in the first flood season*

A stable circulation background is the significant situation of this kind of rainstorms. At the upper level (100 hPa or 200 hPa) there is a westerly in high and middle latitudes and South China is usually at the boundary of a high. The interaction of middle and low latitudes' systems is clearly at 500 hPa. We can see the maintenance for a long time of the circulation of high and middle latitudes and the site of Subtropical High. The High is in lower latitude than usual, and there is cold air goes southward continuously. In south China there is a cold front maintaining for a long time (and always turns to a stationary front). At lower level there are shears and eddies, and a steady jet supplies water vapor to the rainstorm region. Complete frontal precipitation systems are the principal cause for long-term and wide-covering precipitation.

For example, in Cases 68-06 and 94-06, though the circulation in high and middle latitude and the site of Subtropical High were not the same, it was steady and long. The isobaric line 588 was at the coastal region of South China. The Subtropical High was at a lower latitude and weaker than usual (the axis of ridge was about 15°N while it should be 20°N as mean situation in June). When the Subtropical High strengthened and stretched westward, and the cold air from the north reduced, the rainstorm process would finish. These were just the situations before the ending of Case 68-06 and 94-06.

Affecting systems at lower levels play an important role in this kind of rainstorms. Cold air that continuously comes southward maintains a quasi-stationary front in northern Guangdong for a long time, and results in continuous precipitation. The maintenance of shears and eddies shows that low-value systems are active in South China. On the other hand, the transport of warm water vapor, which helps maintain the precipitation, cannot be omitted. The analysis result of physical quantities shows that during this kind of processes, the entire South China area is in a stratifica-

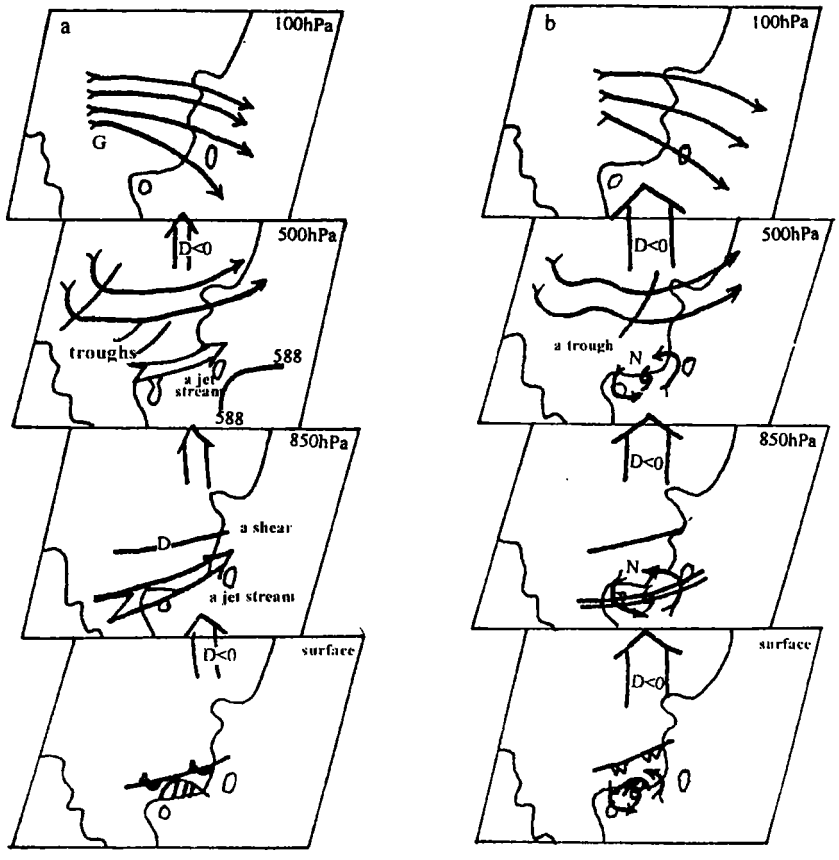

Fig. 1 Synoptic background of two kinds of rainstorms
a. "Front" rainstorm in first flood season b. "Tropical cyclone" rainstorm in second flood season

tion instability with negative Showalter index. Water vapor index is not large but distributed evenly and widely. For instance, during Case 94-06, there was a stable southwest~northeast transportation of water vapor in South China from 8th to 17th June.

So we can say that the continuos and large-scale precipitation of Xijiang R. and Beijiang R. is in close relation to the long-term stability of circulation. That is (see Fig.1a): westerly in high and middle latitude; stable situation of one trough/one ridge or a wide trough over northern Europe-Asia; stable Subtropical High which is weaker and at a lower latitude than usual (the axis of ridge is near 15°N); strong southwest jet, shear systems and active eddies existing at 700hPa or 850hPa and stationary front in the ground. The complete combination of these systems makes the rainstorm affect a large region. The basic factor, which makes the long-term maintenance of the rainstorm process, should be the stability of the Subtropical High. For the High is at a further location from land than usual, cold air from the north can come southward to control South China, and with the help of water vapor transportation, it produces continuous precipitation. Rains will go on falling down till the Subtropical High strengthens and stretches westward to control this area, and the low latitude's systems take the place of the high and middle latitudes' ones.

2. *Rainstorms related to tropical cyclones in the second flood season*

The triggering mechanism of this kind of rainstorms is simpler, often a tropical cyclone only.

The situation in upper level is stable, the location of Subtropical High often changes, and in lower level there is obvious cyclonic circulation.

Of course not all tropical cyclones can bring about heavy rains. Those who can do this have such characteristics:

- Long life period. These cyclones existed for over 10 days;
- Strong intensity. They were all severe tropical storms or even typhoons;
- Slow movement. The rainstorm process would begin just when the cyclone slowed down even if it had once moved quickly.

The slowly moving cyclones stayed over the sea and gathered a great amount of energy so that it will easily create strong precipitation. And the process often happens around the landing time when the cyclone turns weaker. In some cases there were still some cyclones that get stronger before landing. Another thing is that the cyclones are often with "unusual" tracks (see Fig.2). Some looped for several times, some revolved on sea or after landing, and some had a sub-center. Only Typhoon No.8607 in 1986 had a "usual" track in these cases.

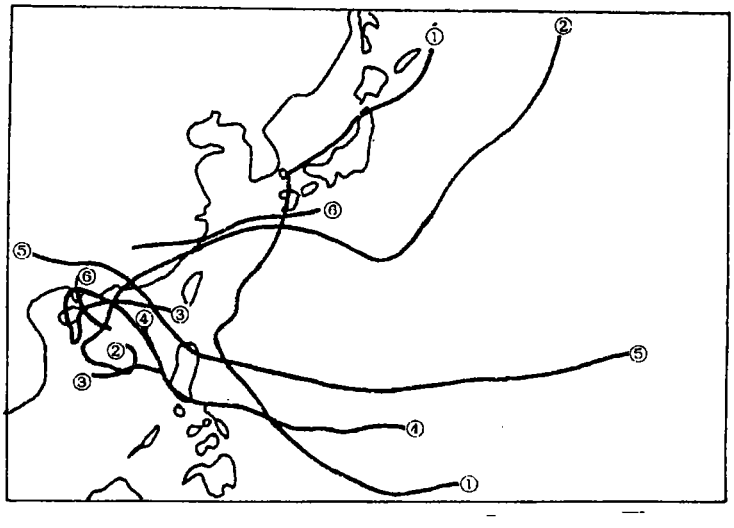

Fig. 2 Tracks of several tropical cyclones of Della ① (1949); Mary ② (1960); ③ Iris (1976); ④ Mac (1979); ⑤ Peggy (1986); ⑥ Russ (1994)

Though these rainstorm floods were caused by tropical cyclones, we should also notice that the weak cold air came from the north. In Cases 76-09 and 79-09, the Subtropical High was weak and far from the continent, small troughs from the westerly of high and middle latitudes moved eastward frequently and cold air came southward to interact with the tropical cyclone, helping strengthen the convergence circulation. Physical quantity analysis shows the same result. In such process, There were much fewer stations with stratification instability record than that in the first kind. The instability area was around rainstorm region. For instance, during Case 76-09 and 79-09, most stations in South China were with positive Showalter indexes, but the western and eastern parts of Guangdong which are near the rainstorm centers showed negative indexes. Water vapor transportation was stronger than in the first kind. Though it covered a narrower area, the water vapor flux was very large. It reached over 40g • s^{-1} • cm^{-1} • hPa^{-1}, and during Case 86-07 it even surpassed 50 g • s^{-1} • cm^{-1} • hPa^{-1}, which showed strong convective activity.

So, this kind of rainstorm has characteristics contrary to the above kind (see Fig. 2b) — The circulation situation is unstable (the intensity and location of the Subtropical High are change-

able). The incursion of cyclonic circulation and the landing of tropical cyclone are direct causes for the rainstorm. As cyclone lands and weakens, the rainstorm also weakens and ends. Some special cyclones can make severe rainstorms that will result in floods. If a cyclone exists for a long time, remains strong enough and moves slowly, it will take lots of water vapor with it and is easily steered by surrounding streamline field, and it has strong vertical movement. Then the weak cold air comes southward and makes the convergence of the cyclone stronger.

3.*Rainstorms related to the two systems*

This kind of rainstorms often happens in Dongjiang R. and other small tributaries, and the causes seem more complex. Among the cases we chose, most of this kind have similar causes as the first kind. They had such weather background: The circulation situation seemed steady and the main affecting systems were like those of the first kind, but factors at middle and upper levels of troposphere should be paid more attention. Westerly of high and middle latitudes seemed more obvious. Though the intensities were different in different rainstorm processes, the locations of Subtropical High were steady. There was still cold air from the north. At 700 hPa or 850 hPa there were still some factors like southwest jets, shears and eddies. Though during Cases 60-06 and 82-05, the locations of the west ridge points of Subtropical High were very different and the axes of ridges were both between 15°N and 20°N. This was a clear difference with the second kind. Generally speaking, this kind is also mainly caused by the interaction of middle and low latitudes' systems, but the existing period of the steady circulation and systems' effects last shorter and the affecting scale is narrower.

Among the cases, Case 64-06 covered a large scale and the circulation characteristics were more similar to that of the first kind. While Case 60-06, which resulted from the interaction of cold air and tropical cyclone, was with circulation that more like in the second kind though it happened in the first flood season.

Results of physical quantities analyses also show that during this kind of rainstorms, the stations with stratification instability are scattered, but there are still obvious instability around the rainstorm centers. Water vapor flux is between the two kinds mentioned above and the transport direction is not so clear and stable as that in the first kind.

So there are two kinds of main causes of very heavy rainstorms in Guangdong. "Frontal precipitation" in the first flood season is the main cause of Xijiang R. and Beijiang R. floods. For the Subtropical High is weak, South China is controlled by precipitation systems of the first flood season. And this situation lasts long and results in continuous rainstorms which cause widely-covering flood. "Tropical cyclone precipitation" in the second flood season is the main cause of floods of coastal rivers and small tributaries of the Pearl River. This kind of rainstorms often begins and terminates suddenly. If a cyclone is strong and moves slowly, and there is cold air coming southward, it'll easily meet heavy rainstorm and cause flood. The third kind of rainstorms can be seen as the composite of the two significant patterns. Tab. 3 gives more detail.

IV. CONCLUDING REMARKS

a. Floods would happen about all tributaries of this river and about coastal rivers. The very heavy rainstorms that cause floods may occur from May to Sept., especially in June. They have strong intensity, long period and large covering scale.

b. The unusually heavy rainstorms causing floods can be divided into three kinds: Rainstorms related to frontal systems in the first flood season, rainstorms related to tropical cyclones in the second flood season and rainstorms related to the two kinds of systems. They have differ-

Tab. 3 The factors of synoptic background of different kinds of rainstorms

Level		"Front rainstorms"	"Tropical cyclone rainstorms"	Rainstorms related to two kinds of systems
Upper	Westerly of high and middle latitudes	*	*	*
Middle	Stable Subtropical High location	*		*
	Changeable Subtropical High location		*	
	Strong Subtropical High			*
	Weak Subtropical High	*		
	Cold air from North			*
Lower	Water vapor transport	*		*
	Shears	*		*
	Eddies	*		*
	Tropical cyclone		*	
Ground	Cold front or stationary front	*		

ent characteristics.

c. The affecting systems are extremely different. And so are the physical quantity characteristics.

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