Article ID: 1006-8775(2003) 01-0080-06

A COMPREHENSIVE ANALYSIS OF INTERACTIONS BETWEEN MESO-SCALE CONVECTIVE CLOUD CLUSTERS IN TYPHOONS AND MESOSCALE HEAVY RAINS

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ABSTRACT: In this paper, time and space distribution regularity of meso-scale heavy rains in five selected typhoons which landed at Fujian from 1996 to 1998 has been analyzed. Besides, with hourly digitized satellite infrared imagery, the features of the mesoscale are revealed for the genesis and evolution of mesoscale convective systems in typhoons. It indicates that the intensity of mesoscale storms is closely connected with the temperature and the area of the coldest cloud cluster. The heavy rainfall usually emerges on the eastern side of the mesoscale convective cloud clusters, where the cloud mass is developing and with a dense gradient and big curvature of isoline of the cloud top temperature.

Key words: typhoons; mesoscale; heavy rains; convective cloud clusters

CLC number: 458.2 **Document code:** A

1 INTRODUCTION

Heavy rains associated with typhoons are one of the important meteorological disasters in the Fujian Province, which brings about greater damage in short-lived, severe precipitation. Much documentation has been reported on the study of the mesoscale convection systems and mesoscale convective complex (MCC) and associated precipitation[1 - 3]. Using landfall cases of tropical cyclones Frankie (No.9607), Gloria (No.9608), Joy (No.9610), Winnie (No.9714) and an unnamed typhoon (No.9802) and hourly infrared cloud imagery, the current work studies the activity of typhoon-related mesoscale convective cloud clusters and their interactions with mesoscale heavy rains. It is hoped that the attempt could lay a scientific foundation for the development of short-term forecasting procedures if we have a deeper understanding of the role of such cloud clusters in the genesis of severe precipitation.

2 TYPHOON-RELATED MESOSCALE CONVECTIVE CLUSTERS AND MESOSCALE HARD RAINS

2.1 *Definition of typhoon-related mesoscale convective cloud clusters and statistical facts*

Any processes will be defined an activity of mesoscale convective cloud clusters if, upon the point of cluster maturity in the typhoon cloud regime, the cloud top temperature is less than –54°C in cold cloud area larger than 20,000 m^2, with the center cooler than –62°C and a life cycle (defined as the duration in which the –54°C cold cloud sector appears) sustaining more than 5 hours. A radius of 300 km from the eye is the line dividing the inner and outer sectors of the

Received date: 2001-08-28; **revised date:** 2003-03-24

Foundation item: National Scaling Scientific Project (Dedicated Item 95-03)

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typhoon and the area 300 km south of the eye is called the rear portion after the northward progress of the storm.

Analyzing the digital cloud imagery for the five typhoons, we find that there are 22 mesoscale convective cloud cluster in activity in Fujian and adjacent areas (22°N - 29°N, 115°E - 121°E) around landfalls on the province. Each of the storms has two at least, but six at most, processes, averaging at 4.4 times. Clusters appear 8 times in the cloud systems in the inner portion, 4 times in the outer portion and 10 times in the wake of the rear portion of the typhoon.

The life cycle of a mesoscale convective cloud cluster in typhoons lasts between 5 and 21 hours, averaging at 9.3 hours. About 82% of them are between 5 and 21 hours. When maturing, the area of the coldest cloud sector is generally between 30,000 and 50,000 m^2 with cloud tops less than –54°C. The most developed cloud cluster can be as large as 100,000 m^2 and the lowest temperature can be from –70°C to –80°C for the cluster center, with the extreme below –90°C.

2.2 *Definition of typhoon-related mesoscale hard rains and statistical facts*

If any of the precipitation data affecting the typhoon processes meets one of the conditions below, it will be defined as a mesoscale heavy rain:

(1) rainfall ≥ 30 mm for every 3 hours for two or more adjacent weather stations and

(2) rainfall ≥ 60 mm for every 3 hours for a single weather station.

If a station has overlapped record for any two time levels, a single mesoscale hard rain process is counted. As shown in 3-h rainfall analysis, there are altogether 20 mesoscale hard rains in the five typhoons, averaging at 2 for each at least but 6 at most, a mean of 4 processes for each storm. The hard rains occur 7 times in the inner portion, 6 times in the periphery and 7 times in the rear portion. Heavy rains associated with typhoons last between 1 and 13 hours, having a mean of 5.3 hours. About half of the cases generate and dissipate in a course of 2 – 3 hours. Seventy percent of the mesoscale heavy rain area covers 2 to 4 stations, 10 at most. The values for the mesoscale heavy rain centers are between 33 mm and 190 mm, averaging at 74 mm. Values between 40 mm and 60 mm take up 50%, with the maximum being 190 mm.

3 INTERACTIONS BETWEEN TYPHOON-RELATED MESOSCALE CONVECTIVE CLOUD CLUSTERS AND MESOSCALE HEAVY RAINS

3.1 *Relationship between the cluster activity and mesoscale heavy rains*

Among the 22 mesoscale convective cloud cluster activity that is associated with typhoons, twenty brought about mesoscale hard rains in the Fujian Province, completely covering all the clusters within the province over corresponding periods of time. The two clusters that did not have mesoscale hard rains did not migrate in it. It is then obvious that mesoscale convective cloud clusters are the main systems in mesoscale heavy rains generation.

As shown in our study, a mesoscale convective cloud cluster is generally with one, sometimes two, heavy rains on the same scale. It may be resulted from moderate or fast-moving clusters in association with discontinuous mesoscale hard rains. There may be occasions when multiple cloud clusters (three at most) are accompanied with one mesoscale heavy rain. It occurs when several cloud clusters developing over different sources are meeting over a location, or a number of them merge, so that continuous heavy rain occurs over the same region.

3.2 *Relationship between the cluster intensity and mesoscale heavy rains*

3.2.1 RELATIONSHIP BETWEEN COLD SECTOR AREA AND MESOSCALE HEAVY RAINS

The typhoon-related convective cloud clusters develop about 1 – 5 hours, averaging at 2.8 hours, earlier than the appearance of mesoscale heavy rains. About 85% of the cases are generated within the mesoscale convective cloud clusters, and particularly so when they have the –62°C cold cloud sectors with area over 10,000 m^2. It is especially useful for the forecasting of the effect of enlarging cold sector area on the occurrence of mesoscale heavy rain, which is 1 – 2 hours in advance.

Some degree of positive correlation exists between the area of cold cloud sectors with mesoscale convective cloud clusters colder than –54°C. The general pattern is that the area of mesoscale heavy rains are about 1/4 – 1/6 of the cold cloud sector area with clusters < –54°C. Then, the larger the cold cloud sectors, the more extensive the region of mesoscale hard rains will be.

3.2.2 RELATIONSHIP BETWEEN COLD SECTOR CLOUD-TOP TEMPERATURE AND MESOSCALE HEAVY RAINS

As shown in Tab.1, the intensity of cold cloud centers of the convective cloud clusters is positively correlated with the rain rates. When the former is between –63°C and –77°C, the 3-hr rainfall is usually less than 70mm, mostly between 40 mm and 60 mm. When it is lower than –77°C, the 3-hr rainfall is usually more than 70 mm and exceeds 100 mm when it is colder than –83°C. In the meantime, the rain rate also has something to do with the ratio of area between the –62°C cold cloud sector and the –54°C cold cloud sector: the larger the area, the more intense the precipitation will be. It shows that a more compact convection cloud cluster will be accompanied by stronger precipitation.

Tab.1 The relation between the meso-scale convective cloud cluster and the intensity and area of the meso-scale rainstorm

Typhoons	No. of cluster	Location of clusters	Life cycle / hr	Min.vorticity at cluster center/ ℃	Max. cluster area / 1000 km^2		Max. Cloud sector area ratio(≤ - 62 ℃/≤ -54 ℃)	strongest rain cluster center /mm/3 h	Max. rain cluster range (station)
					≤-62 ℃	≤-54 ℃			
Frankie	1	Inner	7	-63	0.1	2.3	0.45	59.3	2
	2	Rear	7	-75	1.9	3.5	0.54	55.0	4
Gloria	1	Periphery	5	-68	0.9	5.0	0.17	65.2	5
	2	Inner	6	-75	2.26	4.8	0.45	78.4	4
	3	Inner	5	-75	0.47	2.0	0.27	84.1	5
	4	Inner	5	-71.5	2.4	6.0	0.4	50.7	2
	5	Rear	12	-91	7.8	9.0	0.87	103.8	10
Joy	1	Rear	12	-82.4	4.8	9.0	0.53	70.4	2
	2	Rear	21	-81.2	4.8	7.3	0.66	61.0	4
	3	Rear	6	-69	0.9	4.2	0.22	61.0	1
	4	Rear	7	-81.2	1.3	2.4	0.55	127.4	3
	5	Rear	10	-83	3.6	4.2	0.86	189.5	2
	6 *	Rear	4	-83	2.2	2.4	0.9	none	none
Winnie	1	Periphery	8	-69	0.9	2.5	0.38	41.0	2
	2	Periphery	19	-81	3.6	4.8	0.75	71.4	4
	3	Inner	9	-83	8.7	9.4	0.93	118.9	4
	4	Rear	14	-81	4.8	6.0	0.80	56.1	2
9802 (unnamed)	1	Periphery	6	-77	10.6	12.7	0.85	58.7	3
	2	Inner	16	-73.3	1.8	3.0	0.6	65.6	6
	3	inner	5	-71	2.2	2.4	0.9	79.8	2
	4	Inner	9	-71	1.3	2.0	0.65	48.0	2
	5 *	rear	11	-77	1.6	2.4	0.65	none	none

Note: Cloud clusters with "*" only expanded to the border of Fujian and no corresponding mesoscale heavy rainstorms were recorded inside the province.

The mesoscale hard rains are also related with the amplitude of temperature variation at the cloud top of the clusters. The larger the temperature varies between two successive levels of time, the higher the rain rate will be.

3.3 *Relationship between the cluster imagery morphology and hyetal regions of mesoscale heavy rains*

As a mesoscale heavy rain generally falls over an area of only 5,000 – 7,000 m^2, which is much smaller than the area of a mesoscale convection cloud cluster, it is difficult to use the latter to pinpoint the hyetal region of the mesoscale heavy rains. As shown in our study, there is close links between the hyetal region of the mesoscale heavy rains and the evolutionary state of the clusters and imagery morphology. The mesoscale hard rains usually fall near areas where the following features appear.

3.3.1 AREAS OF DENSEST GRADIENTS OF CLOUD-TOP TEMPERATURE EAST OF THE CLOUD CLUSTERS

As revealed in the analysis of cloud imagery, most of the cloud-top isotherms are not symmetric in distribution. They are usually denser on one side, which has the maximum gradient of cloud-top temperature (and usually points to the direction in which the cloud cluster moves). About 75% of the clusters clearly show such traits. Among them, about 73% of the cases occur on the side of the area in which the temperature gradient is the maximum in the cloud top east of the clusters. Typhoon Joy was of the type, which caused severe precipitation in the Longyan Prefecture. Being east of the center of a severe convection cloud cluster, the area was right beneath the maximum sector of the cloud-top temperature gradient (about 10°C / km) and severe precipitation was recorded around it (Fig.1).

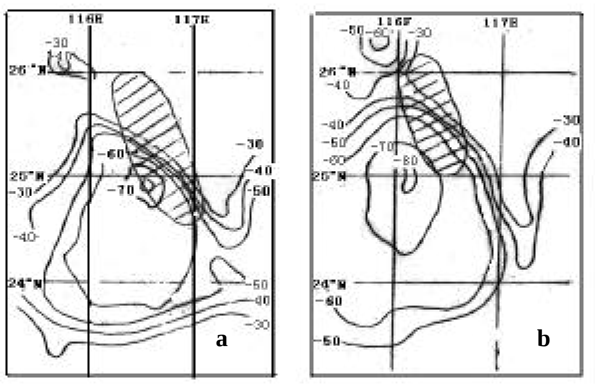

Fig.1 Cloud-top isotherms in cloud imagery for Typhoon Joy on August 8th, 1996 at 4:30 (a) and 7:30 (b). The shadow is for the hyetal area where $R_3 \geq 30$ mm.

3.3.2 AREAS OF LARGE CURVATURES OF CLOUD-TOP ISOTHERMS

It is a well-found fact in the study of satellite imagery that the curvature usually increases one side or the other of the cloud-top isotherms. It can be grouped into two. One is mutual incorporation of two developing cloud clusters when the isotherms have obvious variation in the curvature between them and mesoscale heavy rains appear right on the side of increasing curvature for the cloud-top temperature of developing cloud clusters. Two examples are Typhoon Gloria, which brought about severe precipitation on the central part of coastal Fujian Province from 0300 to 1000 (L.T., same below), 1 August 1996, and Typhoon Joy, which resulted in severe rainfall in the Longyan Prefecture of the province on August 8th in the same year. The other group features temperature rise at scattered points of the cluster centers so that they overtake the other side of the cluster centers, when the latter develop to its full strength. An example is Typhoon Gloria, which caused severe precipitation in southern Fujian in the early morning of August 2nd, 1996, with the hyetal area right on the side where the cloud-top temperature shows a zigzag profile[5] (Fig.2).

3.3.3 AREAS OF DEVELOPING CLOUD CLUSTERS

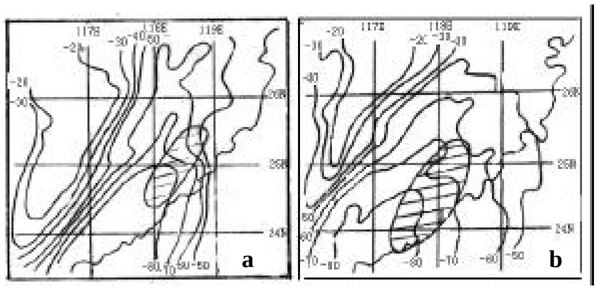

Fig.2 Cloud-top isotherms in cloud imagery for Typhoon Gloria on August 2nd, 1996 at 3:30 (a) and 6:30 (b). The shadow is for the hyetal area where $R_3 \geq 30$ mm.

In determining whether a cloud cluster would develop or not, one could judge by examining the difference map showing cloud-top temperature for all points within it between the current level of time and the previous one. If it falls at some points of the top, the suggestion is that the cluster is in the development phase; if it rises, the cluster is believed to be weakening. On most occasions, mesoscale heavy rains appear on the side of a developing cloud cluster, like in the case of Typhoon Winnie. Between 0500 and 1000 on August 30th 1997, the cloud-top temperature kept decreasing on the northeastern side of a severe cloud cluster, indicating a development phase for it; a mesoscale hard rain was on this side of the cluster. The phenomenon was also repeated evidently during the life cycles of Typhoons Gloria and Joy.

Given that the area of the coldest cloud sectors and minimum temperature for cloud cluster centers are generally the same, precipitation vary in intensity if the cloud cluster is in different stages of the development. If the cloud-top temperature drops over an extensive area, precipitation is expected to increase, being favorable for mesoscale heavy rains to appear; if it rises over widespread areas, the rains will reduce rapidly even though the area does not shrink for the coldest cloud sectors $<$54°C.

It is possible for a convection cloud cluster to have the above 2 – 3 characteristics at once on digitized cloud imagery. All of them must be taken into account when determining where mesoscale heavy rains would appear. If they appear over more than a region, the judgement is made by combining the most outstanding feature with previous tendency of precipitation.

4 INTERACTIONS BETWEEN TYPHOON-RELATED MESOSCALE CONVECTIVE CLOUD CLUSTERS / MESOSCALE HEAVY RAINS AND TERRAIN

For typhoon-related mesoscale convective cloud clusters that affect the province, most of them generate over coastal areas of central and northern Fujian while the rest over the southern part of the province. Similar features are found in the analysis of the hyetal area of the mesoscale hard rains in relation to the distribution of typhoon center location. Around the point of eye landfall, there is a concentrated area of rainfall to its right front portion, with heavy rain mainly in the plain of the Shacheng Bay, Sanwan Bay and Mouth of the Mingjiang River. With the center inland, the hyetal areas shift to the part south of the eye, with stations of heavy rainfall in upper- and middle- reaches of the Jingjiang River and the plain south of the Jiulongjiang River, which are east of the Daiyuan Mountain.

For the typhoon-related convective cloud clusters and mesoscale heavy rains, their areas of preferred genesis are closely associating with the terrain of the province. A mountain range with an altitude of 1600 m above sea level lines northeast-southwest in its eastern part, to the east of which spiral rain belts are usually seen in the northwestern periphery of tropical cyclones. When the typhoon is approaching, the easterly flow at the periphery has a normal intersection with the mountain range so that the spiral cloud bands from outside of the typhoon and the mesoscale convective cloud clusters around the eye are facilitated in development and enhancement and mesoscale heavy rains strengthened. When the typhoon moves further inland after landfall on the central and southern parts of the province, the parent cloud clusters or the wake clusters increase the mesoscale cloud clusters due to the combined effect of topographic lifting and gulf convergence, if the ambient field is right. In this way, another area of frequent genesis of mesoscale heavy rains is identified to the southeast of the storm center.

5 CONCLUDING REMARKS

a. Mesoscale heavy rains are caused by mesoscale convective cloud clusters. Their appearance is especially likely when the area of a cold cloud sector $<$ –62°C expands to 10,000 m^2 or more;

b. The intensity of mesoscale heavy rains are negatively correlated with the temperature of the coldest cloud sectors in the clusters but positively correlated with its area;

c. Mesoscale heavy rains mostly occur in areas with dense gradients of cloud-top temperature, large curvature of cloud-top temperature profiles and developing cloud clusters.

d. The hyetal areas of heavy rain are closely associated with terrain. Areas of high values are mainly seen in favorable areas in middle hillsides and harbors in the northeastern and southeastern parts of the province.

Acknowledgements: Mr. CAO Chao-xiong, who works at the Institute of Tropical and Marine Meteorology, CMA, Guangzhou, has translated the paper into English..

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