ANOMALOUS VARIATIONS OF GUANGDONG PRECIPITATION IN SUMMER IN RELATION TO MONSOON

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The relationship between the variation of precipitation in Guangdong Province is investigated using the correlation analysis and composite comparison methods in conjunction with precipitation data from 36 surface weather stations in the province and reanalyzed 850 hPa data from NCEP, U.S.A. A significant positive correlation is found between the variation of precipitation in summer there and the intensity of the southwesterly over the South China Sea, though without being so inconclusive that a strong southwesterly over the sea is accompanied by more rain in Guangdong. For the front-associated flood season in April – June, the former is a carrier of rainwater for Guangdong but with insignificant linkage with the intensity of the southwest monsoon. There is even such a situation in which the precipitation gets stronger though with a weakened southwest monsoon from the tropics in May – June, which is mainly attributable to the increase of monsoon from the subtropics. For the typhoon-associated flood season in July – September, the Guangdong precipitation increases as the southwest monsoon strengthens over the central and northern South China Sea and the subtropical monsoon reduces its effects on the province.

Key words: precipitation anomalies, summer monsoon, Guangdong

I. INTRODUCTION

In the much research regarding the behavioral rules governing the variation of precipitation amount in south China (Wu and Liang, 1992; Wu, Huang and Xue, 1990), they have been preliminarily analyzed in terms of factors affecting the precipitation in this part of the country, such as the subtropical high, sea surface temperature, low-latitude circulation systems (Liang, 1994; Liang, 1991; Li and Liang, 1993 and Li and Wu 1996). Nothing specific has been done in the aspect of the relationship between the variation of rainfall in Guangdong and that of the summer monsoon.

It is a well-known fact that the summer monsoon is a provider of abundant rain for China. Studies in this aspect are documented as early as in the 1930's when Zhu (1979) addressed the relationship between the advancement/retreat of the summer monsoon and the rain zones in flood season in China. It is also a subject in the book *Monsoon in East Asia* by Chen, Zhu and Luo (1991). Zhao and Zhang (1996) put forward their argument on how the intensity of East Asian Monsoon is related to the summer rain zones in China. The work above is all about the movement of rain zones and leaves much to investigate into how anomalous local precipitation varies with the intensity of summer monsoon.

It is for this purpose that we attempt to study the relationship between the changes in precipitation amount in Guangdong and the summer monsoon with the reanalyzed data from NCEP and rainfall data from the province between 1979 and 1995.

II. DATA

The data used in this work are the daily amount of precipitation recorded at 36 ground observation stations in the province. Being provided by the meteorological archives of the Guangdong

Provincial Bureau, they have been arranged and compiled. With the treatment, the daily data are changed into one over pentads or every ten days of the month and the average rainfall in Guangdong is represented by the mean value of the sum for all of the 36 stations. For the reanalyzed grid data used, the resolution is on the order of 2.5°×2.5° and the period spans between April and September in 1979 – 1995.

III. RELATIONSHIP OF PRECIPITATION IN GUANGDONG AND INDEX OF SOUTHWEST MONSOON IN SOUTH CHINA SEA

The period between April and September is generally defined as the rainy season in Guangdong Province, of which the time from April to June is the so-called first flood season and the one from July to September the second flood season. The rainy season varies by a twin-peak pattern, with the principle peak in June and the secondary one in August.

On a pentad basis, Fig.1 presents the precipitation in Guangdong and the curves of variations of the index of the southwest monsoon in the South China Sea in April – September averaged over 1979 through 1995. The index of the southwest monsoon is computed in:

$$I_{SCSMS} = (V_{SW}-1.0)/a+(235-V_{OLR})/b$$

where I_{SCSMS} is the index, V_{SW} the southwesterly component at 850 hPa in unit of m/s, V_{OLR} the value of OLR in W/m^2. The latter two are both regional pentad mean for the South China Sea (5-20°N, 105-120°E) and a and b are the constants, in which a=1 m/s and b=10 W/m^2.

As shown in the figure, the precipitation has its peaks in the 1st – 3rd pentad in May and from the 6th in May to the 2nd pentad in June while the monsoon index for the South China Sea is growing in jumps in Pentads 3 – 4 in May and Pentads 1 – 4 in June. It appears that the precipitation (especially those on higher scales of intensity) in Guangdong does not increase at the same but rather a faster rate with the southwest monsoon over the South China Sea. It remains to be resolved whether it is linked with the supposition that the precipitation in Guangdong serves as a trigger for the establishment and intensification of the monsoon in the sea during the particular period of the first flood season. Correspondence in the variation does exist in some extent in the second flood season between them. A small monsoon index in July goes with a mild

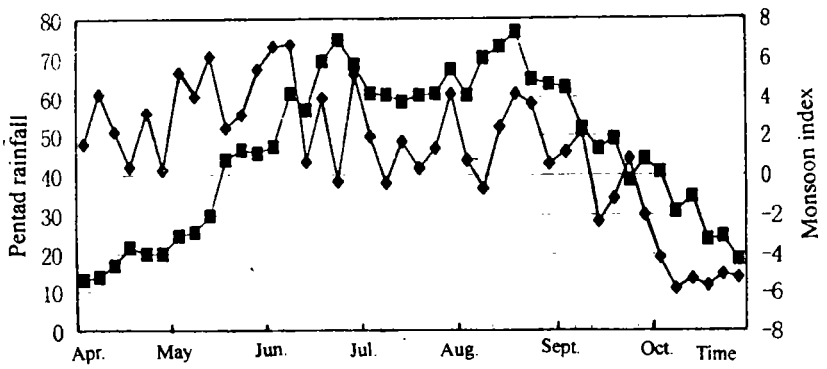

Fig.1. Five-day evolution curves of rainfall in Guangdong (lozenge dotted line, mm/10 days) and the summer monsoon index for the South China Sea (square dotted line) averaged over 1979-1995.

amount of precipitation in the province; a peak for the former in the middle of August also appears in phase with the latter; the monsoon index begins to decrease from September onwards and so does the rainfall.

Studying the results of correlation analysis, we find that the two preceding series are in moderate positive correlation with each other. It does not indicate that they are irrelevant with each other as the monsoon index is used in the sense of average conditions for the area of the South China Sea, with the stress on the variation of the monsoon for the central and southern part of the sea (Liang and Wu, in press). The precipitation in Guangdong may be affected by the southwesterly wind over the northern part of the sea and this is what we endeavor to find out in the work.

Ⅳ. CORRELATION OF GUANGDONG PRECIPITATION WITH GENERAL CIRCULATION AT 850 hPa

For more understanding of the relationship between the precipitation in Guangdong and the Asian summer monsoon, we have computed the distribution of correlation coefficients for anomalous series of pentad-based precipitation (removing climatological deviations, same below) in Guangdong in April – September from 1979 to 1975 and that of *u*/*v* components at 850 hPa over the same period and the results are shown in Fig.2. In the figure, the arrows for the vectors are composed of coefficients correlating with the *u*/*v* components, in which the magnitude of the horizontal (vertical) component stands for the correlation coefficient of *u* (*v*) component. Grid points are marked on the figure if the absolute values are larger than 0.30 for the correlation coefficient. It is then clear that the maximum correlation zone is located in the northern part of the South China Sea where the variation of precipitation in Guangdong is positively correlated with the southwesterly for the area north of 10 °N in the sea. In addition, the former is also positively correlated with the westerly or southwesterly in the Indo-china Pen. northern part of the Bay of Bengal and northwest Indian Pen. and the effects are present over as farther east as the west

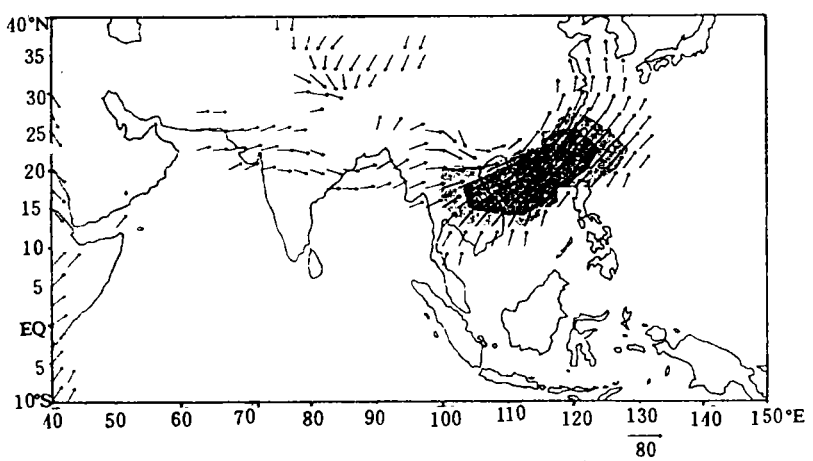

Fig.2. Distribution of correlation coefficient between Guangdong rainfall anomalies and *u*/*v* components at 850 hPa in April–September of 1979–1995. The horizontal and vertical directions of vectors stand for correlation coefficients with *u*/*v* components respectively. Light shadow is for correlation coefficients greater than 0.5, the deep shadow for correlation coefficients greater than 0.6.

Pacific till 130°E and as farther north as the Yellow Sea. It is then our conclusion that an increased southwesterly in northern South China Sea brings about more precipitation in Guangdong and the same is true otherwise.

Following the denotation as in Fig.2, Fig.3 gives the distribution of correlation coefficients for anomalous series of pentad-based precipitation in Guangdong and that of *u*/*v* components at 850 hPa. There is a common feature for the figures: the anomalous variation of precipitation in Guang- dong is in significant positive correlation with that of the southwesterly over northern South China Sea. With the exception of September, the former is also positively correlated with the northeasterly north of the province. Some particular characteristics are found with individual months. The precipitation in Guangdong is positively correlated with the northwesterly in northeastern India through southeastern Bay of Bengal in April, with the easterly in southern South China Sea through southern Bay of Bengal in June, with the southerly from southeastern Bay of Bengal to southern Indo-china Pen. in July and with the southwesterly or westerly from the Indian Ocean to the Indian Pen. and Indo-china Pen. and further towards a strip over eastern China and the Yellow Sea in September..

A composite analysis is conducted for comparison to have deeper understanding of the circulation patterns corresponding to the preceding correlative relationships. For each month from

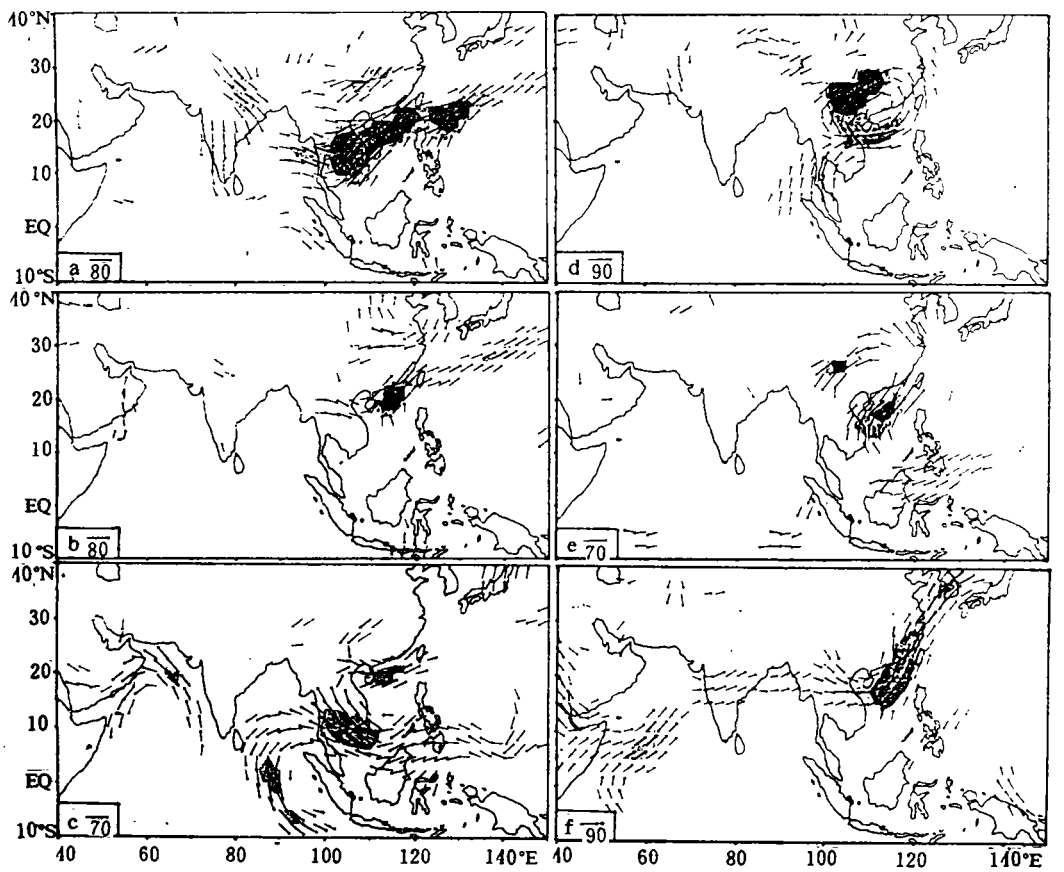

Fig.3. Same as Fig.2 but for April – September individually.

April to September in 1979 – 1995, five ten-day periods that have the maximum precipitation in Guangdong are selected from a total of 120 pentads for the analysis. The distribution of circulation patterns and anomalies are presented in Figs. 4 – 9 for the level of 850 hPa in these periods. A better-defined picture can be obtained by examination of the figures for circulation systems associated with the precipitation in each individual month in Guangdong.

From Fig.4a, we know that a ridge from the subtropical high in west Pacific is a dominant feature over the region of the South China Sea in April when it is a pre-onset period for the monsoon there and the southwesterly, which causes heavy precipitation in Guangdong, is located over southern China and northern part of the South China Sea to the northwest of the subtropical high. The southwesterly is much stronger in the northern South China Sea than the average (Fig.4b), which is not caused by the subtropical high. The western ridge can even be weakening and traveling towards the east over the region of the South China Sea by showing a negatively anomalous geopotential height over the region and a westerly anomalies over the central and

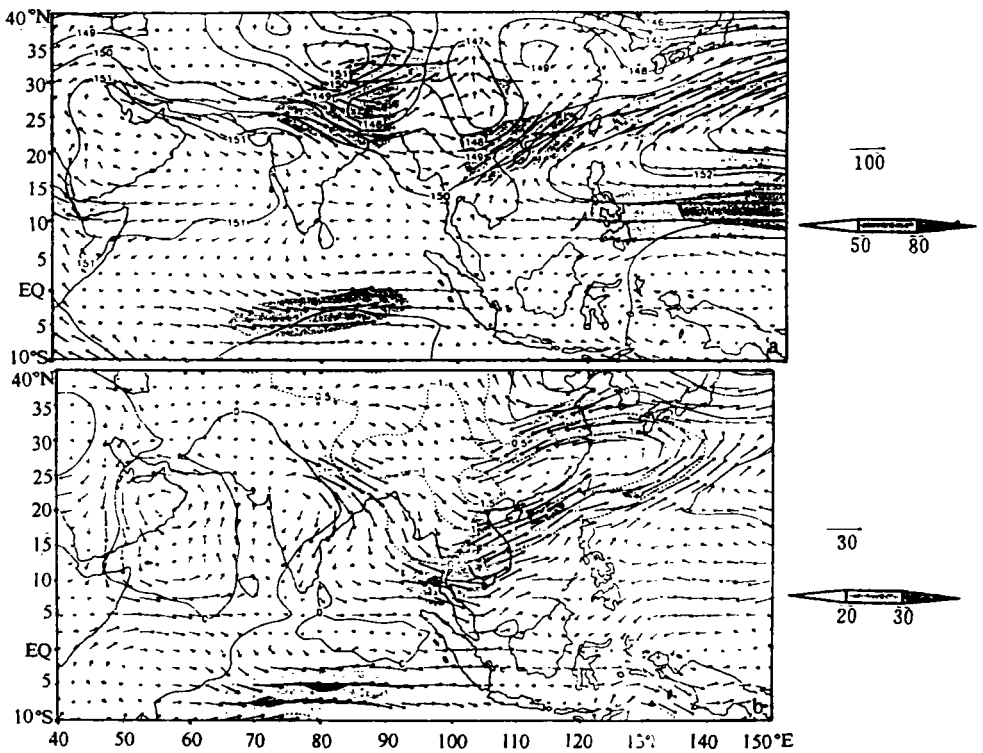

Fig.4. Distribution of circulation at 850 hPa for the five decades of maximum rainfall in Guangdong and their anomalous distributions in April. The vectors are for winds and lines for contour height.

southern South China Sea. The stronger southwesterly is resulted from a deepened trough over southwestern China and the Bay of Bengal favoring the strengthening of the northeasterly in the rear of the trough and the southwesterly in front of it. The increased southwesterly flow has caused the increase of precipitation in Guangdong among other factors.

In Fig.4b, there is a noticeable feature that extensive anomalies of easterly or northeasterly occur in areas north of Guangdong. The northeasterly flow as shown in Fig.4a over central China is an indicator that the southward advancement of cold air from the north is of the essential fac-

tors behind the heavy rainfall in Guangdong. It can be thought that the interaction between the warm and humid air from the Bay of Bengal and northern cold air masses rather than the tropical monsoon plays an important role for the heavy precipitation in Guangdong.

We know from what we have at hand that the average date of the southwesterly monsoon establishment is in the middle ten-day period in May for in the South China Sea. Some researchers study the southwest monsoon from a separate view of northern and southern portions of the sea, suggesting that the monsoon establishes earlier in the northern part than in the southern (Yan, 1997). It is known from Fig.5a that the southwesterly is composed of three flows converging from a southwesterly diverting from the western end of the subtropical high, a southwesterly formed over the Bay of Bengal and the Indo-china Pen. moving northeastward from a strong westerly around 80°E at the Equator and a southwesterly formed by deviation from a northwesterly over the Bay of Bengal flowing over the northern part of the Indian Pen. Converging over the region of south China, the three air currents become a strong combined southwesterly wind when the Indian summer monsoon has not established yet and the easterly is in dominance over the central and southern South China Sea due to more westward extension (with the contour of 1510 gpm lying near 117°E at the most western point and the monthly mean position near 125°E) of the subtropical high ridge over the region of the South China Sea.

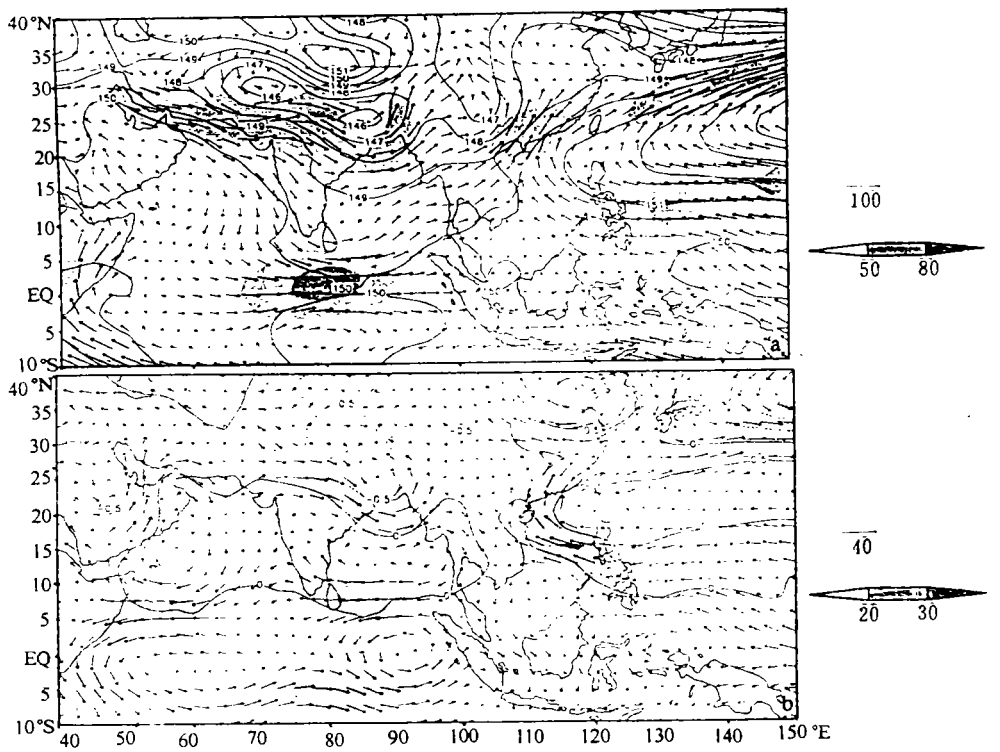

Fig.5. Same as Fig.4 but for the month May.

Following the definition of Yan (1997), we can only have the assumption that the southwest monsoon has established in northern rather than southern South China Sea at the time of the year. Results from statistical surveys of climatological data have shown that the five pentads having the heaviest precipitation in the month are all between the dates for the establishment of the

southwest monsoon for the northern and southern part of the South China Sea (the information of dates come from Yan [1997]). A noticeable fact is that the strengthened southwest monsoon extending from the strong westerly over the Bay of Bengal at the Equator is not causing the anomalous more precipitation in Guangdong (on the contrary, the equatorial westerly and the southwesterly over the Indo-china Pen. is weaker than the mean); it has very much to do with a stronger subtropical high. It is said to be strong if it has a more westward location of the western ridge and an anomalously positive geopotential height for the bulk of the subtropical high (Fig.5b), together with a strengthened anticyclonic air flow. It must be noted that an increasing subtropical high is not necessarily in favor of heavier precipitation in Guangdong in view of the fact that a strong subtropical high covering as far west as the Bay of Bengal is accompanied by moderate amount of precipitation in Guangdong. Besides, the cold air activity from the north is also an important factor in bringing about heavy rainfall in the province.

It is seen from Fig.6a that the Asian summer monsoon system has generally set up by June and becomes one of the principle mechanisms to offer abundant rainfall in China. Fig.6b indicates that most of the zonal area bounded by 5 – 15°N and 50 – 130°E is dominated by the easterly anomalies while stronger northerly cross-equatorial current is present over much of the areas at the Equator. It is then known that it is true at least for Guangdong that precipitation tends to be unexpectedly strong when the southwest monsoon is weak in Asia.

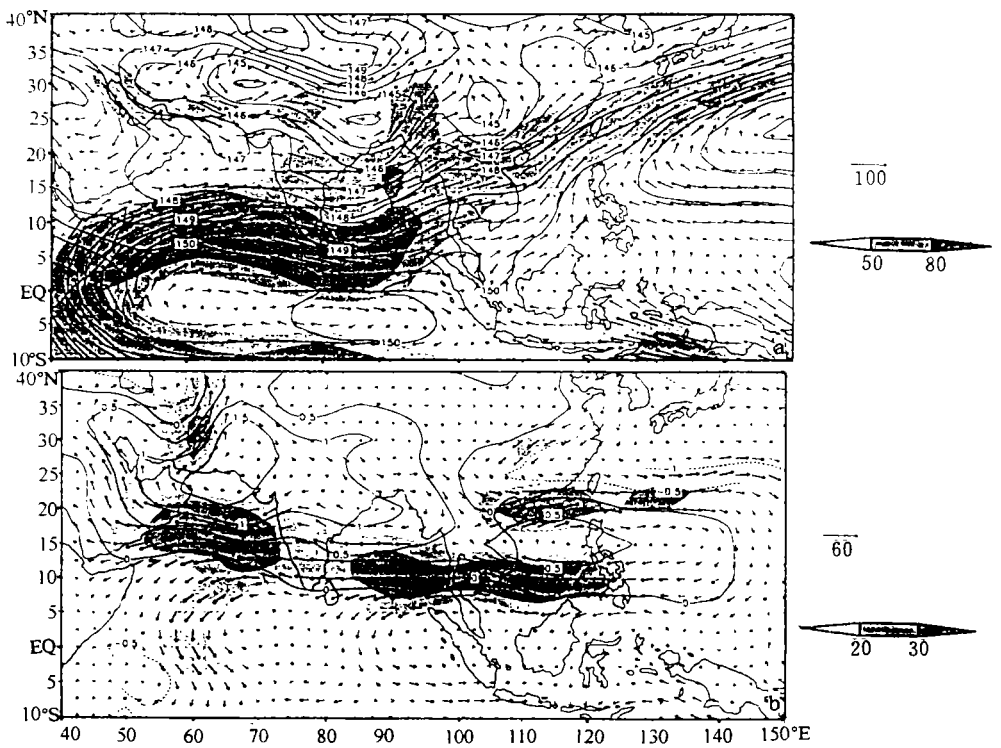

Fig.6. Same as Fig.4 but for the month June.

From what is shown in Fig.6a, we know that the average ridge line of the subtropical high over the 120°E – 130°E region is 15°N (being determined by the component of the southerly). By June, the line has shifted to 20°N. Fig.6b also gives such a picture that negative geopotential

anomalies are extensive over areas north of 20°N and positive ones south of it for the South China Sea and west Pacific, with the center of the positive anomalies right across the middle part of the sea. It is then clear that apart from a weak Asian summer monsoon, the westward and southward extension of the subtropical high is also a (more effective) factor causing the intensification of precipitation in Guangdong. It agrees with Liang (1994). The activity of cold air is, of course, an additional influential factor, which is not to be addressed in details as the current topic concerns only with the effect of tropical systems like the monsoon.

By July, the southwest monsoon has influenced farther north in the country (Fig.7a) and its high intensity becomes an essential factor in causing heavy precipitation in Guangdong. A southerly or southwesterly anomaly appears from the southern Indo-china Pen. to the central and northern South China Sea as indicated in Fig.7b and significant correlation is revealed in relevant analysis between them and precipitation in Guangdong. It is suggested that the latter tends to be larger when the southwest monsoon is stronger than its monthly mean. A northeasterly anomaly north of the province shows a weaker southwest monsoon there. It is then concluded that precipitation tends to increase if the southwest monsoon intensifies over the central and northern South China Sea.

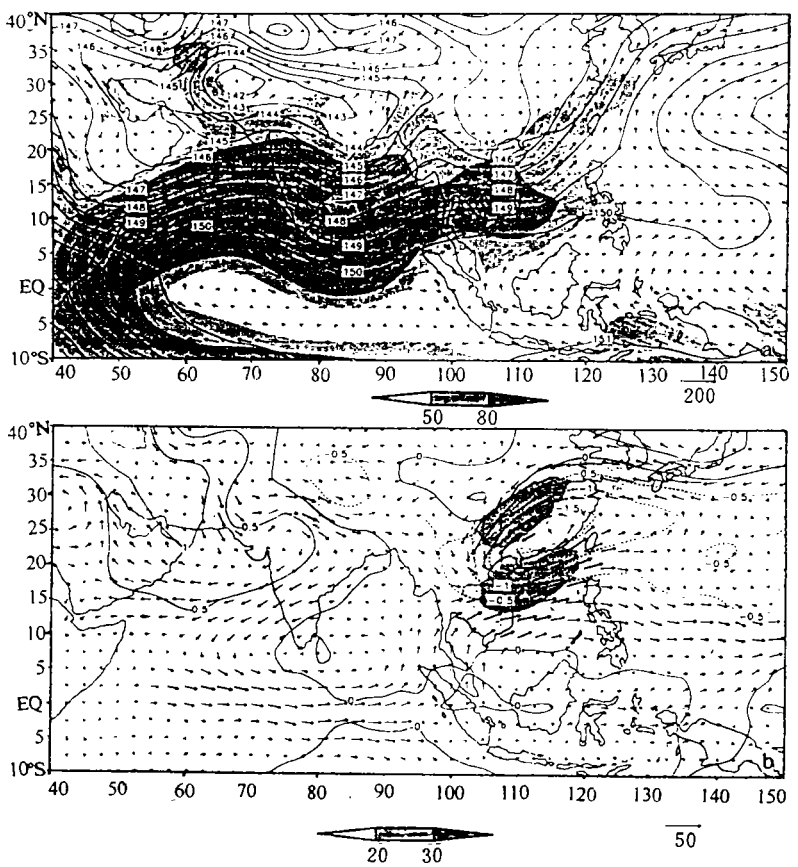

Fig.7. The same as Fig.4 but for July.

The southwest monsoon is still a major mechanism for intensifying the precipitation in Guangdong when it comes to August (Fig.8a). In comparison with the monthly mean, a positive

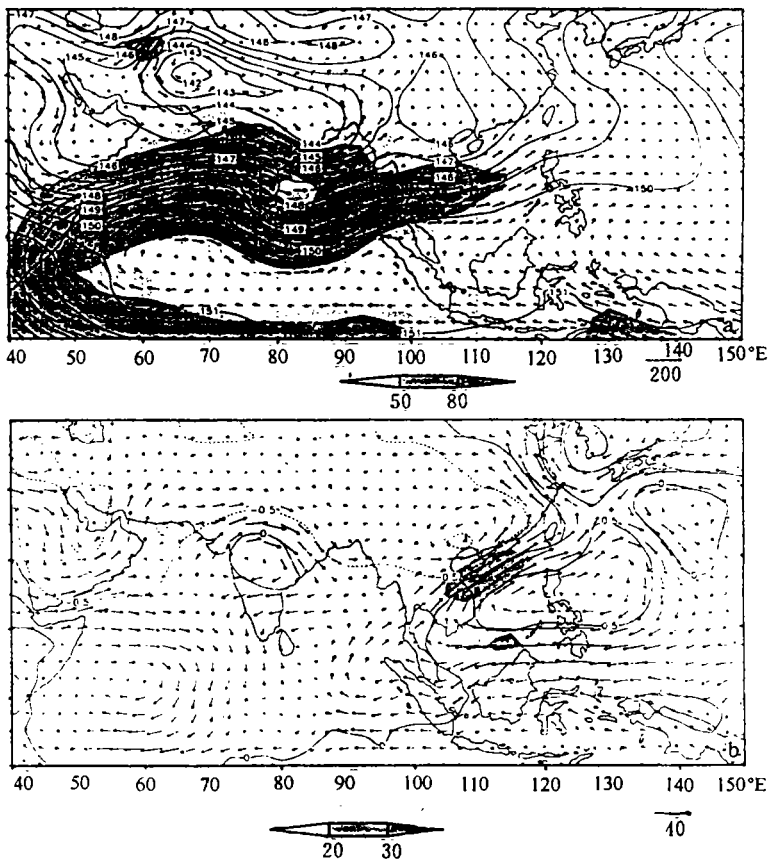

Fig.8. The same as Fig.4 but for August.

southwesterly and an easterly anomaly cover the northern and southern parts of the South China Sea, respectively with high correlation (Fig.3e), suggesting that the Guangdong precipitation increases as the southwest monsoon gets stronger in the north but weaker in the south of the sea, i.e. the zone of gales shifts northward for the southwest monsoon.

With a much southward retreat than in August, the southwest monsoon has been weakened in Asia in September (Fig.9a), leaving Guangdong in the control of an easterly flow converging from the southwesterly over the southern South China Sea and the easterly south of the subtropical high. A southwesterly anomaly from the northern South China Sea to the Yellow Sea, as indicated in the anomalous distribution in Fig.9b, is in company of a strong westerly anomaly over areas from the equatorial Indian Ocean, Indian Pen. through the Indo-china Pen., correlating positively with the change in precipitation in Guangdong. It is then clear that there is more rainfall in Guangdong when the southwest monsoon is relatively stronger in Asia.

V. CONCLUSIONS AND DISCUSSIONS

a. The summer monsoon is the most important system of all that affects China by supplying large amount of water vapor and precipitation. The effect is not obvious for the Guangdong Province in that no significant correlation exists between the variation of southwest monsoon

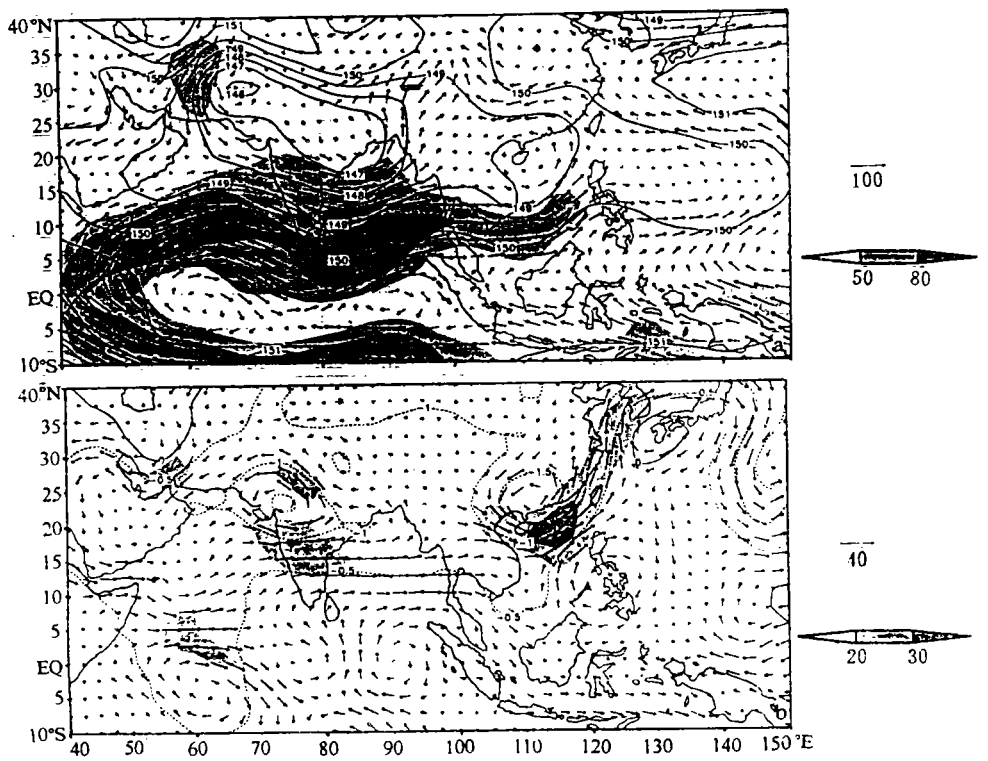

Fig.9. Same as Fig.4 but for September.

intensity in the South China Sea and that of precipitation anomalies. Concluding the correlative analysis and composite analysis done above, we find that the change in the precipitation in Guangdong is positively correlated with the intensity of the southwesterly in northern South China Sea, though no conclusion may be drawn that a strong southwest monsoon in this region goes with heavy precipitation in the province and each individual month is marked with particular rule of behavior.

b. The southwesterly that brings much rain in Guangdong is caused by the deepening of a trough over the Bay of Bengal as the summer monsoon is not yet established in April. With the definition that the southwesterly over the Indian Ocean-South China Sea is called the tropical monsoon and the southwesterly formed from a southeasterly turning the direction south of the ridge line of the subtropical high over the west Pacific is called the subtropical monsoon, we can then argue that the intensification of the subtropical high (and the tropical monsoon is not yet set off or relatively weak at the time) is the major cause for the anomalously heavy precipitation in May in Guangdong – the easterly flow increases south of the increased high and turns to become a southwesterly over the north part of the South China Sea. In June, the heavy precipitation is caused by the southward and westward movement of the subtropical high, i.e. the intensification of the subtropical high. It is now clear that the southwesterly does bring precipitation in Guangdong though the precipitation varying insignificantly with the intensity of the southwest monsoon in the tropics. An anti-correlation even occurs in May and June when a weak appearance of the latter is accompanied by heavy precipitation in the province. It is because the subtropical monsoon has played a vital part.

c. For the second flood season in July – September, the correlation is much closer between the precipitation changes in Guangdong and the intensity variation of the tropical southwest monsoon than in the first one. When there is anomalously strong precipitation in July in the province, the tropical monsoon, especially the southwest monsoon over the South China Sea, intensifies over the central and northern regions of the sea while the subtropical monsoon weakens. The anomalous precipitation intensity in July is also caused by the increased tropical monsoon over that part of the sea. By the time of September, Guangdong is mainly subject to the subtropical southeast monsoon, which weakens while the tropical southwest monsoon enhances when there is anomalously strong precipitation. It is then clear that precipitation increases in the second flood season in Guangdong as a result of the intensification of the tropical monsoon.

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