SEASONAL VARIATIONS OF CONVECTIVE ACTIVITIES OVER THE SOUTH CHINA SEA AND ITS NEIGHBORHOOD AND THEIR COMPARATIVE ANALYSES IN THE STRONG AND WEAK CONVECTION YEARS *

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ABSTRACT

The seasonal variations of convective activities over the South China Sea (SCS) and its neighborhood, as well as the similarities and differences of convection in the different key regions during the strong and weak convection years are analyzed by using the pentad data of TBB from 1980 to 1993. The results show that in winter and summer the seasonal variations of the convective activities are synchronous over the SCS and its neighborhood, the anomalous convection amplitudes are obviously different in different regions. The significant extents of convective activities have somewhat seasonal differences in the strong and weak convection years. In the strong convection years, it is in winter, spring and autumn that the convection anomaly is more evident than that in the normal years, however, after the summer monsoon onset the convection is sustained, stable and similar to that in the normal years. In the weak convection years, the convection weakens greatly in each season, but the primary weakening occurs in spring, summer and autumn. No matter in the strong or the weak convection years, the convective activities are somewhat of difference in the Bay of Bengal, the Indochina Peninsula, the SCS and the Philippines. In addition, the convective activities are also different over the south and the north parts of the SCS, the convection variation in the strong year is similar to that in the weak year over the north part of the SCS, but over the south part there are great differences.

Key words: convective activities, seasonal variations, South China Sea (SCS), comparative analysis, Empirical Orthognal Function (EOF)

I. INTRODUCTION

Recently, more and more meteorologists apply the finer resolution TBB data to studying the climatic features of the SCS monsoon, the monsoon onset and evolution, the mechanism of monsoon onset, tropic circulation systems, and so on. The previous studies have shown that TBB is a good indicator for the onset date of the SCS summer monsoon, and can perfectly reflect the sudden change of atmospheric circulation and the evolution of monsoon during the monsoon onset period (see Chen et al. 1999; Liu et al. 1998; Jin

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1999). The convective activities over the SCS have important impacts on the intraseasonal variation of the summer monsoon and the summer climate anomalies in East Asia. the precipitation in the Yangtze River Valley and the activities of the western Pacific subtropical high (see Huang and Sun 1994). After the monsoon onset. the strong and sustaining convective activities not only affect the local climate elements but also significantly change the distribution of heat sources and the features of large-scale vertical circulation. The previous studies on the convective activities over the SCS mainly focus on the characteristics of TBB during and before the monsoon onset. In this paper the seasonal variations of convective activities and the composite convective activities in the strong and the weak convection years are analyzed to reveal the similarities and differences of convection in different key regions and different ocean areas of the SCS by using TBB data.

Here what we want to mention is that usually in summer and autumn the lower value of TBB reflects the top temperature of convective cloud. whereas in winter and spring it reflects the top temperature of non-convective cloud. Therefore it is difficult to distinguish the convective and non-convective cloud systems by TBB value only. However. in our paper the tropical belt is mainly concerned and convection may exist there in winter. Therefore. we do not distinguish the convective and non-convective cloud systems and uniformly call them convection.

II. DATA AND METHOD

The data used in this paper are pentad mean TBB data. The resolution is $2^{\circ}\times 2^{\circ}$. and the selected region is from 90°E to 130°E and from 10°S to 30°N. Firstly the annual variation of convective activities is discussed. For this purpose the departure field of multi-yearly pentad mean TBB data from the total mean TBB data over 14 years is expanded in terms of EOF. The seasonal variations of convective activities are obtained by analyzing the EOF spatial and temporal fields. Then the interannual variations of convection anomalies are discussed. To this end the seasonal-annual features of convection are analyzed based on the difference between the regionally averaged pentad data of each year and the corresponding pentad data of multi-yearly mean. The strong and the weak convection years are selected and composed. respectively. according to the annual standard deviation. Finally the standard departure fields of composite strong and weak convection years are expanded in terms of EOF. The similarities and differences of convection anomalies as well as the relationship between convective activities and the SCS monsoon in composite strong and weak convection years. in different key regions and in different parts of the SCS are comparatively analyzed.

III. THE SEASONAL VARIATION OF CONVECTIVE ACTIVITIES OVER THE SCS AND ITS NEIGHBORHOOD

The departure fields of multi-yearly pentad mean TBB data from the total mean TBB data over 14 years are expanded in terms of EOF. The variance contributions of the first three eigenvectors are 74%. 8% and 7%. respectively. The first eigenvector is the most important one and can reflect the major seasonal variation of convective activities over the

SCS and its neighborhood. The spatial distributions of the first, second and the third eigenvectors and their corresponding temporal coefficients are shown in Fig. 1.

The spatial field of the first eigenvector (Fig. 1a) reveals that the features of convective activities are in the same phase over the SCS, the Philippines, the Bay of Bengal (BOB) and the Indochina Peninsula, that is, the convective activities in these areas are strengthened or weakened simultaneously. Figure 1a also reveals the out-of-phase features of convective activities north and south of the equator. From the figure it is evidently shown that the degree of seasonal variation of convection in the Northern Hemisphere is different in different regions. The middle parts of the SCS (12—18°N) and the BOB are two higher variation centers. These two regions are the strongest regions of convection north of the equator. Moreover, the seasonal variation of convection over the BOB is more evident than that over the SCS. The contours at two sides of these two regions are basically zonal, illustrating the similarities of seasonal variation.

The time coefficient of the first eigenvector (Fig. 1b) reflects that the seasonal conversion of convective activities from winter to summer is clear over the SCS and its neighborhood as well as the Northern and Southern Hemispheres. Before the 25th pentad,

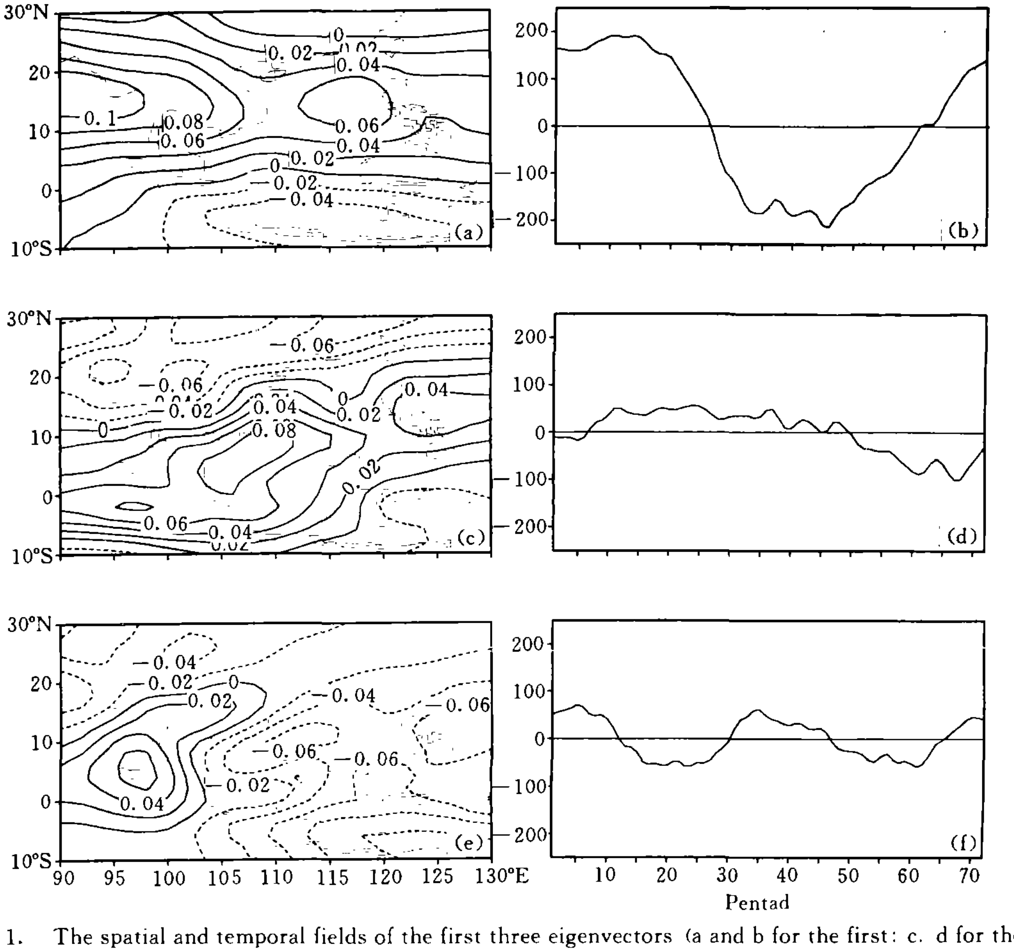

Fig. 1. The spatial and temporal fields of the first three eigenvectors (a and b for the first; c, d for the second; e, f for the third. x-axis is the series of pentad).

the time coefficient is positive and the TBB anomalies are negative south of the equator. which indicates that the convection in the Southern Hemisphere is active. however. the convection in the Northern Hemisphere is weaker than that in the normal years. After 25th pentad. the tropical convection in the Southern Hemisphere weakens quickly. whereas the convection over the BOB and the SCS strengthens suddenly. such a case is obviously connected to the monsoon onset. At the middle of June (33th pentad) the first maximum value of convection appears. at this time the convection over the SCS reaches the strongest. while the Indian monsoon is at the beginning. From June to September the convection keeps strong. there is some little change during this period and this corresponds to the Asian monsoon active phase and break phase. After October (66th pentad). the convection weakens gradually. this means the weakening of the summer monsoon and the beginning of the winter monsoon.

The contributions of the second and the third eigenvectors are much smaller than that of the first one. They are the modification of the first one. The spatial field of the second eigenvector is different from that of the first one. In the second spatial field (Fig. 1c) the east of Philippines and the mid part of the SCS are two higher positive centers. while the west of 105°E and the north of 15°N as well as the east of 105°E and the north of 20°N are two negative centers. The distribution over land and sea is contrary. In addition. there are another two negative centers at the south of the Tibetan Plateau. this may reflect that the thermal status of the Tibetan Plateau has some relationship with the SCS monsoon before the monsoon onset. The corresponding time coefficient (Fig. 1d) shows that the convection of this pattern changes in a way of spring—summer and autumn—winter. The convection over the land is active in spring and summer. whereas over the sea it is in autumn and winter that the convection is active. moreover its variation amplitude is large. This mainly reflects the effects of thermodynamic difference between sea and land. The third spatial field (Fig. 1e) reveals the contrary variability over the BOB and the SCS. that is. under the same phase of convective variation (see the spatial field of the first eigenvector). the convection also has some seasonal differences in these two activity regions. The corresponding time coefficients (Fig. 1f) show that there is a clear period of 6 months and the seasonal variations of convection in this pattern are clear. The convection over the BOB is strong in spring and autumn and weak in other two seasons. whereas it is contrary over the SCS. This reflects the zonal thermodynamic difference of sea-land and the asynchronism of seasonal variation in the tropic region.

The above analyses show that the SCS and the BOB are the key regions of the convection. The convective activities in these two regions change basically in the same phase. but there are still some differences in the seasonal variation. The convection over the BOB and the Indochina Peninsula is stronger than that over the SCS. In addition. the convection is on the contrary over land and sea. the thermodynamic status in the south of Tibetan Plateau and Indochina Peninsula may has close relationship with the SCS monsoon (see Wang and Qian 2000).

IV. THE INTERANNUAL VARIATION OF CONVECTIVE ACTIVITIES OVER THE SCS

In order to analyze the seasonal difference in the strong and weak convection years

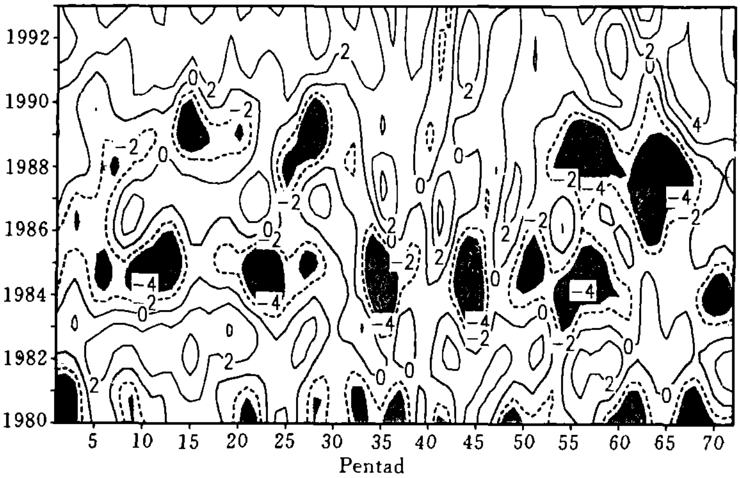

Fig. 2. The seasonal-annual variations of convective activities during 1980 to 1993 (the shaded areas represent the negative departure. x-axis is the series of pentad. y-axis is the series of year).

over the SCS. we calculate the seasonal-annual pentad anomalies (Fig. 2), which is the difference between the regionally averaged pentad data of each year and the multi-yearly averaged pentad data. This seasonal-annual anomaly has removed the annual variation of the convective activities.

It can be seen from Fig. 2 that the convective activities are strong in 1980. 1981. 1984. 1985. 1986. 1988 and 1989. and the TBB anomalies are almost negative in the whole year. especially in 1984 and 1985 the TBB anomalies in summer reach the lowest among all these strong convection years. However in 1982. 1983, 1987. 1990, 1991. 1992. and 1993 the convective activities are relatively weak. In 1982. 1983 and 1993. the TBB anomalies are almost positive in the whole year. but the convection in the winter of 1987 is relatively strong. Except for 1980 these strong and weak years are basically in agreement with those mentioned by Huang and Sun (1994). During these 14 years. the strong and weak convection has a period of 2 — 3 years. The regionally averaged annual departure (unit K) and the annual standard deviation are shown in Table 1. It can be found from the table that. the absolute value of standard deviation in 1986 and 1990 are less than 0. 5. their convection anomalies are smaller than that of the other years. The annual departure and the standard deviation in 1984 are —4. 64 and —1. 93. respectively. they are much larger than that of the other years. this may be related to the default values in most grids from the 32nd pentad to the 36th pentad in 1984.

According to the absolute values of the standard deviation (>0. 5). we select the following six years 1982. 1983. 1987. 1991. 1992 and 1993 to compose as the weak convection year. as well as another six years 1980. 1981. 1984. 1985. 1988 and 1989 to compose the convective strong year. The similarities and differences of convection in strong and weak convection years are discussed respectively. The statistic results show that most monsoon onsets in these weak convection years are in the middle of June and basically later than that in the normal years. moreover these weak years are just the El Nino years. This seems to reflect that the interannual variation of convective activities over the SCS has close relationship with El Nino.

Table 1. The Annual Departure Averaged in the Selected Region

Years	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
D*	−1.79	−1.82	2.90	2.23	−4.64	−1.90	−1.00	2.22	−2.73	−1.73	1.03	1.94	2.24	3.03
SD**	−0.75	−0.76	1.21	0.93	−1.93	−0.79	−0.42	0.93	−1.14	−0.72	0.43	0.81	0.93	1.27

* D is departure; ** SD represents standard deviation.

In order to check whether the selected strong and the weak years are reasonable, we analyze the TBB variance of each pentad in the strong, the weak, and the normal years over the BOB, the Indochina Peninsula and the SCS. Also we compare the annual

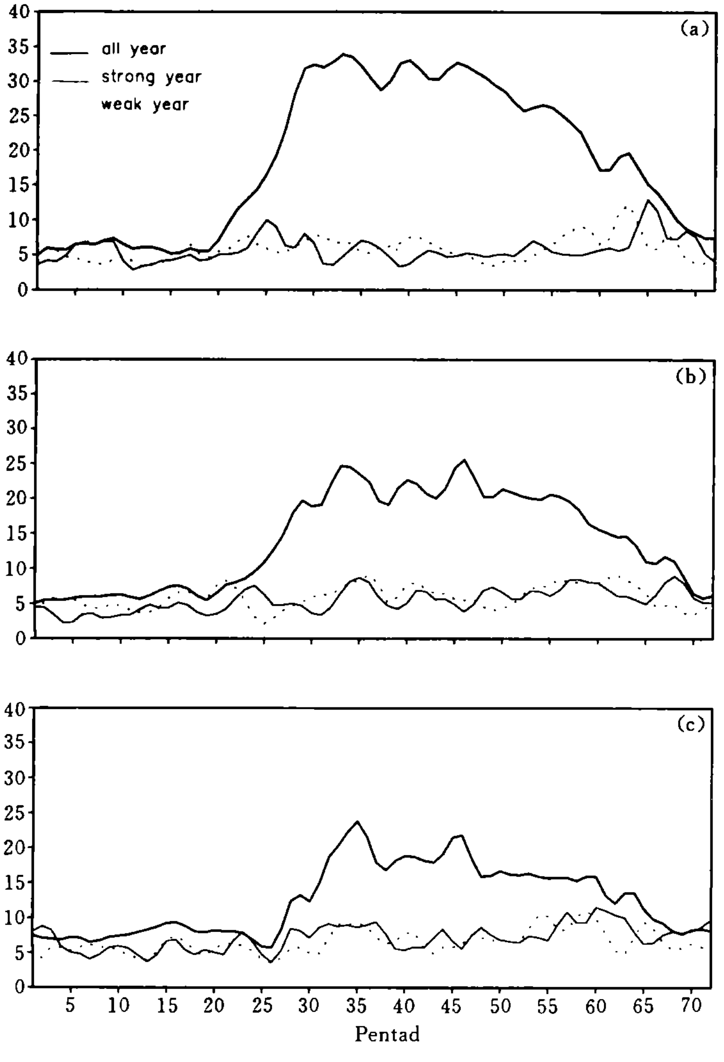

Fig. 3. The TBB variance of each pentad in strong, weak convection and normal years in the BOB (a), the Indochina Peninsula (b) and the SCS (c).

variation of convection in the strong and weak convection years with that in the normal years shown in Fig. 3.

Figure 3 shows that the characteristics of the TBB variance in these three regions are similar. In the normal year including both the strong and weak convection years the variance in summer and autumn is larger than that in winter and spring, moreover there are somewhat fluctuations. This illustrates that the interannual difference of convection is small in winter and spring, whereas it is large in summer and autumn. The time of variance increasing suddenly at the end of spring and at the beginning of summer is different for different areas. Over the BOB and the Indochina Peninsula it occurs between 20th and 25th pentad and is earlier than that over the SCS where it occurs between 25th and 30th. In the strong and weak convection years the variance is much smaller than that in the normal years, especially in summer and autumn, and the value of each pentad is close. This implies that the selected strong and weak convection years in these three key regions have good representativeness. From Fig. 3 we can also see that the BOB is the most significant area of the interannual variation, the second is the Indochina Peninsula. The SCS is the least one.

V. THE EOF ANALYSES OF CONVECTIVE ACTIVITIES IN THE STRONG AND WEAK YEARS

The standard departures of composite strong and weak years are expanded in terms of EOF, respectively. The variance contributions of the first three eigenvectors in the strong year are 34%, 12% and 9%, respectively, in weak year are 41%, 9% and 7%, respectively. The first spatial (a, b) and temporal (c, d) patterns in the strong and the weak years are shown in Fig. 4.

It can be seen from Fig. 4a and Fig. 4b that the zero lines in the strong and the weak years are basically located in 18°N. The convection anomalies at the south and the north sides of it change in the opposite phase. The convection amplitudes are large in Sumatera, Kalimantan Islands and the equatorial western Pacific. They are the sensitive regions of convection, especially the value in Kalimantan Island is much larger. The convection anomalies in Hainan Island at the north of the SCS (north of 18°N) and the Beibu Gulf are contrary to that in the middle of the SCS because they are affected by land. This pattern implies that in the strong convection years the strong and weak convection over land and sea are on the contrary, that is, when the convection is strong over sea, it is weak over land and vice versa. From the corresponding time coefficients (Fig. 4c) we can see that the convection anomalies may occur in all seasons except in summer. The variation amplitudes of time coefficients are large from spring to monsoon onset (about the 28th pentad), and this explains that the convection is evident in the transitional season of winter and spring. Over the SCS, the southern part of the BOB and the equatorial regions the convective activities are more active than that in the normal years. After early autumn (about 52th) the variation amplitude of convection is similar to that of spring, moreover the convection is stronger than that in the normal years. But the difference of convection between summers of the strong year and the normal year is small and the variation amplitude of time coefficient is much smaller than that of the other seasons.

The convection in the weak year (Fig. 4b and Fig. 4d) is very different from that in

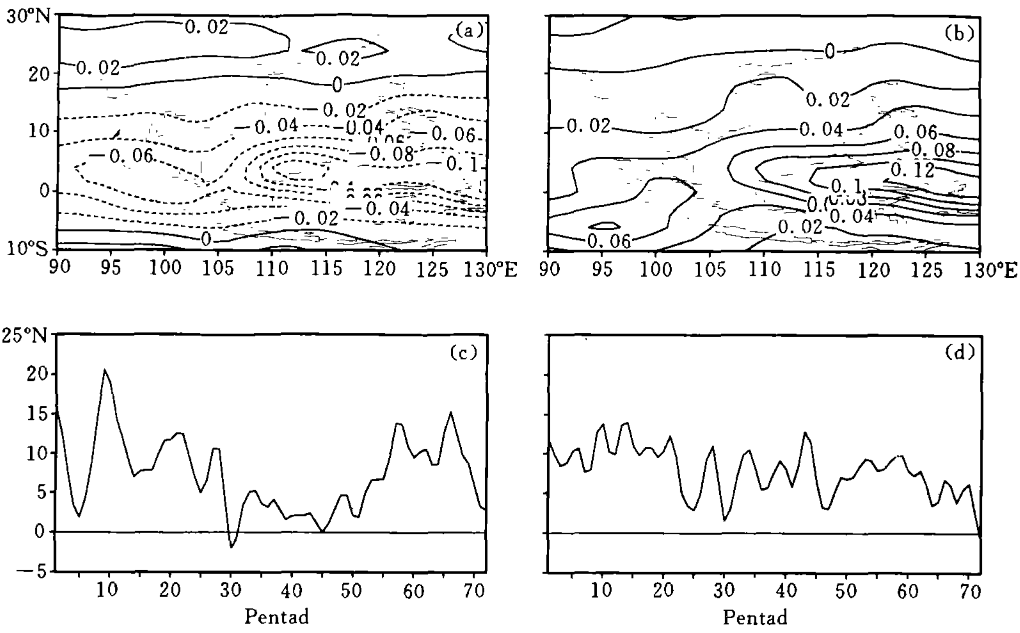

Fig. 4. The first spatial fields (a, b) and the corresponding temporal coefficients (c, d) in the strong and the weak years.

the strong year. It can be seen from Fig. 4b, the convection anomalies at the south of 20°N vary at the same phase, and the most significant regions of the convection anomalies are located at the Philippines and to south of it (5°S − 5°N, 120 − 130°E). Although the convection anomaly over the land north of 20°N is contrary to that over the sea, the anomalous value is small. The location of the convection anomalies is consistent with that of the strong year. The corresponding time coefficient (Fig. 4d) shows that the convection in each season of the weak year weakens greatly, but the significant weakening occurs in spring, summer and early autumn.

The second spatial pattern (figures omitted) reveals that the convection anomalies in the Indian Ocean south of 5°N are contrary to that at the middle and the southern part of the SCS as well as the Pacific east of the SCS. This anomaly mainly occurs in winter and spring. Moreover no matter in strong or weak convection years there is a period of 6 − 7 pentads between the strong and the weak convection. That is, during one period the convection is stronger than that of the normal year, whereas during another period it is weaker than that of the normal year. This kind of feature also exists in the time field of the first mode, especially in the strong convection year. The third spatial pattern reveals that the convection difference over the SCS and its neighborhood is in the pattern of south-north direction. Besides the BOB, Indochina Peninsula, the mid part of the SCS and the equatorial western Pacific revealed in the first spatial pattern, the Asia mainland north of 20°N is also a sensitive convection region, moreover its value is much larger than that of the other regions. This anomaly mainly occurs in spring, summer and autumn in the strong convection years, whereas in the weak convection years it mainly occurs at the end of spring, the beginning of summer as well as autumn, and also has clearly periodic variations.

Thus we can conclude from above analyses that the convection anomalies over the SCS and its neighborhood vary at the same sign as a whole no matter in the strong or the weak years, but the seasonal variation of convection in the strong and weak year is different. So the similarities and the differences of the convective activities over the SCS, the BOB and the southern and the northern parts of the SCS are discussed further below.

VI. SIMILARITIES AND DIFFERENCES OF CONVECTIVE ACTIVITIES IN THE SCS AND THE BOB IN STRONG AND WEAK CONVECTION YEARS

The latitude-time section of TBB along the BOB from 90°E to 108°E and the SCS from 110°E to 120°E in the strong and weak years are shown in Fig. 5.

It can be seen that in the strong convection year the convection east of the BOB, the Indochina Peninsula (Fig. 5a) and the middle and northern parts of the SCS (Fig. 5c) are weaker before the 25th pentad. The SCS is controlled by the subtropical high. The area of lower TBB value less than 270 K related to the equatorial convergence zone (ITCZ) maintains at the north of 7°N. The lower TBB value region at the north of 30°N is controlled by westerlies. At the 25th pentad, the ITCZ over the BOB suddenly stretches northward, and TBB quickly decreases to 265 K. At the 27th pentad (in the middle of May), the value of TBB has already decreased to 255 K, and the primary part of the ITCZ extends to 15°N. Deep convection (TBB<260 K) outbreaks and stretches quickly to 20°N. At the 35th pentad (by the end of June), the deep convection stretches northward again

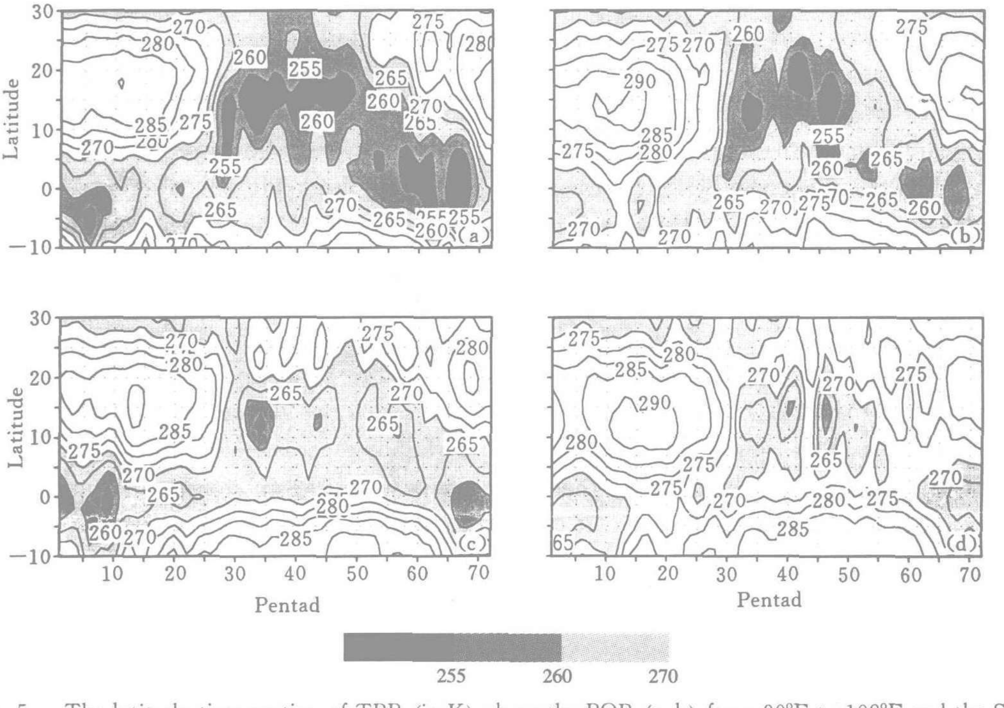

Fig. 5. The latitude-time section of TBB (in K) along the BOB (a, b) from 90°E to 108°E and the SCS (c, d) from 110°E to 120°E in the strong (a, c) and the weak (b, d) years.

and reaches the north of 30°N. The convection over the BOB has reached the strongest. At the 43rd pentad (in the early Aug.), the convection at the north of 30°N retreats southward and reaches to 25°N, the convection over the BOB begins to weaken gradually. At the 50th pentad (in the first ten days of Sep.), the lower TBB zone lower than 270 K also begins to move slowly southward, the south end has reached to the equator, but the convection keeps strong all the time. In Fig. 5c, the convection over the SCS is similar to that over the BOB before 25th pentad, but the time of the ITCZ stretching northward is about one pentad later than that of the BOB. According to Chen et al. (1999) the regions of lower TBB zone over the BOB and the SCS stretch northward synchronously when higher TBB zone related to the subtropical high withdraws out from the SCS, that is the normality. By the end of May (30th pentad), the deep convection (TBB $<$ 260 K) outbreaks, and the onset date lags that of the BOB. Therefore, before the SCS monsoon onset, the deep convection over the BOB has already broken and is stronger than that over the SCS. At the 35th pentad (by the end of June and the beginning of July) when the convection over the BOB reaches the strongest the convection over the SCS has already began to weaken gradually and is weaker than that before the monsoon onset. The strong center maintains in the 8—18°N.

In the weak convection year (Fig. 5b) the location of the ITCZ over the BOB departs a little further south than that in the strong year. The time of ITCZ stretching northward is also 2—3 pentads later than that in the strong year. The deep convection maintains from June to September and the onset time is later and the ending time is earlier than that in the strong year. After the 50th pentad, the deep convection (TBB $<$ 260 K) no longer maintains, however, it changes at a period of 2—4 pentads, the strong centers sustain between 5°N and 5°S. The convection over the SCS region (Fig. 5d) changes in the same way except that the convection is weaker than that over the BOB as well as than that in the strong year. During the summer monsoon, the convection variation over the SCS is more obvious than that over the BOB. By the end of July and the beginning of August there is an evident convection break, this is connected to the break of the SCS monsoon. It also can be seen from the figure that no matter in the strong or weak convection years, after the convection outbreak the low-frequency fluctuation is clear over both the SCS and the BOB.

The above analyses show that in the weak year the common features in these two regions are that the ITCZ departs more south than that in the strong year, the convection onset is later, and the sustaining time interval of the deep convection is shorter. A study (see Xie et al. 1998) showed that in these late-onset years the sustaining time of easterly wind is longer than that in the normal year. The West Pacific subtropical high anomaly sustains over the SCS. All these do not benefit for the ITCZ stretching northward. Consequently, the deep convection over the SCS is restrained.

VII. SIMILARITIES AND DIFFERENCES IN SOUTH AND NORTH PARTS OF THE SCS

The longitude-time section of TBB along the northern part (10 — 20°N) and the southern part (0 — 9°N) of the SCS are shown in Fig. 6. Figures 6a and 6b are the convective variation at the northern part of the SCS in the strong and weak convection

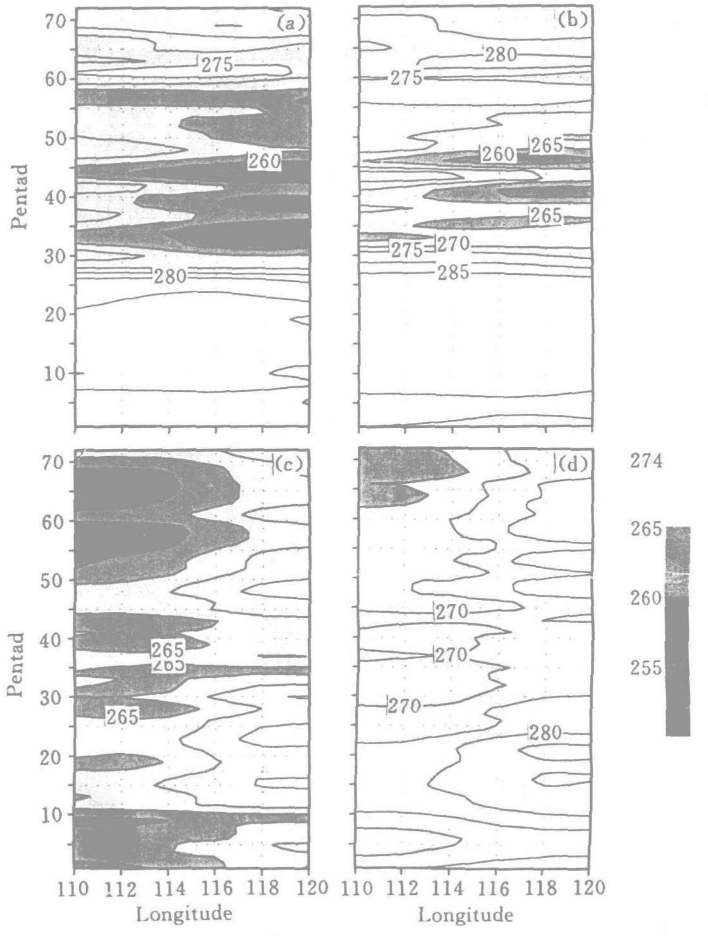

Fig. 6. The longitude-time section of TBB (in K) along the north (a, b) and the south part (c, d) of the SCS in the strong (a, c) and the weak (b, d) years.

years. Fig. 6c and Fig. 6d are the same as Fig. 6a and Fig. 6b but for the southern part of the SCS.

In the strong convection year the strong centers at the northern part (Fig. 6a) and the southern part (Fig. 6c) of the SCS deviate eastward (at 120°E) and westward (at 112°E), respectively. The strong convection in the southern part breaks firstly at the 27th pentad, then stretches eastward. In the northern part it breaks at the 33th pentad, moreover the strength is stronger (TBB$\leqslant$260 K) and the strong convection maintains between 30th and 45th pentads. After the 45th pentad the convection in the northern part begins to weaken, while it strengthens in the southern part simultaneously. The convection in the southern part is active in winter and is stronger than that in summer. This is related to the active cold front of winter in the strong convection year. Yan (1997) pointed out that the difference of monsoon onset date in the southern and the northern parts reflects the different impacts of air currents coming from different sources.

In the weak year, the convection in the northern part is similar to that in the strong convection year except that the sustaining time is shorter and the onset date is later a little. But in the southern part the difference of convection in the strong and weak years is large. In the weak year. the convection in the southern part of the SCS is very weak in spring. that is. in the transition seasons of winter and spring the convection is very weak and the onset date is also later than that in the strong year. This is in agreement with the result pointed out by Xie et al. (1998) who thought that in these late monsoon years the late wind transforming only occurs in the southern and the mid parts of the SCS and it is normal in the northern part. Therefore it is evident that whether the convection in the middle and the southern part is strong or not will affect the onset date of the SCS monsoon in the transition seasons of winter and spring. In addition. the convection does not extend eastward. This is owing to that the West Pacific subtropical high sustains anomalously over the SCS.

VIII. CONCLUSIONS

From above analyses and discussions the following conclusions may be drawn.

The middle and the southern parts of the SCS. the BOB and the Indochina Peninsula are the key regions of the convection. The convective activities in these regions change basically in the same phase. but there are still some differences of the seasonal variation. The convection over the BOB and the Indochina Peninsula is stronger than that over the SCS. In addition. the convection is on the contrary over land and sea. the thermodynamic status of the south of Tibetan Plateau and the Indochina Peninsula may have close relationship with the SCS monsoon.

In the normal years including both the strong and weak convection years the interannual difference in summer and autumn is larger than that in winter and spring. The BOB is the most significant area of the interannual variation. Next is the Indochina Peninsula. The last is the SCS.

No matter in the strong or weak convection years the seasonal anomalies of the convection over the SCS and the BOB vary at the same sign as a whole. but the seasonal variation is on the contrary. In the strong convection year. the convection at the transition season of winter and spring is much stronger than that in the normal year and also the anomaly is much clear. After the summer monsoon onset the strong convection is similar to that in normal years and sustains stably. however it is on the contrary in the weak convection year. The convection anomalies over the SCS monsoon region vary differently during different periods. In addition. there are several sensitive areas of the convection over the SCS and its neighborhood. including the BOB. the Indochina Peninsula. the middle and south parts of the SCS. the equatorial western Pacific and the Asia mainland north of 20°N.

No matter in the strong or weak convection years. the convection over the BOB is stronger than that over the SCS and bursts earlier. After the summer monsoon onset the convection over the BOB sustains stably. whereas over the SCS the convection varies differently during different periods. but the low-frequency fluctuation is clear in both areas. In the weak convection year. the convection bursts later and ends earlier and the sustaining time is shorter.

In the strong convection year the strong convection centers in northern and southern parts of the SCS deviate eastward and westward, respectively. The variation of convection in both strong and weak years is similar, but there is large difference in the southern part of the SCS. In the strong convection year the winter convection in the southern part of the SCS is active and is stronger than that in summer, but in the weak convection year, the spring convection of the southern part is very weak. Whether the convection in the middle and the southern parts of the SCS is strong or not will affect the onset date of the SCS monsoon in the transition seasons of winter and spring.

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