A Study on the Mesoscale Convective Systems during the Summer Monsoon Onset over the South China Sea in 1998 Part II: Effect of Mesoscale Convective Systems on Large-Scale Fields*

LIU Yanju[1,2,3] (柳艳菊) and DING Yihui[2] (丁一汇)

[1] *Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing* 100029

[2] *National Climate Center, Beijing* 100081

[3] *Graduate School of the Chinese Academy of Sciences, Beijing* 100039

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ABSTRACT

The apparent heat sources and apparent moisture sinks, and large-scale wind, temperature as well as the surface pressure fields during the summer monsoon onset over the northern South China Sea (SCS) in 1998 were diagnosed. The results suggested that there was a kind of positive feedback mechanism between large-scale circulations and mesoscale convective systems (MCSs). Before the monsoon onset, the large-scale background provided favorable synoptic and dynamic conditions for the summer monsoon onset and the formation of mesoscale convective activities, whereas after the summer monsoon onset, occurrence of the persistent and extensive mesoscale convective activities produced obvious feedback effect on large-scale circulations. Because of the release of latent heating produced by enhanced convective activities, the intense atmospheric heating appeared over the northern SCS, which resulted in: (1) the meridional temperature gradient over the SCS reversed from upper-level to low-level and then the large-scale circulations were changed seasonally; (2) correspondingly, the surface pressure over the northern SCS deepened continually and formed a broad monsoon trough and the obvious pressure-fall areas, thus making the subtropical high move out of the SCS eventually; (3) with the development of the low pressure circulations in the middle and low troposphere, the MCSs further enhanced and extended southward, which was conducive to the SCS monsoon onset and maintenance over the middle and southern SCS; and (4) the deepening of monsoon trough facilitated the monsoon flow and moisture transport on its southern side, thus the monsoon onset reaching peak period.

Key words: mesoscale convection, apparent heat sources, apparent moisture sinks, feedback.

1. Introduction

The strong convective weather is developed under the favorable large-scale circulations, which demonstrated the large-scale weather system's controlling effect on strong convections. Once the convection is formed, it will produce the feedback effect on the large-scale environmental conditions by transporting momentum, heat and moisture upward, and influence or change the environmental wind, humidity, temperature, atmospheric stratification fields and so on, thus forming the new large-scale meteorological fields (Ding, 1991). Monsoon onset and prevalence are always accompanied by the strong convective weather, which will bring about the occurrence of heavy rains. Hoskins (1995, 1996) suggested that during the monsoon maintaining period, the long span atmospheric heat sources released by the latent heat will influence the anomaly of atmospheric circulation. The Asian monsoon broke out earlier in the South China Sea (SCS) and the India-China Peninsula (ICP), the latent heat release and distribution of the atmospheric heat sources resulting from the SCS monsoon played an important role in the variation of atmosphere circulation (Luo and Yanai, 1984; Yanai and Tomita, 1998). The results by Luo and Yanai (1984) and Yanai and Tomita (1998) revealed during the monsoon onset period, the convection over South China and the northern SCS

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made a contribution to enhancement of the total precipitation amount and diabatic heating in the Asian monsoon region. Xie (1986) and Chen and Luo (1989) also illuminated that release of the latent heat driven by moisture played an important role in maintaining the SCS monsoon. It was because the kinetic energy of wind field in the monsoon region during the monsoon onset period would increase sharply, while the kinetic energy was transformed from the available potential energy. According to the energy equation, it demanded diabatic heating (mainly from release of the latent heat) to produce available potential energy. Johnson and Ciesielsk (2002) investigated the characteristics of the SCS monsoon onset over the northern SCS and the diabatic heating derived from the convection in 1998. They demonstrated that the SCS monsoon onset over the northern SCS in the mid-May was accompanied by 1 week to 10-day long strong convection and consequently a great amount of heat and moisture were transported upward, forming the heating center over the northern SCS. However, they did not discuss the relationship between the MCSs and heating field and moisture field as well as their possible effect. In the first part of the paper, we investigate the large-scale circulation conditions that the strong convection occurred during the monsoon onset over the northern SCS in 1998 and the forming mechanism of MCSs (Liu et al., 2005). On the basis of the previous work, the second part will mostly investigate the effect of MCSs on large-scale environmental fields and stress the atmospheric heating function played by the release of latent heat in the SCS monsoon region.

2. Data and method

The principal datasets used in this study are the assimilation data four times a day and TBB data eight times a day made by Japan Meteorological Agency (JMA) during the GAME/HUBEX in 1998 (resolution is $2.5° \times 2.5°$), which assimilated most of the field observation data of SCSMEX. The daily OLR data from NOAA and daily precipitation data from Global Precipitation Climatology Project (GPCP) in 1998 are also employed. The apparent heat sources Q_1 and the apparent moisture sinks Q_2 (e.g., Yanai et al., 1973) are computed from

$$\left\{\begin{array}{l} Q_1 = c_p(\frac{\partial T}{\partial t} + \overrightarrow{\boldsymbol{v}} \bullet \bigtriangledown T + (\frac{p}{p_0})^k \omega \frac{\partial \theta}{\partial p}) \\ \quad = Q_R + L(\overline{c} - \overline{e}) - \frac{\partial}{\partial p}(\overline{S'\omega'}) \\ Q_2 = -L(\frac{\partial q}{\partial t} + \overrightarrow{\boldsymbol{v}} \bullet \bigtriangledown q + \omega \frac{\partial q}{\partial p}) \\ \quad = L(\overline{c} - \overline{e}) + L\frac{\partial}{\partial p}(\overline{q'\omega'}). \end{array}\right. \tag{1}$$

Vertically integrating Eq(1), we have

$$\left\{\begin{array}{l} < Q_1 >= \frac{1}{g}\int_{p_t}^{p_s} Q_1 \mathrm{d}p = LP + Q_\mathrm{s} + < Q_\mathrm{R} > \\ < Q_2 >= \frac{1}{g}\int_{p_t}^{p_s} Q_2 \mathrm{d}p = L(P - E_\mathrm{s}) \end{array}\right. \tag{2}$$

where T is the temperature, θ is the potential temperature, q is the mixing ratio, v is the horizontal velocity vector, ω is the vertical velocity in p coordinates, κ= R/C$_p$, with R and C$_p$ being the gas constant and the specific heat at constant pressure of dry air, respectively, L is the latent heat of condensation, $P_0 = 1000$ hPa, Q_R is the radiative heating (or cooling) rate and $< Q_R >$ is the vertical integration of Q_R. During the period under study, $< Q_R >$ is a small amount and could be omitted. $S = C_pT + gz$ is the dry static energy, c is the rate of condensation per unit mass of air, e is the rate of re-evaporation of cloud and rainwater. Overbar "-" denotes the horizontal moving average, superscript "′" denotes the deviation from the average caused by unresolved eddies, such as cumulus convection and turbulence. Q_s is the surface sensible heat transport, P and E_s is the precipitation rate and evaporation rate per unit area, respectively.

3. Variation of precipitation

Monsoon onset and prevalence are always accompanied by the strong convective weather, which will produce local intensive precipitation. Here periods May 11-15, May 16-20, and May 21-25 denote pre-onset phase, the first monsoon onset phase and the second monsoon onset phase, respectively. Figure 1 delineates the difference distributions of precipitation and OLR before and after the South China Sea (SCS) monsoon onset. From Figs.1a and 1b, it can be seen that in the first phase of monsoon onset, the convection and precipitation increasing areas appeared in the northern part of the Bay of Bengal (BOB), the northern SCS and waters to the south of Japan, while in the second phase (Figs.1c and 1d), the convection and precipitation increasing areas changed and were mainly

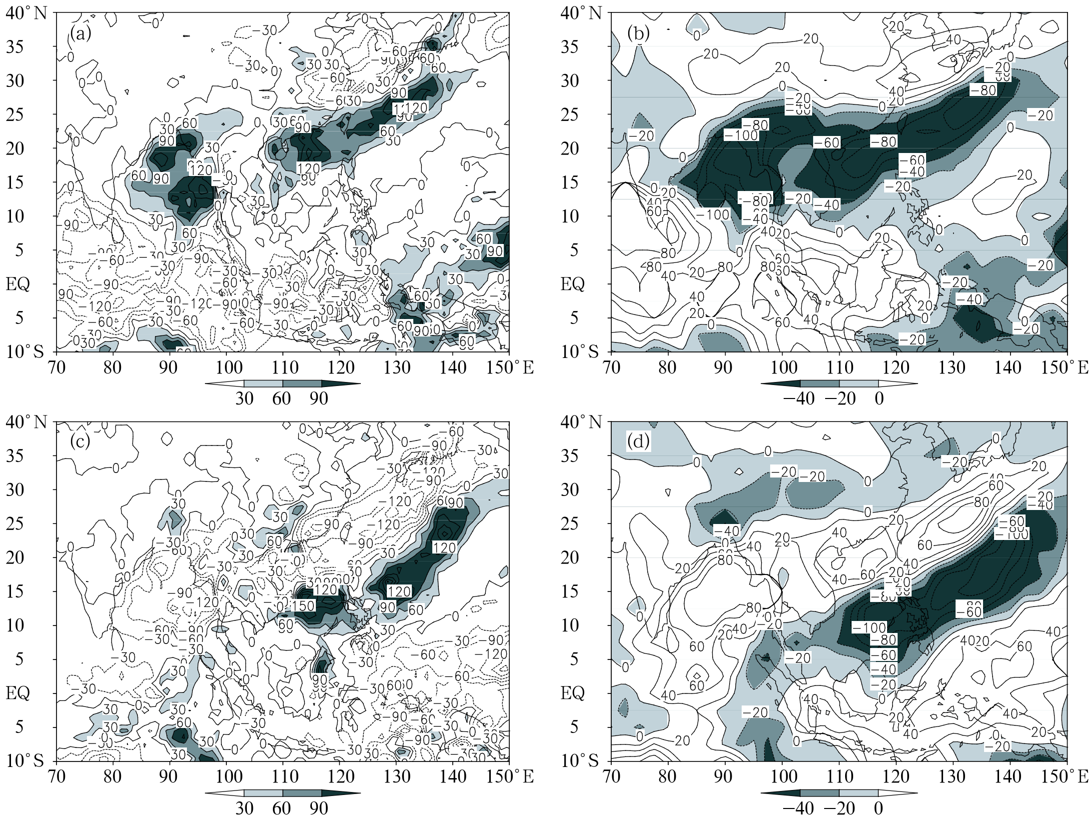

Fig.1. Difference distribution of precipitation ((a) and (c), unit: mm) and OLR ((b) and (d), unit: W m^{-2}) before and after the South China Sea (SCS) monsoon onset. (a) and (b), difference between May16-20 and May11-15; (c) and (d), difference between May 21-25 and May 16-20; For (a) and (c), the values exceeding 30 mm are shaded, the contour interval is 30 units; For (b) and (d), the values less than zero are shaded, the contour interval is 20 units.

concentrated over the middle and southern SCS as well as to the east of the Philippines. The convection and precipitation over the BOB saliently weakened and decreased. The variation of precipitation and convection further demonstrated the two-phase SCS monsoon onset. Then, what effect on earth the monsoon onset and occurrence of convection in the first phase would produce on the monsoon onset in the second phase as well as the whole large-scale circulation condition? The following will discuss this problem from many aspects.

4. Analysis of apparent heat sources (Q_1) and moisture sinks (Q_2)

The cumulus convections are developed under the large-scale and mesoscale environmental conditions. Once the cumulus convections occur, they will have a feedback effect on the large-scale environmental conditions by transporting variety of physical elements upward. However, the direct computation of these elements may be difficult. Hereby, we adopt a budget method to compute the distribution of vertically integrated Q_1 and Q_2 on the left side of Eq.(2) so as to determine the property of heat sources. Comparing the vertical profiles of Q_1-Q_R and Q_2 in Eq.(1) can make sure that the latent heating is caused by precipitation of stratiform clouds or convective clouds, then further understand the effect of cumulus convections on large-scale circulations (Li and Yanai, 1996).

Figure 2 shows the difference distribution of vertically integrated Q_1 and Q_2 before and after the SCS monsoon onset. It can be seen that variations of Q_1 and Q_2 in the two phases of SCS monsoon onset were prominent. In the first phase, South China, the northern SCS and the waters to the south of Japan correspondingly became distinct enhancing areas of heat sources and moisture sinks, while the middle and southern SCS was mainly the heat decreasing and moisture weakening areas (Figs.2a and 2b). In the second phase, the position of increasing heat sources and moisture sinks areas greatly moved southward(Figs. 2c and 2d. Also, comparing the distributions of Q_1 and Q_2, one can see that they were very close to that of precipitation in either position or intensity. The enhancing areas of heat sources corresponded to the active convection and precipitation increasing areas. It revealed that with the prevalence of southwesterlies over the SCS, the convection enhanced and the latent heating of condensation became the major atmospheric heat sources, which was related with the development of active convections and MCSs. Besides, we analyzed the difference distribution of Q_1 and Q_2 in the upper troposphere (between 300 and 500 hPa) before and after the SCS monsoon onset (figure not shown). It suggested that its distribution was nearly equal to that of the whole layer, only the values a bit smaller, which also illustrated that the latent heating driven by the moisture was mostly distributed in the upper troposphere. It was obviously the outcome of convection heating.

From the daily variation of vertically integrated Q_1 and Q_2 over the northern and southern SCS as shown in Fig.3, it could be seen before the monsoon onset, the values of Q_1 and Q_2 were negative, which indicated that the atmosphere was heat sinks. For the northern SCS, the atmospheric heating rapidly established on May 15 and the values of heating continually increased with the time. About May 18, the maxima of Q_1 and Q_2 appeared and they kept almost the same variation trend. For the southern SCS, the time of Q_1 and Q_2 turning into positive values was about on May 21. After that, Q_1 and Q_2 rapidly increased and reached maximum on May 23 (100 W m^{-2} greater than that over the northern SCS). From

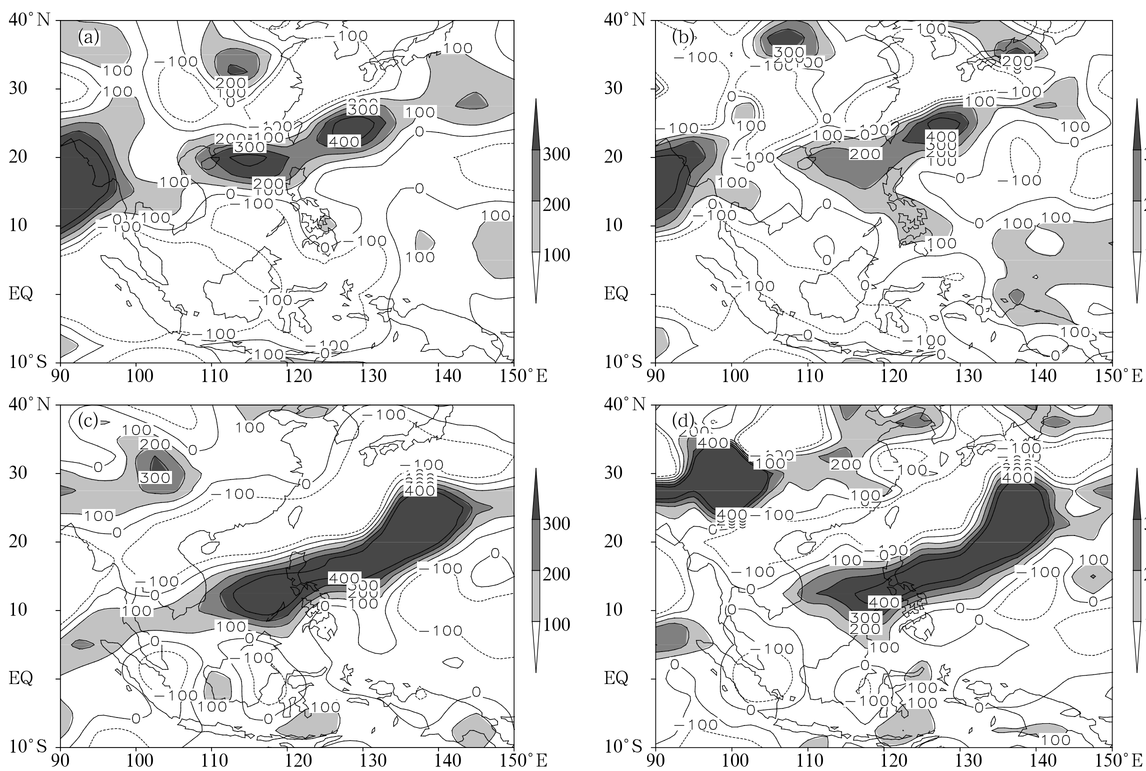

Fig.2. Difference distribution of vertically integrated Q_1 ((a) and (c) unit: W m^{-2}) and Q_2 ((b) and (d); unit:W m^{-2}) before and after the SCS monsoon onset. (a) and (b) difference between May 16-20 and May 11-15; (c) and (d) difference between May 21-25 and May 16-20; the values exceeding 100 W m^{-2} are shaded, the contour interval is 100 units.

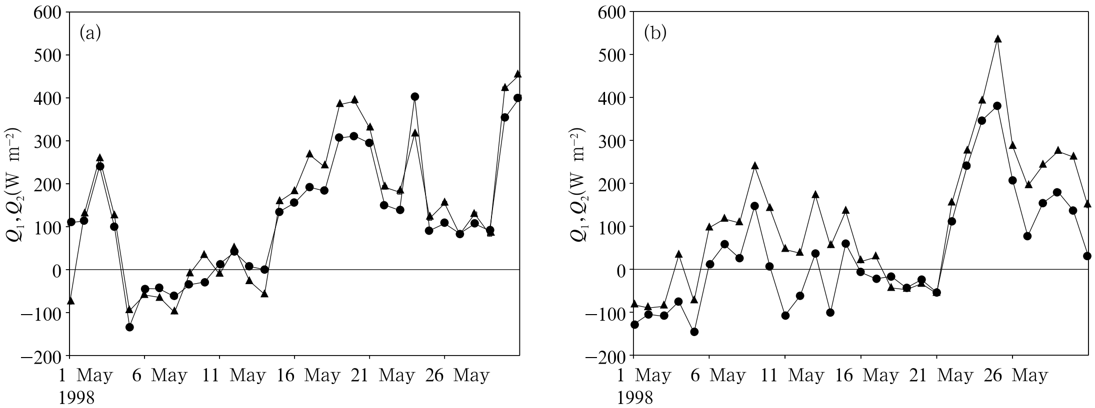

Fig.3. Daily variations of vertically integrated Q_1 (symbol ▲) and Q_2 (symbol •) (unit: W m^{-2}) over (a) northern SCS (15°-22.5°N, 110°-120°E), and (b) southern SCS (5°-15°N, 110°-120°E).

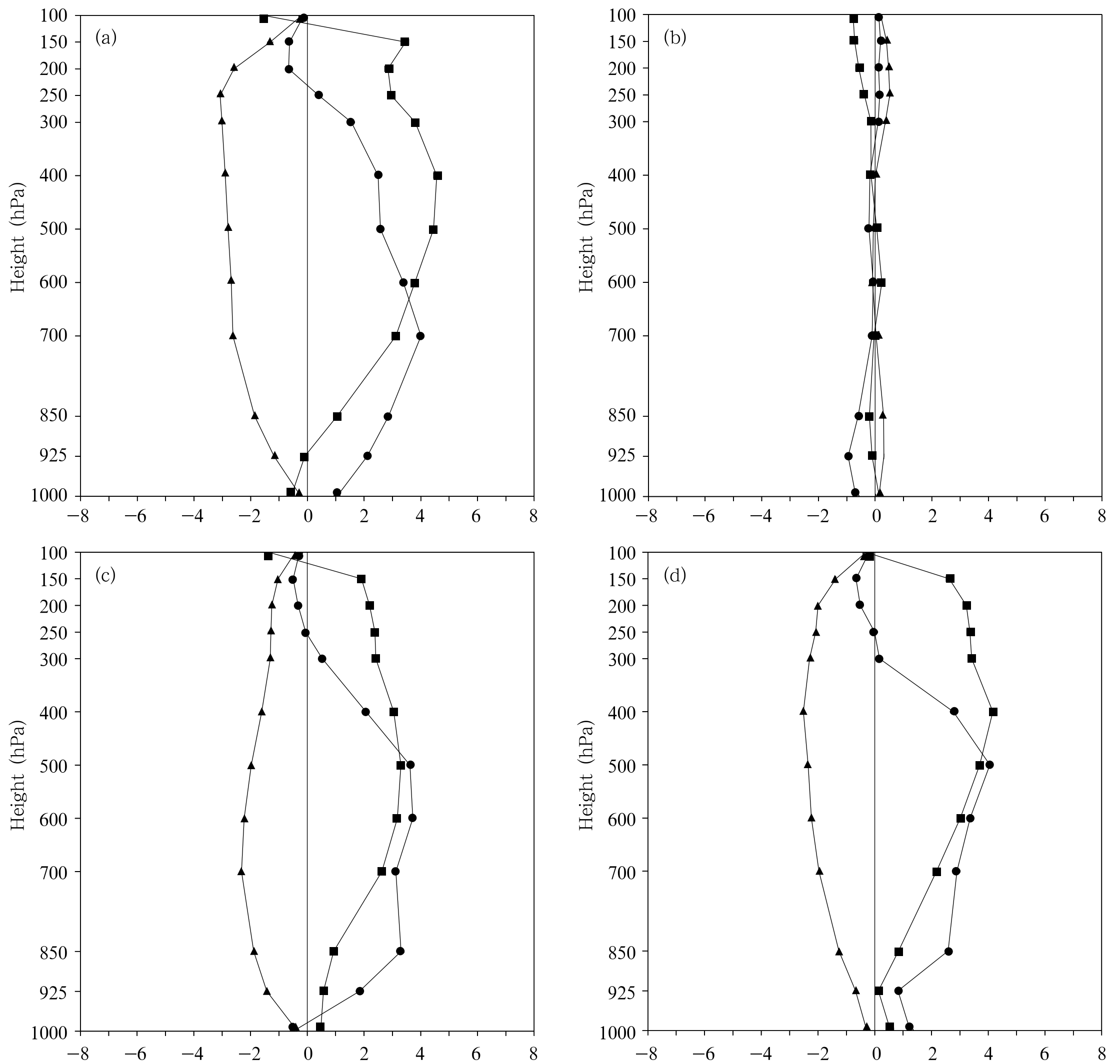

Fig.4. Vertical profiles of ω (trigons, unit: hPa h^{-1}), Q_1 (solid squares, unit: K d^{-1}), and Q_2 (circles, unit: K d^{-1}) during the first (a, b) and second phase (c, d) of the SCS monsoon onset over northern SCS (a and c) and southern SCS (b and d).

this view-point, latent heating over the northern SCS started to appear one pentad earlier than that over the southern SCS.

The following will investigate the vertical distribution of Q_1 and Q_2 so as to further judge the latent heat was condensed from the stratiform clouds or convective clouds and substantiates the importance of cumulus transporting heat and moisture. If the peaks of their profiles are approximately at the same height, then the heating is mainly caused by the frontal (or continuous) precipitation. Otherwise, the latent heat is greatly related with the convections and the peaks of their profiles are at different height. Figure 4 depicts the profiles of vertical velocity (ω), Q_1 and Q_2 during the monsoon onset (in two phases). It could be seen form Fig.4a that the Q_1, Q_2 and ω over the northern SCS in the first phase of monsoon onset enhanced more obviously than that before the monsoon onset (figure omitted). The ω in the whole layer was negative and kept ascending motion with peaks at 200-250 hPa. Also, the profiles of Q_1 and Q_2 were separated obviously at the certain height and the maximum heating appeared at 400-500 hPa, the maximum moistening below 700 hPa. For the southern SCS, there was no any weather phenomenon observed in the first phase of monsoon onset (Fig.4b). The values of Q_1 , Q_2 and ω were very small and tended to be zero, which means that the southern SCS monsoon did not break out at this time. In the second phase of monsoon onset, the convections over the northern SCS were somewhat weaker than before (Fig.4b). In contrast for the southern SCS, the vertical motion enhanced markedly and Q_1 kept positive in the whole layer. The profiles of Q_1 and Q_2 were separated at the height. When the profiles of Q_1 and Q_2 were separated at heights, Q_2 was greater than Q_1 in the lower troposphere, while in the upper level, the situation was the contrary, with a peak of 4-5 K d^{-1} at 400 hPa. The vertical distribution of Q_1 and Q_2 clearly indicated that the latent heating was closely associated with the cumulus convections during the monsoon onset period. During the two phases of SCS monsoon onset, the precipitation was mainly convective and the convections transported large amount of heat and moisture upward, which further demonstrated feedback effect of cumulus convection on large-scale circulations.

By the above analysis, it could be deduced that there was a kind of positive feedback mechanism between large-scale circulations and MCSs: namely, during the monsoon onset in the first phase, the deep and strong convections appeared in the northern SCS. Under the condition of active convections, the vertical sub-grid eddy transport was very strong, which was conducive to the release of latent heating in the middle and lower troposphere and was transported upward. Thus, the upper troposphere was intensively heated and then changed the large-scale circulations and made the surface pressure decrease. With the monsoon trough establishing in the middle SCS and the cold air invading southward, the SCS monsoon broke out on a large-scale and the convections as well as precipitation took place. Further, a new positive feedback mechanism began to establish over the southern SCS. The possible effect of MCSs on large-scale circulations will be investigated below based on observation data.

5. Feedback effect of MCSs on large-scale fields

In this section, the large-scale wind, humidity, temperature and stratification fields before and after the monsoon onset will be analyzed one by one in order to further illustrate the existence of positive feedback mechanism between the large-scale circulations and MCSs during the SCS monsoon onset period. Note that though we cannot quantitatively separate the MCSs' effect on large-scale field from the variation of large-scale fields, we can deduce the existence of this kind of feedback effect from the bulk variation of large-scale fields.

5.1 *Feedback effect of MCSs on large-scale wind field*

Based on the difference distribution of Webster-Yang (W-Y for short) monsoon index (U850-U200) (Webster and Yang, 1992), it could be seen that after the monsoon onset in the first phase, the SCS was the negative easterly shear area and the major westerly

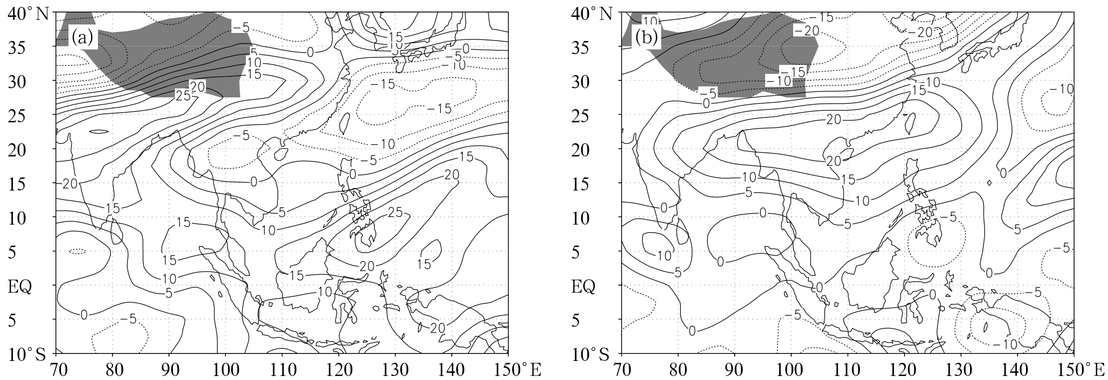

Fig.5. Difference distribution of W-Y monsoon index (U_{850}-U_{200}) before and after the SCS monsoon onset (unit: m s^{-1}). (a) Difference between May 16-20 and May 11-15, and (b) difference between May 21-25 and May 16-20.

shear region was over the eastern BOB and the region to the east of Philippines (Fig.5a). After the monsoon onset in the second phase (Fig.5b), the positive westerly shear areas swiftly covered the northern BOB, most areas of the SCS and the waters east of the SCS it, with its center's intensity exceeding 20 m s^{-1}. It suggested that during the second phase of monsoon onset, the convections greatly enhanced and MCSs frequently formed and developed, thus inducing the southwesterly to remarkably reinforce. Further investigating the difference distribution of divergence at 850 and 200 hPa (not shown) showed that the intensification (weakening) of high-level divergence responded to the low-level convergencen, divergence. During the first phase of monsoon onset, the intensification areas of convergence in the low level were mainly concentrated in the BOB and northern SCS, correspondingly these areas at 200 hPa were enhancing areas of divergence. During the second phase of monsoon onset, the low level over the BOB became the strengthening divergence areas, while convergence intensification areas moved to the middle and southern SCS as well as the region to the east of Philippines, which was observed concurrently with the SCS monsoon whole onset. The configuration at upper levels was reverse with that at low levels. This kind of dynamical configuration between upper and lower levels is favorable for the strong ascending motion to transport heat and moisture upward. The distribution of vertical motion was also in correspondence with it (not shown).

5.2 *Feedback effect of MCSs on thermodynamic field*

A major characteristic of the seasonal transition in the Asian monsoon region is the reversal of meridional temperature gradient in the troposphere, namely the temperature gradient changes from the south-to-north orientation in wintertime to the north-to-south orientation in summertime. Many results suggested that the basic cause for the SCS monsoon onset is the reversal of the meridional temperature gradient over the SCS (Li and Yanai, 1996; He and Luo, 1996). Figure 6 presents the height-time cross-section of meridional temperature variation ($\partial T/\partial y$) over the SCS. Here the positive value means

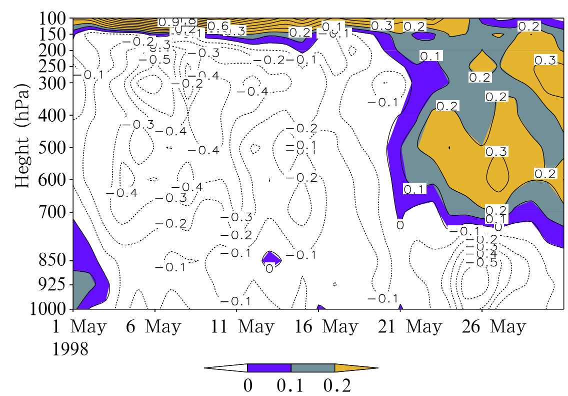

Fig.6. The height-time cross section of meridional temperature variation ($\partial T/\partial y$) over the SCS (5°-22.5°N, 110°-120°E) during the SCS monsoon onset (unit: °C/2.5° latitude).

that the temperature distribution is high in the north and low in the south, and the negative value means that the temperature is high in the south and low in the north. On May 21, the distribution of temperature gradient changed suddenly. The area of positive ($\partial T/\partial y$) expanded and extended downward to 700 hPa from the upper troposphere (200 hPa), which indicated that the temperature over the SCS on a large scale changed markedly. It was concurrent with the SCS monsoon onset on a large-scale. In terms of the above analysis, the reverse temperature gradient lagged one pentad behind the monsoon onset in the first phase. It means that the latent heat firstly heated the atmosphere and transported heat and moisture upward. Consequently, the distribution of atmospheric heat sources and temperature gradient changed, thus influencing the large-scale circulations. With the reverse of the meridional temperature gradient, the large-scale circulation changed seasonally and resulted in the whole monsoon onset over the SCS as well as the monsoon region migrating eastward and westward. As such, the monsoon onset in the first phase in 1998 did not only bear regional and local meaning, but in fact it was also the symbol that Asian monsoon started to break out on a large-scale.

Comparing the difference distribution of the thickness between 300 and 500 hPa before and after the SCS monsoon onset (Fig.7a), it could be found that the thickness over the northern part of the Indian Peninsula and the waters to the east of Philippines remarkably enhanced in the first phase of monsoon onset, which was greater than that before the monsoon onset (not shown). It also indicated that the temperature over these regions changed the earliest. The difference of thickness over the SCS was also positive but not evident. Compared with the first phase, the thickness changed greatly during the second phase of SCS monsoon onset. The amplitude of thickness variation was more dramatic (Fig.7b), which demonstrated that temperature increasing in the upper troposphere was prominent over the SCS and South China, and the convections continually transported heat upward. In contrast, the northern SCS and the BOB were the reducing temperature areas at low levels (925 hPa) during the first phase of monsoon onset (not shown), which mainly resulted from that the latent heat from precipitation condensation was upward transported and the temperature near the surface level obviously fell after the southwesterly set in over the northern SCS. During the second phase of monsoon onset, extensive area of reducing temperature still controlled South China, the northern and middle SCS and the region to the south of Korean Peninsula. Above results indicated that with the monsoon onset over the whole SCS, the upper troposphere rapidly became warm and the low level boundary swiftly got cold. This phenomenon justly resulted from upward heat transport by the convections (Luo and Yanai, 1984; Yanai and Tomita, 1998).

5.3 *Feedback effect of MCSs on moisture field*

From the difference distribution of the moisture flux divergence before and after the SCS monsoon onset (Fig.8), one may clearly see that the increasing convergence areas corresponded to the precipitation enhancement. In the first phase of monsoon onset, the increasing convergence areas were mainly concentrated over the northern SCS and the BOB (Fig.8a). In the second phase of monsoon onset, the convergence areas were mostly located over the middle and southern SCS and the region to the east of it, while the weakening moisture areas were over the northern SCS and BOB (Fig.8b). The curves of specific humidity at 300 and 925 hPa (figure not shown) demonstrated that in the first phase of monsoon onset, the specific humidity at the low level (925 hPa) weakened whereas that at the upper level (300 hPa) increased, which suggested that after the monsoon onset in the first phase, the moisture in the low level was transported to the upper level, thus producing the high-level wet and low-level dry distributions. After the monsoon onset in the second phase, the low level over the middle and southern SCS with obvious convections and precipitation was

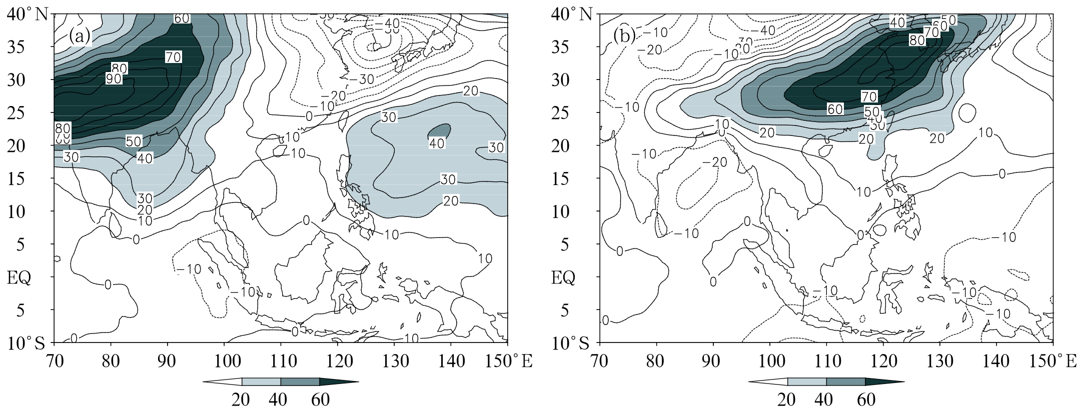

Fig.7. Difference distribution (unit: gpm) of the thickness between 300 and 500 hPa before and after the SCS monsoon onset. (a) Difference between May16-20 and May11-15, and (b) difference between May21-25 and May16-20.

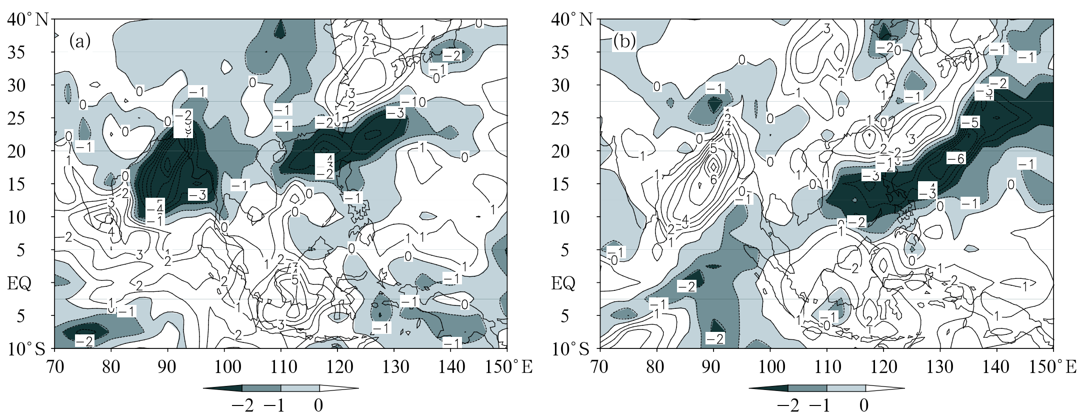

Fig.8. Difference distribution of the moisture flux divergence before and after the SCS monsoon onset (unit: 10^{-5} kg m^{-2}s^{-1}). (a) Difference between May 16-20 and May 11-15; and (b) difference between May 21-25 and May 16-20.

still dry. Combining the previous results (convection transporting heat), the strong convections transporting heat and moisture will result in the temperature and humidity increasing in the upper level after the monsoon onset, while the low level (boundary layer) became dry and cold.

5.4 *Influence of MCSs on atmospheric stratification*

Figure 9 is the difference distribution of 300 and 925 hPa pseudo-equivalent temperatures before and after the monsoon onset. From Fig.9a, it could be seen that in the first monsoon onset phase, the areas with temperature and humidity increasing was mainly located over the middle and northern SCS and the distribution was basically concurrent with that of thickness between 300 and 500 hPa. It illuminated that after the monsoon onset in the first phase, the upper troposphere became highly warm and wet because of heat and moisture continually being transported there. In the second phase of monsoon onset (Fig.9c), the temperature and humidity increasing in the upper troposphere was considerably evident over the middle and southern SCS, which was related with a great deal of warm and wet air upward transported in this area after the monsoon onset. Although the negative values were not observed in this area on the difference distribution of 925 hPa pseudo-equivalent temperature

(Fig.9d), the temperature and humidity increasing was not very strong. A possible explanation could be that the heat and moisture were continually transported to the surface level because of higher sea surface temperature, which could weaken the intensity of dryness and coldness on the surface.

5.5 *Influence of MCSs on surface pressure (SP)*

The above results indicated that the atmospheric heating resulting from the mesoscale convective activities in the first monsoon onset phase could induce the convergence reinforcement by CISK mechanism and consequently the SP to deepen. Figure 10 clearly demonstrates this process. On the difference distribution between the first monsoon onset phase and prior period (Fig.10a), it could be seen that after the monsoon onset in the first phase, the major areas of the SCS still maintained positive pressure variations and the decrease of SP was not obvious. But in the second phase of monsoon onset, the SP changed greatly and the SCS was in the prominent negative pressure change areas. The SP continually deepened (Fig.10b). Figure 11 is the composite map of daily surface stream field and TBB. It can be seen that at 00Z 21 May, an obvious mesoscale cyclonic circulation formed corresponding to the low pressure center near the middle SCS, Taiwan and Bashi Strait. Afterwards, the low pressure circulation continually deepened and moved toward northeast, during which the strong convections maintained over the middle SCS all the time (Fig.11b). During May 24-25, the convections over the middle SCS evidently enhanced and the cloud systems began to appear over the southern SCS. In the meantime, the low pressure developed (Fig.11c), which was in good accordance with the situation of SCS monsoon whole onset. In terms of the above analysis, with the convections enhancing, the ascending motion strengthened and precipitation occurred. The latent heat release in the middle-upper troposphere was helpful to the

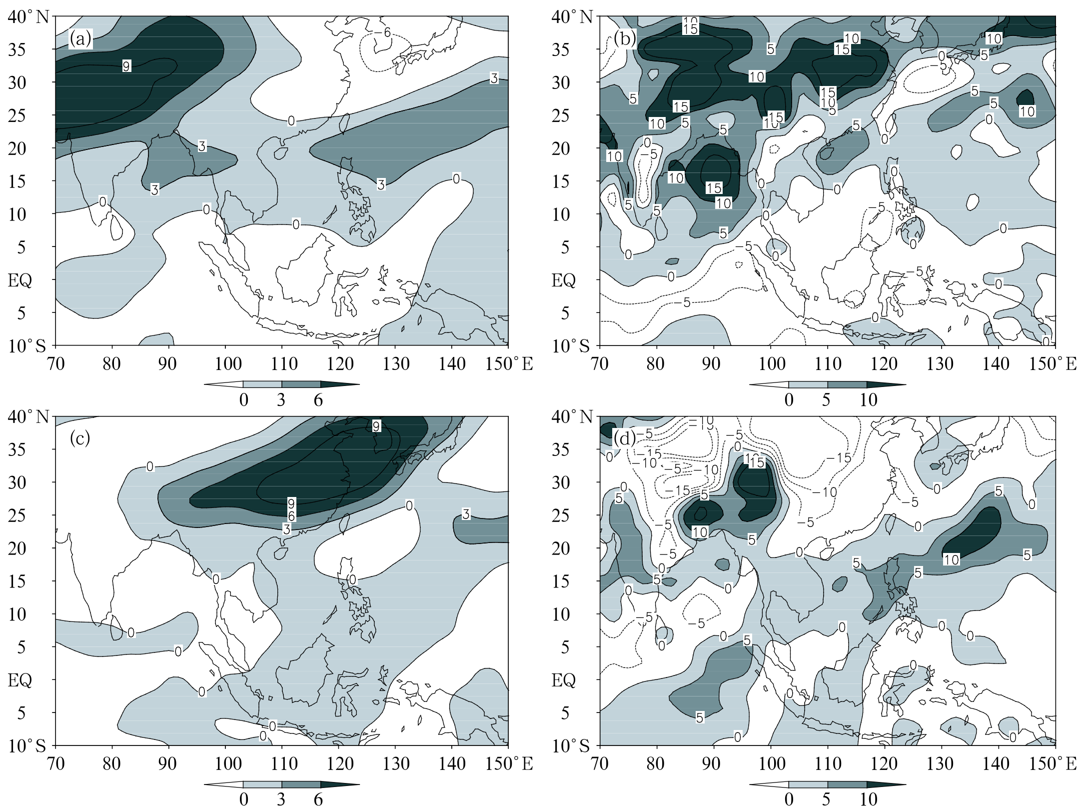

Fig.9. Difference distribution of the pseudo-equivalent temperature at 300 hPa (a, c) and 925 hPa (b, d) before and after the SCS monsoon onset (unit: $10^{-6}s^{-1}$). (a, b) Difference between May 16-20 and May 11-15; and (c, d) difference between May 21-25 and May 16-20.

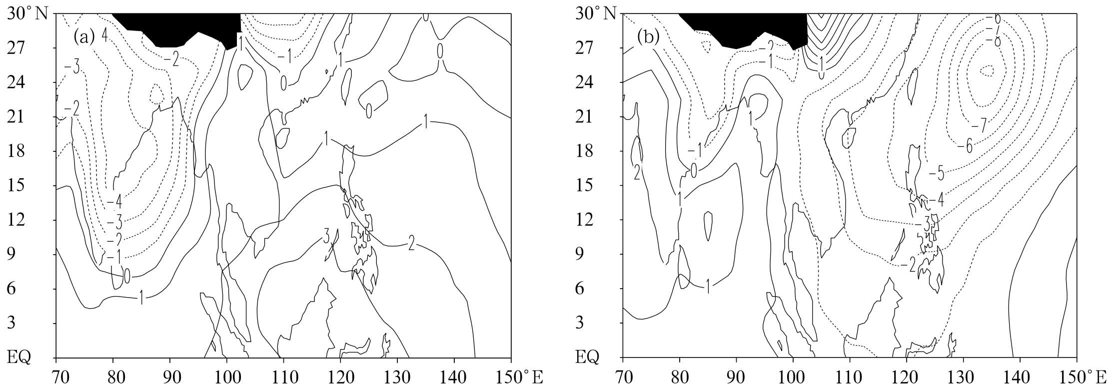

Fig.10. Difference distribution of the surface pressure before and after the SCS monsoon onset (unit: hPa). (a) Difference between May 16-20 and May 11-15, and (b) difference between May 21-25 and May 16-20.

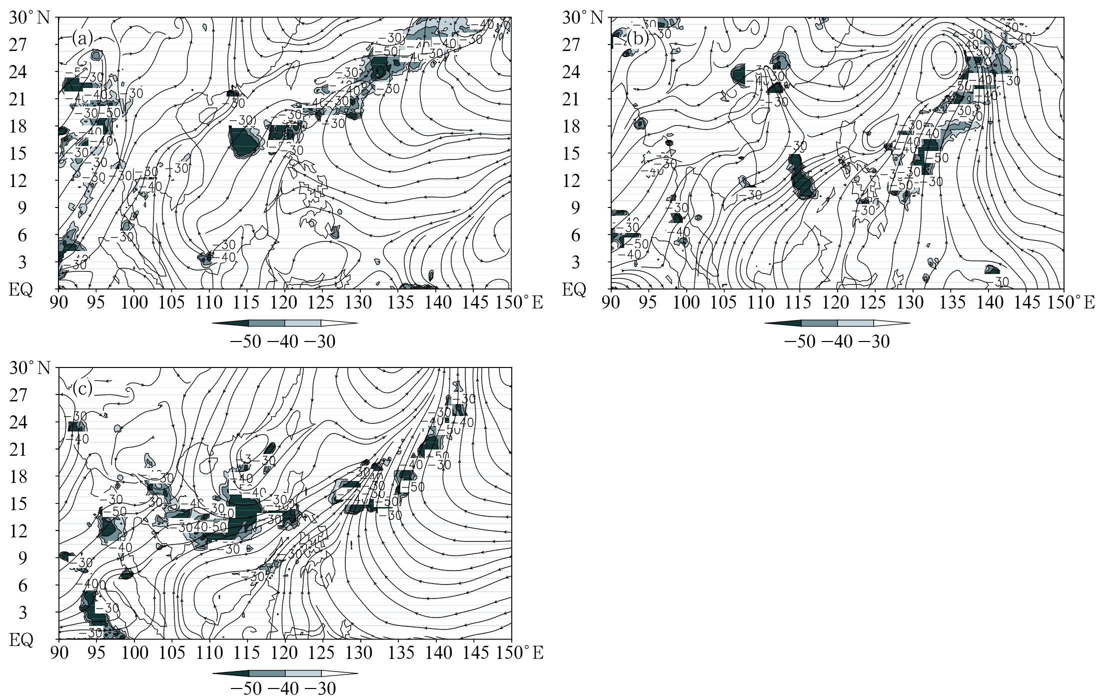

Fig.11. Daily surface stream field and TBB (shaded area, unit: °C) at (a) 00Z 21 May, (b) 00Z 23 May, and (c) 00Z 25 May 1998.

enhancement of divergence in the upper level and reinforcement of moisture convergence and convection. Thereby, a kind of feedback mechanism was formed. Then, the surface pressure continually deepened and a wide low trough area came into being. The mesoscale cyclonic circulation and low pressure center near Taiwan and Bashi Strait may be the outcome of this kind of positive feedback. With regard to this, more researches should be needed to further document with numerical model (Lin and Kueh, 2003).

Based on the above analysis, it could be suggested that there was a kind of positive feedback mechanism between large-scale circulation and MCSs. During the monsoon onset in the first phase, the deep and strong convection appeared over the northern SCS. Under the condition of active convections, the vertical eddy transport was very strong, which was favorable to the latent heating released in the mid-low troposphere to be transported upward. Thus, the upper troposphere was intensively heated and made the warm-center

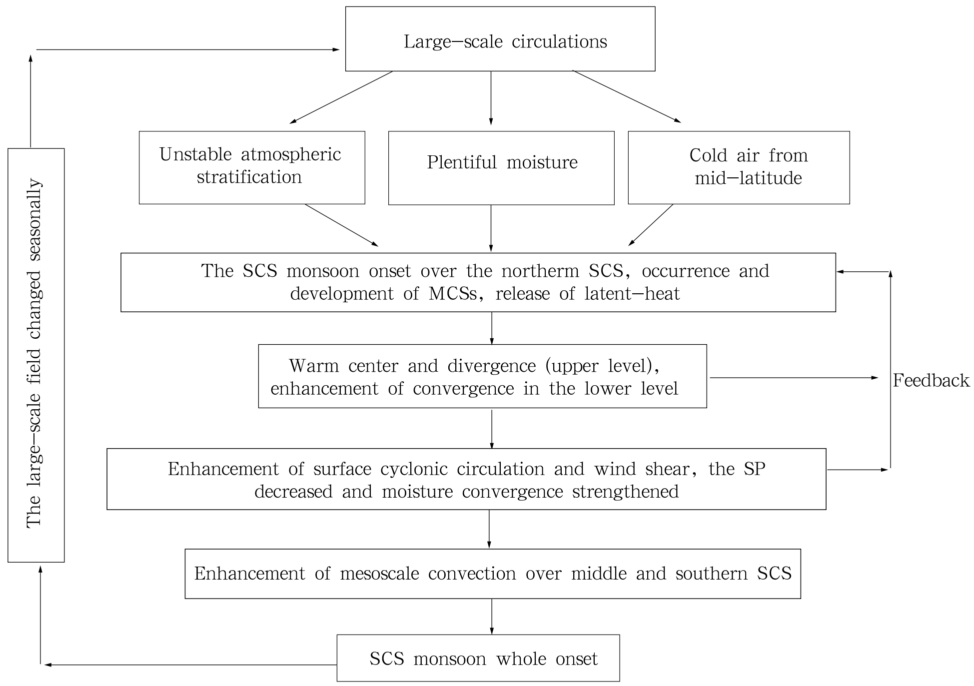

Fig.12. Schematic diagram of positive feedback between large-scale circulations and mesoscale convective systems.

structure maintain. This kind of configuration was in favor of the development of anticyclone circulation and the enhancement of divergence, and then further promoted the monsoon trough deepening and the convergence of low level flow, namely forming the environmental conditions for the later vigorous convections. The SCS monsoon onset and change of large-scale circulation may be just the outcome of this positive feedback mechanism (Fig.12).

6. Conclusions

The apparent heat sources and apparent moisture sinks, and large-scale wind, temperature as well as surface pressure during the summer monsoon onset over the northern South China Sea (SCS) in 1998 were diagnosed. The results suggested that there was a kind of positive feedback mechanism between the large-scale circulations and mesoscale convective systems (MCSs). Before the monsoon onset, the large-scale background provided favorable synoptic and dynamic conditions for the summer monsoon onset and formation of mesoscale convective activities, whereas after the summer monsoon onset, occurrence of persistent and extensive mesoscale convective activities produced obvious feedback effect on large-scale circulations. After the monsoon onset in the first phase, the convections were active. Under the condition of active convections, the vertical eddy transport was very strong, which was favorable to the latent heating released in the mid-low troposphere to be transported upward. Thus, the upper troposphere was intensively heated and made the warm-center structure maintain. This kind of configuration was in favor of the development of anticyclone circulation and enhancement of divergence, and then further promoted the monsoon trough deepening and the convergence of low level enhancing, which made the monsoon onset continually enhance and extend intensively, namely the subsequent whole onset. During this process, the positive feedback mechanism played an important role, which also suggested that the process of the SCS monsoon onset was the result of multi-scale interaction.

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