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LARGE-SCALE ENVIRONMENTAL CONDITIONS FOR THUNDERSTORM DEVELOPMENT

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ABSTRACT

The large-scale environmental conditions for thunderstorm development have been studied with 40 selected synoptic processes during 1972—1983. It is shown that the thunderstorms in eastern China can be divided into two types: pre-trough and post-trough. The convective instability before the pre-trough thunderstorms is established primarily by the dry and moist differential advection and that before the post-trough thunderstorms by the cold and warm differential advection. The subsynoptic scale circulation has direct effects on the establishment and release of instability. The pre-trough thunderstorms occur in the overlapping region of the ascending motion in the upper baroclinic waves and the ascending branch of the low-level jet strong wind core circulation and the post-trough thunderstorms occur in the lower convergent region below the ascending branch of the jet-front circulation. The effect of the lower dry and warm lids, the coupling of the low-and upper-level jets and the dry advection in the middle-level jet are the favorable factors for the severe storm formation.

I. INTRODUCTION

The thunderstorm outbreak is governed by environmental conditions. As early as the mid-forties, H. R. Byers and R. R. Braham[1] proposed three conditions for the thunderstorm outbreak: moisture, conditional instability and lifting mechanism. Since the discovery of convective storms in the sixties, there has been further understanding of the conditions for its outbreak: (1) strong potential unstable stratification, sometimes with inversion in the lower layer of the atmosphere; (2) moist tongue and strong moisture convergence at low levels; (3) triggering mechanism inducing the release of unstable energy; (4) upper- and low-level jets, sometimes middle-level jets; and (5) intense vertical wind shear[2,3]. Much progress has been made in the studies on this subject. Nevertheless, there remain some questions to be answered, e. g. what are the differences between the environmental conditions for the thunderstorm outbreak in different synoptic-scale distrubances? what are the key conditions for the outbreak and maintenance of thunderstorms?

In this paper, 40 selected thunderstorm processes that occurred during 1972—1983 in eastern China are divided by the upper-level trough area at 500 hPa into two types: pre-trough and post-trough, and the former type is subdivided into northern branch troughs (occurring 8 times), southern branch troughs (11), and high rears (10); the latter type into cold vortexes (4) and short wave troughs (7). Studies show dramatical difference between the environmental conditions for the pre-trough and post-trough types and the subsynotptic circulation related to the synoptic scale disturbance plays an important role in the outbreak and maintenance of thunderstorms.

II. ENVIRONMENTAL PARAMETERS BEFORE THUNDERSTORM OUTBREAK

Prior to the pre-trough thunderstorm outbreak, a moist tongue, with its central value of 12—14 g/kg in the composite specific humidity field at 850 hPa, extended from southern China toward eastern China and its lower moisture axis ran basically in the same direction as the southwesterly flow or low-level jet. Due to the back-tilted structure of the low trough, over the moist tongue at 850 hPa was the very dry area at 500 hPa and the composite specific humidity was less than 4 g/kg. The moisture distribution, dry at a high level and moist at a low level, formed a convective unstable area of negative $\Delta\theta_{se}{}_{850}^{500}$ which ran in the same direction as the lower moist tongue, the central value of composite $\Delta\theta_{se}{}_{850}^{500}$ being -8.8°C. The build-up of the pre-trough thunderstorm convective unstable energy was primarily the result of the vertical moisture distribution. The moisture in the post-trough thunderstorm was concentrated in the boundary layer. Also, near the earth's surface was found a moist tongue, extending from south to north into eastern China, and its central value of composite specific humidity could be as high as 16 g/kg. But just above 850 hPa was a dry area and the moist layer was rather thin. Cold air invasion into the rear of the post-trough at 500 hPa and a remarked warm ridge at 850 hPa extending from west to east toward eastern China accounted for the increasing of conditional instability and the composite value of ΔT_{850}^{500} was 28.4°C, higher than that of the pre-trough type 25.6°C. The central value of composite $\Delta\theta_{se}{}_{850}^{500}$ of the post-trough type was -10°C, and the distribution of convective unstable area conformed with the warm ridge at 850 hPa, which was basically determined by the vertical temperature distribution.

Figs. 1 and 2 show cross-sections of the composite two-dimensional flow and $\frac{1}{g}\nabla\cdot q\mathbf{V}$ in the southern branch trough and short wave trough, respectively, representing the flow structures of the pre-trough and post-trough thunderstorms before their outbreak. It is seen from these figures that moisture convergence existed at the low level in both types, and particularly in the southern branch, the intense moisture flux convergence was 30×10^{-8} g/(cm^2 hPa sec), which was directly due to the flow convergence in front of the strong wind core in the low-level jet. The moisture convergence of the post-trough was confined only in the surface boundary layer, but it was consistent with the southerly flow in the shallow layer. The layers of moisture flux divergence were found all above the moisture convergent layer, which was therefore favorable for the formation and maintenance of the convective instability. Nevertheless, the convective instability caused by this kind of vertical distribution of moisture was found only below 700 hPa.

Before the thunderstorm outbreak, the environmental atmosphere gradually changed its descending motion to the ascending one with the maximum value between 700—500 hPa, which was also the position of nondivergent layer. As for the vertical distribution of vorticity, the value of vorticity in the pre-trough diminished with height, and even changed from the positive to the negative, an indication for the appearance of thunderstorms to the south of the upper-level jet or in the high ridge. On the contrary, the whole layer was of positive vorticity. As a consequence of the lower warm ridge, the value of vorticity diminished from the surface up to 850 hPa. And higher up the positive vorticity steadily increased, showing the deep structure characteristic features of the cold trough (vortex).

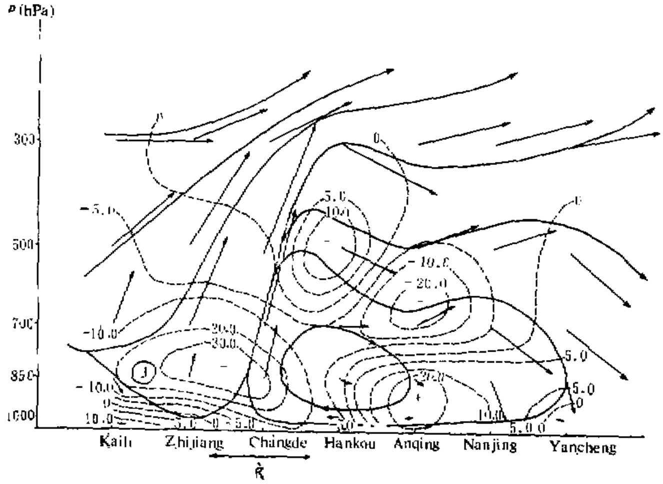


Fig. 1. Cross-section of composite flow structure in the southern branch trough.
Cross-section line is on the left side of low-level jet axis and in the direction of the jet stream.
Solid line: streamline; Dashed line: $1/g\nabla\cdot qV$ line.

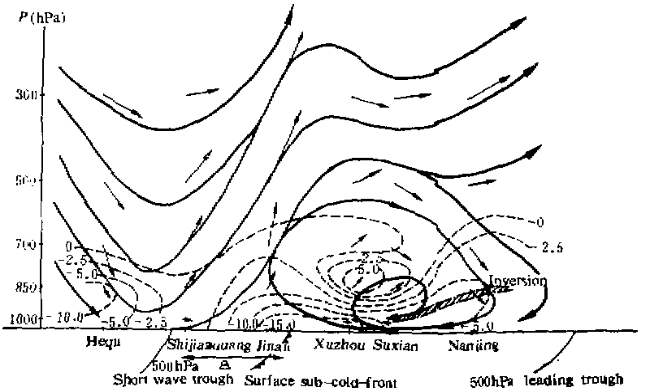


Fig. 2. Cross-section of composite flow structure in the short wave trough.
Cross-section line is the direction of upper air flow.
Solid line: streamline; Dashed line: $1/g\nabla\cdot qV$ line.

About 44.8% of the 29 pre-trough jets were upper-level jets and 68.9% low-level jets, and 63.7% of the 11 post-trough jets were upper-level jets and 18.2% low-level jets. The low-level post-trough jets appearing within the boundary layer were much weaker than the low-level pre-trough jets. Most of the thunderstorms occurred on the left side or in left front of the low-level jet strong wind core, and in the right rear of the upper-level jet strong wind core or near the jet axis.

For the U shears in both the pre-trough and the post-trough, the composite value of the former between 850—300 hPa was $1.4\times10^{-3}s^{-1}$ and that of the latter $3.0\times10^{-3}s^{-1}$. The composite value of the former between 850—500 hPa was $1.5\times10^{-3}s^{-1}$ and that of the latter $2.2\times10^{-3}s^{-1}$. In the post-trough below 100 hPa, all were southerly wind components, in the pre-trough below 100 hPa, except the weak northerly wind components above 100 hPa, while in the post-trough, all were northerly components above 850 hPa, with southerly wind components only found in the boundary layer. Their V shears between the upper-level and low-level, and between the middle-level and low-level were very small. In the post-trough the veering of wind between 850—500 hPa was on the average 25°. In the pre-trough type, the average veering of wind between 850—500 hPa was only 1°. The stronger the thunderstorm, the greater the difference in wind direction between 850—500 hPa. During severe weather occurring in the post-trough, the wind direction veered more than 90°.

III. THE EFFECTS OF SUBSYNOPTIC SCALE CIRCULATION

Usually, thunderstorms occurred in updraft which was, for the most part, conditioned by the secondary circulation in synoptic-scale disturbances. The pre-trough thunderstorms were characterized by the low-level jet strong wind core circulation and the post-trough thunderstorms by the upper-lever jet-front circulation.

1. *The Upper-level Jet-Front Circulation*

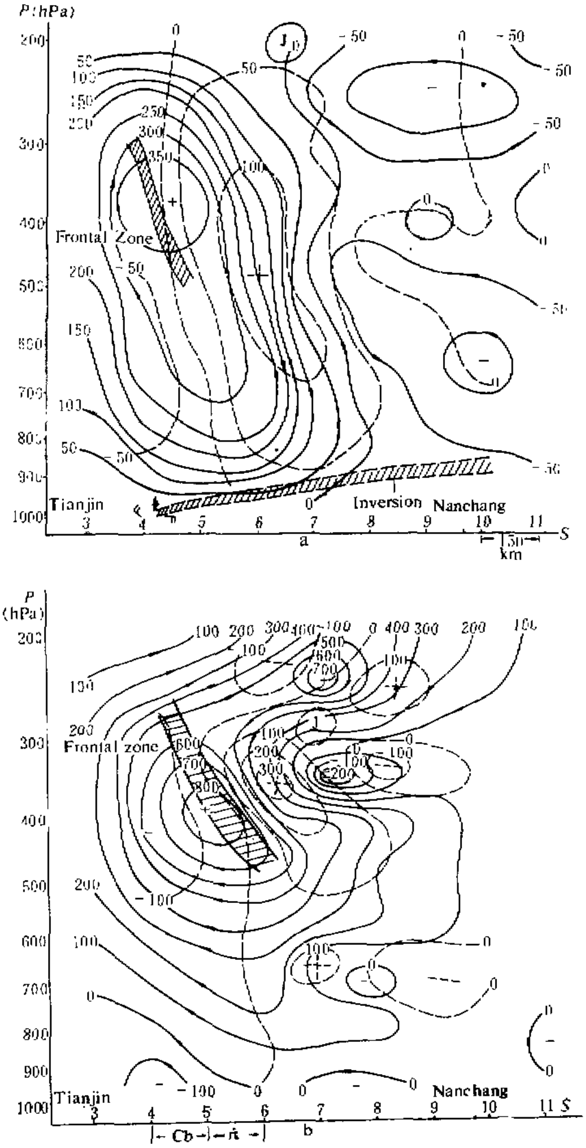
In advance of the post-trough thunderstorm, there happened the outburst of cold air associated with the upper-level short wave trough in the rear of the main trough (vortex), which caused the upper frontogenesis on its leading edge and the forming of upper jet-front by the combination of the frontal zone with the pre-trough jet stream. The jet-front system is of synoptic scale, or even larger, while its transverse structure, including the thermodynamic gradient as well as the transverse circulation produced in the geostrophic deformation field in the jet-frontal zone as all of subsynotpic scale[4].

Under the adiabatic and non-viscous condition, the equation for frontal ageostrophic transverse circulation on the Y-P plane is as follows:

$$-\gamma\frac{\partial\theta}{\partial P}\ \frac{\partial^2\psi}{\partial y^2}+2\frac{\partial m}{\partial P}\ \frac{\partial^2\psi}{\partial y\partial P}-\frac{\partial m}{\partial y}\ \frac{\partial^2\psi}{\partial P^2}=-2J_{yp}(U_g,V_g)$$

where $m=(U_g-fy)$ is absolute momentum; $\partial m/\partial y$ inertial stability; $\partial m/\partial P$ baroclinic stability; $\partial\theta/\partial P$ static stability; $-J_{yp}(U_g,V_g)$ geostrophic deformation field; and $\gamma=\frac{R}{fp_0}\left(\frac{P_0}{P}\right)^{C_v/C_p}$.

A diagnosis by using the above equation of the jet-front circulation and its evolution indicates that the direction and intensity of the jet-front circulation are closely related to the baroclinic wave in the process of the upper cold air outburst. By utilizing the geostrophic deformation field in the real upper-level jet-frontal zone during the process of the post-trough squall-line cluster on 17 June 1982, we have resolved the above equation satisfying $J_{yp}(m,\theta)\geqslant0$ giving the evolution of the jet-front circulation as shown in Fig. 3[5]. At 00 Z 17 when the temperature trough of baroclinic waves was behind the pressure trough, the cold air kept entering the upper-level jet zone in front of the pre-trough, which resulted in the development of baroclinic waves and the jet frontogenesis, causing an indirect circulation with the descending warm air and ascending cold air (see Fig. 3a). By 1200 Z, the cold air had all entered the jet zone and the pressure trough basically overlapped with the temperature trough and as a result the baroclinic waves and the jet-front indirect circulation both developed to the peak (see Fig. 3b). At 00 Z 18, as the temperature trough moved in advance of the pressure trough and the cold air left the jet zone, the baroclinic waves tended to become weakened, and the jet-front dissipated. Thus the frontal zone circulation was adjusted into a direct one (see Fig. 3c).



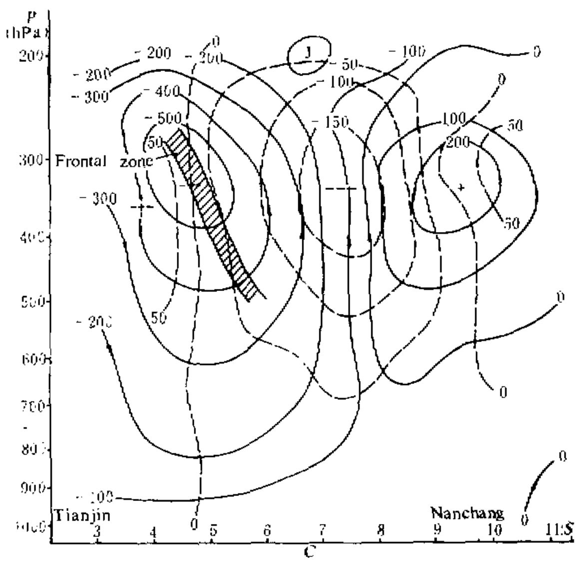


Fig. 3. Evolution of the jet-front circulation during 17—18 June 1982.
(a) At 00 Z 17 (b) At 1200 Z 17 (c) At 00 Z 18
Solid line: ψ (m/s hPa); Dashed line: ω (10^{-4} hPa/s)

When there was an indirect circulation in the jet-front, the convergent line of subsynoptic scale appeared in the rear of the high behind the upper-level trough. In the stretch of descending zone behind the main trough, a narrow ascending zone was formed contributing to the deep convection outbreak when the ascending motion on the convergent line and the ascending branch of the jet-front circulation were overlapped. Meanwhile, in the descending branch of the circulation, the convection development was impeded, which was favorable to the accumulation of convective unstable energy by the reinforcement of the lower dry and warm lid.

During the afternoon of 17 June, four squall lines were formed successively in the south of Shandong Province and the north of Jiangsu and Anhui Provinces, all in the rear of the upper cold vortex. The cluster of squall lines, which had developed in the ascending branch area of the jet-front circulation, moved from north to south, reaching the low level of the descending branch of jet-front circulation where they became weakened and died out. On the other hand, in the place where the ascending branch of circulation and the surface convergent area of air flow were linked, new squall lines arose in succession and at 1200 Z 17, and the cluster of squall lines was traveling southward one after another (see Fig. 4). Then with the adjustment of the jet-front circulation from the indirect to the direct, the squall line source came to be controlled by downdraft and new squall lines were no longer found in the north. Thus, the squall-line cluster became collapsed.

2. *The Low-level Jet Strong Wind Core Circulation*

Before the occurrence of the pre-trough thunderstorm, there often arose the southwesterly low-level jet. The wind speed of the low-level jet on the west side of the Pacific subtropic high was distributed unevenly, the spacing of the strong wind core being subsynoptic. Usually a longitudinal circulation was formed in front of the strong wind core in the direction of air flow; and a transverse circulation originated from the friction in the boundary layer. These two vertical circulations in the low-level jet were both of subsynoptic scale. The heat and moisture transfer by the lower jet was concentrated in front of the strong wind core, so that the convective unstable stratification in the lower atmosphere could be formed and maintained; and the overlapping of the ascending branch in the low-level jet circulation with the ascending motion due to the middle- and upper-level baroclinic waves would make for the deep convection outbreak in the left front of the low-level jet strong wind core, thus inducing heavy rainfall.

When the disturbance scale is less than the adjustment scale $L_0=\frac{C}{\sqrt{2}f}$, where $C=\frac{R^2T}{g}(\gamma_d-\gamma)$[6], the departure of thermal wind vorticity in the low as $\hat{\xi}-\frac{1}{f}\nabla^2\hat{\phi}>0$, and in the high as $\hat{\xi}-\frac{1}{f}\nabla^2\hat{\phi}<0$, the reinforcement of the ascending on the low pressure side and the descending on the high pressure side would intensify the transverse vertical circulation penetrating the jet axis and contribute to enhancing the kinetic energy of the air particles. This would exert further effects on the low-level jet strong wind core circulation. Now the evolution of the thermal wind vorticity within the 500—850 hPa has been calculated from the data obtained during the low-level jet thunderstorm in the warm sector during 24—25 May 1980. At 1200 Z 23, two subsynotpic-scale lows were found in the warm trough at 85 hPa in front of the upper-level trough and to the left side of the low-level jet. The calculation for the distribution of the thermal wind vorticity between 500—850 hPa shows that a positive departure of thermal wind vorticity was in these two lows on the left side of the

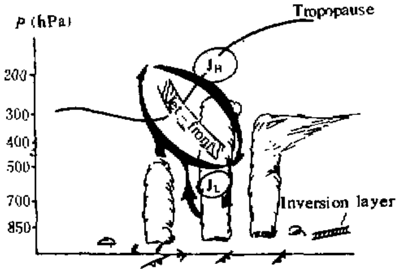


Fig. 4. Effects of the jet-front circulation on the development of the squall-line cluster.

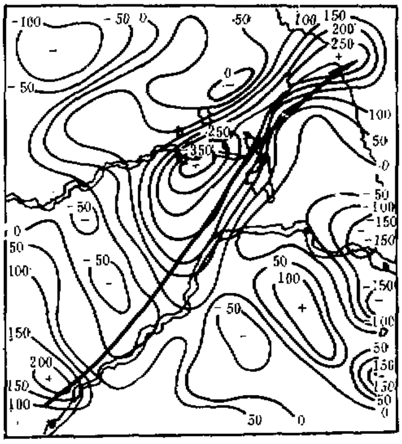


Fig. 5. Distribution of moisture flux divergence (10^{-8} kg/s) in unit air column at 1200 Z 24 (positive as convergence and negative as divergence).

low-level jet, and a negative on the right, a situation in favour of the increasing of the low-level jet transverse circulation. At 00 Z 24, the low-level jet developed to its maximum, with the central value at 850 hPa up to 38 m/s at Shou county, Anhui Province and 24 m/s at Hankou. During 24—25 the thunderstorm rain bands, about 1000 km long and 200 km wide, were separately formed in the areas of northern Anhui and Jiangsu Provinces and north of Dabie Mountain ahead of the two strong wind cores.

The ascending branch of the low-level jet strong wind core circulation and the convergence *of the low-level moisture acted significantly upon the formation of the thunderstorm* rain bands. Fig. 5 shows the distribution of moisture flux divergence in unit air column $I=\frac{1}{g}\int_{1000}^{100}\nabla_3\cdot\mathbf{V}_3 q\,dP$ in eastern China[7], at 1200 Z 24 when the development of subsynoptic low on the left side of the low-level jet reached its maximum. The maximum moisture convergent centres shown in Fig. 5 were located near Binhai and Xuyi Counties of Jiangsu Province, quite coincident with the rainstorm centre. The calculation for the horizontal moisture flux divergence in the lower troposphere $\frac{1}{g}\int_{1000}^{600}\nabla_2\mathbf{V}q\,dP$ and the moisture vertical transportation $-\frac{1}{g}\omega_B q$ caused by the convergence due to boundary layer friction reveals that they account for around 65% and 33% of the net convergent amount of moisture in the whole air column, respectively, near the center of the thunderstorm rain. This goes to show that the low-level jet strong wind core and the subsynoptic-scale low are of considerable importance to the transportation and concentration of moisture. The convective unstable energy built-up under this condition would trigger heavy rain by the ascending branch of the low-level jet strong wind core.

In the process of the pre-trough thunderstorms, there were also many cases in which the low-level jets appeared in the warm sector ahead of or above the cold front line. After the cold front combined with the low-level jet, the transverse circulation in the frontal zone determined by the geostrophic deformation field would act on the development of the convection. Usually, to the left of the low-level jet, a direct circulation with warm air ascending and cold air descending was formed along the frontal zone. This would be advantageous to the occurrence of large-scale thunderstorm rain, providing the ascending branch of the circulation would arise ahead of the upper-level trough.

Of course, the real conditions are rather complicated, for occurrence of thunderstorms is also conditioned by the low-level jet longitudinal circulation. For instance, in the process of the southern branch trough thunderstorms on 14 May 1981, the cold front was located in the rear of the low-level jet strong wind core, where the cold front was impelled to dissipate because of the divergence and the descending motion, while the downdraft with middle-level westerly wind momentum reached the lower layer and formed a new convergent line in the warm sector ahead of the cold front, which caused a new convective development, resulting in an intense squall line.

IV. CONDITIONS FOR THE SEVERE THUNDERSTORM DEVELOPMENT

1. *Lower Warm, Dry Lids*

Before the outbreak of the severe post-trough thunderstorm the lower layer was usually characterized by the stratification with the descending inversion, but such was not the case with the pre-trough thunderstorm. Fig. 6 indicates the pressure distribution of the lower inversion, being typical of the cold vortex type (Fig. 6a) and the short wave trough type (Fig. 6b). They shared the common features: the inversion layers existed below 700 hPa, with their bases higher on the south than on the north; in the boundary layer under the inversion was the transporting of moist underrunning from south to north; above the inversion were warm, dry westerly downdrafts in the rear of the troughs; the border of the inversion layer came down to the surface where there was the confluent flow band of surface dry line and air flow.

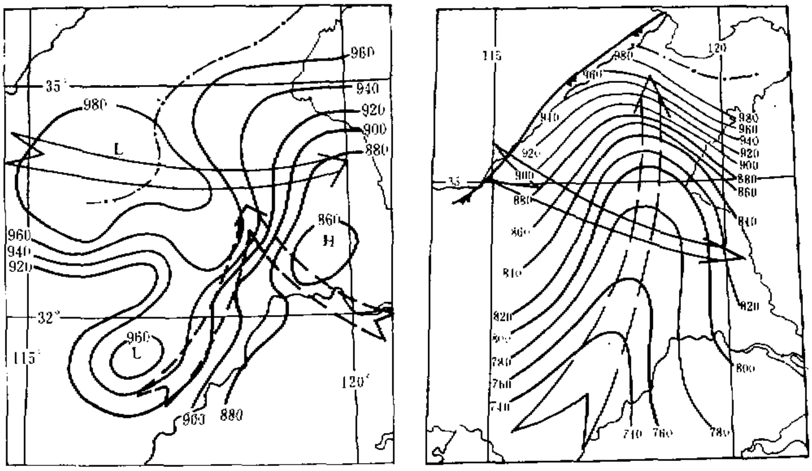


Fig. 6. Distribution of the lower inversion layer before the severe convection. Lid base analyses at 00 Z 17 June 1982 (cold vortex type) (left) and at 00 Z 17 June 1974 (short wave trough type) (right). —·— dry line; —— isobar; solid arrows, middle-level dry, warm air flow; dashed arrows, underrunning.

Acting as a "lid", the lower inversion helps the lower unstable energy to be accumulated and its existence provides an advantageous thermodynamic condition for the arising of a severe thunderstorm. This is in agreement with the result of the study by T. N. Carlson[6], except that the dry, warm lids in his analysis appeared in the updraft ahead of the westerly wind trough with a distribution lower on the south side than on the north, and the inversion was caused by the different temperature advections at the upper and low levels.

In both of the above processes, large-scale severe convective weather was observed in eastern China, the latter process being more severe than the former. The reason for this difference could also be found from the analysis of the thermodynamic structure. Fig. 7 shows the typical stratification curves at Nanjing at 00 Z 17 June 1974, in which the thickness of inversion near 780 hPa was about 400 m, $T-T_d$ in the dry area at 700 hPa was 20°C. In the layer below the inversion, about 80 hPa in thickness, was a moist layer close to saturation. At Gaoyou County, there was also an inversion at 850 hPa, but its thickness was 270 m. The maximum $T\text{-}T_d$ in the dry layer above the inversion was 12°C, with the moist layer below also close to saturation. It is shown that severe thunderstorms are common in the United States, where tornadoes are most frequently observed in the world. Fig. 7c illustrates the average stratification curve before the tornado outbreak in Oklahoma and its neighbouring states[9]. It is very similar to the stratification of the post-trough severe weather process. It is seen from Fig. 7c that the inversion was near 800 hPa, about 500 m in thickness, with greater difference between the upper dry air and the lower moist air; at 790 hPa above the inversion the $T\text{-}T_d \cong$ 25°C dry layer stretched up to 500 hPa and above with its thickness over 300 hPa. It is obvious that the more intense the inversion and the greater the difference between the upper dry air and the lower moist air, the more severe the convective weather will become.

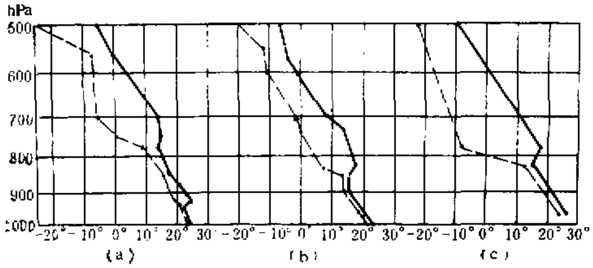


Fig. 7. The soundings before the outbreak of severe weather.
(a) The stratification curve at Nanjing at 00 Z 17 June 1974. (—— T-profiles, ----- T_d-profiles)
(b) The stratification curve at Gaoyou County at 00 Z 17 June 1982.
(c) The average stratification curve before the tornado outbreak in the United States.

2. *The Low-level Jet Coupling with the Upper-level Jet*

The coupling of the low- and upper-level jets is often one of the dynamic conditions for the outbreak and maintenance of severe convective weather. The situation, as described by Uccellini[10], in which the low- and upper-level jets' coupling led to severe weather, is not infrequent during thunderstorms in eastern China. But there are some distinctive characteristics. As stated above, the occurrence of the post-trough thunderstorms is directly related to the jet-front circulation. When the jet-front circulation is an indirect one, there exists at about 600—700 hPa an ageostrophic wind blowing from south to north which is responsible for the super-geostrophic property of the lower air flow. Under the action of Coriolis force, the wind speed will increase rapidly and a westerly low-level jet is formed. For example, during the development of the squall-line cluster on 17—18 June 1982, a new subsynoptic-scale low-level jet was generated around 600—700 hPa with the intensity of 22 m/s at 1200 Z 17 and along with the maintenance of the indirect circulation the speed of the westerly wind would continue to increase. A 1200 Z 17 the ageostrophic wind V_a was 3.2 m/s near 600 hPa, as shown in Fig. 8, thus causing the westerly wind component acceleration, from which the westerly wind increment can be inferred to be 11.4 m/s at

00 Z 18. It is clear that the low-level jet generated during the adjusting process of this wind and pressure field is considerably great in intensity.

The formation and intensification of the westerly low-level jet would contribute to the maintenance and reinforcement of the squall lines when the cyclonic vorticity and ascending motion region on its left side combine with the ascending branch of the jet-front circulation; on the contrary, the maintenance would be impeded when the anti-cyclonic vorticity and the descending motion region are on the right side of the low-level jet.

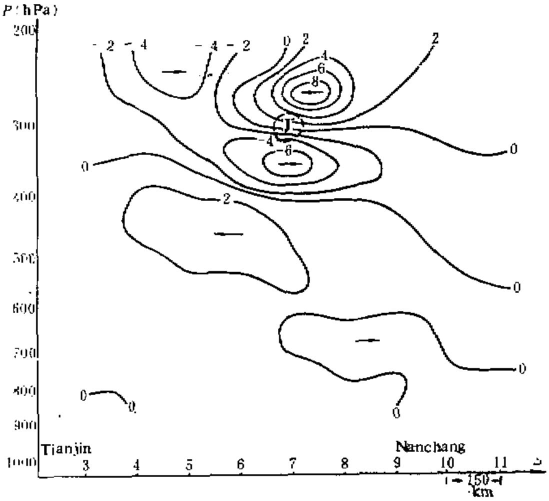


Fig. 8. Distributon of the ageostrophic wind in the jet frontal zone at 1200 Z 17 June 1982.

The coupling of double upper-level jets with a low-level jet is often the situation responsible for the outbreak of more severe convective weather[11]. On the 200 hPa chart at 00 Z 17 June 1974, as shown in Fig. 9, there was an extratropic jet stream in the north and a subtropic one in the south, and within the boundary layer was also found a jet stream penetrating the southern branch jet axis pointing to the right rear of the strong wind core in the northern branch jet. Under these conditions, initially the squall lines were formed in the right rear of the extratropic jet strong wind core, then moved toward the subtropic jet area, and became reinforced until they reached their peak, and eventually faded away on the right side of the subtropic jet. On the cross-section of the south-north-oriented two-dimensional air flow along the boundary layer jet were observed an updraft on the south side of the extratropic jet, a downdraft on the north side of the subtropic jet and a southerly air flow within the boundary layer between these two northerly air flows. Along the meridian existed an indirect circulation. At the base of the circulation circle, the transfer of moisture and heat to the north by the southerly air flow resulted in the forming of the surface moist tongue and the lower convective unstable areas extending from the southern part of Jiangsu, Anhui Provinces to Sandong Peninsula. The dry, warm lids in the southern descending branch effectively accumulated unstable energy while the northern ascending branch helped to trigger and release unstable energy, resulting in squall lines, which became very severe convective weather when reaching the south side of the subtropic jet.

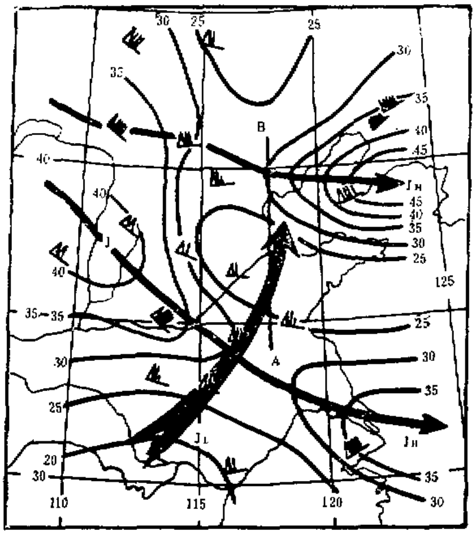


Fig. 9. Distribution of upper wind speed at 200 hPa at 00 Z 17 June 1974.

3. *Dry Advection in the Middle-level Jet*

During most of the post-trough thunderstorms, dry advections were found at the middle level, and also in the middle-level jet when the weather was exceptionally severe. On the 500 hPa chart as shown in Fig. 10a, behind the diffluent trough near 40°N there was a strong wind core in the middle-level jet (>20 m/s) and an apparent invasion of dry air over the squall line occurring areas. The dry advection in the middle-level jet increased the convective instability and the convergence of the middle-level air flow. This resulted in the stretching of the convergent layer up to the middle level and helped the rapid extension of the convectiive cloud up to the upper air. Consequently, the "6.17" squall line was accompanied at its very beginning thunderstorm winds close to 20 m/s and precipitation process between 20—30 mm. On the contrary, above 500 hPa there was moderate dry advection, even moist advection, so the resulting convective weather was rather weak. As shown in Fig. 10b, the advection at the middle level over eastern China was moist at 1200 Z 22 May 1982, and during the period of 1800 Z 22 to 00 Z 23 occurred weak thunderstorms without strong ,wind or hail.

The same was true of the pre-trough thunderstorms, i. e., the dry advection would occur in the middle-level jet were whenever associated with severe thunderstorms. At 00 Z 26 June 1980, there occurred the middle-level jet with the central value of its strong wind speed as high as 32 m/s ahead of the southern branch trough at 500 hPa. And there were severe dry advections over Jiangsu, Zhejiang and Anhui Provinces. During the time of 1900 Z 25 to 0300 Z 26, widespread severe weather, such as hail and thunderstorm wind, hit these areas. It was obvious that the dry advection in the middle-level jet was also one of the important thermodynamic and dynamic factors responsible for the thunderstorm reinforcement.

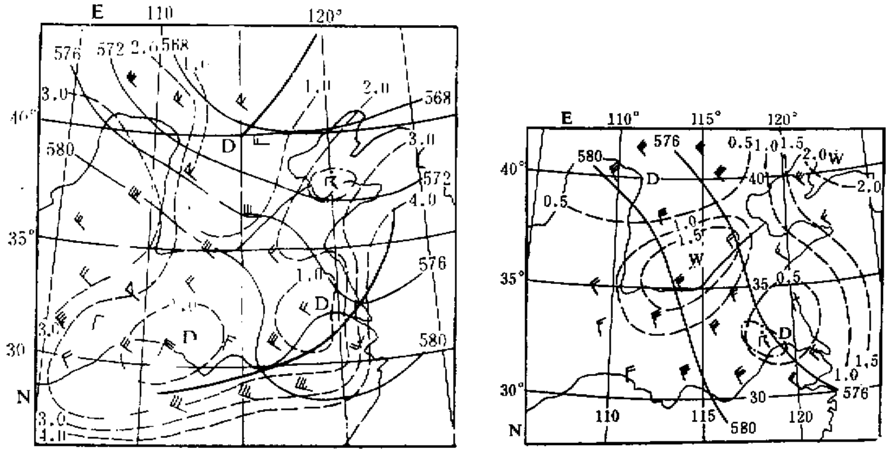


Fig. 10. Middle-level moisture advection prior to the convective weather in the post-trough.
Shown here are the fields of air flow and specific humidity at 500 hPa at 00 Z 17 June 1974 (left) and 1200 Z 22 May 1982 (right). D—dry; W-wet.

V. CONCLUSIONS

(1) The thunderstorms occurring in eastern China can be divided into two main types: pre-trought and post-trough. Prior to the pre-trough thunderstorms the upper- and low-levels are both relatively moist with thick moisture convergence and small potential instability[1]; and in most cases there are low-level jets with small difference between the middle- and low-level wind directions. Prior to the post-trough thunderstorms, moisture convergence is found in the surface boundary layer, with great potential instability, and in most cases, there are upper-level jets with great difference between the middle- and low-level wind directions, the whole layer being of positive vorticity. These two types, however, share some common features for their development. Chiefly, they are: occurring in the deep updraft layer; both with divergence and moisture flux divergence distributed as the lower level convergence and upper level divergence; the vorticity being positively distribute and decreasing with height below 850 hPa and increasing with height within 700—500 hPa.

(2) The convective unstable stratification before the pre-trough thunderstorms is primarily established by the dry and moist differential advection, with the upper dry air coming from behind the trough or the west side of the subtropic high and the lower moist air mainly from the south or south-west moist sectors. And the convective instability in the post-trough

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[1] Here it refers to both convective and conditional instability.

thunderstorms is built up primarily by the cold and warm differential advection, with the upper cold advection coming from the northwest behind the trough and the lower warm advection from the west. The subsynoptic-scale circulation has a direct effect on the establishment and releasing of unstable energy. The pre-trough thunderstorms occur in the overlapping region of the ascending motion of upper baroclinic waves and the ascending branch of strong wind core circulation in the low-level jet. The post-trough thunderstorms occur in the lower convergence region below the ascending branch of the jet-front circulation.

(3) The effect of the lower dry warm lids, the coupling of the upper- and low-level jets and the dry advection in the middle-level jet all provide favorable conditions for the formation of severe thunderstorms. The occurrence of convective storms and severe weather is very often due to the comprehensive effect of several favorable factors.

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