# Case Study on the Impact of the Vortex in the Easterlies in the Tropical Upper Troposphere on the Western Pacific Subtropical Anticyclone*

YAO Xiuping[1,2†](姚秀萍), WU Guoxiong[1](吴国雄), LIU Yimin[1](刘屹岷), and LIU Huanzhu[3](刘还珠)

1*National Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics(LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing* 100029

2 *China Meteorological Administration Training Center, Beijing* 100081

3 *National Meteorological Center, Beijing* 100081

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## ABSTRACT

By employing the NCEP/NCAR reanalysis data (1000–10 hPa, 2.5° × 2.5°), the impact of the vortex in the easterlies (EV) over the tropical upper troposphere on the zonal movement of the western Pacific subtropical anticyclone (WPSA) during 19–25 June 2003 is analyzed in this paper. It is shown that the EV can extend from middle troposphere to the height of 50 hPa, reaching a maximum at 200 hPa. The vertical thermal distribution appears to be "warmer in the upper layer and colder in the lower layer". The WPSA retreats eastward abnormally when the EV and the vortex in the westerlies (WV) encounter around the same longitude while they move toward each other. It is also shown that the vorticity variation extends from the troposphere to the height of 50 hPa, with the most prominent change occurring at 200 hPa by the diagnostic analyses of the vertical vorticity equation. The WPSA appears to retreat abnormally eastward while the negative/positive vorticity change becomes stronger near the east/west side of the EV, and the areas with positive vorticity tendency both in the EV and WV join together into one belt along 130°E during the process of the EV and the WV moving toward each other. In the vorticity equation, the positive contribution caused by the hotizontal advection term is the maximum, and the minimum is caused by the $\beta$ effect. It is also found that enhanced horizontal vorticity advection and $\beta$ effect, as well as the "barotropic development" resulted from the in-phase superposition of the southerly and the northerly winds in the easterlies and westerlies near 130°E, are in agreement with the WPSA eastward retreat.

**Key words:** vortex in the easterlies (EV), western Pacific subtropical anticyclone (WPSA), eastward retreat, vertical vorticity equation

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## 1. Introduction

The western Pacific subtropical anticyclone (WPSA) is an important component of the East Asian monsoon system. It is closely related to the heavy rainfall process in Meiyu season in the eastern part of China. The movement of the WPSA directly affects the location of the Meiyu rainfalls. Tao and Xu (1962) and Huang (1963) have investigated a lot about the impact of the WPSA on weather and climate of China. Their conclusion that the seasonal northward jump of the WPSA signifies the Meiyu development over the Jianghuai (short for the Yangtze and Huaihe River) Valley, serves as a basic theory for research of the WPSA and forecast of the Meiyu. Some investigators systematically studied the character of the zonal shift and northward jump of the WPSA (Bi, 1989; Yu and Yang, 1995), and showed that the short-term shift of the WPSA played a key role in the large-scale background circulation that induces the anomalous precipitation. It was previously found that the abnormal rainfall over the Jianghuai Valley had a close

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†Corresponding author: yaoxp@cma.gov.cn.

relationship with the abnormal shift of the WPSA in 2003 (Yao and Yu, 2003; Zhao et al., 2005). Wu et al. (2002) have disclosed many new facts and mechanisms about WPSA. On the mechanism for the short-term variation of WPSA, Ding et al. (1987) pointed out that the mean divergent circulation at 200 hPa had a close relationship with the WPSA. In addition, Yu and Yang (1995) also found out the relationship between the intraseasonal abnormal shift of WPSA and the divergent circulation at 200 hPa over the Northeast Pacific, as well as a possible mechanism for middle-range shift of the WPSA. On the other hand, the strengthening of the East Pacific subtropical anticyclone could stimulate abnormal disturbances in the middle troposphere. The disturbances could transmit over the North Pacific along 25°N, and finally lead to the strengthening and westward advancing of the WPSA (Zhong and Wu, 1999). The above is about the climate character of the WPSA. For the short-term scale character of the WPSA, Liu and Wu (2000) indicated that it was complex and challenging about how atmospheric inner process and external forcing influence the zonal and meridional shifts of the WPSA. Ren and Wu (2003) pointed out that the dynamical and thermal mechanism of the short-term shift of the WPSA was closely related to the abnormal circulation system in the mid and high latitudes. In detail, Ren et al. (2004) further investigated the abnormal character of the splitting and developing of the WPSA in 1998, and found that the short-term abnormal shift of the WPSA was influenced by the cold and warm air activities in the edge of the WPSA, related directly to the development of the meridional wind. It was discovered that the short-term abnormal shift of the WPSA was associated with the anomalous evolution of the mid-latitude synoptic systems, especially the activity of the cold air.

The abnormal shift of the WPSA was related not only to the structure of the WPSA but also to the related synoptic systems. Previous studies have indicated the mid-latitude synoptic system influences on the WPSA. The questions to be addressed in this paper are: Is there any relationship between the WPSA and the synoptic system in the low-latitude easterlies? How do the zonal shift of the WPSA and the synoptic system in the easterlies and westerlies correlate? In this study, a NCEP/NCAR 2.5°×2.5° reanalysis dataset was used, which includes 1000–10-hPa daily average data and four times daily data. The main purpose of this paper is to study the influence and its mechanism of the easterlies on the WPSA through a case investigation and to further understand the role of the WPSA and the factors that influence its movement.

## 2. WPSA zonal shift and zonal wind disturbance

In 2003, after the beginning of the Meiyu period (21–23 June), over the Jianghuai Valley, the first heavy rainfall happened with the westward spreading of the WPSA. On 24 June, after the eastward retreating of the WPSA, the rainfall process ended (figure omitted).

It was shown that disturbance in the easterlies (noted as E) to the south of the WPSA moved westward with the westward movement of the WPSA from the zonal deviation of wind vectors (zonal deviation means difference from the zonal average in this study) and geopotential height at 500 hPa, from 10 June 2003. Meanwhile, the high-level trough in Asian mid-latitude westerlies developed with its eastward movement and formed a low vortex (noted as W) at 115°E on 22 June (shown in Fig. 1a); on 23 June (Fig. 1b), the WPSA turned into the strip belt, and its west ridge point reached 110°E while the low vortex in easterlies (shorten as EV below) lay at 135°E, and low vortex in the westerlies (shorten as WV) lay at 122.5°E; on 24 June (Fig. 1c), while the disturbances in the westerlies/easterlies moved toward each other to around 130°E, nearly in the same longitude, the west ridge point of the WPSA broke and retreated eastward to 130°E (Fig. 1d). After that, disturbances in the easterlies/westerlies moved westward/eastward, and the WPSA began to move slowly westward (figure omitted). It appears that the zonal shift of the WPSA

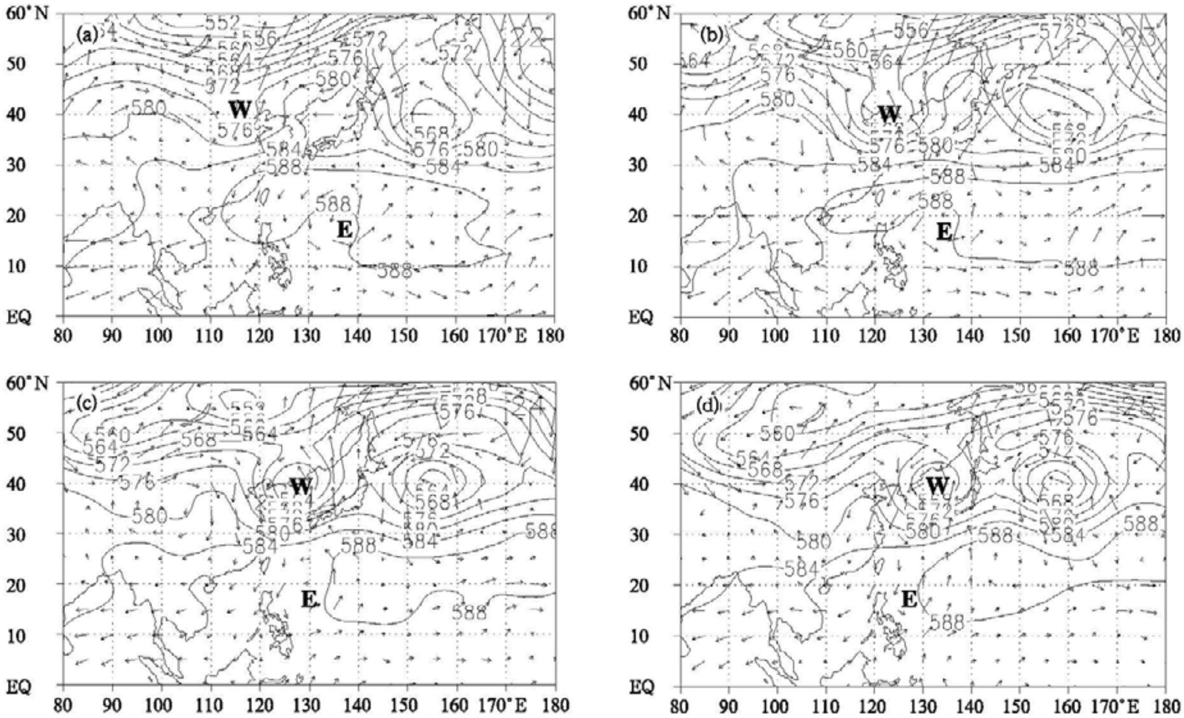

**Fig. 1.** The height field (dagpm) and the zonal anomalous wind vector (m s$^{-1}$) at 500 hPa from 22 to 25 June 2003. (a) 22 June, (b) 23 June, (c) 24 June, and (d) 25 June. W and E are the central locations of the EV and WV, respectively.

is associated with the movement of the disturbances in the easterlies/westerlies.

### *2.1 Vertical structure and temporal-spatial evolution of disturbance in the easterlies/westerlies*

Figure 2a illustrates that the negative center of the zonal deviation height in the easterlies corresponds to the location of the positive vorticity center, and the positive vorticity can be used to stand for the EV. The EV can extend from 700 to 50 hPa with a center of the maximum intensity at 200 hPa. It is also shown from the intensity of the deviation height and the vorticity around the EV center that the EV strengthens, extends in the vertical direction and even reaches 50 hPa with the westward movement of the WPSA. While the WPSA retreated eastward from 24 to 25 June, the westward moving EV weakened and shrank in the vertical.

Figure 2c shows that the EV is "warmer in the upper level (100 hPa) of the upper troposphere and colder in the lower level (350 hPa)" in thermally. The warmer area exists above the maximum vorticity and the colder area exists below. The warmer/colder center is located around 100 hPa/350 hPa, and the boundary of them is around 200 hPa. The intensity of the warmer center of the EV is stronger than that of the colder center. It is obvious that the EV is different from the synoptic system such as tropical storm and typhoon. With the westward movement of the EV and the enhancement of the colder and warmer centers, the maximum temperature gradient appears on 24 June, and then the WPSA retreats eastward and breaks.

In addition, the negative deviation height of the WV and the positive vorticity which reaches around 200 hPa are located mainly in the upper troposphere (Fig. 2b). When the WV moves eastward, the distribution of the positive vorticity turns into the erect structure. In thermally, the WV is "colder in the upper troposphere and warmer in the lower" before 23 June. Then, on 23 June (Fig. 2d) warmer center in the upper level strengthened, and new colder area appeared at 850 hPa. Finally, on 24 June (figure omitted) when the WPSA retreated eastward, colder area

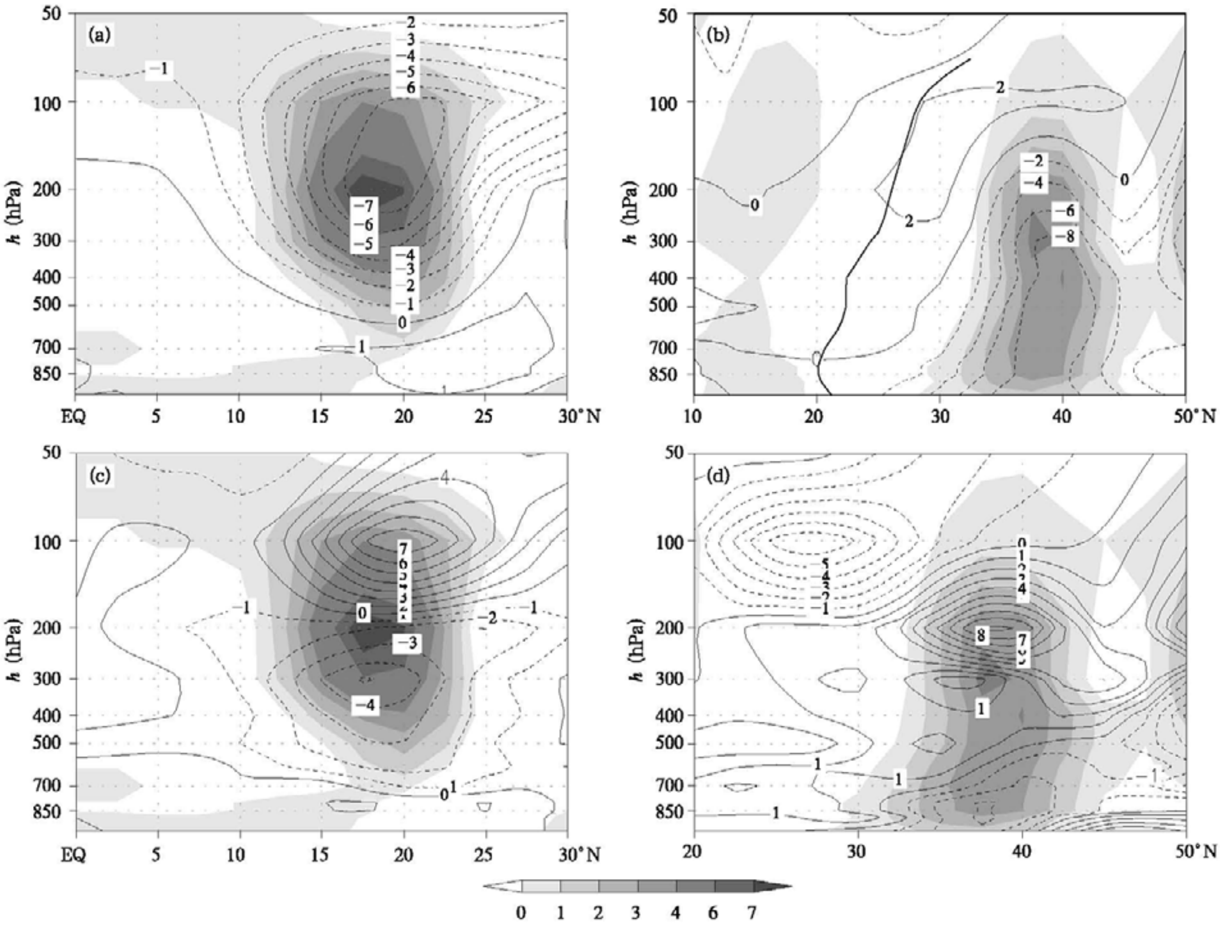

**Fig. 2.** Meridional cross sections of the zonal deviation height (a, b; dagpm) and zonal deviation potential temperature (c, d; K) along 135°E (a, c)/122.5°E (b, d) across the center of the easterlies/westerlies disturbances, respectively, on 23 June 2003. Shadings denote the positive vorticity at intervals of $10^{-5}s^{-1}$.

in the lower level extended upward to 300 hPa in which the vertical thermal structure "warmer in the upper troposphere and colder in the lower level" of the WV was similar to the EV.

### *2.2 Relationship between EV/WV and zonal shift of the WPSA*

It is shown from the above analysis that the EV is mainly in the upper troposphere and the WV is in the mid-upper level. For the better analysis of the relationship between the WPSA and the EV/WV, the evolution of the EV vorticity center at 200 hPa, the WV vorticity center at 500 hPa, and the westernmost point of the 588-dagpm contour are shown in Fig. 3.

Figure 3 illustrates the relationship between the EV/WV and the shift of the WPSA in the zonal direction. At the beginning of the last 10 days of June 2003, when disturbance in the easterlies (E in Fig. 3) advanced westward and disturbance in the westerlies (W in Fig. 3) moved eastward, the WPSA (G is the westernmost of the WPSA) and EV were in the same phase. On 23 June, the G advanced westward around 110°E. On 24 June, in the south/north of the WPSA, the disturbances in the easterlies/westerlies moved toward each other to around 130°E in the same longitude. In the meantime, the WPSA retreated abnormally eastward for about 25 degrees in longitude.

Figure 4 shows that positive vorticity disturbance (shaded) in the upper-level easterlies advanced westward with time and reached the maximal intensity $8\times10^{-5}s^{-1}$ on 22 and 24 June which exceeded the planetary vorticity ($f$) in this longitude. At the same time, positive vorticity disturbance (contour) in the westerlies moved eastward, which also reached the maximum $8\times10^{-5}s^{-1}$ on 24 June. Because of the westward advancing of the WPSA, the first heavy rainfall happened over the Jianghuai Valley during 21–23 June. From 23 to 24 June, when the disturbances in the westerlies/easterlies reached the same longitude, the WPSA abnormally retreated and jumped eastward, resulting in the break of the first rainfall during

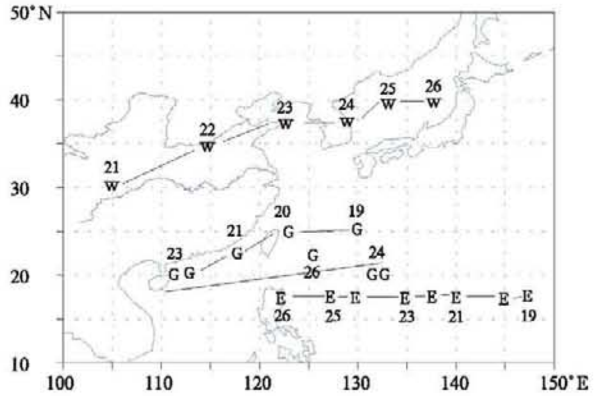


**Fig. 3.** Evolution of the EV and WV (the vorticity centers of the EV and WV, respectively, denoted as E and W), and the most western point of the 588-dagpm contour (denoted as G) from 19 to 26 June 2003. The number denotes the date, e.g., "23" denotes 23 June 2003.

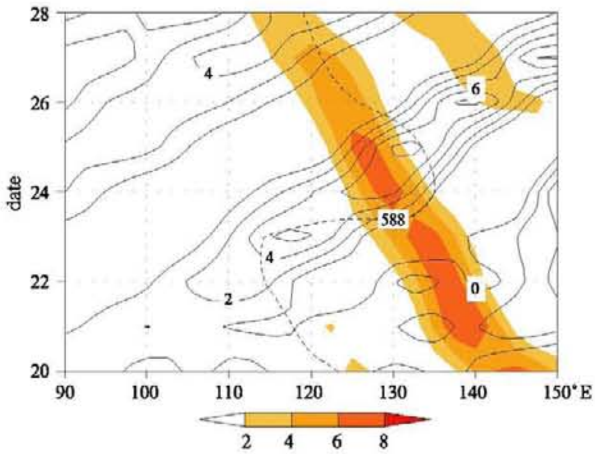


**Fig. 4.** The longitude-time cross section for the vorticity ($10^{-5}s^{-1}$) averaged over 15°–20°N (shaded) at 200 hPa, and over 35°–45°N (solid line) at 500 hPa and the longitude position of the 588-dagpm contour of WPSA at 25°N (dashed line) from 20 to 28 June 2003.

the Meiyu period.

In the preceding sections we have provided evidence for the relationship between the WPSA and disturbances in the easterlies/westerlies. The zonal evolution and abnormally retreating of the WPSA was related to the disturbances in the south/north of the WPSA in the easterlies/westerlies. Furthermore, the eastward retreating of the WPSA changed the thermal and kinetic structure of the disturbances in the easterlies/westerlies.

## 3. The dynamical mechanism for disturbance from easterly wind belt over the tropical troposphere influencing zonal shift of the WPSA

### *3.1 Evolution of the horizontal divergence and the vertical movement*

Figure 5a illustrates that it was a divergence/convergence area in the east/west side of the EV before the WPSA retreating eastward on 24 June. With the westward advancing of the EV, the divergence/convergence gradually diminished and finally changed to convergence/divergence after the WPSA retreating eastward (on 24 June). Corresponding to the divergence, the zonal evolution (Fig. 5b) of the vertical velocity shows that before the WPSA retreating eastward, the ascending/descending movement was in the east/west side of the EV, and after the WPSA retreating, the distribution of the vertical velocity changed suddenly, then showed an opposite distribution.

It was shown from the evolution characteristics of the vertical velocity in the vicinity of the EV that the divergence/convergence was matched with the ascent/descent in the east/west side of the EV while the main body of the EV was advancing westward at 200 hPa. But after the WPSA retreating eastward, the distribution of the divergence and the vertical velocity was reverse.

### *3.2 The diagnosis of the vorticity equation*

The large-scale movement equation could be

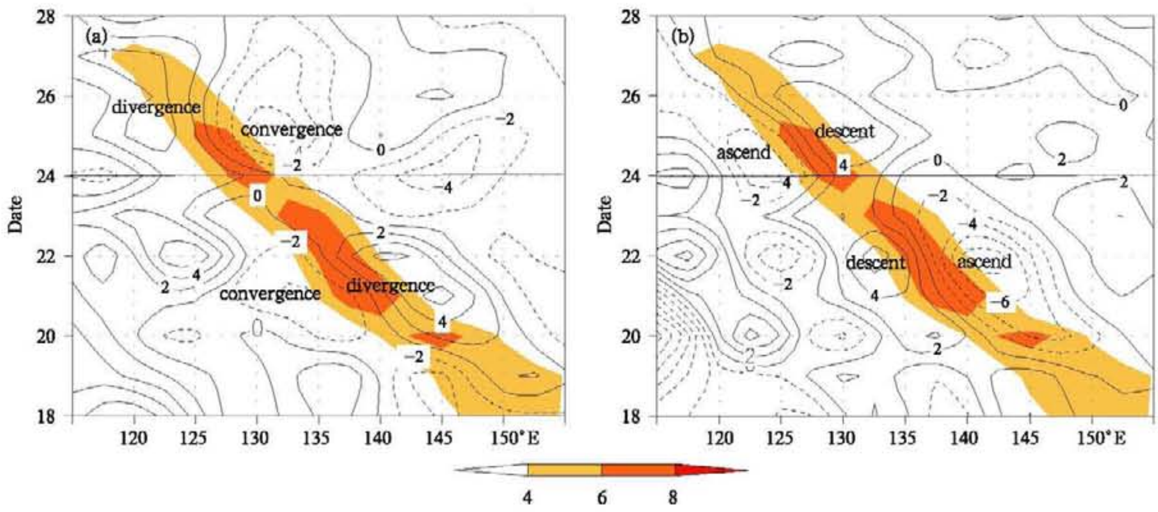


**Fig. 5.** Longitude-time cross sections averaged over 15°–20°N at 200 hPa during 18–28 June 2003 for (a) divengence ($10^{-6}$ s$^{-1}$) and (b) vertical velociyt $\omega$ ($10^{-2}$ Pa s$^{-1}$). Vorticity greater than $4\times10^{-5}$ s$^{-1}$ is shaded.

simply written as

$$\underset{A}{\frac{\partial\zeta}{\partial t}} = \underset{B_1}{-(u\frac{\partial\zeta}{\partial x}+v\frac{\partial\zeta}{\partial y})} \underset{B_2}{-\beta v} \underset{C}{-(f+\zeta)\cdot(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y})} \underset{DE}{+R(\zeta)}. \quad (1)$$

Equation (1) shows that local relative vorticity trend (A) is related with advection terms (B, in which $B_1$ is the advection term of the relative vorticity, and $B_2$ is the term for advection of the planetary vorticity and $\beta$ effect), the absolute vorticity divergence term (C), and the new residual term (DE) which includes the tilting term (twisting term) effect, boundary friction, and subgrid-scale cumulous convection.

Figure 3 illustrates that the EV basically advances westward along 17.5°N, and thus we analyze the zonal vertical section along 17.5°N. Figures 6a and 6b show that the vorticity trend from the westward advancing of the EV is negative/positive in the east/west side of the EV and the positive/negative area exists from the whole troposphere to 50 hPa (stratosphere). And the maximum value of the vorticity trend is at 200 hPa which shows that the EV mainly exists in the upper troposphere.

It is clearly seen from Figs. 6c and 6d that vorticity trend at 200 hPa in the east/west side of the EV in the upper troposphere is negative/positive. On the contrary, the distribution of the vorticity trend of the WV from 110° to 130°E is opposite, i.e., the west/east side of the WV is negative/positive. It is notable that negative vorticity trend separates the WV and EV before 24 June while the EV and the WV are moving toward each other. On 23 June (Fig. 6c), the negative vorticity trend area in the vicinity of (20°N, 120°E) corresponds to the WPSA advancing westward. Figure 6d (on 24 June) shows that positive vorticity trends at 17.5° and 37.5°N connected within 120°–130°E and the positive vorticity change rate exceeds $6\times10^{-10}$s$^{-2}$ within 15°–35°N. The vorticity change can create positive vorticity larger than $2.5\times10^{-5}$s$^{-1}$ at 12 h. Compared with the characteristic vorticity ($-10^{-6}$s$^{-1}$) of the WPSA, this positive trend is great enough to apparently weaken the high ridge and the negative vorticity in the west of the WPSA which reaches 110°E at 500 hPa. Therefore, at 500 hPa the characteristic line of the WPSA, i.e., 588-dagpm contour line, retreats eastward. It is obvious that while the EV and the WV are moving toward each other, the connecting of the positive vorticity trend in the north and south in the west side of the EV is in favor of the "eastward retreating" of the WPSA.

In order to find out the influence factors which make the positive vorticity trend area connecting from

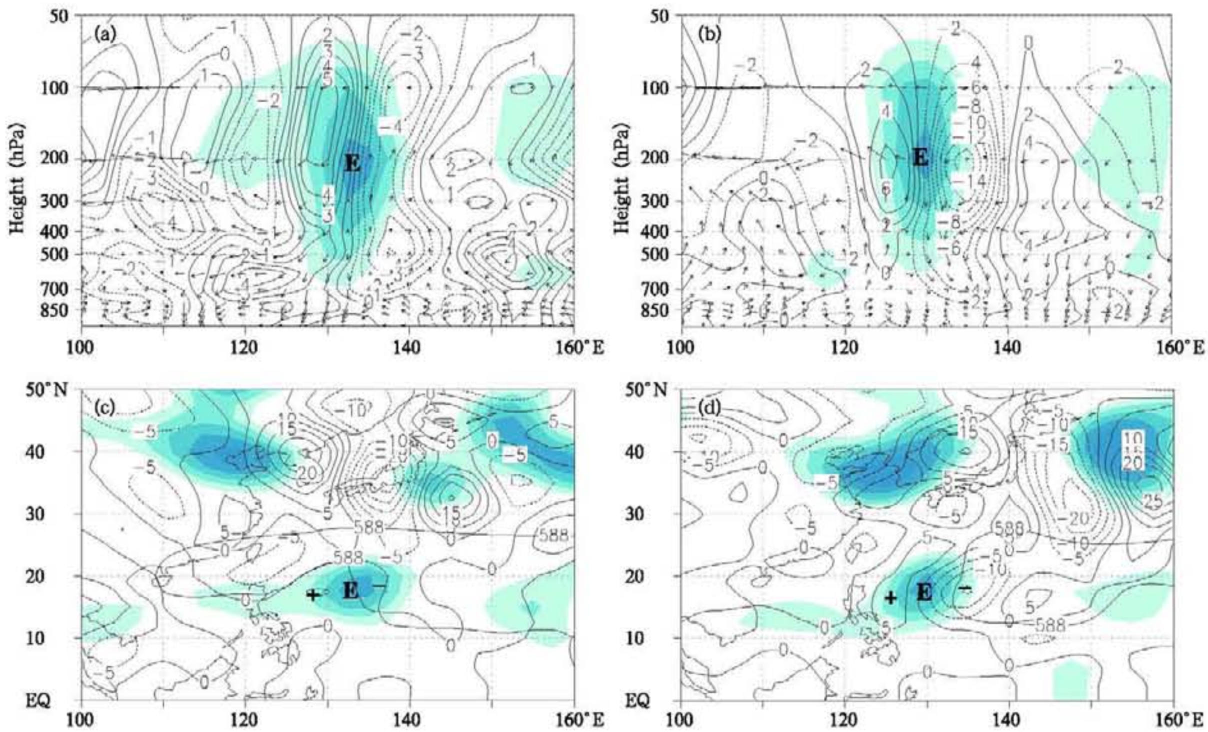

**Fig. 6.** Zonal vertical sections of the vorticity trend term and vertical circulation along 17.5°N ($u$, -$\omega\times100$) (a/b) and their pattern at 200 hPa (c/d) during 23–24 June 2003. The positive vorticity is shaded; the thick solid line in (c/d) is 588-dagpm contour; E denotes the center of the easterly disturbances; the positive vorticity area is shaded at intervals of $2\times10^{-5}\text{s}^{-1}$ (unit: vorticity trend: $\times10^{-10}\text{s}^{-2}$; vorticity: $\times10^{-5}\text{s}^{-1}$). "+" and "–" denote the positive and negative vorticity change centers, respectively.

the north to the south, the following study will analyze the contribution of each term in the vorticity equation. It is shown from the vertical distribution (Fig. 7) of each term in Eq. (1) along 17.5°N on 24 June that the integrated effect of the advection and the divergence terms (B+C; Fig. 7a) is the same in magnitude as the residual term (Fig. 7b). It illustrates that the residual term could not be neglected. The integrated term (B+C) mainly exists in the mid-upper troposphere, and has negative/positive effects in the east/west side of the EV. Furthermore, it pronouncedly enhanced on 24 June. The effect of the residual term will be discussed in the other study.

Among the integrated effects of the advection and divergence terms, the horizontal vorticity advection term ($B_1$; Fig. 7c) is the largest one, and has negative/positive distributions in the east/west side of the EV. The $\beta$ effect term ($B_2$; Fig. 7d) is a little less than the horizontal vorticity advection term ($B_1$) and the absolute vorticity divergence term (C), but has "positive/negative distributions in the west/east of the EV" which is similar to the distribution of the horizontal vorticity advection term ($B_1$) and extends upward to the stratosphere. The horizontal vorticity advection term and the $\beta$ effect make the positive contribution to the vorticity trend in favor of the westward advancing of the EV. The distribution of the absolute vorticity divergence term (C; Fig. 7e) is different completely before and after the eastward retreat of the WPSA. Before the eastward retreat of the WPSA, it is negative/positive in the east/west side of the EV, but after that it distribute reversely, i.e., "positive/negative in the east/west side".

At the same time, before the retreat of the WPSA, the central value of the horizontal vorticity advection (figure omitted) is $2\times10^{-10}\text{s}^{-2}$ in the west side of the EV at 200 hPa, and increases to $7\times10\ \text{s}^{-2}$ during the retreating (Fig. 7c). Such big positive vorticity change rate is in favor of the weakening of the negative vorticity in the west side of the WPSA.

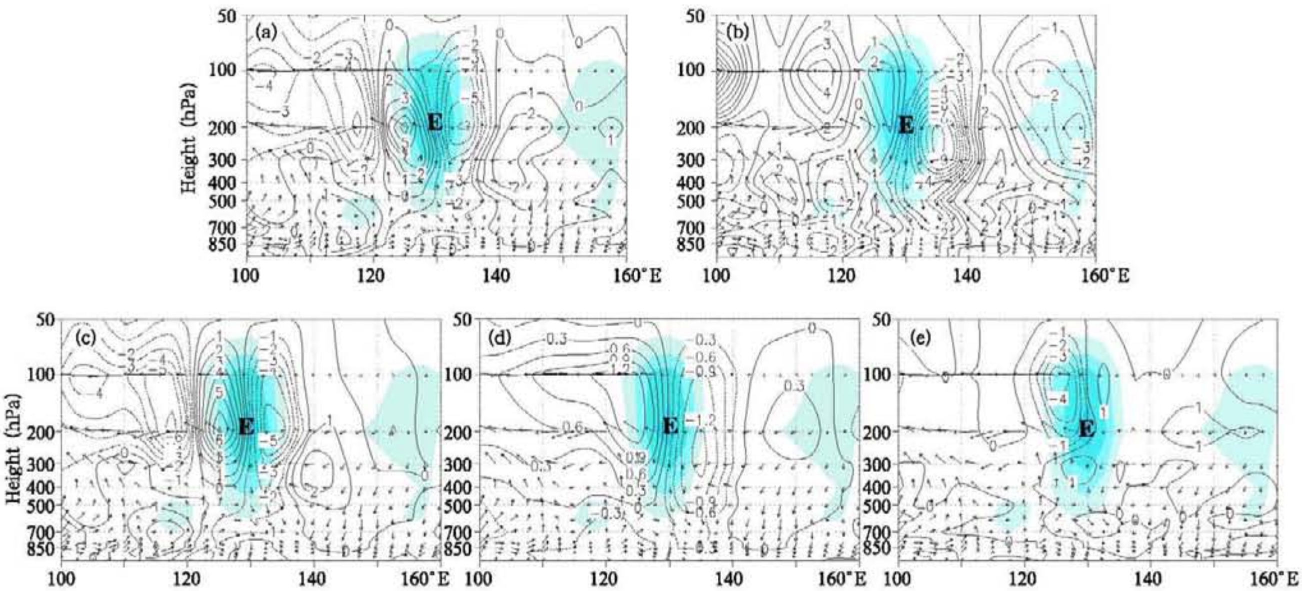

**Fig. 7.** The vertical pattern for all terms in the vorticity equation along 17.5°N on 24 June 2003. (a) $B_1+B_2+C$, (b) DE, (c) $B_1$, (d) $B_2$, and (e) C. E denotes the EV center. Unit: vorticity trend: $\times10^{-10}s^{-2}$; vorticity: $\times10^{-5}s^{-1}$.

It is obvious that the integrated effect of the divergence and advection terms of the EV mainly exhibits in the upper troposphere, among that the contribution from the horizontal vorticity advection is the maximal, and that from the $\beta$ effect is a little bit. Under the influence of the enhancing negative/positive vorticity change rate resulting from the enhancement of the horizontal vorticity advection and the $\beta$ effect terms in the east/west side of the EV, the positive/negative vorticity in the west/east side of the WPSA strengthens in favor of the eastward retreat of the WPSA.

Figures 7, 6c, and 6d illustrate that the eastward retreat of the WPSA is also related to the interaction between the EV and WV. Then how does the interaction between the disturbances in the westerlies/easterlies influence the eastward retreat of the WPSA? The comparison among those terms on the right of Eq. (1) before and after the eastward retreat of the WPSA (Fig. 8) shows that only the horizontal vorticity advection does make the positive contribution to the eastward movement of the disturbance in the westerlies. In the easterlies, all terms make the positive contribution to the westward movement of the disturbance except the absolute vorticity divergence term. The contribution to the vorticity trend from horizontal vorticity advection term (Figs. 8a and 8e) is the maximal. In the west of the center of the EV/WV, it is positive/negative, and vice versa in the east.

On 23 June, there was a negative vorticity advection area, which was corresponding to the westward movement of the WPSA at 500 hPa from South China Sea to the West Pacific along 20°–30°N. On 24 June, the opposite movement of the disturbances in the westerlies and easterlies, which led to the meridional connection of the positive areas of the horizontal vorticity advection along 130°E (Fig. 8e), made the positive vorticity trend $\frac{\partial\zeta}{\partial t}>0$. Because of the equivalent barotropic structure of the EV with deep vertical scale, the evolution of the vorticity trend analyzed above 200 hPa can correspond to the splitting and eastward retreating to the east of 130°E.

Here, we will discuss the contribution from the $\beta$ effect term. The vorticity trend from the $\beta$ effect is $\left(\frac{\partial\zeta}{\partial t}\right)_\beta=-v\beta$, and $\beta>0$, therefore it is only related to the winds in the meridional direction. For the cyclonic disturbance, there is the southerly wind ($v>0$) in its east and the northerly wind ($v<0$) in its west, and thus the vorticity trend from the $\beta$ effect is negative/positive in its east/west side, and the

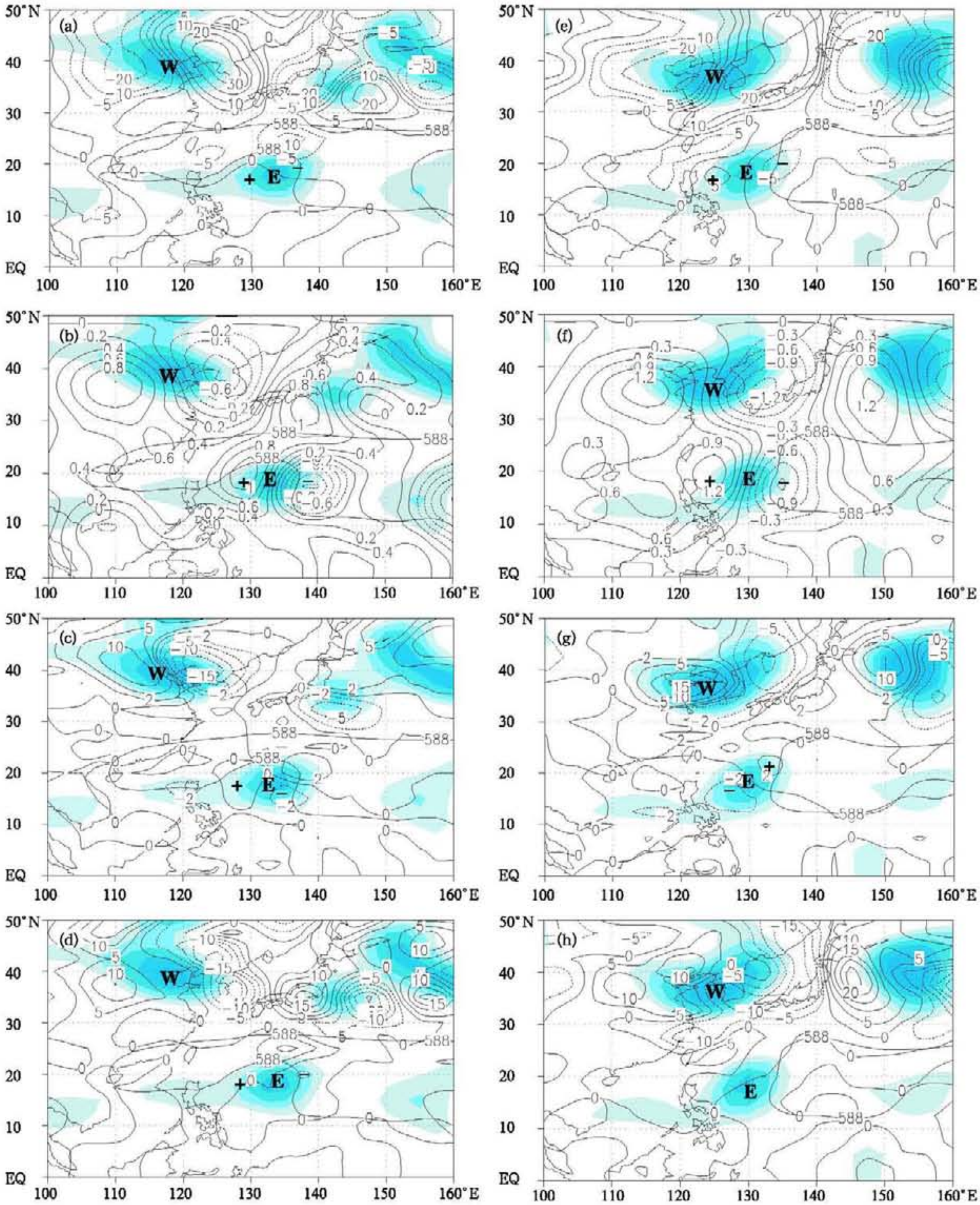

**Fig. 8.** The horizontal pattern for all terms in the vorticity equation at 200 hPa on 23 June 2003 (a–d) and 24 June 2003 (e–h). (a) and (e) for $B_1$, (b) and (f) for $B_2$, (c) and (g) for C, and (d) and (h) for DE. The units and symbols are the same as in Fig. 6.

$\beta$ effect is conducive to the westward advancement of the EV, but not favor the eastward movement of the WV. Compared Fig. 8b with Fig. 8f, it can be seen that although the contribution from $\beta$ effect is a little less than that from the horizontal advection term, it appears to be "barotropic development" (Hoskins et al., 1985), resulting from the separately meridional connection of the positive and negative areas of the $\beta$ effect in the west and east sides of the easterlies and westerlies which means the meridionally in-phase superposition of the south and north wind components in the easterlies and westerlies. On 24 June (Fig. 8f), at 200 hPa, in the east of 130°E, there are negative $\beta$ effect areas, $\left(\frac{\partial \zeta}{\partial t}\right)_\beta <0$, resulting in the enhancement of the negative vorticity in the upper troposphere which is in favor of the maintenance of the WPSA; in the west of 130°E, $\left(\frac{\partial \zeta}{\partial t}\right)_\beta >0$, the enhancement of the positive vorticity in the upper troposphere does not favor the maintenance of the WPSA. In addition, because of the deep structure of the disturbance in the easterlies, the strong positive/negative vorticity change is also in favor of the eastward retreat of the WPSA at 500 hPa.

Before eastward retreat of the WPSA (Fig. 8c), the absolute vorticity divergence term favors the westward movement of the EV, and after that (Fig. 8g), it does not. The absolute vorticity divergence term in the east and west sides of the EV is obviously different before and after the retreat of the WPSA, but it is weaker than the horizontal vorticity advection term in intensity.

For the residual term (Figs. 8d and 8h), it has a contribution similar to the horizontal advection term in favor of the westward advancement of the EV. Therefore it is still deserved to further analyze the twisting term, friction term, and the cumulus effect.

## 4. Summary and discussion

In the summer of 2003, a heavy rainfall appeared over the whole Jianghuai Valley, and the high temperature persisted in Jiangxi and Fujian Provinces of China. These anomalous synoptic processes are directly related to the anomaly evolution of the WPSA. In this study, during the first heavy rainfall process in Meiyu period over the Jianghuai Valley in 2003, by analyzing the relationship among the EV, WV, and the anomaly zonal movement of the WPSA, a possible mechanism was put forward, revealing the interaction between the former two factors and their influences on the latter one. The results are as follows:

(1) During the first heavy rainfall in 2003, in the vicinity of 17.5°N, to the south of the WPSA existed a cyclonic disturbance in the easterlies, and a cyclonic disturbance in the westerlies at 37.5°N to the north of the WPSA. With the westward advancement of the main part of the WPSA, the EV advanced westward, and the WV moved eastward, then rainfall began to strengthen over the Jianghuai Valley. When the EV and the WV moved oppositely to the same longitude (about 130°E), the main part of the WPSA retreated eastward. It indicates that this anomalous zonal movement of the WPSA is closely associated with the low cyclonic disturbance in the easterlies in the south of the WPSA.

(2) The cyclonic disturbance in the easterlies was a deep low pressure system from the mid-upper troposphere to the stratosphere, reaching the maximum intensity at 200 hPa, thermally exhibited the vertical distribution of "warmer in the upper level and colder in the lower level". The boundary of the colder and the warmer distributions was at 200 hPa, and the intensity of the warmer core was stronger than that of the colder one.

(3) The analyses of the vorticity trend equation show that there was a negative/positive vorticity trend in the east/west side of the EV from the whole troposphere upwards to 50 hPa, with its most prominent effect at 200 hPa, and the positive/negative vorticity trend in the east/west side of the WV. When the positive vorticity trend areas in the east of the mid-latitude trough and in the west of the disturbance were connected in the meridional direction, the WPSA obviously weakened in these areas. In the vorticity trend equation, the contribution to the vorticity trend from the horizontal advection term was the maximum, and that from the $\beta$ effect was the minimum. It was also found that the meridional connection of the positive horizontal vorticity advection in the east and west

sides of the easterlies/westerlies, as well as the positive and negative $\beta$ effects resulting in the "barotropic development" was in agreement with the anomalous eastward retreat of the WPSA.

It is seen from the results that the sudden eastward retreat of the WPSA with the pause of the first heavy rainfall over the Jianghuai Valley after the beginning of the Meiyu period in June 2003 is closely related to the disturbance in the easterlies in the upper troposphere in the tropics. Because of a regular movement of the disturbance, the disturbance can be used as a forecasting factor for the short-term evolution of the WPSA. But the above conclusions are only summarized from one case, and the results need to be approved by more cases.

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