CHARACTERISTICS OF ATMOSPHERIC HEATING AND ATMOSPHERIC CIRCULATION DURING ACTIVE PERIOD OF 500 hPa HIGH OVER THE TIBETAN PLATEAU IN SUMMER *

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ABSTRACT

In correspondence with the establishment of the "upper high and lower high" pressure pattern due to the activities of 500 hPa high over the Tibetan Plateau in summer, a series of changes of the East Asia atmospheric circulation will take place. In this paper, the distributions of divergence and vertical velocity of 500 hPa high, the evolutions of atmospheric heat source, the variations of vorticity and zonal wind at 100 hPa level and vertical meridional cell over the Tibetan Plateau etc. are statistically analyzed. Thus, we can see that the ascending motion and the convective heating over the Tibetan Plateau, the South Asia high and the westerly jet on the north of the Plateau at 100 hPa level are weakened. The northern branch and the southern branch of the easterly jet on the south of the Plateau merge into a single whole and situate on the south of the former northern branch. In the meantime, thermodynamic land–sea discrepancy in South Asia and the convective heating over the Bay of Bengal is enhanced. It will play an important role in the maintenance of the easterly jet and the South Asia monsoon.

Key words: atmospheric heating, East Asia atmospheric circulation, 500 hPa high, Tibetan Plateau

I. INTRODUCTION

Commonly, there is a planetary–scale South Asia high in the upper troposphere and there are some synoptic–scale low pressure systems at 500 hPa level in the lower troposphere over the Tibetan (Qinghai–Xizang) Plateau in summer, which is called as "upper high and lower low" pressure pattern. In some cases, all layers from 500 hPa to 100 hPa over the Plateau are controlled by high pressure systems, which is called as "upper high and lower high" pressure pattern as the result of the activities of 500 hPa high pressure systems over the Plateau. These facts have been revealed by many scientists (Yeh and Gao 1979; Sun 1987; Duan et al. 1991; 1992).

During the active period of 500 hPa high over the Plateau, a series of changes of East Asia atmospheric circulation will take place in correspondence with the break of the rain season over the Plateau. By the use of data in 1983, first of all we analyse the characteristics of divergence field and vertical velocity in 500 hPa high, and the relation between the activities of 500 hPa high and the atmospheric heating, after that we compute the 100 hPa vorticity during the active period of 500 hPa high over the Plateau, the mean 100 hPa zonal wind and the vertical cell over the Plateau and its adjacent regions. Comparing them with the mean state of summer, we can obtain some characteristics of East Asia atmospheric circulation during the active period

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of 500 hPa high, that is the establishment of "upper high and lower high" pressure pattern over the Plateau.

II. THE OUTLINES OF THE ACTIVITIES OF 500 hPa HIGH OVER THE PLATEAU IN SUMMER 1983

By the use of ECMWF data in 1983, after statistically computing the mean altitude in every 2.5° grid point at 30, 32.5 and 35°N zones in the range between 75°E and 105°E, we get daily altitude-time variations at 500 hPa level over the Plateau during June to August (figure omitted), which represents the change of altitude at 32.5°N zone over the Plateau. Making a check against the synoptic chart, we can see that there are six times of high pressure processes at 500 hPa level over the Plateau in summer 1983: 15—17 June, 29 June—1 July, 21—24 July, 31 July—9 August, 18—19August, and 23—28 August. The active period of 500 hPa high over the Plateau accounts for 28 days from 92 days of the whole summer. In this paper the active period of 500 hPa high is just defined as the 28 days' mean state.

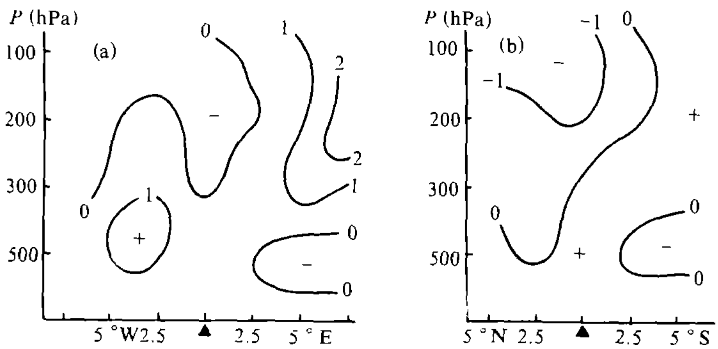

Fig. 1. The zonal (a) and meridional (b) vertical section diagrams of the horizontal divergence through the center of 500 hPa high (▲ shows the center of 500 hPa high, unit: 10^{-5} s^{-1}).

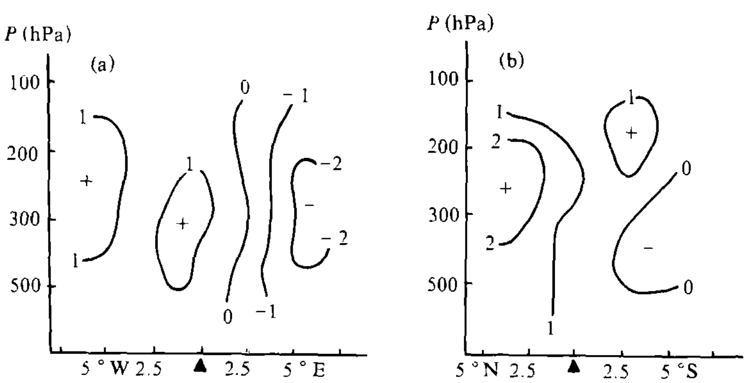

Fig. 2. The zonal (a) and meridional (b) vertical section diagrams of the vertical velocity (unit: 10^{-3} hPa s^{-1}) through the center of 500 hPa high (▲ is the same as in Fig. 1).

III. THE DISTRIBUTIONS OF DIVERGENCE AND VERTICAL VELOCITY IN THE 500 hPa HIGH OVER THE PLATEAU

From the ECMWF data in June—August 1983, we get the daily divergence of every point at each layer (ground, 500 hPa, 300 hPa, 200 hPa and 100 hPa) in area 75—105°E, 25—40°N. And, using the ground altitude given by Berkofsky and Bertoni(1955), we get the vertical velocity by kinematics method, in which the effects of the underlying surface are included. Thus, we obtain the distributions of divergence and vertical velocity in the 500 hPa high by compositive method.

Figure 1 is the vertical section diagram of zonal and meridional mean divergence through the center of 500 hPa high. Figure 2 is almost the same as Fig. 1 but for vertical velocity. At the center of 500 hPa high, there is divergence in the lower troposphere and convergence in the upper, and non-divergence layer is at 300 hPa level. Correspondingly, the descending motion will occupy a dominant position over the 500 hPa high center. On the west and north of the high center, the upper convergence and lower divergence are more obvious, where descending motion is stronger. But on the east and south of high center, lower convergence and upper divergence are obvious, causing the ascending motion. All these show that the activities of 500 hPa high can cause the descending motion over the Plateau especially on the northwest of 500 hPa high center, and then can restrain the convective activities over the Plateau in summer.

IV. THE RELATIONS BETWEEN THE ACTIVITIES OF 500 hPa HIGH AND THE ATMOSPHERIC HEAT SOURCE OVER THE PLATEAU

To investigate the effect of the activities of 500 hPa high on the atmospheric heating over the Plateau, we compute the apparent heat source Q_1 and the apparent moist sink Q_2 in a pentagonal area formed by Deqen, Garze, Golmud, Tuotuohe and Lhasa from the actual data of observation at 08 00 and 20 00 BT in June—August 1983 (see Duan and Reiter 1990). Figure 3 is the daily evolution diagram of Q_1 in June—August 1983. In comparison with the activities of 500 hPa in the lower part of the figure, we can find five strong negative Q_1 over the Plateau

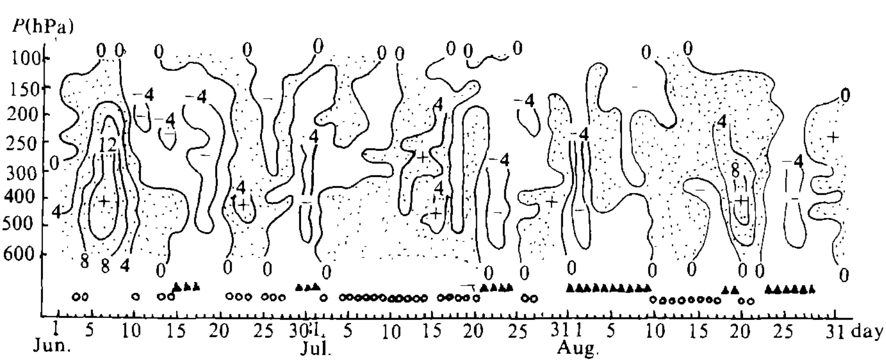

Fig. 3. Altitude–time cross–section of the apparent heat source (Q_1) in June—August 1983 over the Tibetan Plateau (unit: 10^{-5} °C s^{-1}, shaded parts indicate the positive values, ▲ indicates the active date of 500 hPa high and ○ indicates the date when the center of 100 hPa South Asia high is situated over the eastern Tibetan Plateau).

in summer 1983 which all correspond with the five 500 hPa high pressure processes, only one 500 hPa high pressure process during August 18—19 appears in the period when there is a weak negative heat source. The relation between Q_2 and the activities of 500 hPa high is similar (figure omitted). These results are not difficult to understand. Because of the activities of 500 hPa high, the vertical ascending motion and the convective activity over the Plateau are restrained, then the atmospheric heating is changed, leading a reduction of heat source and even the appearance of cold source which is a favorable condition to the activities of 500 hPa high in return.

By the way, we can see that there is close relation between the atmospheric heating over the Plateau and the activities of 100 hPa South Asia high. The small circles in the lower part of Fig. 3 represent the dates of South Asia high centers (including the main and the secondary) to the east of 90°E over the Plateau. There are 40 days occupied by high centers at 100 hPa level on the east of the Plateau in June—August 1983, in which 36 days are corresponded with the heat source below 400 hPa and the rest (26—27 June and 16—17 August) above 300 hPa. This result can further demonstrate that 100 hPa South Asia high is thermodynamical and its center is also in correspondence with the atmospheric heat source.

From Fig. 3, we can get another significant result that the 100 hPa high center on the east of the Plateau can not appear at the same time as 500 hPa high over the Plateau. That is to say, when there is high pressure system at 500 hPa level over the Plateau, there is no possibility for the 100 hPa South Asia high to establish a center on the east of Plateau. This is the inevitable outcome of the changes of heating field due to the activities of 500 hPa high.

V. THE DISTRIBUTIONS OF 100 hPa VORTICITY DURING THE ACTIVE PERIOD OF 500 hPa HIGH

Generally, the distributions of 100 hPa vorticity can reflect the position and strength of South Asia high. Figure 4 indicates the distributions of the mean vorticity at 100 hPa level during the whole summer and during the active period of 500 hPa high, using the ECMWF grid-point data. Their common characteristic is that there is a vast negative vorticity area in the upper troposphere from 20°N to 40°N over the Plateau with the biggest negative value at the zone from the Tibetan Plateau to Iranian Plateau because of the stable control of South Asia high over there. In the figure of the whole summer (Fig. 4a), the biggest negative center is situated at the western Plateau (35°N, 82. 5°E) with the value of -4.2×10^{-5} s^{-1}. The eastward-extended zone of strong negative vorticity can control the central and eastern Plateau. Besides, there is a weaker negative vorticity center over the Iranian Plateau in comparison with the former.

During the active period of 500 hPa high over the Plateau (Fig. 4b), some changes of 100 hPa vorticity will take place: the negative vorticity over the whole Plateau will be weakened, the biggest negative vorticity center over the western Plateau decreases to -3.6×10^{-5} s^{-1}, the negative vorticity zone controlling the central and eastern Plateau is broken, leaving a weaker negative vorticity center with the value of -3.1×10^{-5} s^{-1} over the southeastern Plateau. But the negative vorticity over the Iranian Plateau is strengthened with the increase of central value from -2.8×10^{-5} s^{-1} to -3.2×10^{-5} s^{-1}. In fact, this phenomenon that the 100 hPa vorticity decreases over the eastern part but increases over the western part just reflects the transition of the South Asia high from east pattern to west pattern during the active period of 500 hPa high over the Plateau.

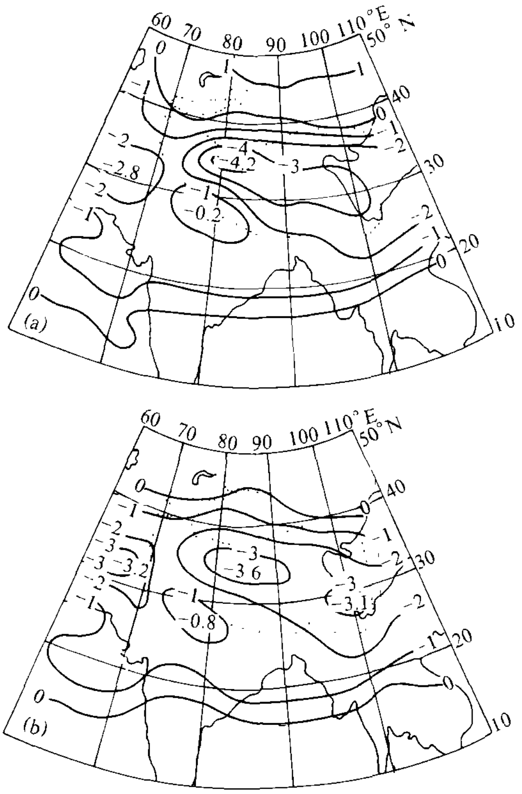

Fig. 4. Distributions of the mean vorticity in summer (a) and during the active period of the 500 hPa high (b) (unit: 10^{-5} s^{-1}).

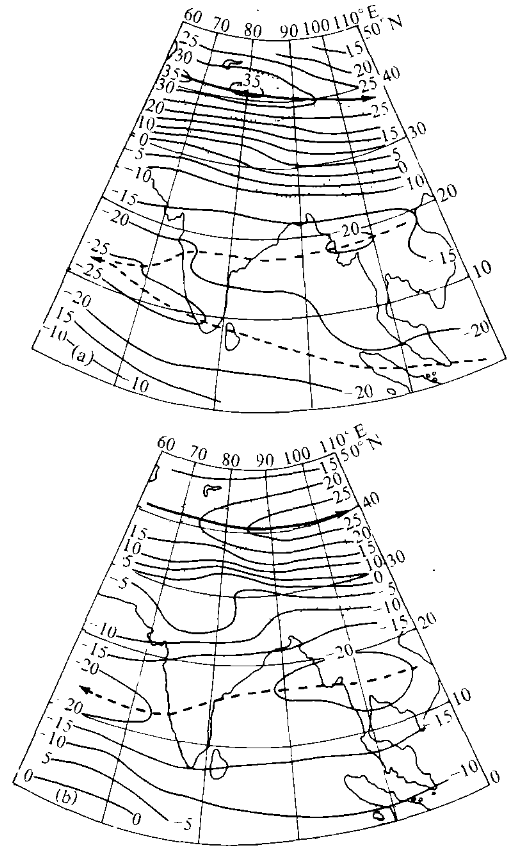

Fig. 5. Distributions of the mean zonal flow at 100 hPa level in summer (a) and during the active period of 500 hPa high (b) (unit: m s^{-1}, the thin line is isotach, the thick solid line is westerly jet and the thick dashed line is easterly jet).

VI. THE DISTRIBUTIONS OF MEAN ZONAL WIND AT 500 hPa LEVEL DURING THE ACTIVE PERIOD OF 500 hPa HIGH

Figure 5 represents the distributions of the mean zonal wind at 100 hPa level during the whole summer and the active period of 500 hPa high over the Plateau. In the figure of the whole summer (Fig. 5a), there is a westerly jet at about 40 °N on the north of the Plateau, the biggest velocity belt on the axis lies along the line from the Salt Sea to the Tianshan Mountain with the value of 35—37 m s^{-1}. There are two branches of easterly jet in the low latitudes of South Asia on the south of the Plateau, the south one is called southern branch of easterly jet which extends to the Arabian Sea through Singapore and Colombo along southeast to northwest with the velocity all over 20 m s^{-1} and that along the line from South India to Arabian Sea over 26 m s^{-1}; the north one called as northern branch of easterly jet is weaker which starts from the Indo-Chinese Peninsula, through Vientiane, Rangoon, the Bay of Bengal and Indian Peninsula, and joins up with the southern branch at the Arabian Sea. The biggest velocity of the northern branch appears near Rangoon with the value of 20 m s^{-1}.

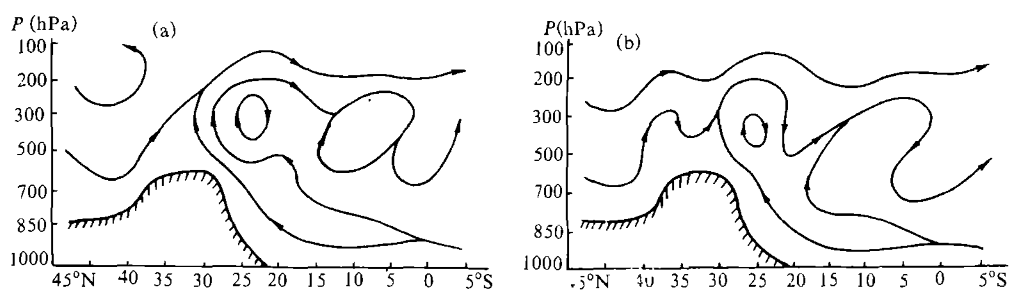

Fig. 6. The mean vertical meridional cell over the Tibetan Plateau and its vicinity in summer (a) and during the active period of the 500 hPa high (b).

During the active period of 500 hPa high (Fig. 5b), a series of changes of zonal current at 100 hPa level will take place, they mainly are: (1) The westerly jet is weakened. The biggest velocity with the value of 26 m s^{-1} appears along the line from Jiuquan to Yinchuan, and the velocity along the line from the Salt Sea to the Tianshan Mountain decreases to 20 m s^{-1} or even smaller. This decrease of westerly jet is related with the evolution of westerly wind circulation at the mid-latitude on the one hand, on the other hand, the restrained convective heating over the Plateau due to the activities of high pressure system at lower layer is another significant cause. (2) The easterly jet is weakened too. The northern branch and the southern branch of the easterly jet merge into a single whole and are situated along the line of about 15°N, on the south of the former northern branch. The strength of its eastern part is similar to that of the former northern branch, but the strength of its western part decreases to 21 m s^{-1} at Arabian Sea. Because the activities of 500 hPa high over the Plateau in summer have changed the characteristics of the atmospheric heating over the Plateau, it is thinkable that the easterly jet on the south of Plateau will be weakened while the 100 hPa vorticity over the Plateau and the westerly jet on the north of Plateau are weakened.

VII. THE CHARACTERISTICS OF THE VERTICAL MERIDIONAL CELL OVER THE SOUTH ASIA AREA DURING THE ACTIVE PERIOD OF 500 hPa HIGH

Figure 6 is the mean vertical meridional cell over the South Asia area during the whole summer and the active period of 500 hPa high. It is obtained by calculating the vertical velocity on each layer at $2.5° \times 2.5°$ grid point in 5°S—45°N, 75—105°E, combining with zonally-averaged meridional wind. In the figure of the whole summer (Fig. 6a), the area in 25—40°N over the Plateau is controlled by ascending motion with the biggest velocity between 25°N and 30°N. There are two small cells in the vast monsoon circulation on the south of the Plateau. One of them situated near the Plateau is composed by an ascending motion from the Plateau and a compensative descending motion on the south of the Plateau, and the other over 10°N may be related with the thermodynamical land- sea discrepancy over South Asia and the convective heating over the Bay of Bengal. But during the active period of 500 hPa high (Fig. 6 b), a series of changes of the vertical meridional cell take place. First, the ascending motion over the Plateau is weakened, even a weak descending motion area appears at about 35°N, so the small cell near the Plateau is weakened. The compensative descending motion between 20°N and 25 °N is somewhat strengthened while the southwest monsoon intruded into the south foot of the

Plateau is weakened in correspondence. This change is obviously caused by the reduction of convective heating over the Plateau. Next, the small cell over 10°N becomes uncomplete while the ascending motion at the north of it is strengthened and the range spreads northward. This change shows that during the active period of 500 hPa high, contrary to the reduction of convective heating over the Plateau the convective heating over the Bay of Bengal is strengthened which plays a significant role in maintaining the easterly jet and even the South Asia monsoon.

VIII. CONCLUSION

Because of the activities of 500 hPa high over the Plateau, the "upper high and lower high" pressure pattern is established, causing the reduction of the ascending motion and atmospheric heating over the Plateau, moreover, leading to the reduction of 100 hPa South Asia high over the Plateau, so the westerly jet on the north of the Plateau is weakened and the northern branch and the southern branch of the easterly jet on the south of the Plateau merge into a single whole situated on the south of the former northern branch. Meanwhile, the thermodynamical land-sea discrepance over South Asia and the convective heating over the Bay of Bengal play an important role in maintaining the easterly jet and even the South Asia monsoon.

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