Impact of Tibetan Plateau surface heating field intensity on Northern Hemispherical general circulations and weather and the climate of China

LI Dongliang (李栋梁), JI Guoliang (季国良) & LÜ Lanzhi (吕兰芝)

Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China

Received July 18, 2001

Abstract The basic climatic characteristics about the Tibetan Plateau surface heating field intensity (TPSHFI) and its anomalous change trend are analyzed by using Lhasa, Yushu and Wudaoliang as the representatves of north-part, east-part and mid-north part of the Tibetan Plateau, respectively. The impact of heating intensity anomalism on NH general circulation and the climate of China is diagnosed.

Keywords: Tibetan Plateau, heating field intensity, general circulation on the Northern Hemisphere, weather and climate anomaly, impact.

The Tibetan Plateau, the highest, largest and the most complex topographical Plateau, has an altitude of over average 4000 m. It stands over the troposphere in the South Asian mainland. Its thermodynamic and dynamical functions exert its influence on the global general circulation evolution as well as on the Chinese and Asian general circulation development. It impacts directly the weather and climatic forming and development, such as the drought and the flood, and other long-range events. From May to August 1979, during the first meteorological scientific experiment[1], the comprehensive study was carried out about the impacts of the Tibetan Plateau on weather and climate of China and its forecasting methods, which is the chief aims of this experiment obtained through the data from added 4 probing stations, 6 heat source observation stations and 1 weather radar observation data in the Plateau. From August 1982 to July 1983, the surface radiation and heat balance observation was conducted. Ji et al.[2,3] calculated the intensity of surface heating field by using the above data again and developed a regression equation:

$$B\text{–}H = a + b\,(\mathrm{Ts}\text{–}\mathrm{Ta}), \tag{1}$$

where a, b are regression coefficients.

Since August 1993, the Wudaoling Surface Energy Budget Observation Station was established in order to study the inter-annual change of the surface heating field and monitor the global change for long-time TPSHFI and supervises the global change for a long time[4].

From May 1998 to August 1998, Chinese scientists originated the second meteorological scientific experiment, named TIPEX[5]. The aims of this experiment were to discover the physical courses of the earth-atmosphere interaction, the boundary layer of Plateau's atmosphere, the structure of troposphere, the course of the cloudy radiation and to further research the effect that the Plateau dynamic and the impact thermodynamic have on general circulation of atmosphere, monsoon, climatic variation, the forming and the development of severe weather. This scientific experiment has created a new situation in the meteorological scientific research about the Plateau.

The study on the thermodynamic function of the Plateau showed that TPSHFI enhances the average trough and ridge intensity of East-Asia general circulation, i.e. high ridge intensified and low trough deepened[6]. Zhang Jijia[7] affirmed through the experiment that the heating intensity anomalism influences the continual torrential rain occurring in the Yangtze River and the Huaihe Basin in summer. Qian Yongfu and his colleagues[8] simulated and pointed out that the thermodynamic function of the Plateau plays an important role in forming 100 hPa Tibetan anticyclone, the disappearance of that southern jet in the early summer and the northward jump of the jet. The heating field of the Plateau and its near places contributed much to the intensity of the eastward wind jet on the upper troposphere and the form of the center of the jet. After Sheng Rujin and his colleagues[9] studied the thermodynamic impact of the Plateau with the model simulating method, he pointed out that the thermodynamic function of the Plateau plays an important role in the forming course of seasonal wind circulation in summer. Meanwhile the Plateau and mainland heating also has impacts on sub-tropic high in the West Pacific. The research carried out by Zhu Fukang and his colleagues[10] showed that the seasonal variation of the general circulation occurring in East Asia in the early summer possibly has something to do with the heating of the western Plateau. Xu Guochang[11] and Li Dongliang[12] chose TPSHFI representative stations in the Plateau with the EOF method based on the calculating equation (1) and set up the TPSHFI climatic sequence. The results showed that TPSHFI has the obvious period of 3 years, 5.5 years and 12 years[11]. TPSHFI has the more intensified duration in winter and impacts on the general circulation occurring in East Asia and the drought in the northwest part of China in the early summer which was proved by Li Dongliang with simulating methods[13,14].

This paper further studies the different change characteristics in the various regional heating intensity and its influence on the Northern Hemispherical general circulation and Chinese climate based on ref. [15].

1 Data and method

According to refs. [11,12], Lhasa and Yushu stations stand for the south and east parts of the Plateau respectively. Eq. (1) obtained from refs. [2, 3] was used to calculate the surface heating field intensity from 1961 to 1999. The Wudaoliang Station stands for the mid-north part of the Plateau, the surface heating field intensity is from the real time observation data from 1980 to 1999. The circulation data are from the Northern Hemispherical 500 hPa monthly average high during 1961—1999; other elements are monthly precipitation and temperature data of 216 stations in China. With correlation methods, the different change characteristics of the various regional surface field heating intensity and their internal relations are studied. With remote-correlation methods, the impact on the Northern Hemispherical general circulation and Chinese climate is also studied.

2 The change characteristics of TPSHFI

2.1 The inter-decade change characteristics of TPSHFI

Figure 1 shows the annual average sequence of TPSHFI. We can find from fig. 1 that the annual average of surface heating field intensity in different regions is not the same. In the south part of the Plateau (fig. 1(a), Lhasa), it basically increased linearly near the 40 years. The turning period from weak to strong was at the end of the 1970s to the early 1980s. The most intensity was in 1997. In the east part of the Plateau (fig. 1(b), Yushu), the change of TPSHFI was divided into two periods: before 1973 it was the trend of going-down, then it rose, but they were both fluctuation around the average period. In the mid-north part of the Plateau (fig. 1(c), Wudaoliang), the change of TPSHFI was only 20 years, for its surface observation started in 1980. The intensified TPSHFI was obvious; its change is similar to that of the south part.

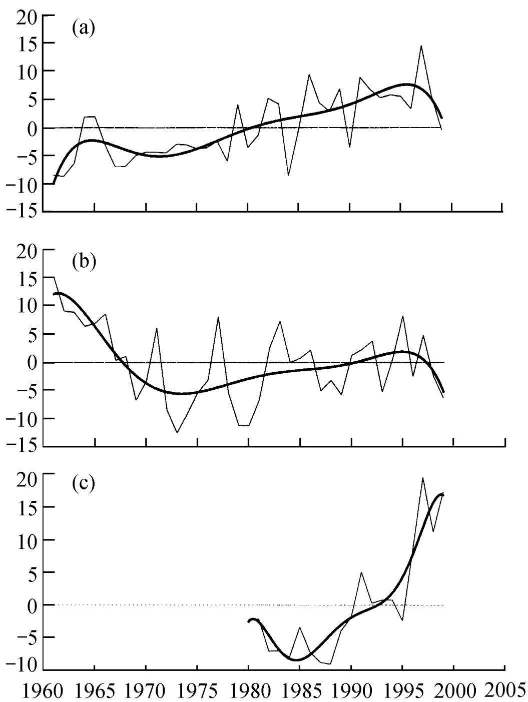

Fig. 1. The annual average surface-heating field intensified on the Plateau (unit: w/m^2). (a) Lhasa; (b) Yushu; (c) Wudaoliang.

Figure 2 shows the average sequence of TPSHFI in winter. Compared with the annual average value, except for the mid-north part of Plateau, TPSHFI in winter has been continually decreasing in the last 40 years, especially in the east part of Plateau. After the 1970s, only in 1980 was it normal but more intensified, in other years it was lower than average value. In the mid-north part of Plateau, the TPSHFI is scarcely changed with time, but TPSHFI in the 1990s was more intensified than that in the 1980s (fig. 3).

The scope of TPSHFI in summer is much larger than that in winter for the inter-annual change, which is connected with the TPSHFI season change itself. Apart from the mid-north parts of the Plateau the inter-annual change trend is the reverse of that in winter. In summer in the south and east part of the Plateau, TPSHFI inter-decade change trend rises mainly from 1961 to 1999, but the inter-annual change is obviously reverse, which is consistent with the sensible heat in this place[15].

From the above analysis, we can find that TPSHFI has an obvious inter-decade change trend, but it is different for different areas and seasons.

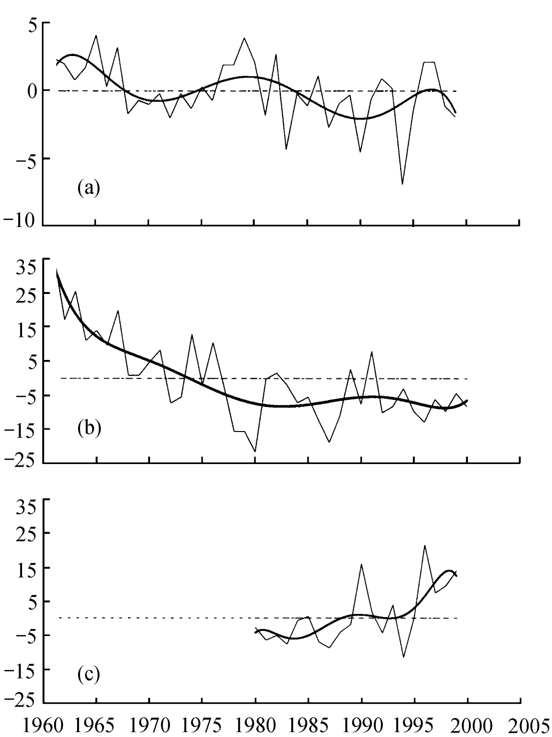

Fig. 2. Same as in fig. 1 but for winter.

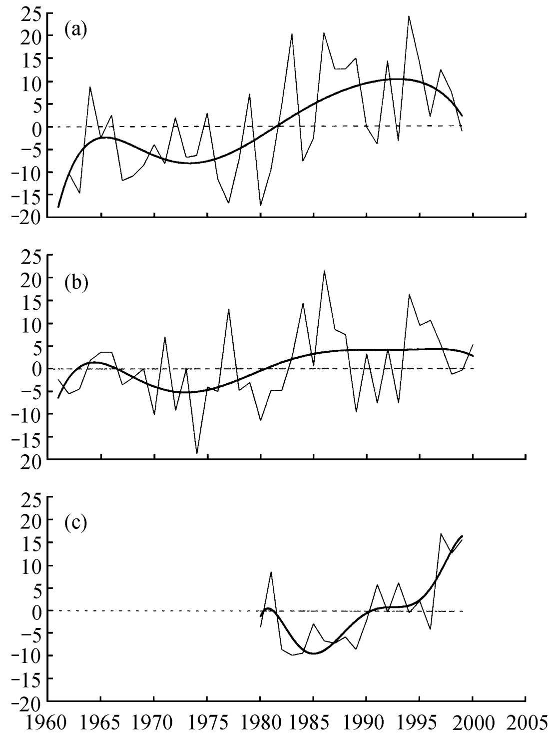

Fig. 3. Same as in fig. 1 but for summer.

2.2 The consistency among different regional TPSHFI change

There are different change trends in different areas and seasons from the above inter-decade change trend. For further study about this characteristic, the co-correlation coefficient is examined (table 1). The south part (Lhasa representative station) and the east part (Yushu representative station) of the Plateau have different correlative degrees, but the total correlation degree is better, except in Step. (– 0.24). In Mar., Jul., Aug., Nov., Dec., the confidence level is over $\alpha_{0.05.}$ The mid-north and south part has weak correlation with the east part; the confidence level is lower than $\alpha_{0.05.}$ In the view of the annual change consistency, the reverse phase is between the mid-north part, the east and the south of the Plateau in summer, the weak consistency in other seasons. These are consistent with the new results of Ji et al.[16].

Table 1 The correlation coefficient of different regional TPSHFI

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
L&Y	0.23	0.27	0.35	0.10	0.11	0.13	0.34	0.35	-0.24	0.25	0.35	0.36
W&L	0.12	0.16	0.18	0.29	0.13	-0.38	-0.02	-0.07	0.24	0.34	0.24	0.31
W&Y	–0.41	0.25	0.04	-0.17	0.03	-0.11	0.21	-0.36	-0.27	0.14	-0.19	-0.20

L: Lhasa ,Y: Yushu, W: Wudaoliang, when N–2=37, $\alpha_{0.05}$=0.33, $\alpha_{0.01}$=0.44; when N–2=18, $\alpha_{0.05}$ = 0.44, $\alpha_{0.01}$=0.56.

2.3 The duration of different regional TPSHFI

In order to study the duration of different regional TPSHFI, table 2 shows the self-correlation coefficient, which lags behind one month. Generally, TPSHFI shows the better duration. In Lhasa from Mar. to Apri., and from Jun. to Oct. the self-correlation coefficient lasting one month reaches $\alpha_{0.05.}$ In Yushu except from Oct. to Nov. and in Wudaoliang from Aug. to Step. every monthly duration is good.

Table 2 The lag self-correlation coefficient of different regional TPSHFI

Station	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sept	Sept-Oct	Oct-Nov	Nov-Dec	Dec-Jan
L	0.12	0.21	0.37	0.18	0.22	0.38	0.31	0.42	0.49	0.27	0.11	0.22
Y	0.31	0.66	0.44	0.49	0.51	0.20	0.58	0.36	0.52	0.18	0.77	0.83
W	0.60	0.45	0.74	0.80	0.80	0.78	0.47	0.22	0.79	0.66	0.56	0.57

As in table 1.

3 The research on the effect of TPSHFI

According to the analysis above, we can see that in the change of TPSHFI, the south of Tibetan Plateau has close consistency with the east of the Plateau. But we lack enough data about that of the middle and the north, the correlation between them is not obvious, so, this paper puts emphasis on the cooperative effect between the south of the Tibetan Plateau and the east of it in the research of TPSHFI. In other words, after getting the average sequence of TPSHFI of Lhasa and Yushu, we can use it to calculate the correlative coefficient among TPSHFI, circulation and precipitation and air temperature of China.

3.1 The effect on 500 hPa of TPSHFI

Because the Tibetan Plateau has an elevation of over 4000 m, the surface heating has direct influence upon the atmosphere in the middle troposphere. It mainly causes important effect that TPSHFI brings to the general circulation.

There are two centers for the polar vortex on the average Northern Hemisphere 500 hPa in winter: the stronger one is located over Baffin Bay that is in the west of the Greenland and the weaker one along the Arctic Ocean which is in East Siberian. The shape of the average circulation is three wave patterns, three average troughs are located in the east coast of Asia, the east coast of North-America, and over Europe of the west of Ural, respectively. The last one is weaker than the former two. Three average ridges are located in the longitude of Alaska, coast of west Europe and Bail area, respectively, in which the ridges over the east of the two oceans are stronger[17]. In fig. 4(a), the correlative coefficient between TPSHFI in Jan. and 500 hPa high in Northern Hemisphere at the corresponding period is shown; we can see that the main correlative areas are negative correlation in the east coastal area of the East-Asia continent, positive correlation in the west of Bail to the west of the Plateau, and the obvious negative correlative area is of Europe, that is, when TPSHFI in winter is stronger, it makes 500 hPa system in Northern Hemisphere at the corresponding period strengthen and move west. The concert expressions are that the big East-Asia trough becomes unusually deeper, and the location is to the west, and the Tibet-Xinjiang ridge strengthens and moves west, European trough is unusually deeper.

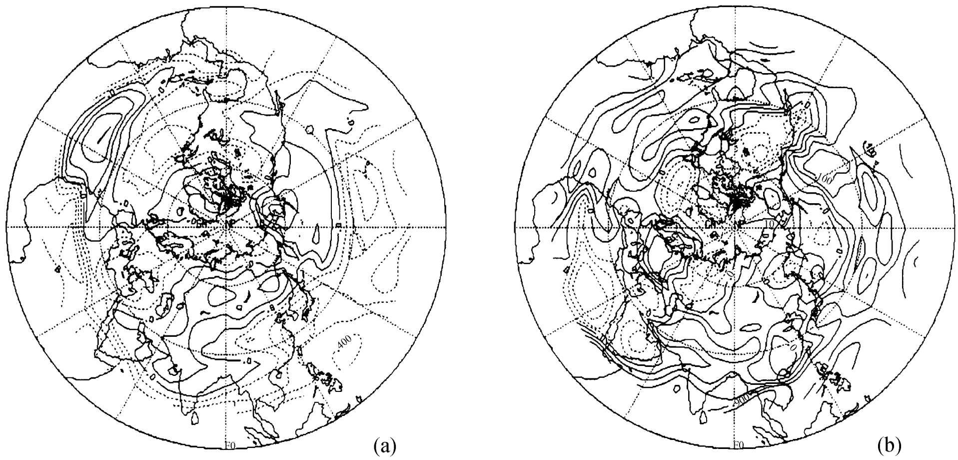

Fig. 4. The corresponding coefficient between TPSHFI and 500 hPa ((a) Jan.; (b) July, the same below).

The corresponding correlative coefficient between TPSHFI in July and Northern Hemisphere 500 hPa high is positive correlation on the Tibetan Plateau–North China, negative correlation on Ural, it is the positive correlation on Europe and it is negative correlation on the Yangtze River basin and Northeast of China, i.e. when TPSHFI in summer is unusually stronger Ural ridge becomes weaker, the European trough filling up West Pacific Subtropical High is to the south, the Tibetan Plateau ridge becomes stronger. The Plateau makes the surface heat go up through correlative action. As a result, the 500 hPa height rises on the Plateau and its surroundings and it is positive correlation. Meanwhile, there is two wave trains originating from the Plateau in the teleconnection fields, one points to the northwest and the other to the northeast, obviously the latter has effect on the weather of China in summer.

3.2 The effect on 100 hPa of TPSHFI

The correlation between TPSHFI in Jan. and Northern Hemisphere 500 hPa high is shown in fig. 5(a). It is known that the anomaly of the middle latitude is the two wave pattern and anomaly ridge located in the south of Greenland and Aleutian Islands, the two anomaly troughs are in Europe and North America respectively. The former is to the west and to the south. The latter is close to the average location of the middle polar vortex in the troposphere. The strengthening of TPSHFI in winter benefits the rise of the high latitude height in the upper troposphere and the weakening of the polar vortex. The horse latitude high becomes weak, in accordance with the drop of the altitude field of the low latitude. The location of the upper air Jet flow is to the south.

In summer (in July) (fig. 5(b)), the outstanding characteristics between TPSHFI with Northern Hemisphere 500 hPa highs are that when TPSHFI becomes stronger, the high on South Asia is unusually strong, the center is on the Tibetan Plateau (correlative coefficient is +0.49), geopotential high is lower on Kanchatka Peninsula; the low on North American is stronger. The polar vortex is located on the Greenland Sea-Barren Sea and the Sub-tropic High becomes stronger.

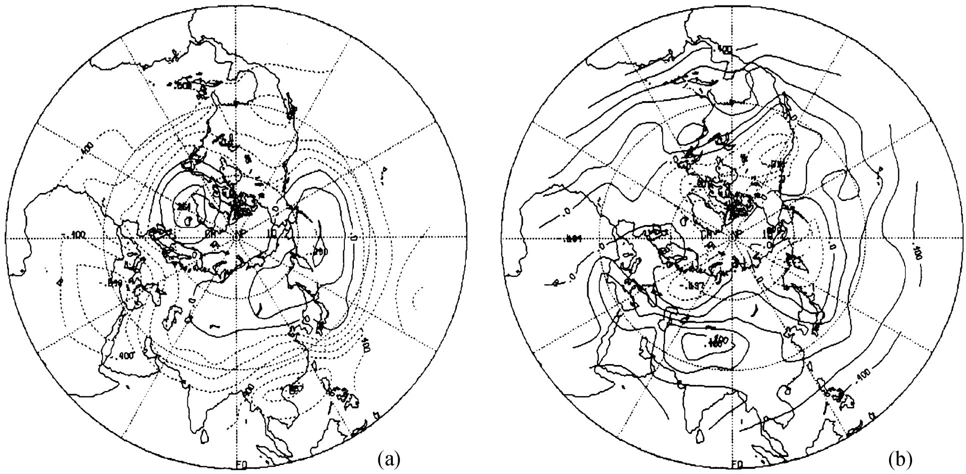

Fig. 5. As in fig. 4 but for 100 hPa.

4 The analysis of climate anomaly of China

From the discussion above, it is known that the unusual TPSHFI is responsible for the corresponding unusual general circulation in the Northern Hemisphere. It also causes the unusual adjustment of 500 hPa height long wave train in the middle troposphere. In 100 hPa on the upper troposphere, its main expression is that the South-Asia anticyclone and the polar vortex is alternatively unusually strong or weak. In order to further study the effect of TPSHFI on the weather anomaly of China, the correlation between TPSHFI and precipitation and temperature of 216 stations in the same period were calculated.

4.1 The effect on precipitation and temperature in winter

In winter, TPSHFI goes down obviously in the south and east of the Tibetan Plateau. What kind of effect does this change have on the weather anomaly of China? To explain it, the correlative coefficient between TPSHFI in Jan. and the corresponding monthly precipitation and temperature are shown in fig. 6. We can see that when TPSHFI is stronger in winter, the precipitation in China reduces unusually, the poor rain area is located in Dongting Lake and Poyang Lake of China (correlation coefficients − 0.4—− 0.6), but it may be more in the southwest of China, the source regions of the Yangtze River and the Yellow River, the east part of Northwest China, the center of Inner Mongolia and the north part of Northeast China (correlation coefficients is 0.2—0.3) (fig. 6(a)). At the corresponding period, the average monthly temperature in China is low (correlative coefficient is 0.2). The main low temperature areas are located in the mid and north of the Tibetan Plateau, the source regions of the Yangtze River and the Yellow River, the Northeast and the south of China (fig. 6(b)), The direct reason is shown in fig. 4 that in accordance with the unusual strengthening of TPSHFI in winter, the Tibetan-Xinjiang ridge strengthens and East Asia trough becomes unusually deep, its location is to the west, the location of upper jet stream is to the south, and the Northwest of China, North China are controlled by the strong northwest airflow. So, it is drought and lacks rain, and cold air goes frequently.

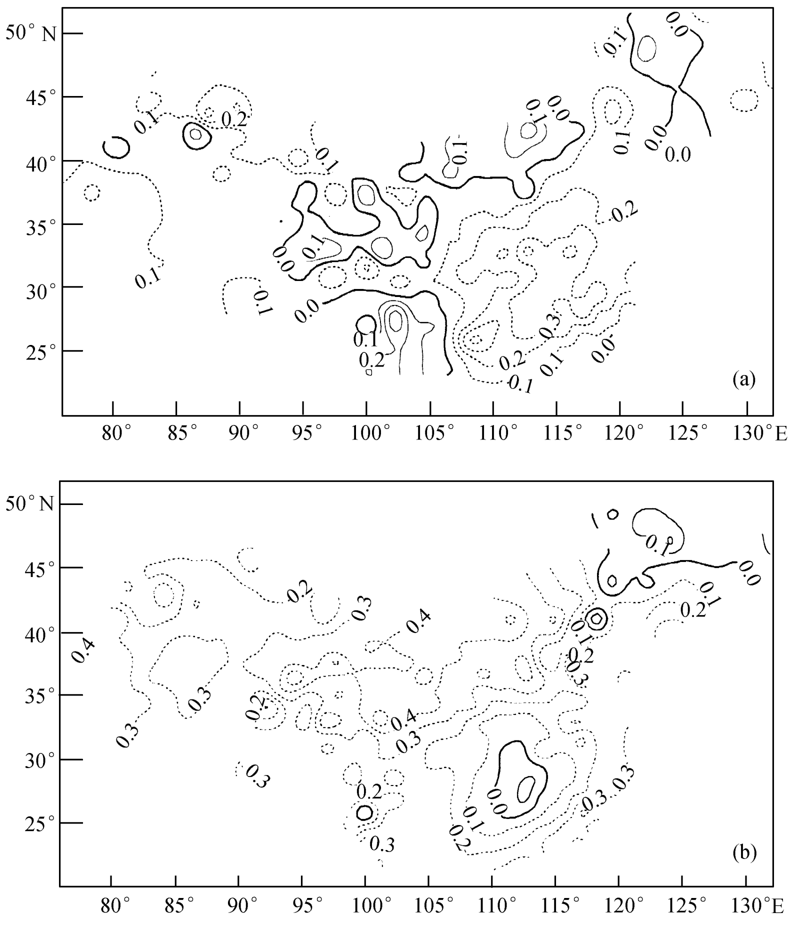

Fig. 6. The correlation coefficient of TPSHFI and the corresponding precipitation and temperature in Jan.

4.2 The effect on the precipitation and temperature in summer

Fig. 7 shows the correlation coefficient of TPSHFI in July and the corresponding monthly precipitation and air temperature in China. It is known that when TPSHFI is stronger in summer, it can make more precipitation in the Yangtze River area. Besides, most places of Northeast China, the west of Xinjiang may be rainy. The Tibetan Plateau, Northwest China, North China are drought. The average monthly temperature is lower than usual in the middle reaches of the Yangtze River, Northeast China, the west of Xinjiang. High-temperature area will appear from the Tibetan Plateau to the Hexi Corridor. The type of the weather anomaly is corresponding to wave train originating from the Plateau and pointing to the northeast as shown in fig. 4(b).

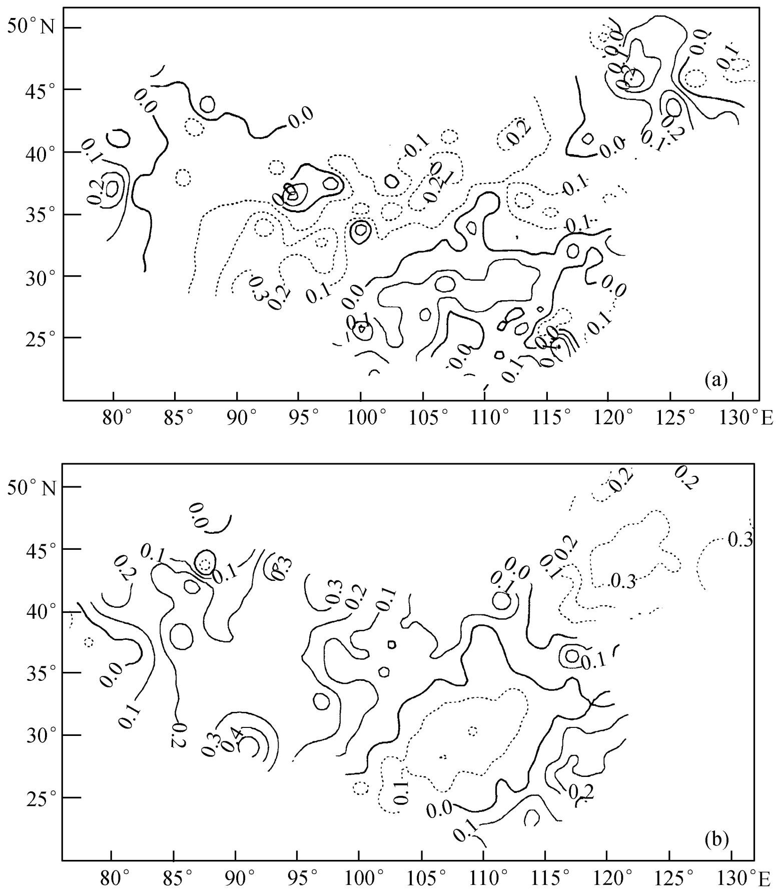

Fig. 7. As fig. 6 except for in Jul.

5 Conclusion and discussion

(1) TPSHFI has an obvious inter-decade change, but in different seasons, such changes are different and the south and north of the Tibetan Plateau have opposite inter-annual changes.

(2) The departure index of the average TPSHFI in Lhasa and Yushu stations shows the basic state of surface condition of southern and eastern Tibetan Plateau.

(3) The unusual increase of TPSHFI in autumn, winter and spring gives rise to the lower air temperature and the increase of precipitation in the source regions of the Yangtze River and the Yellow River. On the other hand, it is good for snow accumulation, can inhibit the plant diseases and insect pests, and protect the ecological environment.

References

1. Zhang, Jijia, Zhu Baozhen, Zhu Fukang et al., Development in Tibetan Plateau Meteorology (in Chinese), Beijing: Science Press, 1988.
2. Ji Guoliang, Yao Lanchang, Yuan Fumao et al., Characteristics of surface and atmospheric heating fields over Qing-

hai-Xizang Plateau during the winter in 1982, Scientia Sinica, Series B, 1986, 29(8): 876—888.

3. Ji Guoliang, Pu Ming, Xi Yunyu, The characteristics of the surface and atmospheric heating fields over the Qinghai-Xizang Plateau in summer of 1983, Plateau Meteorology (in Chinese), 1986, 5(2): 155—166.
4. Ji Guoliang, Jiang Hao, Zou Jiling et al., Characteristics of surface radiation budget in Wudaoliang region, The Collected Papers for Studies on the Formation, Evolution, Environmental changes and Ecosystems of the Tibetan Plateau (1995) (in Chinese), Beijing: Science Press, 1996, 211—217.
5. Tao Shiyan, Chen Lianshou, Xu Xiangde et al., Study Advanced of the 2nd TIPEX (1) (in Chinese), Beijing: Meteorological Press, 1999.
6. Ye Duzheng, Zeng Qingcun, Guo Yufu, Current Research in Climate (in Chinese), Beijing: Meteorological Press, 1991, 152—160.
7. Zhang Jijia, Li Weijing, Xu Xiangde et al., The experiment of deaf with $T_{42}L_9$ model for dekad and monthly mean circulation anomaly during the summer heavy rainfall period in 1991, Acta Meteorollgica Sinica (in Chinese), 1994, 52(2): 180—186.
8. Qian Yongfu, Yan Hong, A.P.E. Numerical weather prediction model with large-scale orography, Scientia Atmospheric Sinica (in Chinese), 1978,2(2): 91—102.
9. Sheng Rujin, Ji Liren, Chen Yuxiang et al., Numerical simulation experiment for the thermal effect in summer on the Tibetan Plateau, The Collected Papers of QXPMEX (3), Beijing: Science Press, 1987, 181—190.
10. Zhu Fukang, Zhao Wei, The observational facts for the effect of surface net radiation on the general circulation, The Collected Papers of QXPMEX (3) (in Chinese), Beijing: Science Press, 1987, 54—61.
11. Xu Guochang, Li Dongliang, Chen liping, The climatic characteristics of surface heating fields over the Qinghai-Xizang Plateau, Plateau Meteorology (in Chinese), 1990, 9(1): 30.
12. Li Dongliang, Chen Liping, The relation of surface heating fields over the Tibet Plateau to the East Asian circulation and the early summer drought in northwest of China, Quart. J. of Applied Meteorology (in Chinese), 1990, 1(4): 383—391.
13. Li Dongliang, Xie Jinnan, Wang Wen, A study of summer precipitation features and anomaly in northwest China, Scientia Atmospheric Sinica (in Chinese), 1997, 21(3): 331—340..
14. Li Dongliang, Xie Jinnan, Zhao Zhonglian et al., A Diagnosis and numerical experiment of responses about summer temperature change in northwest China on surface sensible heat anomaly in the Qinghai-Xizang Plateau, Climatic and Environmental Research (in Chinese), 1997, 2(4): 377—386.
15. Li Dongliang, Zhang Jijia, Wu Hongbao, A diagnostic study on surface sensible heat flux anomaly in summer over the Qinghai-Xizang Plateau, Plateau Meteorology (in Chinese), 1997, 16(4): 367—375.
16. Zhang Jijia, Ge Lin, Sun Zhaobo, Mid-Long-Range Weather Forecast Basis (revised version) (in Chinese), Beijing: Meteorological Press, 1994, 1—36.
17. Ji Guoliang, Shi Xinghe, Gao Wuxiang, The variation of surface heating field over the Northern Tibetan Plateau and its effect on the climate, Plateau Meteorology (in Chinese), 2001, 20(3): 239—244.