The Wave Train Characteristics of Teleconnection Caused by the Thermal Anomaly of the Underlying Surface of the Tibetan Plateau. Part I: Data Analysis

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ABSTRACT

The effect of the thermal anomaly of the underlying surface of the Tibetan Plateau in the previous winter and spring on the precipitation over the middle and lower reaches of the Yangtze River (MRYR) in the subsequent summer was investigated. Through data analysis, the influence of "strong signal" features of the three-dimensional thermal anomaly of the Plateau upon the precipitation anomaly over MRYR in the subsequent summer was revealed. This feature of the signal shows that from 0 cm to 320 cm under the surface of the ground, the soil temperature anomalies of the Tibetan Plateau manifest out of phase distribution in flood years and drought years over MRYR. In flood years over MRYR, there is a positive soil temperature anomaly in the region of the southern Tibetan Plateau (to the south of 30°N) and a negative anomaly in the region of the middle and northern Tibetan Plateau (to the north of 30°N), while in drought years the distribution of the soil temperature anomaly is opposite to the one in flood years. The maximum value of the soil temperature anomaly lies in the levels between 40 cm and 160 cm under the surface of the ground. Meanwhile, the data analysis also shows that the general circulation in the Northern Hemisphere may respond to the thermal anomaly of the Tibetan Plateau and form the propagation of a low frequency wave train with a seasonal time scale, and this wave train may affect the precipitation over MRYR in the subsequent summer. Analyses reveal that the thermal anomaly of the underlying surface of the Tibetan Plateau in the previous winter and spring is one of the key influencing factors for the subsequent summer precipitation over MRYR.

Key words: the Tibetan Plateau, thermal anomaly, the middle and lower reaches of the Yangtze River (MRYR), precipitation anomaly

1. Introduction

The Tibetan Plateau accounts for one quarter of China's area and whose average altitude is about 4000 m above sea level. It is the largest plateau, with the most complicated terrain in the world. Both operational work and scientific research in recent years have shown that the Tibetan Plateau, acting as a powerful forcing source, has dynamical and thermal effects on the general atmospheric circulation. The underlying surface of the Tibetan Plateau directly heats the troposphere due to its rising terrain height and large area. Therefore, meteorologists in China and abroad have been attracted to study the thermal function of the Tibetan

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Plateau. The studies of Nitta (1983) and Yanai et al. (1992) indicated that the heating of the atmosphere due to the Tibetan Plateau plays an important role in the Asian monsoon system. Flohn (1968) also pointed out that the heating of the Tibetan Plateau is the main mechanism for the onset and maintenance of the summer monsoon, and this heating is strongly affected by the sensible heat and latent heat release over the Tibetan Plateau. Zheng and Wu (1995) and Gao et al. (1990) studied the role of the Tibetan Plateau during the seasonal transition of early summer in East Asia. Their results showed that the heating of the Tibetan Plateau prompts the northward shift of the subtropical westerly jet stream. Many research results show that the heating of the underlying surface of the Tibetan Plateau plays an important role in the formation and variety of the atmospheric circulation. The second Tibetan Plateau Experiment (TIPEX) in 1998 obtained new data on the radiation balance and the intensity of the heating source, which favors the study of the heat role of the Tibetan Plateau.

Soil temperature and humidity directly affect the exchange of the sensible heat and latent heat between land and air. Through analyzing the soil temperature and precipitation data, Tang et al. (1986, 1987) found that there is a remarkable correlation between the soil temperature (from 80 cm to 320 cm under the ground surface) and the subsequent precipitation in the same region and its adjacent region, i.e., the higher (lower) the soil temperature in the prophase, the more (less) precipitation in the later stage. The deeper the underground levels of the soil temperature anomaly, the longer the lag influence time for subsequent precipitation. They considered that this phenomenon is the result of energy feedback between the land and atmosphere in the vertical direction. This feedback may create vacillation with a period of several months, and the correlation between soil temperature and precipitation is the result of this energy feedback. The study of Tang et al. (1986) also pointed out that there is a time lag correlation between the soil temperature of the Tibetan Plateau and subsequent precipitation, and the distribution of the rain belt over East China was controlled by the previous winter's location of the disturbed thermal source–vortex over West China (Liu and Tang 2001). Tang et al. (2000) also discussed the gestation process of severe flooding along the Yangtze River and the Huanghe River from the viewpoint of quick evolvement of the solid–earth. They thought that the intensive development of the thermal earth vortex is the direct cause of the severe flooding, and the thermal earth vortex usually develops in the east region of the Tibetan Plateau.

Zhang et al. (1995) had studied the relationship between the anomalous thermal forcing of the Tibetan Plateau and the anomalous distribution of cloud fraction. They revealed some correlation characteristics between the thermal forcing of the Tibetan Plateau and the cloud fraction, and pointed out that there is obvious correlation between the atmospheric circulation and the thermal status of the Tibetan Plateau. In the early stage, a proper temperature increase (including its area and strength) in the Tibetan Plateau is favorable to the formation and maintenance of the Meiyu circulation pattern in East Asia in the subsequent summer. Therefore, the anomalous thermal forcing of the underlying surface of the Tibetan Plateau can result in the formation of the rain belt along MRYR, thus, the thermal anomaly of the underlying surface of the Tibetan Plateau is an important factor for persistent precipitation along MRYR in the summer. Up to now, though there have been many studies about the thermal function of the Tibetan Plateau and its effect on weather and climate, the study of the soil temperature anomaly in the early stage in the Tibetan Plateau and how it affects the subsequent precipitation over MRYR is still not enough, and the mechanism needs further

clarification. In this paper, the thermal anomaly of the underlying surface of the Tibetan Plateau in the previous winter and spring and its effect on the subsequent precipitation over MRYR in the summer are analyzed and discussed.

2. Data and objective analysis method

The data used in this paper include soil temperature, precipitation, air temperature and the 500 hPa geopotential height field. The 9 levels of soil temperature data, given by over 300 stations from 1961 to 1990 and over 600 stations from 1991 to 1995, are 0 cm, 5 cm, 10 cm, 15 cm, 20 cm, 40 cm, 80 cm, 160 cm, and 320 cm under the ground surface. The precipitation and air temperature data are given by 160 stations in China, spanning 1961 to 1995.

The Cressman objective analysis method is used in the paper for interpolating station data to gridded data.

The rainfall (R) and its anomaly percentage (RAP) over MRYR (where 17 stations are selected as representatives) are calculated from 1961 to 1995. A year is denoted a flood year when its RAP is 20 percent or greater, a drought year when its RAP is −20 percent or less, and a normal year otherwise. According to this criterion, from 1961 to 1995, the drought years over MRYR in the summer (June, July, and August) are seven (1961, 1966, 1967, 1976, 1978, 1981, and 1985), and the flood years are five (1969, 1980, 1983, 1991, and 1993). Note, however, that an exception to this rule is made for 1968. Even though the RAP in 1968 is less than −20 percent, this year is defined as normal considering that more precipitation fell to the south of the Yangtze River that year.

3. The anomalous thermal signal features of the underlying surface of the Tibetan Plateau

First, the correlation coefficient between the 9 soil temperature levels in the previous winter and spring in China and the precipitation over MRYR in the subsequent summer are calculated. The correlation between the land–air temperature difference in the previous winter and spring in China and the precipitation over MRYR in the subsequent summer are also calculated (correlation figures omitted). From the ground surface to 320 cm below, the correlation coefficients in the Tibetan Plateau are relatively higher than in other regions. This indicates that the thermal anomaly of the underlying surface of the Tibetan Plateau in the previous winter and spring may affect the precipitation over MRYR in the subsequent summer.

In the winter and spring preceding a year of summer drought (flood) over MRYR, the land–air temperature difference is a little higher (lower) in the south of the Tibetan Plateau and a little lower (higher) in the north of the Tibetan Plateau, (figures omitted). In Fig. 1, the distribution of soil temperature anomaly at 40 cm under the ground surface also takes on the analogous pattern. Especially, in the middle, east and southeast of the Tibetan Plateau, the contrary anomaly distribution of the soil temperature is very obvious for summer drought and summer flood years over MRYR. From the correlation (figures omitted) of the soil temperature in China with the precipitation over MRYR and from the anomaly of the soil temperature (including the land–air temperature difference), it is very clear that the correlation field is similar to the anomaly field of the soil temperature in flood years, but opposite to that in drought years. The Tibetan Plateau is an overlapping region of high correlation (the correlation between the soil temperature and the precipitation over MRYR) and an out–of–phase soil temperature anomaly (the sign of the anomaly is opposite in drought years and versus

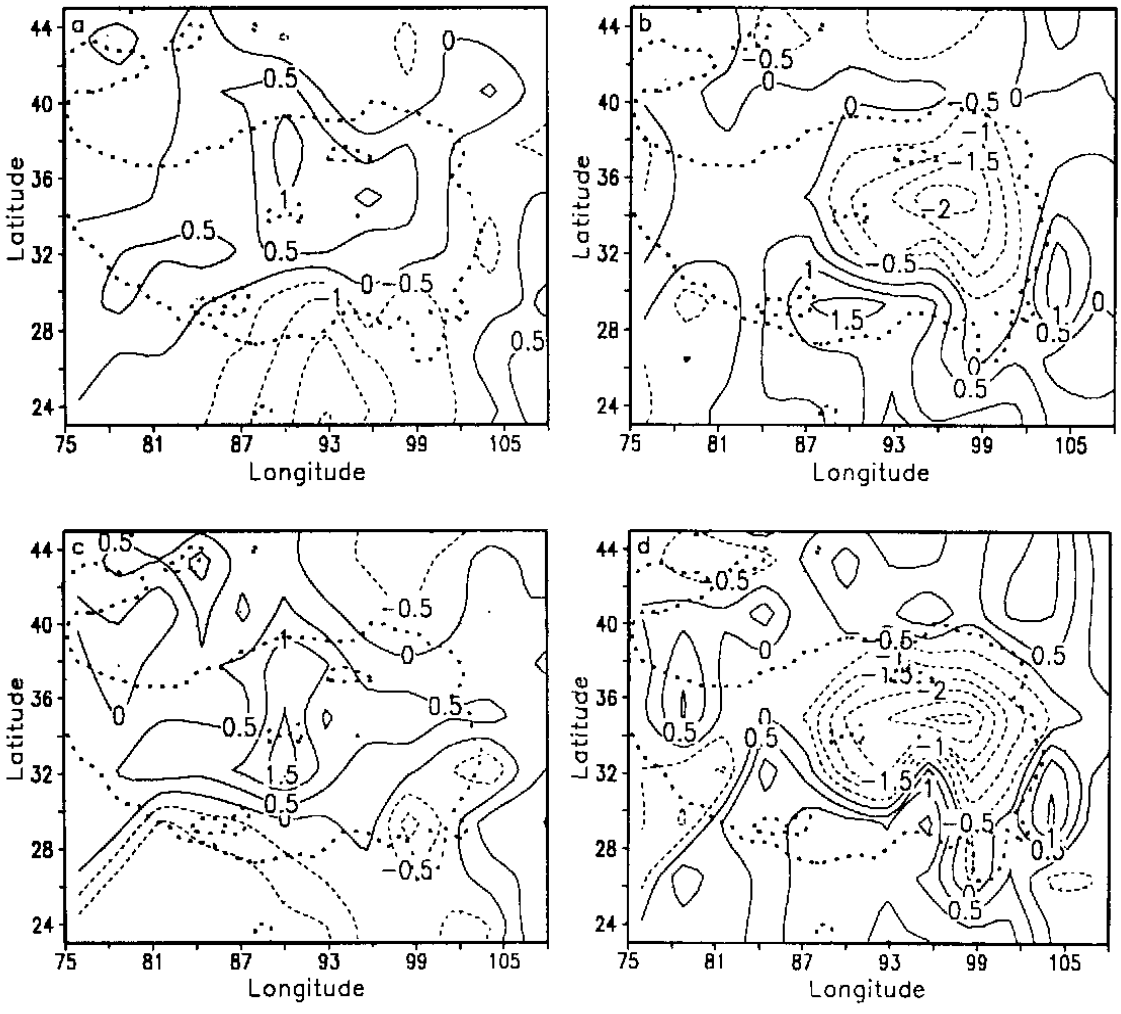

Fig. 1. The distribution of soil temperature anomaly at 40 cm under the ground surface in the Tibetan Plateau in the previous winter and spring before the drought or flood occurs over MRYR in the subsequent summer. Dotted line: the profile of the Tibetan Plateau at 3000 m. (a) In winter before drought years, (b) in winter before flood years, (c) in spring before drought years, (d) in spring before flood years. units: °C.

flood years). The thermal anomaly of the underlying surface in the previous winter and spring is a "strong signal" for the precipitation anomaly over MRYR in the subsequent summer.

4. The three–dimensional thermal anomaly distribution of the underlying surface of the Tibetan Plateau

Tang et al. (1987) showed that the oscillation period of soil temperature became longer with increasing depth, and that short period weather variations affect the shallow levels underground, while the long period weather variations affect the deeper levels. Therefore, the soil is just a good filter, and the soil temperature of different levels can be used to forecast weather with different time–scales. The soil temperature at deep levels may affect long–term synoptic processes. Based on this, the persistent anomaly of soil temperature in the Tibetan Plateau should not be neglected for its impact on synoptic and climatic systems. Fig. 2 also

shows that from the ground surface to 320 cm under the ground, the distributions of the soil temperature anomalies in the south of the Tibetan Plateau and the middle and north of the Tibetan Plateau are out of phase. In the south of the Tibetan Plateau (26°–30°N, 88°–104°E), where the soil temperature in the previous winter and spring is higher (lower), a flood (drought) year would occur along MRYR in the subsequent summer. In the middle and north of the Tibetan Plateau (30°–38°N, 88°–104°E), the anomalous signal is opposite to the one in the south of the Tibetan Plateau. From the values of the regional averages, from 160 cm to 320 cm under the ground surface, the fast variations of the anomaly in both drought and flood years occur in the middle and north of the Tibetan Plateau and the slow variations occur in the south of the Tibetan Plateau, but the amplitude of the anomalous variation is not large, generally around 0.1°C / 160 cm. The highest anomaly region occurs at levels from 40 cm to 160 cm below, where the absolute value of the anomaly is not less than 0.4°C and the maximum value of the anomaly is higher than 0.8°C. The sub–maximum of the anomaly occurs at levels from 20 cm to 40 cm below. The soil temperature anomaly from 5 cm to 20 cm is less than that at levels deeper than 40 cm. For flood years, the maximum variation of the anomaly occurs at levels from 5 cm to the ground surface, and reaches up to 0.7°C / 5 cm in the previous winter for subsequent summer flood years, and 0.5°C / 5 cm in the previous spring for drought years. This indicates that the most anomalous region is located in the south of the Tibetan Plateau. Though the anomalous signal of the soil temperature is the same from the ground surface to 320 cm below, the anomalous values and their variation with depth are obviously distinct. The reason may be that the response of the time scales of the soil temperature at different depths to synoptic variation is different. The analyses in this section clearly revealed that the sensitive levels of soil temperature in the Tibetan Plateau which respond to synoptic variation with seasonal time scale are the levels from 40 cm to 160 cm. The anomaly magnitudes of the soil temperature are different in the vertical direction, which correspond to the filter function of the soil.

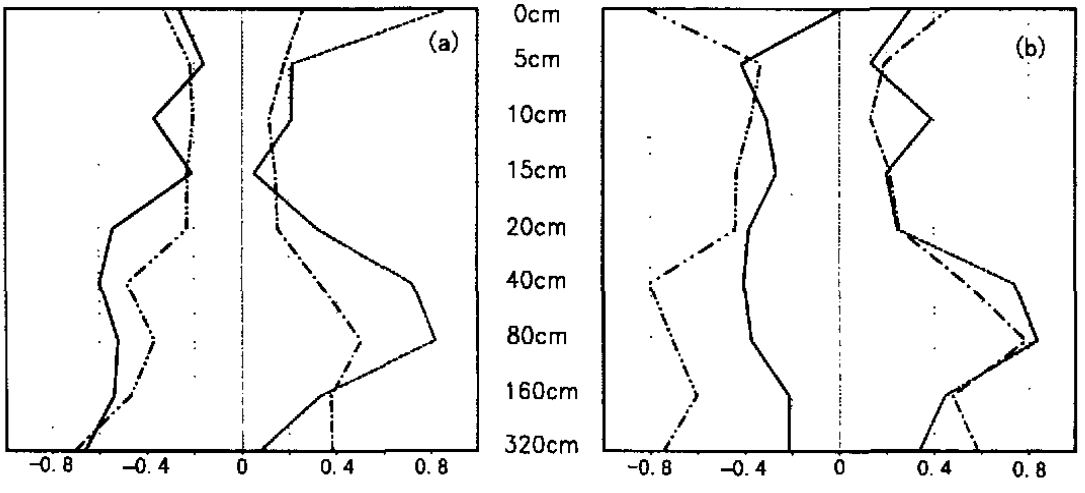

Fig. 2. The vertical distribution profile of soil temperature anomalies in the south and middle and north of the Tibetan Plateau (a) in winter and (b) in spring. Solid line: the south of the Tibetan Plateau in drought years, dashed line: the south of the Tibetan Plateau in flood years, dot dashed line: the middle and north of the Tibetan Plateau in drought years, dot dot dashed line: the middle and north of the Tibetan Plateau in flood years. units: °C.

Figure 2 gives the three–dimensional distribution of the soil temperature in the Tibetan Plateau. Acting as a lifted heat source in the middle troposphere, once the heating of the Tibetan Plateau is imposed upon the thermal effect caused by the different distribution of land and sea, this thermal forcing will play an important role in the atmospheric circulation in winter and summer in East Asia and in the Northern Hemisphere. According to the statistical analyses from 1961 to 1978 by Qiao and Zhang (1994), the thermal status of the Tibetan Plateau in the previous winter and spring has a good relationship with the ridge line of the West Pacific subtropical High in the subsequent midsummer. Namely, when the anomaly of the soil temperature in the Tibetan Plateau is positive, the ridge line of the West Pacific subtropical High is located further north than normal. Likewise, a negative anomaly corresponds to a southward shift of the ridge line. The relationship between the thermal status of the Tibetan Plateau and the West Pacific subtropical High is linked by the thermal circulation in the east–west direction. This means the activities of the West Pacific subtropical High are controlled by the east–west thermal circulation during the midsummer and therefore, affected by the thermal status of the Tibetan Plateau. For the precipitation over MRYR in the summer, the thermal status of the underlying surface of the Tibetan Plateau is a "strong signal". When the soil temperature anomaly in the Tibetan Plateau is positive in the south and negative in the middle and north during the previous winter and spring, the precipitation over MRYR is above normal in the subsequent summer. If the distribution of the soil temperature is opposite to the above pattern, the precipitation is below normal. It is necessary to point out that Ge et al. (2001) also found the anomalous distribution of soil temperature is out of phase in the south and north of the Tibetan Plateau when they studied the correlation between the Meiyu over MRYR and the thermal anomaly of the Tibetan Plateau. Their results differ from those in this paper, perhaps caused by two reasons: (1) the selected periods of precipitation and the representative stations of MRYR are not consistent, and (2) the origins of the data used in the analysis are different. The data used by Ge et al. (2001) are NCEP re–analysis data, whereas this paper uses observational station data.

5. The relationship between the thermal anomaly of the underlying surface of the Tibetan Plateau and the subsequent summer precipitation over MRYR

Zhou (1998) discussed the relationship among the soil temperature of the Tibetan Plateau in the previous winter and spring, the 500 hPa geopotential height field, and the precipitation over MRYR in the subsequent summer from the viewpoint of the key synoptic system leading to the precipitation over MRYR. At the 500 hPa geopotential height field, the key systems that have effect on the summer precipitation over MRYR are the blocking high located at the mid–high latitude in Europe and Asia, the low pressure system at middle latitude, and the West Pacific subtropical High at low latitudes. These systems were steadily maintained when a flood occured over MRYR in 1991, 1998, and 1999 in the summer. In the correlation figure (Fig. 3) between the summer precipitation over MRYR and the 500 hPa geopotential height field during the same period, we find three key systems that are conducive to the precipitation over MRYR: the low latitude West Pacific subtropical High located in 100°–180°E and to the south of 25°N, the mid–latitude low pressure system located in 100°–180°E and 30°–45°N, and the high–latitude blocking high located in 80°–180°E and 45°–75°N. For further analysis, the correlations between the soil temperature of the Tibetan Plateau in the previous winter and in the previous spring with the 500 hPa geopotential height field in the following summer are calculated respectively, and a "correlation fitting" (Miao

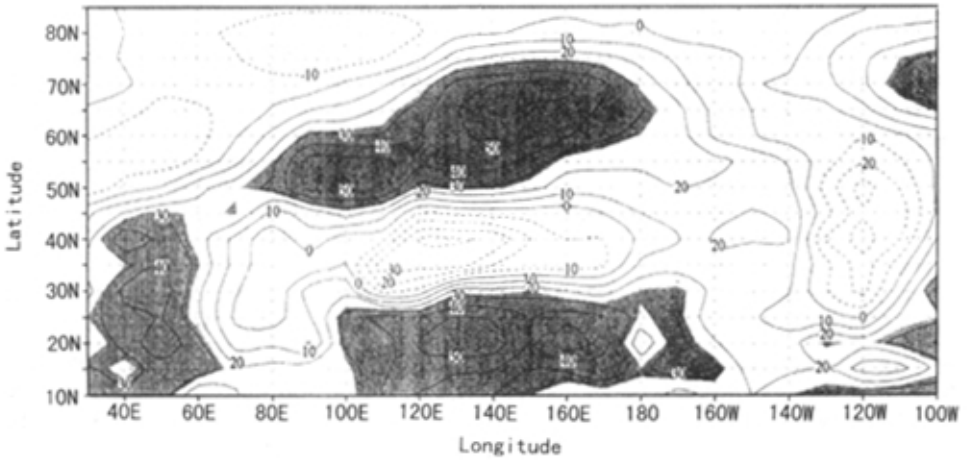

Fig. 3. The same period correlation between the 500 hPa geopotential height and the precipitation over MRYR in the summer.

and Xu 1998) of this correlation and the correlation between the Tibetan Plateau soil temperature with the 500 hPa geopotential height is processed. In the "correlation fitting" figures (omitted), the three key systems are seen clearly: the blocking high within the area of 80°–180°E, 45°–75°N, the low pressure system within the area of 100°–160°E, 30°–45°N and the West Pacific subtropical High, which is relatively larger and located to the south of 30°N, most of which is between 100°E and 140°W. The fitting results demonstrate that there exists a relationship among the Tibetan Plateau soil temperature, the summer precipitation over MRYR, and the atmospheric circulation, i.e., the thermal anomaly of the underlying surface of the Tibetan Plateau could result in the anomaly of the atmospheric circulation through the earth–air energy transmission, which causes the abnormal precipitation over MRYR.

From the above analysis, we know that the correlation (between the soil temperature and the precipitation) and the different anomalous distributions of the soil temperature between drought and flood years both show that the thermal factor of the underlying surface of the Tibetan Plateau in the previous winter and spring may serve as a "strong signal" for the precipitation over MRYR in the subsequent summer. The thermal forcing of the soil temperature of the Tibetan Plateau may influence the precipitation over MRYR by affecting atmospheric circulation.

6. The dynamical mechanism of the thermal anomaly of the Tibetan Plateau and its effect on the precipitation over MRYR

Teleconnection or teleresponse indicates that such a characteristic exists in atmospheric circulation evolution: a variation in one place relates closely to variations in a remote area. With regard to energy, it seems that the perturbation kinetic energy is transmitted from one place to another. This kind of transmission is very fast but not the same as propagation itself, and is called an energy dispersion process. Considering the energy dispersion characteristics of planetary wave propagation on a two–dimensional sphere, Hoskins and Karoly (1981) and

Hoskins and Ambrizzi (1993) put forward the theoretical mechanics that abnormal heat sources could create teleconnection, which was demonstrated by real observations (Horel and Wallance 1981). Furthermore, the wave train path of the teleconnection or teleresponse could be reasonably explained by great circle theory. Xu and Miao (1993) demonstrated through numerical simulation that the correlation wave train was similar to the characteristic of a great circle path.

Now the effect of the thermal anomaly of the underlying surface of the Tibetan Plateau upon the precipitation over MRYR will be analyzed in detail through calculating a one–seasonal interval correlation between the soil temperature at different levels in the Tibetan Plateau and the 500 hPa geopotential height field in the Northern Hemisphere, namely, the correlation between the soil temperature of the Tibetan Plateau in the previous winter and the 500 hPa geopotential height field in the subsequent spring, and the correlation between the soil temperature of the Tibetan Plateau in the previous spring and the 500 hPa geopotential height field in the subsequent summer. The time deviation field of the two correlation fields (i.e., the correlation field of the soil temperature in the Tibetan Plateau in the previous spring with the 500 hPa geopotential height field in the subsequent summer minus the correlation field of the soil temperature in the Tibetan Plateau in the previous winter with the 500 hPa geopotential height field in the subsequent spring) is used to describe the characteristics of the correlation wave train with the seasonal time scale, most likely created by the anomalous thermal forcing of the Tibetan Plateau. From Fig. 4, it can be seen that the time deviation correlation field between the soil temperature at the ground surface (0 cm) in the Tibetan Plateau and the 500 hPa geopotential height takes on an obvious wave train structure. Similar to that of Fig. 4, the time deviation correlation field between the soil temperature at different levels in the Tibetan Plateau and the 500 hPa geopotential height also shows obvious wave train structures (figures omitted). These wave trains start from the Tibetan Plateau and can propagate downstream from the Plateau. The thermal anomaly of the Tibetan Plateau may have an effect on MRYR through the propagation of these correlation wave trains. Through the diagnostic analyses, from the viewpoint of statistical correlation, one result put forward by this paper is the following: the delay correlation with seasonal time scale between the thermal anomaly of the underlying surface of the Tibetan Plateau and the circulation pattern of the Northern Hemisphere may conform to the dynamic mechanics of the propagation of teleconnection wave trains, and these teleconnection wave trains are the key link to the effect of the thermal anomaly of the underlying surface of the Tibetan Plateau upon the precipitation over MRYR.

According to the soil temperature anomalies in the Tibetan Plateau corresponding to drought years and flood years over MRYR, and by using the Community Climate Model (CCM3), the control simulation and sensitive simulations on the effect of the anomalous soil temperature in the Tibetan Plateau upon the precipitation over MRYR have been done. The deviations in drought years and flood years over MRYR are respectively added to the soil temperatures at all levels in the Tibetan Plateau to form the soil temperature anomaly. The results of the control simulation and sensitive simulations also show that there is above (below) normal precipitation when the year is a flood (drought) year. There are obvious wave trains in the deviation fields of stream and vorticity at 500 hPa, and these wave trains are similar to the wave trains obtained from statistics methods. The simulation results will be discussed in Part II of this paper.

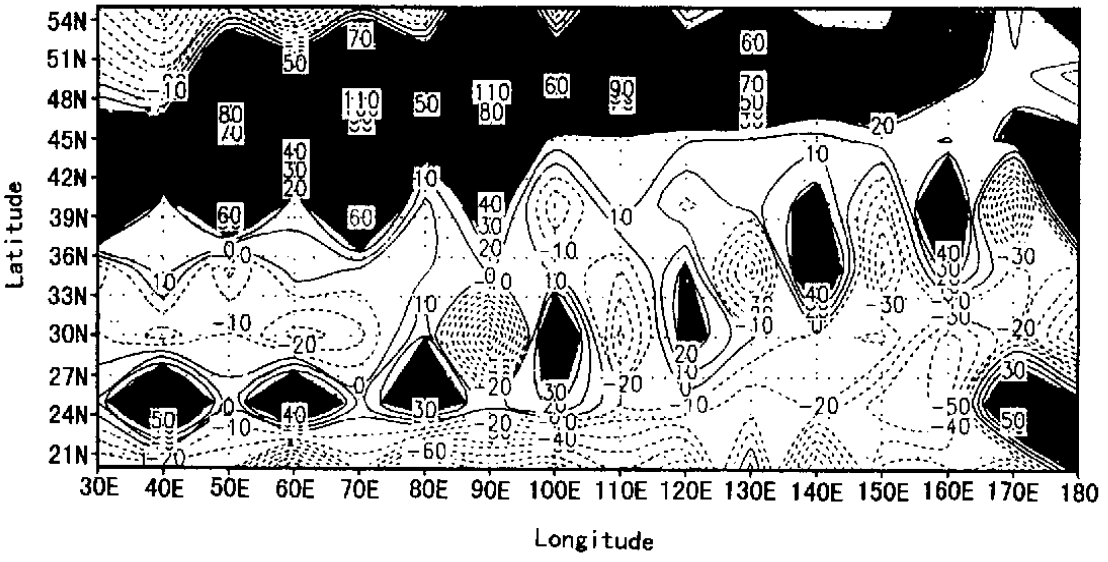

Fig. 4. The time deviation fields of correlation with a seasonal interval between the soil temperature of the Tibetan Plateau at the ground surface (0 cm) and the 500 hPa geopotential height field.

7. Conclusion

Based on the above analyses, the following conclusions are drawn.

(1) There exists an obvious correlation between the soil temperature of the Tibetan Plateau in the previous winter and spring and the precipitation over MRYR in the subsequent summer. Before the anomalous precipitation over MRYR occurs in the summer, the thermal forcing of the Tibetan Plateau in the previous winter and spring has strong signal features. The time scale of the soil temperature effect on the precipitation over MRYR is a seasonal time scale.

(2) Before the anomalous precipitation over MRYR occurs in the summer, the three–dimensional thermal anomaly of the soil temperature in the Tibetan Plateau in the previous winter and spring is different. The distribution of the anomaly of the soil temperature in the Tibetan Plateau shows a positive anomaly in the southern and a negative anomaly in the middle and northern region before flooding occurs over MRYR in the summer. A contrasting distribution (i.e., a negative anomaly in the southern region and a positive anomaly in the middle and northern region) of the soil temperature in the Tibetan Plateau appears in the previous winter and spring before drought occurs over MRYR in the summer. The maximal anomalous values of the soil temperature are at levels from 40 cm to 160 cm under the ground surface.

(3) By using a statistical method, one of the dynamic mechanisms of the effect of the three–dimensional thermal anomaly of the Tibetan Plateau upon the precipitation over MRYR is put forward, which is related to the triggering and propagation of the correlation wave trains. These correlation wave trains are the key factors of the effect of the thermal anomaly of the underlying surface of the Tibetan Plateau upon the precipitation over MRYR.

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REFERENCES

Flohn H., 1968: Contribution to a meteorology of the Tibetan Plateau Highlands. *Atmos. Sci.*, Paper, No.130, Colorado State University, Ft. Collins.

Gao Shouting, Tao Shiyan, and Ding Yihui, 1990: The generalized E–P flux of wave–meanflow interactions. *Science in China* (series B), **33**(6), 704–715.

Ge Xuyang, Tao Liying, Zhu Yongti, and Li Shuohua, 2001: Statistic analysis and numerical experiments on the relationship of Tibetan Plateau thermal conditions and the Meiyu Yangtze river basin. *Quarterly Journal of Applied Meteorology*, **12**(2), 159–166 (in Chinese).

Horel, J. D., and J. M. Wallance, 1981: Planetary–scale atmospheric phenomena associated with the southern oscillation. *Mon. Wea. Rev.*, **109**(4), 813–829.

Hoskins, B. J., and D. J. Karoly, 1981: Steady linear response of a spherical atmosphere to thermal and orographic forcing. *J. Atmos. Sci.*, **38**(6), 1179–1196.

Hoskins, B. J., and T. Ambrizzi, 1993: Rossby wave propagation on a realistic longitudinally varying flow. *J. Atmos. Sci.*, **50**(12), 1661–1676.

Liu Yanxiang, and Tang Maocang, 2001: Relationship of winter disturb source vortex over West and summer rain belt over East China. *Plateau Meteorology*, **20**(1), 109–112 (in Chinese).

Miao Qiuju, and Xu Xiangde, 1998: Correlation–chain model for regional drought / flood and characteristic distribution of sea surface temperature. *Quarterly Journal of Applied Meteorology*, **9**(supplement), 47–56 (in Chinese).

Nitta, Ts., 1983: Observational study of heat source over the eastern Tibetan Plateau during the summer monsoon. *J. Meteor. Soc. Japan.*, **61**, 590–605.

Qiao Quanming, and Zhang Yagao, 1994: *The Synoptic Meteorology on the Tibetan Plateau*. Beijing: China Meteorological Press, 250pp, (in Chinese).

Tang Maocang, Yin Jianhua, and Cai Jieping, 1986: The statistical analysis of the correlation between the distribution of soil temperature in winter and rainfall in summer. *Plateau Meteorology*, **5**(1), 40–51, (in Chinese).

Tang Maocang, Wang Jingxiang, and Zhang Jian, 1987: A primary method for predicting the spring rainfall by the winter soil temperature at a depth of 80 cm. *Plateau Meteorology*, **6**(3), 244–255 (in Chinese).

Tang Maocang, Gao Xiaoqing, Liu Yanxiang, Guo Weidong, and Wang Zhongrui, 2000: The analysis on the evolution of the earth system before the floods in the Yangtze River and Yellow River. *Plateau Meteorology*, **19**(4), 441–449 (in Chinese).

Xu Xiangde, and Miao Junfeng, 1993: The Relationship between the drought / flood over the Yangtze–Huaihe basin and the route of the meridional teleconnection wave in the atmosphere. *Scientia Meteorologica Sinica*, **13**(1), 81–86 (in Chinese).

Yanai, M., C. F. Li, and Z. S. Song, 1992: Seasonal heating of the Tibetan Plateau and its effects on the evolution of the Asian summer monsoon. *J. Meteor. Soc. Japan*, **70**(1), 319–351.

Zhang Jijia, Xu Xiangde, and Miao Junfeng, 1995: A numerical experiment on the effect of the anomalous thermal forcing of the Tibetan Plateau ground surface on the formation of persistent heavy rain in summer over the Yangtze–Huaihe basin. *Scientia Atmospherica Sinica*, **19**(3), 270–276 (in Chinese).

Zheng Qinglin, and Wu Jun, 1995: Numerical study on the dynamic and thermodynamic effects of the Qinghai–Xizang Plateau on the seasonal transition in the early summer in East Asia. *Acta. Meteror. Sinica*, **9**(1), 35–47.

Zhou Yushu, 1998: The Study on the characteristics of the teleconnection caused by the underlying surface of the Tibetan Plateau. M.S. thesis, Chinese Academy of Meteorological Sciences, 74pp (in Chinese).

青藏高原下垫面热力结构遥相关影响特征
I: 资料分析

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摘　要

探讨了前期青藏高原下垫面热力结构异常对后期长江中下游地区降水的影响。通过资料分析揭示出长江中下游地区夏季降水异常前期冬、春季青藏高原下垫面三维热力结构强信号特征，即长江中下游夏季旱涝前期高原南部和北部各层次的地温距平呈反位相分布。从地面 0 cm 到地下 320 cm 的地温距平分布为：涝年高原偏南部(30°N 以南)为正，中部和北部(30°N 以北)为负，旱年时相反。其中地温距平的大值区在 40 cm 到 160 cm 层之间。同时揭示了北半球环流型对青藏高原下垫面热力异常可能产生遥响应，并形成季尺度低频波的传播，从而影响长江中下游地区后期的降水，反映了遥相关是区域性旱涝形成的一个动力机制。资料分析结果表明前期青藏高原下垫面三维热力结构异常是后期长江中下游地区降水异常的重要原因之一。

关键词：青藏高原，热力异常，长江中下游地区，旱涝异常