The Characteristics of Climate Change over the Tibetan Plateau in the Last 40 Years and the Detection of Climatic Jumps

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ABSTRACT

Through analyzing the yearly average data obtained from 123 regular meteorological observatories located in the Tibetan Plateau (T-P), this article studies the characteristics of climate change in T-P in the last 40 years. From the distribution of the linear trend, it can be concluded that the southeastern part of T-P becomes warmer and wetter, with an obvious increase of rainfall. The same characteristics are found in the southwestern part of T-P, but the shift is smaller. In the middle of T-P, temperature and humidity obviously increase with the center of the increase in Bangoin–Amdo. The south of the Tarim Basin also exhibits the same tendency. The reason for this area being humid is that it gets less sunshine and milder wind. The northeastern part of T-P turns warmer and drier. Qaidam Basin and its western and southern areas are the center of this shift, in which the living environment is deteriorating. Analyzing the characteristics of the regional average time series, it can be found that in the mid-1970s, a significant sudden change occurred to annual rainfall, yearly average snow-accumulation days and surface pressure in the eastern part of T-P. In the mid-1980s, another evident climatic jump happened to yearly average temperature, total cloud amount, surface pressure, relative humidity, and sunshine duration in the same area. That is, in the mid 1980s, the plateau experienced a climatic jump that is featured by the increase of temperature, snow-accumulation days, relative humidity, surface pressure, and by the decrease of sunshine duration and total cloud amount. The sudden climatic change of temperature in T-P is later than that of the global-mean temperature. From this paper it can be seen that in the middle of the 1980s, a climatic jump from warm-dry to warm-wet occurred in T-P.

Key words: Tibetan Plateau, linear trend, climatic jump

1. Introduction

Global warming has been one of the key issues absorbing a great deal of attention (Hansen And Lebedeff, 1987). Scientists and governments in many countries devote much attention to the environmental and eco-systematic changes possibly caused by global warming (Karl et al., 1993). The effects of the climate changes in T-P on the global climate change are significant and worthwhile studying (Liu et al., 1998). It has been pointed that the temperature change in the Plateau is earlier than that in the eastern part of China (Tang et al., 1988). Thus, T-P is regarded as the "origin" of the climatic changes on the timescale of a hundred years. But the research on the climatic change over T-P has in the past analyzed only one or a few meteorological factors, due to the shortage of data on the Plateau. This article first uses a set of data obtained from the regular observatories on the Plateau, including temperature (T_{a}), minimum temperature ($T_{\min}$), maximum temperature ($T_{\max}$), rainfall, snow-accumulation days, snow-accumulation depth, relative humidity, surface pressure, sunshine duration, total cloud amount, and low-cloud amount, a total of 11 factors. By analyzing these factors, the characteristics of climatic change in T-P are fully revealed.

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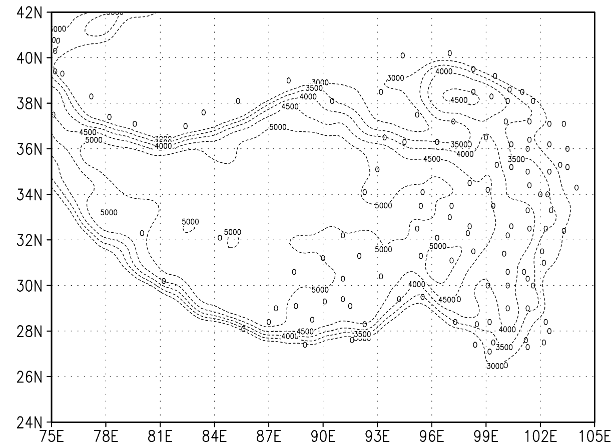

Fig. 1. The locations of the 123 observatories used in this article.

2. The linear trend distribution of each factor over T-P in the last 40 years

2.1 *The locations of the observatories and data handling*

This article uses the data obtained from regular meteorological observatories in T-P region, including Qinghai, Tibet, and the areas adjacent the plateau in Xinjiang, Gansu, Sichuan, Yunnan, and Guizhou provinces. Since most of the plateau meteorological observatories do not have continuous data until the 1960s, the data from 1961 to 1998 are analyzed in this article. First, we interpolated the lacking data by averaging the values of the previous year and the following year and taking it as the lacking value, doing this only once for every missed value. If the value is still missing, it is calculated based on the spatial interpolation. That is, we select all the stations around the data-missing stations within a radius of 1° latitude, then perform a weighted average with the weights based on the inverse ratio of the distance from the selected station to the data-missing station (doing this only once for every missing value). Thus, there are 123 observatories that have continuous data (for the distribution of these stations, see Fig. 1). Then based on the data obtained from the 123 stations, the yearly average values of each factor are obtained. In particular, the rainfall we calculate both the summer amount (June–August) and the annual amount, while the snow is average only in winter (November to next March) because many stations do not take any observation for snow in the summer season.

2.2 *The distribution of the linear trend of each factor in the last 40 years*

The key issues discussed in this section are the linear trend and its spatial distribution for the meteorological factors over T-P in the last 40 years.

Using x_i to indicate one climatic variable, where the sample size is n, for example, temperature, and using t_i to indicate the time corresponding to x_i, a mono-regression equation is established to show the relationship between x_i and t_i, $x_i = a + bt_i$ $(i = 1, 2, 3, 4, \ldots, n)$, where a, b are the regression constant and regression coefficient, respectively. These can be estimated by using the least squares method:

$$b = \frac{\sum_{i=1}^{n} x_i t_i - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} t_i\right)}{\sum_{i=1}^{n} t_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} t_i\right)^2} , \tag{1}$$

$$a = \bar{x} - b\bar{t}$$

where

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i ,$$

$$\bar{t} = \frac{1}{n}\sum_{i=1}^{n} t_i .$$

b is the linear regression coefficient also called the linear tendency. After calculating b, whether the trend is significant must be detected. In order to do this, we test the correlation coefficient r between t and x. Only if r passes the confidence test is the tendency significant in statistics. Otherwise, it is not significant. r can be calculated through the following formula:

$$r = \sqrt{\frac{\sum_{i=1}^{n} t_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} t_i\right)^2}{\sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2}} \tag{2}$$

The linear tendency distribution of each factor in the last 40 years is shown in Figs. 2a–k. All of them are drawn only based on the stations passing the 95% confidence test, that is $r > 0.32$. The stations that do not pass this test are skipped. In these figures, the light shadow areas are the large negative values of the tendency, while the dark shadow areas are the large positive values of the tendency. Figure 2a shows the linear tendency of T_a. It can be seen that there are three centers of temperature increasing in T-P, at the Qaidam Basin, Bangoin, and Tingri, respectively. Only the areas around the boundary of Sichuan Province, Qinghai Province, and Tibet show less T_a increasing tendency. Figures 2b and 2c indicate the linear tendencies of minimum temperature ($T_{\min}$) and maximum temperature ($T_{\max}$). From these two figures, it can be found that the center with $T_{\min}$ increasing is consistent with that of T_a increasing in Fig. 2a. Furthermore, the tendency of $T_{\min}$ increasing is more obvious than that of T_{max}. And the center of T_{max} increasing does not include Bangoin. Thus, the increasing tendency of T_a is mainly caused by the increase of T_{min} in T-P. Figures 2d and 2e are the trend distributions of annual rainfall and summer rainfall, respectively. It can be seen that these two figures are not very consistent. The differences are in the northeastern part of Tibet, the plateau of western Sichuan, and the plateau of southern Qinghai. In these three areas, the tendency of the annual precipitation is increasing, while it is decreasing in summer. This fact indicates that besides summer rainfall, the precipitation (including snowfall) in the other seasons has a very important contribution to annual precipitation. The comparatively identical patterns of these two figures lie in the areas around Qilian Mountain with precipitation increase, and in the boundary area of Gansu, Qinghai, and Sichuan provinces with precipitation decreasing.

This article also calculates the linear trend of snow-accumulation days (see Fig. 2f) and the snow-accumulation depth. Figure 2f shows that the snow-accumulation days in winter (November to next March) increase in most areas of T-P, and the decreasing tendency only appears in Qilian Mountain. Since the tendency of snow-accumulation depth of most stations could not pass the 95% confidence test, the figure was omitted. Figure 2g shows the trend distribution of relative humidity. It obviously turns dry in the areas from Qaidam Basin and its west side to Qilian Mountain, to the boundary area of Gansu, Qinghai, and Sichuan provinces. Bangoin is the center where humidity increases enormously. The southeastern and southwestern areas of the plateau, and the areas south of the Tarim Basin turn wet mildly. Figure 2h indicates the distribution of the linear tendency of surface pressure. It can be seen that the pressure increases in the southeastern plateau, and decreases in the northwestern plateau. Figure 2i is the trend distribution of the sunshine duration. The areas with sunshine duration increasing are found in the middle and eastern part of T-P, with the sunshine duration decrease in the southeastern part of T-P, Qaidam Basin, and Lanzhou region. The total cloud amount shows a decreasing tendency (see Fig. 2j). The low-cloud amount over the plateau shows a decreasing trend also, except for the Tarim Basin, the south of Qaidam Basin, and the eastern part of the plateau where it is increasing (see Fig. 2k).

The conclusion can be draw from summarizing Figs. 2a–2k that the areas of the northeastern plateau, from Qaidam Basin and the west of it to Qilian Mountain, are the centers where temperature is obviously

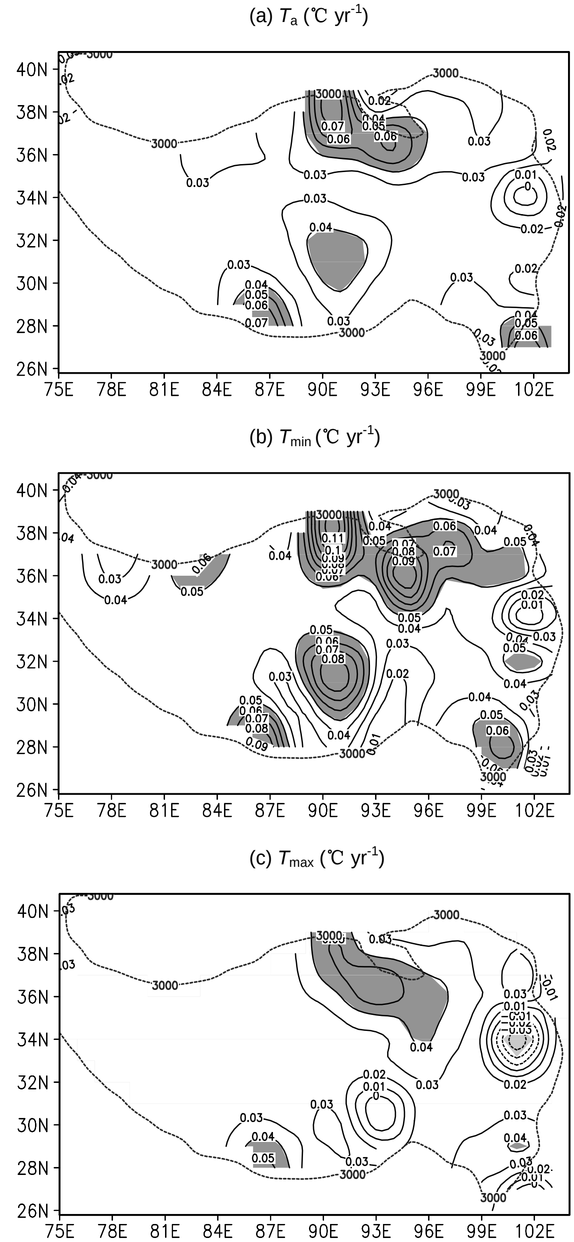

Fig. 2. The distribution of the linear tendency of each factor in T-P from 1961 to 1998. Here $T_a, T_{\min}, T_{\max}$, relative humidity, surface pressure, sunshine duration, total cloud amount, and low-cloud amount are all yearly average values, while snow-accumulation days are winter average values.

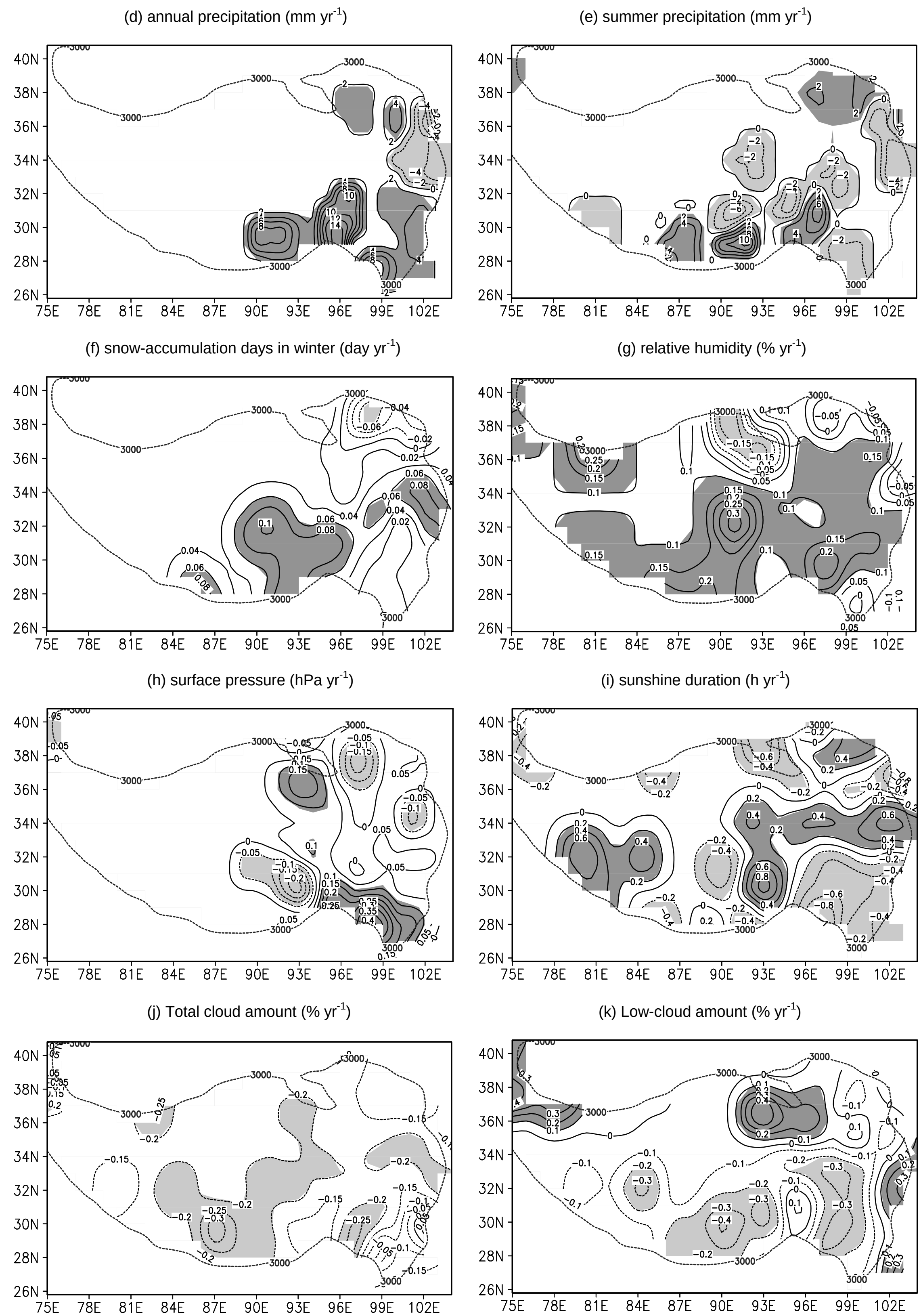

Fig. 2. (Continued)

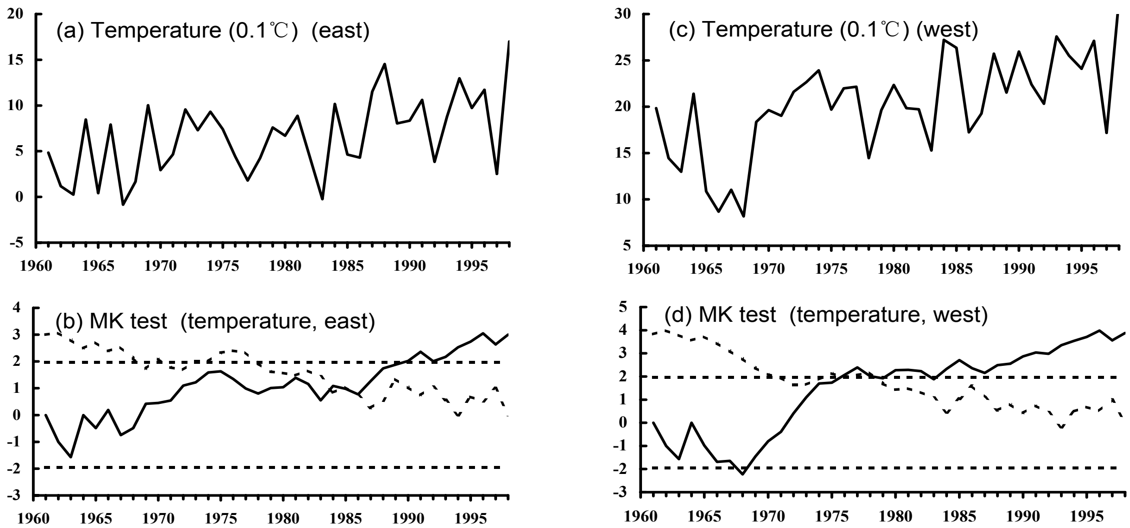

Fig. 3. Regional interannual variations of temperature in the eastern plateau (a), in the southwestern plateau (c), and corresponding examination of the climate jump (b), and (d) during the period from 1961–1998. EP: within (26°–41°N, 90°–103°E) and above 3000 m altitude. SWP: within (26°–33°N, 78°–90°E)) and above 3000m altitude. The two straight dashed lines are the 95% critical lines. The critical value: $|u|_{0.05} = 1.96$, in which the subscript 0.05 is confidence limit.

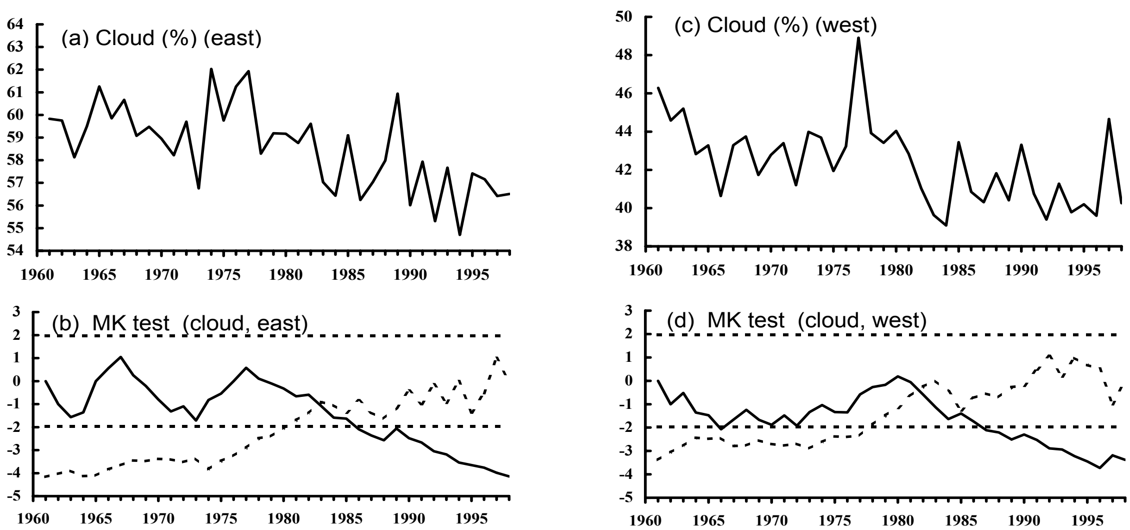

Fig. 4. The same as Fig. 3 but for total cloud amount.

increasing. Meanwhile, these areas are also featured by the biggest tendency of becoming dry. Although the annual precipitation and summer rainfall show increasing tendency, these areas are still turning dry. This is possibly directly related to the evaporation increase that is caused by the enormous increase in both air and surface temperature. The environment for living in these areas is deteriorating. What especially needs attention is that the increase of the temperature in this area is not caused by an increase of the sunshine. On the contrary, the sunshine duration there shows a decreasing tendency. Similar situations occur in Bangoin and Tingri. The reasons for these occurrences are worthy of further research.

The boundary area of Gansu, Qinghai, and Sichuan Provinces (nearly 35°N, 102°E) obviously turns dry, while the increase of temperature is not obvious. This is related to the increase of sunshine duration (except for Lanzhou region where bad pollution results in sunshine duration decrease), and the decrease of annual (summer) rainfall. Meanwhile, the area south of Tarim Basin shows a mild increase in both temperature and

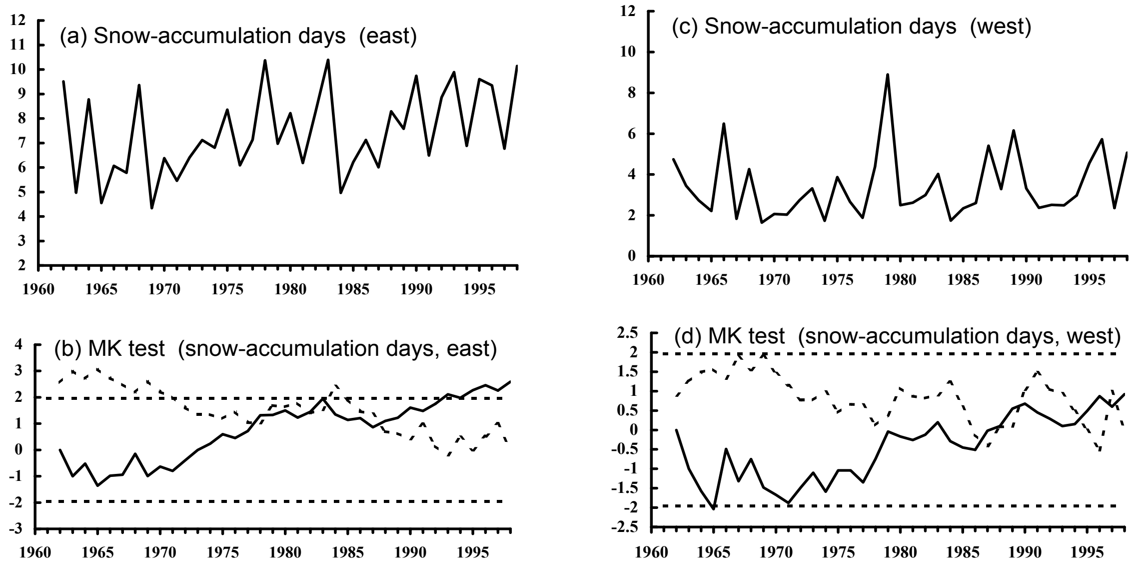

Fig. 5. The same as Fig. 3 but for snow-accumulation days.

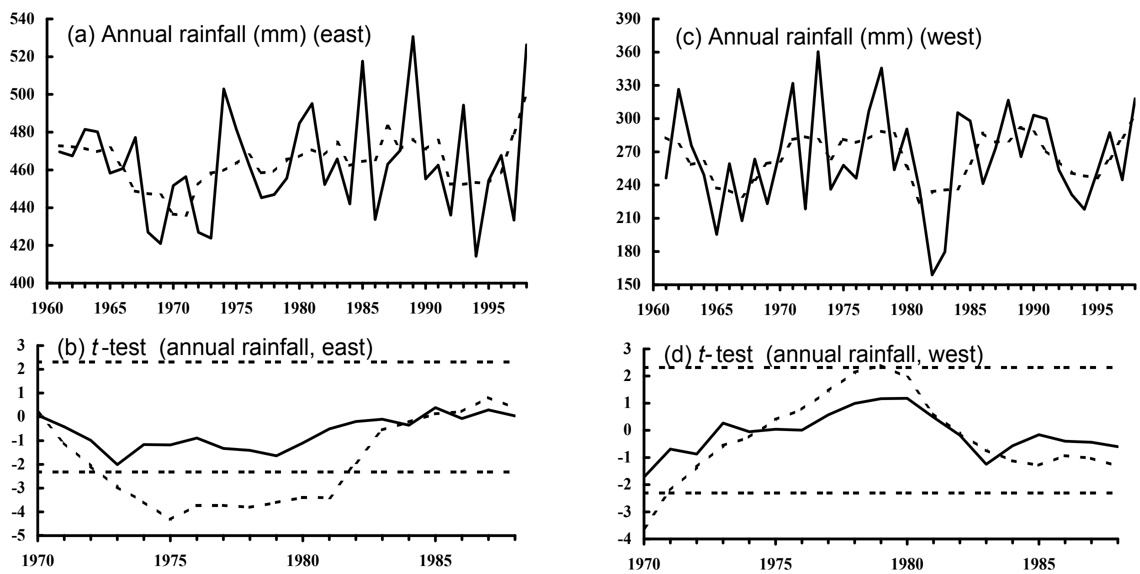

Fig. 6. The same as Fig. 3 but for annual precipitation. The critical value: $|t|_{0.05} = 2.31$.

humidity. This is related to the obvious decrease of the evaporation amount caused by the sunshine duration decreasing over there. The increases of temperature and humidity also exist in the southeastern part of T-P, which are related to the increase of annual precipitation there. It is also found that sunshine duration is obviously decreasing in the boundary areas of Sichuan Province, Tibet, and Guizhou Province, although in these areas surface pressure increases and cloud amount goes down. This phenomenon might be related with anthropogenic pollutions which increase continuously due to the rapidly increasing population.

3. The general characteristics of climate change in T-P and the examination for climatic jump

The key issues discussed in this section are the general characteristics of climatic change in T-P. Figure 1 shows that most of the observatories are located in the east of T-P, a few of them are located in the southwestern part of T-P, and none in the northwestern part of T-P. Thus, the area within (26°–41°N, 90°–103°E) and above 3000 m altitude is defined as the eastern Plateau (EP), while the area within (26°–33°N, 78°–90°E) and above 3000 m altitude is defined as the southwestern

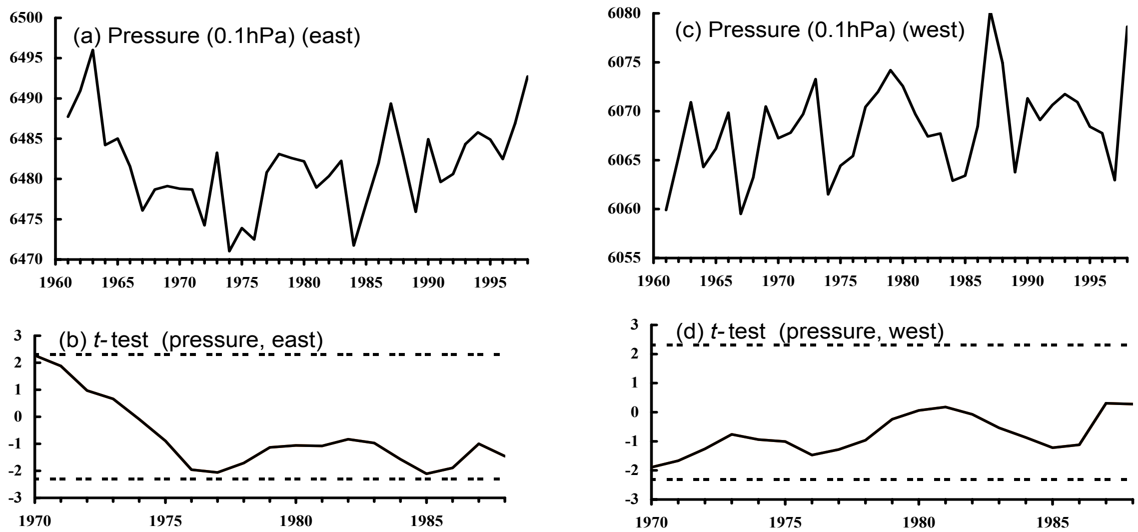

Fig. 7. The same as Fig. 3 but for surface pressure. the critical value: $|t|_{0.05} = 2.31$.

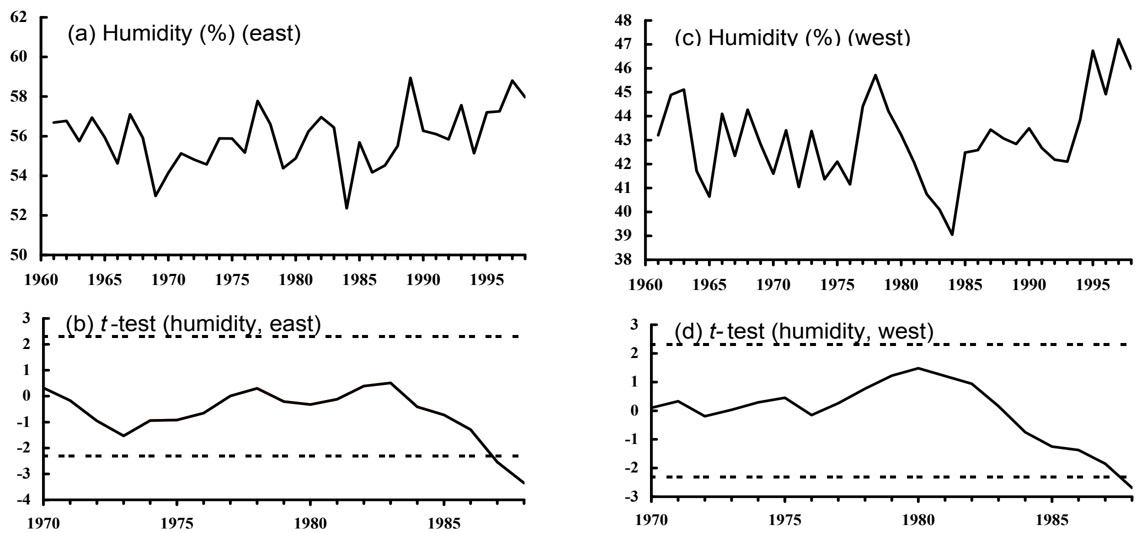

Fig. 8. The same as Fig. 3 but for relative humidity. The critical value: $|t|_{0.05} = 2.31$.

Plateau (SWP).

First, the yearly average values of station data are interpolated into average $2° \times 2°$ grid dataset. Then the values from the grids above 3000 m altitude are average with weights based on the areas of the grids. Therefore we get the regional interannual variation series that represent the general characteristics of EP and SWP. In this section, seven factors are discussed, including temperature, annual precipitation, snow-accumulation days, surface pressure, sunshine duration, relative humidity, and total cloud amount.

Figures 3a–9a are the regional interannual variation series of the seven factors in EP. Figures 3c–9c are the same but for SWP. They show that all the factors had sudden changes to some extent. Thus, it is necessary to detect these sudden changes. Since the method of the Mann-Kendall (MK) test has its advantages in doing this examination (Wei and Cao, 1995), we can use this method to identify the start of the climatic jump, so the MK method is firstly adopted in this section. The results show that some factors can pass the 95% confidence test, including temperature, total cloud amount, and snow-accumulation days. The MK test indexes for these three elements are shown in Figs. 3b–5b and Figs. 3d–5d corresponding to Figs. 3a–5a and 3c–5c, respectively. The other factors could not pass the 95% confidence test, including surface pressure, annual precipitation, sunshine duration and rela-

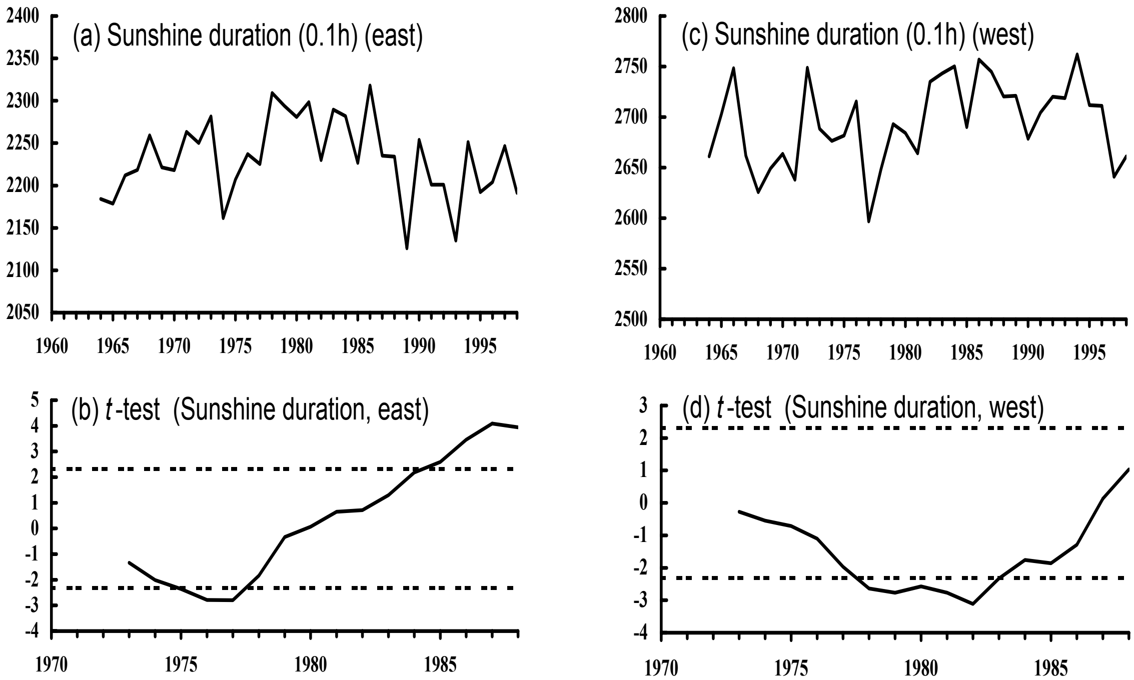

Fig. 9. The same as Fig. 3 but for sunshine duration. The critical value: $|t|_{0.05} = 2.31$.

tive humidity. If carefully scrutinized, we can find that the time series of these four elements have the feature of a parabola. Because the MK method was initiated for detecting linear tendencies of time series, there are difficulties in detecting those curves analogous with a parabola. Actually (Fu and Wang, 1992), there is no effective method to detect sudden changes with a turning jump. In this article, the moving t-test, the basic method, is used to detect whether there are abrupt changes occurring in these four elements. The lengths of the sub-series are 10 years. Figures 6b–9b show the indexes of the moving t-test corresponding to Figs. 6a–9a, and Figs. 6d–9d are the indexes of the moving t-test corresponding to Figs. 6c–9c.

It can be concluded from Fig. 3a and 3b that the temperature of EP has a increasing tendency from 1961 to 1998, with a sudden change in 1984, at which EP enters a more obvious warming period. The temperature of SWP has the same tendency as that of EP, shown in Figs. 3c and 3d. But the beginning time of the sudden change cannot be determined from Fig. 3d. Summarizing Figs. 3c and 3d, it can be said that the year the sudden change happened is also around 1984 in SWP. From Figs. 4a and 4b, it can be read that the total cloud amount over EP has a linear decreasing tendency, with a sudden change in 1983, and from this time it enters into an obvious decreasing period. Figures 4c and 4d show that the total cloud amount in SWP maintaining a high value from the early 1960s to the early 1980s with a sudden change occurring in 1982, after which it maintains a low value. From Figs. 5a and 5b, it can be inferred that the snow-accumulation days in EP have an obvious increasing tendency with a sudden change in 1978. However, summarizing Fig. 5c and 5d, it can be seen that snow-accumulation days in SWP do not have any sudden change from 1961–1998. Figures 6a and 6b show that the annual precipitation in EP has large fluctuation, and the index of sudden change (the solid line in Fig. 6b) does not pass the 95% confidence test. Since the research on abrupt change focuses on the long-term variations, we do a 5-year moving-average for precipitation (the dashed line in Fig. 6b) then detect this moving-average curve using a t-test. It is apparent that there is a sudden change in annual rainfall in the middle of the 1970s over EP. Based on Figs. 6c and 6d, it is evident that annual precipitation in SWP changed suddenly at the end of the 1970s. It can be obtained from Figs. 7a and 7b that the pressure over EP has two peaks occurring at the end of the 1970s and the middle of the 1980s, respectively. Although the sudden change index does not pass the 95% confidence test, it passes the 90% confidence test (critical value $|t|_{0.01} = 1.86$). From Fig. 7c and Fig. 7d, it can be read that the tendency of the pressure over SWP shows an increasing trend without any sudden change. It is disclosed from Fig. 8a and Fig. 8b that humidity increase

Table 1. Climatic jump detection in EP during the period from 1961 to 1998.

Element	T_a	Total cloud	Snow-accumulation days	Annual precipitation	Surface pressure	Relative humidity	Sunshine duration
Time of climatic jumps	1984	1983	1978	Mid-1970s	1975 & 1985	Mid-1980s	Mid-1980s
Test method	MK	MK	MK	Moving-t	Moving-t	Moving-t	Moving-t
Confidence	95%	95%	95%	95%	90%	95%	95%

Table 2. Climatic jump detection in SWP during the period from 1961 to 1998.

Element	T_a	Total cloud	Snow-accumulation days	Annual precipitation	Surface pressure	Relative humidity	Sunshine duration
Time of climatic jumps	1984	1982	No	End of 1970s	No	Late of 1980s	Early of 1980s
Test method	MK	MK	MK	Moving-t	Moving-t	Moving-t	Moving-t
Confidence	95%	95%		95%		95%	95%

is obvious in EP, with a sudden change occurring in the middle of the 1980s. The relative humidity of SWP fluctuates with the low values around 1984 and a sudden change in the late 1980s; after this it becomes wetter and wetter. From the middle of the 1990s, the humidity increases enormously there. Figures 9a and 9b indicate that sunshine duration in EP has a sudden change from less to more at the end of the 1970s and another one from more to less in the middle of the 1980s. Since that time, the sunshine duration has remained at low values. The sunshine duration in SWP increases with a sudden change at the beginning of the 1980s; after this it remains at high values.

The times when the climatic jumps occurred are listed in Tables l and 2 for reference.

It can be inferred from Table 1 that in the middle of the 1970s a climatic jump occurred in EP, including the regional average annual precipitation, snow-accumulation days, and surface pressure. In the middle of the 1980s, sudden changes also happened in the same area, including regional average temperature, total cloud amount, surface pressure, relative humidity, and sunshine duration.

From Table 2 it is discovered that at the end of the 1970s in SWP, a sudden change occurred in the regional average annual precipitation. In the early 1980s, an abrupt change occurred in the regional average total cloud amount and the sunshine duration. In the mid-1980s, regional average temperature has a jump. In the late 1980s, regional average relative humidity has an abrupt change, but both surface pressure and snow-accumulation days do not have a climatic jump in SWP. All of the above indicate that the variations of the meteorological factors in SWP are more complicated than those in EP. This might be related to the fact that there are few observatories located in SWP where the relief is more complicated, so each station holds a large weighting when calculating a regional average value.

Through a comparatively strict MK test, it can be indicated that the climatic jump of temperature occurred in the mid-1980s in T-P. According to the IPCC report by Houghton et al. (1995) and the study by Wang and Yie (1995), it can be assumed that in the late 1970s there was a sudden change of global-mean temperature. Therefore, the sudden temperature change in T-P is later than that of the global-mean temperature.

4. The relationships among all seven factors in EP

Because the observatories are mostly located in EP, this section just focuses on EP. The following discusses the relationships among the seven meteorological factors, including regional average temperature, annual precipitation, snow-accumulation days, surface pressure, sunshine duration, relative humidity, and the total cloud amount in EP.

In order to preserve the long-term climatic variations while filtering out the short-term fluctuation, we do a 5-year moving average on each regional inter-annual variation curve in EP. Figures 10a–10g show these moving-average curves corresponding to Figs.

3a–9a. The correlation coefficients between temperature and the other six factors as well as between precipitation and the other six factors are calculated, respectively, and the values are listed in Table 3. It can be read that the relations between temperature and snow-accumulation days and relative humidity are all positive, i.e., in EP when temperature is increasing, snow-accumulation days and relative humidity are rising too. This synchronization is very obvious since 1970 (see Fig. 10). This positive relation can be explained from synoptic meteorology, i.e., snow is a result of cold-dry air meeting warm-wet air, so in winter when warm-wet air is strong it is snowy, otherwise, it is cold and dry over the region. The relation between temperature and total cloud amount is negative, i.e., the more (less) the cloud, the lower (higher) the temperature. This is easily understood based on synoptic meteorology. The annual precipitation has significant positive relations with snow-accumulation days, relative humidity, and surface pressure. Since the annual precipitation includes the snowfall, the positive relation shows that the snow has a great effect on the annual precipitation. It is also easy to understand that the relation is positive between the annual precipitation and the relative humidity. Further, the positive relation between annual precipitation and surface pressure might be the result of the night-rainfall (snowfall) that usually occurs after sunny days, caused by the special topographic conditions over T-P. However, there is no relation between the annual precipitation and the yearly average temperature in EP.

Summarizing Fig. 10 and section 3, it can be concluded that T-P experienced a climatic jump in the middle of the 1980s, featured by significant increases of temperature, snow-accumulation days, relative humidity, and pressure, and by decreases of sunshine duration and total cloud amount.

5. Conclusions

(1) From the distribution of the linear tendency, it can be concluded that all of the yearly average $T_a, T_{\min}$, and $T_{\max}$ increased in the last 40 years, in which $T_{\min}$ gained the most. The centers of increasing temperature lie in the Qaidam Basin, Bangoin, and Tingri. The annual precipitation is mainly increasing in most areas of T-P, only decreasing in the boundary area of Gansu, Qinghai, and Sichuan provinces. Summer rainfall is mainly decreasing in most areas. The relative humidity increases in most areas, especially in SP. Only in the areas of the northeastern plateau does the relative humidity become lower.

Therefore, most areas of T-P are becoming warmer and wetter, except for the northeastern plateau. This is similar with the issues of the study by Niu et al. (2002).

(2) In the middle of T-P, sunshine duration is increasing, while in the southeast of the plateau, in Qaidam Basin, and in the south of Tarimu Basin, sunshine duration is decreasing. The major variation of cloud amount is decreasing over T-P.

(3) In T-P, two climatic jumps occurred in the 1970s and 1980s, respectively, with the latter being more obvious. In the mid-1970s, a significant sudden

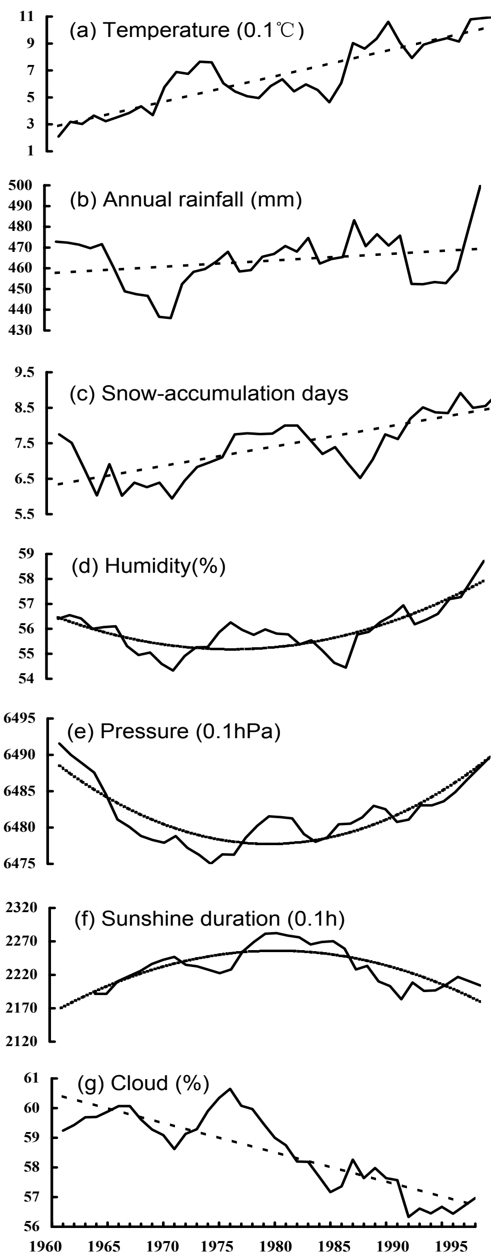

Fig. 10. 5-year moving average curves corresponding to Figs. 3a–9a.

Table 3. The relationship among the factors over EP.

Factor	Temperature	Precipitation	Snow-accumulation days	Relative humidity	Surface pressure	Sunshine duration	Total cloud
Temperature	1.0	0.20	**0.66**	**0.41**	0.05	0.12	**–0.76**
Precipitation	0.20	1.0	**0.37**	**0.60**	**0.47**	–0.22	–0.14

Note: The bold numbers pass the 95% confidence test, $|r|_{0.05} = 0.32$.

change took place to the regional average annual precipitation, snow-accumulation days, and surface pressure. In the mid-1980s, a sudden change also happened to the regional average temperature, total cloud amount, surface pressure, relative humidity, and sunshine duration; i.e., the temperature, snow-accumulation days, relative humidity, and pressure all increase, while the sunshine duration and the cloud amount all decrease. It is worth mentioning that the sudden change of temperature in T-P is later than that of the global-mean temperature.

(4) The regional average temperature has a positive relation with the snow-accumulation days and relative humidity, and has a negative relation with the total cloud amount over EP. The annual precipitation has a positive relationship with snow-accumulation days, relative humidity, and surface pressure.

6. Discussion

From this paper it can be seen that a climatic jump from warm-dry to warm-wet occurred in T-P in the middle of the 1980s. Summarizing this result with the issue of climatic shift from warm-dry to warm-wet in Northwest China (Shi et al., 2003), it can be concluded that a climatic shift from warm-dry to warm-wet occurred in the western part of China in the middle of the 1980s.

REFERENCES

Fu Congbin, and Wang Qiang, 1992: The definition and detection of the abrupt climatic change. *Chinese Journal of Atmospheric Sciences*, **16**(4), 483-493. (in Chinese)

Hansen, J., and S. Lebedeff, 1987: Global trends of measured surface air temperature. *J. Geophys. Res.*, **92**, No.D11, 13345–13372.

IPCC, 1995: *Climate Change 1995: The Science of Climate Change*. Houghton J. T. et al., Eds., Cambridge University Press, U. K., 142pp.

Karl, T. R., P. D. Jones, and R. W. Knight, 1993: A new perspective on recent global warming: Asymmetric trends of daily maximum and minimum temperature. *Bull. Amer. Meteor. Soc.*, **74**(6), 1007–1023.

Liu Xiaodong, Zhang Minfeng, and Hui Xiaoying, 1998: Contemporary climatic change of the Qinghai–Xizang Plateau and Its response to greenhouse effect. *Scientia Geographica Sinica*, **18**(2), 113–121. (in Chinese)

Niu Tao, Chen Longxun, and Wang Wen, 2002: REOF analysis of climatic characteristics of winter temperature and humidity on the Xizang-Qinghai Plateau. *J. of Appl. Meteor. Sci.*, **13**(5), 560–570. (in Chinese)

Shi Yafeng, Shen Yongping, Li Dongliang, Zhang Guowei, Ding Yongjian, Kang Ershi, and Hu Ruji, 2003: *An Assessment of the Issues of Climatic Shift from Warm-dry to Warm-wet in Northwest China*. China Meteorological Press, Beijing, 124pp.

Tang Maocang, Li Cunqiang, and Zhang Jian, 1988: The contemporary climate changes over the Tibetan Plateau and its vicinity. *Plateau Meteorology*, **7**(1), 39–48. (in Chinese)

Wang Shaowu, and Yie Jinlin, 1995: An analysis of global warming-up during the last one hundred years. *Chinese Journal of Atmospheric Sciences*, **19**(5), 545–553. (in Chinese)

Wei Fengying, and Cao Hongxing, 1995: Detection of abrupt changes and trend prediction of the air temperature in China, the northern hemisphere and the global. *Chinese Journal of Atmospheric Sciences*, **19**(2), 140–148. (in Chinese)