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Regional characteristics of the interdecadal turning of winter/summer climate modes in Chinese mainland

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Tomé and Miranda's climate trend turning discriminatory model is used to identify the spatial-temporal characteristics of the interdecadal turning of winter/summer climate modes at stations and in eight sub-areas over Chinese mainland based on the 1961–2000 observations. It is found that the stations with close occurrence years of the interdecadal trend turning (ITT) and coincident trends after the ITT exhibit a zonal distribution. A view is accordingly proposed that the interdecadal turnings of climate modes in China have remarkably regional structures. The research results show that after the early 1980s, winter climate over Chinese mainland overall trends towards a "warm-wet" mode, while summer climate had an abrupt change into "warm wet" mode in the late 1980s, suggesting that the time of the "warm-wet" mode turning for winter climate is earlier than that for summer climate. The regional characteristics and test results of the ITTs in eight sub-areas suggest that winter climate exhibits a distinctive "warm-dry" trend in North China after the late 1970s, and a slight "warm-dry" trend in Northeast China, South China, and Southwest China after the late 1980s. A "warm-wet" trend appears in the rest four sub-areas (the middle and lower reaches of the Yangtze River and the Huaihe River Valley, briefly Jianghuai, the east of the Tibetan plateau, and the east and west of Northwest China) after the early 1980s. The summer climate trends towards a "warm-dry" mode in Northeast China, North China and the east of Northwest China after the late 1980s, but a "warm-wet" mode appears in Southwest China and the east of the Tibetan plateau after the middle 1970s, as well as in Jianghuai and the west of Northwest China after the early 1980s. Specially, summer climate in South China started a "cold-wet" trend in 1984.

climate mode, interdecadal trend turning, regional characteristics

Under the background of global warming, the impact of climate change on the environment, water resources, industrial-agricultural production and daily life is becoming more and more significant, thus drawing more and more attention. A lot of studies have been conducted to seek the modern climate change regularities in China. Chen et al.[1] found that for the period 1951—1995, the annual mean temperature (AMT) over China showed a rising trend, but there still existed some cooling areas. The annual precipitation (AP) slightly reduced mainly in North China and the areas to the south of the Yangtze River, but increased in the Yangtze-Huaihe River Valley. During 1951—2000, the AMT over China remarkably rose after the 1980s, and a rising trend also existed in the low temperature region of Southwest China after the 1990s[2]. Recently, Chen et al.[3] analyzed the characteristics of climate changes in China since the 1920s. They found that the AMT started rising in northern China (north of 35°N) since the early 1980s, as well as in southern China (south of 35°N) since the late 1980s. The AP over Chinese mainland was less than normal in the

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1960s—1970s, and it started increasing in Northwest China, Northeast China, and the middle and lower reaches of the Yangtze River since the 1980s. Precipitation over eastern China varied within the major periods of 3.3 and 26.7 years[4]. The former might be associated with ENSO, while the latter reflected the distinctive interdecadal change. Lu et al.[5] revealed that the temperature rose since the 1970s in northern China, and the higher the latitude, the earlier the warming occurred. They also found that the temperature almost changed simultaneously over the whole eastern China, but in different periods in western China due to the vigorous impact of the Tibetan plateau. Liu et al.[6] pointed out that the rising of surface temperature over China accelerated after the 1990s. Analyzing temperature changes during 1961–2000 were based on the daily surface temperature data from 498 stations in China, and Qian et al.[7] found that the number of "warm days" increased in the upper and middle reaches of the Huanghe River and the south coastal region, but decreased at scatted stations in the central and eastern China.

Meteorologists have paid much attention to summer drought/flood disasters and megathermal weather lasting a long period due to their close relations with social economy and people's life. Huang et al.[8] pointed out that the summer precipitation in China exhibited distinctive interdecadal changes leading to severe climatic disasters, especially the sustained droughts resulting in the lack of water resources in North China and frequent floods causing massive economic losses in the Yangtze River Valley. A recent study suggested that the summer precipitation obviously increased in the area to the south of the Yangtze River after the 1990s, but distinctively reduced in North China and Northeast China[2]. Hu et al.[9] analyzed the long-term trend of summer climate in eastern China based on the observational data and the CMIP2 model outputs. They found that the summer precipitation mainly exhibited a decreasing trend in the north of eastern China, and an increasing trend in the central part, especially in the middle and lower reaches of the Yangtze River. The summer temperature displayed a warming trend in the whole eastern China except a cooling trend in its central part. Furthermore, a cooling/warming trend generally coexisted with a wetting/drying trend, respectively. Investigating the interdecadal change of the North China flood-season (July-August) precipitation, Lu[10] discovered the sudden reduction of the flood-season precipitation in the late 1970s. Gong et al.[11] found that the summer precipitation in the middle and lower reaches of the Yangtze River abruptly changed around 1979. They also held that the abrupt change in summer precipitation was related to the strengthening of the west Pacific subtropical high. Shi et al.[12] revealed the climate turning from a "warm-dry" mode to a " warm-wet" mode in 1987 in Northwest China (mainly in Xinjiang). Relevant research results also suggested that a distinctive abrupt climate change occurred in Northwest China near 1986, and both temperature and precipitation increased after the abrupt change[13]. In the last 50 years, summer precipitation exhibited a decreasing trend in the south of Northeast China, North China, and Sichuan Basin, but an increasing trend in western China, the Yangtze River Valley, and the southeast coastal region[14].

As for winter, the rising trend of temperature is the strongest among four seasons both in western and eastern China. Chen et al.[15] pointed out that the winter temperature rose in Northeast China, the east of Northwest China, Qaidam Basin, the upper and middle reaches of the Yangtze River, the upper reaches of the Huanghe River and South China, but dropped in Sichuan, Hanzhong Basin, Hunan, and the north of Jiangsu from the 1950s to 1980s. Yao[16] also discovered that the winter temperature generally rose in most areas of Northwest China and the Tibetan plateau. The winter precipitation increased generally in the most areas of China, especially in most areas of Northwest China, the Tibetan plateau, and Southwest China, and slightly decreased only in Inner Mongolia, Northeast China and the north of North China[17]. Recently, based on the daily precipitation data from 740 stations in China in the last 50 years, Zhai et al.[14] found that the winter precipitation displayed an increasing trend in western China and the south of eastern China, but a decreasing trend in the north of eastern China.

However, the interdecadal climate change in China and its formation mechanism remain to be further explored. For example, whether the interdecadal turning of climate modes is a distinctively regional character, or only an unordered rule with isolated and discrete distribution is unclear. What is the main difference between the interdecadal turnings of winter/summer climate modes? Deeply exploring of these problems will lead to a better understanding about the evolution and abrupt changes of climate modes in China under the background of global change. This paper employs the Tomé and Miranda's climate trend turning discriminatory model, a piecewise linear fitting model (PLFIM)[18], to analyze the interdecadal trend turning (ITT) of winter/summer temperature and precipitation at 160 stations and in eight sub-areas in Chinese mainland from 1961 to 2000, and explore regional structures of the interdecadal turning of winter/summer climate modes in China, as well as the features of the interdecadal turning of sub-area climate modes, so as to gain more objective and scientific understanding of interdecadal changes of regional climate in China in the last 40 years.

1 Data and methods

1.1 Data description

The monthly mean temperature and precipitation data from January 1960 to December 2000 from 600 surface meteorological stations provided by the National Meteorological Information Center of China Meteorological Administration (CMA) are used to compute the regionally mean values of temperature and precipitation over China and its eight sub-areas (Figure 4) and to test the ITTs of climate. The mean temperature and total precipitation of winter (December-January-February, i.e., DJF) and summer (June-July-August, i.e., JJA) at each station are computed from 1961 to 2000, and then their time series for the whole China and the eight sub-areas in the same period are taken as the spatial means.

The monthly mean temperature and rainfall data from January 1960 to December 2000 from 160 surface meteorological stations in China provided by the National Climate Center of CMA are used to calculate the single station time series of the mean temperature and total precipitation of winter and summer from 1961 to 2000. These single station time series are analyzed respectively to get characteristics of interdecadal turning of winter/summer climate modes for each station.

1.2 Brief introduction to the PLFIM

The analysis of the linear trend of time series is frequently used in climate change research. The linear trend is able to reflect the overall trend of climate change over some period, but cannot describe the wavy character of climate change in a long time. Therefore, Tomé and Miranda[18] put forward a new method, namely PLFIM. According to the time scale of the studied problem, a minimum time interval between trend turning points is given. For different research purposes, the discriminatory conditions of trend turning could be different, such as the changing sign of linear trends between two consecutive time segments or the change extent exceeding a particular percentage. Under the precondition of the time interval between two consecutive breakpoints being equal to or greater than the minimum interval, i.e., filtering off the climatic waves whose period is less than the minimum interval, many combinations of time segments could be obtained. By computing the linear trend for each time segment in each combination respectively, and judging whether the trend turning takes place or not based on the discriminatory condition of trend turning, the best combination of segments can be determined by using the principle of statistical analyses, yielding the test result of trend turning points on the imposed time scale and the linear trend for each time segment.

Climate abrupt changes might be categorized into three types, i.e., the abrupt change of mean value, change rate, and trend[19]. They indicate the sudden change from a basic climate state (represented by a mean value) to another basic state, the distinctive difference in the change rates of two consecutive climatic states without obvious difference between their mean values, and the sudden change of the completely opposite trends, respectively. For the moment, methods frequently used in climate abrupt change research include low-pass filtering, running *t*-test, Cramer method, and M-K method[20]. However, these methods are mainly suitable for the test of the abrupt change of mean value. Methods for the test of the abrupt change of change rate and trend are very few. The two-phase linear regression model[21] and the two-phase quadratic curve fitting method[22], which developed on the basis of the former, are relatively effective, but the number of turning points in both methods must be subjectively given. In comparison with these two methods, the PLFIM need not give the number of turning points in advance. Subjected to the two constraints on the minimum distance between trend turning points and the changing sign between the linear trends of two consecutive segments (the abrupt change of trend) or the obvious difference of change rates exceeding a critical value (the abrupt change of change rate), the best continuous time segments can be gained. The number and positions of trend turning points computed in such a way would be more reasonable. The mathematical principle of the PLFIM is referred to ref. [18].

2 Regional structures of the interdecadal turning of winter/summer climate modes in China

In order to investigate the ITTs of winter/summer temperature and precipitation in the last 40 years, the two imposed conditions are given. They are changing sign of linear trends between two consecutive time segments and a minimum 11-year interval between trend turning points. The ITTs of winter/summer mean temperature and precipitation over whole China from 1961 to 2000 are tested respectively with PLFIM (thick straight lines in Figure 1). To verify whether the test results of PLFIM can reflect the interdecadal change characteristics of the climatic variables or not, the 11-year running means, i.e., the interdecadal components (IC) of the four time series (thick curves in Figure 1), are also computed and compared with the test results of PLFIM.

On interdecadal time scale, the entire-country-mean winter temperature (WT) turned from a cooling trend to a warming one in 1971, and the warming trend is more remarkable than the cooling trend. The IC of WT also confirms the robust warming trend (Figure 1(a)). With regard to the entire-country-mean winter precipitation (WP), two ITT points were determined in 1971 and 1982 respectively, indicating an increasing trend in the 1960s, followed by a decreasing trend in the 1970s, and an increasing trend again after the early 1980s. The evolution of IC of WP is in good agreement with the test results of the ITT (Figure 1(b)). Therefore, it can be concluded from the above results that winter climate in China trends towards a "warm-wet" mode after the early 1980s.

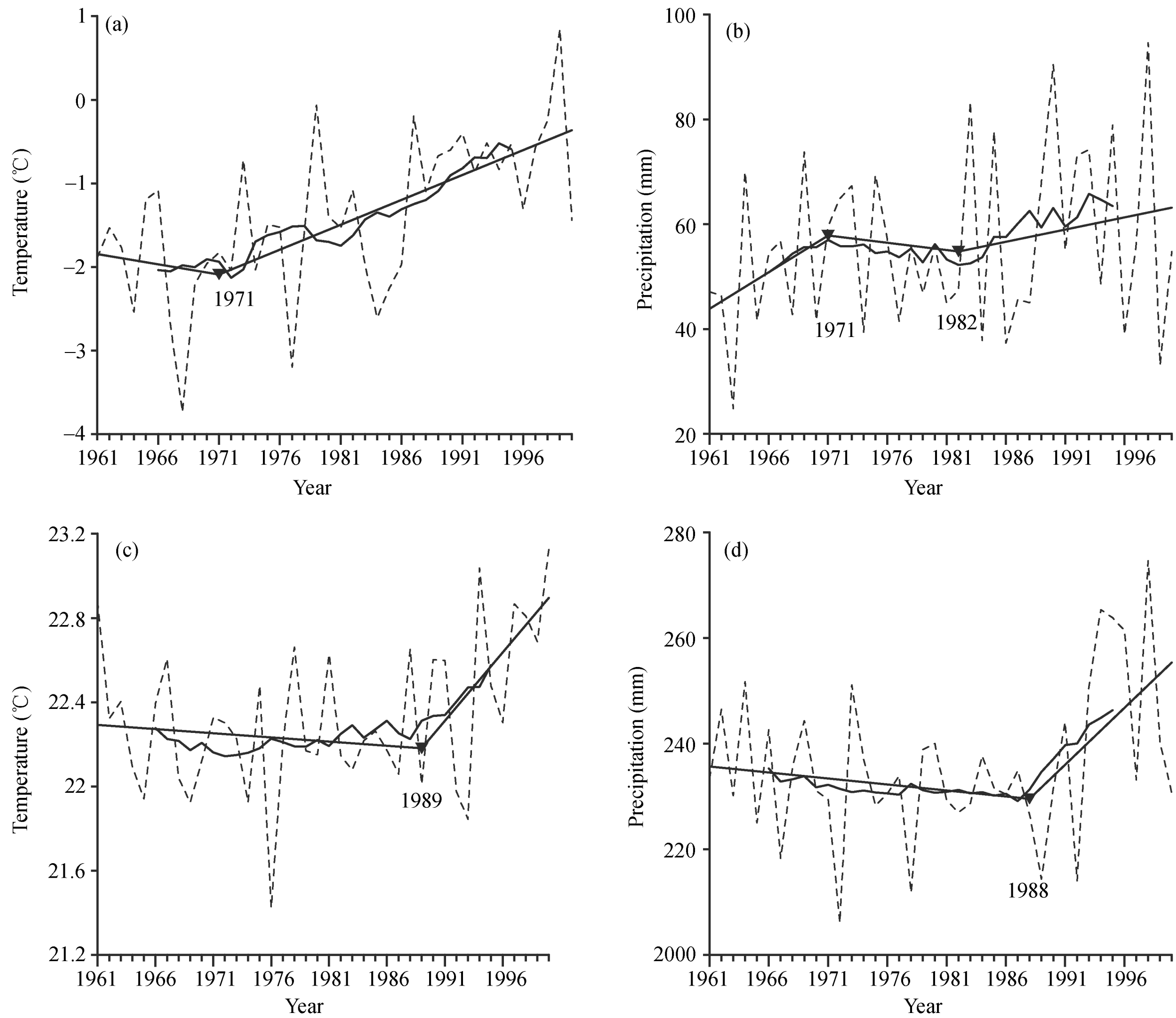

Figure 1 Time series (dash lines) of winter/summer mean temperature ((a)/(c)) and precipitation ((b)/(d)) over whole China from 1961 to 2000, their 11-year running means (thick curves), and test results of the ITT (thick straight lines where labeled ▼ with figures denotes the year of the ITT points).

The ITTs of summer temperature (ST) and precipitation (SP) are similar to each other. Both ITTs of the two climatic variables from weakly decreasing trend to remarkably increasing trend took place in the late 1980s. The ICs of ST and SP remarkably rose after the late 1980s (Figures 1(c) and (d)), that is to say, both the entire-country-mean ST and SP decreased before the late1980s, and increased afterwards. Therefore, summer climate in China trends towards a "warm-wet" mode after the late 1980s. Besides, it can be observed from Figure 1 that the trends of ICs of winter/summer temperature and precipitation are similar to the test results of PLFIM, indicating it is feasible to use the PLFIM to analyze the climatic trend, and the trend turning points mathematically computed are more objective than other methods.

The ITTs for the 1961—2000 WT and WP at 160 stations are further tested station by station with PLFIM. The occurrence time of the last ITTs and the linear trends after that (i.e., the latest linear trends) are analyzed. Figure 2(a) shows the results of WT at 160 stations. It can be seen that in northern China (about north of 30°N), except linearly increasing in the last 40 years without ITT at some stations, the WT at most stations had ITTs from a cooling trend to a warming trend in the early 1970s. These stations concentrate in the central and eastern parts of northern China (light gray shaded region). A few stations are mainly located in Northwest China with ITTs from a warming trend to a cooling trend in the late 1980s (black shaded regions). In southern China (about south of 30°N), the latest warming trends of WT at most stations appear after the middle 1980s (dark gray shaded region), that is to say, the ITTs with the latest warming trend occur one decade earlier at most stations in northern China than those in southern China. The situation of WP is more complicated than that of WT. The stations with an increasing trend after the last ITT mainly concentrate in the west of Northwest China, the lower reach of the Yangtze River, the east of South China, and parts of Southwest China, North China and Northeast China (dark gray shaded regions). Their last ITTs mostly took place in the early 1980s. The stations with the latest decreasing trend concentrate in a southwest-northeast oriented zonal area, i.e., the south of Northeast China, the upper and middle reaches of the Yangtze River, the west of South China, the east of Northwest China, and the east of the Tibetan plateau (black shaded regions). Their last ITTs mainly occurred in the late 1980s (Figure 2(b)).

Likewise, the ITTs for ST and SP are also tested with PLFIM, and the results are given in Figure 3. Figure 3(a) shows the regional characteristics of the last ITTs of ST at 160 stations in the last 40 years. It can be seen that in northern China, the last ITTs at most stations occurred in the middle and late 1980s (dark gray shaded region) and the latest linear trends are warming, except the most stations in North China, where ITTs occurred in the early 1970s (light gray shaded region) and much earlier than that in the rest regions of northern China. In southern China, the last ITTs with a latest cooling trend happened at most stations in the 1980s (black shaded region). Figure 3(b) reveals the regional characteristics of the last ITTs of SP. The last ITTs with a latest increasing trend occur at most stations mainly located in South China, the lower reach of the Yangtze River, the south of Southwest China, and the west of Northwest China (dark gray regions). The last ITTs with a latest decreasing trend happen at some stations in Northeast China, central China, and parts of Northwest China and North China (black shaded regions). Furthermore, the last ITTs of SP, with either a latest increasing trend or a latest decreasing trend, mostly occurred in the 1980s.

The comparison between Figure 3(a) and (b) shows that after the last ITTs, the obviously reverse trends of ST and SP appear at most stations between Northeast China and the south to the Yangtze River, that is to say, ST increases and SP reduces in Northeast China, showing a "warm-dry" trend, but in the areas to the south of the Yangtze River, ST deceases and SP increases, showing a "cooling-wet" trend. Meanwhile, the occurrence time of the last ITTs of ST and SP at most stations in these two regions is close.

3 Interdecadal turnings of winter/summer climate modes in sub-areas

From the ITT characteristics of winter/summer temperature and precipitation at 160 stations, it is easy to find that climates in various regions in China change faster than in a unanimous way, showing distinctive regional features. For the purpose of analyzing the interdecadal turnings of sub-area winter/summer climate modes, Chinese mainland is divided into eight sub-areas primarily based on administrative divisions and the characters of the monsoon climate of China (Figure 4).

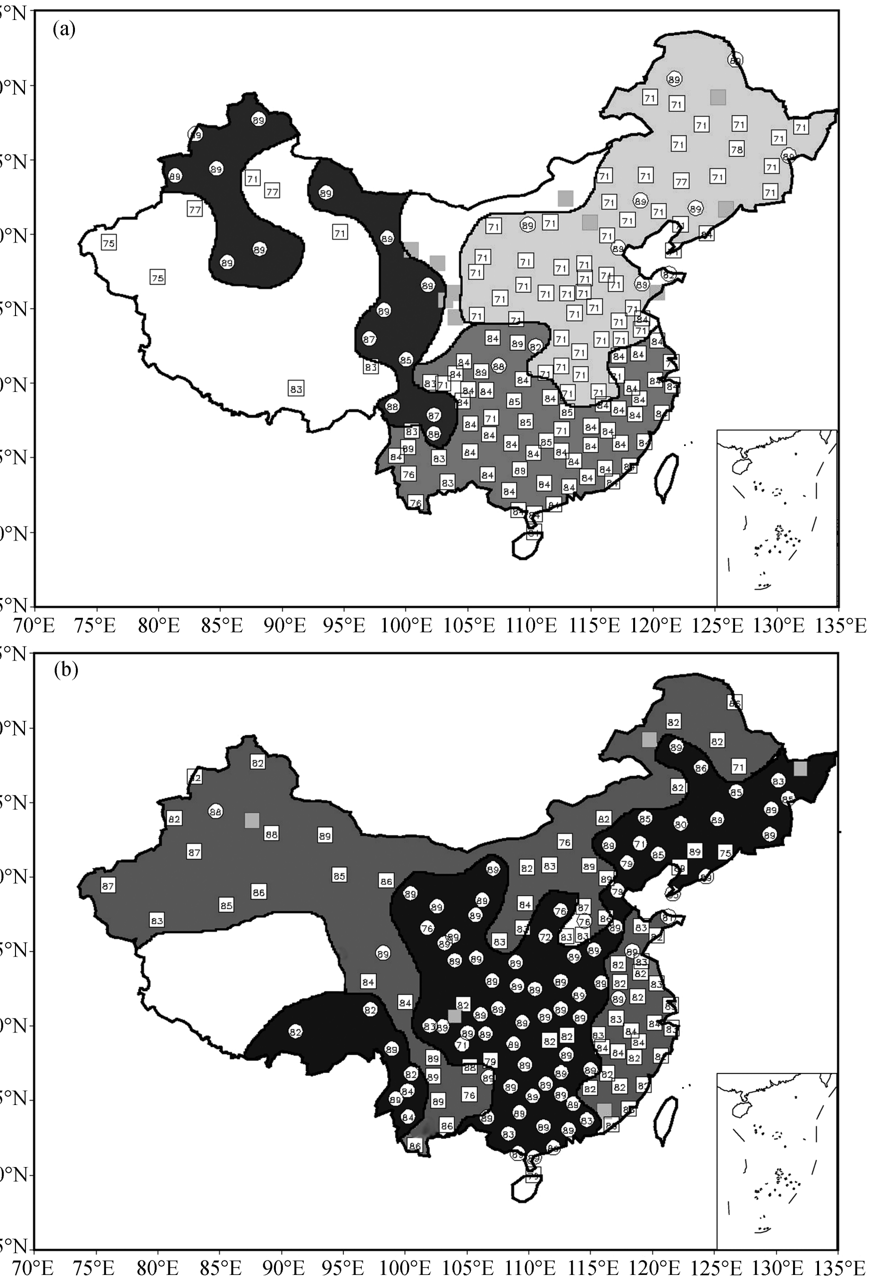

Figure 2 The last ITTs of winter temperature (a) and precipitation (b) at 160 surface meteorological stations over Chinese mainland in 1961—2000. The open circle/square denotes the decreasing/increasing trend after the last ITT, respectively, and the figure within the circle or square is the year of the last ITT point (the year in 1960—2000 is represented by the last two numbers). The solid square denotes no ITT occurring and a linear increasing trend during 1961—2000.

They are (1) Northeast China (north of 42.5°N, east of 110°E), (2) North China (35°N—42.5°N, east of 110°E), (3) the middle and lower reaches of the Yangtze River and the Huaihe River Valley, briefly Jianghuai (27.5°N—35°N, east of 107.5°E), (4) South China (south of 27.5°N, east of 107.5°E), (5) Southwest China (south of 35°N, 97.5°E—107.5°E), (6) the east of the Tibetan plateau (south of 35°N, west of 97.5°E, because of the lack of stations in the west of the plateau, the analysis results of this area only represent the situations in the east of the plateau), (7) the west of Northwest China (north of 35°N, west of 97.5°E), (8) the east of Northwest China (north of 35°N, 97.5°E—110°E). The division of the four sub-areas in eastern China roughly considers the northward advances of the East Asian summer monsoon as well as administrative divisions. The south of western

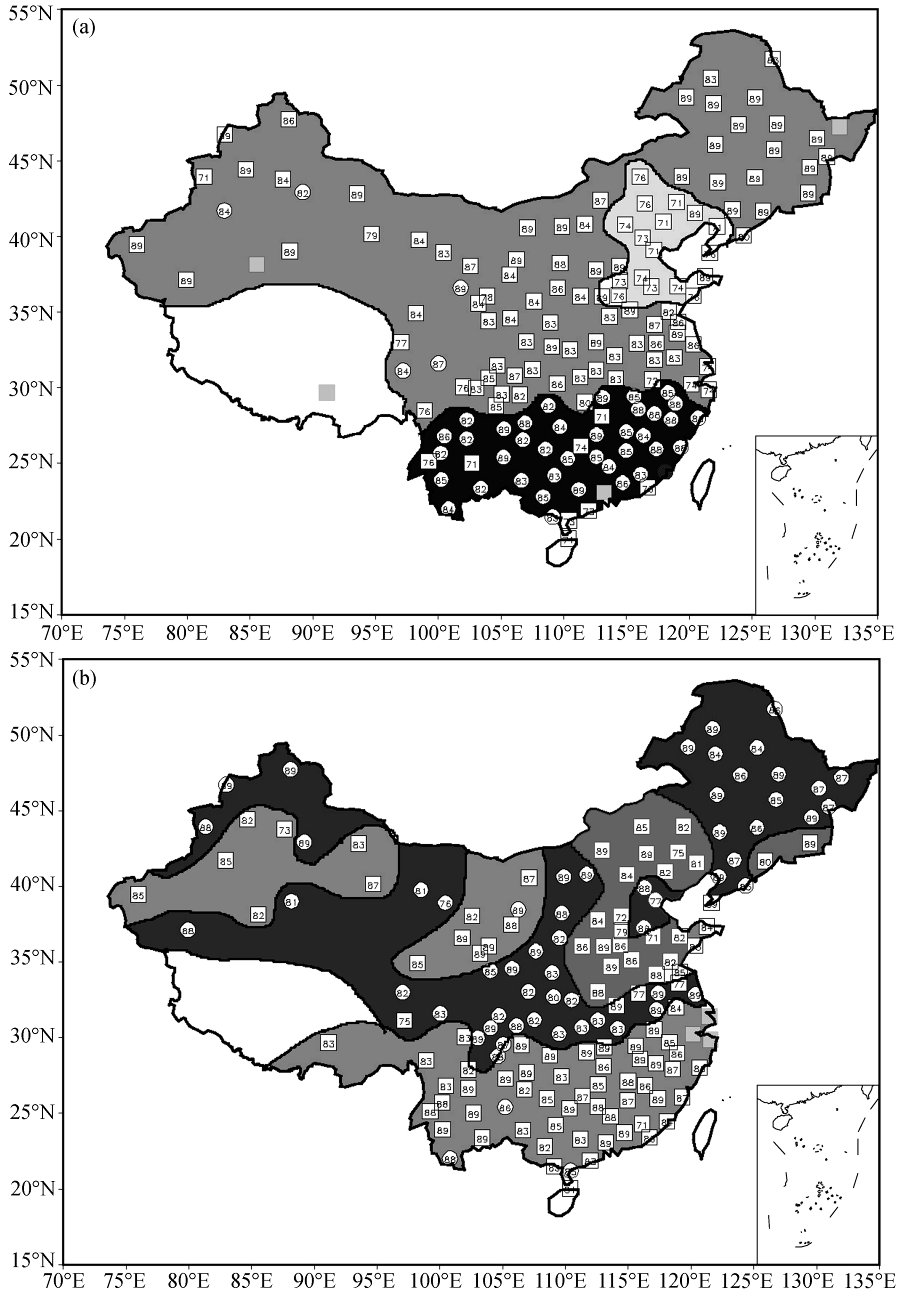

Figure 3 The same as Figure 2 except for summer temperature and precipitation. The solid circle denotes that no ITT occurred and a linear decreasing trend during 1961－2000.

China is divided mainly based on administrative divisions, attempting to make Southwest China cover as much more regions of Yunnan, Guizhou, Sichuan and Chongqing as possible. According to the fact that there are precipitation increasing and decreasing regions, respectively[13], Northwest China is divided into the east and west sub-areas. The time series of winter/summer mean temperature and total precipitation in eight sub-areas are computed using the observation data from 600 surface meteorological stations in China during 1961－2000, and their ITT characteristics are tested with the PLFIM.

Analyzing the test results of the ITTs of winter/summer temperature and precipitation in the four sub-areas in northern China, it is found that the ITT of WT in North China is consistent with that of whole China, with an ITT point from a slowly cooling trend to a rapidly warming trend in 1971 (Figure 5(a)). The ITT

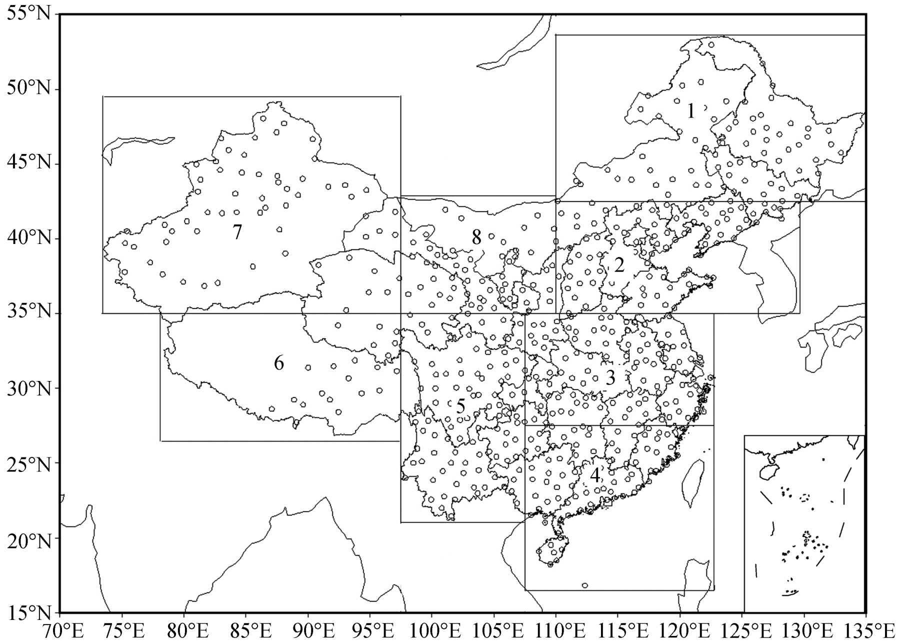

Figure 4 Positions of 600 surface meteorological stations in China and their regionalization.

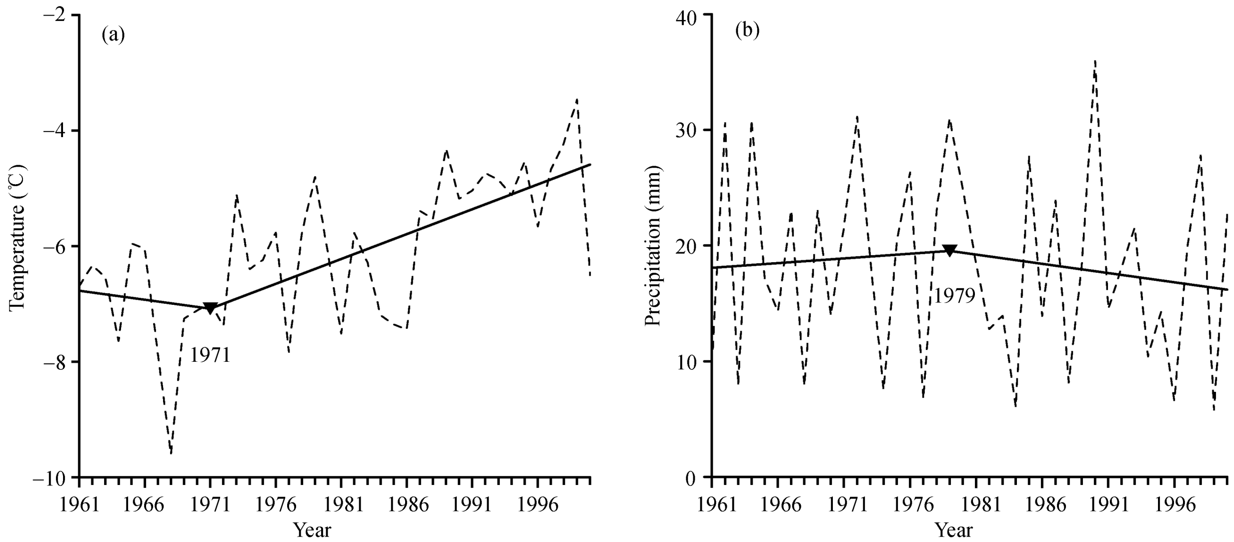

Figure 5 The ITTs of winter temperature (a) and precipitation (b) in North China during 1961—2000.

point of WP in North China from a slowly increasing trend to a slowly decreasing trend was in 1979 (Figure 5(b)). The ITTs of WT from cooling to warming in Northeast China and the west of Northwest China also took place in the early 1970s. The WT in the east of Northwest China has no ITT, suggesting a linear increasing trend during 1961—2000. In the last 40 years, the WP in Northeast China had two ITTs. The first one from a decreasing trend to an increasing trend occurred in 1975 and the second one from an increasing trend to a decreasing trend happened in 1989, respectively. The ITTs of the WP in the east and west of Northwest China are very consistent with each other. They showed an increasing trend before 1972 followed by a decreasing trend during 1972—1983, and an increasing trend again after 1983 (figure omitted).

With regard to the four sub-areas in southern China, the change of WT in Jianghuai is consistent with that in Northeast China, North China and the average change of WT in the whole China, with an ITT from cooling to warming in 1971. The changes of WT in Southwest China and the east of the Tibetan plateau are unanimous, with the first ITT from warming to cooling in 1972 and the second one from cooling to warming in 1984 (figure omitted). The change of WT in South China is similar to that in Southwest China and the east of the Tibetan plateau, with the first ITT from warming to cooling in 1973 and the second one from cooling to warming in 1984 (Figure 6(a)). Comparing the test results of four sub-areas in southern China with those of four sub-areas in northern China, it can be discovered that the occurrence of the last ITTs of WT from cooling to warming in northern China is overall earlier than that in southern China, basically in agreement with the test results of 160 stations. Furthermore, the warming trends in northern China are more remarkable than those in southern China after the last ITTs.

The year of 1971 is the occurrence time of the first ITT of WP from increasing to decreasing in Jianghuai, and 1982 is the occurrence time of the second ITT from decreasing to increasing (Figure omitted). An ITT of WP from increasing to decreasing in South China occurred in 1989 (Figure 6(b)). The ITT of WP in Southwest China is in agreement with that in Northeast China. It exhibits a decreasing trend during the 1960s to the early 1970s, followed by an increasing trend from the early 1970s to the late 1980s, and a decreasing trend again after the late 1980s. There is no ITT of WP in the east of the Tibetan plateau in the last 40 years, showing a linear increasing trend (figure omitted).

According to the test results of the ITTs of WT and WP in the eight sub-areas, the following conclusions can be drawn. A "warm-dry" trend of winter climate started in the late 1970s in North China and in the late 1980s in Northeast China, South China and Southwest China. A warm-wet" trend of winter climate began after the early 1980s in Northwest China, Jianghuai and the east of the Tibetan plateau.

In the same way, the ITTs of ST and SP from 1961 to 2000 in the eight sub-areas are tested with the PLFIM. It is discovered that the interdecadal changes of ST in Northeast China and the west of Northwest China are unanimous, with 1978 being the occurrence time of the first ITT from a weak warming trend to a weak cooling trend, and 1989 being the occurrence time of the second ITT from the weak cooling trend to a distinctive warming trend. The ST in North China showed a weak cooling trend before 1989 and a distinctive warming trend after 1989. In the east of Northwest China, an ITT of ST from a cooling trend to a distinctive warming trend occurred in 1984. An ITT of ST in Jianghuai from a cooling trend to a warming trend took place in 1982. The ITTs of ST in Southwest China and the east of the Tibetan plateau are similar. Their ITTs from a cooling trend to a warming trend occurred in 1974 and 1976, respectively (figure omitted). Therefore, viewed from the occurrence time, the last ITTs of ST from a cooling trend to a warming trend in the three sub-areas of southern China are earlier than those in the four sub-areas of northern China, which is just opposite to the winter case. Viewed from the amplitude of temperature changes, the warming amplitudes of ST after the last ITTs in northern

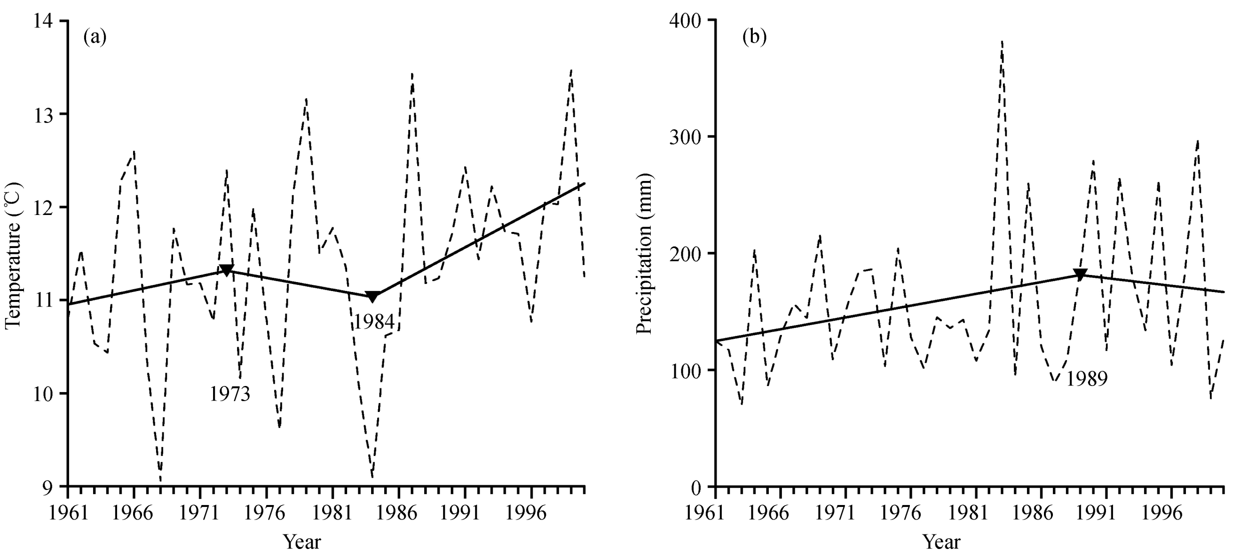

Figure 6 The ITTs of winter temperature (a) and precipitation (b) in South China during 1961－2000.

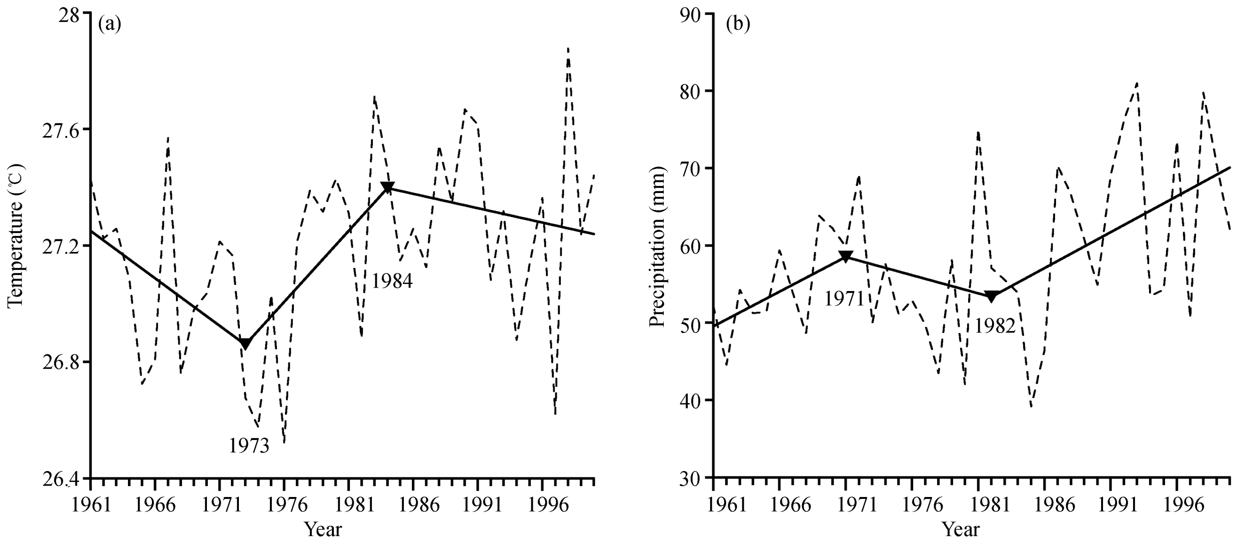

Figure 7 The ITTs of summer temperatures in South China (a) and summer precipitation in the west of Northwest China (b) during 1961—2000.

China are still larger than those in southern China. As a particular case, the ST in South China exhibited a cooling trend between 1961 and 1973, followed by a warming trend from 1973 to 1984, and a cooling trend again after 1984 (Figure 7(a)), which is basically in agreement with the research result of Wang et al.[2] This cooling trend after 1984 might be related to the radiation forcing of aerosols brought by human activities[3].

The decreasing trend of SP in North China is most prominent. Although a very weakly increasing trend appeared during 1972—1989, it is in a decreasing trend as a whole. Two ITTs of SP in Northeast China took place in 1976 and 1987 respectively, with two decreasing trends separated by an increasing trend, showing a wavy character. The SP in the east of Northwest China increased before 1978, and decreased afterwards (Figure omitted). The change of SP in the west of Northwest China is special. It displayed an increasing trend before the early 1970s, followed by a decreasing trend during 1971—1982, and an increasing trend again after the early 1980s (Figure 7(b)), showing an "out-of-phase" evolutional character with respect to that of SP in the other three sub-areas of northern China. In combination with the analysis results of the ITTs of ST, it can be summed up that a "warm-dry" trend of summer climate occurred in Northeast China, the east of Northwest China and North China after the 1980s, while in the west of Northwest China, a "warm-wet" trend appeared after the late 1980s. It basically accords with the conclusions of ref. [13] and [23]. Among the four sub-areas in southern China, the SP in Jianghuai has no ITT, showing a linear increasing trend in the last 40 years, that is to say, its summer climate undergoes an evolving process of "warm-dry"—"cold-wet"—"warm-wet". The SP in South China evolves in an out-of-phase with respect to its ST, with 1973 being the occurrence time of an ITT from an increasing trend to a decreasing trend and 1984 being the occurrence time of the subsequent ITT from the decreasing trend to an increasing trend. Consequently, its summer climate undergoes an interdecadal evolving process of "warm-dry" — "cold-wet" — "warm-dry"—"cold-wet". The ITTs of SP in Southwest China and the east of the Tibetan plateau are accordant with a decreasing trend before 1972 and an increasing trend after 1972 (figure omitted).

The test results of the ITTs of ST and SP in sub-areas suggest that summer climate trends towards a "warm-dry" mode in Northeast China, North China and the east of Northwest China after the late 1980s. A "warm-wet" trend occurs in Southwest China and the east of the Tibetan plateau after the middle 1970s, and also in Jianghuai and the west of Northwest China after the early 1980s. South China is an exception, because of its summer climate trending towards a "cold-wet" mode in 1984.

4 Conclusions

Using PLFIM, comprehensive analyses are made on the regional structure of the interdecadal turnings of climate modes at stations and the characteristics of the interdecadal turnings of sub-area climate modes in winter/summer in China from 1961 to 2000. Main conclusions are as follows.

(1) As far as the cases of the entire-country-mean are concerned, an ITT of WT from cooling to warming occurred in 1971, while the WP undergoes two ITTs with the latest increasing trend starting from 1982. Therefore, winter climate in China trends towards a "warm-wet" mode after the early 1980s. The characteristics of the ITTs of ST and SP are similar. An ITT from weakly decreasing to remarkably increasing occurred in the late 1980s, i.e., summer climate in China also trends towards a "warm-wet" mode after the late 1980s.

(2) The test results of the ITTs of winter/summer temperature and precipitation at 160 surface meteorological stations in China suggest that the ITTs of WT at most stations in northern China from cooling to warming happened in the early 1970s, but in southern China in the middle 1980s. The WP at most stations in the west of Northwest China, the lower reaches of the Yangtze River, the east of South China, and parts of Southwest China, North China and Northeast China turned to an increasing trend in the early 1980s. However, the WP at most stations in the south of Northeast China, the upper and middle reaches of Yangtze River, the west of South China, the east of Northwest China, and the east of the Tibetan plateau turned to a decreasing trend in the late 1980s. The last ITTs of the ST with a latest warming trend occurred at the stations in northern China in the middle and late 1980s, while the last ITTs with a latest cooling trend took place at most stations in southern China in the 1980s. After the last ITTs in the 1980s, the SP increases at most stations in South China, the lower reaches of the Yangtze River, the south of Southwest China, and the west of Northwest China, but decreases mainly in Northeast China, central China, and parts of Northwest China and North China. The stations with close occurrence years of the last ITTs and coincident latest trends exhibit a zonal distribution, indicating remarkably regional structures.

(3) The test results of the ITTs of sub-area WT and WP indicate that winter climate shows a "warm-dry" trend in North China after the late 1970s, and in Northeast China, South China, and Southwest China after the late 1980s. In the rest four sub-areas, winter climate trends towards a "warm-wet" mode after the early 1980s. The ITTs of sub-area ST and SP were also investigated. It is found that summer climate trends towards a "warm-dry" mode in Northeast China, North China, and the east of Northwest China after the late 1980s. A "warm-wet" trend of summer climate occurred in Southwest China and the east of the Tibetan plateau after the middle 1970s, as well as in Jianghuai and the west of Northwest China in the early 1980s. South China is a particular area, where the summer climate shows a "cold-wet" trend after 1984.

(4) The regional structures of ITTs at stations and the test results of eight sub-areas suggest that the last ITTs of temperature from cooling to warming in northern China occur earlier than those in southern China in winter, but later in summer. However, the latest warming trends of WT and ST in northern China are both more remarkable than those in southern China. After the last ITTs, an increasing trend of SP appears in most areas of southern China, but a decreasing trend in northern China except the west of Northwest China, showing a notable "south-flood and north-drought" situation in China.

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