SCIENCE CHINA
Earth Sciences

• RESEARCH PAPER •

November 2014 Vol.57 No.11: 2676–2689
doi: 10.1007/s11430-014-4889-1

# Climate change regionalization in China (1961–2010)

SHI PeiJun[1,2,3*], SUN Shao[1,2,3], WANG Ming[1,3], LI Ning[2,3], WANG JingAi[4,5], JIN YunYun[1,3], GU XiaoTian[2,3] & YIN WeiXia[4,5]

[1] *State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing 100875, China;*
[2] *Key Laboratory of Environmental Change and Natural Disaster of Ministry of Education, Beijing Normal University, Beijing 100875, China;*
[3] *Academy of Disaster Reduction and Emergency Management, Ministry of Civil Affairs & Ministry of Education, Beijing 100875, China;*
[4] *School of Geography, Beijing Normal University, Beijing 100875, China;*
[5] *Key Laboratory of Regional Geography, Beijing Normal University, Beijing 100875, China*

Received November 14, 2013; accepted January 14, 2014; published online July 14, 2014

Since climatic condition is the important foundation for human subsistence and development and the key factor in sustainable development of economy and society, climate change has been a global issue attracting great attentions of politicians, scientists, governments, and the public alike throughout the world. Existing climate regionalization in China aims to characterize the regional differences in climate based on years of the mean value of different climate indexes. However, with the accelerating climate change nowadays, existing climate regionalization cannot represent the regional difference of climate change, nor can it reflect the disasters and environmental risks incurred from climate changes. This paper utilizes the tendency value and fluctuation value of temperature and precipitation from 1961 to 2010 to identify the climate change quantitatively, and completes the climate change regionalization in China (1961–2010) with county administrative regionalization as the unit in combination with China's terrain feature. Level-I regionalization divides China's climate change (1961–2010) into five tendency zones based on the tendency of temperature and precipitation, which are respectively Northeast China-North China warm-dry trend zone, East China-Central China wet-warm trend zone, Southwest China-South China dry-warm trend zone, Southeast Tibet-Southwest China wet-warm trend zone, and Northwest China-Qinghai-Tibet Plateau warm-wet trend zone; level-II regionalization refers to fourteen fluctuation regions based on level-I regionalization according to the fluctuation of temperature and precipitation.

**climate change, regionalization, temperature, precipitation, tendency, fluctuation, China**

**Citation:** Shi P J, Sun S, Wang M, et al. 2014. Climate change regionalization in China (1961–2010). Science China: Earth Sciences, 57: 2676–2689, doi: 10.1007/s11430-014-4889-1

Intergovernmental Panel on Climate Change (IPCC) issued the Fourth Assessment Report in 2007, which shows that the linear trend of global surface temperature in the past 50 years (1956–2005) is 0.13°C/10 a, almost twice that for the past 100 years (1906–2005). According to the latest report issued by IPCC in September 2013, by the end of the 21st century, the temperature will rise by 1.5°C compared with the period from 1850 to 1900 under the minimum emission scenarios. And *The Second National Assessment Report on Climate Change* issued by China indicates that temperature rising trend in China is basically the same as the global one on a century time scale; and the linear trend of China's surface temperature from 1951 to 2009 is 0.23°C/10 a. In 2012, IPCC issued Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (hereinafter referred to as SREX), which defines the climate change as "a change in the state of the climate

*Corresponding author (email: spj@bnu.edu.cn)

that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use". It is clearly stated in SREX that a changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events; and economic losses from weather- and climate-related disasters have increased (high confidence).

Climate change has been a global issue attracting great attention of politicians, scientists, governments, and the public alike and it can be tackled mainly through three ways: reducing vulnerability, improving recoverability and advancing adaptation. This paper proposes that climate change adaptation shall be suitable to local conditions, that is, the concrete adaptation measures shall be prepared according to different climate change types in different regions and the relation between different climate change types and disaster and environmental risk. At present, much research has been conducted for climate regionalization worldwide and mostly focuses on regionalization of the climate state instead of that of climate change, thus not meeting current demand of climate change adaptation.

On a global scale, Köppen proposed the world's first quantitative climate classification index and method in 1918 on the basis of two climate elements, namely, temperature and precipitation, and in combination with distribution characteristics of the world's main vegetation types. In 1948, Thornthwaite presented the concept and calculation method of potential evapotranspiration and defined humidity index in combination with precipitation, and he further classified and regionalized the state of the world's climate by combining the two indices. In 1959, Strahler developed the world's climate classification system on the basis of climate dynamics and accomplished the world's climate regionalization according to different source regions as well as dynamic and frontal surface distribution of air masses of different properties and by reference to two climate elements indices, i.e., temperature and precipitation.

China is one of the countries in the world that developed research on climate regionalization early. *Climate classification in China* issued by Chu in 1929 marked the beginning of China's modern research on climate regionalization. In 1959, Natural Regionalization Committee of Chinese Academy of Sciences took accumulated temperature in the period with daily mean temperature not less than 10°C stably as a main index to evaluate heat resources of China, took dryness as a main index to evaluate humidity of China, and then divided China into 8 level-I climate region as well as 32 level-II climate provinces and 68 level-II climate prefectures in combination with China's terrain feature and administrative regionalization. The concept of climate change was established formally in 1984, and many scholars began to concentrate on climate changes, especially the impact of climate warming on China's climate boundary (Ding, 2013; Sha et al., 2002; Ye et al., 2003; Zheng et al., 2013; Bian et al., 2013; Yang et al., 2002); they also discussed possible change scenarios of China's climate regionalization in the context of climate warming in the future(Huang, 1993; Zhao, 1995; Zhou et al., 1996; Shen et al., 1996; Ci et al., 2002).

In conclusion, climate indices adopted in the previous climate regionalization are the mean, such as annual mean temperature, annual mean accumulated temperature not less than 10°C, annual mean precipitation, etc. in a certain period of time. In recent years, some scholars have been concerned with the impact of climate change on climate boundary and have analyzed results of regionalization of different time periods by comparison, but such works are still regionalization of the climate state in essence. Under the background of global climate change, the regionalization of the climate state based on the mean of climate elements cannot meet the demand of addressing climate change. Thus we desperately need a set of classification methods in favor of identifying regional difference of climate change and its impact to achieve climate change regionalization and reveal different types of disaster and environmental risk possibly incurred from climate change in different regions, so as to put forward adaptation measures suitable to local conditions. This paper classifies climate change into linear tendency, fluctuation change, and change in extreme climate or weather events based on the essence of climate change, utilizes the tendency value and fluctuation value of temperature and precipitation from 1961 to 2010 to recognize the climate change quantitatively, and completes the climate change regionalization in China (1961–2010) with county administrative regionalization as the unit in combination with China's terrain feature, thus providing a basis for China to develop plans for adapting to regional difference of climate change.

## 1 Data and methods

### 1.1 Data source

Data used in the research mainly include meteorological data and topographic data.

Meteorological data are from Daily Surface Meteorological Observation Data Sets of China provided by National Meteorological Information Center of China Meteorological Administration. The data sets refer to the daily observation data sets of 756 national-level meteorological stations of China from 1951 to the present and the elements include mean temperature, daily maximum temperature, daily minimum temperature, precipitation, evaporation, mean wind velocity, sunshine duration, etc. As most of China's meteorological stations were established from 1951 to 1960, time series used in the research is 1961–2010 on the principle of keeping maximum stations as much as possible and ensuring continuous observation time, and the main indices chosen are mean temperature and precipitation. And available temperature observation stations amount to 533 and available precipitation observation stations amount to 537 after stations with missing observation data in this time period are removed.

Topographic data are from Global 30 Arc-Second Elevation (GTOPO30) data sets provided by the United States Geological Survey. And spatial resolution of data sets is 0.0833°×0.0833° (1 km resolution).

## 1.2 Calculation methods

Climate change can be divided into nine modes based on tendency (rise/decline/not significant) and fluctuation (increase/decrease/not significant) of the climate change (Figure 1). This paper utilizes the tendency value and fluctuation value of time series of annual mean temperature and annual precipitation to diagnose the climate change and takes it as the basis for climate change regionalization.

Considering the disturbance of periodic vibration to original series, we first determine moving average series by calculating on the basis of the original series of annual mean temperature and annual precipitation and then utilizes the moving average series to calculate the tendency value and fluctuation value. For the original series of 50 years, moving length is set as five years. Thus, for the series $x_j$ with sample size of $n$, its moving average series $y_j$ every $k$ years is represented as below:

$$y_j = \frac{1}{k}\sum_{i=1}^{k} x_{j+i-1} \quad (j = 1, 2, \cdots, n-k+1). \tag{1}$$

Calculation method of the tendency value is as follows:

For moving average series $y_j$ with sample size of $n$, $t_j$ is used to represent corresponding time so as to develop a simple linear regression equation between $y_j$ and $t_j$:

$$y_j = a + bt_j, \tag{2}$$

where $a$ refers to regression constant and $b$ regression coefficient, which can be calculated through the least square method.

$$\begin{cases} b = \dfrac{\sum_{j=1}^{n} y_j t_j - \dfrac{1}{n}\left(\sum_{j=1}^{n} y_j\right)\left(\sum_{j=1}^{n} t_j\right)}{\sum_{j=1}^{n} t_j^2 - \dfrac{1}{n}\left(\sum_{j=1}^{n} t_j\right)^2}, \\ a = \dfrac{1}{n}\sum_{j=1}^{n} y_j - b\dfrac{1}{n}\sum_{j=1}^{n} t_j. \end{cases} \tag{3}$$

The symbol of regression coefficient $b$ represents linear trend of variables. $b$ greater than 0 indicates that $y$ is on the rise along with time while $b$ less than 0 means that $y$ is on the decline along with time. The size of $b$ reflects the rate of rising or declining, namely, the degree of rising or declining of tendency. This paper calls regression coefficient $b$ tendency value of variables.

Calculation method of the fluctuation value is as follows:

A simple linear regression equation is developed by use of $a$ and $b$ calculated in the above step, and thus absolute residuals series $z_j$ of moving average series $y_j$ with sample size of $n$ and linear regression series $\hat{y}_j$ is

$$z_j = \left| y_j - a - bt_j \right| \quad (j = 1, 2, \cdots, n). \tag{4}$$

The mean $\overline{z_j}$ of absolute residuals series $z_j$ is called mean fluctuation value, and the calculation formula is

$$\overline{z_j} = \frac{1}{n}\sum_{j=1}^{n} z_j. \tag{5}$$

For absolute residuals series $z_j$ with sample size of $n$, $t_j$ is used to represent corresponding time so as to develop a simple linear regression equation between $z_j$ and $t_j$:

$$\hat{z}_j = c + dt_j. \tag{6}$$

Similarly, regression constant $c$ and regression coefficient $d$ can be calculated through the least square method.

The symbol of regression coefficient $d$ represents linear trend of absolute residuals series. $d$ greater than 0 indicates

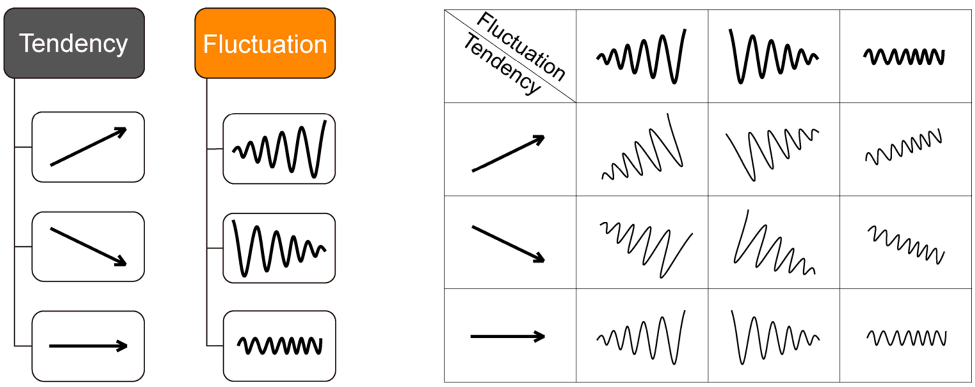


**Figure 1** Nine modes of climate change.

that $z$ is on the rise along with time, that is, the fluctuation of variables increases; $d$ less than 0 means that $z$ is on the decline along with time, that is, the fluctuation of variables decreases. The size of $d$ reflects the rate of rising or declining, namely, the degree of increasing or decreasing of fluctuation. This paper calls regression coefficient $d$ fluctuation value of variables.

Taking Beijing Meteorological Station for example, after conducting moving averaging for annual mean temperature series (1961–2010) every 5 years, we can obtain the following information from the change curve (Figure 2(a)) of annual mean temperature: (1) mean value: mean value of Beijing's annual mean temperature is 12.3°C; (2) tendency value: tendency value of Beijing's annual mean temperature is 0.56°C/10 a; (3) mean fluctuation value: mean fluctuation value of Beijing's annual mean temperature is 0.24°C; and (4) fluctuation value: fluctuation value of Beijing's annual mean temperature is –0.08°C /10 a. Similarly, we can obtain the following information from the change curve (Figure 2(b)) of annual precipitation series (1961–2010) of Beijing Meteorological Station: (1) mean value: mean value of Beijing's annual precipitation is 549.4 mm; (2) tendency value: tendency value of Beijing's annual precipitation is –26.6 mm/10 a; (3) mean fluctuation value: mean fluctuation

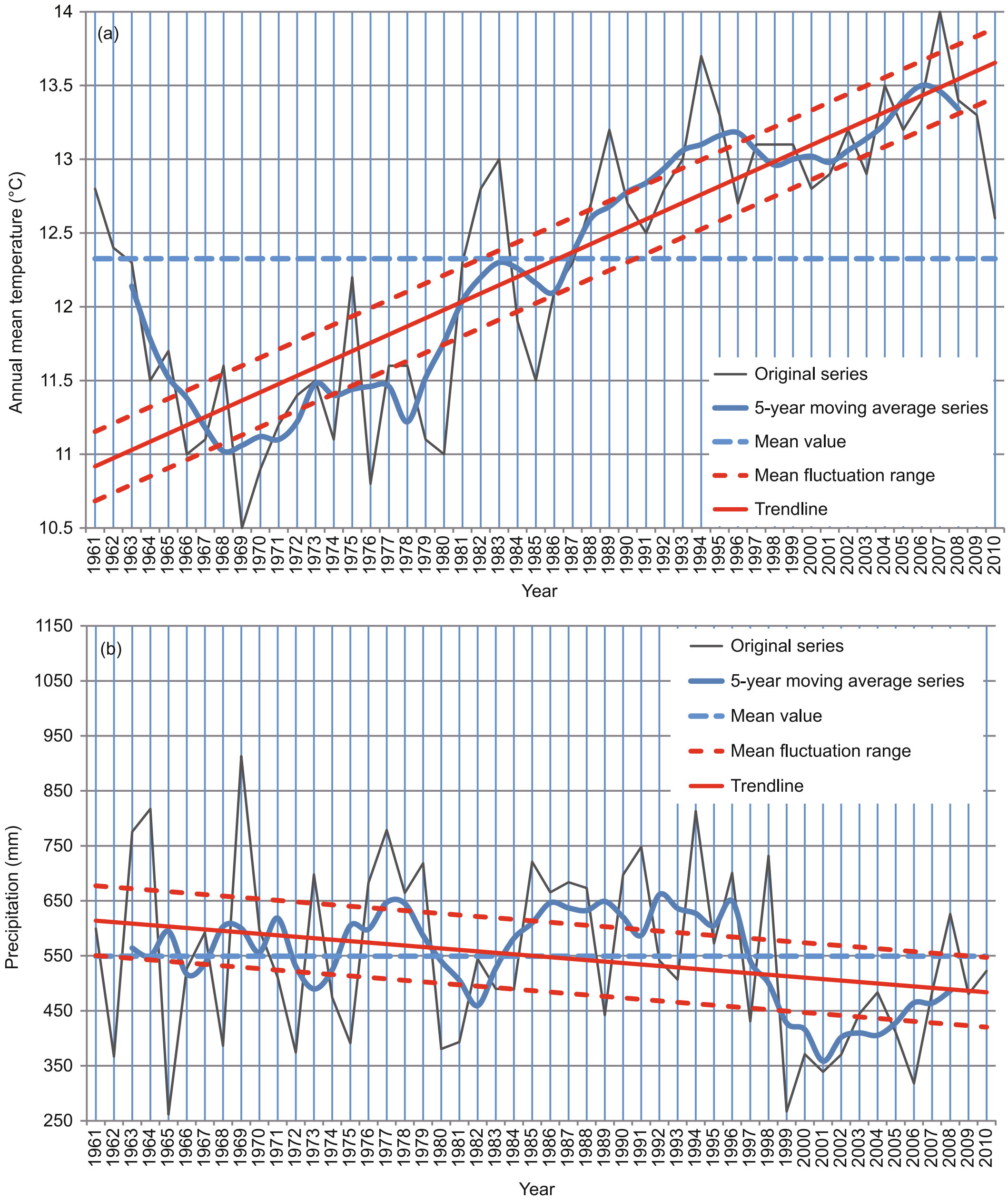


**Figure 2** Annual mean temperature series and annual precipitation series of Beijing meteorological station (1961–2010). (a) Annual mean temperature series; (b) annual precipitation series.

value of Beijing's annual precipitation is 63.4 mm; and (4) fluctuation value: fluctuation value of Beijing's annual precipitation is 9.1 mm/10 a.

## 1.3 Confidence test

The confidence is calculated based on significance level at the same time when linear regression is conducted for time series of variables. The condition that meteorological stations pass the test is counted according to the given confidence (Figure 3) and the stations that can pass the test are classified by reference to confidence classification standard in SREX (Table 1). In the table, "Not significant" means that certain index of meteorological stations cannot pass the test under this confidence, that is, there is no significant tendency or significant fluctuation under this confidence.

According to the results, in level-I indices, the rate of meteorological stations passing the test in respect of temperature tendency reaches 97% under the confidence of 99% to 100% and only less than 3% of stations fail to pass the test. The rate of passing the test in respect of precipitation tendency is lower than that in respect of temperature tendency, but under the confidence of 90% to 100%, more than 50% of stations can pass the test as guaranteed.

In level-II indices, the rates of passing the test in respect of temperature and precipitation fluctuation are basically the same, but they are generally lower than the rates in respect of tendency. Under the confidence of 66% to 100%, more than 50% of stations can pass the test; under the confidence of 90% to 100%, about 1/3 of stations pass the test; under the confidence of 99% to 100%, about 10% of stations pass the test.

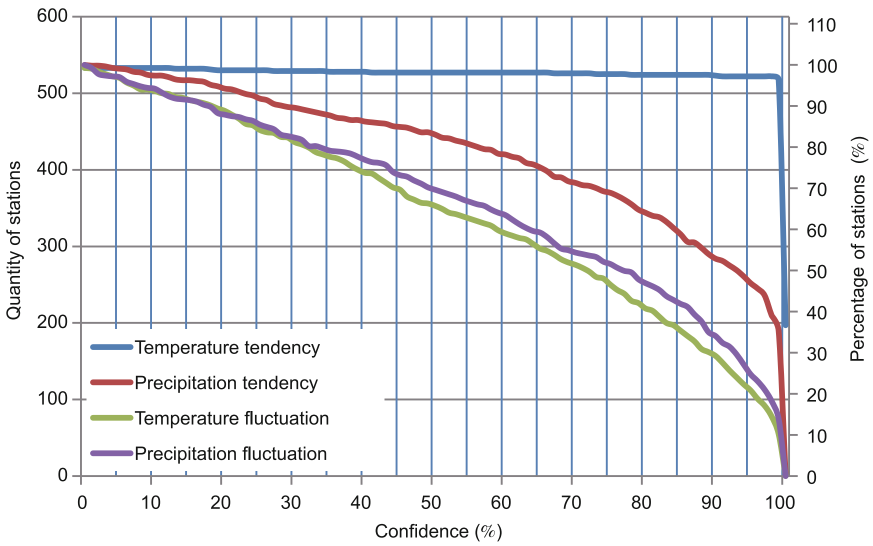


**Figure 3** Conditions of meteorological stations passing the test under different confidences.

**Table 1** Results of classified statistic of stations under different confidences (%)

| Classification of index | | | Confidence | | | |
|---|---|---|---|---|---|---|
| | | | 0–100% | 66%–100% (likely) | 90%–100% (very likely) | 99%–100% (virtually certain) |
| Level-I indices | Temperature tendency | Rise | 99 | 98 | 97 | 96 |
| | | Decline | 1 | 1 | 1 | 1 |
| | | Not significant | | 1 | 2 | 3 |
| | Precipitation tendency | Rise | 51 | 37 | 27 | 18 |
| | | Decline | 49 | 37 | 26 | 17 |
| | | Not significant | | 26 | 47 | 65 |
| Level-II indices | Temperature fluctuation | Increase | 46 | 25 | 14 | 5 |
| | | Decrease | 54 | 31 | 16 | 5 |
| | | Not significant | | 44 | 70 | 90 |
| | Precipitation fluctuation | Increase | 58 | 36 | 21 | 9 |
| | | Decrease | 42 | 22 | 13 | 5 |
| | | Not significant | | 42 | 66 | 86 |

### 1.4 Classification of modes

Tendency and fluctuation of temperature and precipitation of various meteorological stations in China can be identified under the given confidence of 90% to 100% (significance level ⩽0.1). Based on nine modes of climate change as shown in Figure 1, the identification results are classified and statistics are conducted on percentage of meteorological stations in respect of changes in temperature and precipitation in the nine modes. Statistic results of temperature change are shown in Table 2 and those of precipitation change are shown in Table 3.

From the perspective of hazard of climate tendency, the hazard of temperature declining is lower than that of temperature rising for China under the background of global warming, so sequence of the hazard of temperature tendency from low to high is: declining, no significant change, and rising. Meanwhile, on the whole, China lacks water, precipitation rising is advantageous for China, and precipitation declining is obviously disadvantageous. Hence, the sequence of the hazard of precipitation tendency from low to high is: rising, no significant change and declining. While from the perspective of hazard of climate fluctuation, no matter whether it is for temperature change or for precipitation change, fluctuation decreasing indicates that instability of climate change decreases, which is obviously advantageous. And fluctuation increasing means that instability of climate change increases, which is disadvantageous, so the sequence of the hazard of climate fluctuation from low to high is: fluctuation decreasing, no significant fluctuation, and fluctuation increasing.

According to Table 2, the proportion of stations with temperature rising in China reaches 97%; therein, the combined mode of temperature rising and fluctuation increasing is most disadvantageous to China, and stations of this type account for 12% of total stations nationwide; stations with temperature rising or not changing significantly account for 3% only. And according to Table 3, the combined mode of precipitation declining and fluctuation increasing is most disadvantageous to China, and stations of this type account for 4%; the combined code of precipitation rising and fluctuation decreasing is most advantageous to China and stations of this type account for 3%. Generally, the hazard of temperature change is higher than that of precipitation change in China in the past 50 years (1961–2010).

**Table 2** Classification of modes of temperature changes in China's meteorological stations (1961–2010) (%)

| Temperature tendency | Temperature fluctuation | | |
|---|---|---|---|
| | Decreasing | Not significant | Increasing |
| | 16 | 70 | 14 |
| Declining 1 | 0 | 0 | 1 |
| Not significant 2 | 0 | 1 | 1 |
| Rising 97 | 16 | 69 | 12 |

**Table 3** Classification of modes of precipitation changes in China's meteorological stations (1961–2010) (%)

| Precipitation tendency | Precipitation fluctuation | | |
|---|---|---|---|
| | Decreasing | Not significant | Increasing |
| | 13 | 66 | 21 |
| Rising 26 | 3 | 17 | 6 |
| Not significant 48 | 7 | 30 | 11 |
| Declining 26 | 3 | 19 | 4 |

## 2 Regional features of climate change

### 2.1 Temperature tendency

Upon calculation of annual mean temperature series of 533 available temperature observation stations, temperature tendency value of each station is obtained (as shown in Figure 4(a)) and distribution features of temperature tendency in China (1961–2010) are analyzed (as shown in Table 4, with characteristic values shown in Table A1, http: link.springer.com).

### 2.2 Precipitation tendency

Upon calculation of annual precipitation series of 537 available precipitation observation stations, precipitation tendency value of each station is obtained (as shown in Figure 4(b)) and distribution features of precipitation tendency in China (1961–2010) are analyzed (as shown in Table 5, with characteristic values shown in Table A1).

### 2.3 Temperature fluctuation

Upon calculation of annual mean temperature series of 533 available temperature observation stations, temperature fluctuation value of each station is obtained (as shown in Figure 5(a)) and distribution features of temperature fluctuation in China (1961–2010) are analyzed (as shown in Table 6, with characteristic values shown in Table A2, http: link.springer.com).

### 2.4 Fluctuation of precipitation

Upon calculation of annual precipitation series of 537 available precipitation survey stations, precipitation fluctuation value of each station is obtained (as shown in Figure 5(b)), and distribution features of precipitation fluctuation in

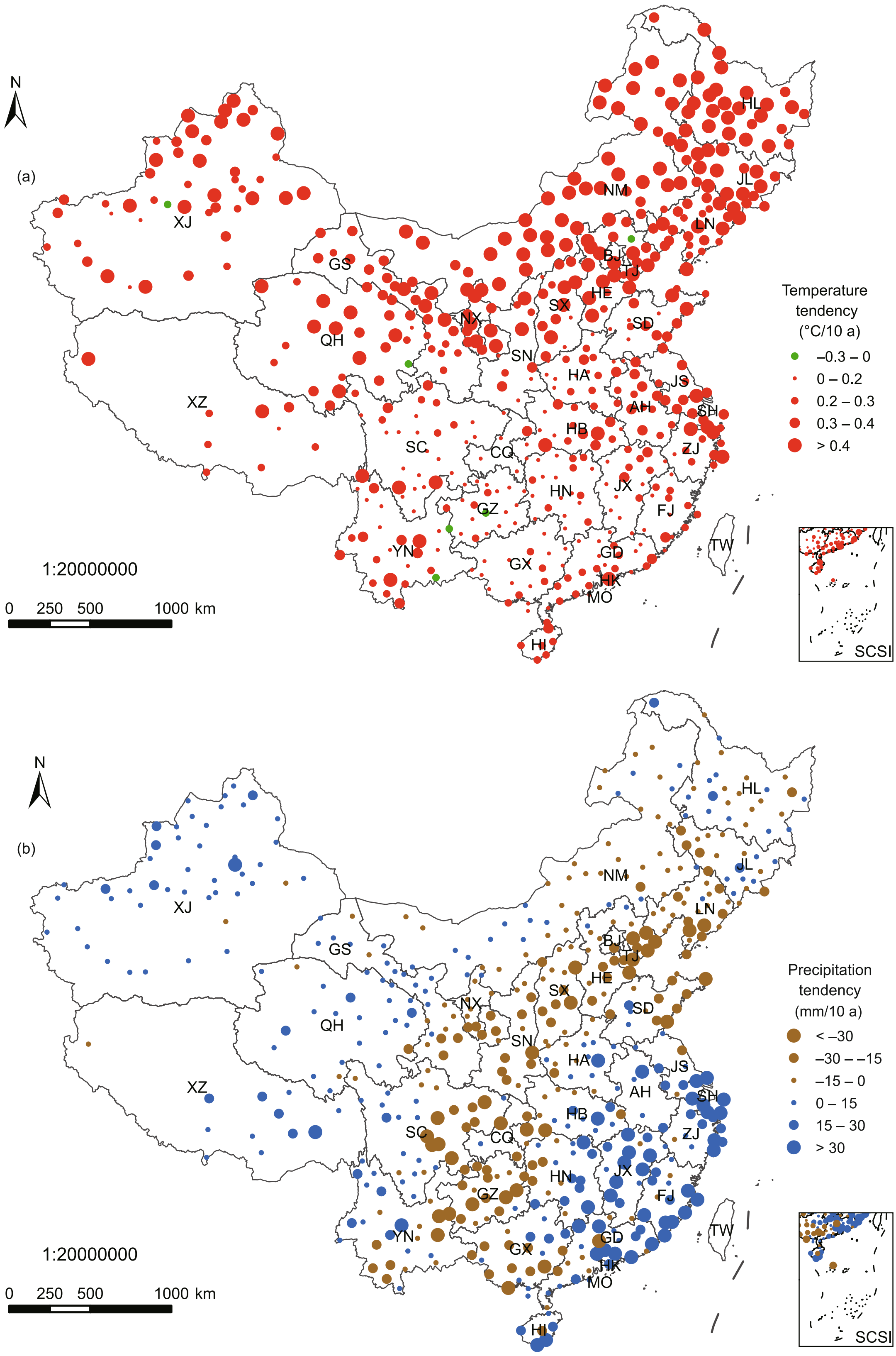


**Figure 4** Distribution of temperature and precipitation tendency values in China (1961–2010). (a) Distribution of temperature tendency Values; (b) distribution of precipitation tendency Values. AH, Anhui; BJ, Beijing; FJ, Fujian; GS, Gansu; GD, Guangdong; GX, Guangxi; GZ, Guizhou; HI, Hainan; HE, Hebei; HA, Henan; HL, Heilongjiang; HB, Hubei; HN, Hunan; JL, Jilin; JS, Jiangsu; JX, Jiangxi; LN, Liaoning; NM, Inner Mongoria; NX, Ningxia; QH, Qinghai; SD, Shandong; SX, Shanxi; SN, Shaanxi; SH, Shanghai; SC, Sichuan; TJ, Tianjin; XZ, Xizhang (Tibet); XJ, Xinjiang; YN, Yunnan; ZJ, Zhejiang; CQ, Chongqing; MO, Macao; HK, Hong Kong; TW, Taiwan; SCSI, South China Sea Islands.

**Table 4** Distribution features of temperature tendency in China (1961–2010)

| Geographical scale | Distribution features | |
|---|---|---|
| Nationwide | Rising rate is high in northern China. | Rising rate is low in southern China. |
| Regional | Rising rate is the highest in Northeast China, North China, and Northwest China. | Rising rate is the lowest in the Yunnan-Guizhou Plateau and Nanling Mountains. |
| Local | Rising rate is low comparatively in South Gansu and South Shaanxi. | Rising rate is high comparatively in the middle and lower reaches of Yangtze River. |

**Table 5** Distribution features of precipitation tendency in China (1961–2010)

| Geographical scale | Distribution features | | |
|---|---|---|---|
| Nationwide | Rising rapidly in East China | Declining rapidly in Central China | Rising slowly in West China |
| Regional | Rising rate is the highest in southeastern coastal areas and the middle and lower reaches of Yangtze River. | Declining rate is the highest in most regions of the second step (excluding Northwest China) and in Circum-Bohai Sea Region | Rising rapidly comparatively in the southeast of Qinghai and Tibet, Altay and the region of Mt. Tianshan |
| Local | Declining in Shandong Peninsula and South Guangxi | Rising slowly in Songnen Plain, Changbai Mountains and the northwest of Yunnan-Guizhou Plateau | Rising rate is comparatively low in Northwest Qinghai, North Gansu, West Inner Mongolia and South Xinjiang |

China (1961–2010) are analyzed (as shown in Table 7, with characteristic values shown in Table A2).

## 3 Climate change regionalization in China (1961–2010)

### 3.1 Principle, indicator, and method of regionalization

#### *3.1.1 Principle of regionalization*

It is the main technical basis of determining indicator and formulating method of regionalization. Mainly the following five basic principles should be considered in the regionalization: (1) keep integrate boundary of county administrative unit. Chinese Mainland is divided into 2,853 county administrative units, so regionalization boundary shall be determined based on the border line of administrative unit; (2) leading factors. It is impossible to take all climate change factors into consideration during regionalization, so the factors of leading role must be selected as the indicator for regionalization; (3) spatial distribution continuity. The essential difference between climatic regionalization and climatic classification lies in that spatial distribution continuity of regions must be considered in climatic regionalization; therefore, appropriate choice should be made according to spatial scope of regionalization to maintain the integrity of regionalization result; (4) combination of key indicator and auxiliary indicator. During the regionalization, tendency/fluctuation of climatic factor is the key indicator while the change rate is auxiliary indicator, both of which should be taken into comprehensive consideration in determining regionalization boundary. Near the boundary, tendency/fluctuation of climatic factors will usually appear alternatively, so prior consideration should be given to the side with a larger change rate, so as to show the region with more obvious climate change characteristic; and (5) consistency of large-scale terrain unit. Given the gradient pattern of three landforms in China and as the regional features of climate change will be affected by large-scale terrain unit due to land-atmosphere interaction, climate change regionalization boundary should be determined comprehensively by referring to the differentiation of large-scale terrain. Given that the meteorological stations selected cannot cover every county unit, for those county units without any meteorological station, divide the county units with relatively consistent large-scale terrain into one climate change zone during regionalization.

According to the above basic principle of climate change regionalization, the regionalization is divided into two levels, namely climate tendency zone and climate fluctuation region.

#### *3.1.2 Indicators of regionalization*

The indicators and standard of dividing climate tendency zones are as follows: (1) temperature tendency and its rate. In view of the integrity of temperature tendency—99% of the meteorological stations show a temperature rise trend, so this paper adopts the average temperature change rate 0.3°C/10 a (1961–2010) of the selected 533 meteorological stations around China as the measuring threshold to represent the regional difference of temperature change rate in all areas greater or smaller than average change rate of China, and divide the whole China into rapid temperature rising zone and slow temperature rising zone on such basis; (2) precipitation tendency and its rate. Precipitation tendency is taken mainly as the criterion to divide China into precipitation rising zone and precipitation declining zone; precipitation

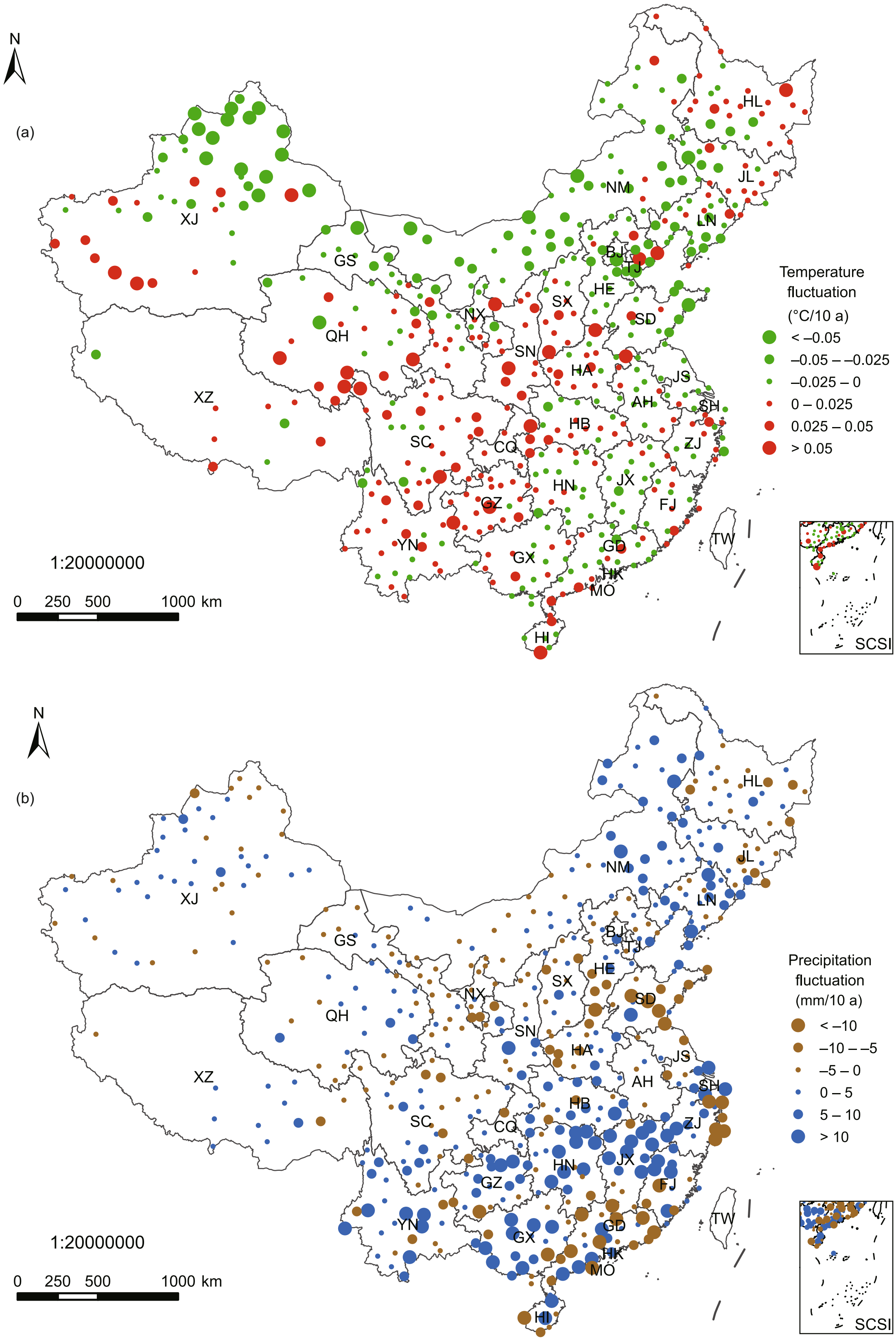


**Figure 5** Distribution of temperature and precipitation fluctuation values in China (1961–2010). (a) Distribution of temperature fluctuation values; (b) distribution of precipitation fluctuation values.

**Table 6** Distribution features of temperature fluctuation in China (1961–2010)

| Geographical scale | Distribution features | | |
|---|---|---|---|
| Regional | Alternately in East China and Northeast China | Increasing in Southwest China and Qinghai-Tibet Plateau | Decreasing in Inner Mongolia and Northwest China |
| Local | Increasing in Lesser Khingan Mountains, Sanjiang Plain and the central and north of Changbai Mountains; decreasing in Circum-Bohai Sea Region | Increasing rate is the highest in middle and high mountains in Southwest China and in valleys of high mountains in the upper reaches of Yangtze River and Yellow River. | Decreasing rate is the highest in North Xinjiang; alternately in South Xinjiang. |

**Table 7** Distribution features of precipitation fluctuation in China (1961–2010)

| Geographical scale | Distribution features | | |
|---|---|---|---|
| Regional | Increasing in South China and on the Yunnan-Guizhou Plateau | Alternatively in North China, Shandong Peninsula and Northwest China, with prominent decreasing | Alternatively in Northeast China and southeastern coast |
| Local | Increasing rate is the highest in plains in the middle and lower reaches of Yangtze River; increasing obviously in large areas of Yunnan, Guizhou and Guangxi | Increasing obviously in Beijing and Tianjin; dominant decreasing in Shandong and South Hebei; alternatively in Shaanxi, Gansu, Ningxia and Xinjiang | Increasing obviously of Greater Khingan; decreasing obviously in Sanjiang Plain and Zhejiang Coastal Area; alternatively in Fujian and Guangdong coastal area |

change rate is regarded as the auxiliary indicator of determining regionalization boundary; and (3) terrain feature of China. Topographic data of China will be taken as the reference indicator during regionalization with key consideration given to the boundary of three terrain ladders.

Indicators and standard for dividing climate fluctuation region are as follows: (1) temperature fluctuation and its rate. Temperature fluctuation is taken mainly as the criterion to divide China into temperature fluctuation increasing region and temperature fluctuation decreasing region, with fluctuation change rate regarded as the auxiliary indicator of determining regionalization boundary; (2) precipitation fluctuation and its rate. Precipitation fluctuation is regarded mainly as the criterion to divide China into precipitation fluctuation increasing region and precipitation fluctuation decreasing region, with precipitation fluctuation change rate considered as the auxiliary indicator of determining regionalization boundary; and (3) terrain features in China. Topographic data of China is taken as the reference indicator during regionalization, with key consideration given to the influence of large-scale geomorphic factors.

#### *3.1.3 Method of regionalization*

According to the regionalization principle and indicator system mentioned above, the method adopted for the regionalization refers to: (1) superposition method. After dividing climate tendency zone and climate fluctuation region, apply GIS spatial superposition method to analyze and compare the boundary of two-level regionalization and superpose the results of level-I regionalization and level-II regionalization; (2) level-I regionalization gives prominence to the common boundary of temperature and precipitation tendency; (3) level-II regionalization gives prominence to the common boundary of temperature and precipitation fluctuation and large-scale topographical change.

### 3.2 Level-I regionalization and its characteristics

The calculation result of temperature tendency value (Figure 4(a) of Section 2.1) and that of precipitation tendency value (Figure 4(b) of Section 2.2) are adopted as the key indicator for level-I regionalization of climate change regionalization in China (1961–2010). This regionalization takes the county administrative unit of China as the basic unit and takes the topographic data of China as the auxiliary reference indicator to divide China into five tendency zones during level-I regionalization, viz. Northeast China-North China warm-dry trend zone, East China-Central China wet-warm trend zone, Southwest China-South China dry-warm trend zone, Southeast Tibet-Southwest China wet-warm trend zone, and Northwest China-Qinghai-Tibet Plateau warm-wet trend zone (Figure 6), and make classification statistics on the characteristic value of all climate tendency zones according to indicators (Table A1).

### 3.3 Level-II regionalization and its characteristics

By regarding county administrative unit of China as basic unit and China's terrain as the auxiliary reference indicator and based on level-I regionalization, take the calculation result of temperature fluctuation value (Figure 5(a) of Section 2.3) and that of precipitation fluctuation value (Figure 5(b) of Section 2.4) as the key indicator for level-II regionalization of climate change in China (1961–2010), to divide China into 14 fluctuation regions and make classification statistics on the characteristics of all climate tendency zones according to indicators of level-II regionalization (Table A2). Then combine level-I regionalization with level-II

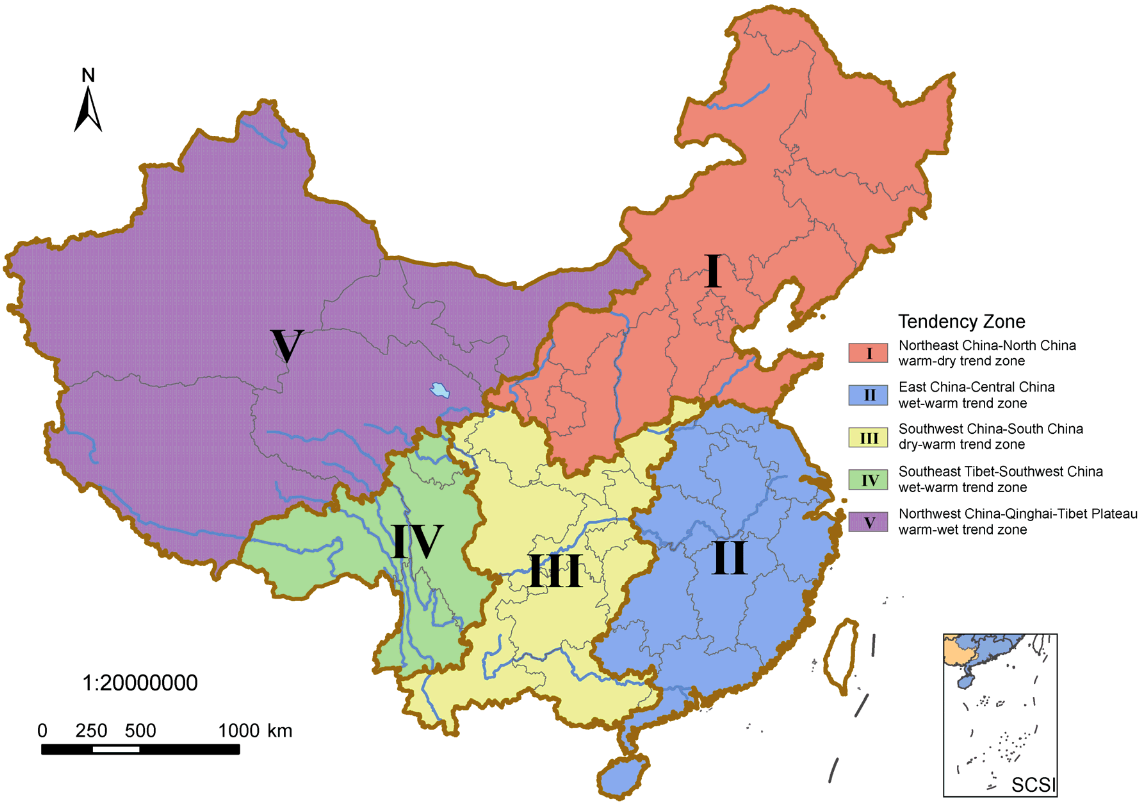


**Figure 6** Level-I regionalization of climate change in China (1961–2010).

regionalization and name them according to geomorphic feature of all areas to finish climate change regionalization in China (1961–2010) (Figure 7). For characteristics of each zone see Table A3, http: link.springer.com.

## 4 Discussion and conclusions

### 4.1 Discussion

*4.1.1 About data reliability*

Reliable data are the basis of conducting all scientific research, and especially for climate change field, the quality and reliability of surface observation data are of critical importance. Currently, scholars have noticed the following two problems when establishing and analyzing surface air temperature series: one is the inhomogeneity of data caused by migration of meteorological station, etc., for which scientists have proposed the method of homogenization (Li, 2011); the second is the problem of meteorological station being affected by urban heat island effect, for which scientists have selected a batch of representative village stations as reference station (Ren et al., 2010). Meanwhile, some scholars discover that atmospheric aerosol concentration increasing due to urbanization also has certain effect on precipitation observation series (Li et al., 2011).

It is discovered through research that meteorological station is usually migrated from urban area to suburb, so the urban heat island effect weakens and the temperature series after migration descends generally, which may have certain effect on temperature tendency and its rate calculation result. Linear temperature decline trend of some stations results from inhomogeneity of observation data; for example, annual average temperature surveyed in Henan County Meteorological Station of Qinghai changes abruptly around 1981, but the temperature series of two sections before and after shows a rise trend. Of course, there are also stations with temperature decline but no inhomogeneity of observation data discovered, such as Kuqa County Meteorological Station of Xinjiang. This indicates that temperature series not receiving homogenization correction will influence the identification of its tendency. However, among the identification results of temperature tendency in this paper, only six meteorological stations show a temperature drop trend, which take up 1% of the total meteorological stations selected, thus a rather limited influence on the whole. In the meanwhile, relative to the temperature series after homogenization correction, temperature change rate of original series may be low. In this research, temperature tendency is one of the key indicators for regionalization, and its change rate is the auxiliary indicator. As a result, its influence on regionalization result is also rather limited. Aiming at the integrity of temperature tendency in China, this paper adopts the average temperature change rate 0.3°C/10 a (1961–2010) of the selected 533 meteorological stations

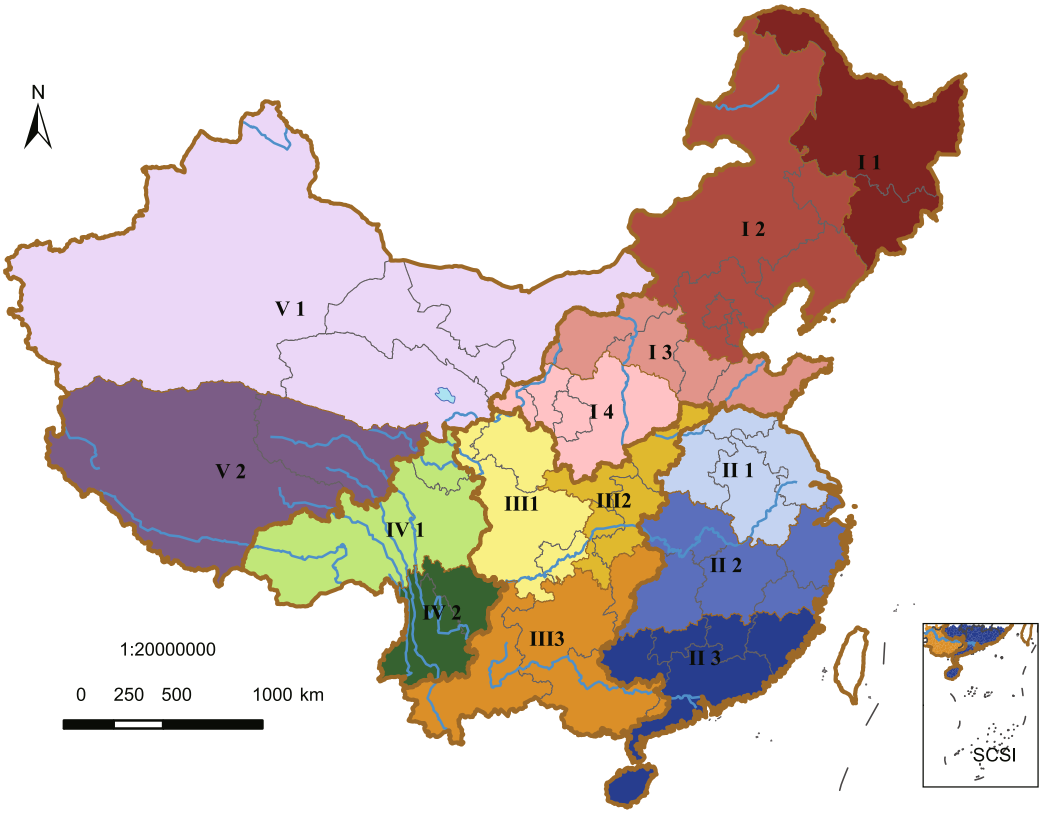


**Figure 7** Climate change regionalization in China (1961–2010). For the meanings of symbols see Table A3.

around China as the threshold and utilizes the regional difference of temperature change rate in each station greater or smaller than average change rate, to divide the whole China into rapid temperature rising zone and slow temperature rising zone.

Till now, there are over 2600 meteorological stations in China, including more than 700 national meteorological stations and 1800 ordinary meteorological stations. The data adopted in this research all refer to surface observation data of national meteorological stations. Considering that most national meteorological stations are in cities and towns, especially in eastern China, they will all be influenced by urbanization. Therefore, the influence of urban heat island effect and aerosol effect on temperature and precipitation observation series can be regarded as a systematic error, also with a rather limited influence on overall regionalization result.

### *4.1.2 About identification method*

Besides the climate change identification method adopted in this paper, ensemble empirical mode decomposition (EEMD) method, Bayesian approach, etc. have also been applied in the research to identify climate change rules, with roughly the same result obtained. Now it is verified that climate change is influenced by both natural factors and human activities to a large extent, so the combined effect of both should be taken into consideration during climate change identification. In the future, we will try new methods of climate change identification to constantly improve the confidence level of climate change identification.

### *4.1.3 About time scale*

Climate change regionalization bears an essential difference with traditional climate state regionalization. The result of climate change regionalization is greatly related to the time scale selected, viz. climate change regionalization result may show a large difference under various time scales. In this paper, only the overall performance of climate change in China from the scale of nearly half a century (1961–2010) is considered, without research on regional difference of interdecadal climate change. As for temperature change, under 0.1 significance level, 98% of the stations pass the inspection, which shows that the change in interdecadal scale only leads to difference of change rate rather than overall influence on temperature tendency of nearly half a century; for precipitation change, the passing rate of stations is only 53%, which indicates that change in interdecadal scale poses influence on overall precipitation tendency of nearly half a century. Next step, we shall carry out research on interdecadal climate change rule to reveal the regional difference of climate tendency "change".

### *4.1.4 About basic unit of regionalization*

This paper selects county administrative regionalization as the basic unit of climate change regionalization, namely, using county line to limit regionalization boundary, the main concern with which is that currently disaster data of China are gathered mainly with county as the unit and this research is aimed at trying to make a probing analysis of the impact mechanism of climate change on disaster risk and evolution thereof and reveal the reason for generation of disaster with county as the unit through understanding of regional difference of climate change.

In the research, we found that meteorological stations and county administrative regions are comparatively densely distributed in East China, and the coverage ratio of meteorological station in each county is also high, and it is rare that a county crosses a large-scale terrain unit. In contrast, meteorological stations are sparsely distributed in West China and the counties also cover larger areas, so the terrain is often referenced for determination of regionalization line, especially in South Xinjiang, more than 10 counties cross the second and third geomorphologic steps of China (Figure 8), which indicates that using county line to limit regionalization boundary has some limitations. Of course, as for the whole nation, county crossing a large-scale terrain unit is just an exception, so its influence on regionalization boundary is very limited. With improvement of statistical accuracy of disaster data in China, township administrative region can be selected as regionalization unit in in-depth work in the future, namely using township line to limiting regionalization boundary, so that the influence of basic regionalization unit on regionalization boundary can be eliminated to some extent.

Works currently completed herein mainly focus on regional rule of climate change without giving any consideration to genetic mechanism of climate change. In the next step, we will make in-depth discussions on regional difference of genetic mechanism of climate change in half a century, such as the impact of monsoon region and non-monsoon region on climate change regionalization in China, etc. Besides, we will focus on the impact of change of extreme climate or weather events on result of climate change regionalization. Climate fluctuation indices adopted in this paper embody the change of extreme events to some extent. However, to profoundly understand significant change of climate on the interannual scale, it is necessary to take into account the changes of various extreme events in frequency and intensity, so as to further reveal regional differentiation regularity of climate change and the relation between the regularity and disaster and environmental risk to provide theoretical basis for China to better deal with climate change.

### 4.2 Conclusions

This paper completes the climate change regionalization in China (1961–2010) with the tendency and fluctuation of

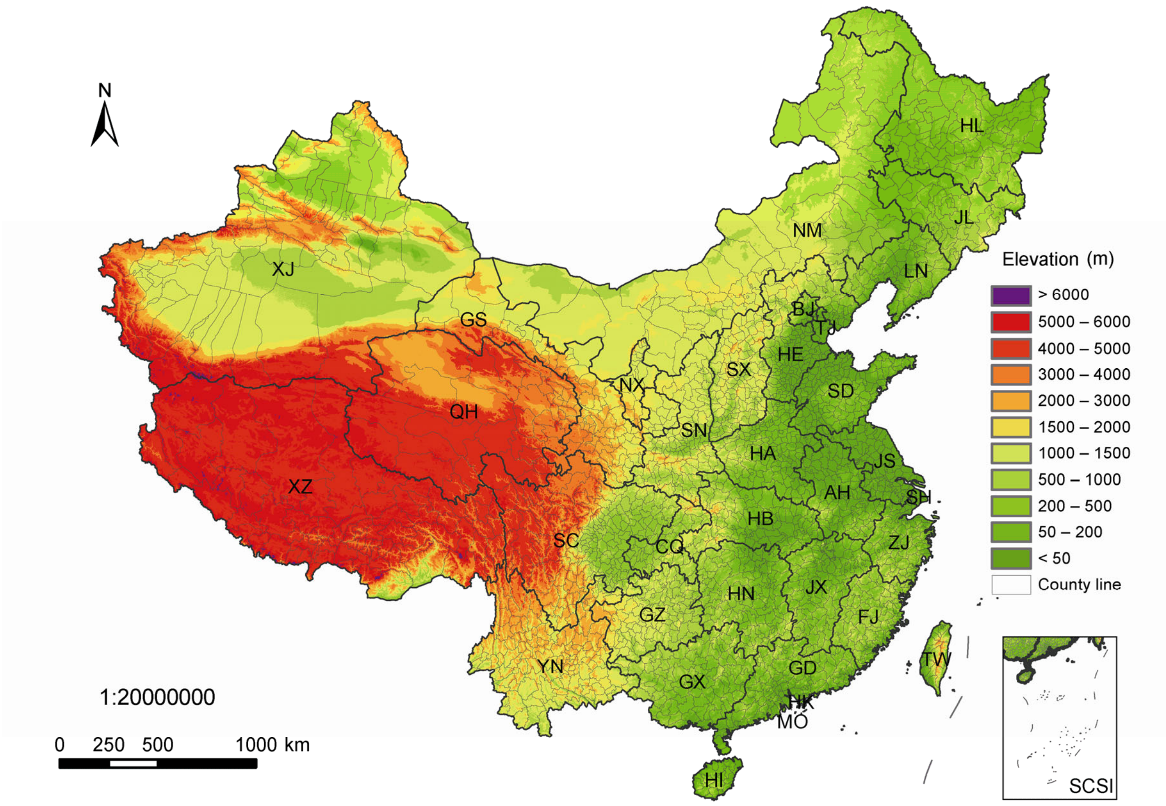


**Figure 8** Topographic maps of China (county line).

temperature and precipitation of 756 national-level meteorological stations in China from 1961 to 2010 as main indices, with the rate of tendency and fluctuation of temperature and precipitation as auxiliary indices, with China's terrain feature as reference indices and with county administrative regionalization as the basic unit. Level-I regionalization divides China's climate change (1961–2010) into five climate tendency zones, which are respectively Northeast China-North China warm-dry trend zone, East China-Central China wet-warm trend zone, Southwest China-South China dry-warm trend zone, Southeast Tibet-Southwest China wet-warm trend zone and Northwest China-Qinghai-Tibet Plateau warm-wet trend zone; Level-II regionalization refers to fourteen fluctuation zones based on level-I regionalization according to the fluctuation of temperature and precipitation. Meanwhile, this paper presents in-depth analysis of characteristics of climate change in each region as well as geographic features like administrative regionalization, geomorphology, vegetation and water system of corresponding region, and also calculates the area, population and other information of each region, to completely reveal regional differentiation regularity of climate change in China (1961–2010).

*We express our thanks to the three reviewers for their valuable comments and suggestions on this research. This work was supported by the National Basic Research Program of China (Grant Nos. 2012CB955404, 2012CB955402) and the National Natural Science Foundation of China (Grant No. 41321001).*

Bian J J, Hao Z X, Zheng J Y, et al. 2013. The shift on boundary of climate regionalization in China from 1951 to 2010. Geogr Res, 32: 1179–1187

Chu K C. 1929. Climate classification in China. Anthology of Chu Kochen Editorial Team, ed. In: Anthology of Chu Kochen. Beijing: Science Press. 124–132

Ci L J, Yang X H, Chen Z X. 2002. The potential impacts of climate change scenarios on desertification in China. Earth Sci Front, 09: 287–294

Ding Y H. 2013. Climate of China. Physical Geography of China (Monography Series). Beijing: Science Press. 392–418

Huang B W. 1993. How to deal with global warming. In: Sixty Years Comprehensive Work of Physical Geography. Beijing: Science Press. 130–142

IPCC. 2007. Climate change 2007: Synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Geneva: IPCC. 1–33

IPCC. 2012. IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX). Cambridge: Cambridge University Press. 1–21

Köppen W P. 1918. Klassifikation der klimate nach temperatur, niederschlag und jahresablauf (classification of climates according to temperature, precipitation and seasonal cycle). Petermanns Geogr Mitt, 64: 193–203, 243–248

Li Q X. 2011. Introduction to Homogenization Research of Climate Data. Beijing: China Meteorological Press. 1–115

Li Z, Niu F, Fan J, et al. 2011. Long-term impacts of aerosols on the vertical development of clouds and precipitation. Nat Geosci, doi: 10.1038/NGEO1313

Ren G Y, Zhang A Y, Chu Z Y, et al. 2010. Principles and procedures for selecting reference surface air temperature stations in China. Meteorol Sci Technol, 38: 78–85

Sha W Y, Shao X M, Huang M. 2002. Climate warming and its impact on natural regional boundaries in China in the 1980s. Sci China Ser D-Earth Sci, 45: 1099–1113

Shen X F, Ding Y G, Shi M S. 1996. Effect of Global Warming on Change in Northern Limit of the Subtropical Zone of China. J Nanjing Institute Meteorol, 19: 108–111

Strahler A N. 1975. Classification of Global Climates. In: Strahler A N, ed. Physical Geography. New York: John Wiley. 243–245

The Compilation Committee of China's National Assessment Report on Climate Change (II). 2011. China's National Assessment Report on Climate Change (II). Beijing: Science Press. 1–78

Thornthwaite C W. 1948. An approach toward a rational classification of climate. Geogr Rev, 38: 55–94

Yang J P, Ding Y J, Chen R S, et al. 2002. The interdecadal fluctuation of dry and wet climate boundaries in China in recent 50 years. Acta Geogr Sin, 57: 655–661

Ye D Z, Jiang Y D, Dong W J. 2003. The northward shift of climatic belts in China during the last 50 years and the corresponding seasonal responses. Adv Atmos Sci, 20: 959–967

Zhang B K, Zhu G K. 1959. Climate Regionalization in China (first draft). Beijing: Science Press. 1–297

Zhao M C. 1995. Impact of $CO_2$ multiplication on the differentiation of physical zones and the potential agricultural productivity in China. J Nat Resour, 10: 148–157

Zheng J Y, Bian J J, Ge Q S, et al. 2013. The climate regionalization in China for 1951–1980 and 1981-2010. Geogr Res, 32: 987–997

Zhou G S, Zhang X S. 1996. Study on climate-vegetation classification for global change in China. Acta Bot Sin, 38: 8–17