Atmospheric Research 138 (2014) 346–355

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos


# Dynamics of temperature and precipitation extremes and their spatial variation in the arid region of northwest China

Haijun Deng [a,b], Yaning Chen [a,*], Xun Shi [c], Weihong Li [a], Huaijun Wang [a,b], Shuhua Zhang [a,b], Gonghuan Fang [a,b]

[a] State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China
[b] The Graduate School of Chinese Academy of Sciences, Beijing 10049, China
[c] Department of Geography, Dartmouth College, Hanover, New Hampshire, USA

ARTICLE INFO

*Article history:*
Received 18 July 2013
Received in revised form 4 December 2013
Accepted 4 December 2013

*Keywords:*
Precipitation extreme indices
Temperature extreme indices
M–K trends test
Arid region of northwest China

ABSTRACT

Climate extremes have more direct and significant impact than average state on social and ecological systems. Using data from 68 meteorological stations in the arid region of northwest China (ARNC) for the past 50 years (1961–2010), we conducted Mann–Kendal nonparametric trend analysis on the time series of temperature and precipitation extremes in different regions of the ARNC. The analysis found that in the past 50 years, 1) overall for the ARNC, three temperature indices, including the annual mean temperature (Tav), annual average daily minimum temperature (Tnav), and annual average daily maximum temperature (Txav) all had increasing trends; 2) overall for the ARNC, three precipitation indices, including the annual mean precipitation (Pav), number of days for daily precipitation ≥ 10 mm (Pn10mm) and annual maximum number of consecutive wet days (Pxcwd) also all had increasing trends; 3) regionally, Tnav and Pn10mm in north Xinjiang considerably increased; in both north and south Xinjiang, annual maximum number of consecutive dry days (Pxcdd) considerably decreased, whereas Pxcwd considerably increased; and the main pattern of Hexi Corridor is that Txav considerably increased; 4) it appears that the increase of Tav in the ARNC in the past 50 years is related to the increase of Tnav and Txav; and 5) the increase of precipitation in north and south Xinjiang is a result of the joint effect of the increases of Pn10mm and Pxcwd. Generally, in ARNC, during the past 50 years the dynamics of climate extremes are closely related to the dynamics of climate average state, and are major contributors to the overall climate change.


## 1. Introduction

Within the context of climate change, climate extremes received increasing attention in the past decades, due to the fact that the extremes have more direct and significant impact than average state on societal, economical, and ecological systems (Trenberth, 1999; Easterling et al., 2000; Hanson et al., 2007; Wigley, 2009; Kaser et al., 2010; Lobell et al., 2011; Insaf et al., 2012). According to the Intergovernment Panel on Climate Change (IPCC), increasing evidence indicates that global warming has resulted in a growing frequency and aggravated severity of extreme climate events in the past decades, such as heat wave, high temperature, and multi-region heavy rainfall and flood (http://www.ipcc.ch/meeting_documentation/meeting_documentation.shtml).

The arid region of northwest China (ARNC) is one of the most sensitive areas in the world in terms of responding to global climate change (Ding et al., 2007; Shi et al., 2007). This vast area (about 2.5 million km$^2$) is located in the middle of Eurasia, with a unique physiography featured by three large mountain ranges separated by two vast basins. The climate of ARNC witnessed a dramatic change beginning in the 1980s:

* Corresponding author at: State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, CAS, No. 818 Beijing Nanlu, Urumqi 830011, China.
*E-mail address:* chenyn@ms.xjb.ac.cn (Y. Chen).

0169-8095/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.atmosres.2013.12.001

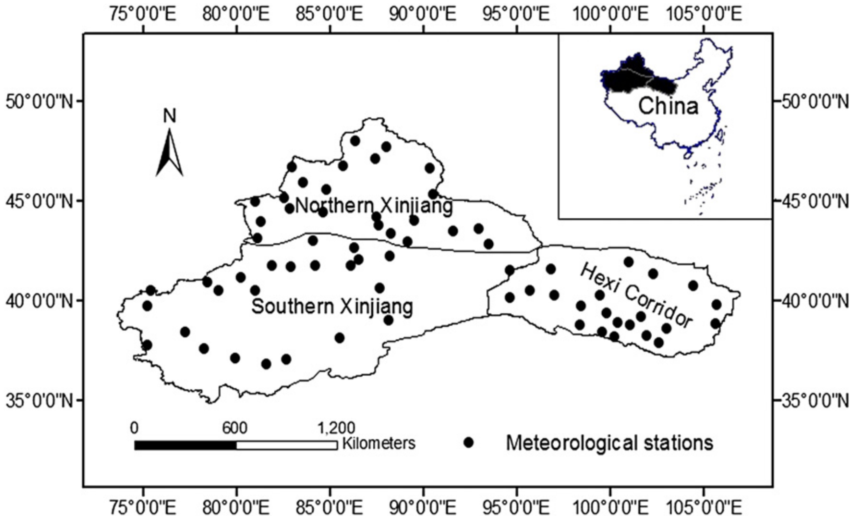


**Fig. 1.** Study area and the meteorological stations.

the warm-and-dry regional climate shifted toward warmer and more humid (Shi et al., 2002). The analysis of Chen and Xu (2005) on the 50-year time series of climate data for the Tarim River basin in the ARNC reveals that the temperature and precipitation had decreasing trends in 1970s, but had significant increasing trends since 1980s. The research of Zhang et al. (2012) based on Standardized Precipitation Index (SPI) indicates that in north Xinjiang in ARNC, the severity of drought has been decreasing and the duration has been shortened, whereas in the southern part of south Xinjiang and the middle part of east Xinjiang, the drought has an increasing trend. Recently, Wang et al. (2013) summarized that for the ARNC, in the past 50 years the warm indices have been rising; the cold indices have been dropping; most precipitation indices have significant increasing trends, daily difference of temperature has been decreasing, and the minimum temperature is greater than that of the maximum temperature.

However, most of those previous works on the climate change in the ARNC are limited to the average state of climate. Researches explicitly on climate extremes are rare, and almost none has been published on the relationship between average state (or overall change) and extremes for this area. In this study, we focused on the temperature and precipitation extremes in the ARNC. We conducted analyses in three aspects: 1) detecting significant trends in the dynamics of climate extremes in the past 50 years; 2) quantifying the relationship between average state and extremes, particularly evaluating the contribution made by extremes to overall change; and 3) characterizing regional variation of climate extremes and their dynamics. Since the ARNC crosses great ranges in both longitudinal and latitudinal dimensions, its different sub-regions are under different controls of multiple air circulations and have different moisture sources, and thus may have different characteristics in climate extremes. These characteristics directly impact regional water resources and ecological systems.

## 2. Materials and methods

### 2.1. Study area

The ARNC is about 2.5 million km$^2$ in size, accounting for about 26% of china's total terrestrial area. It is located in the innermost part of Asia, largely defined by 34°54′–49°19′N and 73°44′–106°46′E (Fig. 1). In the ARNC, the primary driven factor for the water vapor transport is Westerly Circulation

**Table 1**
Temperature and precipitation indices selected for this study.

| Indices | Definitions | Units |
|---|---|---|
| *Temperature indices* | | |
| Tav | Mean Tmean | °C |
| Tnav | Mean Tmin | °C |
| Txav | Mean Tmax | °C |
| Txf10 | % days Tmax < 10th percentile | |
| Txf90 | % days Tmax < 90th percentile | |
| Tnf10 | % days Tmin < 10th percentile | |
| Tnf90 | % days Tmin < 90th percentile | |
| *Precipitation indices* | | |
| Pav | Mean climatological precipitation | mm/year |
| Pn10mm | No. of days precip > = 10 mm | days |
| Pxcdd | Max no. of consecutive dry days | days |
| Pxcwd | Max no. of consecutive wet days | days |
| Px3d | Greatest 3-day total rainfall | mm |

**Table 2**
The test results of change of the temperature extreme index in the northern Xinjiang.

| Region | Indices | Trend test | | Significance |
|---|---|---|---|---|
| | | Trend rate (°C/a) | Z_value | |
| Northern Xinjiang | Tav | 0.037 | 4.82 | 0.01 |
| | Tnav | 0.056 | 6.14 | 0.01 |
| | Txav | 0.023 | 3.11 | 0.01 |

**Table 3**
The test results of change of the temperature extreme index in the southern Xinjiang.

| Region | Indices | Trend test | | Significance |
|---|---|---|---|---|
| | | Trend rate (°C/a) | Z_value | |
| Southern Xinjiang | Tav | 0.029 | 5.04 | 0.01 |
| | Tnav | 0.043 | 6.78 | 0.01 |
| | Txav | 0.023 | 3.36 | 0.01 |

(Wang et al., 2005; Liu et al., 2009). It is surrounded by massive mountains, including Altai Mountain, Kunlun Mountain, Qilian Mountain, and Helan Mountain. These mountains block air masses brought about by atmospheric circulations. The long distance to oceans makes it hard for the marine vapor to reach this area, resulting in a dry regional climate. The spatial distribution of precipitation is largely determined by the regional physiographical features.

The ARNC has a typical continental climate. Its annual mean precipitation is below 250 mm and temperature has a wide range. The area is largely controlled by Mongolia–Siberian High in winter, the average temperature in winter varying between −5.8 °C and −11 °C. The land surface quickly warms up in summer, due to the vast desert. The weather transitions in the spring and autumn are rapid.

### 2.2. Materials

We acquired daily observation data from 68 meteorological stations in the ARNC for the period 1961–2010 (Fig. 1). Using these data and STARDEX (http://www.cru.uea.ac.uk/projects/stardex/), we calculated all the 57 climate extreme indices supported by this software, including 24 precipitation extreme indices and 33 temperature extreme indices. We then ran a factor analysis and selected seven temperature extreme indices and five precipitation extreme indices for the following analysis (Table 1).

### 2.3. Methods

#### 2.3.1. Mann–Kendall test for monotonic trend

The Mann–Kendall nonparametric trend test has been widely-used in long-term trend analysis on meteorological and hydrological time series (Kadioglu, 1997; Yue et al., 2002; Gemmer et al., 2004; Gocic and Trajkovic, 2013; Pingale et al., 2014). In this study, we employed it to detect the changes in temperature and precipitation extremes.

**Table 4**
The test results of change of the temperature extreme index in the Hexi Corridor.

| Region | Indices | Trend test | | Significance |
|---|---|---|---|---|
| | | Trend rate (°C/a) | Z_value | |
| Hexi Corridor | Tav | 0.039 | 5.52 | 0.01 |
| | Tnav | 0.045 | 6.41 | 0.01 |
| | Txav | 0.031 | 4.55 | 0.01 |

#### 2.3.2. Multiple regression models

In this study, we used the multiple regression models to estimate the influence of climate extreme state on the average state, and determine the contribution of each extreme index. First, we conducted standardization to climate extreme indices, because different indices had different units and magnitudes. Second, we conducted regression analysis based on the standardized data:

$$Y_s = a_{1*}x_{1s} + a_{2*}x_{2s} + \ldots + a_{n*}x_{ns} \quad (1)$$

where, $Y_s$ is a standardized index of the average state; $x_{1s}, x_{2s}, \ldots, x_{ns}$ are the standardized index of extreme climate; $a1, a2, \ldots, an$

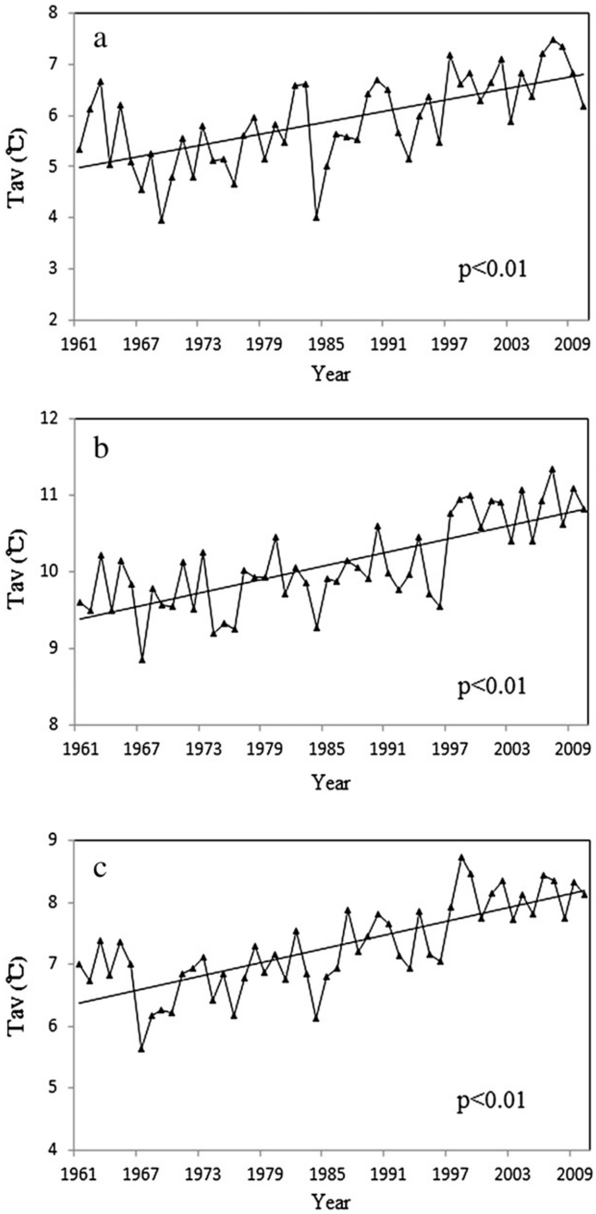


**Fig. 2.** The trends of the Tav in the northern Xinjiang (a), southern Xinjiang (b) and Hexi Corridor (c), for the period 1961–2010, based on 68 meteorological stations.

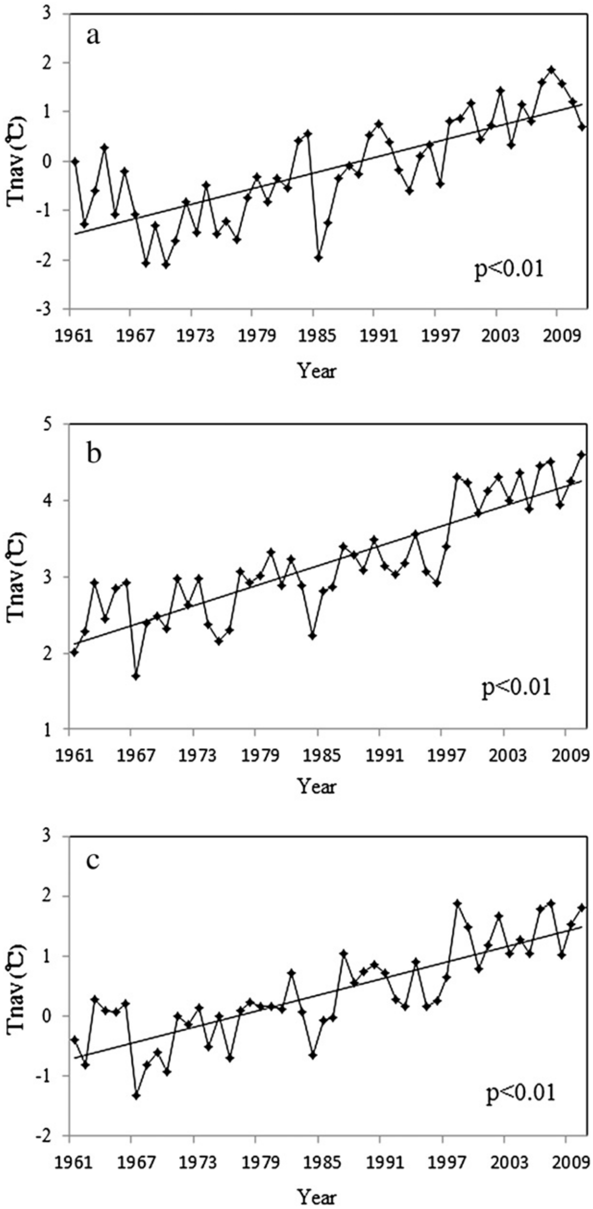


**Fig. 3.** The trends of the Tnav in the northern Xinjiang (a), southern Xinjiang (b) and Hexi Corridor (c), for the period 1961–2010, based on 68 meteorological stations.

are the regression coefficients. Based on the regression results, in the following formula (Zhang et al., 2010), we calculated the contribution of each independent variable on the dependent variable as follows:

$$\rho_1 = |a_1|/a_{1*}(\Delta x_{1s}/\Delta Y_s) \tag{2}$$

where, $\rho_1$ is the actual contribution of the change of $x_1$ to the change of Y; $\Delta Y_s$ is the change of $Y_s$; $\Delta x_{1s}$ is the change of $x_{1s}$.

## 3. Results

### 3.1. Trends analysis

#### 3.1.1. Trends analysis of temperature extreme indices

The Mann–Kendal analysis revealed that the air temperature in ARNC increased in the past 50 years. For the whole area, the three temperature extreme indices (Tav, Tnav, and Txav) had statistically significant trends. The regional trends of temperature extreme indices are shown in Tables 2, 3, and

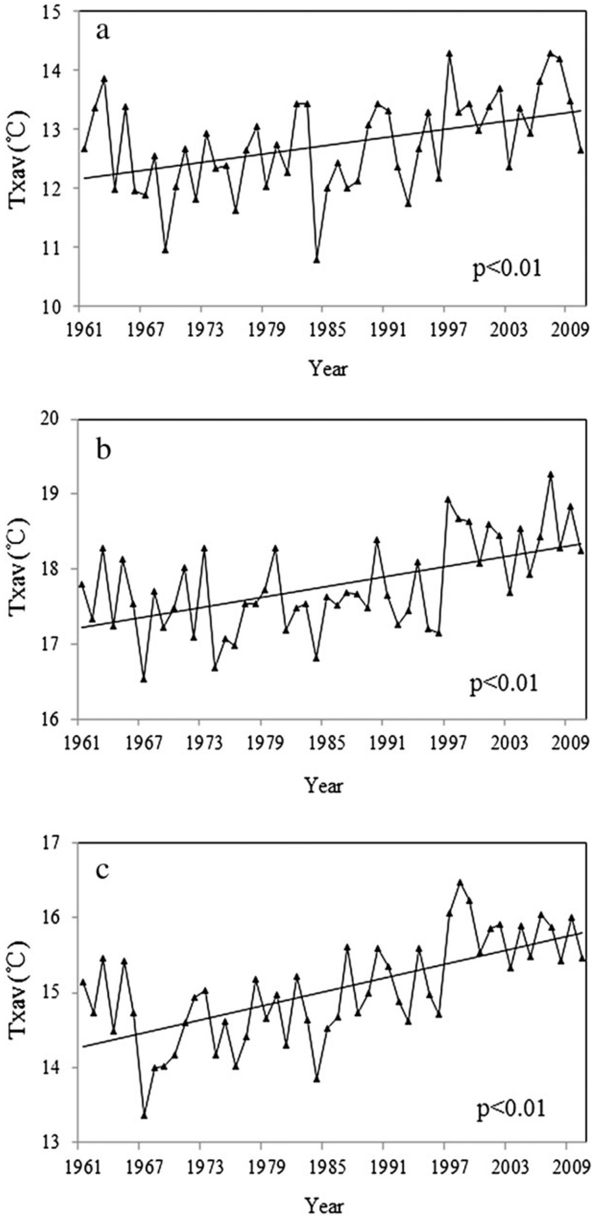


**Fig. 4.** The trends of the Txav in the northern Xinjiang (a), southern Xinjiang (b) and Hexi Corridor (c), for the period 1961–2010, based on 68 meteorological stations.

**Table 5**
The trends test results of the precipitation extreme indices in the northern Xinjiang.

| Region | Indices | Trend test | | Significance |
|---|---|---|---|---|
| | | Trend rate | Z_values | |
| Northern Xinjiang | Pav | 1.17 mm/a | 3.31 | 0.01 |
| | Pn10mm | 0.03 day/a | 3.36 | 0.01 |
| | Pxcdd | −0.28 day/a | −3.18 | 0.01 |
| | Pxcwd | 0.007 day/a | 2.59 | 0.01 |

4. As shown in Table 4 and Fig. 2, the Tav had a stronger increasing trend in the Hexi Corridor than the northern and southern Xinjiang. The results also show that the increasing rate of average temperature in the ARNC is higher than that of China (0.025 °C/a, Ren et al., 2005; Ding et al., 2007) and that of the entire world (0.013 °C/a, IPCC, 2007). Tables 2 and Fig. 3 show that Tnav had a stronger trend of northern Xinjiang than those of the Hexi Corridor and the southern Xinjiang. For Txav, the Hexi Corridor had a stronger trend (Table 4 and Fig. 4-c) than those of the northern Xinjiang (Table 2 and Fig. 4-a) and the southern Xinjiang (Table 3 and Fig. 4-b).

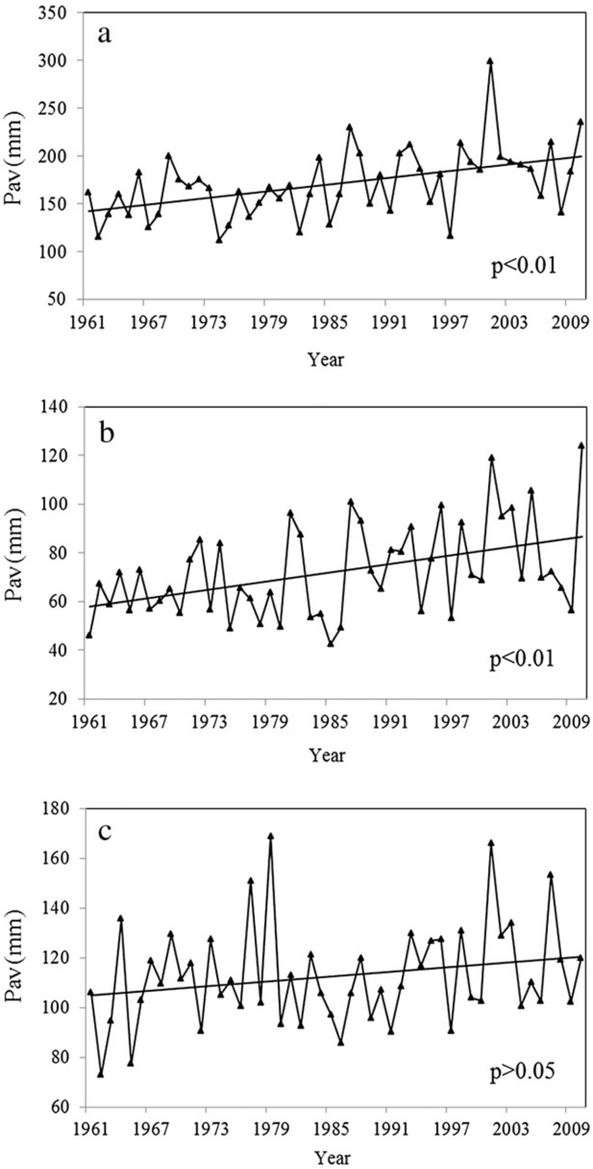


**Fig. 5.** The trends of the Pav in the northern Xinjiang (a), southern Xinjiang (b) and Hexi Corridor (c), for the period 1961–2010, based on 68 meteorological stations.

Among Tav, Tnav, and Txav, the increasing trend of Tnav (0.043–0.056 °C/a) was the strongest, followed by those of Tav (0.029–0.039 °C/a), and Txav (0.023–0.031 °C/a). Spatially, air temperature had significant increasing trends in all three sub-regions (northern Xinjiang, southern Xinjiang, and Hexi Corridor), with rates of 0.0385, 0.0316 and 0.0383 °C/a, respectively, indicating that the northern Xinjiang's temperature has been rising faster than other sub-regions. Tnav is overwhelmingly positive in the entire area; with the northern Xinjiang having the strongest trend (Tables 2, 3 and 4). The increasing trends of the Tav and Txav are strongest in the Hexi Corridor.

The Tav had a decreasing trend in the northern Xinjiang in the 1960s, and increasing trends since 1970s in the three sub-regions, namely the northern Xinjiang, southern Xinjiang, and Hexi Corridor, especially since the late 1980s (Fig. 2). The Tnav had a decreasing trend in the northern Xinjiang in the 1960s, but relatively strong increasing trends in the three sub-regions since the 1970s (Fig. 3). The Txav had a decreasing trend in the northern Xinjiang and Hexi Corridor in the 1960s and increasing trends in the three sub-regions since the late 1980s (Fig. 4).

### 3.1.2. Trend analysis of precipitation extreme indices

Precipitation had an increasing trend in the past five decades in ARNC. However, there is considerable regional variation in the precipitation extreme indices. Pav had positive trends in the northern Xinjiang (Table 5, and Fig. 5-a) and southern Xinjiang (Table 6, and Fig. 5-b), and significant at $p < 0.01$, with rates of 1.17 and 0.58 mm/a, respectively. In the Hexi Corridor, there is an increasing trend of Pav (Table 7, and Fig. 5-c), with a rate of 0.32 mm/a, but is not significant at 0.05 level. The northern Xinjiang showed a highly positive trend for Pn10mm (Table 5, and Fig. 6-a), significant at the 0.01 level, with a rate of 0.03 day/a. The southern Xinjiang (Table 6, and Fig. 6-b) and Hexi Corridor (Table 7, and Fig. 6-c) also showed increasing trends for Pn10mm, but are only significant at 0.05 level, and the rates were 0.014 and 0.012 day/a, respectively. Pxcdd

**Table 6**
The trend test results of the precipitation extreme indices in the southern Xinjiang.

| Region | Indices | Trend test | | Significance |
|---|---|---|---|---|
| | | Trend rate | Z_values | |
| Southern Xinjiang | Pav | 0.58 mm/a | 2.66 | 0.01 |
| | Pn10mm | 0.014 day/a | 2.05 | 0.05 |
| | Pxcdd | −0.33 day/a | −2.18 | 0.05 |
| | Pxcwd | 0.008 day/a | 2.53 | 0.05 |

**Table 7**
The trend test results of the precipitation extreme indices in the Hexi Corridor.

| Region | Indices | Trend test | | Significance |
|---|---|---|---|---|
| | | Trend rate | Z_values | |
| Hexi Corridor | Pav | 0.32 mm/a | 1.41 | – |
| | Pn10mm | 0.012 day/a | 2.02 | 0.05 |
| | Pxcdd | −0.15 day/a | −1.31 | – |
| | Pxcwd | 0.001 day/a | 0.22 | – |

had negative trends in the northern Xinjiang (Table 5, and Fig. 7-a), southern Xinjiang (Table 6, and Fig. 7-b), and Hexi Corridor (Table 7, and Fig. 7-c), with rates of −0.28, −0.33, and −0.15 day/a, respectively. However, the trend of Pxcdd for the Hexi Corridor was not significant at the 0.05 level. Pxcwd had significant positive trends in northern Xinjiang, southern Xinjiang, and the Hexi Corridor (Tables 5–7, and Fig. 8), with rates of 0.007, 0.008, and 0.001 day/a, respectively.

During the past 50 years, the Pav, Pn10, and Pxcwd had increasing trends of southern and northern Xinjiang (Figs. 5, 6, and 8), and the Pxcdd had a relatively strong decreasing trend in the three sub-regions (Fig. 7). In summary, in the past 50 years the northern Xinjiang shows the strongest increasing trend of precipitation extreme indices, followed by southern Xinjiang and Hexi Corridor.

### 3.2. Temporal variation in the temperature and precipitation extremes

Previous study reveals that Tav and Pav had dramatic changes around late 1980s (Chen et al., 2006). Accordingly, we divided the past 50 years into two time periods: 1961–1985 and 1986–2010. Fig. 9-a shows that for Tav, in all the three regions (northern Xinjiang, southern Xinjiang, and Hexi Corridor) the increase in the second period is larger than that in the first period. Fig. 9-b shows a similar general pattern for Pav, but with a more obvious regional variation: the difference between the two periods is the largest in northern Xinjiang, followed by the southern Xinjiang; and the difference in the Hexi Corridor is fairly small.

As for Tnav, the value for 1986–2010 was greater than that for 1961–1985 by 1.5 °C in the northern Xinjiang; by 1.12 °C in the southern Xinjiang, and by 1.22 °C in the Hexi Corridor (Fig. 10-a). The value is below zero of the Tnav from 1961 to 1985 in the northern Xinjiang and Hexi Corridor, but this value has been above zero since 1986. Txav had a similar increasing pattern in the three sub-regions, but the magnitude of increase was smaller than that of Tnav (Fig. 10-b). Based on this finding, it can be inferred that the significant increasing trend of Tnav in the past 50 years is mainly due to the great increases of Tnav and Txav during 1986–2010, and between the two, Tnav contributed more than Txav.

Fig. 11 shows a comparison of precipitation extreme indices for the two periods in the three sub-regions. Fig. 11-a shows that Pn10mm in 1986–2010 is greater than that in 1961–1985 by 0.88 days in the northern Xinjiang; by 0.44 days in the southern Xinjiang; and by 0.22 days in the Hexi Corridor. Fig. 11-b shows that the value of Pxcwd increased from 2.76 days in 1961–1985 to 3.02 days in 1986–2010 (9.4%) in the northern Xinjiang, and from 2.09 days to 2.36 days (12.8%) in the southern Xinjiang, while in the Hexi Corridor it decreased from 2.72 days in 1961–1985 to 2.71 days in 1986–2010 (−0.2%). Fig. 11-c shows that Pxcdd had strong decreasing trends in all three sub-regions.

### 3.3. Contribution analysis

Based on the above analysis, it can be seen that the annual temperature and precipitation are likely to be related to the increases of temperature and precipitation extremes. We

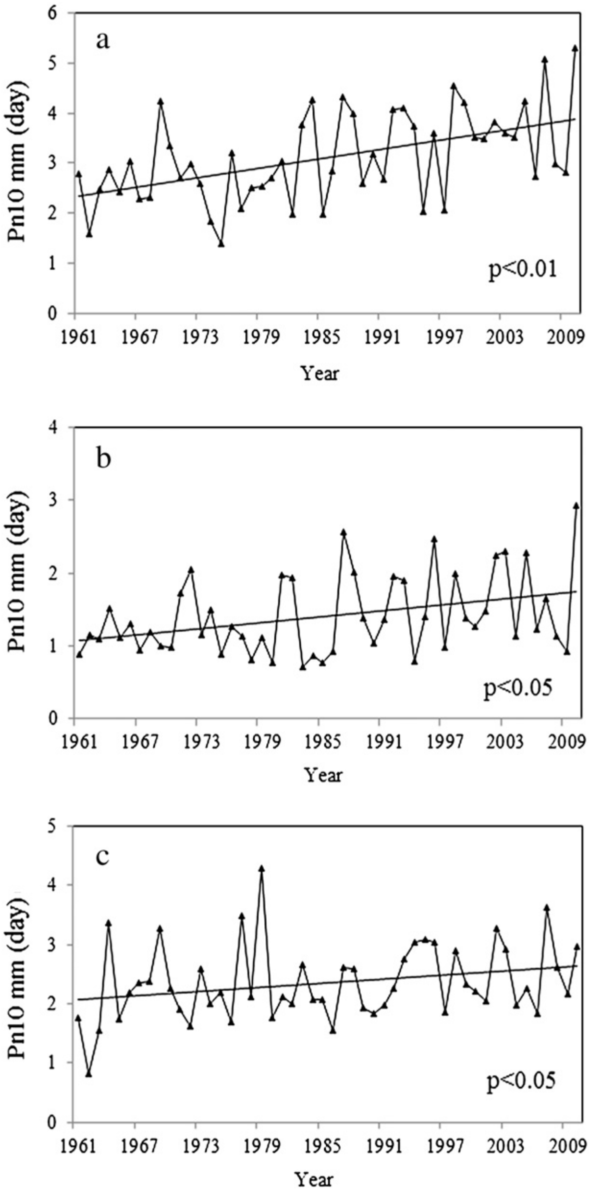


**Fig. 6.** The trends of the Pn10mm in the northern Xinjiang (a), southern Xinjiang (b) and Hexi Corridor (c), for the period 1961–2010, based on 68 meteorological stations.

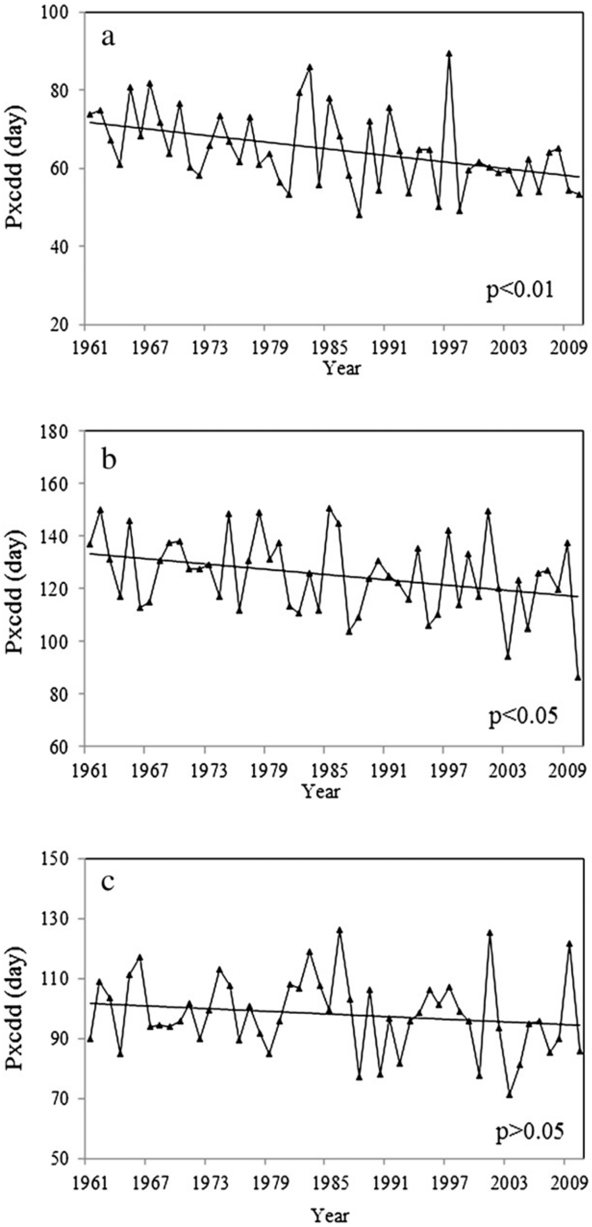


**Fig. 7.** The trends of the Pxcdd in the northern Xinjiang (a), southern Xinjiang (b) and Hexi Corridor (c), for the period 1961–2010, based on 68 meteorological stations.

used multi regression analysis model to analyze contributions of the temperature and precipitation extremes to the average states from 1986 to 2010.

In the multiple regression analysis of the contribution rate of the precipitation extremes, the Pav was the dependent variable, and the Pn10mm, Pxcdd, Pxcwd and Px3d were independent variables. First of all, the precipitation extreme indices were standardized in order to eliminate differences caused by unit and magnitude. The calculated contributions of the Pn10mm, Pxcdd, Pxcwd and Px3d are given by Table 8. The Tav contribution to the Pav is only 0.84%, less than the contribution made by the precipitation extreme index (Table 8). The results indicate that in all precipitation extreme indices, the Pn10mm contributed most to the Pav for 1986–2010.

We used the same methods to calculate the actual contributions of the temperature extremes to the average states. The results indicate that among all the temperature extreme indices, the Tnav contributed most to the Tav during the period of 1986–2010, followed by Txav (Table 9). It seems that Tnav and Txav were major factors for the rise of Tav since 1986.

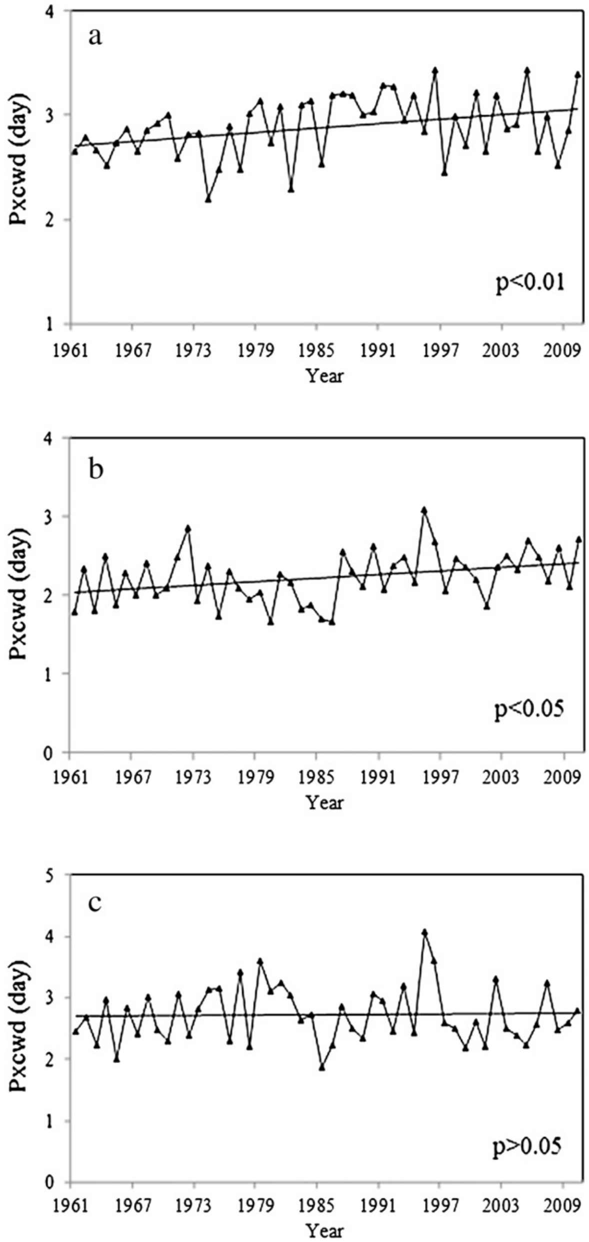


**Fig. 8.** The trends of the Pxcwd in the northern Xinjiang (a), southern Xinjiang (b) and Hexi Corridor (c), for the period 1961–2010, based on 68 meteorological stations.

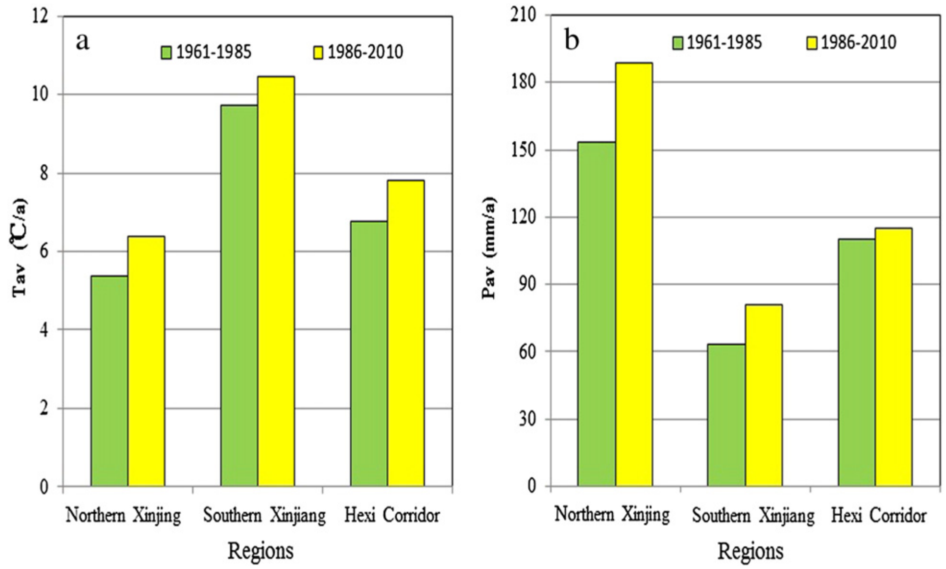


**Fig. 9.** Two time periods of change of the annual average temperature and precipitation in Northwest China (1961–1985, 1986–2010).

## 4. Conclusions and discussion

In this study, we investigated the regional and temporal variation in temperature and precipitation extremes in the arid region of northwest China (ARNC) during the past 50 years. In addition, we calculated contributions of the climate extremes to the climate average states.

Due to its unique physiographic characteristics and geographic location, the arid region in the northwest China is a sensitive area to global warming (Li et al., 2012). The detailed analysis of the dynamics of climate extremes in this study, represented by the variability of those climate extreme indices, substantiates the general understanding of the association of regional climate dynamics to global warming, and thus should contribute to a better understanding of the complex interactions between the regional climate system and the global climate change.

In the past 50 years, the increase of the Tnav and Txav is larger than those of the other temperature extreme indices. Spatially, the increasing rate of Tnav in the northern Xinjiang

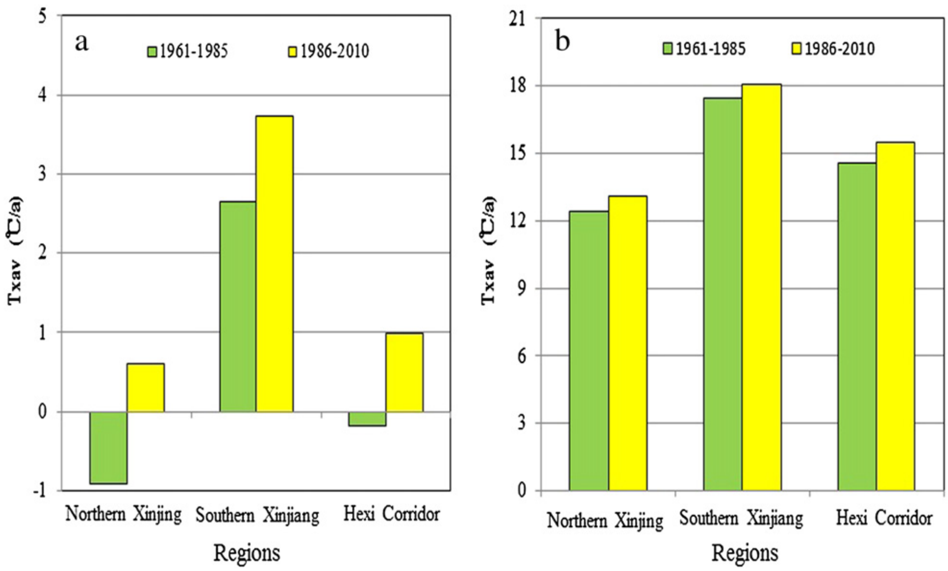


**Fig. 10.** Two time periods of change of annual minimum temperature and maximum temperature in Northwest China (1961–1985, 1986–2010).

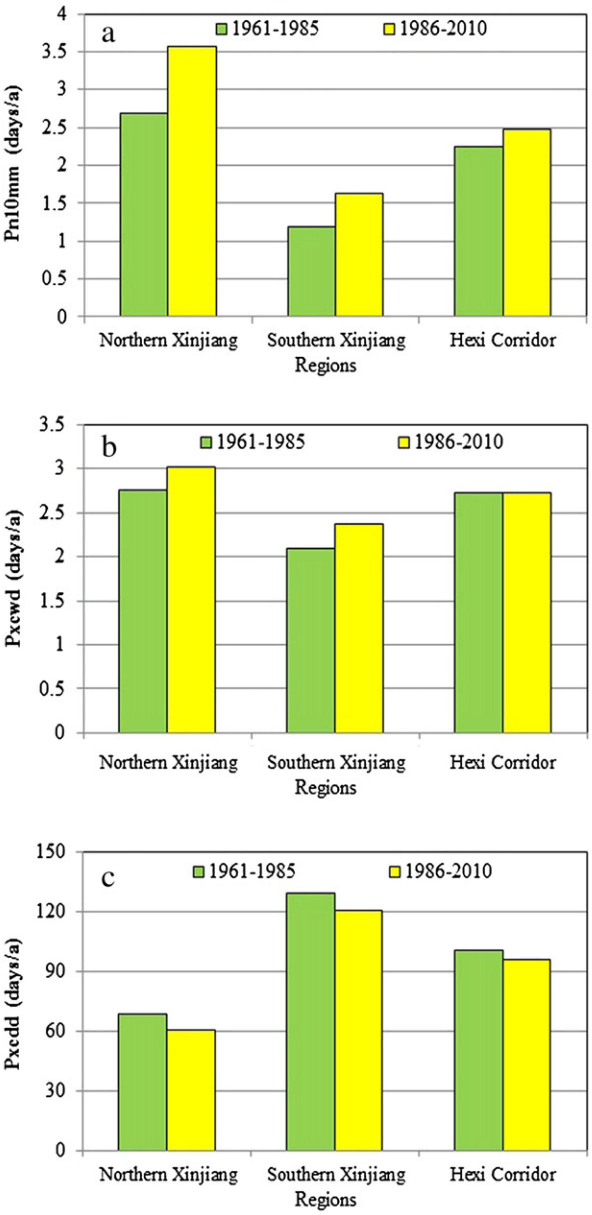


**Fig. 11.** Two time periods of change of precipitation extreme indices in Northwest China (1961–1985 and 1986–2010).

was higher than those of the other sub-regions. While there was regional variation, generally all tested temperature extreme indices had significant positive trends in the entire region over the last half century.

The values of the tested precipitation extreme indices have strong regional variation as well. The increasing trends in the northern Xinjiang are stronger than the other two sub-regions. The increasing trends are not remarkable in the Hexi Corridor, with 3 out of the 4 tested indices not statistically significant at the 0.05 level. Increasing rate of the Pav in the northern Xinjiang during the study period is higher than other two sub-regions; the Pn10mm increased more considerably, and the increasing rate is about three times the southern Xinjiang and Hexi Corridor; meanwhile, the Pxcwd of the northern Xinjiang has been significantly increasing, while the Pxcdd has been significantly decreasing.

The increasing trends of Tnav and Txav were higher during 1986–2010, compared with 1961–1985, and the increase of precipitation measured by Pn10mm and Pxcwd was higher during 1986–2010, compared with 1961–1985. Tnav and Txav are major factors for the rise of Tav during 1986–2010 in the ARNC, and the Pn10mm contributed most to the increase of Pav. The contribution of Tav to the Pav was less than that of the precipitation extreme index (Table 8). This should be because the vast desert and sparse vegetation coverage in the area have abated that the effects of temperature increase on the regional water vapor content to almost none. In summary, we found that since 1986 the significant increase in the climate average state of the ARNC has been pulled by the significant increase in the climate extremes in the area.

The water vapor in the ARNC is largely transported to the area by the Westerly Circulation. The recent 50 years have witnessed positive anomalies of precipitation in the northwest China, which may be a result of the anomalies of Westerly Circulation due to the anomalous anti-cyclone Siberian High that is associated with an enhanced water vapor convergence (Zuo et al., 2012). At the same time, the anomalous circulation is an important factor of anomalous precipitation in the northwest China. The positive anomalies of the anti-cyclone circulation may have contributed to the strengthening of downdraft and decrease of precipitation, and the positive anomalous of cyclone circulation may contribute to the strengthening of updraft and increase of precipitation (Zhou and Huang, 2010). The temperature rise in the recent 50 years in the northwest China is closely related to anomalies of the Siberian High index, especially since the late 1980s (Li et al., 2012). In general, the process of the atmospheric circulation that may have impacted on the precipitation and temperature in the arid region of northwest China is highly complex, and to gain an in-depth understanding of this complexity is an important item on our future research agenda.

## Acknowledgments

The research is supported by the National Basic Research Program of China (973 Program: 2010CB951003) and the National Natural Science Foundation of China (41305125). The authors thank the National Climate Central, China Meteorological Administration, for providing the meteorological data for this study.

**Table 8**
The actual contribution rate of the temperature and precipitation extremes states for the average states.

| | Pav | Pn10 | Pxccd | Pxcwd | Px3d | Tav |
|---|---|---|---|---|---|---|
| 1961–1985 | −0.474 | −0.477 | 0.371 | −0.391 | −0.351 | −0.652 |
| 1986–2010 | 0.494 | 0.498 | −0.401 | 0.444 | 0.383 | 0.7 |
| Δ | 0.968 | 0.975 | −0.772 | 0.835 | 0.734 | 1.352 |
| Coefficients | | 0.759 | −0.158 | 0.092 | 0.039 | 0.006 |
| ρ (%) | | 76.45 | 12.6 | 7.94 | 2.96 | 0.84 |

Δ is the variable quantity; ρ is the actual contribute rate.

**Table 9**
The actual contribution rate of the temperature extreme states for the average states.

| | Tav | Txav | Tnav | Txf10 | Txf90 | Tnf10 | Tnf90 |
|---|---|---|---|---|---|---|---|
| 1961–1985 | −0.652 | −0.519 | −0.732 | 0.72 | −0.684 | 0.431 | −0.54 |
| 1986–2010 | 0.7 | 0.567 | 0.779 | −0.778 | 0.719 | −0.509 | 0.58 |
| Δ | 1.352 | 1.086 | 1.511 | −1.498 | 1.403 | −0.94 | 1.12 |
| Coefficients | | 0.547 | 0.585 | 0.021 | −0.03 | 0.009 | −0.045 |
| ρ (%) | | 43.94 | 65.38 | −2.33 | −3.11 | −0.63 | −3.73 |

Δ is the variable quantity; ρ is the actual contribute rate.

## References


Chen, Y.N., Xu, Z.X., 2005. Plausible impact of globe climate change on water resources in the Tarim river basin, China. Sci. China Earth Sci. 48 (1), 65–73.

Chen, Y.N., Takeuchi, K., Xu, C.C., Chen, Y.P., Xu, Z.X., 2006. Regional climate change and its effects on river runoff in the Tarim Basin, China. Hydrol. Process. 20 (10), 2207–2216.

Ding, Y.H., Ren, G.Y., Zhao, Z.C., Xu, Y., Luo, Y., Li, Q.P., Zhang, J., 2007. Detection, causes and projection of climate change over China: an overview of recent progress. Adv. Atmos. Sci. 24 (6), 954–971.

Easterling, D.R., Evans, J.L., Groisman, P.Y., Karl, T.R., Kunkel, K.E., Ambenje, P., 2000. Observed variability and trends in extreme climate events: a brief review. Bull. Am. Meteorol. Soc. 81 (3), 417–425.

Gemmer, M., Becker, S., Jiang, T., 2004. Observed monthly precipitation trends in China 1951–2002. Theor. Appl. Climatol. 77 (1–2), 39–45.

Gocic, M., Trajkovic, S., 2013. Analysis of changes in meteorological variables using Mann–Kendall and Sen's slope estimator statistical tests in Serbia. Global Planet. Change 100, 172–182.

Hanson, C.E., Palutikof, J.P., Livermore, M.T.J., Barring, L., Bindi, M., Corte-Real, J., Durao, R., Giannakopoulos, C., Good, P., Holt, T., Kundzewicz, Z., Leckebusch, G.C., Moriondo, M., Radziejewski, M., Santos, J., Schlyter, P., Schwarb, M., Stjernquist, I., Ulbrich, U., 2007. Modelling the impact of climate extremes: an overview of the mice project. Clim. Change 81, 163–177.

Insaf, T.Z., Lin, S., Sheridan, S.C., 2012. Climate trends in indices for temperature and precipitation across New York State, 1948–2008. Air Qual. Atmos. Health 6 (1), 247–257.

Intergovernmental Panel on Climate Change (IPCC) (2007) Climate Change, 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Solomon, S., et al. (Eds.), Cambridge Univ. Press, Cambridge, U.K.

Kadioglu, M., 1997. Trends in surface air temperature data over Turkey. Int. J. Climatol. 17 (5), 511–520.

Kaser, G., Grosshauser, M., Marzeion, B., 2010. Contribution potential of glaciers to water availability in different climate regimes. Proc. Natl. Acad. Sci. U. S. A. 107 (47), 20223–20227.

Li, B.F., Chen, Y.N., Shi, X., 2012. Why does the temperature rise faster in the arid region of northwest China? J. Geophys. Res. 117.

Liu, J.R., Song, X.F., Sun, X.M., Yuan, G.F., Liu, X., Wang, S.Q., 2009. Isotopic composition of precipitation over Arid Northwestern China and its implications for the water vapor origin. J. Geogr. Sci. 19 (2), 164–174.

Lobell, D.B., Schlenker, W., Costa-Roberts, J., 2011. Climate trends and global crop production since 1980. Science 333 (6042), 616–620.

Pingale, S.M., Khare, D., Jat, M.K., Adamowski, J., 2014. Spatial and temporal trends of mean and extreme rainfall and temperature for the 33 urban centers of the arid and semi-arid state of Rajasthan, India. Atmos. Res. 138, 73–90.

Ren, G.Y., Xu, M.Z., Chu, Z.Y., 2005. Changes of surface air temperature in China during 1951–2004[in Chinese with English abstract]. Clim. Environ. Res. 10, 717–727.

Shi, Y.F., Shen, Y.P., Hu, R.J., 2002. Preliminary study on signal, impact and foreground of climate shift from warm–dry to warm–humid in northwest China [in Chinese with English abstract]. J. Glaciol. Geocryol. 3, 219–226.

Shi, Y.F., Shen, Y.P., Kang, E., Li, D.L., Ding, Y.J., Zhang, G.W., Hu, R.J., 2007. Recent and future climate change in Northwest China. Clim. Change 80 (3–4), 379–393.

Trenberth, K.E., 1999. Conceptual framework for changes of extremes of the hydrology with climate change. Clim. Change 42 (1), 327–339.

Wang, K.L., Jiang, H., Zhao, H., 2005. Atmospheric water vapor transport from westerly and monsoon over Northwest China. Adv. Water Sci. 16 (3), 432.

Wang, H.J., Chen, Y.N., Xun, S., Lai, D.M., Fan, Y.T., Li, Z., 2013. Changes in daily climate extremes in the arid area of Northwestern China. Theor. Appl. Climatol. 112 (1–2), 15–28.

Wigley, T.M.L., 2009. The effect of changing climate on the frequency of absolute extreme events. Clim. Change 97 (1–2), 67–76.

Yue, S., Pilon, P., Cavadias, G., 2002. Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. J. Hydrol. 259 (1–4), 254–271.

Zhang, S.H., Liu, S.X., MO, X.G., Shu, C., Sun, Y., Zhang, C., 2010. Assessing the impact of climate change on reference evapotranspiration in Aksu River Basin [in Chinese with English abstract]. Acta Geograph. Sin. 65 (11), 1363–1370.

Zhang, Q., Li, J.F., Singh, V.P., Bai, Y.G., 2012. SPI-based evaluation of drought events in Xinjiang, China. Nat. Hazards 64 (1), 481–492.

Zhou, L.T., Huang, R.H., 2010. Interdecadal variability of summer rainfall in Northwest China and its possible causes. Int. J. Climatol. 30 (4), 549–558.

Zuo, Z.Y., Zhang, R.H., Wu, B.Y., Rong, X.Y., 2012. Decadal variability in springtime snow over Eurasia: relation with circulation and possible influence on springtime rainfall over China. Int. J. Climatol. 32 (9), 1336–1345.