Characteristics of climate change and its relationship with land use/cover change in Yunnan Province, China

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Abstract

This study analyzed the characteristics of climate change (including temporal trend and spatial distribution of temperature and precipitation) in Yunnan Province during 1961-2011 based on the observed data from 22 meteorological stations, and its relationship with land use/cover change (LUCC) was also discussed. The results showed that: (1) Significant increasing trend in temperature was observed at the annual scale, especially for the period 1987-2011. At the seasonal scale, such trend was the most prominent in winter. (2) Temporally, the annual precipitation showed a non-significant decreasing trend, which was dominant by the rainy season; spatially, the annual precipitation showed the east-to-west and north-to-south increasing trends over this region. (3) This study analyzed the impacts of elevation and geographical location on climate change patterns, and the statistical equations to estimate the annual temperature and precipitation as well as their changing rates were established based on longitude, latitude and elevation. (4) Through analyzing the relationship between climate change and the LUCC, the correlation between the LUCC and temperature was stronger than that between the LUCC and precipitation. The results would be valuable for researchers and managers to better understand the characteristics of climate change as well as its relationship with the LUCC and to make better decisions in future.

Key words: Climate change; Temperature; Precipitation; Extremes; Land use/cover change

1. Introduction

In the past century, global climate change (e.g., the increase in temperature), which has greatly influenced water circulation and hydrological processes (Hartmann *et al.*, 2013; IPCC, 2013; Shi *et al.*, 2016a, 2018), has attracted a great deal of attentions from researchers worldwide. As two basic meteorological variables, temperature and precipitation have been widely used in the fields of meteorology, climatology, hydrology and so on (e.g., Shi and Wang, 2015; Zhou *et al.*, 2016; Almeida *et al.*, 2017). It was reported that the global mean surface temperature had increased by 0.85 [0.65 to 1.06] ºC over the period 1880-2012 (IPCC, 2013) and the global annual mean precipitation over land had shown statistically significant increasing changes (i.e., 2.77, 2.08 and 1.48 mm/decade for the CRU TS 3.10.01, GHCN V2 and GPCC V6 datasets) over the period 1901-2008 (Hartmann *et al.*, 2013). However, the spatial-temporal characteristics of these two variables might present significant discrepancies among different regions. As reported by IPCC (2013), the changing rate of temperature in the Arctic was almost twice as much as the global mean value in the past century. With reference to precipitation, a wetting trend was found in eastern North and South America, northern Europe, northern and central Asia, compared to a drying trend in the Mediterranean, southern Africa and parts of southern Asia (e.g., Groisman *et al.*, 2005; Hartmann *et al.*, 2013; IPCC, 2013; Westra *et al.*, 2013; Shi *et al.*, 2016a). Therefore, the key scientific issue concerning the changing characteristics of temperature and precipitation has been investigated by numerous researchers over different regions (e.g., Zhai *et al.*, 20005; Cao and Pan, 2014; Colucci and Guglielmin, 2015; Zhou *et al.*, 2016; Almeida *et al.*, 2017). Moreover, extreme temperature and precipitation are, sometimes, more sensitive to climate change than the mean values (Easterling *et al.*, 1997, 2000), and a number of relevant studies have been conducted, e.g., at the global scale (Alexander *et al.*, 2006), in central and southern Asia (Klein Tank *et al.*, 2006), western and southeastern Africa (Aguilar *et al.*, 2009), Caribbean region (Peterson *et al.*, 2002), Europe (Klein Tank and Können, 2003) and Middle East (Zhang *et al.*, 2005). In addition, the rapid development of land use/cover change (noted as LUCC hereafter), including urbanization, deforestation, agricultural expansion and so on, has been regarded as a vital social and environmental issue with implications for climate change and sustainable development of resources (e.g., water, food and energy) (Foley *et al.*, 2005; Gibbard *et al.*, 2005; Bonan, 2008; Cinar, 2015; Chen *et al.*, 2016). As a result, the relationship between climate change and the LUCC has been regarded as an essential factor to understand the interactions between land and atmosphere (Dale, 1997; Tanaka *et al.*, 2013; Zhang et al., 2014a; Cao *et al.*, 2015).

In the past several decades, warming trends have been prevalent in most regions of China, but temperature has also shown decreasing trends in some regions such as parts of the lower Yangtze River basin in summer (Ding *et al.*, 2006). With reference to precipitation, increasing trends have been found in most regions of China, including the western China, the Yangtze River basin, and the southeastern coast; however, precipitation has shown decreasing trends over the north and northwestern China (Liu *et al.*, 2005; Zhai *et al.*, 2005; Ding *et al.*, 2006; Liu et al., 2008; Shi *et al.*, 2016a). Moreover, through analyzing the spatial-temporal variations of various extreme temperature and precipitation indices based on the observed data recorded at 303 meteorological stations in China, You *et al.* (2011) reported the overall warming trends in temperature indices, the largest increasing trend in precipitation indices at the stations in the Yangtze River basin, southeastern and northwestern China, and the largest decreasing trend in precipitation indices at the stations in the Yellow River basin and northern China. Thus, it is important and necessary to investigate the spatial-temporal characteristics of temperature and precipitation for the designated region.

Specifically, Yunnan Province, which is located in southwestern China with complex topography and influenced by two Asian summer monsoons, is sensitive to climate change (Cao *et al.*, 2012; Zhang *et al.*, 2014b). Besides, as there are several rivers (e.g., the Mekong River and the Nujiang River) flowing through this region, changes in climate pattern may have an important impact on hydrological cycle and increase the risk of flood or drought. According to previous studies, extreme climate events (e.g., extreme floods, debris flows, and droughts) have frequently occurred in Yunnan Province during the last several decades, causing enormous losses of lives and property (Lu *et al.*, 2012; Zhang *et al.*, 2013; Li *et al.*, 2015). Therefore, this study aims to provide a better understanding of the spatial-temporal characteristics of climate change as well as its relationship with the LUCC in Yunnan Province. The daily air temperature and precipitation data recorded at 22 meteorological stations during 1961-2011, the monthly NDVI (normalized difference vegetation index) data from the GIMMS (Global Inventory Modeling and Mapping Studies) dataset during 1982-2006, and the 30-m-resolution global artificial terrestrial surface dataset in 2010 (i.e., GlobeLand30_ATS2010) are used in this study. Compared to previous studies (e.g., Fan *et al.*, 2011; Fan *et al.*, 2013; Chen *et al.*, 2015; Li *et al.*, 2015), the significance of this study can be described as follows: (1) to quantify the temporal trends and spatial patterns of both the mean and the extreme temperature and precipitation; (2) to establish statistical equations to estimate the annual temperature and precipitation as well as their changing rates based on longitude, latitude and elevation, which would be useful to better understand the local climate; and (3) to quantitatively analyze the relationship between climate change and the LUCC. This would be helpful to provide a scientific basis for the changing characteristics of temperature and precipitation in such regions.

2. Data and method

2.1. Study area

Yunnan Province is located in southwestern China (98°E-106°E, 21°N-29°N), with an area of 3.9×10^5 km^2. It borders Myanmar, Lao, and Vietnam, extending to the southeastern rim of the Himalayas. The elevation ranges from 76 m (i.e., the Yuanjiang river valley) to 6740 m (i.e., the Kawagarbo Peak) (Fig. 1). This region extends from the tropical, the sub-tropical to the temperate zones, mainly dominated by a plateau monsoon climate (i.e., the Indian summer monsoon and the East Asian summer monsoon) (Cao *et al.*, 2012). Normally, the mean temperature ranges from approximately 9-11ºC in January to around 22ºC in July, and the annual mean precipitation ranges from 1100 mm to 1600 mm. For the seasonal analysis of temperature, four seasons, i.e., spring (from February to April), summer (from May to July), autumn (from August to October) and winter (from November to January), are divided by the

Solar Terms. By contrast, for the seasonal analysis of precipitation, two seasons, i.e., the rainy (from May to October, including summer and autumn) and dry (from November to April of the next year, including winter and spring) seasons, are divided according to the precipitation amount (e.g., Huang, 2011; Fan *et al.*, 2013; Yang *et al.*, 2015; Li *et al.*, 2016). Due to the summer monsoons, precipitation in this region mainly occurs in the rainy season, which can take up more than 80% of the annual total precipitation. Moreover, there are several rivers flowing through this region, including the Nujiang River, the Yangtze River, the Red River, and the Mekong River.

According to the previous studies (e.g., Zhao *et al.*, 2013; Wu *et al.*, 2015), the major type of land use/cover in Yunnan Province is the forest land, which can take up more than 50% of the total area, followed by the grass land and the cultivated land. Moreover, the built-up land is mainly distributed around cities such as Kuming and Dali. In reference to historical LUCC events in this region, it is worth noting that the two ecological rehabilitation projects (i.e., the Natural Forest Conservation Program started from 1998 and the Grain to Green Program started from 1999) conducted by the Chinese Government may have great effects on the increase of the forest/grass land and the decrease of the cultivated land (Weyerhaeuser *et al.*, 2005; Xu *et al.*, 2006; Zhang *et al.*, 2014a; Shi *et al.*, 2016b). However, due to the China Western Development Program implemented from 2000, the demands for various resources with the rapid socio-economic development have brought more infrastructure constructions (e.g., roads and buildings), which may lead to the increase of the built-up land through the accelerated urbanization (Lai, 2002; Zhang *et al.*, 2007; Wu *et al.*, 2015).

2.2. Research data

There are 32 meteorological stations in Yunnan Province. The daily meteorological data (i.e., temperature and precipitation) can be downloaded for free on the official website of China Meteorological Administration (China Meteorological Administration, 2016). As most of these stations were built in the late 1950s, only the data from 1961 are used in this study to ensure that the lengths of the data from different stations are consistent. For the designated meteorological station, the missing data are interpolated with the inverse distance weighting (noted as IDW hereafter) method (see subsection 2.5 for details) based on the data of the nearest two stations in the same years; however, stations with serious lack of data (i.e., the data in more than twenty years are missing in total or the data in more than five consecutive years are missing) are excluded directly. Moreover, the erroneous records (e.g., the negative precipitation values) are detected and processed with the same method as the missing data. After such a data quality control process, there are 22 meteorological stations remaining with complete daily observations from 1961 to 2011 (Fig. 1). The annual and seasonal values can be derived from the daily values. To test the general trends of temperature and precipitation over this region, data from different stations are interpolated with the same weight to obtain the mean annual and seasonal values because these stations are basically evenly distributed in space (Fig. 1). Yearly anomalies are achieved by removing the long-term means.

Satellite-measured vegetation greenness indices such as the NDVI can be regarded as an important indicator of the LUCC (e.g., Sahebjalal and Dashtekian, 2013; Jung and Chang, 2015; Xu *et al.*, 2016; Hereher, 2017). The red and near-infrared reflectance is used to estimate the amount of above-ground green vegetation cover, and the NDVI value ranges from -1.0 to 1.0 (Weier and Herring, 2000). The NDVI data used in this study are derived from the GIMMS (Global Inventory Modeling and Mapping Studies) dataset with the spatial resolution of 8 km from 1982 to 2006. This dataset is provided by the AVHRR (Advanced Very High Resolution Radiometer) instrument onboard the NOAA (National Oceanic and Atmospheric Administration) satellite series with good data quality assurance (Tucker *et al.*, 2004, 2005). The relationship between climate change and the LUCC represented by the NDVI data is examined through regression analysis. In addition, to separately investigate the urbanization effects on climate change in the study area, the 30-m-resolution global artificial terrestrial surface dataset in 2010 (GlobeLand30_ATS2010) is adopted in this study (Chen *et al.*, 2014). This dataset includes land use types of residential land, industrial land, commercial land, transportation land, and so on, which can reflect the impacts of various human activities on the LUCC.

2.3. Extreme indices

The 27 core climate change indices, which are calculated based on daily temperature and precipitation data (*http://etccdi.pacificclimate.org/list_27_indices.shtml*), have been defined by Karl *et al.* (1999). In this study, nine temperature extreme indices and eight precipitation extreme indices are selected (see Table 1), and an R-language based program, RClimDex, developed by Xuebin Zhang and Feng Yang (*http://etccdi.pacificclimate.org/software.shtml*), is adopted to calculate these indices.

2.4. Trend test and change point test methods

A number of previous studies have proved that the Mann-Kendall trend test and the Pettitt change point test methods are useful for researches on meteorology, hydrology and sedimentology (e.g., Shi and Wang, 2015; Shi *et al.*, 2016a; Shi *et al.*, 2017a, 2017b). The Mann-Kendall trend test is a non-parametric rank-based statistical test that was proposed by Mann (1945) and Kendall (1975), and the slope of the series can be estimated by using a non-parametric procedure (Sen, 1968) as follows:

$$Q_i = \frac{x_j - x_k}{j - k}, i = 1, 2, ..., N, j > k \tag{1}$$

where x_j and x_k are the j-th and k-th values, respectively. If there are n values in the series, we can get as many as $N = n(n\text{-}1)/2$ slope estimates Q_i. The Sen's estimator, Q, is the median of these N values of Q_i ranked from the smallest to the largest. Then, Q is tested by two-sided test; and finally, the slope is obtained by the non-parametric test.

$$Q = \begin{cases} Q_{\frac{N+1}{2}}, & if \;\; N \;\; is \;\; odd \\ \frac{1}{2}(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}), & if \;\; N \;\; is \;\; even \end{cases} \tag{2}$$

The Pettitt change point test is a non-parametric rank-based statistical test used to identify the change points in the series (Pettitt, 1979). When the first change point is found, the series will be divided into two subsequences; and additional change points in these subsequences may generate more subsequences.

2.5. Spatial interpolation method

To interpolate the missing data of the designated meteorological stations and compute the spatial distribution of the designated meteorological variables over the study area, a spatial interpolation method is necessary. Considering both simplicity and accuracy, this study selects the IDW method (e.g., Shi *et al.*, 2014, 2016a, 2017a), the general form of which can be expressed as follows:

$$X_p = \frac{\sum_{i=1}^{N} \frac{1}{D_i^{\beta}} X_i}{\sum_{i=1}^{N} \frac{1}{D_i^{\beta}}} \tag{3}$$

where N is the number of used meteorological stations, X_p is the interpolated value at the point of interest, X_i is the value at the i-th given station, D_i is the distance from the i-th given station to the point of interest, and β is the power of D_i. Following common practice (e.g., Goovaerts, 2000; Mito *et al.*, 2011; Shi *et al.*, 2016a, 2017b), this study sets the value β to be 2, and the IDW method turns into the inverse distance squared method.

2.6. Normalization method

In order to facilitate the evaluation of the significances of the variables in a regression model, it is better to use the normalized values of these variables rather than the original values. Generally, the normalization method is as follows:

$$NY_i = \frac{Y_i - Y_{\min}}{Y_{\max} - Y_{\min}} \tag{4}$$

where NY_i is the normalized value, Y_i is the i-th original value, and Y_{max} and Y_{min} are the maximum and minimum values among the original values, respectively.

3. Results and discussion

3.1. Temperature

3.1.1. Annual and seasonal variations

The annual temperature in the study area showed a significant increasing trend (i.e., 0.26 ºC/decade, $p<0.01$) during 1961-2011 (Fig. 2 and Table 2), which was twice as large as the global mean (i.e., 0.12 [0.08 to 0.14] ºC/decade during 1951-2012, IPCC, 2013). However, this was almost consistent with the result in the study of Fan *et al.* (2011), which indicated a warming trend of 0.3 °C/decade over this region during 1961-2004. Different from the study of Fan *et al.* (2011), this study further analyzed the annual variation of temperature during the subsequences and the seasonal variation of temperature in all the four seasons. An abrupt change was found in 1986 in the annual temperature series using Pettitt change point test. Before 1986, the annual temperature of only one year (i.e., 1981) was larger than the long-term mean value, and the annual temperature fluctuated greatly with a non-significant increasing trend of 0.08 ºC/decade ($p>0.1$) during 1961-1986. In contrast, most of the anomalies were positive after 1987 except a few years (1989, 1990, 1992, 1993 and 1997), and the annual temperature increased much faster with the changing rate of 0.31 ºC/decade ($p<0.01$) during 1987-2011 which was nearly four times as large as that during 1961-1986. The accelerated climate warming over Yunnan Province since the middle 1980s has also been investigated by other researchers (e.g., You *et al.*, 1998; Cheng and Xie, 2008), which was basically the same as the variation characteristics of the global mean temperature (IPCC, 2013). In addition, temperature in the four seasons all showed the significant increasing trends during 1961-2011, with the changing rates of 0.22 ºC/decade in spring, 0.22 ºC/decade in summer, 0.24 ºC/decade in autumn and 0.38 ºC/decade in winter, respectively (see Fig. 3 and Table 2). Compared to the results (i.e., 0.26 ºC/decade in summer and 0.33 ºC/decade in winter) in the study of Fan *et al.* (2011), the changing rate in summer was a little lower but that in winter was a little higher. It is worth noting that there was a cooling period during 1961-1986 in autumn, despite the general increasing trend over the whole study period for this season. However, such a decreasing trend was non-significant (Table 2). Overall, temperature in Yunnan Province has experienced the rising trend during the last half century at both annual and seasonal scales. The changing rates were relatively lower during 1961-1986 and much higher during 1987-2011. Among the four seasons, winter had the most pronounced increasing trend.

With reference to spatial distributions, the annual temperatures recorded at all the 22 stations presented the increasing trends during 1961-2011, and most of the trends (i.e., 20 in 22, except the Luxi and Yuanjiang stations) were significant (Table 3). This was inconsistent with the result in the study of Fan *et al.* (2011), which indicated that the stations located in the hot-dry valleys along the Yangtze and Red River basins had experienced cooling during 1961-2004. The reason for this might be the difference in the length of the datasets. Moreover, the Deqing station showed the highest changing rate of 0.46 ºC/decade (p<0.01), followed by the Kunming station (0.43 ºC/decade, p<0.01) and the Simao station (0.41 ºC/decade, p<0.01). However, before 1986, the annual temperature values recorded at only 7 stations showed the significant increasing trend, compared to 17 stations during 1987-2011. Moreover, there were 6 stations showing the decreasing trends in annual temperature during 1961-1986, but only two of them were significant (Table 3).

3.1.2. Temperature extremes

Table 4 lists the changing rates of 9 selected temperature extreme indices during 1961-2011. The 4 indices representing hot extremes (i.e., TXx, TNx, TX90p and TN90p) all showed the significant increasing trends. For the 4 indices representing cold extremes (i.e., TXn, TNn, TX10p and TN10p), TXn and TNn significantly increased with the changing rates of 0.24 and 0.48 ºC/decade, respectively; while TX10p and TN10p significantly decreased with the changing rates of -0.55 and -2.79 %/decade, respectively. As the changing rates of the minimum temperature indices (i.e., TXn and TNn) were larger than those of the maximum temperature indices (i.e., TXx and TNx), the diurnal temperature range (DTR) showed a significant decreasing trend during 1961-2011 (i.e., -0.17 ºC/decade, $p<0.01$). It is worth noting that the changing rate of the DTR was much higher than the global values of -0.066 ºC/decade during 1950-2004 and -0.032 ºC/decade during 1979-2004 (Vose *et al.*, 2005). However, compared to the previous studies in this region (Fan *et al.*, 2011) and neighboring regions, e.g., southwestern China (Li *et al.*, 2012) and Tibetan Plateau (Liu *et al.*, 2006), this study showed similar results.

With reference to spatial distributions, most of the 22 stations showed increasing trends in the indices representing hot extremes during 1961-2011 (Fig. 4), i.e., 15 stations for TXx, 22 stations for TNx, 21 stations for TX90p, and 22 stations for TN90p. Among them, significant trends were found in 4 stations for TXx, 19 stations for TNx, 21 stations for TX90p, and 21 stations for TN90p. Moreover, most stations showed increasing trends in two indices representing cold extremes (i.e., 21 stations for TXn and 20 stations for TNn) but decreasing trends in the other two (i.e., 19 stations for TX10p and 21 stations for TN10p) during 1961-2011 (Fig. 4). Among them, significant trends were found in 5 stations for TXn, 19 stations for TNn, 9 stations for TX10p, and 21 stations for TN10p. In addition, there were 19 stations showing decreasing trends in the DTR during 1961-2011 except for the Deqing, Yuanjiang and Luxi stations, among which, the increasing trends were statistically significant ($p<0.01$) for the Deqing and Yuanjiang stations. Overall, a warming trend and a more frequent extreme climate pattern were observed in the whole study area, especially in the middle, eastern and northwestern parts.

In addition, correlations among the selected temperature indices were analyzed in this study using the Kendall's tau correlation coefficient (noted as CC hereafter), and the relevant results were listed in Table 5. The annual temperature was well correlated with all the 9 extreme indices ($p<0.01$), showing the largest positive CC of 0.78 for TN90p and the largest negative CC of -0.72 for TN10p. It is worth noting that most correlations among the extreme indices were statistically significant. Specifically, the DTR had closer correlations with the extreme indices of daily minimum temperature (i.e., TNx, TN90p, TNn and TN10p) than those of daily maximum temperature (i.e., TXx, TX90p, TXn and TX10p), indicating that the DTR was mainly influenced by the former four extreme indices.

3.2. Precipitation

3.2.1. Annual and seasonal variations

The annual precipitation in the study area showed a non-significant decreasing trend (i.e., -8.84 mm/decade, $p>0.1$) with great fluctuations during 1961-2011 (Fig. 5), and no abrupt change could be found in the annual precipitation series using Pettitt change point test. This was inconsistent with the statistically significant increasing trend of the global means during 1901-2008 (Hartmann *et al.*, 2013) as well as the results in some previous studies in this region (e.g., Chen *et al.*, 2015); however, this was consistent with the results in some other previous studies in this region (e.g., Fan *et al.*, 2013). The reason for this might be the differences in the number of stations, the length of the datasets and the temporal resolution of the datasets used in different studies (Shi *et al.*, 2017b). Fig. 6 shows the variation of the seasonal precipitation in Yunnan Province during 1961-2011, and precipitation in the rainy and dry seasons both showed the non-significant decreasing trends (i.e., -10.6 and -1.15 mm/decade in the rainy and dry seasons, respectively, $p>0.1$). Chen *et al.* (2015) reported an increase trend in precipitation for spring but a decrease trend in precipitation for summer, autumn and winter over this region, and therefore, the much smaller changing rate in the dry season (including winter and spring) was probably caused by the increase trend in precipitation for spring. Moreover, the variation pattern of precipitation in the rainy season was similar to that of the annual precipitation. In contrast, the variation pattern of precipitation in the dry season was quite different, with relatively weaker fluctuations after the middle 1980s.

With reference to spatial distributions, the annual precipitations recorded at 8 stations presented the increasing trends while those of the other 14 stations presented the decreasing trends during 1961-2011 (Table 6). Among them, only the trends of Zhanyi station (i.e., -49.3 mm/decade, $p<0.01$), Luxi station (i.e., -48.1 mm/decade, $p<0.01$) and Kunming station (i.e., -34.2 mm/decade, $p<0.05$) were statistically significant. In addition, Fig. 7 shows the spatial distribution of the changing rates of the annual precipitation in Yunnan Province during 1961-2011, which was interpolated by using the IDW method. Generally, the changing rates of the annual precipitation over this region presented the east-to-west increasing trend.

Precipitation in Yunnan Province is mainly affected by the Indian summer monsoon and the East Asian summer monsoon. Several previous studies (e.g., Duan and Yao, 2003; Yu *et al.*, 2004; Wang and Zhou, 2005) reported that the two monsoons had the weakening trends, which might be considered as the main reasons for the decrease in annual precipitation. Moreover, Yang *et al.* (2013) reported a significant upward trend in precipitation in eastern Himalayas during 1971-2007, which could partly explain the increasing trend in annual precipitation in northwestern part of Yunnan Province because this region borders eastern Himalayas. Furthermore, the Asian summer monsoons can be influenced by large scale weather patterns such as the El Niño Southern Oscillation (ENSO) (Immerzeel and Bierkens, 2010), which may have played an important role in affecting the changing characteristics of precipitation (e.g., Kumar *et al.*, 1999; Yang *et al.*, 2004; Shi *et al.*, 2016a). Generally, warm ENSO events can lead to the weak Indian summer monsoon (Kumar *et al.*, 1999), and thus, less precipitation than usual. For example, warm ENSO events were recorded in 1968-1969, 1991-1992, 2002-2003 and 2009-2010, which might explain the relatively lower precipitation anomalies in those years. In contrast, cold ENSO events were recorded in 1999-2001, which might be the reason for the relatively higher precipitation anomalies in 1999 and 2001.

3.2.2. Precipitation extremes

Table 4 lists the changing rates of 8 selected precipitation extreme indices during 1961-2011. Among them, only three indices (i.e., SDII, CDD and CWD) were statistically significant. For other indices, RX1day showed the increasing trend (i.e., 0.17 mm/decade) while RX5day (i.e., -0.47 mm/decade) and R10 (i.e., -0.39 days/decade) showed the decreasing trends; however, none of them was statistically significant. Moreover, the slight increases in R25 (i.e., 0.05 days/decade) and R95p (i.e., 1.59 mm/decade), as well as the significant increase in SDII (i.e., 0.08 mm/day/decade), demonstrated the trend of a higher intensity of precipitation events. The above results of trend analysis were basically consistent with those in the previous studies (Chen *et al.*, 2015; Li *et al.*, 2015), except for the slight differences in the significant levels or trend values.

With reference to spatial distributions, CDD had the largest number of stations (i.e., 19) showing the increasing trends while RX5day had the largest number of stations (i.e., 13) showing the decreasing trends. Fig. 8 shows the spatial distributions of changing rates of precipitation extremes. Compared to the study of Chen *et al.* (2015), this study shows the similar results except for the spatial distribution of changing rates of CDD. In this study, only 2 stations located at the northwestern part of Yunnan Province showed the decreasing trends in CDD, while Chen et al. (2015) found that more stations located at the middle and southern parts of Yunnan Province had such trends. It is worth noting that the western part of this region experienced more CDDs and few CWDs, indicating that this region might experience extreme events such as drought. Moreover, a drying trend could be found in the eastern part of this region due to the decreases in RX1day, RX5day, SDII, R10, R25, CWD and R95p, but the increase in CDD.

In addition, several studies (e.g., You *et al.*, 2011; Wang *et al.*, 2013) have pointed out the strong correlations between the annual precipitation and the extreme precipitation indices, which could also be proved by the CCs listed in Table 7. In this study, the correlations were statistically significant at the significance level of p=0.01 except for CDD, among which, the largest positive CC was 0.80 for R10 (i.e., number of heavy precipitation days). With reference to the correlations among the extreme indices, it is observed that most of them were statistically significant. However, weak correlations were found between CDD and other extreme indices, mainly due to that CDD is an indicator of dry period.

3.3. Impacts of elevation and geographical location

In previous studies (e.g., Shi *et al.*, 2016a, 2017b), elevation and geographical location (i.e., longitude and latitude) were regarded as important factors in influencing meteorological variables such as precipitation and potential evaporation. Therefore, in this study, longitude, latitude and elevation of the 22 meteorological stations were taken into account to establish the relationships of elevation and geographical location with temperature and precipitation, and these three variables were normalized with Eq. (4) before using the multiple regression method. Thereupon, the statistical equations to estimate the annual temperature (T_a) and precipitation (P_a) were obtained as follows.

$$T_a = 0.73N\_lon - 0.026N\_lat - 17.29N\_ele + 23 \qquad (R^2=0.99,\ p<0.01) \qquad (5)$$

$$P_a = -502N\_lon - 1733N\_lat + 705N\_ele + 1852 \qquad (R^2=0.56,\ p<0.01) \qquad (6)$$

where *N_lon*, *N_lat* and *N_ele* denote the normalized longitude, latitude and elevation of each station, respectively. The R^2 value of Eq. (5) was quite high, which indicated that the annual temperature could be well estimated by using Eq. (5). However, it is worth noting that only elevation was significant for Eq. (5) ($p<0.01$), and the R^2 value could reach 0.98 even if longitude and latitude were not included. Therefore, Eq. (5) could present the high-to-low increasing trend in the annual temperature over this region, and this was consistent with the results reported in a number of studies (e.g., Running *et al.*, 1987; Thornton *et al.*, 1997; Shi *et al.*, 2014) that temperature may decrease along with the increase of elevation. By contrast, the R^2 value of Eq. (6) was relatively lower, and longitude and latitude were significant for Eq. (6) at the significant level of $p<0.05$ and $p<0.01$, respectively; however, elevation was not significant for Eq. (6) ($p>0.1$). Moreover, Eq. (6) showed that the annual precipitation over this region could present the east-to-west and north-to-south increasing trends. The reasons for this are as follows: precipitation in the study area is mainly dominated by a plateau monsoon climate (i.e., the Indian summer monsoon and the East Asian summer monsoon) (Cao *et al.*, 2012); therefore, for a designated location in the study area, there will be less precipitation if it is farther from the Indian Ocean or the Pacific Ocean, leading to the north-to-south and east-to-west increasing trends in the annual precipitation over this region.

Furthermore, it is observed that the changing rates of meteorological variables may also be related to elevation and geographical location. For example, Shrestha *et al.* (1999) pointed out that high-elevation region was more sensitive to warming trend through analyzing the temperature variations using the data from 49 stations in Himalaya and Nepal. Therefore, this study also investigated the impacts of elevation and geographical location on the changing rates of temperature (T_{cr}) and precipitation (P_{cr}), and the relevant statistical equations were as follows:

$$T_{cr} = -0.13N\_lon - 0.56N\_lat + 0.66N\_ele + 0.31 \quad (R^2=0.53,\ p<0.01) \tag{7}$$

$$P_{cr} = -39.84N\_lon + 25.61N\_lat - 20.22N\_ele + 6.54 \quad (R^2=0.51,\ p<0.01) \tag{8}$$

Eq. (7) showed that the changing rate of temperature had the east-to-west, north-to-south and low-to-high increasing trends over this region. That is because all these three variables (i.e., longitude, latitude and elevation) were significant for Eq. (7) at the significant level of $p<0.05$, $p<0.01$ and $p<0.01$, respectively. By contrast, only longitude was significant for Eq. (8) ($p<0.01$), and therefore, Eq. (8) showed that the changing rate of precipitation had the east-to-west increasing trend (Fig. 7). It is worth noting that the R^2 values of Eqs. (7) and (8) were just over 0.5, which indicated that about 50% of the observed variations might be due to other factors. For this reason, the importance of these two regression equations would be reduced to some extent, which might limit the practical value in applications. Nevertheless, the proposed equations could be regarded as a pilot exploration of interpreting the changes of temperature and precipitation over this region from the perspective of utilizing geographic information.

To quantitatively evaluate the performances of these regression equations, a residual analysis was implemented in this study. Table 8 lists the residuals of the annual temperature and precipitation values as well as the changing rates of temperature and precipitation estimated by Eqs. (5-8), and Fig. 9 shows the distributions of the residuals associated with the estimated values. It is observed that, for each equation, the residuals were uniformly and randomly distributed on both sides of the zero line (Fig. 9), which could follow a normal distribution with zero mean (Table 8). In addition, the relative errors (REs) of the estimated values against the observed values were calculated (Table 8). For the annual temperature, the REs were all within ±8%, which indicated the high accuracy of Eq. (5); while for the annual precipitation, the REs were all within ±37%. With reference to the changing rates, most REs of T_{cr} were within ±48% except for that at Dali station (i.e., 123%). Through comparing to the REs in the two nearest stations, which were -13% at Baoshan station and 8% at Jingdong station, it is inferred that such overestimation was mainly caused by the much larger elevation of Dali station (i.e., 1991 m) than those of Baoshan station (i.e., 1652 m) and Jingdong station (i.e., 1162 m). Moreover, the REs of P_{cr} were generally quite large, which indicated that the changing rate of precipitation could not be accurately estimated by Eq. (8). Overall, the above results revealed that the proposed regression equations could provide better estimations of the annual values of temperature and precipitation than the changing rates.

3.4. Relationship between climate change and the LUCC

The LUCC can have great impacts on the NDVI (Guerschman *et al.*, 2003); however, the NDVI may also be affected by other factors. Therefore, it is worth noting that the following results may interpret only part of rather than all the impacts of the LUCC because the NDVI is regarded as an indicator of the LUCC in this study (e.g., Jung and Chang, 2015; Xu *et al.*, 2016; Hereher, 2017). Fig. 10a shows the variations of the annual NDVI in Yunnan Province during 1982-2006, and a slight increase in the annual NDVI was found with the changing rate of only 9.0×10^{-4} per decade. As the NDVI values were much higher in the rainy season than that in the dry season, the variations of the NDVI in the rainy season during 1982-2006 were also shown in Fig. 10b, and a significant decreasing trend was found with the changing rate of -0.01 per decade ($p<0.05$). However, no abrupt change could be found in the series of the annual NDVI or the NDVI in the rainy season using Pettitt change point test. Moreover, at the monthly scale, the NDVI decreased from June to October, among which only the decreasing trend in October was significant ($p<0.05$); in contrast, the NDVI increased or had no trend in the other months, among which only the increasing trend in April was significant ($p<0.01$). Therefore, it is inferred that the decrease in the NDVI mainly occurred in the rainy season. With reference to spatial distributions (Table 9), most of the significant changing rates were found in stations located in the southern part of Yunnan Province because the forests in this region have been degraded rapidly during the last several decades (Li *et al.*, 2008). The lowest mean value of the annual NDVI (i.e., 0.2203) and the highest decreasing trend (i.e., -0.041 per decade, $p<0.01$) were found at Kunming station (Table 9). Kunming, the largest city in Yunnan Province, has been experiencing rapid urbanization in the past decades (e.g., Yi *et al.*, 2001); therefore, the remarkable change in the NDVI could reflect the impacts of the LUCC (e.g., urbanization) to some extent. By contrast, the quite low mean value of the annual NDVI at Deqing station (i.e., 0.2268) might be caused by its location with high altitude and cold climate (Fig. 1).

Furthermore, the relationships of the NDVI with temperature and precipitation in Yunnan Province were analyzed at different spatial and temporal scales using the Kendall's tau CC. First, on the provincial mean level, the relationships were shown as follows. At the annual scale, positive correlation (CC=0.20, p>0.1) was detected between the NDVI and temperature while the correlation between the NDVI and precipitation was weak. At the seasonal scale, negative correlation (CC=-0.22, p>0.1) between the NDVI and temperature and positive correlation (CC=0.05, p>0.1) between the NDVI and precipitation were detected in the rainy season. At the monthly scale, the correlations of the NDVI with temperature (CC=-0.059, p>0.1) and precipitation (CC=0.002, p>0.1) were both weak. Overall, the relationships of the NDVI with temperature and precipitation were not significant on the provincial mean level, among which the correlations at the seasonal scale were relatively stronger. Therefore, the relationships of the NDVI with temperature and precipitation in the rainy season were further analyzed on the station level, and the relevant results were shown in Fig. 11. Compared to precipitation, temperature had the stronger correlation with the NDVI. The CC values between the NDVI and temperature varied from -0.409 (p<0.01) to 0.312 (p<0.05), and the correlations in 5 stations (i.e., Kunming, Simao, Jionghong, Baoshan and Tengchong) were statistically significant. It is worth noting that all the 5 stations had the remarkable changing rates of the NDVI as shown in Table 9, which might indicate the impacts of the LUCC on regional climate (e.g., temperature). For example, significant increasing trends in temperature and decreasing trends in the NDVI were detected at Kunming and Simao stations, where the surrounding areas have been experiencing rapid urbanization in recent decades (Li *et al.*, 2008; Bai, 2015). Since local urbanization was proved to have remarkable effects on regional climate change (e.g., Chen *et al.*, 2011; Grawe *et al.*, 2013; Doan and Kusaka, 2016), such close correlations between temperature and the NDVI at these two stations might be associated with their developments of urbanization. In contrast, the CC values between the NDVI and precipitation varied from -0.245 (p>0.1) to 0.221 (p>0.1), and none of the correlations was statistically significant (Fig. 11). It indicated that, besides the LUCC represented by the NVDI change in this study, other factors might have important impacts on precipitation in this region.

In order to separately investigate the urbanization effects on climate change in Yunnan Province, this study employed the 30-m-resolution global artificial terrestrial surface dataset in 2010 (GlobeLand30_ATS2010) (Chen *et al.*, 2014), and Fig. 12 shows the artificial terrestrial surface (i.e., red pixels) in Yunnan Province. As reported by Zhao *et al.* (2013), the total area of the built-up land in Yunnan Province had been changing significantly with an increasing rate of 6% during 1985-2008. In particular, Luo *et al.* (2014) pointed out that the total area of the built-up land had increased continuously since the early 2000s (e.g., from 9300 km^2 in 2002 to 9964 km^2 in 2007), which was closely related to the rigid demands resulting from population growth, economic development, urbanization, industrialization, and infrastructure construction. It is observed in Fig. 12 that the red pixels which denote the built-up land are mainly distributed around Kunming, Dali, Mengzi, Baoshan, and Zhanyi stations in 2010. Comparing with the changing rates of the annual temperature at all the stations during 1987-2011 (Table 3), Kunming station had the highest changing rate of 0.61 ºC/decade (p<0.01), much higher than those at other stations; and the changing rates of the annual temperature at Mengzi (i.e., 0.45 ºC/decade) and Dali (i.e., 0.44 ºC/decade) stations were also quite high. In addition, comparing with the changing rates of the annual precipitation at all the stations (Table 6), it is inferred that the statistically significant changes at Zhanyi and Kunming stations might be caused by the increasing area of the built-up land.

4. Conclusions

This study contributed to better understand the characteristics of climate change (including temporal trend and spatial distribution of temperature and precipitation) in Yunnan Province during 1961-2011 based on the observed data recorded at 22 meteorological stations, and its relationship with the LUCC was also discussed. The main conclusions of this study can be summarized as follows.

First, significant increasing trend in temperature was observed at the annual scale during 1961-2011, especially for the period 1987-2011. At the seasonal scale, such trend was the most prominent in winter. The warming trend could also be confirmed by the temperature extremes.

Second, the annual precipitation in Yunnan Province showed a non-significant decreasing trend during 1961-2011, which was dominant by the rainy season. Moreover, the changing rates of the annual precipitation showed the east-to-west increasing trend over this region.

Third, this study analyzed the impacts of elevation and geographical location on climate change patterns. These factors might have great influences in determining the sources of moisture, which are closely related to the distances between the designated location and the oceans. Moreover, statistical equations to estimate the annual temperature and precipitation as well as their changing rates were established based on longitude, latitude and elevation.

Fourth, through analyzing the relationship between climate change and the LUCC in Yunnan Province, it is concluded that temperature had the stronger correlation with the NDVI than precipitation. Moreover, the close relationships of the built-up land with the annual temperature and precipitation changes in some stations might be associated with their developments of urbanization.

The conclusions in this study would be valuable in the fields of integrated water resources management, eco-environment assessment and climate change. Nevertheless, we also need fully aware the following limitations, which are mainly related to three aspects. First, several studies (e.g., Runnalls and Oke, 2006; Fujibe, 2011) pointed out that the surroundings around meteorological stations may affect the accuracy of the observed meteorological data, and whether any stations have been moved during the study period is another important issue. Therefore, remote sensing data could be considered as an effective supplement, which could be combined with the station data to address this problem in future (Shi *et al.*, 2017a). Second, the spatial resolution of the NDVI data (i.e., 8 km) used in this study was relatively coarse, which might cause uncertainties when analyzing the relationship between climate change and the LUCC. Third, this study preliminarily analyzed the possible impacts of urbanization in the study area, and other methods could be adopted to further investigate the urbanization effects in future.

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References

Aguilar E, Aziz Barry A, Brunet M, Ekang L, Fernandes A, Massoukina M, Mbah J, Mhanda A, do Nascimento D, Peterson TC, Thamba Umba O, Tomou M, Zhang X. 2009. Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955-2006. *Journal of Geophysical Research: Atmospheres* **114**: D02115, doi: 10.1029/2008JD011010.

Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank A.MG, Haylock M., Collins D, Trewin B, Rahimzadeh F., Tagipour A, Rupa Kumar K, Revadekar J, Griffiths G, Vincent L, Stephenson DB, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre JL. 2006. Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research: Atmospheres* **111**: D05109, doi: 10.1029/2005JD006290.

Almeida CT, Oliveira JF, Delgado RC, Cubo P, Ramos MC. 2017. Spatiotemporal rainfall and temperature trends throughout the Brazilian Legal Amazon, 1973-2013. *International Journal of Climatology* **37**(4): 2013-2026.

Bai Y. 2015. Analyses of the influences of unbanization on the changes in rainfall – flood regime, in central downtown of Simao city. *Pearl River* **36**(5): 58-61. [in Chinese]

Bonan GB. 2008. Forests and climate change: forcings, feedbacks, and the climatebenefits of forests. *Science* **320**: 1444-1449.

Cao J, Hu J, Tao Y. 2012. An index for the interface between the Indian summer monsoon and the East Asian summer monsoon. *Journal of Geophysical Research: Atmospheres* **117**: D18108, doi:

10.1029/2012JD017841.

Cao LG, Pan SM. 2014. Changes in precipitation extremes over the Three-River Headwaters region, hinterland of the Tibetan Plateau, during1960-2012. *Quaternary International* **321**: 105-115.

Cao Q, Yu DY, Georgescu M, Han Z, Wu JG. 2015. Impacts of land use and land cover change on regional climate: a case study in the agro-pastoral transitional zone of China. *Environmental Research Letters* **10**(12): 124025.

Chen FL, Chen HM, Yang YY. 2015. Annual and seasonal changes in means and extreme events of precipitation and their connection to elevation over Yunnan Province, China. *Quaternary International* **374**: 46-61.

Chen J, Liao AP, Chen LJ, et al. 2014. GlobeLand30_ATS2010. *Global Chane Research Data Publishing & Repository* doi: 10.3974/geodb.2014.02.02.V1.

Chen J, Li Q, Niu J, Sun L. 2011. Regional climate change and local urbanization effects on weather variables in southeast China. *Stochastic Environmental Research and Risk Assessment* **25**(4): 555-565.

Chen J, Shi HY, Sivakumar B, Peart MR. 2016. Population, water, food, energy and dams. *Renewable & Sustainable Energy Reviews* **56**: 18-28.

Cheng JG, Xie ME. 2008. The analysis of regional climate change features over Yunnan in recent 50 years. *Progress in Geography* **27**: 19-26. [in Chinese]

China Meteorological Administration. 2016. *Daily meteorological observation data sets of China*. http://data.cma.gov.cn/data/detail/dataCode/SURF CLI CHN MUL DAY V3.0.html.

Cinar İ. 2015. Assessing the correlation between land cover conversion and temporal climate change -

A pilot study in coastal Mediterranean city, Fethiye, Turkey. *Atmosphere* **6**(8): 1102-1118.

Colucci RR, Guglielmin, M. 2015. Precipitation-temperature changes and evolution of a small glacier in the southeastern European Alps during the last 90 years. *International Journal of Climatology* **35**(10): 2783-2797.

Dale VH. 1997. The relationship between land-use change and climate change. *Ecological Applications* **7**(3): 753-769.

Ding Y, Ren G, Shi G, Gong P, Zheng X, Zhai P, Zhang D, Zhao Z, Wang S, Wang H, Luo Y, Chen D, Gao X, Dai X. 2006. National assessment report of climate change (I): Climate change in China and its future trend. *Advances in Climate Change Research* **2**(1): 3-8. [in Chinese]

Duan K, Yao T. 2003. Monsoon variability in the Himalayas under the condition of global warming. *Journal of the Meteorological Society of Japan* **81**(2): 251-257.

Doan QV, Kusaka H. 2016. Numerical study on regional climate change due to the rapid urbanization of greater Ho Chi Minh City's metropolitan area over the past 20 years. *International Journal of Climatology* **36**(10): 3633-3650.

Easterling DR, Horton B, Jones PD, Peterson TC, Karl TR, Parker DE, Salinger MJ, Razuvayev V, Plummer N, Jamason P. 1997. Maximum and minimum temperature trends for the globe. *Science* **277**(5324): 364-367.

Easterling DR, Meehl GA, Parmesan C, Changnon SA, Karl TR, Mearns LO. 2000. Climate extremes: Observations, modeling, and impacts. *Science* **289**(5487): 2068-2074.

Fan H, Hu J, He D. 2013. Trends in precipitation over the low latitude highlands of Yunnan, China. *Journal of Geographical Sciences* **23**(6): 1107-1122.

Fan Z, Bräuning A, Thomas A, Li JB, Cao KF. 2011. Spatial and temporal temperature trends on the Yunnan Plateau (Southwest China) during 1961-2004. *International Journal of Climatology* **31**(14): 2078-2090.

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK. 2005. Global consequences of land use. *Science* **309**: 570-574.

Fujibe F. 2011. Urban warming in Japanese cities and its relation to climate change monitoring. *International Journal of Climatology* **31**(2): 162-173.

Gibbard S, Caldeira K, Bala G, Phillips TJ, Wickett M. 2005; Climate effects of global land cover change. *Geophysical Research Letters* **32**: 705-714.

Grawe D, Thompson HL, Salmond JA, Cai XM, Schlunzen KH. 2013. Modelling the impact of urbanisation on regional climate in the Greater London Area. *International Journal of Climatology* **33**(10): 2388-2401.

Goovaerts P. 2000. Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall. *Journal of Hydrology* **228**: 113-129.

Groisman PY, Knight RW, Easterling DR, Karl TR, Hegerl GC, Razuvaev VN. 2005. Trends in intense precipitation in the climate record. *Journal of Climate* **18**:1326-1350.

Guerschman JP, Paruelo JM, Burke IC. 2003. Land use impacts on the normalized difference vegetation index in temperate Argentina. *Ecological Applications* **13**(3): 616-628.

Hartmann DL, Klein Tank AMG, Rusticucci M, Alexander LV, Brönnimann S, Charabi Y, Dentener FJ, Dlugokencky EJ, Easterling DR, Kaplan A, Soden BJ, Thorne PW, Wild M, Zhai PM. 2013.

Observations: Atmosphere and Surface. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker TF, et al., (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Hereher ME. 2017. Effect of land use/cover change on land surface temperatures - The Nile Delta, Egypt. *Journal of African Earth Sciences* **126**: 75-83.

Huang ZY. 2011. Changes of Dry-wet Climate in the Dry Season in Yunnan (1961–2007). *Advances in Climate Change Research* **2**(1): 49-54.

Immerzeel WW, Bierkens MFP. 2010. Seasonal prediction of monsoon rainfall in three Asian river basins: the importance of snow cover on the Tibetan Plateau. *International Journal of Climatology* **30**: 1835-1842.

Intergovernmental Panel on Climate Change (IPCC). 2013. Summary for policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker TF, et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jung M, Chang E. 2015. NDVI-based land-cover change detection using harmonic analysis. *International Journal of Remote Sensing* **36**(4): 1097-1113.

Karl TR, Nicholls N, Ghazi A. 1999. CLIVAR/GCOS/WMO workshop on indices and indicators for climate extremes: Workshop summary. *Climatic Change* **42**: 3-7.

Kendall MG. 1975. *Rank Correlation Measures*. London: Charles Griffin.

Klein Tank AMG, Können GP. 2003. Trends in indices of daily temperature and precipitation extremes in Europe, 1946-99. *Journal of Climate* **16**(22): 3665-3680.

Klein Tank AMG, Peterson TC, Quadir DA, Dorji S, Zou X, Tang H, Santhosh K, Joshi UR, Jaswal AK, Kolli RK, Sikder AB, Deshpande NR, Revadekar JV, Yeleuova K, Vandasheva S, Faleyeva M, Gomboluudev P, Budhathoki KP, Hussain A, Afzaal M, Chandrapala L, Anvar H, Amanmurad D, Asanova VS, Jones PD, New MG, Spektorman T. 2006. Changes in daily temperature and precipitation extremes in central and south Asia. *Journal of Geophysical Research: Atmospheres* **111**: D16105, doi: 10.1029/2005JD006316.

Kumar K, Rajagopalan B, Cane MA. 1999. On the weakening relationship between the Indian monsoon and ENSO. *Science* **284**: 2156-2159.

Lai HH. 2002. China's western development program: its rationale, implementa-tion, and prospects. *Modern China* **28**: 432-466.

Li H, Ma Y, Aide TM, Liu W. 2008. Past, present and future land-use in Xishuangbanna, China and the implications for carbon dynamics. *Forest Ecology and Management* **255**(1): 16-24.

Li S, Birk S, Xue L, Ren HD, Chang J, Yao XH. 2016. Seasonal changes in the soil moisture distribution around bare rock outcrops within a karst rocky desertification area (Fuyuan County, Yunnan Province, China). *Environmental Earth Sciences* **75**: 1482.

Li YG, He DM, Hu JM, Cao J. 2015. Variability of extreme precipitation over Yunnan Province, China 1960-2012. *International Journal of Climatology* **35**(2): 245-258.

Li Z, He Y, Wang P, Theakstone WH, An W, Wang X, Lu A, Zhang W, Cao W. 2012. Changes of daily climate extremes in southwestern China during 1961–2008. *Global and Planetary Change* **80**: 255-272.

Liu B, Xu M, Henderson M, Qi Y. 2005. Observed trends of precipitation amount, frequency, and intensity in China, 1960-2000. *Journal of Geophysical Research: Atmospheres* **110**: D08103, doi: 10.1029/2004JD004864.

Liu Q, Yang ZF, Cui BS. 2008. Spatial and temporal variability of annual precipitation during 1961-2006 in Yellow River Basin, China. *Journal of Hydrology* **361**: 330-338.

Liu X, Yin ZY, Shao X, Qin N. 2006. Temporal trends and variability of daily maximum and minimum, extreme temperature events, and growing season length over the eastern and central Tibetan Plateau during 1961–2003. *Journal of Geophysical Research: Atmospheres* **111**: D19109, doi:10.1029/2005JD006915.

Lu JM, Ju JH, Ren JZ, Gan WW. 2012. The influence of the Madden-Julian Oscillation activity anomalies on Yunnan's extreme drought of 2009-2010. *Science China - Earth Sciences* **55**(1): 98-112.

Luo J, Zhan JY, Lin YZ, Zhao CH. 2014. An equilibrium analysis of the land use structure in the Yunnan Province, China. *Frontiers of Earth Science* doi: 10.1007/s11707-013-0425-z.

Mann HB. 1945. Non-parametric tests against trend. *Econometrica* **13**: 245-259.

Mito Y, Ismail MAM, Yamamoto T. 2011. Multidimensional scaling and inverse distance weighting transform for image processing of hydrogeological structure in rock mass. *Journal of Hydrology* **411**(1-2): 25-36.

Peterson TC, Taylor MA, Demeritte R, Duncombe DL, Burton S, Thompson F, Porter A, Mercedes M, Villegas E, Semexant Fils R, Klein Tank A, Martis A, Warner R, Joyette A, Mills W, Alexander L, Gleason B. 2002. Recent changes in climate extremes in the Caribbean region. *Journal of*

Geophysical Research: Atmospheres **107**: 4601, doi: 10.1029/2002JD002251.

Pettitt AN. 1979. A non-parametric approach to the change-point problem. *Applied Statistics* **28**(2): 126-135.

Runnalls K, Oke TR. 2006. A technique to detect microclimatic inhomogeneities in historical records of screen-level air temperature. *Journal of Climate* **19**(6): 959-978.

Running SW, Nemani RR, Hungerford RD. 1987. Extrapolation of synoptic meteorological data in mountainous terrain and its use for simulating forest evapotranspiration and photosynthesis. *Canadian Journal of Forest Research* **17**: 472-483.

Sahebjalal E, Dashtekian K. 2013. Analysis of land use-land covers changes using normalized difference vegetation index (NDVI) differencing and classification methods. *African Journal of Agricultural Research* **8**(37): 4614-4622.

Sen PK. 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association* **63**: 1379-1389.

Shi HY, Chen J, Wang KY, Niu J. 2018. A new method and a new index for identifying socioeconomic drought events under climate change: A case study of the East River basin in China. *Science of The Total Environment* **616-617**: 363-375.

Shi HY, Fu XD, Chen J, Wang GQ, Li TJ. 2014. Spatial distribution of monthly potential evaporation over mountainous regions: case of the Lhasa River basin, China. *Hydrological Sciences Journal* **59**(10): 1856-1871.

Shi HY, Li TJ, Wei JH, Fu W, Wang GQ. 2016a. Spatial and temporal characteristics of precipitation over theThree-River Headwaters region during 1961-2014. *Journal of Hydrology: Regional*

Studies **6**: 52-65.

Shi HY, Li TJ, Wang K, Zhang A, Wang GQ, Fu XD. 2016b. Physically based simulation of the streamflow decrease caused by sediment-trapping dams in the middle Yellow River. *Hydrological Processes* **30**(5): 783-794.

Shi HY, Li TJ, Wei JH. 2017a. Evaluation of the gridded CRU TS precipitation dataset with the point raingauge records over the Three-River Headwaters region. *Journal of Hydrology* **548**: 322-332.

Shi HY, Li TJ, Wang GQ. 2017b. Temporal and spatial variations of potential evaporation and the driving mechanism over Tibet during 1961-2001. *Hydrological Sciences Journal* **62**(9), 1469-1482.

Shi HY, Wang GQ. 2015. Impacts of climate change and hydraulic structures on runoff and sediment discharge in the middle Yellow River. *Hydrological Processes* **29**(14): 3236-3246.

Shrestha AB, Wake CP, Mayewski PA, Dibb JE. 1999. Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971–94. *Journal of Climate* **12**(9): 2775-2786.

Tanaka T, Sato T, Watanabe K, Wang Y, Yang D, Inoue H, Li KZ, Inamura T. 2013. Irrigation system and land use effect on surface water quality in river, at lake Dianchi, Yunnan, China. *Journal of Environmental Sciences* **25**(6): 1107-1116.

Thornton PE, Running SW, White MA. 1997. Generating surfaces of daily meteorological variables over large regions of complex terrain. *Journal of Hydrology* **190**(3-4): 214-251.

Tucker CJ, Pinzon JE, Brown ME. 2004. *Global Inventory Modeling and Mapping Studies, NA94apr15b.n11-VIg, 2.0*. Global Land Cover Facility, University of Maryland, College Park, Maryland.

Tucker CJ, Pinzon JE, Brown ME, Slayback D, Pak EW, Mahoney R, Vermote E, El Saleous N. 2005. An extended AVHRR 8-km NDVI data set compatible with MODIS and SPOT vegetation NDVI data. *International Journal of Remote Sensing* **26**(20): 4485-4498.

Vose RS, Easterling DR, Gleason B. 2005. Maximum and minimum temperature trends for the globe: an update through 2004. *Geophysical Research Letters* **32**: L23822, doi:10.1029/2005GL024379.

Wang SJ, Zhang MJ, Sun MP, Wang BL, Li XF. 2013. Recent changes in daily extremes of temperature and precipitation over the western Tibetan Plateau, 1973-2011. *Quaternary International* **313-314**: 110-117.

Wang Y, Zhou L. 2005. Observed trends in extreme precipitation events in China during 1961–2001 and the associated changes in large-scale circulation. *Geophysical Research Letters* **32**: L09707, doi:10.1029/2005GL022574.

Weier J, Herring D. 2000. *Measuring Vegetation (NDVI & EVI)*. http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php

Westra S, Alexander LV, Zwiers FW. 2013. Global increasing trends in annual maximum daily precipitation. *Journal of Climate* **26**(11): 3904-3918.

Weyerhaeuser H, Wilkes A, Kahrl F. 2005. Local impacts and responses to regional forest conservation and rehabilitation programs in China's northwest Yunnan province. *Agricultural Systems* **85**: 234-253.

Wu G, Gao Y, Wang Y, Wang YY, Xu D. 2015. Land-use/land cover changes and their driving forces around wetlands in Shangri-La County, Yunnan Province, China. *International Journal of*

Sustainable Development & World Ecology, **22**(2): 110-116.

Xu J, Yin R, Li Z, Liu C. 2006. China's ecological rehabilitation: unprecedentedefforts, dramatic impacts, and requisite policies. *Ecological Economics* **57**: 595-607.

Xu LL, Li BL, Yuan YC, Gao XZ, Zhang T, Sun QL. 2016. Detecting different types of directional land cover changes using MODIS NDVI time series dataset. *Remote Sensing* **8**(6): 495.

Yang J, Tan C, Zhang T. 2013. Spatial and temporal variations in air temperature and precipitation in the Chinese Himalayas during the 1971–2007. *International Journal of Climatology* **33**(12): 2622-2632.

Yang S, Lau KM, Yoo SH, Kinter JL, Miyakoda K, Ho CH. 2004. Upstream subtropical signals preceding the Asian summer monsoon circulation. *Journal of Climate* **17**: 4213-4229.

Yang Z-Y, Yang S-Y, Yan H-S, Zhang J-W, Gu S-H. 2015. Impact of SSTA of Southern Hemisphere on flood season precipitation anomalies in Yunnan. *Journal of Tropical Meteorology* **21**(3): 255-264.

Yi Q, Zhao X, Tan S, He S. 2001. On urbanization characteristics and development tactics in Kunming metropolitan economic zone. *China Population, Resources and Environment* **11**(52): 82-84. [in Chinese]

You Q, Kang S, Aguilar E, Pepin N, Flügel WA, Yan Y, Xu Y, Zhang Y, Huang J. 2011. Changes in daily climate extremes in China and their connection to the large scale atmospheric circulation during 1961-2003. *Climate Dynamics* **36**(11-12): 2399-2417.

You WH, Duan X, Deng ZW, Wu CB. 1998. The multihierarchical structure and the jumpfeatures of climate changes for the globe, China and Yunnan during the last one hundred years. *Journal of*

Tropical Meteorology **14**(2): 173-180. [in Chinese]

Yu R, Wang B, Zhou T. 2004. Tropospheric cooling and summer monsoon weakening trend over East Asia. *Geophysical Research Letters* **31**: L22212, doi:10.1029/2004GL021270.

Zhai P, Zhang XB, Wan H, Pan XH. 2005. Trends in total precipitation and frequency of daily precipitation extremes over China. *Journal of Climate* **18**: 1096-1108.

Zhang JL, Pham T-T-H, Kalacska M, Turner S. 2014a. Using Landsat Thematic Mapper records to map land cover change and the impacts of reforestation programmes in the borderlands of southeast Yunnan, China: 1990-2010. *International Journal of Applied Earth Observation and Geoinformation* **31**: 25-36.

Zhang KX, Pan SM, Cao LG, Wang Y, Zhao YF, Zhang W. 2014b. Spatial distribution and temporal trends in precipitation extremes over the Hengduan Mountains region, China, from 1961 to 2012. *Quaternary International* **349**: 346-356.

Zhang Q, Ma Y, Liu WJ, Li HM. 2007. Regional land use dynamics of plateau wetlands in the northwest of Yunnan Province, China. *Journal of Mountain Science* **25**: 265-273.

Zhang W, Zheng J, Ren J. 2013. Climate characteristics of extreme drought events in Yunnan. *Journal of Catastrophology* **28**(1): 59-64. [in Chinese]

Zhang X, Aguilar E, Sensoy S, Melkonyan H, Tagiyeva U, Ahmed N, Kutaladze N, Rahimzadeh F, Taghipour A, Hantosh TH, Albert P, Semawi M, et al. 2005. Trends in Middle East climate extreme indices from 1950 to 2003. *Journal of Geophysical Research: Atmospheres* **110**: D22104, doi: 10.1029/2005JD006181.

Zhao CH, Deng XZ, Yuan YW, Yan HM, Liang H. 2013. Prediction of Drought Risk Based on the

WRF Model in Yunnan Province of China. *Advances in Meteorology* **2013**: 295856.

Zhou BT, Xu Y, Wu J, Dong SY, Shi Y. 2016. Changes in temperature and precipitation extreme indices over China: analysis of a high-resolution grid dataset. *International Journal of Climatology* **36**(3): 1051-1066.

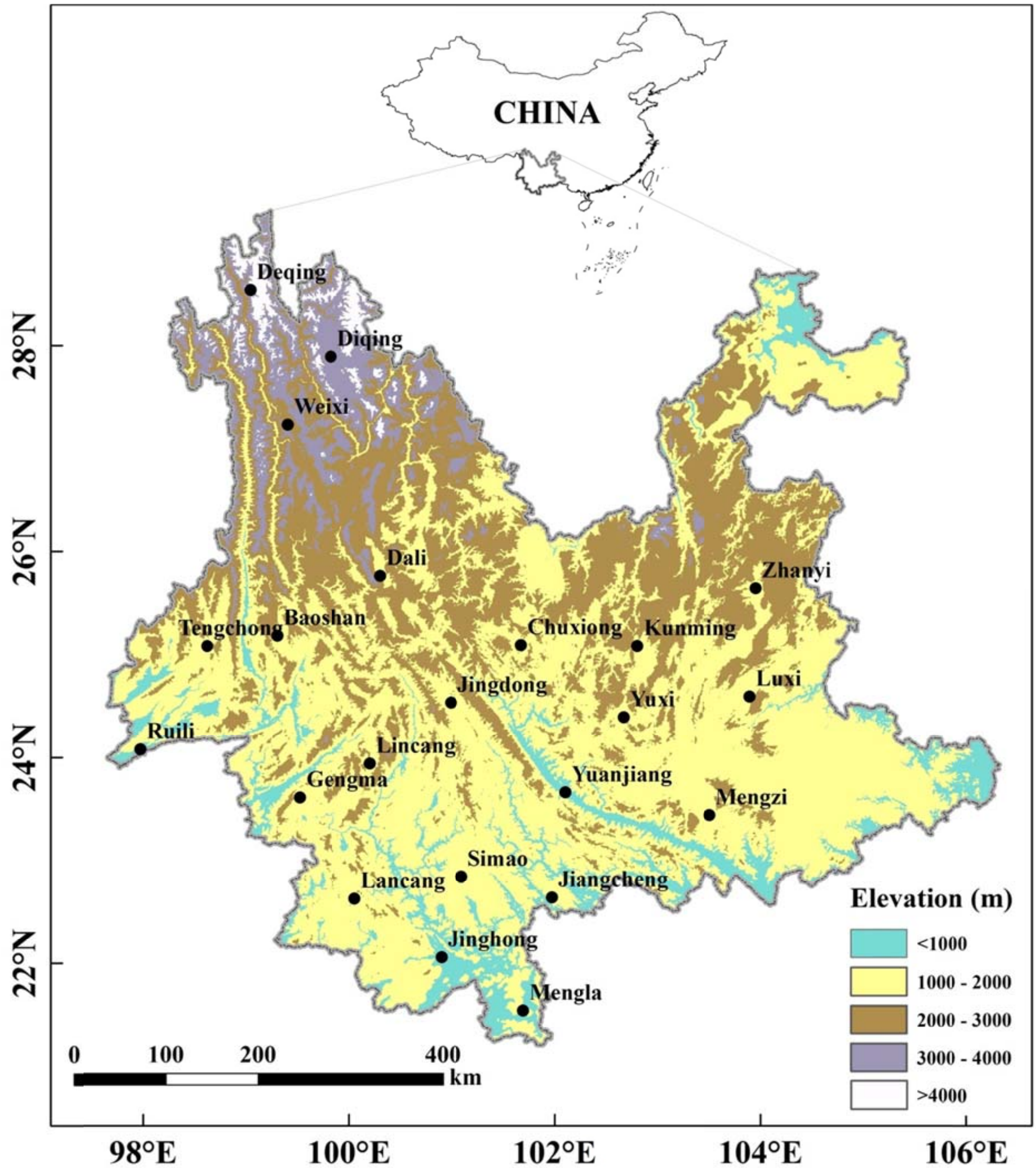

Fig. 1 Location of Yunnan Province and the 22 meteorological stations.

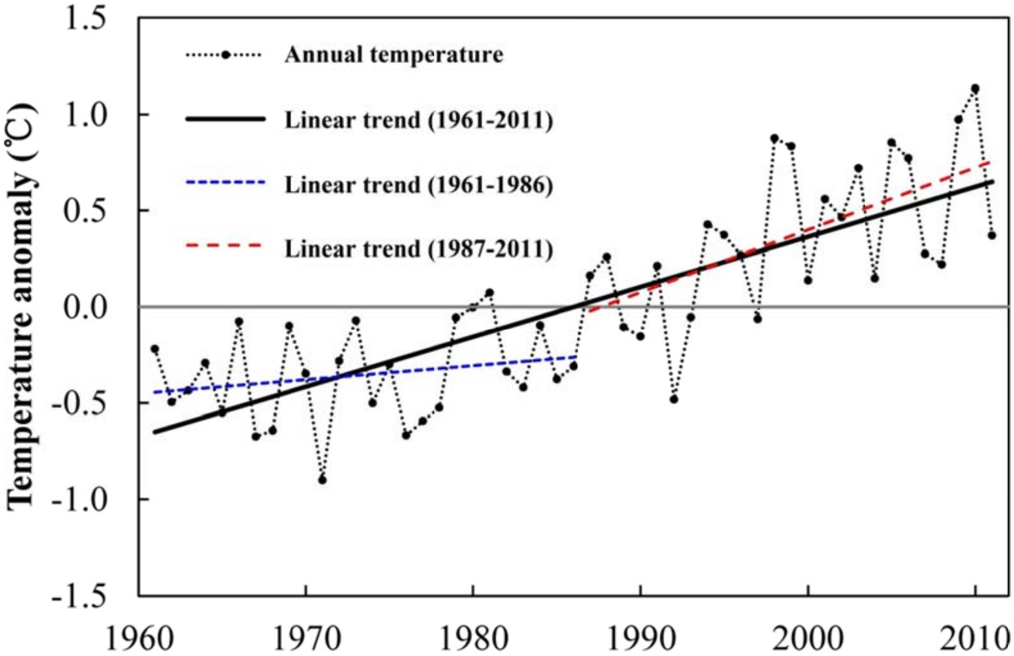

Fig. 2 Variations of the annual temperature in Yunnan Province during 1961-2011.

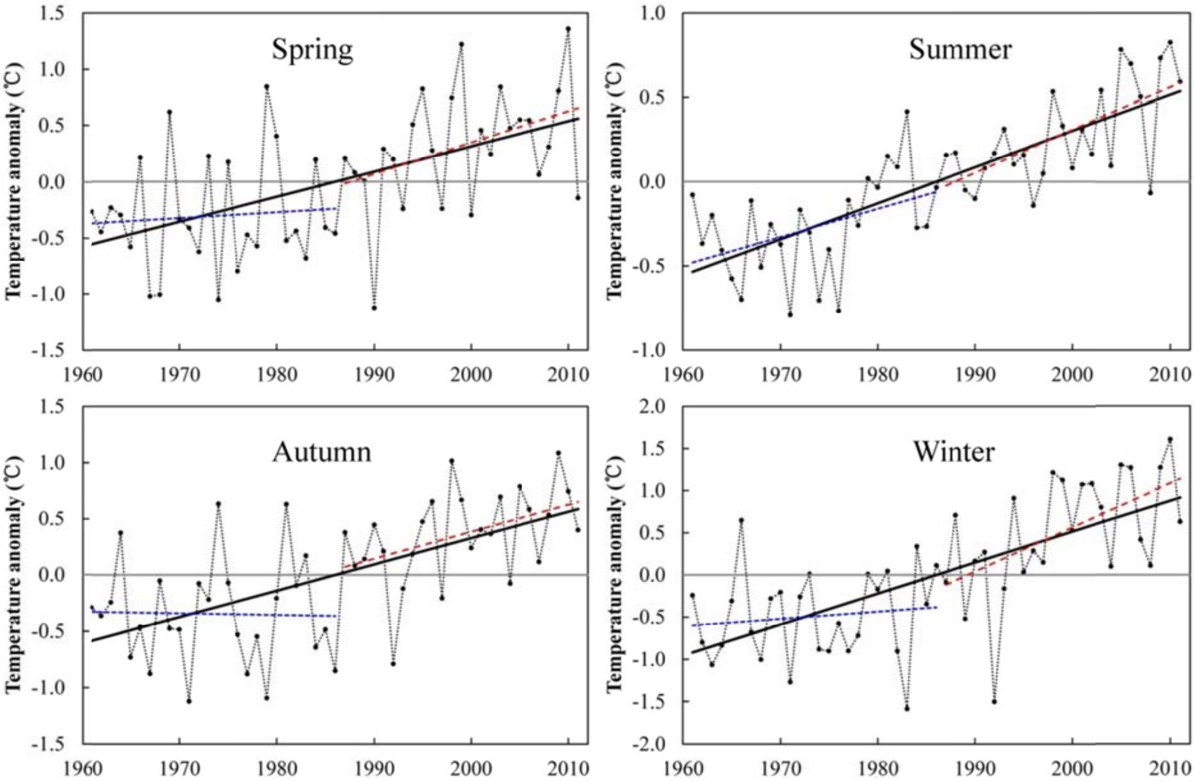

Fig. 3 Variations of the seasonal temperature in Yunnan Province during 1961-2011. Note: The black solid line, the blue dash line and the red dash line denote the linear trend during 1961-2011, 1961-1986 and 1987-2011, respectively.

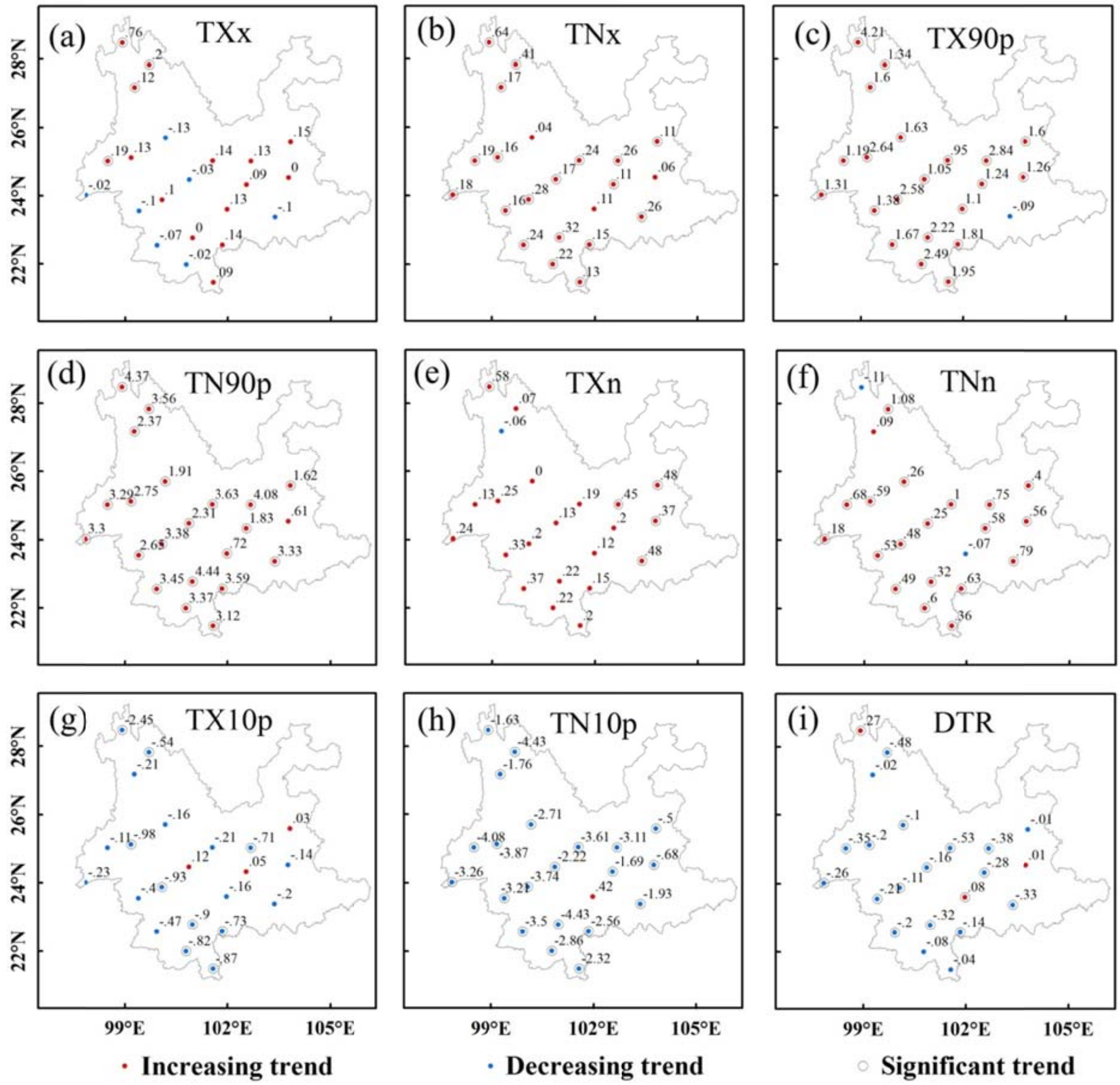

Fig. 4 Changing rates of temperature extremes in 22 stations during 1961-2011.

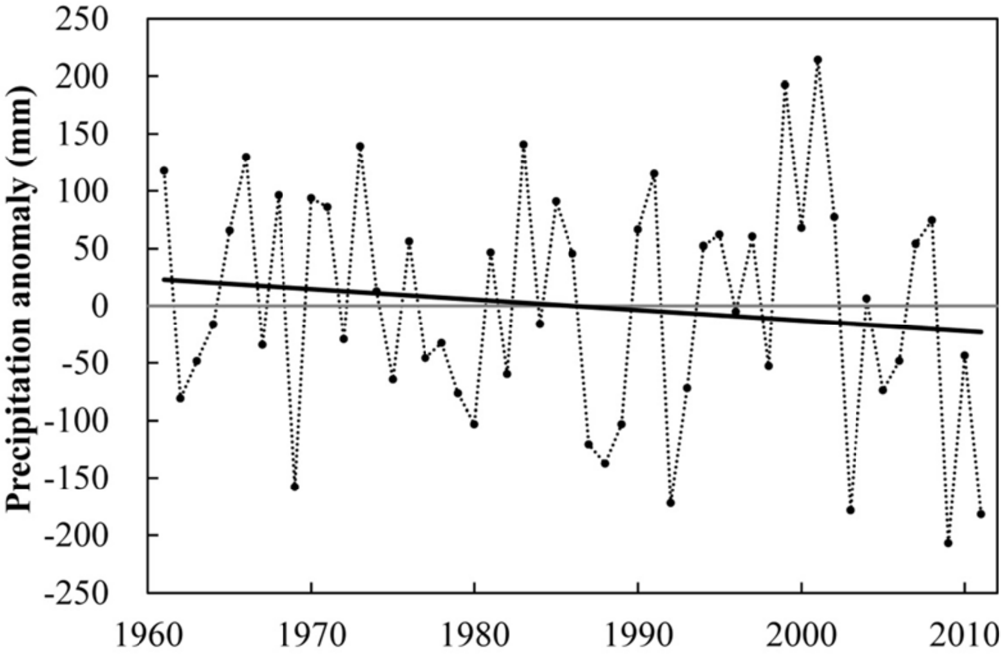

Fig. 5 Variations of the annual precipitation in Yunnan Province during 1961-2011. Note: The black solid line denotes the linear trend.

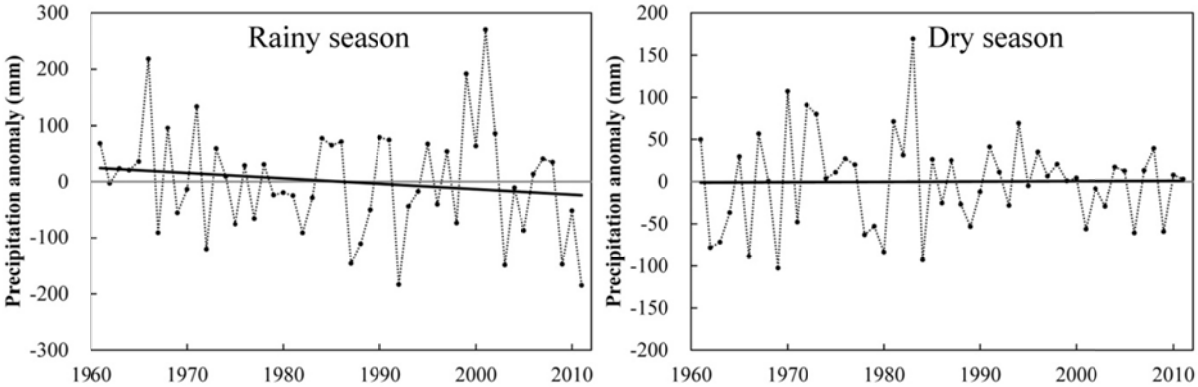

Fig. 6 Variations of the seasonal precipitation in Yunnan Province during 1961-2011. Note: The black solid line denotes the linear trend.

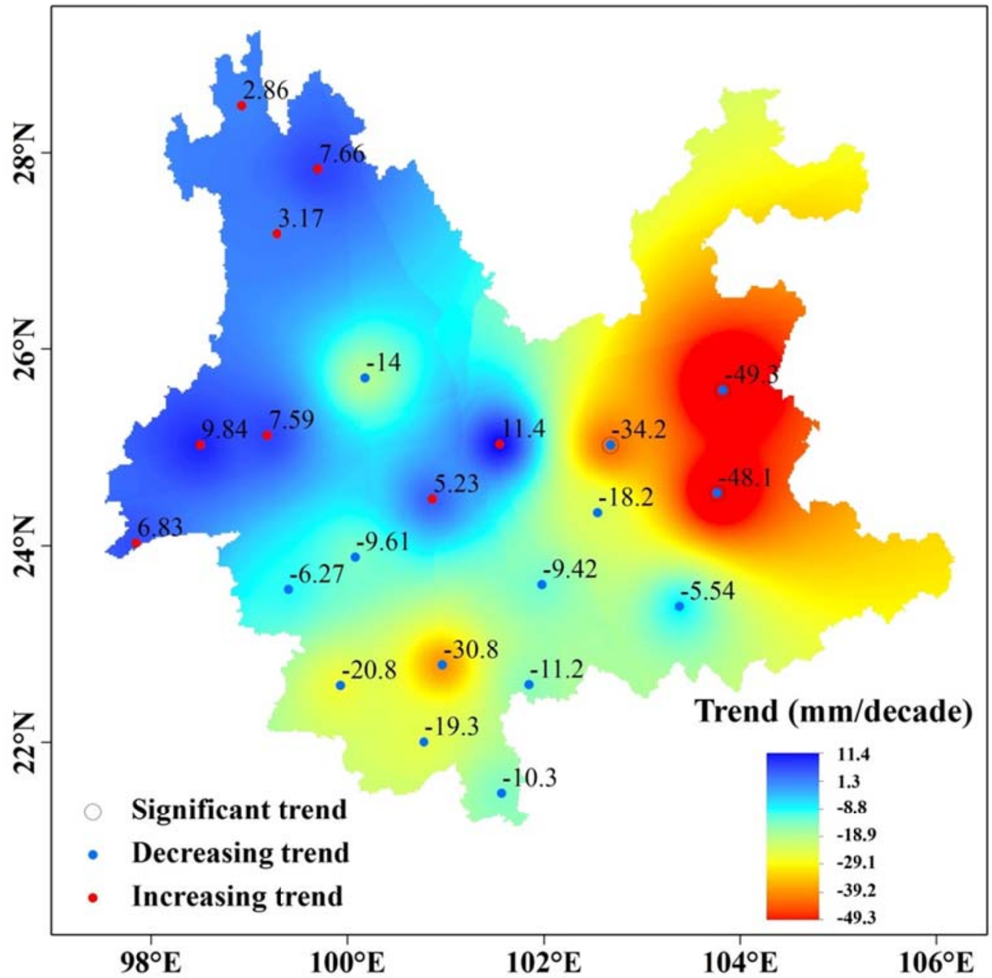

Fig. 7 Spatial distribution of the changing rates of the annual precipitation in Yunnan Province during 1961-2011.

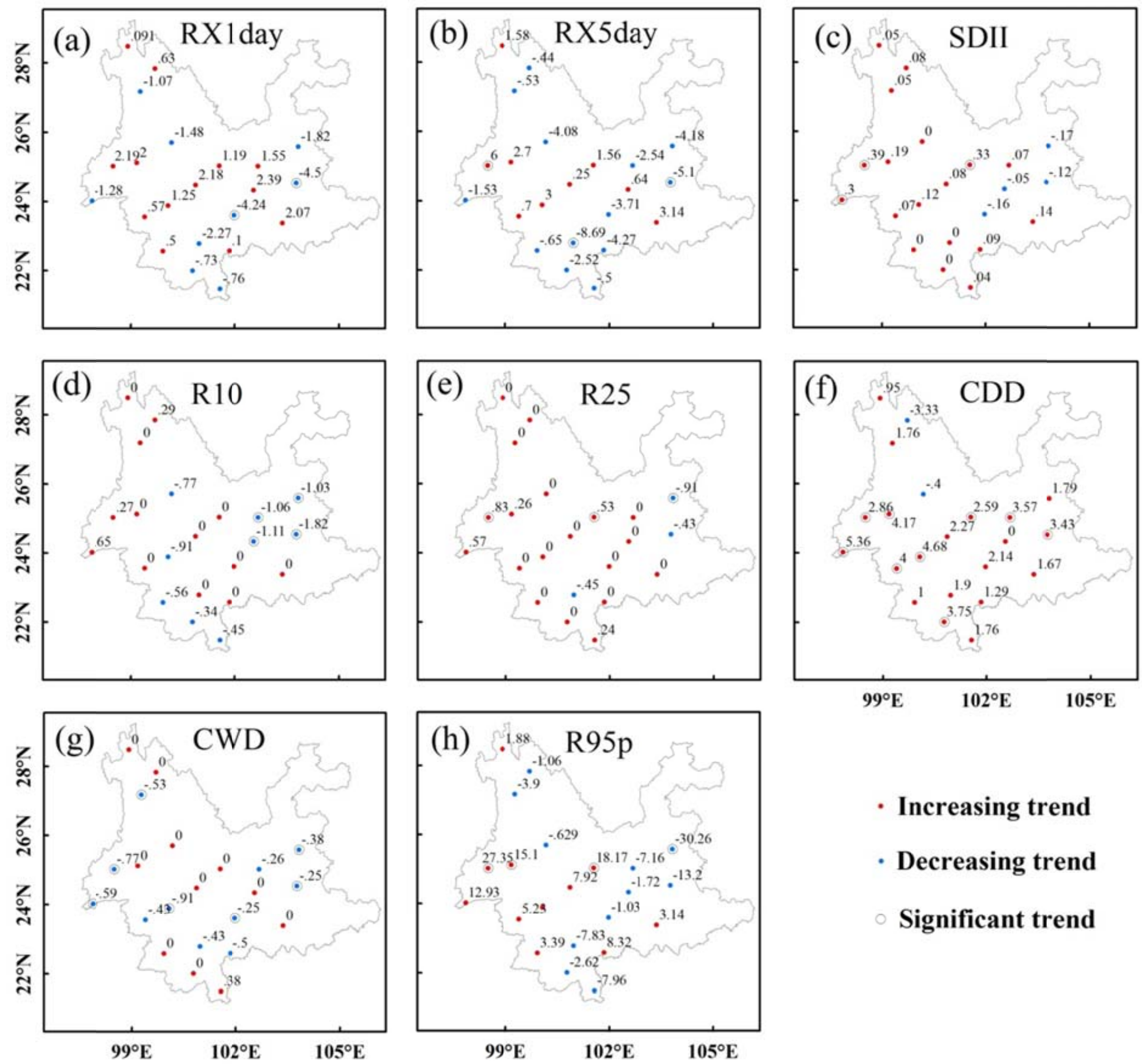

Fig. 8 Changing rates of precipitation extremes in 22 stations during 1961-2011.

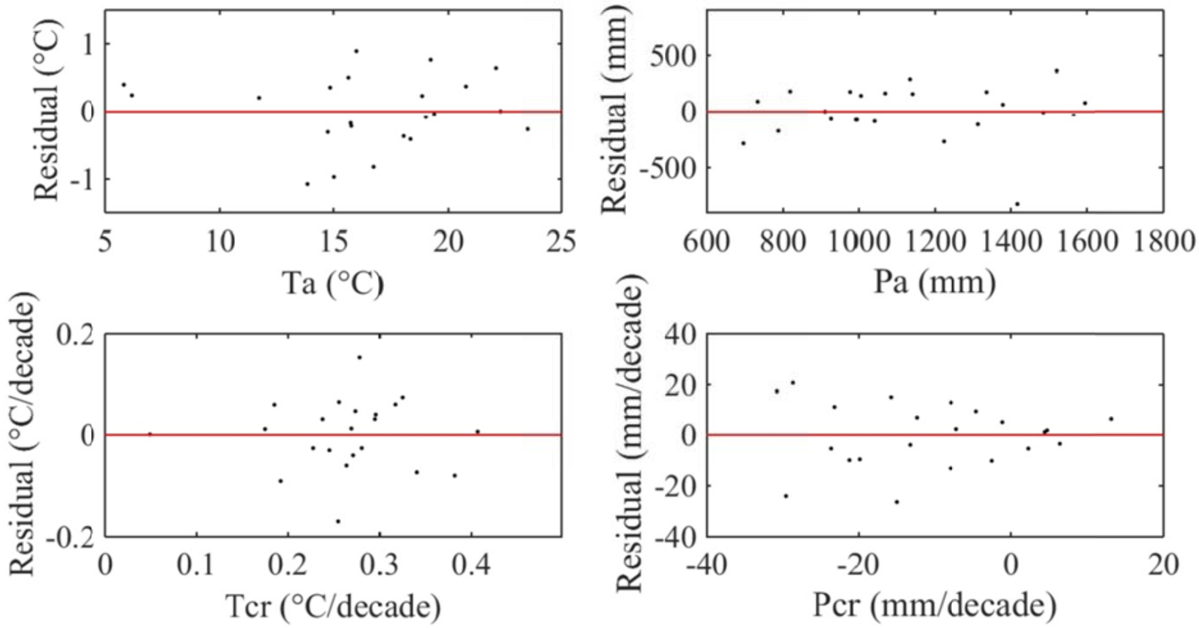

Fig. 9 Residual analysis of the regression equations, i.e., Eqs. (5-8).

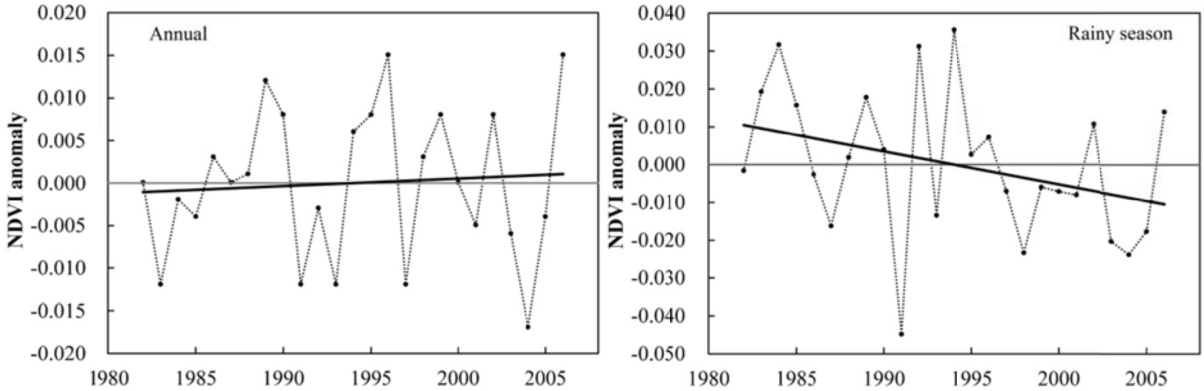

Fig. 10 Variations of the annual and seasonal NDVI in Yunnan Province during 1982-2006.

Note: The black solid line denotes the linear trend.

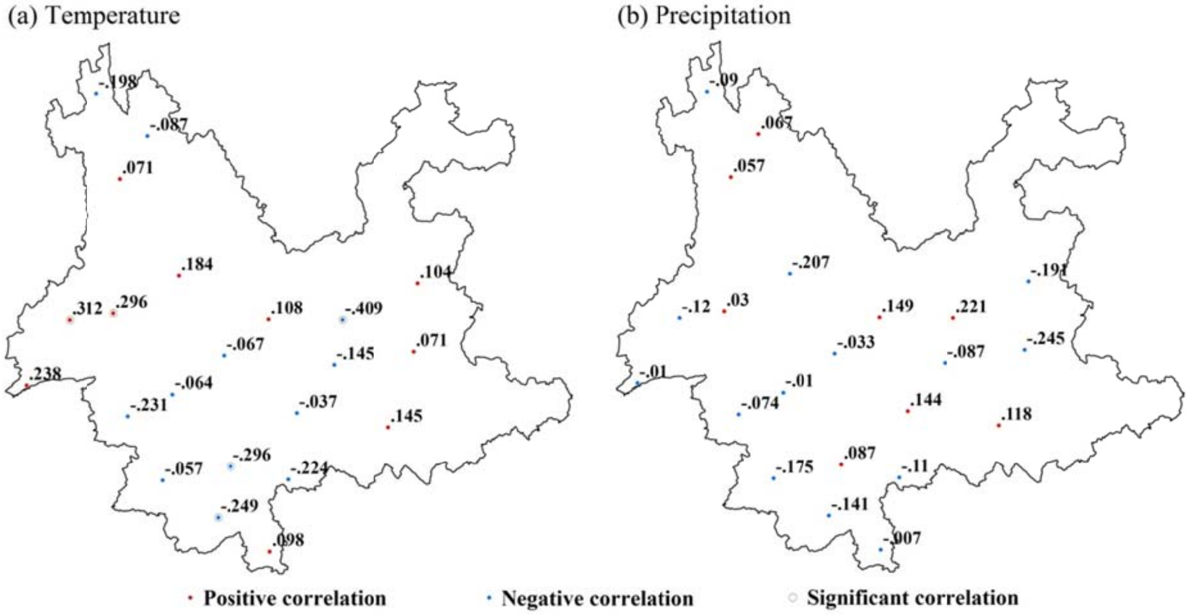

Fig. 11 Correlations of the NDVI with temperature and precipitation in the rainy season in 22 stations during 1982-2006.

Fig. 12 The artificial terrestrial surface (i.e., red pixels) in Yunnan Province in 2010.

Table 1. Definitions of the selected climate change indices

Index	Indicator	Definition	Unit
TXx	Max TX	Monthly maximum value of TX	ºC
TNx	Max TN	Monthly maximum value of TN	ºC
TX90p	Warm days	Percentage of days when TX>90th percentile	days
TN90p	Warm nights	Percentage of days when TN>90th percentile	days
TXn	Min TX	Monthly minimum value of TX	ºC
TNn	Min TN	Monthly minimum value of TN	ºC
TX10p	Cool days	Percentage of days when TX<10th percentile	days
TN10p	Cool nights	Percentage of days when TN<10th percentile	days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	ºC
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
RX5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple precipitation intensity index	RR on wet days divided by the number of wet days in a year	mm/day
R10	Number of heavy precipitation days	Annual count of days when prep>=10mm	days
R25	Number of very heavy precipitation days	Annual count of days when prep>=25mm	days
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	days
R95p	Very wet days	Annual prep when RR>95th percentile	mm

Note: TX is daily maximum temperature, TN is daily minimum temperature, and RR is daily precipitation amount.

Table 2. Changing rates (ºC/decade) of the annual and seasonal temperatures during different periods

Period	Annual	Spring	Summer	Autumn	Winter
1961-1986	0.08	0.01	0.16*	-0.06	0.14
1987-2011	0.31**	0.25*	0.27**	0.22*	0.47**
1961-2011	0.26**	0.22**	0.22**	0.24**	0.38**

Note: ** and * mean the trend at the significance level of p=0.01 and 0.05, respectively.

Table 3. Changing rates (ºC/decade) of the annual temperature at 22 meteorological stations during different periods

Station	1961-1986	1987-2011	1961-2011
Deqing	0.29**	0.53**	0.46**
Diqing	0.22**	0.54**	0.40**
Weixi	0.09	0.33*	0.19**
Tengchong	0.08	0.34**	0.26**
Baoshan	-0.02	0.35**	0.31**
Dali	-0.05	0.44**	0.13**
Chuxiong	0.11*	0.16	0.32**
Kunming	0.06	0.61**	0.43**
Zhanyi	0.00	0.28*	0.13**
Ruili	0.00	0.40**	0.28**
Jingdong	0.08	0.09	0.16**
Yuxi	-0.19*	0.30*	0.23**
Luxi	-0.08	0.08	0.05
Gengma	-0.20*	0.46**	0.26**
Lincang	0.09	0.36**	0.26**
Lancang	0.15*	0.31**	0.25**
Jinghong	0.32**	0.08	0.28**
Simao	0.24**	0.47**	0.41**
Yuanjiang	-0.01	0.09	0.05
Mengla	0.31**	0.23**	0.31**
Jiangcheng	0.08	0.36**	0.26**
Mengzi	0.04	0.45**	0.21**
Significant increasing trend	7 in 22	17 in 22	20 in 22

Note: ** and * mean the trend at the significance level of p=0.01 and 0.05, respectively.

Table 4. Changing rates (per decade) of the extreme indices during 1961-2011

Temperature indices	Changing rate / decade	Precipitation indices	Changing rate / decade
TXx (ºC)	0.09*	RX1day (mm)	0.17
TNx (ºC)	0.21**	RX5day (mm)	-0.47
TX90p (%)	1.79**	SDII (mm/day)	0.08*
TN90p (%)	2.93**	R10 (days)	-0.39
TXn (ºC)	0.24*	R25 (days)	0.05
TNn (ºC)	0.48**	CDD (days)	2.08*
TX10p (%)	-0.55**	CWD (days)	-0.39**
TN10p (%)	-2.79**	R95p (mm)	1.59
DTR (ºC)	-0.17**		

Note: ** and * mean the trend at the significance level of p=0.01 and 0.05, respectively.

Table 5. Correlation coefficients of temperature indices during 1961-2011

Indices	Annual	TXx	TNx	TX90p	TN90p	TXn	TNn	TX10p	TN10p	DTR
Annual	1									
TXx	0.30**	1								
TNx	0.55**	0.45**	1							
TX90p	0.68**	0.43**	0.51**	1						
TN90p	0.78**	0.25*	0.55**	0.64**	1					
TXn	0.38**	0.17	0.19*	0.30**	0.31**	1				
TNn	0.53**	0.20*	0.38**	0.43**	0.51**	0.33**	1			
TX10p	-0.56**	-0.30**	-0.35**	-0.48**	-0.40**	-0.42**	-0.31**	1		
TN10p	-0.72**	-0.19	-0.49**	-0.48**	-0.70**	-0.26**	-0.49**	0.39**	1	
DTR	-0.30**	0.11	-0.21*	-0.14	-0.44**	-0.01	-0.27**	-0.04	0.50**	1

Note: ** and * mean the correlation at the significance level of p=0.01 and 0.05, respectively.

Table 6. Changing rates (mm/decade) of the annual precipitation at 22 meteorological stations during 1961-2011

Station	Changing rate	Station	Changing rate
Deqing	2.86	Yuxi	-18.2
Diqing	7.66	Luxi	-48.1**
Weixi	3.17	Gengma	-6.27
Tengchong	9.84	Lincang	-9.61
Baoshan	7.59	Lancang	-20.8
Dali	-14.0	Jinghong	-19.3
Chuxiong	11.4	Simao	-30.8
Kunming	-34.2*	Yuanjiang	-9.42
Zhanyi	-49.3**	Mengla	-10.3
Ruili	6.83	Jiangcheng	-11.2
Jingdong	5.23	Mengzi	-5.54

Note: ** and * mean the trend at the significance level of p=0.01 and 0.05, respectively.

Table 7. Correlation coefficients of precipitation indices during 1961-2011

Indices	Annual	RX1day	RX5day	SDII	R10	R25	CDD	CWD	R95p
Annual	1								
RX1day	0.27**	1							
RX5day	0.39**	0.50**	1						
SDII	0.35**	0.32**	0.36**	1					
R10	0.80**	0.18	0.34**	0.35**	1				
R25	0.65**	0.27**	0.42**	0.56**	0.59**	1			
CDD	-0.04	0.19	0.17	0.20*	-0.05	0.04	1		
CWD	0.36**	0.11	0.28**	0.13	0.38**	0.34**	0.06	1	
R95p	0.55**	0.44**	0.48**	0.57**	0.42**	0.65**	0.16	0.25*	1

Note: ** and * mean the correlation at the significance level of p=0.01 and 0.05, respectively.

Table 8. The residuals and relative errors of the annual temperature (T_a) and precipitation (P_a) values as well as the changing rates of temperature (T_{cr}) and precipitation (P_{cr}) estimated by Eqs. (5-8)

Station	T_a		P_a		T_{cr}		P_{cr}	
	Residual	*RE*	*Residual*	*RE*	*Residual*	*RE*	*Residual*	*RE*
Deqing	0.41	0.08	93.61	0.15	-0.08	-0.17	1.94	0.68
Diqing	0.25	0.04	182.94	0.29	0.01	0.02	-10.14	-1.32
Weixi	0.21	0.02	-171.59	-0.18	0.07	0.35	1.32	0.42
Tengchong	0.51	0.03	-266.27	-0.18	0.03	0.12	-3.37	-0.34
Baoshan	-0.17	-0.01	160.36	0.16	-0.04	-0.13	-5.26	-0.69
Dali	-1.08	-0.07	-71.25	-0.07	0.15	1.23	9.44	-0.67
Chuxiong	-0.97	-0.06	145.29	0.17	-0.06	-0.19	-26.38	-2.31
Kunming	-0.30	-0.02	-64.14	-0.06	-0.17	-0.40	11.18	-0.33
Zhanyi	0.36	0.03	-283.35	-0.29	0.06	0.48	20.62	-0.42
Ruili	0.38	0.02	-112.78	-0.08	-0.09	-0.32	6.40	0.94
Jingdong	0.24	0.01	-83.86	-0.07	0.01	0.08	-13.15	-2.51
Yuxi	-0.21	-0.01	166.22	0.18	0.05	0.21	-5.26	0.29
Luxi	0.89	0.06	4.62	0.01	-0.03	-0.10	17.33	-0.36
Gengma	-0.08	0.00	66.31	0.05	0.01	0.05	5.18	-0.83
Lincang	-0.82	-0.05	177.60	0.15	0.06	0.24	2.44	-0.25
Lancang	-0.03	0.00	-31.27	-0.02	0.07	0.30	12.94	-0.62
Jinghong	0.01	0.00	364.12	0.31	-0.03	-0.11	6.97	-0.36
Simao	-0.36	-0.02	-2.46	0.00	-0.07	-0.18	15.07	-0.49
Yuanjiang	-0.26	-0.01	179.28	0.22	0.00	0.04	-3.80	0.40
Mengla	0.64	0.03	80.98	0.05	-0.03	-0.08	-9.54	0.93
Jiangcheng	0.77	0.04	-826.28	-0.37	0.04	0.16	-9.87	0.88
Mengzi	-0.41	-0.02	291.94	0.35	0.03	0.15	-24.04	4.34
Mean value	0.00	0.00	0.00	0.04	0.00	0.08	0.00	-0.12

Table 9. Mean values and changing rates (/decade) of the annual NDVI at 22 meteorological stations during 1982-2006

Station	Mean value	Changing rate	Station	Mean value	Changing rate
Deqing	0.2268	-0.010	Yuxi	0.3995	-0.018*
Diqing	0.4336	-0.011	Luxi	0.3865	0.001
Weixi	0.4148	-0.017	Gengma	0.4591	-0.021*
Tengchong	0.5104	0.030*	Lincang	0.4952	0.015
Baoshan	0.4036	0.005*	Lancang	0.4975	-0.002
Dali	0.2768	0.003	Jinghong	0.5716	-0.018**
Chuxiong	0.4374	-0.001	Simao	0.4841	-0.036**
Kunming	0.2203	-0.041**	Yuanjiang	0.4584	-0.003
Zhanyi	0.3768	0.003	Mengla	0.5924	0.009
Ruili	0.4934	0.008	Jiangcheng	0.5572	-0.016*
Jingdong	0.4640	-0.023**	Mengzi	0.3907	0.001

Note: ** and * mean the trend at the significance level of p=0.01 and 0.05, respectively.