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He Yunling and Zhang Yiping

Climate Change from 1960 to 2000 in the Lancang River Valley, China

Archival data of monthly air temperature and precipitation series were used to investigate climate change trends and characteristics during 1960–2000 at 19 stations along Lancang River from the north to the south, in the mountainous Himalayan region of southwest China. The magnitude of a trend was estimated using Sen's Nonparametric Estimator of Slope approach. The station significance of a trend was assessed by the MK test. Over the observation period of 41 years, mean annual air temperature increased at the rate of 0.01°C/yr to 0.04°C/yr in 12 stations at the significance level α = 0.01. The changes in precipitation in different areas are very dissimilar and complex. Mean annual precipitation that decreased from –2.86mm/yr to –5.29mm/yr at 3 stations, and mean annual precipitation that increased from 5.77mm/yr and 7.44mm/yr at 2 stations, were statistically significant at the significance level α = 0.05. The lower reaches of Lancang River experienced much more severe temperature increase, precipitation decrease, and drought development than the upper reaches in the past 41 years.

Keywords: *Climate change; long-term temperature series; regional variation; Lancang River valley (Mekong); China.*

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Introduction

The question of whether climate has changed significantly is of substantial interest and requires a better understanding of climate behavior and climate impact problems associated with ecological, economic, and social matters (Schönwiese et al 2003). Analyses of climate change and its impacts over the past centuries have been performed on global, hemispheric, and regional scales (Onate and Pou 1996). Global surface temperatures have increased by about 0.3 to 0.6°C since the late 19th century and by about 0.2 to 0.3°C over the last 40 years (IPCC 2001). Analyses of temperature time series in China indicate a rate of warming of 0.04°C per decade between 1951 and 1990 (Chen et al 1998).

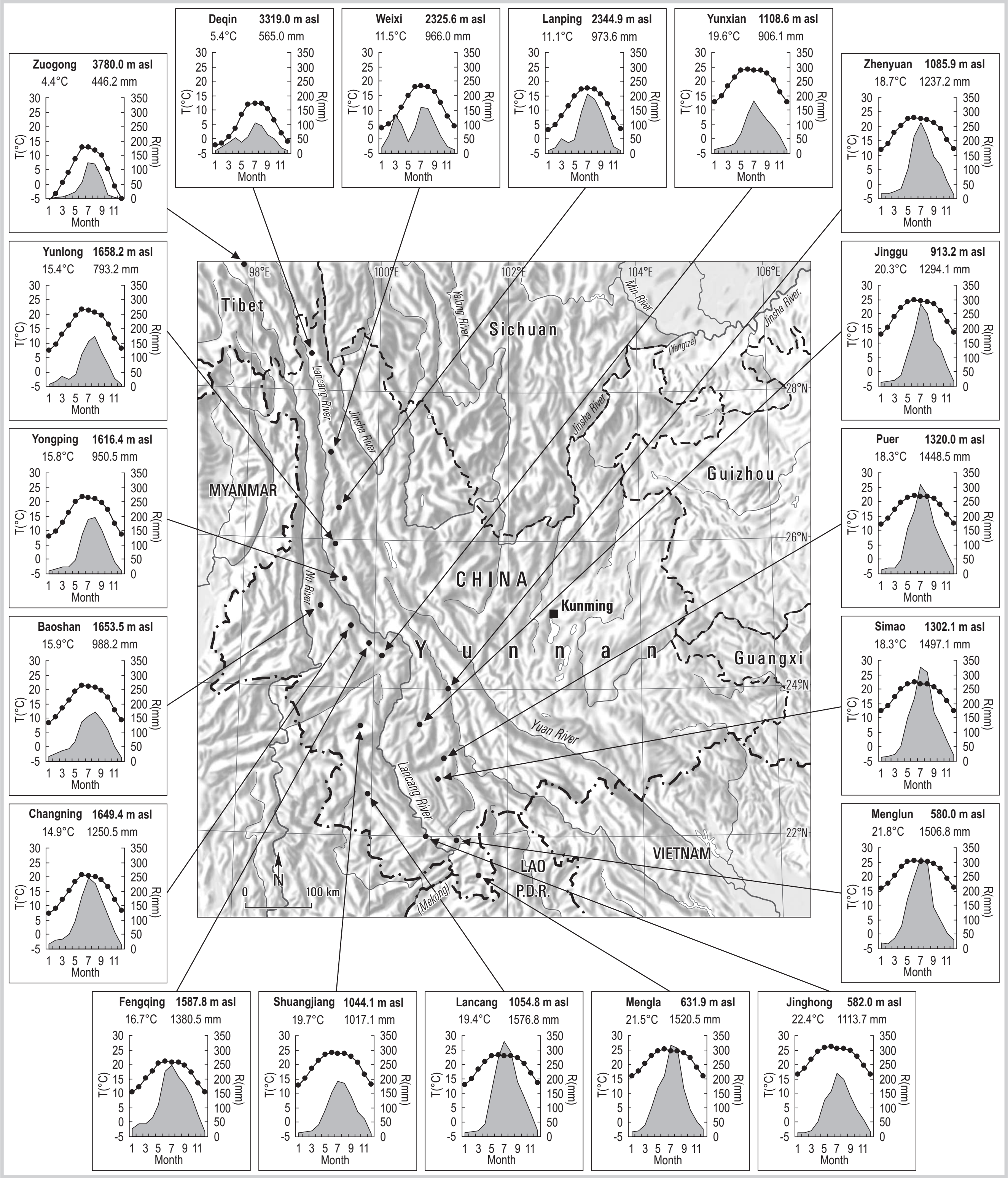
Having sufficient information about climatic change in the recent past is necessary to improve the certainty and accuracy of estimates about the future, and the role of this information is particularly important in assessments of regional climate change (Brunetti et al 2004). The climate of a specific location cannot be considered a constant environmental factor. Regional climate change has regional peculiarities that are often not consistent with global patterns. The particular Lancang River valley orography and the location of the Longitudinal Range-Gorge Region in southwest China imply a strong influence of local circulation. For this reason investigation of climate change in this region may be very appropriate for understanding such differences. Identification of long-term trends in climate change is providing information for decision-makers and resource managers that allows them to better anticipate and plan for the potential impacts of climate variability and change. Further advances in climate science will serve the nation by providing improved knowledge to enable more scientifically informed decisions across a broad array of climate-sensitive sectors. In the past, some authors have analyzed climate change in some weather stations in this area. For example, Li (2001) determined that one main cause of the climate change from 1959–2000 in Menglun was change in tropical forest cover.

The present study further investigated long-term trends in annual and seasonal mean temperatures and precipitation series in the Lancang River valley. Changes in these series were measured by correlating them with linear trends. The magnitude of a trend was estimated using Sen's Nonparametric Estimator of Slope approach. The Mann Kendall (MK) nonparametric test was applied to assess the statistical significance of a trend.

General situation of the area of interest

The Lancang River is the largest and longest river on the Asian continent: it flows through China, Myanmar, Laos, Thailand, Cambodia, and Vietnam, before finally merging into the South China Sea. The Lancang River originates on the eastern Tibetan Plateau; near the county with the highest elevation, Deqin, it enters Yunnan province and plunges through deep gorges, hemmed in on both sides by mountains. The tectonic collision between the South Asian and Eurasian continental plates that formed the Himalaya caused an abrupt fold in the topography in the northwestern part of Yunnan, and shaped a series of north/south ranges known as the Hengduan Mountains (Longitudinal Range-Gorge Region in southwest China). In this formidable terrain, the Lancang River flows south through Yunnan province, hemmed in by mountains ranging in height from 3000 to 4000 m in the north, 1500 to 2200 m in the middle, and 500 to 1000 m in the south. South of the Chinese border, the Lancang River is known as the Mekong River. Active geotectonics result in topographic

FIGURE 1 Location of the 19 meteorological stations studied in Yunnan Province, southwest China, with climate diagrams showing annual average temperature (T) and rainfall (R) for 1960–2000. (Map by Andreas Brodbeck, climate diagrams by He Yunling)



unconformity; the rich and diverse ecosystems formed and influenced by unique environmental patterns in this region have attracted the strong interest of geologists and ecologists.

Most meteorological stations along the Lancang River valley were established in the 1950s. For this paper, 19 meteorological stations were selected according to geography and climate. Their location and general situation are shown in Figure 1 and Table 1. The locations of the selected stations run from the north to the south along the Lancang River and cut across the hinterland as well as the climatic region that includes the plateau temperate zone, plateau subtropical zone, and the plateau tropical zone.

The Pacific Ocean and the Indian Ocean lie to the south, while northern sites located on the Tibetan Plateau join the Lancang River area to the Asian continent. Controlled by seasonal winds, and under the influence of the Tibetan Plateau, within short distance and latitude, the climatic conditions differ greatly from one selected area to the other; moreover, the environment is complex. In terms of geography and climate, the entire region is characterized by different climatic patterns. Temperature generally increases from the north to the south, with an average annual temperature below 11°C in the north, and above 15°C in the south. The water vapor gradually reduces as the intruding southwest air mass moves north, and there is little precipitation in the inland region. Annual precipitation generally decreases from the south to the north, with 1000 mm in the north, 900–1300 mm in the middle, and 1000–1500 mm, with peaks above 1500 mm, at the southern sites. Precipitation is also uneven throughout the year. There is plenty of rain during the rainy season (accounting for 80.7–92.9% of the whole year), while precipitation is scarce in the dry season, particularly from January to March, with the longest precipitation-free period lasting one month (He et al 2004). Thus, primarily owing to the monsoon from the Indian Ocean, a major feature of the Lancang River valley's climate is the clear-cut changes between the two seasons: the dry season (November–April), and the rainy season (May–October).

TABLE 1 General characteristics of the selected meteorological stations.

Name	Northern latitude	Eastern longitude	Elevation (m asl)	Climatic region
Zuogong	29° 40′	97° 50′	3780.0	Plateau, northern-temperate zone
Deqin	28° 29′	98° 55′	3319.0	Plateau, northern-temperate zone
Weixi	27° 10′	99° 17′	2325.6	Plateau, southern-temperate zone
Lanping	26° 25′	99° 25′	2344.9	Plateau, southern-temperate zone
Yunlong	25° 54′	99° 22′	1658.2	Plateau, northern-subtropical zone
Yongping	25° 28′	99° 31′	1616.4	Plateau, northern-subtropical zone
Baoshan	25° 07′	99° 10′	1653.5	Plateau, central-subtropical zone
Changning	24° 50′	99° 37′	1649.4	Plateau, central-subtropical zone
Fengqing	24° 36′	99° 54′	1587.8	Plateau, central-subtropical zone
Yunxian	24° 27′	100° 08′	1108.6	Plateau, central-subtropical zone
Zhenyuan	24° 00′	101° 06′	1085.9	Plateau, southern-subtropical zone
Jinggu	23° 30′	100° 42′	913.2	Plateau, southern-subtropical zone
Shuangjiang	23° 28′	99° 48′	1044.1	Plateau, southern-subtropical zone
Puer	23° 02′	101° 03′	1320.0	Plateau, southern-subtropical zone
Simao	22° 47′	100° 58′	1302.1	Plateau, southern-subtropical zone
Lancang	22° 34′	99° 56′	1054.8	Plateau, southern-subtropical zone
Jinghong	22° 00′	100° 47′	582.0	Plateau, northern-tropical zone
Menglun	21° 56′	101° 15′	580.0	Plateau, northern-tropical zone
Mengla	21° 29′	101° 34′	631.9	Plateau, northern-tropical zone

With regard to temperature and precipitation, the selected meteorological stations from the north to the south thus represent the climatic situations of most areas in the Lancang River valley. The distinguishing feature of this region's eco-environment is its frailness, particularly on slopes where the environment is unstable and prone to deteriorate, expressed by the following aspects: 1) active geotectonics result in topographic unconformity, characterized by a gorge area with mountains and steep valleys; 2) heat is sufficient, but there is occasional occurrence of abnormal cold in spring; 3) precipitation is moderate, yet unevenly distributed throughout the year; storms often occur, whereas aridity is evident; 4) there are many slopes and fewer flatlands, and conditions for settlement are poor; 5) social and economic standards are too low for settlements to withstand natural disasters (He et al 2004).

Methodology

Data

Monthly air temperature and precipitation data were obtained from the archives of the National Meteorological Service. Except for the 1978–2000 series for Zuogong and 1977–2000 series for Yunlong, the series for the other 17 stations were available for the 41-year period (1960–2000) of this study. These data were examined visually with time series plots, and then subjected to statistical homogeneity tests. The annual series and seasonal series for the dry season and the rainy season were computed from their monthly series.

Magnitude of a trend

The magnitude of a trend in a time series is determined using a nonparametric method known as Sen's Nonparametric Estimator of Slope approach (Sen 1968), shown below as:

$$b = median\left(\frac{X_{i'} - X_i}{i' - i}\right) \qquad \text{(Eq 1)}$$

where b is an estimate of the slope of a trend, $X_{i'}$ is the data measurement at time i', X_i is the data measurement at time i, and i' is the time after time i. The slope estimated for a monotonic trend by this approach has been widely used in hydro-meteorological time series (Lettenmaier et al 1994; Yue and Hashino 2003).

Significance of a trend by the MK test

The statistical significance of a trend for annual or seasonal series at a site was analyzed using the Mann Kendall (MK) test (Mann 1945; Kendall 1975; Sneyers 1990), which is the rank-based nonparametric test often applied to a series of observations in order to find out whether or not there is a trend. It is widely used in environmental science because it is simple and robust, and can cope with missing values as well as values below a detection limit (Buffoni et al 1999; Yue and Hashino 2003).

In a time series (x_i, $i = 1,2,\ldots, n$) of data, for each element x_i, the number n_k of lower elements x_j ($x_j < x_i$) preceding it ($j < i$) was calculated and the test statistic t_i defined as:

$$t_i = \sum_{k=1}^{i} n_k \qquad \text{(Eq 2)}$$

The distribution function of the test statistic t_i has a mean and a variance as:

$$E(t_i) = \frac{n(n-1)}{4} \qquad \text{(Eq 3)}$$

$$\mathrm{var}(t_i) = \frac{n(n-1)(2n+5)}{72} \qquad \text{(Eq 4)}$$

If no trend is present in the time series (null hypothesis), the test statistic is asymptotically (large n) normally distributed, with $u(t_i) = \frac{t_i - E(t_i)}{\sqrt{\mathrm{var}(t_i)}}$ being the standard normal distribution.

The null hypothesis can therefore be rejected for high values of $|u(t_i)|$, the probability $P(u)$ of rejecting the null hypothesis when it is true given by:

$$P(u) = P(|u| > |u(t_i)|) \qquad \text{(Eq 5)}$$

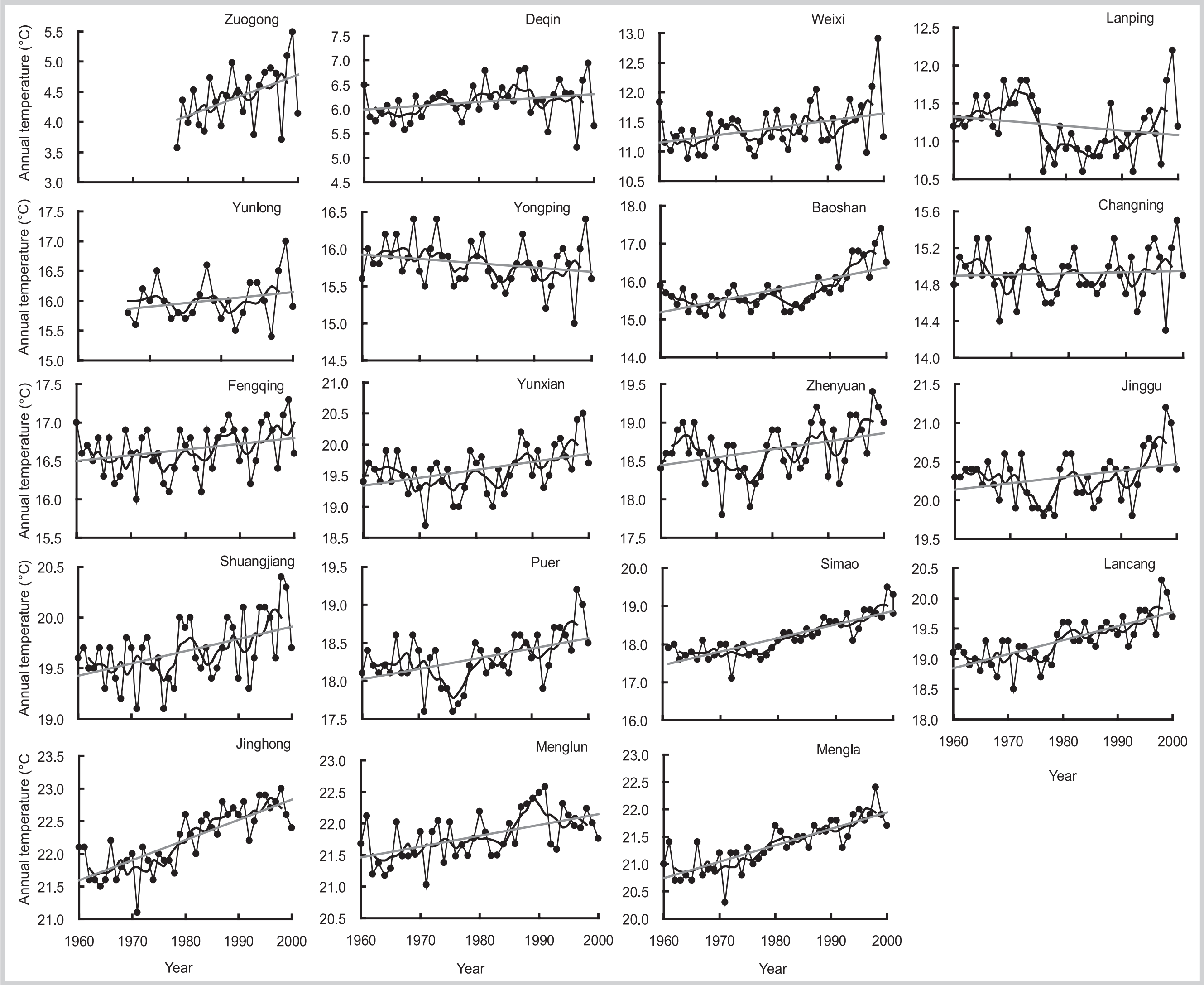
The significance level (α) is generally set to be 0.05. The smaller the value of α, the greater the confidence in determining that the null hypothesis is false. Given the significance level (α), if the value P (probability value, p) $<\alpha$, then a trend is considered to be statistically significant.

Climate change

Air temperature

The Lancang River valley is vast and its environment is highly diverse; hence climate change is also diverse. But different areas are almost the same in terms of reflecting global climate change. Trends assumed to be linear are displayed in Figure 2, where the coldest period in the last 41 years is shown to have been during the 1960s at most stations; from the beginning of the 1980s, annual temperatures increased gradually in all series. The magnitude of a trend in annual air temperature series was calculated using Eq 1. Annual temperature increased at 17 stations and decreased at 2 stations, but statistically significant upward trends from 0.01°C/yr to 0.04°C/yr were evident at 12 stations at the significance level (α) of 0.01 with P values < 0.01. The 2 series with downward trends in annual temperature do not show a significant trend.

FIGURE 2 Time series (—•—) for annual air temperature (°C) from 1960 to 2000 in different regions of the Lancang River valley. The curve shows the 5-year running mean and the straight line illustrates the linear trend of the series.



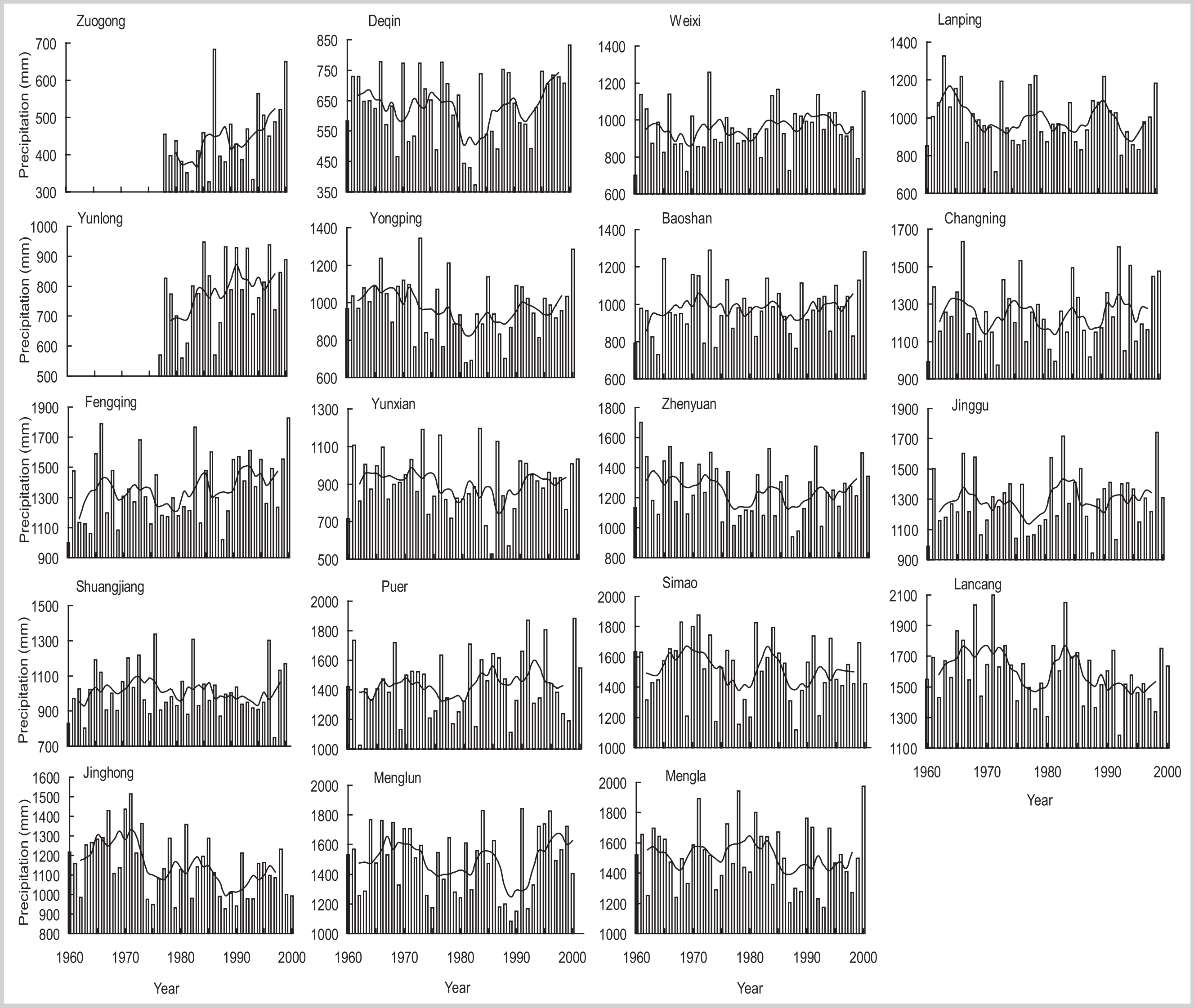
The magnitude of a trend in dry season and rainy season series estimated using Eq 1, and the P values of trends in these series assessed by the MK test, indicated upward trends at most stations with greater increases in the dry season. Except for a few sites, changes in the series were statistically significant at $\alpha = 0.05$, with the P values of most sites <0.001.

The upward trends with larger amplitudes in annual temperature were statistically significant even at $\alpha = 0.001$, with P values <0.001 in the southern subtropical and northern tropical zones (the middle-to-lower reaches of the Lancang River).

Precipitation

In general, the consistency of precipitation change from the north to the south of the Lancang River was not as great as that of air temperature. Figure 3 shows that changes in precipitation in different areas were very different; the wettest period in the Lancang River valley was during the 1960s at most stations. But annual extremes differ depending on the area. Since the early 1970s, precipitation has decreased, with more obvious fluctuations in rainy seasons appearing in different areas. Though the mean precipitation in most areas tended more or less to increase during the 1990s, it was still less than in the 1960s or 1970s. By assuming that precipitation trends are linear, the magnitude of a trend, estimated using Eq 1 and the P value of the trend in annual and seasonal series assessed by the MK test, indicated that annual precipitation increased at 9 stations and decreased at 10 stations, but statistically significant downward trends from –2.86mm/yr to –5.29mm/yr (the sites located in the lower reaches of the Lancang River) were evident at 3 stations at the significance level (α) of 0.05. Two series (the sites located in the upper reaches of the Lancang River) with upward trends in annual precipitation from 5.77mm/yr to 7.44mm/yr were also statistically significant at a significance level (α) of 0.05.

FIGURE 3 Distribution of annual precipitation (mm) from 1960 to 2000 in different regions of the Lancang River valley. The curve shows the 5-year running mean of the series.



To present the fluctuation situation of precipitation during the 1960–2000 period, a stability index of precipitation variation rate was defined and formulated:

$$V = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Xi - \bar{X}}{\bar{X}}\right| \times 100\% \qquad \text{(Eq 6)}$$

where V is the relative precipitation variation rate, X_i is the precipitation data measurement at time i, $\bar{X}$ is the mean of precipitation data during a time series, and n is the length of time. When the value of V is greater, the distribution of precipitation during a time series is more uneven.

Thus relative precipitation variation rates (V) in all 19 regions were examined for different periods using Eq 6. For most sites the greatest relative precipitation variation rate was found in the dry season, followed by the rainy season, then by the year. During the past 41 years, fluctuations in precipitation were most serious (ie uneven) in the 1980s at most sites. However, the relative precipitation variation rates in different regions during the 1990s were remarkably low.

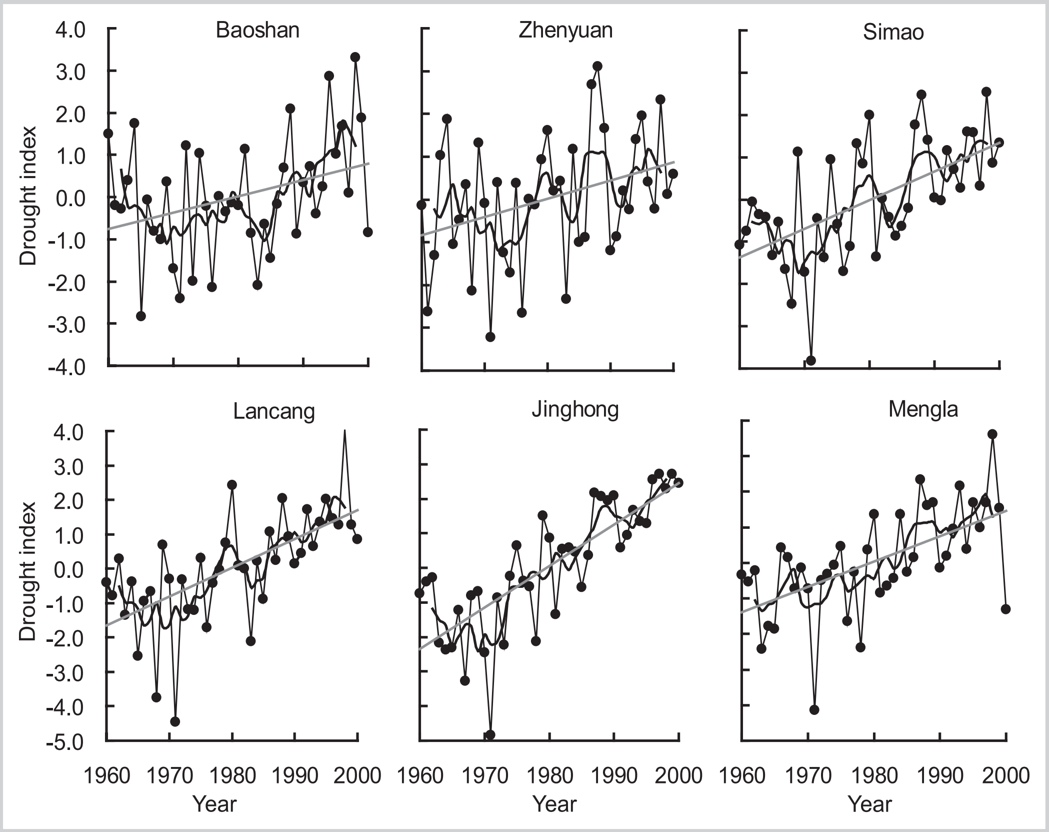
Drought index

Human activity, economic development, and ecological evolution have been closely linked with changes in climate (temperature and precipitation) and environment (drought and wetness) (Qian and Zhu 2001). A large number of climate change studies have appeared in recent decades, investigating the impact of temperature and precipitation anomalies on the life-supporting environment (Gruza et al 1999). Here a drought index for the area of interest was estimated using an approach proposed by Qian and Zhu (2001):

$$DI = \Delta T/S_T - \Delta P/S_P \qquad \text{(Eq 7)}$$

where DI is the drought index, ΔT and ΔP are the anomalies (departures from the average for the full

FIGURE 4 Drought index time series for 6 locations.



period of common record) of surface air temperature and precipitation relative to the mean between 1960–2000, and S_T and S_P are the standard deviations of temperature and precipitation.

The *DI* indicates that higher surface air temperature and less precipitation will result in drier climate in the defined region. The year-to-year variation of the drought index at each station was then calculated using Eq 7. The index increased at 14 stations and decreased at 5 stations. The upward trends at 4 stations (Simao, Lancang, Jinghong, and Mengla, located in the lower reaches of the Lancang River) were statistically significant at $\alpha = 0.001$. At $\alpha = 0.05$, the upward trends at another 2 stations (Baoshan and Zhengyuan) also become statistically significant (Figure 4). None of the series with downward *DI* trends showed a significant trend. Recent and major periods of drought started in most of the stations in this region in the 1980s. However, drought development varied in different regions. In the north, the major drought periods appeared in the early 1980s, while this occurred in the late 1980s in the south. Trends in drought development over the lower reaches of the Lancang River will require special attention in the coming decade.

According to a survey in 2004 (He et al 2004), though the variation in the long-term annual runoff of the Lancang River was found to be relatively slight, rapid concentration of sediment led to increasing loss of beddings and bays, and major mountain disasters including soil and water loss, landslides, mudflows, and collapse occurred more frequently in the lower reaches of the Lancang River. The above analysis showed that important features of climatic change in the lower reaches of the Lancang River were increased temperature, reduced precipitation, and greater drought, which likely became obstacles to the sustainable development of a life-sustaining system. Potential climate change events could well intensify eco-environmental frailty where human activities lead to increased risk, resulting in greater sensitivity to climate change.

Conclusion

This study investigated long-term climate change at 19 stations across the Lancang River from the north to the south. Over the observation period of 41 years, mean annual air temperature increased at the rate of 0.01°C/yr to 0.04°C/yr at 12 stations at the significance level $\alpha = 0.01$. Precipitation change in different areas was very different. Mean annual precipitation decreased from –2.86mm/yr to –5.29mm/yr at 3 stations, and mean annual precipitation increased from 5.77mm/yr and 7.44mm/yr at 2 stations, statistically significant at the significance level $\alpha = 0.05$.

On a seasonal basis, the climate change trend in air temperature was more significant in the dry season than in the rainy season, with precipitation showing converse behavior. On a spatial basis, the lower reaches of the Lancang River experienced much more severe climate change (temperature increase, precipitation decrease, and drought development) than the upper reaches in the past 41 years.

In summary, climate change differs from climate element to climate element, region to region, and season to season. Great differences exist in the magnitude and significance of climate change between different parts of the Lancang River valley.

These results are consistent with the previous studies of He and Zhang (2004), who also observed increases in temperature and decreases in precipitation and relative humidity. The upward trend in temperatures was also consistent with those in China (Chen et al 1998), in which temperatures also showed significant increases during the last 45 years, especially in winter. Globally, our results confirm that there are great differences in responses to recent global climate change in the Lancang River valley and other areas of southwest China. Moreover, in addition to some common features (temperature increase, tendency towards a decrease in precipitation), other data (the magnitude of a trend) behaved differently.

Though the present study did not propose extending work on the attribution analyses, some evidence that climate underwent remarkable changes in different regions along the Lancang River in the past 41 years has been revealed by this preliminary study. This can be information useful to the local government, who will need to pay attention to the impacts of such climate change on the systems that support montane life. Sahai (1998) summarized the main causes of climate change in recent decades as:

1. Variation in atmospheric composition (mixing ratios of carbon dioxide and ozone, aerosols loading, etc) due to volcanic eruptions and human activity;
2. Variation in land surface characteristics due to land use (deforestation, desertification, etc); and
3. The urban heat island.

Further study in a specific region or nation may be needed to further clarify this issue (Yue and Hashino 2003). The present information could be the basic foundation for future study activities to understand the impact of climate change on human well-being. Adaptation strategies can then be devised to assist development planning in this mountainous region.

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AUTHORS

He Yunling and Zhang Yiping
Kunming Section, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, 88 Xuefu Road, Kunming 650223, People's Republic of China.
hyl@xtbg.ac.cn (H.Y.); yipingzh@xtbg.ac.cn (Z.Y.)

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