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Temperature Change and Its Elevation Dependency in the Source Region of the Yangtze River and Yellow River

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Abstract

The study of temperature change and its elevation dependency in the source region of the Yangtze River and Yellow River have been insufficient owing to the lack of adequate observation stations and long-term climatic data. In this study five temperature indices of 32 stations from 1961 to 2007 in and near the source region are used. The 32 stations all have experienced significant warming; the warming amplitudes are higher than the mean warming amplitude of the Qinghai-Tibetan plateau. The warming amplitudes and the numbers of stations showing significant warming trends in mean minimum temperature and extreme minimum temperature are higher than that of the mean maximum temperature and extreme maximum temperature. The elevation dependency of climatic warming and the amount of significant warming stations are not obvious; the influence of human activity and urbanization may be higher. The warming amplitudes of 26 stations above 3000 m tend to be uniform, and there is no significant law at 6 stations below 3000 m. On the contrary, the ratio of stations showing significant warming in minimum temperature above 4000 m is far less than that of the stations below 4000 m.

Keywords: warming amplitude, significant level, elevation dependency, the source region of the Yangtze River and Yellow River, global warming

1. Introduction

Regional climate change is significant to study the origin of climate and the effects of regional climate change on ecosystem and social-economical system. With the global warming, the regional climate change will influence the human activities and ecosystem, also, these feed back to the global warming. As regional climate varies in the space, many studies had proved a relationship between the warming trend and elevation. Using experimental data, such as meteorological and ice core data, researches in some regions had showed the warming increases as the elevation increases. The warming speed at high elevations was greater than that at low elevations in Alpine mountain areas (Benistion & Rebetez, 1996); Diaz et al. (1997) found that relationship appears to be more closely regarding to increases in daily minimum temperature than changes in the daily maximum temperature (Diaz & Bradley, 1997). Some studies in the Qinghai-Tibetan Plateau also showed this relationship: the data of five meteorological stations in Mt. Jolmo-Lungma showed the warming trend is obvious, and the warming amplitude is maximum at Dingri where altitude is the highest (Yang et al., 2006); the ice data in the source region of Yangtze river in Qinghai-Tibetan plateau showed the warming response is more sensitive at high altitudes (Kang et al., 2007); the increase in amplitude of mean temperature increases with the increase of altitude and this trend is verified by the ice data (Liu et al., 2000); the study in Qinghai-Tibetan Plateau also shows there is no warming below 500 m, the increase amplitude from 1500 m–2500 m is about 0.12 °C/10 yr and 0.25 °C/10 yr above 3500 m, the result shows the response to global climate change at high altitudes is more sensitive (Yao et al., 2000).

Experimental data are important to study the relationship between warming trend and elevation. However, the climate model provides another possible way to assess the elevation dependency on longer time scales against independent proxy records. A nested regional climate model shows the elevation dependency, and the model also showed that the warming was more pronounced at high elevation compare to that at low elevation in winter and spring (Giorgi et al., 1997); according to the study of the climatic model, it is the snow surface reactions due to the increase of the snowline, the surface temperature increased obviously at high elevations (Fyfe et al., 1999).

However, enhanced warming with the increase of elevation in some regions showed contrasting patterns: lower elevation at the west of the Andes have experienced the greatest warming, while the warming is moderate at high elevations in the east (Vuille et al., 2003); the temperature ascending rate of surface temperature is less at the high altitude of the Qinghai-Tibetan plateau (Li et al., 2005); and the study also shows there is no remarkable correlation between the temperature extremes and the elevation on the Tibetan Plateau (You et al., 2008).

Rivers, lakes, glaciers and jokuls are widely distributed at the source region of Yangtze River and Yellow River. It's the most important and extensive ecological function zone in China and it is called the Chinese Water Tower. It located in the hinterland of the Qinghai-Tibetan plateau, which is the driver and amplifier of the Global Climatic Change (Pan & Li, 1996), and its thermal action is important to the climate of China even the world (Gao et al., 2003). With the background of global climatic change, the study of climatic change in the source region of the Yangtze River and Yellow River is very significant to the ecosystem and water resource security in this region. Some studies show the warming is obvious in the last 40 years on Qinghai-Tibetan plateau; whereas, there is still a controversy regarding the elevation dependency of temperature variation and significant level. Based on the 5 temperature indices over 47 years at the 32 weather stations in the source region of Yangtze River and Yellow River which are located in the hinterland of Qinghai-Tibetan Plateau, the study investigate the warming trend and analyze their elevation dependency.

2. Study Area and Data

The source region of the Yangtze River and Yellow River is located in the hinterland of the Qinghai-Tibetan plateau, and belongs to the Naqu-Guoluo subhumid and QiangTang semiarid area. The entire study area is in the Qinghai-Tibetan plateau subfrigid zone with the mean elevation about 3900 m. It is the main water source reserve and runoff-generation area of the Yangtze River and Yellow River, and is the key source region that maintains the natural ecological security and social economically sustainable development (Wang et al., 2001).

The meteorological data of 32 weather stations in which the time series are relatively complete from year 1961–2007, are provided by the national meteorological center of the China Meteorological Bureau. The weather stations are widely distributed in QingHai, Tibet, SiChuan and GanSu Province. And the elevation extent is from about 2238.1 m–4801.0 m (Figure 1). There are five temperature variables examined with the goal of understanding the temperature change and its elevation dependency which are the mean annual temperature, mean annual maximum temperature, mean annual minimum temperature, extreme maximum temperature and extreme minimum temperature.

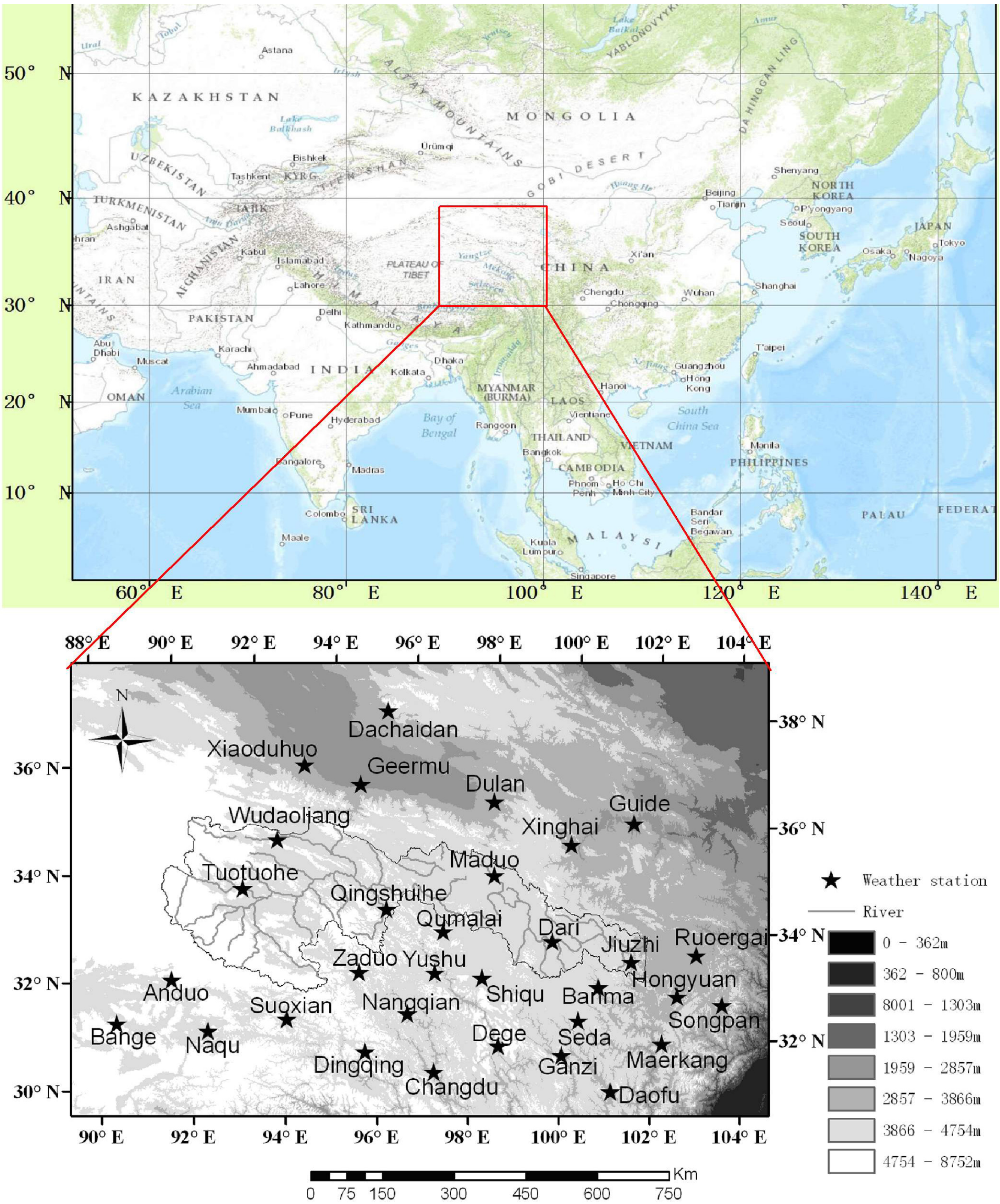

Figure 1. The weather station in and near the study area

3. Steps and Method

The systematic approach that was adopted herein to determine the warming trend and its elevation dependency can be summarized in the steps outlined below:

The fist step was to calculate the lag-1 serial correlation coefficient (r_1) of the sample data; if $r_1 > 0.1$, the data set to be "pre-whitened"; if $r_1 < 0.1$, it keeps invariant.

The second step was to check the presence of trends and significant level in the data set, and this was done using the Mann-Kendall non-parametric test.

The third step was to determine the change in amplitude; and the sen's estimator was used here.

The fourth step was to calculate the elevation dependency of the warming trend; the linear parametric test and the coefficient of variation were used here, β_{alt} was used to repress the warming amplitude with the elevation. The steps outlined above are described in the sections that follow:

Pre-whitened

A positive serial correlation in the sample data, the non-parametric will suggest a significant trend which is actually random more often than specified by the significance level, the data set to be "pre-whitened" to eliminate the effect of serial correlation before applying the Mann-Kendall test. If r_1 < 0.1, the Mann-Kendall test is applied to original values of the data set; if r_1 > 0.1, the "pre-whitened" data set (Y_t) may be obtained as follows (Sheng & Wang, 2002):

$$Y_t = X_t - r_1 X_{t-1}$$

The lag-1 serial correlation coefficient (r_1) will be calculated as follows:

$$r_1 = \frac{(1/(n-1))\sum_{t=1}^{n-1}[X_t - E(X)][X_{t+1} - E(X)]}{(1/n)\sum_{t=1}^{n}[X_t - E(X)]^2}$$

$$\mathrm{E(X)} = \frac{1}{\mathrm{n}}\sum_{t=1}^{n} X_t$$

Mann-Kendall trend test

The Mann-Kendall test is a non-parametric test and has been widely used to test for randomness against trends in hydrology and climatology (Xu et al., 2003; Jin et al., 2003).

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S-1}{\sqrt{V(S)}} & S < 0 \end{cases}$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(X_j - X_i)$$

$$\mathrm{sgn} = \begin{cases} 1 & if \quad \theta > 0 \\ 0 & if \quad \theta = 0 \\ -1 & if \quad \theta < 0 \end{cases}$$

For independent, identically distributed random variables with no tied data values

$$V(S) = \frac{n(n-1)(2n+5)}{18}$$

When some data values are tied, the correction to $V(S)$ is

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i i(i-1)(2i+5)}{18}$$

$$P = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z} e^{-t^2/2} dt$$

Sen's estimator

The non-parametric robust estimate of the magnitude of the slope β (Xu et al., 2003),

$$\beta = Median\left(\frac{X_j - X_i}{j - i}\right) \qquad j > i$$

4. Result and Discussion

4.1 The Temperature Change in the Last 47 (1961–2007) Years

The elevation and the warming amplitude of each station are shown in the Figure 2. The change trend of five temperature indices at 32 stations in and near the source region all exceed 0, and show the warming trend in all the stations. There is a uniform warming trend in the source region. The warming amplitude of annual mean temperature is about 0.32 °C/10 yr, and it exceeds the warming amplitude of annual mean temperature 0.16 °C/10 yr which studied by Liu et al. (2000) and 0.26 °C/10 yr studied by Du (2001) on the Qinghai-Tibetan plateau. The source region is the most sensitive region to global warming on the whole Qinghai-Tibetan plateau. The warming trend of annual mean maximum temperature, annual mean annual minimum temperature, annual extreme maximum temperature and annual extreme minimum temperature are 0.233 °C/10 yr, 0.426 °C/10 yr, 0.308 °C/10 yr and 0.739 °C/10 yr, respectively. The value of warming amplitude in annual mean minimum temperature and extreme minimum temperature is the greatest, and the result is consistent with the whole Qinghai-Tibetan plateau (Figure 2).

The warming trend in annual mean temperature is observed at 93.75% and 100% of stations at level of 0.05 and 0.1 respectively. There is a significant warming trend in annual mean temperature across the whole source region, and the level is also higher than the whole Qinghai-Tibetan plateau (Table 1). The ratios and numbers of the warming stations with mean annual minimum temperature and extreme minimum temperature at the significant level of 0.05 and 0.1 are higher than the level of the mean annual maximum temperature and extreme maximum temperature, but it is consistent with the warming amplitude too (Figure 3).

The source region is located in the hinterland of Qinghai-Tibetan plateau, the glacier, wetland and water system are widely distributed here, and it is extremely susceptible to the global warming trend, and the warming amplitude and the significant warming stations are much higher than the entire Qinghai-Tibetan plateau. According to five temperature indices: there is an obvious increase of the warming amplitude and the number of warming significant stations in annual mean temperature, annual mean minimum temperature and extreme minimum.

Table 1. The number and proportion of station which the warming is significant at the confidence of 0.05 and 0.1

	Confidence level	Annual mean temperature	Annual maximum temperature	Annual minimum temperature	Extreme maximum temperature	Extreme minimum temperature
Station number	0.05	30	17	29	18	25
Station proportion (%)		93.75	53.125	90.625	56.25	78.125
Station number	0.1	32	24	31	22	27
Station proportion (%)		100	75	96.875	68.75	84.375

Table 2. The elevations depency of warming at 26 stations above 3000 m

		Annual mean temperature	Annual maximum temperature	Annual minimum temperature	Extreme Maximum temperature	Extreme minimum temperature
Linear test	P	0.559	0.700	0.595	0.625	0.829
	β_{alt} (°C/10yr/1km)	0.020	0.015	0.033	0.034	0.036
	coefficient of variation	0.268	0.450	0.372	0.580	0.564
Mean warming (°C/10yr)		0.312	0.218	0.415	0.294	0.723

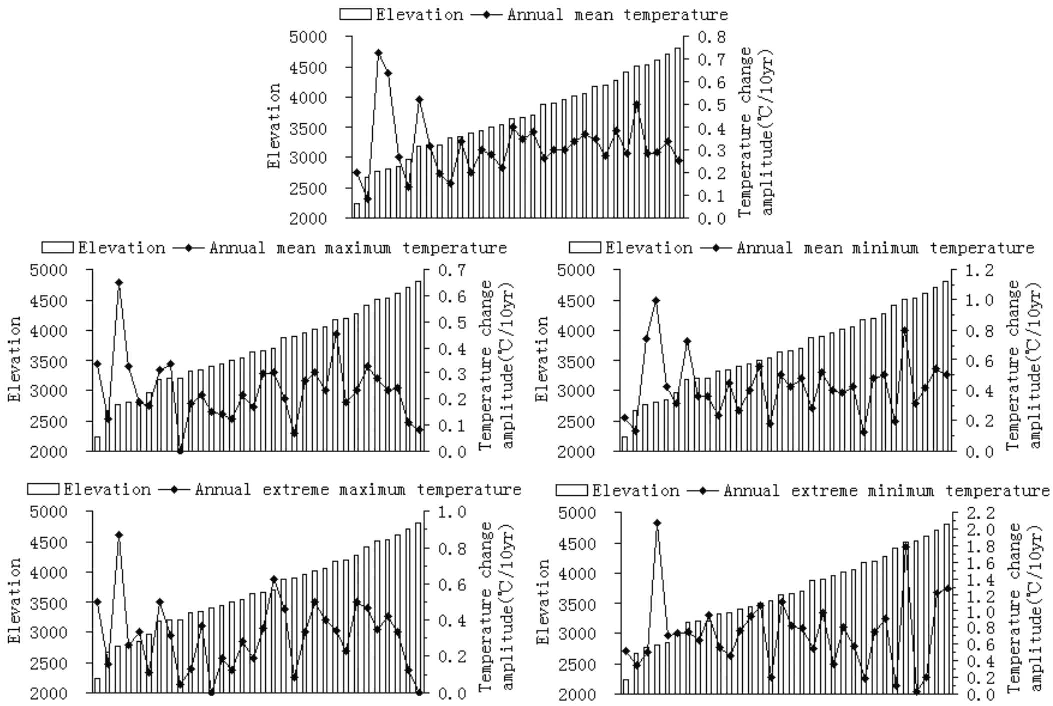

Figure 2. The temperate change amplitude of five temperature indices

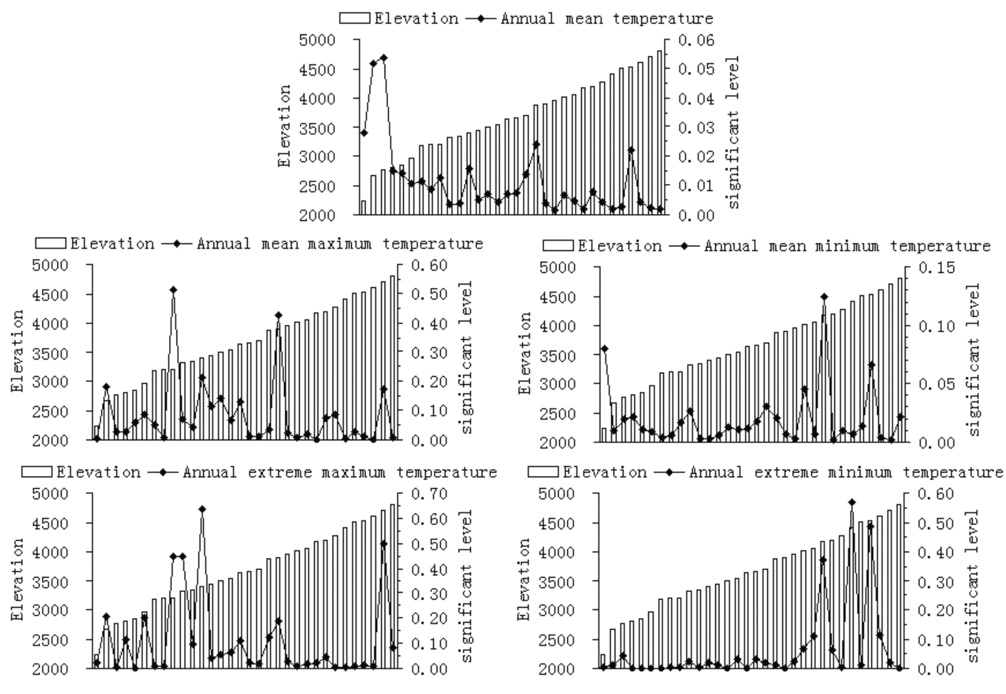

Figure 3. The warming significant level of five temperature indices

4.2 The Elevation Dependency of Temperature Change

With the global warming, the regional temperature changes at different elevations showing different characteristics and their elevation dependency are widely disputed. The study of the warming trend of elevation dependency is relatively weak and the conclusions are different because of the scarce of the weather stations and the integrity of the data set on the Qinghai–Tibetan Plateau. In our study, there are 32 stations, the 6 of which are at 2000 m~3000 m, the other 26 stations are at 3000 m~5000 m. The warming amplitude at 6 stations at 2000 m~3000 m have no significant changes with the elevation, while the influence of human activity is more obvious at the region of 2000 m~3000 m. The study by You et al. (2008) also shows the effect of urbanization to warming is higher than the elevation dependency. The elevation dependency of warming amplitude of five temperature indices are studied by the linear parametric test, the results show that the confidence level is not significant, and also, the change trend is not significant. The coefficients of variation of five temperature indices are 0.268, 0.450, 0.370, 0.580, and 0.564 respectively. The discrete degree of annual mean temperature is least, the discrete degree of annual mean minimum temperature and annual extreme minimum temperature is less than that of annual mean maximum temperature and annual extreme maximum (Table 2). The warming amplitude of the five temperature indices at the different stations of 3000 m~5000 m is well coincident, and there is no significant elevation dependency between altitude and temperature change.

The elevation dependency of warming significant stations of five temperature indices is not obvious. Most stations above 4000 m show an unobvious warming trend ($P > 0.05$) in extreme minimum temperature. There are 11 stations above 4000 m, of which only 4 stations show a significant increasing trend in extreme minimum temperature while the other 21 stations below 4000 m all show a significant increasing trend.

5. Conclusion

The regional warming is significant and extensive in and near the source region of the Yangtze River and Yellow River, the significant warming of the annual mean temperature at the 32 stations at the confidence level of 0.05 and 0.1 are 93.75% and 100% respectively, and the warming amplitude is 0.318 °C/10 yr, and it is higher than the mean temperature of the whole Qinghai-Tibetan plateau; the warming amplitude and the number of warming significant stations of annual mean minimum temperature and annual extreme minimum temperature at the confidence of 0.05 and 0.1 are higher than the annual mean maximum temperature and annual extreme maximum temperature.

The warming of 6 stations below 3000 m has no significant change. The warming amplitude of 26 stations above 3000 m is coincident, and the elevation dependency of warming amplitude is not obvious. The study of warming significant stations also show that there is no remarkable relationship between elevation and the significance level of warming. The proportion of stations showing warming significant trend in extreme minimum temperature above 4000 m less than that below 4000 m.

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