The trend of temperature of the Qilian Mountains in the Northwest of China

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Abstract. Temperature is one of the important climatological factors which affects the hydrological processes in a watershed, and is commonly used to investigate the change of climate. The distribution and trend of annual and seasonal mean temperature for 44 meteorological stations in Qilian Mountains over a period of 1960 to 2017 were analyzed by using linear regression. The mean annual temperature ranges from -2.8 to 9.7°C, and is above 0°C below middle mountains. However, the mean temperature of summer is maximum above 43.1°C, and is minimum in winter below -41.6°C. Vertical of mean annual temperature is distributed significantly. The distribution of mean annual temperature is higher in northern slope than in southern, and higher in northwest than in southeast. The warming trend is very strong in winter, and has a certain dependence on the altitude above the 37.5° of northern latitude, which is different in different seasons. The result of the present research would be helpful to promote ecological protection, adjustment of agricultural structure, and management of water resources in the Qilian Mountains.

1. Introduction
As one of the key indicators of climate change, temperature plays a vital role in surface energy balance because of over a time scale. It can influence the atmosphere cycle, hydrologic cycle, agro-ecological zoning, and human lives [1-4]. Temperature is one of the conventional elements to be measured in surface meteorological observations, and can be obtained through manual or automatic observation using appropriate measuring devices. Although the temperature measurement is affected by location and topography, the accuracy of the data is more than other meteorological elements. According to the Fifth Assessment Report (AR5) of Intergovernmental Panel on Climate Change (IPCC), the mean temperature has increased by 0.85°C during 1880 to 2012 in global [3, 5]. But, the mean temperature of China has increased by 1.1°C in the past century, which is higher than the global average warming and thus a higher warming can be expected. The increasing trend is varied in different regions of China. In recently years, numerous studies have shown that mean temperature with a increasing rate of 0.26°C/decade in the eastern part is valid, whereas a low rate of 0.18°C/decade has been evident in the western part of China [6-7]. Over seasonal, the mean temperature has shown a significantly increasing trends in spring and winter in the eastern part compared to the western part of China. However, a lower trend in summer and autumn in eastern part than those in the western part of China [8-9]. In time series, the mean
temperature showed an increase at a rate of 0.16 °C ± 0.02 °C/decade in the period of 1901–2015, whereas with an accelerated warming rate of 0.26 °C ± 0.04 °C/decade during 1951 to 2015 [10-11].

In arid and semi-arid regions, high mountain regions serve as important sources of water in maintaining the ecology, environment and social development [12-13]. A number of glaciers and snow fall develop in the high mountains which are the source regions of freshwater and origin of many inland rivers. Due to faraway of ocean and sparse precipitation, the ecological environment of arid and semi-arid regions is considered as most fragile and sensitive to climate change [14-16]. Several studies have shown that the temperature follows an increasing rate of warming, which has both positive and negative influence on the ecological environment in the mountains [17-18]. At present, the relationship between temperature warming trends with altitude is controversial in mountain regions. Some studies revealed that warming trend is depended on altitude and it is faster at high altitude [19-20]. However, other studies have reported that warming trend of temperature has no dependency on altitude, rather it even decreases with altitude [21-23]. Therefore, it is need to explore further the relationship between temperature changes and altitude on a spatial-temporal which will be helpful understand the impact of climate change on environment.

In this study, the trends of annual and seasonal temperature are analyzed using simple linear regression. The dependence of temperature warming trend on altitude in the Qilian Mountains were also studied. It is crucial that the investigation of temperature variation is a better understanding of the response of mountain changes to global warming.

2. Study area and data

2.1. Study area
The Qilian Mountains is located in the northwestern China which extended for approximately 850 km from west to east and 250-400 km from south to north, with an average altitude of approximately 4000 m (Figure 1). It is located in the hinterland of Eurasia, and the boundary between monsoon and non-monsoon regions of China. In the high mountains, there are about 2683 modern glaciers. A large number of glaciers act as the origin of many inland rivers, such as Shiyang-, Heihe-, and Shule River on the northern slope, and Buha- and Datong River on the southern slope. Plenty of glacial and snow meltwater are discharged into those rivers which are flown in the downstream region and function as important water resources. This abundant water resource is used to maintain agricultural irrigation and societal development in the Hexi Corridor. In this region, on one hand, in the lower mountains (below 2500 m), annual mean temperature ranges from 2 to 5°C and the annual precipitation ranges from 235 to 330 mm. On the other hand, in the high mountains (above 3200 m), annual mean temperature ranges −1.5 to −0.7°C and annual precipitation ranges above 500 mm with cold and humid climate.

Figure 1. The distribution of the stations in the Qilian Mountains.
2.2. Data
For the data collection over a period of 1960-2017, a total of 50 stations were selected in the study regions. Six stations had missing temperature data for more than 3 months, which were excluded from the present analysis. The monthly temperatures for rest of the 44 stations were collected for carrying out the analysis and the places were located at elevations between 1140 and 3418 m. Due to the complex terrain, there is paucity of measurement stations and unreasonable distribution throughout the Qilian Mountains.

The daily mean temperatures of 44 stations from the National Climate Centre of China (China Meteorological Administration - CMA) were selected inside and surrounding the Qilian mountains for the period of 1960-2017 (Figure 1). In the meteorological stations, the temperature data were measured with a resolution of 0.1 °C. Of the total measuring stations 82% are located in the lower and middle terrain below 3000 m, and a very few are located in high mountain regions. The monthly, seasonal and annual mean temperatures were calculated by using the recorded daily temperature values. In general, the seasons over the months of a year were defined as spring (March, April and May); summer (June, July and August); autumn (September, October and November); and winter (December, January and February).

2.3. Linear regression
Generally, if the sample size is larger than 10, meteorological data are consistent with normal distribution, such as the data on temperature and precipitation. The trend is estimated by using the simple linear regression [18]. In the present investigation the trend has been calculated by using the following formula:

\[ T_{rend} = bX + a \]  

where \( T_{rend} \) is the dependent variable, \( b \) is the slope of the line, and \( a \) is the \( T_{rend} \) intercept.

3. Results

3.1. The distribution of temperature
Using the supplied data on air temperature for a period of 1960-2017, the mean annual temperature values for 44 stations were calculated, and spatially interpolated using inverse distance weighted (IDW) (Figure 2). The mean annual temperature ranges from -2.8 to 9.7°C. The minimum temperature occurred in January and the maximum in July. The mean annual temperature surrounding Qinghai Lake is lower than other regions in Qilian Mountains. On the whole, the mean annual temperature over 85% percent of Qilian Mountains is above 0°C. The characterization has shown that the mean annual temperature in north slope is higher than that in south slope, and higher in northwest than that in southeast of Qilian Mountains. The pattern of seasonal temperature distribution is consistent with the annual temperature distribution. The mean temperature of summer is maximum and ranged from 8.5 to 24°C, and the mean temperature is minimum with range of -15.6 to -3.1°C. However, the mean temperature in the southeast is higher than that in the northwest in winter, which did contrast with the annual temperature distribution.

Despite the complex terrain and uneven land use, there is a good relationship between temperature and altitude in the Qilian Mountains. The mean annual temperature decreases significantly decreased with the increasing in altitude. The gradient accounts for 0.42°C/100 m, slightly below the standard level of 0.6 °C/100 m (Figure 3a). The seasonal temperature also shows significant decrease with increasing the altitude (Figure 3b, 3c, 3d, 3e). The gradient in summer is maximum with 0.56°C/100 m, then in spring and autumn with 0.47°C/100 m, 0.41°C/100 m, respectively. The relationship between temperature and altitude is complex in winter. The temperature increases with rising of altitude up to 2000 m, then decreases with a rising in altitude.
3.2. **The trend of temperature**

Using the linear regression analysis, the distribution trend of mean annual temperature has been presented in Figure 4. The value of trend for all stations is above zero which indicated that the process of warming has been going on significantly in Qilian Mountains. Among them, the warming trend of mean annual temperature is most obvious in XZH and DT of southern slope of Qilian Mountains with a rate of exceeding 0.6 °C/decade. However, the warming trend is weak in XN with a rate of 0.1 °C/decade as a significant impact on human activities. By and at large, the warming trend is high in the southwestern of Qilian Mountains. Temperature of this area is affected since it is nearby the Tibetan
Plateau. While, the warming trend is slow in northwestern of Qilian Mountains, where the effect is caused simply by its location.

Figure 4. The distribution of trend for mean annual temperature.

Figure 5 illustrates the trend of seasonal temperature in Qilian Mountains. Obviously, the warming trend is higher in winter than other seasons. In order to explain the reason, the monthly trend of temperature for all stations was analyzed. The result has shown that the trend is highest in February than in other months. The trend of seasonal temperature is followed by autumn for most part of Qilian Mountains. The warming trend in spring is higher than in summer below 2000 m. On the contrary, the warming trend in summer is higher than in spring above 2000 m.

Figure 5. The trend of seasonal temperature in Qilian Mountains.

3.3. Altitude dependency of warming trends
Figure 6 has shown the mean annual and seasonal temperature trend with altitude as observed by analyzing the data from 1960 to 2017 in the Qilian Mountains. The annual warming trend of temperature shows a higher variability ranging from about 0.103 °C to 0.625 °C/decade. There is non-significant dependency between annual and seasonal temperature with altitude in the whole of Qilian Mountains. The reason may be influence by different vapor sources in different regions. However, the warming trend of mean annual temperature is clearly increase with altitude above the 37.5° of northern latitude over Qilian Mountains. The warming trend of mean annual temperature increases with the increase in altitude, but above 3000 m, it decreases with the increase in altitude. The warming trend of summer and autumn is presented by similar patterns with altitude. Just above 2000 m, the warming trend of seasonal temperature is slowed. The linear trend is obvious of spring and winter warming. In spring, the warming trend decreases with a rise in the altitude, but increases with the altitude arising in winter. The variation is weak and not significant with low correlation coefficient.
4. Conclusions
In the Qilian Mountains, the distribution and trend of annual and seasonal temperature were analyzed by using the linear regression for 44 stations during the period of 1960 to 2017. The distribution of mean annual temperature shown higher values in north slope than that in south slope, and higher in northwest than that in southeast of Qilian Mountains. The relationship has shown harmony between annual and seasonal temperature and altitude except for winter. The gradient is lower than that in the plain regions. The warming trend is very significant, the higher in the southern slope than in northern slope, in the southwest than that in northwest of Qilian Mountains. There is certain dependency on warming trend of temperature with altitude above the 37.5° of northern latitude. The warming in summer and autumn showed a logarithmic trend with altitude rise, while it showed a linear trend in spring and winter which is just the reverse. The variation of seasonal trend has caused annual dependency which has shown an increase at low altitude, but decrease at high altitude.

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