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The Climate Change in Qingdao during 1899-2015 and Its Response to Global Warming

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Abstract

In this work, the average mean (TAvg), maximum (TMax), and minimum temperature (TMin) and precipitation records of Qingdao from 1899 to 2015 are analyzed. The TAvg, TMax and TMin all go through several warm and cold periods, and exhibit statistically significant linear warming trend especially in spring and winter, as a response to global warming. Besides, the TAvg reflects more the TMin evolution for the most part, either as a trend or an abrupt change, and the contribution of TMin to Tavg is far greater than that of TMax. The abrupt change year of climate is also around 1979 in Qingdao, and it is 2 or 3-years later than the TAvg for the TMin, while there is no abrupt change of TMax. In terms of the precipitation in Qingdao, it varies periodically and dramatically with a slow increasing trend. As for the seasonal precipitation, the precipitation varies widely year by year for the four seasons but with no obvious variation trend except for spring.

Keywords

Climate Trend, Global Warming, Temperature, Precipitation

1. Introduction

The global climate has changed dramatically since the industrial revolution. More and more people start to concern the climate change as the technology advances and the dramatic development of communicating technology. The climate refers to a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer [1]. Though the internal processes and/or external forcing can induce the climate change, the increase of anthropogenic greenhouse gases such as CO_2 is considered primarily to cause the climate change especially for temperature in recent decades [1]. The IPCC Fourth Assessment Report (IPCC) [1] published in 2007 presented new estimates of global warming trends for the past 100 years since 1906, the global mean temperature increased by about 0.74˚C per 100-yr. The temperature series and new assessment results have not only confirmed the ascending trend of global mean temperature, but also enhanced the reliability of estimates on warming.

Until recently, studies on the climatic change were focused for the most part on the analysis of temperature data especially for the annual mean temperature. Examples of this are the works of Balling *et al.* [2], Tang *et al.* [3], and so on. Besides, some climatologist [4] had analyzed the minimum and maximum temperatures in some parts of the world, finding asymmetric trend. Under the global warming, the change of extreme low temperature varies more dramatically [5] [6], and is more sensitive to the global climate change than the extreme high temperature. Trenberth *et al.* [7] pointed out that the global warming induces the increase of the surface evaporation rate and the water-holding capacity of the atmosphere, and causes more intense rainfall or snowfall events. Thus, the climate change impacts a lot in fields such as atmospheric circulation, temperature, precipitation, agriculture, water resources, and so on [8] [9] [10] [11] [12]. Climate change has impacts on abnormal first and last frost date [13]. The results from Zhang *et al.* [14] showed that the comprehensive agricultural loss rate increased by an average of 0.5% per decade in the past 50 years, and the risk increased significantly under the climate change.

In the last decades, an increasing number of Chinese studies on climate and associated climate change were accomplished [15], but most of them dealt with effects occurring in the past 50 years [16]. There are few studies on temperature or precipitation change in the past 100 years due to limited data availability [12]. In order to obtain meaningful results, it requires a longer period of the observations to study the characteristics and laws for climate change. However, only few stations have the temperature and precipitation records longer than 100 years in China.

Qingdao station occupies significant position in the Chinese meteorological history, which is one of the first three cities (Hongkong, Shanghai, and Qingdao) to set up the weather station. Though the Qingdao Observatory has went through several vicissitudes since it was built in 1898 [17], the observation has been suspended only twice from June 1914 to March 1915, and from September 1937 to January 1938. We have constructed the time series of temperature and precipitation from 1898 to 2015 so far. In order to obtain the continuous time series of average temperature and precipitation, we replenished the missed data using their climate mean (30 years), which will not change their climate trend. Based on the long-term data, we investigated the possible trends and abrupt changes of the maximum, minimum, and mean temperatures and precipitation, to obtain a better knowledge of the climate change in the past 117 years in Qingdao. Qingdao is located in the northeast coast of China, its climate change features are representative of some of common climate characteristics in the northeastern China.

2. Data and Method

The Qingdao meteorological observatory is one of the National Basic Weather Station, which located at Guanxiang hill from 1899-1960 and then moved to Fulong hill in 1961. The two stations are only 700 m apart and their height difference is less than 1m, so the observation environment is basically the same. Almost all the regular meteorological elements (for example, temperature including daily maximum and minimum temperature, precipitation, and wind) have being observed since January 1899. In this paper, the seasonal mean and annual mean temperature (TAvg) or precipitation is the arithmetic mean of the temperature for the four seasons or the whole year. The annual maximum/minimum temperature (TMax/TMin) is the maximum/minimum temperature in every year. Based on the annually/monthly mean temperature, maximum/minimum temperature and precipitation, the characters of short-term and long-term climate trend and oscillation, and their responses to global warming were analyzed using the power spectrum, linear trend analysis, Mann-Kendall (MK) method, five-point sliding average method, and so on. Mann-Kendall (MK) method is a trend detecting method proposed by Mann Goossens [18], this method gained ability to detect the abrupt change. In the MK method, if the value of UF or UB is greater than 0, the series has an increasing trend; if the value is smaller than 0, the series has a decreasing trend. When these parameters exceed critical values, a significant increase or decrease is indicated, and the amount by which they exceed the critical value indicates the time over which the abrupt change occurred. If the UF and UB curves intersect and the point of intersection is within the critical line, the time at which they intersect is the time when an abrupt change began [19]. More information about the MK method can be gained from the research by Chen [20].

The meteorological data from January 1899 to December 2015 was adopted in this study. It should be noted that the time series of maximum and minimum temperature broke from 1914 to 1915, and from 1937 to 1938. Nevertheless, these discontinuous do not affect the analysis for the features of the climate change in this paper.

3. The Features of Climate Trends in Qingdao during the Past 117 Years

3.1. Temperature

For the past 117 years from 1899 to 2015, the TAvg changes in a periodic and obvious fluctuating way (green line in **Figure 1(a)**), and the average temperature is 12.4˚C. The annual mean lowest temperature was 10.9˚C and occurred in

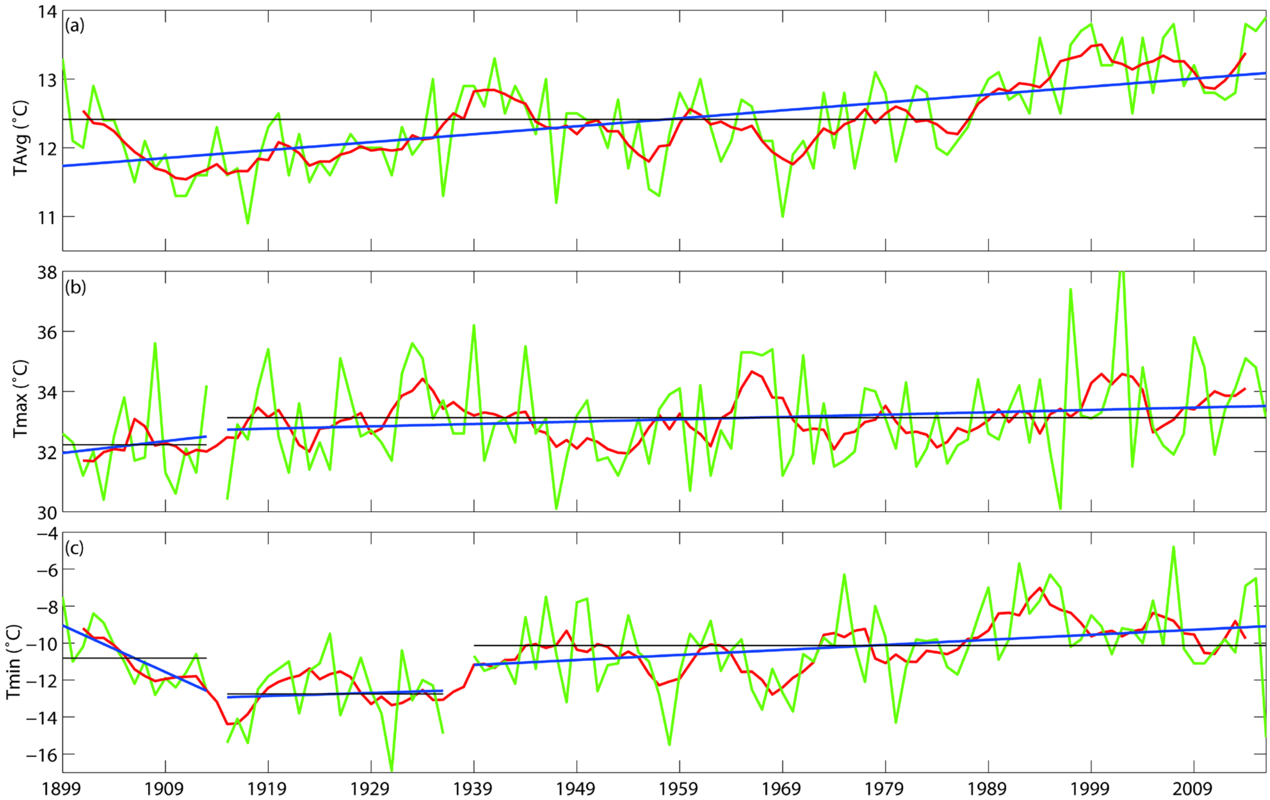

Figure 1. Time series of TAvg (a), the TMax (b) and TMin (c) (green line) and their climate mean (black line), linear trend (blue line) and 5-year running mean (red line) during 1899-2015.

1917, while the highest temperature was 13.8˚C and occurred three times in 1999, 2007, and 2014 respectively. It is worth noting that the lowest and highest temperature occurred in the previous and last two decades separately since the observations available. The time series of TAvg reveal a statistically significant linear warming of 1.11 per 100-year over the period 1899 to 2015. The warming rate in this study is a little bit higher than the result of 0.90˚C per 100a from Chen *et al.* [21] and 0.94 per 100a from Pang *et al.* [22]; this could be because of the longer data coverage in our study. In order to discuss various short-term climate changes, the high frequency signals were removed by five-point sliding average method. The TAvg had a decreasing trend from the early twentieth century, dropped its bottom in 1910s, and then rose in volatility (red line in **Figure 1(a)**). From the results of TAvg MK (**Figure 2(a)**), the UF was negative from 1899, but turned to be positive around 1937, which indicated the coming of warm period. However, this warm stage only lasts for less than 10 years, and then turns to cold stage in 1944. These results are consistent with the result from Chen *et al.* [21]. The temperature in Qingdao had an evident interdecadal variation with two warm and cold stages during the year 1944 to 1979 (**Figure 1(a)**). The MK shows a jump point in 1979 (**Figure 2(a)**), which indicates that Qingdao entered into an evident warming period since 1979 under the global warming. Reide [23] confirmed that the 1980s regime shift represented a major change

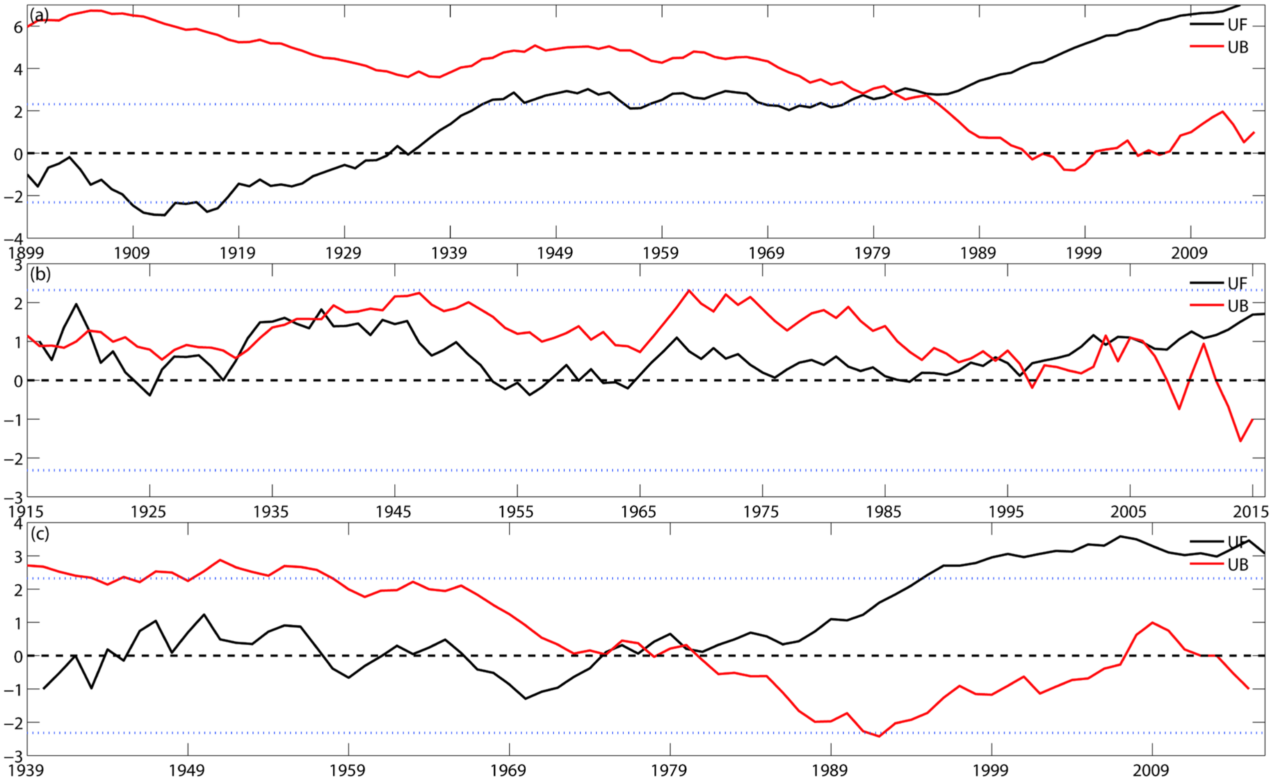

Figure 2. Mann-Kendall abrupt change test of TAvg (a), TMax (b) and TMin (c) in Qingdao.

in the Earth's biophysical systems from the upper atmosphere to the depths of the ocean and from the Arctic to the Antarctic, and occurred at slightly different times around the world. The average TAvg is 12.94˚C during the year 1979 to 2015, which is 0.54˚C higher than the climate mean (1899-2015).

Figure 1(b) and Figure 2(b) show the time series and their MK abrupt change test for the TMax. The TMax has a broader fluctuation range than the TAvg, but its warming rate is much less than the TAvg (Figure 1(a) and Figure 1(b)). The average TMax is 32.23˚C from 1899 to 2013. After the observation restarted in 1915, the average TMax is 33.12˚C with an increase rate (0.80 per 100a) from 1915 to 2015. The UFs fluctuate above zero for most years (Figure 2(b)), which suggest a slower warming. The TMax in the year 1949 and 1996 (30.1˚C) is the lowest for the past 117 years, which is 3.02˚C lower than the climate mean (33.12˚C), and the highest TMax (38.9˚C) occurred in 2002 is 5.78˚C higher than the climate mean. From 1899 to 1947 (49 years), the interannual amplitude is large, and the difference between the crest and bottom of the time series is up to 4.5˚C (36˚C at the peak and 31.5˚C at the bottom). But the TMax comes to a stabilization period in a fluctuant range of 3˚C from 1948. The decreasing UF means that the TMax slowly declines during this period. The TMax rises and falls acutely during the year 1965-1972. After then, Qingdao has 23 years of climate peace of TMax, the oscillating amplitude of the TMax is 2.5˚C - 3˚C from 1973 to 1995. The range for oscillation of TMax (4˚C - 5.5˚C) becomes larger again over the past two decades (1996-2015). There is no abrupt change point of TMax in Qingdao, and its extremes occurred during the highly oscillatory periods.

The climate mean of annual minimum temperature (TMin) is −10.81˚C from 1899 to 1913. The TMin has a prominent declining tendency (**Figure 1(c)**) during this period, which is probably concerned with its internal periodic changes. After then, the TMin changes smoothly and its climate mean is −12.75˚C from 1915 to 1936. Overall, this is a cold period with the extreme minimum temperature in 1931 (−16.9˚C). While the climate mean of TMin for the period 1939-2015 is only −10.07˚C, it grows about 2.54˚C in 77 years, which shows the strongest increase by 3.30˚C per 100 years. From the estimation through 5-year running average time series (red line in **Figure 1(c)**), it can be concluded that the TMin regularly surges with the variation of years, and there is no obvious rising and falling. After a short period of decreasing from 1966 to 1971, the UF index begins to increase in 1972, and an abrupt change of TMin occurs around 1982, which suggests that the TMin starts to increase dramatically from 1982. It is worth reminding that the time point of abrupt change for the TMin is 2 or 3-years later than the TAvg, and that the warming rate for the TMin is 4 times more than the TMax during the past 117 years. In addition, the correlation coefficient between the TAvg and TMin is up to 0.67, while it is only 0.33 between TAvg and TMin. It seems that the TAvg reflect more the TMin evolution for the most part, either as a trend or an abrupt change. We can thus speculate that the contribution of TMin to Tavg is far greater than that of TMax.

From the trend analysis for the TAvg, TMax, and TMin, it is found that they all go through several warm and cold periods, but they all increase with different warming rates as a response to global warming. Based on the above results, we perform trend analyses in different periods (shown in **Figure 3**). During the year 1899-1910, the TAvg in Qingdao decreases 1.05˚C in 12 years, Qingdao goes into a cold period with decreasing rate of −0.95 per decade; after that, the TAvg keeps warming at a rate of about 0.37 per decade, which is only about one third of the cooling rate for the first period; the TAvg varies peacefully from 1944 to 1979, and it only increases 0.12˚C in 36 years, whose warming rate is only 0.04˚C per decade; Qingdao enters into a rapid warming period with a warming rate of 0.30˚C per decade from 1980 to 2015, though the TAvg grounded to a halt (global warming hiatus) for a short time [24] [25].

As for the TMax (**Figure 3(b)**), due to the suspending of the observations in 1914, we analyzed the variations of the TMax from 1899 to 1913. During this period, the TMax has risen 0.55˚C in 15 years with a warming rate of 0.3˚C per decade, while the TAvg gradually decrease contemporarily, that is to say, the variation of TMax contributes negatively to the TAvg; after then, the TMax varies slowly with a weak warming rate of 0.10˚C per decade in 1915-1947 and 1948-1964; from 1965 to 1972, the TMax decreases 3.38˚C, but it is not regarded as a trend variation because there is only 8 years; during 1973 to 1995 and 1996

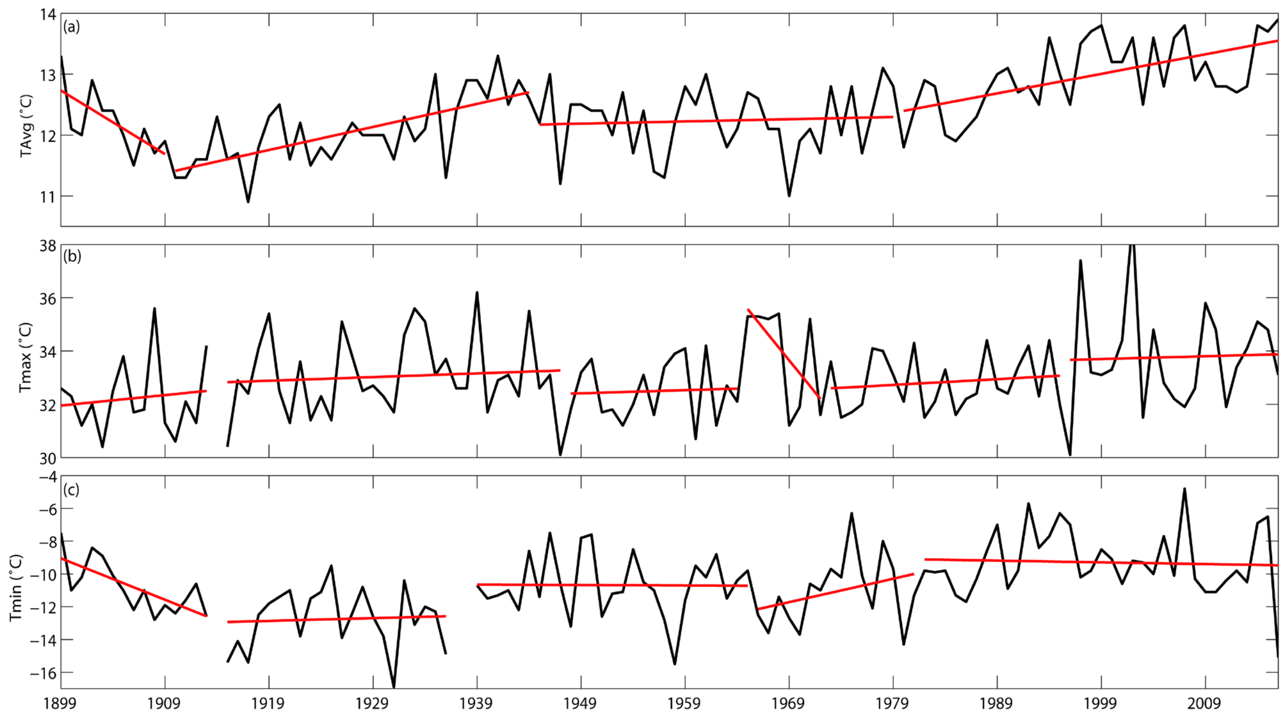

Figure 3. Linear trends of TAvg (a), TMax (b) and Tmin (c) in Qingdao during different periods.

to 2016, the warming rate of TMax are both 0.20˚C per decade. As a whole, the warming rate of TMax changes more slowly than that of the TAvg.

For the TMin (**Figure 3(c)**), a similar cooling trend variation with the TAvg occurs for the TMin, whose decreasing rate is up to −2.36 per 10a during 1899-1913, that is far more quickly than that of TAvg. This rapid temperature falling for the TMin to a certain extent are offset by the warming of the TMax, which helps keep the TAvg from decreasing too much during this period; the TMin increases about 0.35˚C in 22 years, and its warming rate is 0.16˚C per decade from 1915 to 1936; there is not any obvious warming or cooling trend during 1939-1965, and the TMin has a cooling rate of 0.03˚C per decade; while, it rises quickly with a warming rate of 1.34˚C per decade from 1966 to 1981; comparing with the preceding period, the TMin rises less rapidly from 1982 to 2015, and it only increases about 0.65˚C in 24 years (0.19˚C per 10a). On the whole, the decrease of the TAvg is closely related with the significant cooling of the TMin in the early nineteenth, whose variation trend contributes more than the TMax to the TAvg during the 117 years.

3.2. Precipitation

For the past 117 years from 1899 to 2015, the annual precipitation in Qingdao varies periodically and dramatically (green line in **Figure 4(a)**) with a slow increasing trend (blue line in **Figure 4(a)**), and the mean precipitation is about 681.78 mm·yr^{-1}. In 1981 Qingdao has the least precipitation, which is only 308.3 mm, while it is up to 1353.2 mm in 2007. From the trend analysis of **Figure 5**,

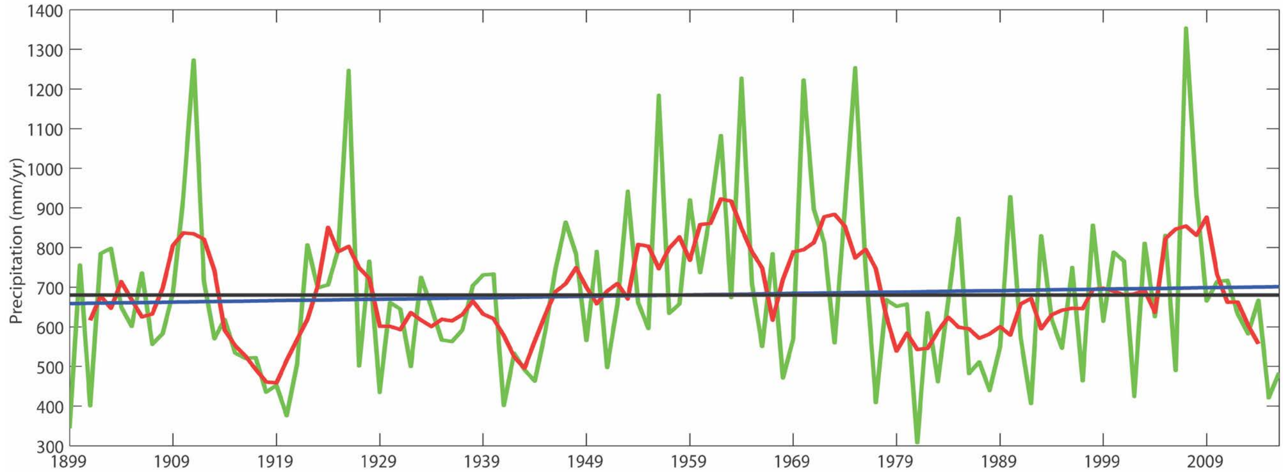

Figure 4. Same as **Figure 1(a)** but for annual accumulative precipitation.

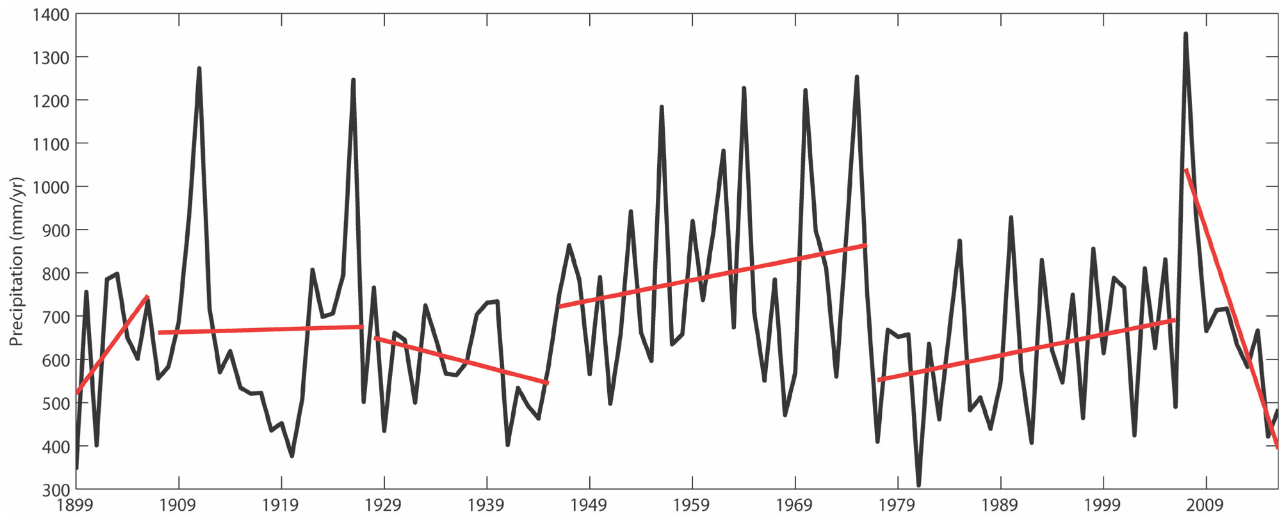

Figure 5. Same as **Figure 3(a)** but for the annual accumulative precipitation.

the precipitation increases greatly during 1899-1906, but this increasing trend may only reflect its interanual oscillation amplitude. The five-point slide smoothing results (red line in **Figure 4**) show obvious interdecadal variation from 1907 to 1927, the yearly precipitation difference in a dry and a wet year is up to 900 mm or so, which is far more than the climate mean precipitation. After then, the yearly precipitation varies in a tight range without extreme events from 1928 to 1945, and most years varies below average with a significant decreasing rate of 58.4mm per decade. The interannual variability of precipitation in Qingdao becomes increasingly obvious with a shorter cycle since 1946. Besides, the UF keeps rising from 1946 to 1976 (**Figure 6**), which indicates that the precipitation is in an increasing tendency (26.1 mm per 10a). In addition, the precipitation is more than the climatology in most of years. However, the precipitation has suddenly dropped to a low level since 1977 (green or red line in **Figure 4**) with decreasing UF (**Figure 6**), which indicates that Qingdao enters a

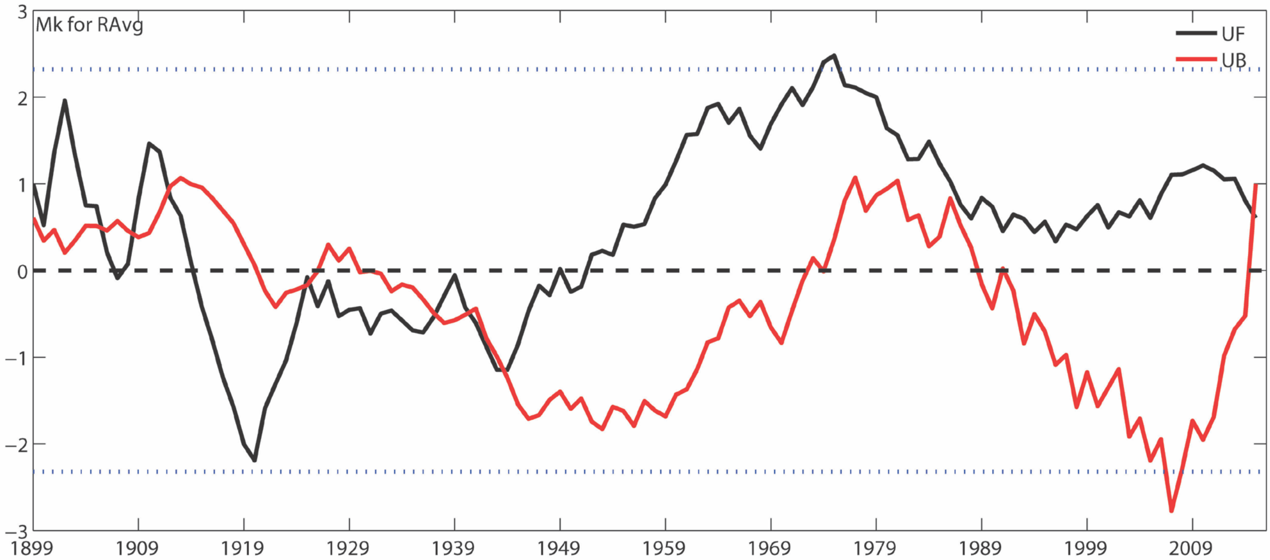

Figure 6. Same as **Figure 2(a)** but for the annual accumulative precipitation.

stage of low precipitation again. Nevertheless, the precipitation keeps increasing (46.5 mm per 10a) slowly after 1977 until it reaches the peak in 2007, which is the most in 117 years. And then it declines year by year.

4. The Trends of Temperature and Precipitation for Different Seasons in Qingdao

Figure 7 shows the yearly seasonal mean temperatures and their linear trends in spring, summer, autumn, and winter from 1899 to 2015. The seasonal temperatures for the four seasons are all on the rise with different increasing rates of 1.44˚C per 100a, 0.67˚C per 100a, 0.88˚C per 100a, and 1.32˚C per 100a. Compared with the increasing rate of 1.11˚C per 100a for the TAvg, the warming rates in summer and autumn especially the former are far below that of the TAvg, the steeper rise of temperature in spring and winter was the mainly distributor to the significant warming of TAvg. That is to say that the significant warming temperature in spring and winter in Qingdao responses the most to global warming.

As for the seasonal precipitation (**Figure 8**), the precipitation varies widely year by year for the four seasons but with no obvious variation trend except for spring. The precipitation increases 28.1 mm, 12.2 mm, and 14.4 mm respectively in spring, summer, and autumn, but decreases about 4.6 mm in winter, and their variation rates are 24.1 mm/100a, 10.4 mm/100a, 12.3 mm/100a, and −3.9 mm/100a.

5. Conclusions

The meteorological data in Qingdao from January 1899 to December 2015 were adopted, and their climate change and their response to global warming were investigated in this study.

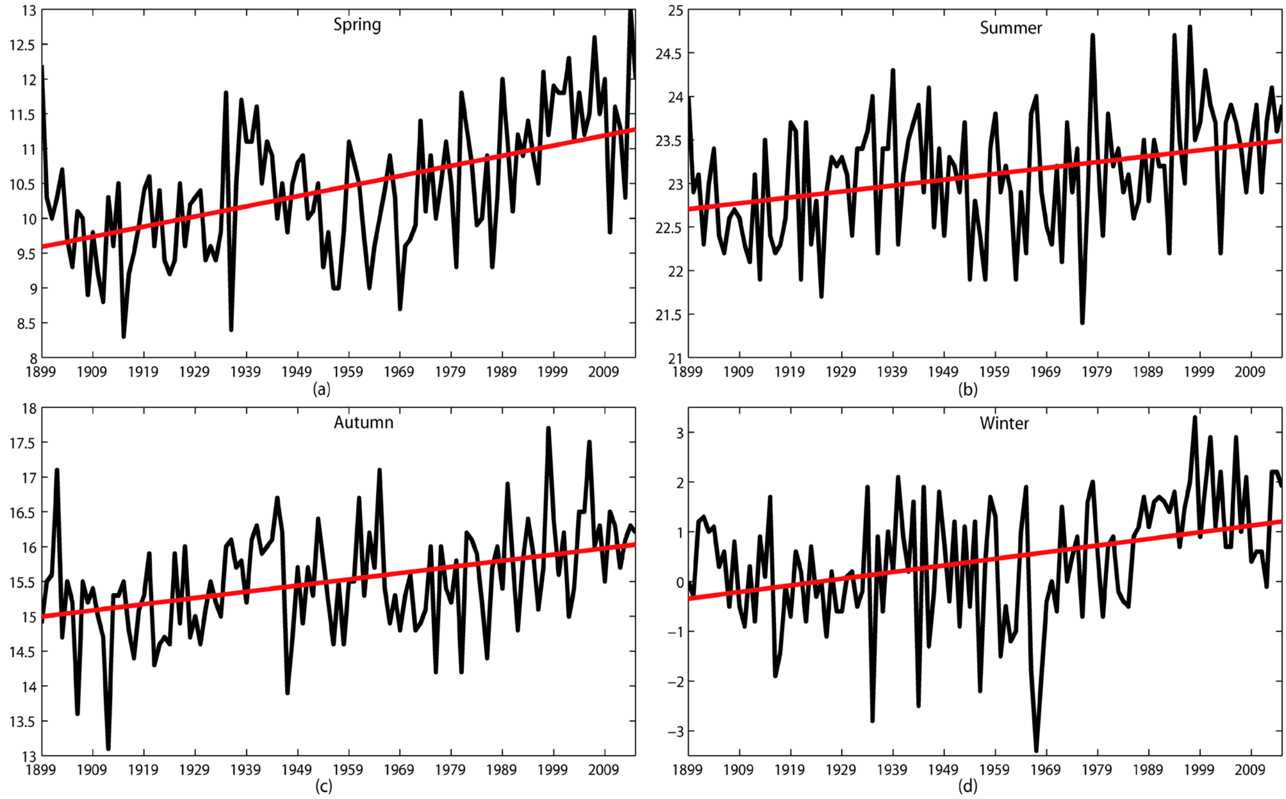

Figure 7. Time series of seasonal mean temperature (black line) and their linear trend (red trend) in spring (a); summer (b); fall (c); and winter (d) during 1899-2015.

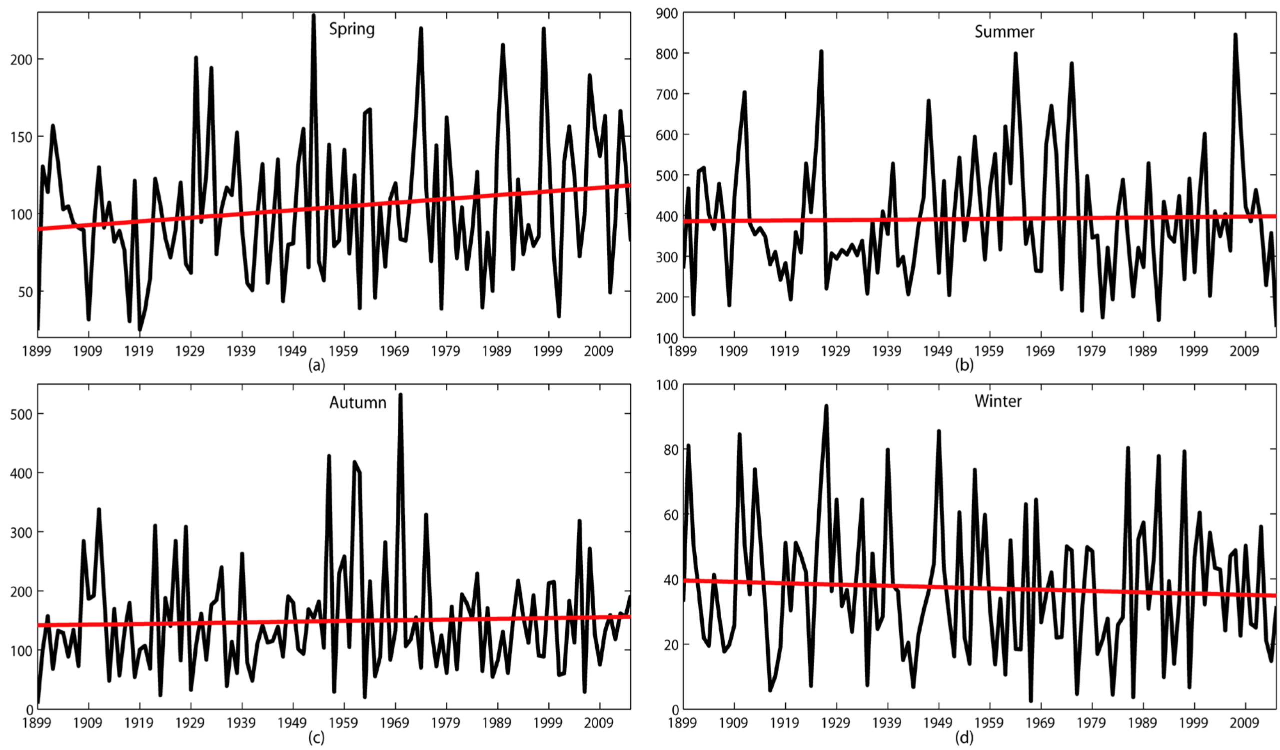

Figure 8. Same as **Figure 7** but for seasonal accumulative precipitation.

For the past 117 years from 1899 to 2015, the TAvg changes in a periodic and obvious fluctuating way, and the average temperature is 12.4˚C. In addition, the lowest and highest TAvg occurred in the previous and last two decades separately since the observations available. The average TMax is 33.12˚C, and the highest TMax (38.9˚C) occurred in 2002 is 5.78˚C higher than the climate mean. The climate mean of TMin is −10.81˚C from 1899 to 1913, and −12.75˚C from 1915 to 1936 respectively. The extreme minimum temperature occurred in 1931 (−16.9˚C) during this cold period. While the climate mean of TMin for the period 1939-2015 rises up to −10.07˚C, which grows about 2.54˚C in 77 years.

As for the climate trend variations about the TAvg, TMax, and TMin, it is found that they all go through several warm and cold periods, and they all increase with different warming rates as a response to global warming during 1899-2015. The TAvg exhibits a statistically significant linear warming of 1.11˚C per 100a over the period 1899 to 2015, which is only 0.80˚C per 100a for the TMax from 1915 to 2015. However, the warming rate of the TMin is 3.30˚C per 100a from 1939 to 2015, which is almost 4 times more than the TMax. Qingdao entered into an evident warming period since 1979, and the time point of abrupt change for the TMin is 2 or 3-years later than the TAvg, while there is no abrupt change of TMax in Qingdao. It seems that the TAvg reflects more the TMin evolution for the most part, either as a trend or an abrupt change. Thus it can be concluded that the contribution of TMin to Tavg is far greater than that of TMax. Besides, the steeper rise of temperature in spring (1.44˚C per 100a) and winter (1.32˚C per 100a) are the mainly distributor to the significant warming of TAvg in Qingdao. That is to say that the significant warming temperature in spring and winter responses the most to global warming.

In terms of the annual precipitation in Qingdao, it varies periodically and dramatically with a slow increasing trend, and the mean precipitation is about 681.78 mm·yr^{-1} for the past 117 years from 1899 to 2015. In 1981 Qingdao has the least precipitation, which is only 308.3 mm, while it is up to 1353.2 mm in 2007. As for the seasonal precipitation, the precipitation varies widely year by year for the four seasons but with no obvious variation trend except for spring.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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