Changes and Drive Mechanism of Climate Extremes During Recent 60 Years in Qilian Mountains, Northwestern China

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Abstract

A interesting study of analyzing the temporal and spatial characteristics and the reason change of extreme climate indexes based on the daily precipitation and temperature data of 24 meteorological stations in Qilian Mountains from 1961 to 2017. The results showed that the interannual change of the warming index of extreme temperature was similar to that of the cold index of extreme temperature. All daily indexes of extreme precipitation except CWD passed the significance level test of 5%. All daily indexes of extreme precipitation except for CDD in Hexi inland river basin, Qaidam inland river basin and Yellow river basin showed an increasing trend. However, the increasing extent of CWD, R10MM, R20MM and R25MM in Yellow river basin was lower than that of Qilian Mountain. The warming range of the four indexes (TX10, TN10, TXN and TNN) decreased from south to north. The spatial distribution of PRCPTOT, SDII, RX1DAY, RX5DAY, R95 and R99 was similar in the Qilian Mountains. The central part of the Qilian Mountains was the area with larger increasing region, and the increase region decreased from inside to outside. TX10, TN10, ID, FD showed a significant negative correlation with altitude, while TXN, TNN showed a significant positive correlation with altitude. The changes of TX10, TN10, TXN, TNN, ID, FD and DTR were the most obvious in the high altitude area (> 2500m), and the changes of TN90, TX90, TXX, TNX and GSL were the most obvious in the low altitude area (< 2500m). Qilian Mountains, Hexi inland river basin and Qaidam inland river basin were greatly affected by the AMO, NTA, CAR, SCSSMI, SAMSMI and were slightly affected by the Nino4, NAO, NP, SOI, AO, MEI. Extreme precipitation days indexes of Yellow river basin is highly correlated with AO and SCSSMI. The effect of the circulation index of Atlantic multidecadal Oscillation, Tropical Northern Atlantic Index, Tropical Southern Atlantic Index, North Tropical Atlantic SST Index, Caribbean SST index on the extreme temperature warm index was stronger than that of extreme temperature cold index.

1. Introduction

The fifth report of the IPCC (IPCC, 2013) shows that the atmosphere and ocean system have warmed and the ice and snow have decreased. These changes led to the sea level risen and the concentration of greenhouse gases increased since the 1950s. The global average surface temperature has been in a significant linear increasing trend from 1880 to 2012, with the risen by 0.85 ℃. Under global warming, extreme low temperature events showed a decreasing trend, but extreme high temperature events shows an increasing trend. Moreover, the heat waves occurred more frequently (Easterling et al, 2000; Roy, 2019; Rashid et al., 2020; Sangkharat et al., 2020). The impacts of extreme climate events (including ecosystem changes, disruptions in food production and water supply, destruction of infrastructure and settlements, and increased morbidity and mortality) have had significant negative impacts (Singh et al., 2019; Li et al., 2019).

Recent years, many scholars have done much research works on variation of extreme climate events at different scales. Cold nights reduced and warm nights increased obviously. But cold day and cold night, warm day and warm night all show warming trend in more than 70% of the region in the world(Alexander et al., 2006; Almazroui and Saeed, 2020). The general tendency of extreme temperature in Australia, West Africa, Asia-Pacific and Indo-Pacific regions change accords with global extreme temperature change, but the regional characteristic is also distinct. The change of extreme temperature in China is generally consistent with global change. Zhai et al (2003) analyzes the extreme minimum temperature and the extreme maximum temperature are warming in northern China in the past 50 years (He et al., 2018; Yin et al., 2020). Zhou et al (2010) finds that the number of frost days and freezing days in mainland China shows a decreasing trend significantly and the areas with significant reduction are concentrated in the northern China. The number of summer days and hot nights increases significantly. The areas with significant increase are mainly in the central and eastern regions. At the same time, scholars at home and abroad have found that the change of extreme precipitation events in different scales: the strong precipitation events in the regions with increased total precipitation are likely to increase significantly in the global scope. Even if the average total precipitation decreases or remains unchanged, there is also the phenomenon of increased heavy precipitation and its frequency (Chen et al., 2009; Cheng et al., 2019). The study of extreme precipitation in Asia Pacific Region (Choi et al., 2009), India Pacific Region (Caesar et al., 2011), the United States (Kunkel et al., 2003), western Africa (Aguilar et al., 2009) and other regions confirmed the above conclusions. The change of extreme precipitation in China is generally consistent with the global change, but the trend of extreme precipitation index shows different trends. You et al (2011) studied the characteristics of extreme precipitation events and pointed out that the total precipitation shows an increasing trend, and most of the extreme precipitation indexes are highly correlated with the total precipitation in China. Zhai et al (2005) have found that there are regional differences in the trend of extreme precipitation change in China. The Yangtze River Basin, western China and southeast coastal areas have showed an increasing trend, while the basins in the south of Northeast China, North China and Sichuan province shows a decreasing trend.

Under climate change from "warm and dry" to "warm and wet" in Northwest China, it is necessary to understand the trend and law of regional climate change. Qilian Mountain located in the intersection of the three plateaus of Qinghai Tibet Plateau, Neimenggu-Xinjiang Plateau and Loess Plateau. It is composed of the mountains in the west of Gansu province and the northeast border of Qinghai Province. It is known as the "lifeline" of Hexi corridor. This area is a typical climate sensitive area and fragile ecological environment zone. The frequency and aggravation of extreme climate events will inevitably have an important impact on its ecological environment. In recent years, most of the studies on climate change in Qilian Mountains have focused on the temporal and spatial distribution of temperature. However, there are few studies on extreme climate, and the research on the causes of their spatial and temporal changes is relatively scarce. Therefore, this study selects 12 extreme temperature indexes and 12 extreme precipitation indexes based on daily temperature and precipitation data of long time series uses linear trend estimation method and spline interpolation method and correlation analysis method to analyze the temporal and spatial variation characteristics of extreme temperature index and extreme precipitation index in Qilian Mountain in recent 60 years. This paper analyzes the response of each extreme temperature index and each extreme precipitation index to the atmospheric circulation index and provides a scientific basis for the comprehensive understanding of the regional climate change.

2. Study Areas And Methods

2.1 Study area

The north of Qilian Mountain is Hexi corridor, west is Altun Piedmont, south is Qaidam Basin and Chaka Basin, and southeast is Qinling Mountains and Liupanshan Mountains. Qilian Mountains (93.4°~103.4°E, 35.8°~40.0°N) sits on two province: Gansu province and Qinghai province, and with an average altitude of 4000-4500 m. Qilian Mountain is a transitional area between the northwest desert area and the Alpine Region of Qinghai-Tibet Plateau, where is far from the ocean and has features of typical continental climate and Plateau climate. The eastern part of the study area is affected by the southeast monsoon and the southwest monsoon. The western part is controlled by the westerly circulation. The central part is at the intersection of the two circulation systems. The natural condition of Qilian Mountains is complex. The difference of hydrothermal condition is big. Annual average temperature is 0.6 ℃. Annual precipitation is from 400 mm to 700 mm. The climate is a typical plateau continental climate. There are many rivers in the Qilian Mountains, and the vegetation distribution presents unique vertical zonal characteristics. The soil system also has a distinct vertical band spectrum.

2.2 Data sources and research methods

The daily temperature data and daily precipitation data of 24 meteorological stations (Figure 1, Table 1) in the Qilian Mountains from 1961 to 2017 were selected in the study. The meteorological data come from China Meteorological Data Network (http://data.cma.cn/). The extreme temperature indexes and extreme precipitation indexes defined in WMO (Peterson, 1998-2001) were used to defined and calculated the extreme indexes, and twelve extreme temperature indexes (Table 2) and twelve extreme precipitation indexes (Table 3) were calculated by RClimDex software (Zhang et al, 2015). In this paper, data sets must pass quality control before they were calculated and considering the uniformity and completeness of data in selected sites from January 1, 1961 to December 31, 2017. Twelve atmospheric circulation indexes are used to study the circulation influencing factors of extreme temperature variation in Qilian Mountains, including: Atlantic Multidecadal Oscillation(AMO),Tropical Northern Atlantic index(TNA), Tropical Southern Atlantic index(TSA), Northern Tropical Atlantic index(NTA), Caribbean SST index(CAR), Northern Atlantic Oscillation(NAO), North Pacific model(NP), Arctic Oscillation(AO), Southern Oscillation index(SOI), Multiple ENSO index(MEI), South China Sea Summer Monsoon(SCSSMI). The South China Sea summer monsoon index are from NOAA Earth System Research Laboratory (https://www.esrl.noaa.gov/psd/data/climateindexes/list/).

When analyzing the temporal variation trends of the extreme temperature and precipitation indexes, we use a linear return equation to fit series variables. And when trying to decide whether the trend of climate change is significant or not, it is necessary to test the correlation coefficient between time and original sequence variables (Wei et al., 1999). By ArcGIS software, the spatial distribution map of climate element tendency rate change is drawn, and the spatial change analysis is carried out. Pearson correlation analysis method is used to analyze the correlation between extreme temperature index and the extreme precipitation indexes and atmospheric circulation index(Yu et al.,1999).

3. Results

3.1 Interannual Variation of Extreme Temperature

As shown in Table 4, TX10 and TN10 showed a significant decrease trend from 1961 to 2017, with a decrease rate of 1.16d/10a and 2.47d/10a, respectively. TXN and TNN showed an increasing trend by the rates of 0.36℃/10a and 0.51℃/10a from 1961 to 2017, respectively. The interannual change of the cold index of extreme temperature was similar. The climate of the study area was warming obviously in the mid-later 80's of 20 centuries. TX10, TN10 and TNN showed an increasing trend significantly in the 1990s. However, the warming decreased from 2000 to 2009 and increased significantly after 2010 (Fig. 2). Compared with the day index, the night index has a larger warming range. More importantly, compared with the cold index, the warming index of extreme temperature showed an increasing trend (Fig.2, Table 4). TN90 and TX90 increased by the rate of 2.39d/10a and 1.68d/10a from 1961 to 2017, respectively, and the results passed the significance level test. TXX and TNX increased significantly during the study period, with the rate of 0.32 ℃/10a and 0.42 ℃/10a, respectively. Moreover, the interannual change of the warming index of extreme temperature was similar to that of the cold index of extreme temperature. The climate of the study area was warming obviously after 1985, especially during the 1990s. But the TXX and TNX decreased from 2000 to 2009 and increased after 2010. The warming index of extreme temperature also confirmed that the warming range of night index was larger than that of day index. Compared with the cold index of extreme temperature, the change range of the warming index of extreme temperature was small.

In the past 60 years, ID and FD have decreased significantly by the rates of 3.30d/10a and 3.86d/10a, respectively (Fig.2). ID had been warming continuously during the study period. FD had been warming slightly before the middle and late 1980s, and then had been warming linearly. DTR decreased significantly by the rate of 0.16 ℃/10a, which confirmed that the night index was warmer than the day index. GSL increased significantly by the rate of 3.48d/10a, and the interannual change showed a fluctuating warming trend, and a large linear warming trend after the middle and late 1980s.

3.2 Regional difference of extreme temperature index

Table 5 showed the results from comparing and analyzing the change range of extreme temperature index in Qilian Mountain, China and other regions in the same period. The analysis showed that the change range of the extreme temperature index of Qilian Mountain was consistent with that of the China and other regions, but also showed regional differences. The cold index of TX10, TN10 and TNN in Qilian Mountain was smaller than that in other areas, while the ID and FD was larger than that in other areas. There was no significant difference in TXN. The TXX, TNX and GSL was larger than that in other areas, and TX90 and TN90 were smaller than that in other areas. DTR was slightly larger than that of the whole country (Zhou et al., 2011), the Qinghai Tibet Plateau (Zhao et al., 2014), far larger than Mount Everest (Du et al., 2016), and smaller than that of Northwest China (Zhao et al., 2017), Tianshan Mountains (Ding et al., 2018). It was worth noting that the relative indexes (TX10, TN10, TX90, TN90) was far smaller than that of the whole country, Northwest China, Qinghai Tibet Plateau, Tianshan mountain area, Mount Everest, and larger than that of the Qilian Mountain and the Taolai River Basin (Gao et al., 2014), which was not significantly different from that of the Qinling Mountain (Zhang et al., 2018). In general, the cold index (ID, FD) and warming index (TXX, TNX, GSL) in Qilian Mountain were larger than that in other areas, which showed that the extreme low temperature events in Qilian Mountain were less than that in other areas, the extreme high temperature events were more than that in other areas, and the trend of climate warming in Qilian Mountain was more obvious.

3.3 Interannual variation of extreme precipitation

PRCPTOT, SDII, RX1DAY, RX5DAY, R95 and R99 of Qilian Mountains changed by the rates of 13.86mm/10a, -0.01mm/d/10a, 0.76mm/10a, 1.37mm/10a, 4.10mm/d/10a and 1.29mm/d/10a from 1961 to 2017, respectively. More importantly, all extreme precipitation indexes except SDII passed the 5% significance level test. The increasing extent of PRCPTOT, SDII, RX1DAY, RX5DAY, R95 and R99 were 41.8%, 3.8%, 27.2%, 31.9%, 72.8% and 66.1% respectively. The extreme precipitation indexes of the three basins in Qilian Mountain were increasing except for the SDII in the Yellow River Basin. Moreover, the increasing extent of the extreme precipitation indexes in the Yellow River Basin was lower than that of the Qilian Mountain, and the inland river basins in Hexi and Qaidam were higher than that of the Qilian mountain or equivalent to that of the Qilian Mountain (Table 6).

As shown in Fig. 3, the interannual variation of PRCPTOT, RX5DAY and R95 indexes in Qilian Mountain showed a large increase in the 1980s and from 2000 to 2017, while showed a small increase or a decrease in the 1990s. The trends of SDII, RX1DAY and R99 indexes were relatively stable. The increasing extent of SDII, RX1DAY and R99 indexes was large after 2010. The trend of PRCPTOT, SDII, RX1DAY, R95, R99 and RX5DAY indexes in Hexi inland river basin were relatively stable. All indexes except RX5DAY showed an increasing trend after 2010. The interannual variation of PRCPTOT, RX5DAY and R95 indexes in Qaidam inland river basin increased significantly in the 1980s and from 2000 to 2017, while decreased during the 1990s. Moreover, SDII, RX1DAY and R99 maintained a stable trend and with a large increase after 2010. The interannual variation of PRCPTOT and R95 indexes in the Yellow River Basin increased significantly in the 1980s and from 2000 to 2017, while decreased during the 1990s. SDII, RX1DAY and RX5DAY kept a stable trend, but increased slightly after 2000. R99 increased significantly from 1980 to 1999 and from 2010 to 2017 and increased slightly from 2000 to 2009.

Rainy days, CWD, R10MM、R20MM and R25MM changed by the rates of 5.79d/10a, 0.06d/10a, 0.40d/10a, 0.09d/10a and 0.05d/10a, respectively. All daily indexes of extreme precipitation except CWD passed the significance level test of 5%. The increasing extent of rainy days, CWD, R10MM、R20MM and R25MM were 43.5%, 12.6%, 47.0%, 62.9% and 64.6% respectively. All daily indexes of extreme precipitation except for CDD in Hexi inland river basin, Qaidam inland river basin and Yellow River Basin showed an increasing trend. However, the increasing extent of CWD, R10MM, R20MM and R25MM in Yellow River Basin was lower than that of Qilian Mountain. But the increasing extent in Hexi inland river basin and Qaidam inland river basin was higher than that of Qilian Mountain (Table 6). The interannual variation of the rainy days, R10MM, R20MM and R25MM in the Qilian Mountains, Qaidam inland river basin and the Yellow River Basin increased significantly in the 1980s and after 2010, while decreased in the 1990s. rainy days in the Hexi inland river basin showed a decreasing trend in the 1990s, and other years increased steadily. R10MM, R20MM and R25MM has a relatively stable increase trend and with a large increase after 2010. The CWD index in Qilian Mountain, Hexi inland river basin and Qaidam inland river basin decreased from 1980 to 1999 and increased after 2000. The CWD index in the Yellow River Basin maintained a stable trend and with a large increase after 2000. CDD decreased significantly by the rate of 26.35d/10a, with a reduction rate of 49%. The reduction in Yellow River basin and Hexi inland river basin was greater than that of Qilian Mountains, while that of Qaidam inland river basin was less than that of Qilian Mountains. The interannual changes of Qilian Mountains and three basins decreased significantly in the 1980s and increased significantly in the 1990s. After 2000, the inland river basin of Qaidam and the Yellow River Basin showed a decreasing trend, and the inland river basin of Hexi increased significantly after 2010 (Fig. 3).

3.4 Spatial distribution of extreme temperature

As shown in Fig. 4, the warming amplitude of 24 stations for TX10 had passed the significance level test. All stations except Xining station for TN10 also passed the significance level test. TXN and TNN of all stations showed a warming trend, while 42% and 58% of the stations have passed the significance level test, and these stations are mainly located in the area with large warming range. In general, the warming range of the four indexes (TX10, TN10, TXN and TNN) decreased from south to north.

As shown in Fig. 4, 60% to 100% of the stations showed significant warming. Meanwhile, TN90 and TNX of all stations show warming range (Fig.4). All stations except Xining station had passed the significance level test. The warming trend of 24 stations for TX90 passed the significance level test. TXX of all stations showed a warming trend, and 67% of stations had passed the significance level test. These stations mainly located in the area of large warming range. The above four indexes all take the middle and east of Qilian Mountains as the small warming range, TN90 and TNX increase in a ring, TX90 and TXX increase in a band.

The ID and FD of all stations showed a warming trend (Fig. 4). All stations except for Dunhuang station for ID and Xining station for FD passed the significance level test. The warming trend of ID and FD decreased from south to north of Qilian Mountains. 92% of stations for DTR showed a decreasing trend, while 75% of stations passed the significance level test. However, Yumen station and Xining station showed a significant increasing trend, which may be due to the acceleration of urbanization process and the change of underlying surface properties, resulted in a higher heating rate of day index than night index (Lin et al, 2017). The 24 stations for GSL passed the significance level test. The spatial distribution of GSL was small in the middle and east of Qilian Mountains, and increasing from inside to outside.

3.5 Spatial distribution of extreme precipitation index

As shown in Fig. 5, the spatial distribution of PRCPTOT, SDII, RX1DAY, RX5DAY, R95 and R99 in the Qilian Mountains was similar. The central part of the Qilian Mountains was the area with larger increasing region, and the increase region decreased from inside to outside. The PRCPTOT of all stations showed an increasing trend, of which 17 stations passed the significance level test. The stations with no significant increasing trend were mainly located in the edge of Qilian Mountain with a small increasing region. The Yeniugou station in the middle of Qilian Mountain had the largest increasing trend, reaching 45.57mm/10a. The SDII of 11 stations showed an increasing trend, mainly located in the Qaidam inland river basin, of which only the tole station showed a significant increase, indicating that the increase of precipitation in this area may be the result of the increase of precipitation intensity. The stations with a decreasing trend of SDII were mainly located in the east and west of the Qilian Mountains, and only the decrease trend of Minhe station passed the significance level test. RX1DAY of 19 stations and RX5DAY of 21 stations showed an increasing trend, while the stations with a significant increasing trend were mainly located in the middle of the Qilian Mountains. However, the stations with a decreasing trend of RX1DAY and RX5DAY mainly located in the eastern part of the Qilian Mountains. Compared with RX1DAY, the areas with a large increasing range of RX5DAY were concentrated in the Qaidam inland river basin. R95 and R99 showed a similar trend of change, R95 and R99 of 19 stations showed an increasing trend. R95 and R99 of 6 stations showed a significant increasing trend, and the significantly increased stations were mainly located in the middle of the Qilian Mountains. R95 and R99 of 5 stations showed a decreasing trend and mainly located in the eastern part of the Qilian Mountains. Compared with R95, R99 showed a significant increase in the region to the East.

The spatial changes of R10MM, R20MM, R25MM and rainy days were similar to those of extreme precipitation index. The central part of Qilian Mountain was a large increasing region, and the increase range was decreasing from inside to outside. R10MM, R20MM, R25MM of more than or equal to 20 stations showed an increasing trend. The significantly increased stations were mainly located in the middle of the Qilian Mountains, while the stations with a decreasing trend were mainly located in the east of the Qilian Mountains. The number of rainy days in all stations showed an increasing trend. Except for Guide station, other stations passed the significance level test. The increasing extent of Yeniugou station in the middle of Qilian Mountain was the most and by reaching 13.26d/10a. The 24 stations that CDD showed a significant decreasing trend. The spatial distribution of the stations was in the central and western of Qilian Mountains, and the decreasing range decreased to the east. The CWD of 19 stations showed an increasing trend, of which the increasing trend of 3 stations passed the significance level test, which mainly located in the western part of Qilian Mountains. The decreasing trend of 5 stations failed to pass the 5% significance level test and mainly located in the middle and eastern part of Qilian Mountains.

4. Discussion

4.1 Influencing factors of extreme temperature index

4.1.1 Relationship between extreme temperature index and elevation

It can be seen from Table 7 that the change range of extreme temperature index in Qilian mountain showed a good statistical relationship with altitude. The correlation coefficients of TX10, TN10, TXN, TNN, ID, FD and altitude passed the significance level test of 0.05. TX10, TN10, ID, FD showed a significant negative correlation with altitude, while TXN, TNN showed a significant positive correlation with altitude. For every 100m elevation increasing, TX10, TN10, ID and FD decreased by 0.03d/10a, 0.07d/10a, 0.13d/10a and 0.09d/10a, respectively. TXN and TNN increased by 0.01 °C/10a and 0.02 °C/10a. As for the altitude, the warming range of night index (TNN, TN10) was larger than that of day index (TXN, TX10).

Linear trends of extreme temperature indexes of different elevations in Qilian Mountainsin 1961- 2017 showed in Table 8. The change characteristics of each index were different. The changes of TX10, TN10, TXN, TNN, ID, FD and DTR were the most obvious in the high altitude area (> 2500m), and the changes of TN90, TX90, TXX, TNX and GSL were the most obvious in the low altitude area (< 2500m). The results showed that the change of cold index and other indexes was the most obvious in high altitude area. The change of warm index was the most sensitive in low altitude area, which was similar to the characteristics of the relationship between extreme temperature index and altitude in Tibet (Du et al., 2013) and southwest area (Li et al., 2012).

4.1.2 Relationship between extreme temperature index and atmospheric circulation

The pearson correlation analysis method is used to establish the correlation between the extreme temperature index and the circulation index, so as to further research the relationship between the extreme temperature index and the circulation index of Qilian Mountain(Table 9). AMO, TNA, TSA, NTA and CAR were indexes indicating the sea level surface temperature (SST) of the Atlantic Ocean. AMO is a long-period interdecadal sea surface temperature anomaly rate mode with basin scale in the North Atlantic region (Folland et al, 1986; Delworth et al, 2000), which has the strongest correlation with each extreme temperature index and has passed the significance level test. Nino4 is the sea level surface temperature (SST) index of the central tropical Pacific Ocean. Compared with the warm index, it has a significant correlation with the cold index of the extreme temperature in the Qilian Mountains. The four major waves (NAO, NP, SOI and AO) cover most of the global ocean area, and have an important impact on the climate of the adjacent land, but the correlation with the extreme temperature index was not significant in Qilian Mountain. SOI and MEI are the indexes of ENSO, but there is no significant correlation between other indexes. Compared with the cold index, the correlation between SCSSMI and extreme air temperature index was significant. The AMO and SCSSMI were positively correlated with TX10, Tn10, ID, FD and DTR, and negatively correlated with other extreme temperature indexes. TNA, TSA, NTA, CAR, Nino4 indexes were negatively correlated with the AMO, SCSSMI and extreme temperature indexes.

4.2 Influencing factors of extreme precipitation index

4.2.1 Relationship between extreme precipitation index change and elevation

The correlation analysis between the change range of extreme precipitation index and elevation in Qilian Mountain, Hexi inland river basin, Qaidam inland river basin and Yellow River Basin was shown in Table 10. The correlation coefficient between all extreme precipitation indexes except CDD and CWD and altitude in Qilian Mountain and Hexi inland river basin passed the significance level test. The correlation between the change range of extreme precipitation index and altitude in Qilian Mountain was lower than that in Hexi inland river basin. The correlation coefficient of RX1DAY, CDD and rainy days with elevation passed the significance level test in Qaidam inland river basin. The correlation coefficient of PRCPTOT, R95, CDD, R10MM and rainy days with altitude also passed the significance level test in the Yellow River Basin. Compared with Qilian Mountain and Hexi inland river basin, the correlation between extreme precipitation index and altitude was relatively low in the Qaidam inland river basin and Yellow river basin. The stations were mainly distributed between 2500 and 3500m above sea level in Qaidam inland river basin, while the stations were widely distributed and the number of stations was only 4 in the Yellow river basin .

There was significant positive correlation between altitude and PRCPTOT, RX1DAY, RX5DAY, R95, R99, R10MM, R20MM, R25MM and rainy days in the Qilian Mountain and Hexi inland river basin. Moreover, there was also significant positive correlation between altitude and the RX1DAY and rainy days in the Qaidam inland river basin. There was significant positive correlation between altitude and PRCPTOT, R95, R10MM and rainy days in the Yellow River Basin. These results reflected the more obvious increase of precipitation and rainy days in the high altitude area. More importantly, the significant positive correlation between altitude and SDII in the Qilian Mountain and Hexi inland river basin, which reflected that the decrease of precipitation intensity decreased with the increase of the altitude. However, the CDD showed a significant negative correlation with the altitude in the Inland River Basin in Qaidam and the Yellow River Basin, which reflected that the decrease of the continuous dry days mainly occurred in the high altitude area. For every 100 m elevation increasing, the decrease of SDII in Qilian Mountain decreased by 0.01mm/d/10a, and the increase of PRCPTOT, RX1DAY, RX5DAY, R95, R99, R10MM, R20MM, R25MM and rainy days increased by 1.23mm/10a, 0.04mm/10, 0.10mm/10a, 0.44mm/d/10a, 0.20mm/d/10a, 0.04d/10a, 0.01d/10a, 0.01d/10a and 0.25d/10a

Table 11 showed the change range of extreme precipitation index in different altitudes of Qilian Mountain. The change range of extreme precipitation indexes except SDII was relatively large in the high altitude area (> 2500m). It can be seen that there were 10 stations above 2500m in Qilian Mountain, among which 6 stations were distributed in Qaidam inland river basin (Table 1). So it can also be seen that the change range of extreme precipitation index was the most obvious in Qaidam inland river basin.

4.2.2 Relationship between extreme precipitation index and atmospheric circulation

As shown in Table 12, the correlation of the extreme precipitation indexes of Qilian Mountain, Hexi inland river basin and Qaidam inland river basin was higher, while that of the Yellow River Basin was lower. AMO was a long period interdecadal sea surface temperature anomaly rate mode with basin scale in the North Atlantic region (Folland et al., 1986; Delworth et al., 2000). The correlation between the extreme precipitation index of Qilian Mountain and Qaidam inland river basin and the extreme precipitation day index of Hexi inland river basin was the strongest. NTA had a high correlation with the index of extreme precipitation in Qilian Mountain and Qaidam inland river basin. CAR had a high correlation with the index of extreme precipitation in Qilian Mountain and Hexi inland river basin, and each extreme precipitation index in Qaidam inland river basin had a high correlation. Nino4 was the sea level surface temperature (SST) index of the middle tropical Pacific Ocean, which had a low correlation with the extreme precipitation index of Qilian Mountain and its three basins. The four major waves (NAO, NP, SOI and AO) cover most of the global ocean area, and have an important impact on the climate of adjacent land. The correlation between the four waves and the extreme precipitation index was not significant in the Qilian Mountain, Hexi inland river basin and Qaidam inland river basin. But the correlation between AO and extreme precipitation day index was high in the Yellow River Basin. SOI and MEI were the indexes of ENSO, but they were not significantly correlated with the extreme precipitation indexes in the Qilian Mountain and its three basins. SCSSMI has a high correlation with the extreme precipitation index in the Qaidam inland river basin, the Yellow River Basin, and the Qilian Mountains and Hexi inland river basin. SAMSMI had a good correlation with the extreme precipitation index in the Qilian Mountain and Qaidam inland river basin, but no correlation with the extreme precipitation index in the Hexi inland river basin and the Yellow River Basin.

The indexes of AMO, NTA and CAR in the Qilian Mountain and its three basins were negatively correlated with the indexes of SDII and CDD, while positively correlated with other extreme precipitation indexes. The AO index was negatively correlated with CDD and positively correlated with other extreme precipitation indexes. The correlation between SCSSMI, SAMSMI and extreme precipitation index was generally opposite to that between AO and extreme precipitation index.

5. Conclusion

Through the analysis of the extreme precipitation and temperature indexes in the Qilian Mountain, it is concluded that: compared with the day index, the night index has a larger warming range. More importantly, compared with the cold index, the warming index of extreme temperature showed an increasing trend. The interannual change of the warming index of extreme temperature was similar to that of the cold index of extreme temperature. The cold index (ID, FD) and warming index (TXX, TNX, GSL) in Qilian Mountain were larger than that in other areas, which showed that the extreme low temperature events in Qilian Mountain were less than that in other areas, the extreme high temperature events were more than that in other areas, and the trend of climate warming in Qilian Mountain was more obvious. The interannual variation of PRCPTOT, RX5DAY and R95 indexes in Qilian Mountain showed a large increase in the 1980s and from 2000 to 2017, while showed a small increase or a decrease in the 1990s. Rain days, CWD, R10MM R20MM and R25MM changed by the rates of 5.79d/10a, 0.06d/10a, 0.40d/10a, 0.09d/10a and 0.05d/10a, respectively. All daily indexes of extreme precipitation except CWD passed the significance level test of 5%. The increasing extent of Rain days, CWD, R10MM, R20MM and R25MM were 43.5%, 12.6%, 47.0%, 62.9% and 64.6% respectively.All daily indexes of extreme precipitation except for CDD in Hexi inland river basin, Qaidam inland river basin and Yellow River Basin showed an increasing trend. However, the increasing extent of CWD, R10MM, R20MM and R25MM in Yellow River Basin was lower than that of Qilian Mountain. The warming range of the four indexes (TX10, TN10, TXN and TNN) decreased from south to north. The spatial distribution of PRCPTOT, SDII, RX1DAY, RX5DAY, R95 and R99 in the Qilian Mountains was similar. The central part of the Qilian Mountains was the area with larger increasing region, and the increase region decreased from inside to outside.

TX10, TN10, ID, FD showed a significant negative correlation with altitude, while TXN, TNN showed a significant positive correlation with altitude. The changes of TX10, TN10, TXN, TNN, ID, FD and DTR were the most obvious in the high altitude area (> 2500m), and the changes of TN90, TX90, TXX, TNX and GSL were the most obvious in the low altitude area (< 2500m). Qilian Mountains, Hexi inland river basin and Qaidam inland river basin were greatly affected by the AMO, NTA, CAR, SCSSMI, SAMSMI and were slightly affected by the Nino4, NAO, NP, SOI, AO, MEI. Extreme precipitation days indexes of Yellow River basin is highly correlated with AO and SCSSMI.The effect of the circulation index of Atlantic multidecadal Oscillation, Tropical Northern Atlantic Index, Tropical Southern Atlantic Index, North Tropical Atlantic SST Index, Caribbean SST index on the extreme temperature warm index was stronger than that of extreme temperature cold index. Central Tropical Pacific SST mainly affects the extreme temperature cold indexes, while South China Sea Summer Monsoon Index mainly affects the extreme temperature warm indexes.

Declarations

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References

Aguilar, E., Aziz Barry, A., Brunet, M., Ekang, L., Fernandes, A., Massoukina, M., ... & Thamba Umba, O. (2009). Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955–2006. Journal of Geophysical Research: Atmospheres, 114(D2).

Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Klein Tank, A. M. G., ... & Tagipour, A. (2006). Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysical Research: Atmospheres, 111(D5):1042-1063.

Almazroui, M., & Saeed, S. (2020). Contribution of extreme daily precipitation to total rainfall over the Arabian Peninsula. Atmospheric Research, 231, 104672.

Caesar, J., Alexander, L. V., Trewin, B., Tse-Ring, K., Sorany, L., Vuniyayawa, V., ... & Jayasinghearachchi, D. A. (2011). Changes in temperature and precipitation extremes over the Indo-Pacific region from 1971 to 2005. International Journal of Climatology, 31(6), 791-801.

Chen, H., Fan, S., & Zhang, X. (2009). Seasonal differences of variation characteristics of extreme precipitation events over China in the last 50 years. Transactions of Atmospheric Sciences, 32(6), 744-751.

Cheng, Q., Gao, L., Zuo, X., & Zhong, F. (2019). Statistical analyses of spatial and temporal variabilities in total, daytime, and nighttime precipitation indexes and of extreme dry/wet association with large-scale circulations of Southwest China, 1961–2016. Atmospheric research, 219, 166-182.

Choi, G., Collins, D., Ren, G., Trewin, B., Baldi, M., Fukuda, Y., ... & Lias, N. (2009). Changes in means and extreme events of temperature and precipitation in the Asia-Pacific Network region, 1955–2007. International Journal of Climatology: A Journal of the Royal Meteorological Society, 29(13), 1906-1925.

Delworth, T. L., & Mann, M. E. (2000). Observed and simulated multidecadal variability in the Northern Hemisphere. Climate Dynamics, 16(9), 661-676.

Ding Zhiyong, Ge Yongxiao, Jilili·Abuduwaili. (2018). Trends of extreme temperature and precipitation in Ebinur Lake basin in Xinjiang during the period from 1957 to 2012. Journal of University of Chinese Academy of Sciences, 35(2): 160-171.(In Chinese)

Du J, Lu H Y, Yuan L. (2016). Spatio-temporal Change of Extreme Temperature Events in Mt. Qomolangma Region of Tibet from 1971 to 2012. Arid Zone Research, Loss of volume (1): Page number range missing. (In Chinese)

Du, J., Lu, H. Y., & Jian, J. (2013). Variations of extreme air temperature events over Tibet from 1961 to 2010. Acta Ecol. Sin, 68, 1269-1280.

Easterling, D. R., Evans, J. L., Groisman, P. Y., Karl, T. R., Kunkel, K. E., & Ambenje, P. (2000). Observed variability and trends in extreme climate events: a brief review. Bulletin of the American Meteorological Society, 81(3), 417-426.

Folland, C. K., Palmer, T. N., & Parker, D. E. (1986). Sahel rainfall and worldwide sea temperatures, 1901–85. Nature, 320(6063), 602-607.

Gao Yan, Feng Qi, Li Zongxing. (2014). The variation of climate extremes in the Taolaihe River Basin in the Qilian Mountains of China during 1957-2012. Journal of Desert Research, 34(3): 814-826.(In Chinese)

He, B. R., & Zhai, P. M. (2018). Changes in persistent and non-persistent extreme precipitation in China from 1961 to 2016. Advances in Climate Change Research, 9(3), 177-184.

Kunkel, K. E., Easterling, D. R., Redmond, K., & Hubbard, K. (2003). Temporal variations of extreme precipitation events in the United States: 1895–2000. Geophysical research letters, 30(17).

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, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014.Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability.Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of theIntergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea,T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken,P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and NewYork, NY, USA, pp. 1-32.

Li, L., Yao, N., Li, Y., Li Liu, D., Wang, B., & Ayantobo, O. O. (2019). Future projections of extreme temperature events in different sub-regions of China. Atmospheric research, 217, 150-164.

Li, Z., He, Y., Theakstone, W. H., Wang, X., Zhang, W., Cao, W., ... & Chang, L. (2012). Altitude dependency of trends of daily climate extremes in southwestern China, 1961–2008. Journal of Geographical Sciences, 22(3), 416-430.

Lin, P., He, Z., Du, J., Chen, L., Zhu, X., & Li, J. (2017). Recent changes in daily climate extremes in an arid mountain region, a case study in northwestern China's Qilian Mountains. Scientific reports, 7(1), 1-15.

Peterson, T. C., Folland, C., Gruza, G., Hogg, W., Mokssit, A., & Plummer, N. (2001). Report of the Activities of the Working Group on Climate Change Detection and Related Rapporteurs, Tech. Doc. 1071, 146 pp., World Meteorol. Organ., Geneva, Switzerland.

Rashid, I. U., Almazroui, M., Saeed, S., & Atif, R. M. (2020). Analysis of extreme summer temperatures in Saudi Arabia and the association with large-scale atmospheric circulation. Atmospheric Research, 231, 104659.

Roy, S. S. (2019). Spatial patterns of trends in seasonal extreme temperatures in India during 1980–2010. Weather and Climate Extremes, 24, 100203.

Sangkharat, K., Mahmood, M. A., Thornes, J. E., Fisher, P. A., & Pope, F. D. (2020). Impact of extreme temperatures on ambulance dispatches in London, UK. Environmental Research, 109100.

Singh, N., Mhawish, A., Ghosh, S., Banerjee, T., & Mall, R. K. (2019). Attributing mortality from temperature extremes: A time series analysis in Varanasi, India. Science of The Total Environment, 665, 453-464.

Yin, Y., Han, C., Yang, G., Huang, Y., Liu, M., & Wang, X. (2020). Changes in the summer extreme precipitation in the Jianghuai plum rain area and their relationship with the intensity anomalies of the south Asian high. Atmospheric Research, 236, 104793.

You, Q., Kang, S., Aguilar, E., Pepin, N., Flügel, W. A., Yan, 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.

Yu Xiulin, Ren Xuesong. (1999). Multivariate statistical analysis [M]. China Statistics Press. (In Chinese)

Wei F Y. (1999). Modern Climatic Statistical Diagnosis and Forecasting Technology. Beijing: China MeteorologicalPress. (In Chinese)

Zhai P M, Pan X H. (2003). Change in Extreme Temperature and Precipitation over Northern China During the Second Half of the 20th Century. ActaGeographicaSinica,1-10.(In Chinese)

Zhai, P., Zhang, X., Wan, H., & Pan, X. (2005). Trends in total precipitation and frequency of daily precipitation extremes over China. Journal of climate, 18(7), 1096-1108.

Zhang, J., Gou, X., Pederson, N., Zhang, F., Niu, H., Zhao, S., & Wang, F. (2018). Cambial phenology in Juniperus przewalskii along different altitudinal gradients in a cold and arid region. Tree physiology, 38(6), 840-852.

Zhao X Y, Luo L, Wang Y R. (2014). Extreme Temperature Events in Eastern Edge of the Qinghai-Tibet Plateau from 1963 to 2012. Resources Science, 36(10): 2113-2122.(In Chinese)

Zhao R F, Su Li, Zhu W. (2017).Extreme Temperature Events in Arid Region of Northwest China during 1961-2012:Seasonal Spatio-temporal Analysis. Chinese Agricultural Science Bulletin, 33(12): 63-73.(In Chinese)

Zhou, Y. Q., & Ren, G. Y. (2010). Variation characteristics of extreme temperature indexes in mainland China during 1956–2008. Climatic and Environmental Research, 15(4), 405-417.

Zhou, Y., & Ren, G. (2011). Change in extreme temperature event frequency over mainland China, 1961– 2008. Climate Research, 50(2-3), 125-139.

Tables

Table 1 the selected weather stations in Qilian Mountains area

Station Number	Station Name	Latitude	Longitude	Altitude(m)
52418	Dun Huang	40.09	94.41	1139.0
52424	An Xi	40.32	95.46	1170.9
52436	Yu Men Zhen	40.16	97.02	1526.0
52447	Jin Ta	40.00	98.54	1270.5
52533	Jiu Quan	39.46	98.29	1477.2
52546	Gao Tai	39.22	99.50	1332.2
52652	Zhang Ye	39.05	100.17	1461.1
52661	Shan Dan	38.48	101.05	1764.6
52674	Yong Chang	38.14	101.58	1976.9
52679	Wu Wei	37.55	102.40	1531.5
52797	Jing Tai	37.11	104.03	1630.9
52876	Min He	36.20	102.50	1813.9
52602	Leng Hu	38.45	93.20	2770.0
52657	Qi Lian	38.11	100.15	2787.4
52737	De Ling Ha	37.22	97.22	2981.5
52765	Men Yuan	37.23	101.37	2850.0
52856	Gong He	36.16	100.37	2835.0
52866	Xi Ning	36.44	101.45	2295.2
52868	Gui De	36.01	101.22	2237.1
52633	Tuo Le	38.48	98.25	3367.0
52645	Ye Niu Gou	38.25	99.35	3320.0
52713	Da Chai Dan	37.51	95.22	3173.2
52754	Gang Cha	37.20	100.08	3301.5
52842	Cha Ka	36.47	99.05	3087.6

Table 2 Definition of extreme temperature indexes

Index Code	Name	Definition	Unit
TX10	Daytime Extreme Low Temperature Days	The number of days when the daily maximum temperature is less than the 10th percentile value in 1961-2017.	d
TN10	Nighttime Extreme Low Temperature Days	The number of days when the daily minimum temperature is less than the 10th percentile value in 1961-2017.	d
TXn	Lowest temperature of the daily maximum	The minimum value of daily maximum temperature of each month.	℃
TNn	Lowest temperature of the daily minimum	The minimum daily temperature of each month.	℃
TN90	Highest temperature days of nights	The number of days when the night minimum temperature is greater than the 90th percentile value in 1961-2017.	d
TX90	Highest temperature days of daytime	The number of days when the daily maximum temperature is greater than the 90th percentile value in 1961-2017.	d
TXx	Highest value of daily maximum temperature	Maximum daily maximum temperature of each month.	℃
TNx	Highest value of daily minimum temperature	The maximum daily minimum temperature of each month.	℃
ID	Freezing days	Days with daily maximum temperature lower than 0 ℃.	d
FD	Frost days	Days with daily minimum temperature below 0 ℃.	d
DTR	Daily temperature range	Difference between daily maximum temperature and minimum temperature in the year.	℃
GSL	Growth season length	The total number of days when the daily average temperature is higher than 5 ℃ for at least 6 consecutive days and the total number of days when the average temperature is lower than 5 ℃ for at least 6 consecutive days after July 1.	d

Table 3 Definition of extreme precipitation indexes

Index Code	Name	Definition	Unit
PRCPTOT	The total precipitation in the rain day	Total precipitation with daily precipitation greater than 1mm	mm
SDII	Precipitation intensity in rainy days	Average rainfall on rainy days with daily precipitation greater than 1mm	mm/d
RX1DAY	Maximum precipitation per day	Maximum precipitation per day in the year	mm
RX5DAY	Maximum precipitation in five days	Maximum precipitation for five consecutive days in the year	mm
R95	Extreme precipitation	The total precipitation in rainy days with daily precipitation greater than the 95th percentile	mm
R99	Very extreme precipitation	The total precipitation of rainy days with daily precipitation greater than the 99th percentile	mm
CDD	Number of continuous dry days	Continuous days with daily precipitation less than 1mm	d
CWD	Number of continuous wet days	Continuous days with daily precipitation more than 1mm	d
R10MM	Daily precipitation more than 10 mm days	Days with daily precipitation more than 10 mm	d
R20MM	Daily precipitation more than 20 mm days	Days with daily precipitation more than 20 mm	d
R25MM	Daily precipitation more than 25 mm days	Days with daily precipitation more than 25 mm	d
\	Rainy days	Days with daily precipitation greater than 1mm	d

Table 4 Inter-annual trends of extreme temperature indexes in Qilian Mountains area

Index	1961-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2017	1961-2017
TX10(d/10a)	5.75	2.17	1.15	-2.94	1.29	**-4.86**	**-1.16**
TN10(d/10a)	-1.81	-1.51	-2.14	-4.49	-1.20	**-6.61**	**-2.47**
TXN(°C/10a)	-3.13	-1.43	2.18	1.10	-1.47	4.55	**0.36**
TNN(°C/10a)	2.13	-0.62	1.43	2.02	-0.42	4.09	**0.51**
ID(d/10a)	3.80	-5.27	-5.83	-2.83	-0.04	-20.58	**-3.30**
FD(d/10a)	-5.39	-3.63	-7.42	**-9.89**	**-13.14**	**-15.14**	**-3.86**
DTR(°C/10a)	-0.88	-0.29	-0.55	0.14	**-0.51**	-0.57	**-0.16**
TN90(d/10a)	-0.29	1.02	4.17	4.52	**6.21**	5.36	**2.39**
TX90(d/10a)	1.42	1.74	2.64	**8.61**	3.19	1.77	**1.68**
TXX(°C/10a)	-1.28	-0.95	0.10	2.65	**-2.41**	-0.12	**0.32**
TNX(°C/10a)	-0.06	-0.51	0.27	1.71	-1.20	0.41	**0.42**
GSL(d/10a)	6.10	2.53	-5.36	3.82	**13.14**	16.52	**3.48**

Note Bold words means passing the 95% confidence significance test

Table 5 Comparison between the linear trends in extreme temperature indexes in Qilian Mountains and other regions

Index	Qilian Mountains 1961-2017	China 1961-2008	Northwestern of China 1961-2012	Qinghai Tibet Plateau 1963-2012	Qingling 1960-2013	Tianshan 1960-2015	Mount Qomolangma 1971-2012	Taonaihe 1957-2012
TX10(d/10a)	**-1.16**	**-3.26**	-1.50	**-2.75**	**-1.79**	**-1.23**	**-6.54**	**-0.84**
TN10(d/10a)	**-2.47**	**-8.23**	**-4.08**	**-5.80**	**-2.05**	**-3.56**	**-8.87**	**-1.13**
TXN(°C/10a)	**0.36**	**0.35**	—	—	**0.38**	0.29	**0.37**	0.30
TNN(°C/10a)	**0.51**	**0.58**	0.46	**0.59**	0.11	**0.62**	**0.64**	0.19
TN90(d/10a)	**2.39**	**8.16**	**4.52**	**4.44**	**2.24**	**3.67**	**12.07**	**1.68**
TX90(d/10a)	**1.68**	**5.22**	**2.44**	**3.45**	**2.59**	**1.73**	**8.17**	**1.54**
TXX(°C/10a)	**0.32**	**0.15**	0.17	**0.31**	0.14	0.09	**0.3**	0.13
TNX(°C/10a)	**0.42**	**0.25**	—	—	0.06	**0.34**	**0.4**	**0.25**
ID(d/10a)	**-3.30**	**-2.32**	—	**-1.86**	**-0.7**	-1.16	**-1.24**	—
FD(d/10a)	**-3.86**	**-3.48**	—	**-4.02**	**-3.01**	**-3.66**	—	—
DTR(°C/10a)	**-0.16**	**-0.15**	**-0.21**	**-0.15**	0.08	**-0.25**	**-0.08**	-0.01
GSL(d/10a)	**3.48**	—	—	**2.90**	**3.15**	**2.94**	**4.81**	—

Note Bold means passing the 95% confidence significance test,"—" indicates missing data

Table 6 The annual trends of extreme precipitation indexes in Qilian Mountains area and basins

Index	PRCPTOT		SDII		RX1DAY		RX5DAY		R95		R99	
	mm/10a	%	mm/d/10a	%	mm/10a	%	mm/10a	%	mm/10a	%	mm/10a	%
Qilian Mountain	**13.86**	41.8	-0.01	3.8	**0.76**	27.2	**1.37**	31.9	**4.10**	72.8	**1.29**	66.1
Hexi Corridor	**10.51**	47.8	-0.02	3.8	**0.81**	31.1	**1.11**	33.0	**3.60**	92.6	**1.10**	78.2
Qaidam Basin	**14.05**	43.3	0.01	8.3	**0.75**	33.5	**1.97**	44.0	**4.48**	97.7	**1.60**	153.5
Yellow River	**24.40**	33.6	-0.03	-2.4	0.63	12.5	1.17	17.4	**5.06**	34.4	1.39	6.5
Index	CDD		CWD		R10MM		R20MM		R25MM		□□□□	
	d/10a	%	d/10a	%	d/10a	%	d/10a	%	d/10a	%	d/10a	%
Qilian Mountain	**-26.35**	-49.0	0.06	12.6	**0.40**	47.0	**0.09**	62.9	**0.05**	64.6	**5.79**	43.5
Hexi Corridor	**-26.74**	-50.2	0.05	15.7	**0.28**	57.4	**0.07**	93.2	**0.04**	87.5	**4.00**	47.6
Qaidam Basin	**-24.42**	-42.0	**0.10**	14.6	**0.43**	48.4	**0.11**	89.2	**0.05**	125.0	**4.20**	37.4
Yellow River	**-28.43**	-59.0	0.01	5.3	**0.75**	35.8	0.12	26.0	0.06	18.6	**7.93**	42.2

(Note□Bold means passing the 95% confidence significance test)

Table 7 Correlation coefficients between elevations and linear trends of extreme temperature indexes in Qilian Mountains from 1961to 2017

Index	b(×10^6)	R^2	Index	b(×10^6)	R^2
TX10	**-26.63**	0.51	DTR	-5.37	0.06
TN10	**-68.45**	0.22	TN90	-11.65	0.02
TXN	**11.03**	0.44	TX90	-5.87	0.02
TNN	**21.52**	0.22	TXX	-1.24	0.01
ID	**-131.20**	0.68	TNX	-3.18	0.05
FD	**-85.94**	0.20	GSL	10.86	0.01

□Note□Bold means passing the 95% confidence significance test□

Table 8 Linear trends of extreme temperature indexes of different elevations in Qilian Mountains from 1961to 2017

Elevation(m)	TX10	TN10	TXN	TNN	ID	FD
1000-1500	**-1.01**	**-1.98**	0.27	0.18	**-2.15**	**-3.21**
1500-2000	**-0.91**	**-2.09**	0.29	**0.58**	**-2.59**	**-3.70**
2000-2500	**-1.19**	**-0.93**	**0.44**	**0.23**	**-2.72**	**-1.26**
2500-3000	**-1.30**	**-3.71**	**0.44**	**0.89**	**-4.60**	**-5.05**
3000-3500	**-1.49**	**-2.90**	**0.46**	**0.57**	**-4.46**	**-4.78**
Elevation(m)	DTR	TN90	TX90	TXX	TNX	GSL
1000-1500	**-0.11**	**2.31**	**1.78**	**0.31**	**0.48**	**3.05**
1500-2000	**-0.17**	**2.91**	**1.57**	**0.32**	**0.43**	**3.92**
2000-2500	**0.15**	**1.19**	**2.06**	**0.52**	**0.27**	**3.37**
2500-3000	**-0.31**	**2.45**	**1.54**	**0.30**	**0.46**	**3.52**
3000-3500	**-0.19**	**2.28**	**1.68**	**0.28**	**0.37**	**3.49**

□Note□Bold means passing the 95% confidence significance test□

Table 9 Correlation coefficients between temperature extremes in Qilian Mountains and atmospheric circulation index

Index	TX10	TN10	TXN	TNN	ID	FD	DTR	TN90	TX90	TXX	TNX	GSL
AMO	**0.34**	**0.42**	**-0.29**	**-0.39**	**0.34**	**0.52**	**0.40**	**-0.54**	**-0.39**	**-0.35**	**-0.37**	**-0.38**
TNA	**-0.45**	**-0.45**	0.17	0.26	**-0.39**	**-0.52**	-0.13	**0.59**	**0.61**	**0.36**	**0.55**	**0.49**
TSA	**-0.41**	**-0.49**	0.23	**0.26**	**-0.36**	**-0.50**	-0.22	**0.48**	**0.54**	**0.30**	**0.33**	**0.47**
NTA	**-0.50**	**-0.55**	0.23	**0.34**	**-0.44**	**-0.59**	-0.23	**0.64**	**0.63**	**0.35**	**0.55**	**0.53**
CAR	**-0.69**	**-0.64**	**0.35**	**0.35**	**-0.51**	**-0.72**	-0.26	**0.77**	**0.67**	**0.43**	**0.60**	**0.68**
Nino 4	**-0.30**	**-0.28**	**0.33**	**0.41**	**-0.42**	-0.23	-0.05	**0.28**	**0.30**	-0.04	0.07	**0.27**
NAO	0.04	-0.08	0.24	0.12	-0.02	-0.02	-0.19	-0.07	-0.15	-0.05	-0.11	-0.02
NP	0.00	0.03	-0.08	-0.15	0.08	-0.12	-0.04	0.09	0.07	0.01	0.02	0.09
AO	-0.12	-0.22	0.17	0.02	-0.10	-0.24	**-0.34**	0.15	-0.05	0.00	0.03	0.20
SOI	0.09	0.20	-0.05	-0.24	0.16	0.18	0.17	-0.10	-0.10	0.09	0.01	-0.08
MEI	-0.24	-0.21	**0.29**	**0.36**	**-0.39**	-0.12	0.01	0.14	0.18	-0.11	-0.13	0.18
SCSSMI	**0.29**	**0.47**	-0.17	-0.24	**0.37**	**0.40**	**0.30**	**-0.41**	**-0.40**	**-0.32**	**-0.38**	**-0.27**

（Note：Bold means passing the 95% confidence significance test）

Table 10 Correlation coefficients between elevations and linear trends of extreme precipitation indexes in Qilian Mountains and basins from 1961 to 2017

Sites	PRCPTOT	SDII	RX1DAY	RX5DAY	R95	R99
Qilian Mountains	**0.74**	**0.48**	**0.43**	**0.60**	**0.68**	**0.55**
Hexi Inland River Basin	**0.98**	**0.68**	**0.65**	**0.69**	**0.96**	**0.83**
Qaidam inland river basin	0.65	0.20	**0.80**	0.66	0.73	0.60
Yellow River Basin	**0.99**	0.71	0.76	0.93	**0.98**	0.81
Sites	CDD	CWD	R10MM	R20MM	R25MM	Rainy day
Qilian Mountains	-0.24	0.24	**0.73**	**0.64**	**0.56**	**0.66**
Hexi Inland River Basin	-0.19	0.50	**0.95**	**0.91**	**0.86**	**0.95**
Qaidam inland river basin	**-0.77**	0.57	0.53	0.63	0.54	**0.82**
Yellow River Basin	**-0.99**	-0.75	**0.96**	0.93	0.86	**0.99**

(Note：Bold means passing the 95% confidence significance test)

Table 11 Linear trends of extreme precipitation indexes of different elevations in Qilian Mountains from 1961 to 2017

elevation(m)	PRCPTOT	SDII	RX1DAY	RX5DAY	R95	R99
1000-1500	**4.29**	-0.04	0.40	0.82	0.63	-0.03
1500-2000	**7.47**	-0.07	0.70	0.56	2.36	-0.16
2000-2500	**11.56**	0.02	0.11	0.60	1.42	0.71
2500-3000	**19.36**	0.01	**0.93**	**2.04**	**5.17**	**2.29**
3000-3500	**28.41**	0.05	**1.34**	**2.64**	**10.35**	**3.86**
elevation(m)	CDD	CWD	R10MM	R20MM	R25MM	Rainy day
1000-1500	**-26.94**	0.05	0.12	0.00	0.01	**2.77**
1500-2000	**-24.83**	0.00	0.13	0.05	0.02	**3.78**
2000-2500	**-15.98**	0.06	0.46	0.04	0.05	**3.59**
2500-3000	**-27.04**	0.11	**0.61**	**0.12**	0.06	**5.34**
3000-3500	**-30.89**	0.08	**0.84**	**0.25**	**0.12**	**7.99**

(Note：Bold means passing the 95% confidence significance test)

Table 12 Correlation coefficients between extreme precipitation indexes in Qilian Mountains and atmospheric circulation index

Index	PRCPTOT	SDII	RX1DAY	RX5DAY	R95	R99	CDD	CWD	R10MM	R20MM	R25MM
AMO	**-0.38**	-0.17	**-0.30**	**-0.30**	**-0.44**	**-0.37**	0.20	-0.16	**-0.38**	**-0.45**	**-0.39**
TNA	**0.30**	-0.02	0.22	0.25	**0.26**	**0.30**	**-0.41**	0.04	**0.28**	0.21	0.19
TSA	**0.30**	-0.14	0.09	0.13	0.12	0.12	-0.38	-0.02	0.24	0.13	0.07
NTA	**0.41**	-0.04	**0.26**	**0.30**	**0.33**	**0.32**	**-0.55**	0.07	**0.38**	0.24	0.23
CAR	**0.42**	-0.07	**0.26**	0.22	**0.35**	**0.35**	**-0.49**	0.08	**0.37**	**0.32**	**0.35**
NINO4	0.11	-0.14	0.00	0.02	0.10	-0.01	**-0.39**	0.03	0.09	0.04	0.04
NAO	0.19	0.11	0.00	0.06	0.19	0.00	-0.21	0.10	0.22	0.16	0.16
NP	-0.11	0.05	0.06	0.00	-0.08	0.02	0.21	-0.04	-0.11	0.01	0.06
AO	**0.33**	0.01	0.09	0.14	**0.26**	0.07	**-0.29**	0.17	**0.31**	**0.28**	0.24
SOI	0.05	0.18	0.13	0.16	0.09	0.14	0.20	0.06	0.07	0.15	0.10
MEI	0.12	-0.16	0.00	-0.02	0.05	-0.04	**-0.39**	0.02	0.08	-0.04	-0.03
SCSMI	**-0.40**	-0.02	-0.23	**-0.29**	**-0.27**	-0.24	**0.38**	-0.14	**-0.38**	-0.19	-0.13

(Note：Bold means passing the 95% confidence significance test)

Figures

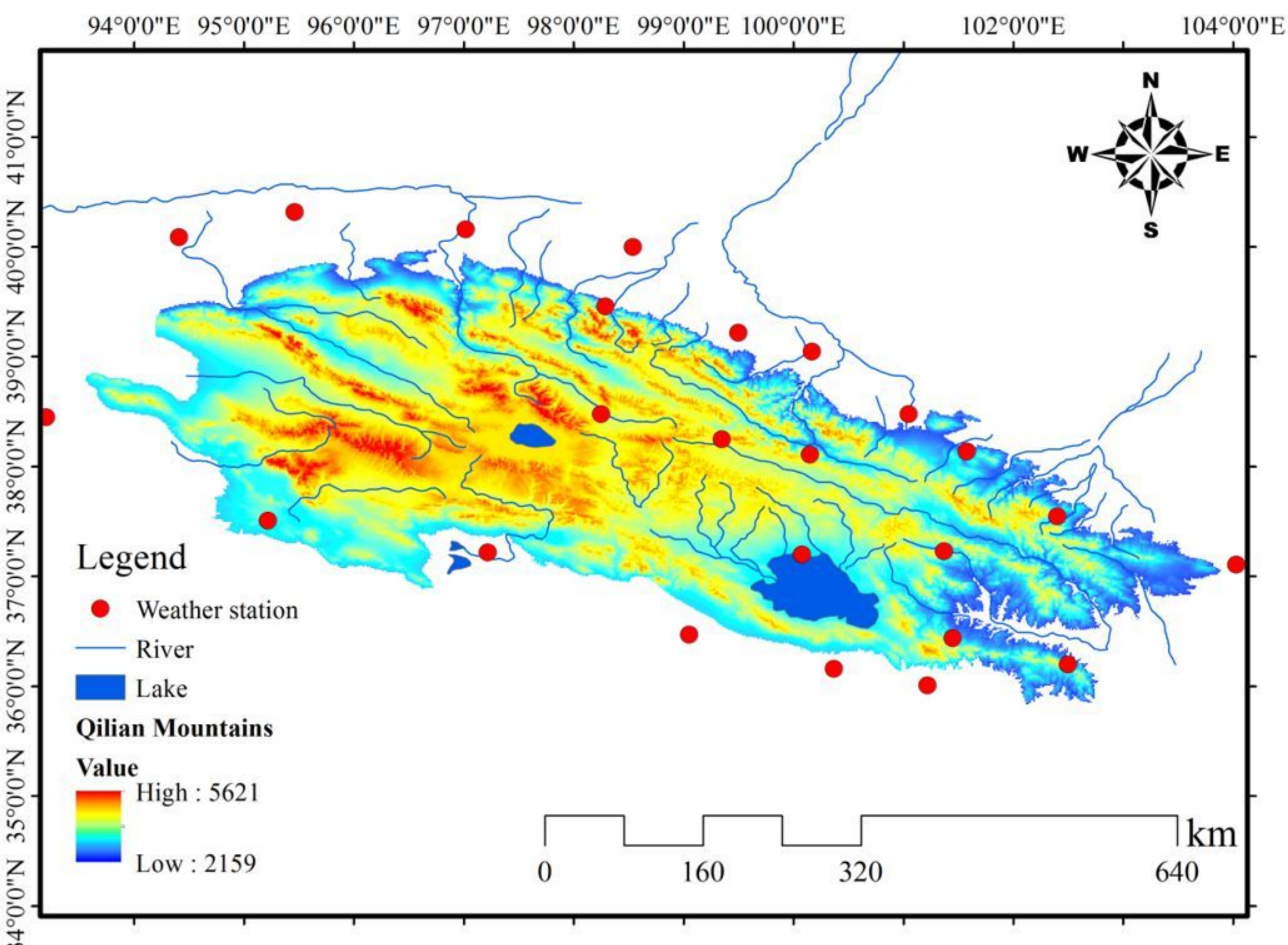

Figure 1

the regional map and platform distribution of the Qilian Mountains. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

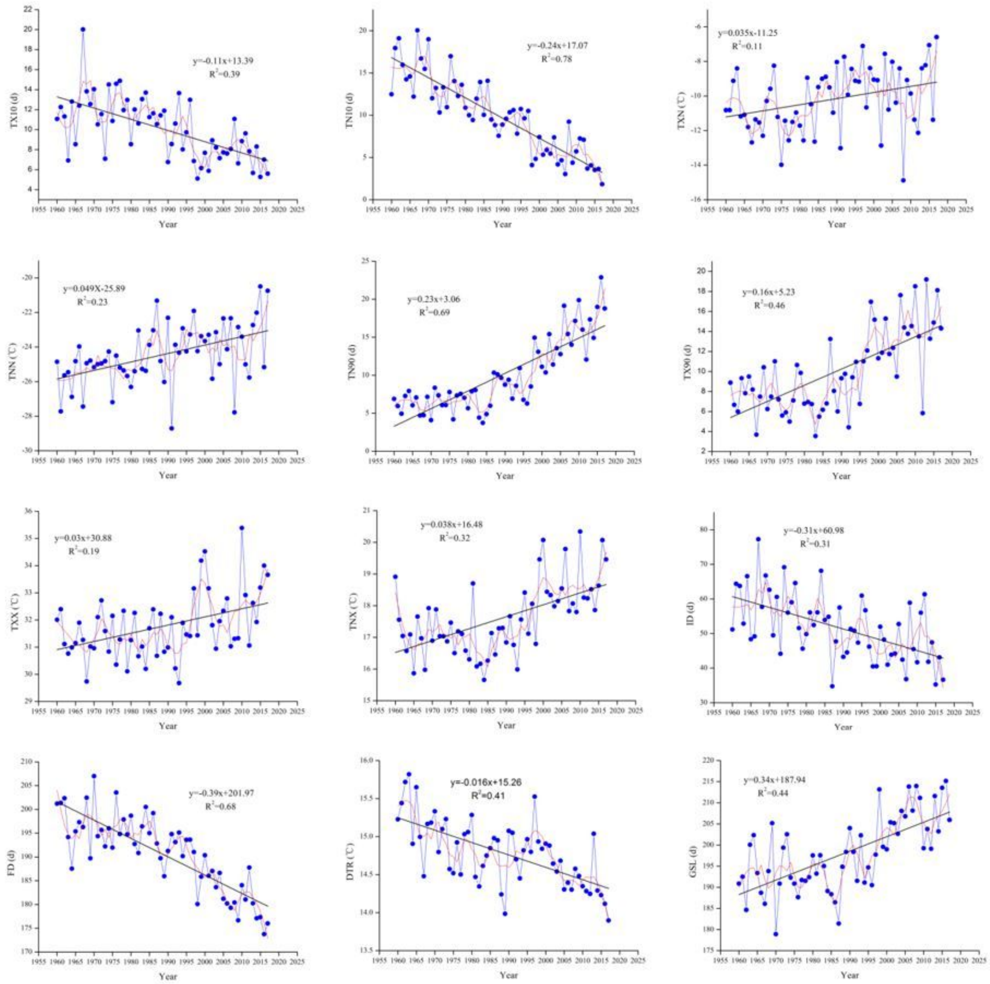

Figure 2

The annual variation curves of extreme temperature in Qilian Mountains from 1961 to 2017

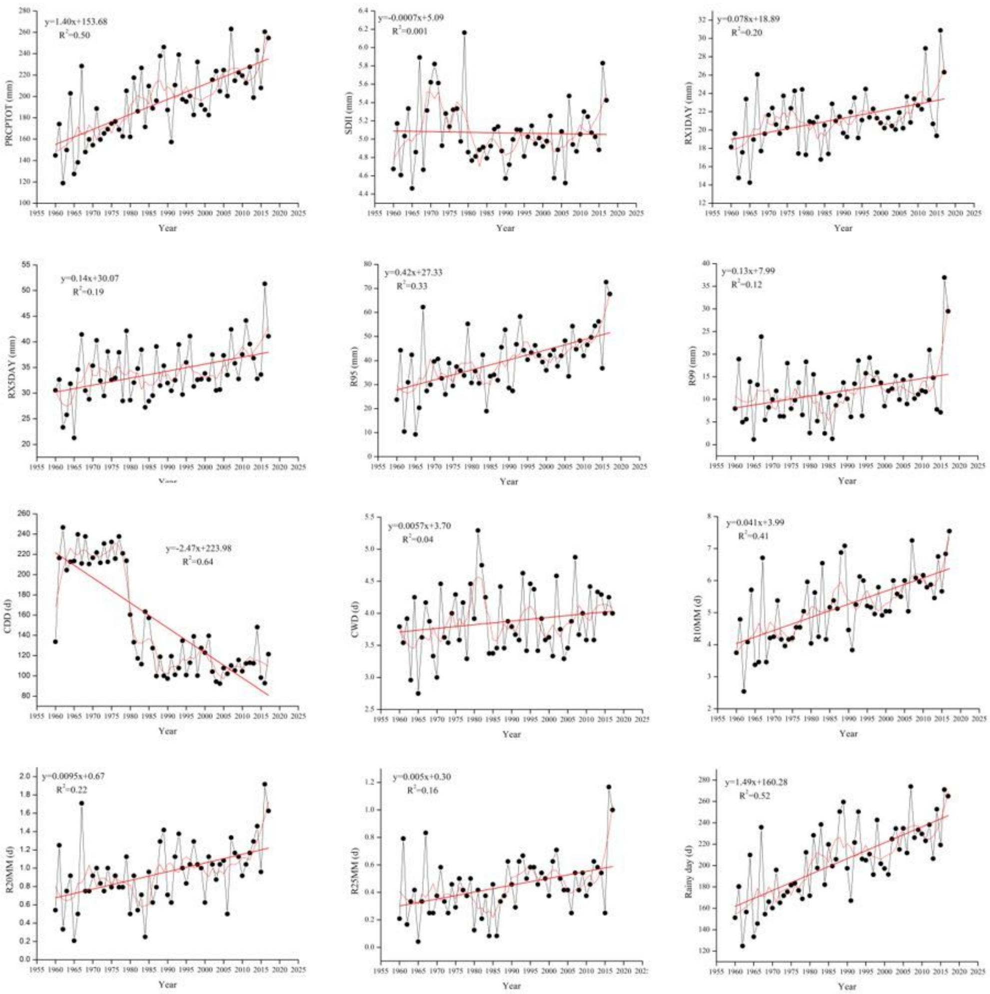

Figure 3

The annual variation curves of extreme precipitation in Qilian Mountains from 1961 to 2017

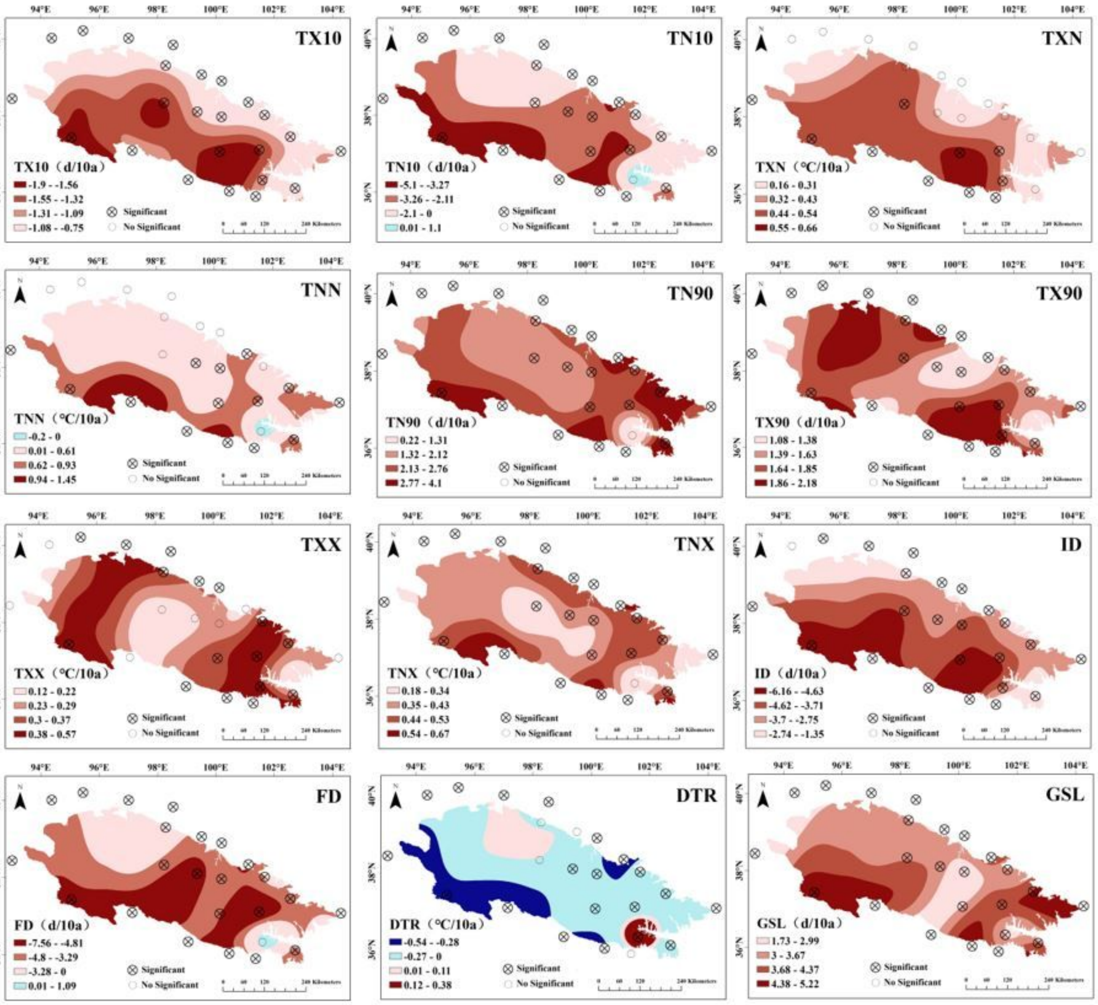

Figure 4

Spatial distribution of change ranges of extreme temperature in Qilian Mountains from 1961to 2017. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

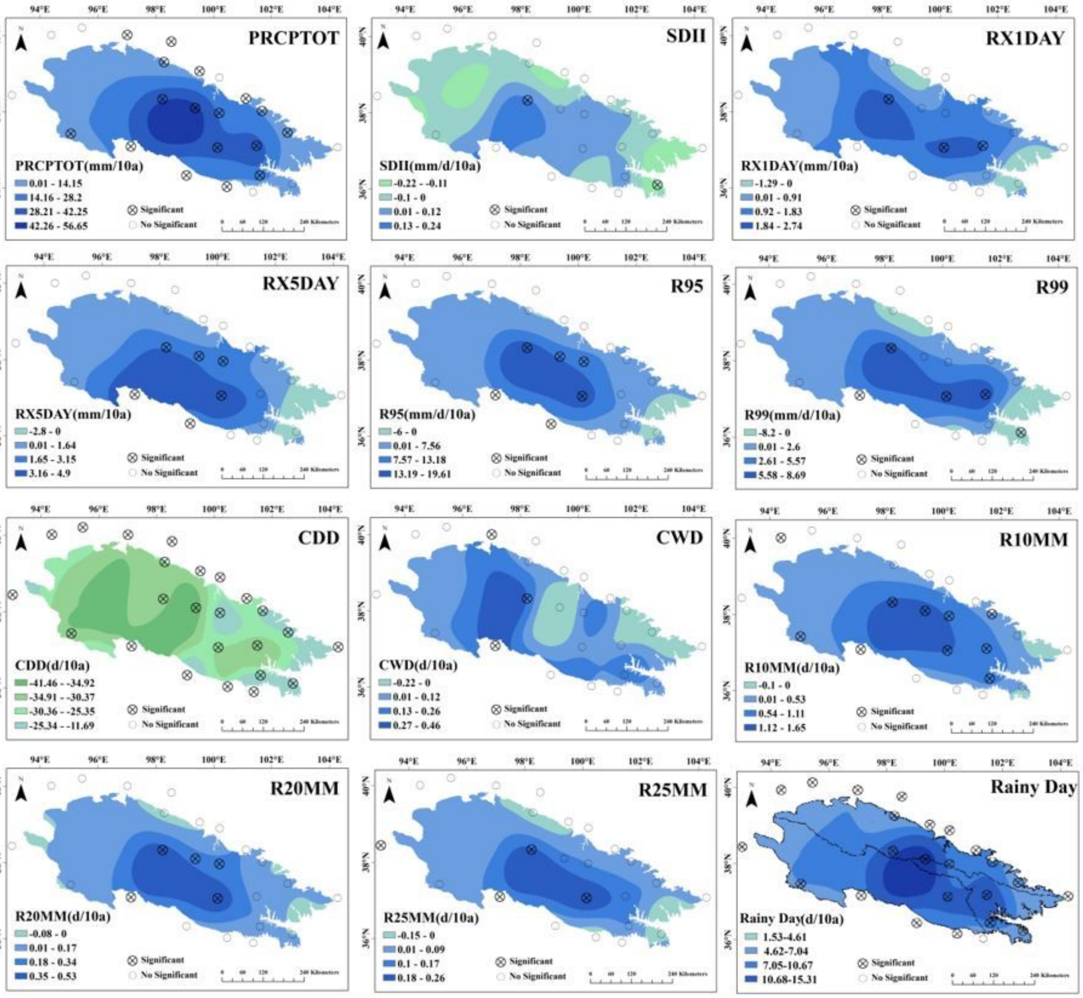

Figure 5

Spatial distribution of change ranges of extreme precipitation indexes in Qilian Mountains and basins from 1961to 2017. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.