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Arid Climate Change Features in Xinjiang, China, During 1961-2011

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Abstract: Temperature and precipitation time series datasets from 1961-2011 at 49 meteorological stations were used to reveal the spatial and temporal trends of climate change and period and abrupt changes and multi-time scale relations in Xinjiang, China. Annual and seasonal mean air temperature and total precipitation were analyzed using Nonparametric statistical test, trend simulate and analysis etc., methods. The results indicate that: The trend shows increasing trend in the past 50 years in Xinjiang, climate warming up mainly in winter which increasing range is 0.47°C/10a ($p<0.01$), annual average precipitation generally shows increasing trend with the range of 9.23 mm/10a and mainly in summer, but arid grade for heat and humidity situation shows increasing trend. Annual average temperature on spatial, shows a significance increasing trend at stations of 95% among in which the biggest increasing range is in Tianshan mountains, secondly is northern Xinjiang and the smallest is southern Xinjiang. The abrupt change on annual average temperature from cold to warm was happened during 1990-1994 and from more to less on annual average precipitation was happened during 1987-1991.

Key words: Climatic changes, abrupt change, arid, Xinjiang

INTRODUCTION

The 4th report of IPCC figured out that earth's surface temperature has increased. The rate of warming up is nearly twice as much in recent 50 years (1956-2005) compared to 100 years ago. A large number of studies indicate that the general trend of climate changing in China stays same step with global one (Ma and Liu, 2009). The speed of warming up in China is about 0.25°C/10a in past 54 years (1951-2004), which is higher than global or halfsphere homochronous average rates of warming up. At present, obviously, it is an incontestable fact that the global climate is warming up (IPCC, 2007). Xinjiang locates in Eurasia hinterland of middle latitude, far from sea. It belongs to the typical area of continental dry climate and ecological fragile with limited water source, less precipitation and strong evaporation (Pu and Zhang, 2011). The main environmental issue is the lack of water, it causes drought which becomes most severe natural disaster in Xinjiang. Dry and water shortage is a major environment feature in Xinjiang and caused drought disaster which become a severe natural hazard. Therefore, it is significant for future to study variation trend of dry climate, discussing the changing of drying and watering of climate in Xinjiang area (Burn and Hag Elnur, 2002).

Recently, a lot of researches about climatic change in Xinjiang have been expended, result demonstrate that recent 100 years, Xinjiang show an obvious temperature increasing trend (Shi *et al*., 2002). A number of studies on drought and low-temperature disaster have great impact on agricultural production (Liu *et al*., 2005; Chen *et al*., 2010; Zhao, 2010). There are also many studies on spatial and temporal distribution for heat and humidity conditions (Zhang *et al*., 2011). These studies have important significance for correct understanding of climatic change in Xinjiang. However, in the past, the studies only focus on temperature and precipitation in southern and northern areas of Xinjiang and the definition for drought index is different, furthermore, the used meteorological factors data is different from meteorological stations.

Regarding time-series temperature and precipitation as basic data during 1961-2011 from selected 49 meteorological stations, with the help of linear intend rate methods, accumulate anomaly, Mann-Kendall method etc., the study also quoted and re-defined arid index, studied the trend, abrupt change and period of temperature and precipitation in Xinjiang, discussed and researched change, rule for arid climate in Xinjiang in past 50 years which can improve understanding the climate change rule in Xinjiang, meanwhile, it has important

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practical significance for sustainable development of ecological environment and it promises to strength ability against threaten and disaster from global warming up.

STUDY AREA OVERVIEW

Xinjiang locates far from the ocean in the center of Eurasia in the border region of northwestern China is impacted by the uplifted Tibetan Plateau, westerly wind circulation effects and high mountain landforms. This region is, thus, an important route by which cold air invades China that has a diverse climate. Northern Xinjiang has a variable continental arid and semi-arid climate, whereas southern Xinjiang has a warm continental arid climate. The ecology of these regions is fragile and has suffered greatly under the influence of climatic change (Wang *et al*., 2012; Zhang *et al*., 2012; Tang *et al*., 2013).

MATERIALS AND METHODS

Research data: In order to ensure synchronism and observation series with longer in each stations, so many stations established after 1961 and lack of observation data was rejected and finally the 49 meteorological stations were selected (Fig. 1). The lack data on each stations adopted closed stations data and made up with multiple regression. Data adopted was with daily average air temperature and precipitation during 1961-2011.

Study method: The seasonal, annual and inter-decadal variation for air temperature and precipitation were studied in this study. The season is divided into spring (March-May), summer (June-August), autumn (September-November) and winter (December-February). An analysis was made for data by adopting linear trend and moving average analysis and carried out climate abrupt detection by using climatic elements series so that judge the change trend of abrupt change year and climatic elements. Climatic elements series period was collected by adopting method. In this method, single-dimensional symmetry was adopted to expand for removing border effect (Tan *et al*., 2007; Deng *et al*., 1997).

RESULT ANALYSIS

Inter-annual variation for air temperature in past 50 years: Figure 2 shows three years moving and average changing curve for spring, summer, autumn, winter and annual average temperature series in Xinjiang. Annual average air temperature variation in Xinjiang is between 6.2~8.8°C during 1961-2010, annual average temperature gradually rise with variation and the climatic tendency rate is 0.32°C/10a which passed the significance test of $\alpha = 0.05$ (Fig. 2). Obviously, it is higher than average increasing warm speed of 0.22°C/10a (Ren *et al*., 2005) in China. Average air temperature of four seasons of Xinjiang show an increasing trend, among which the biggest increasing range is winter that reach to

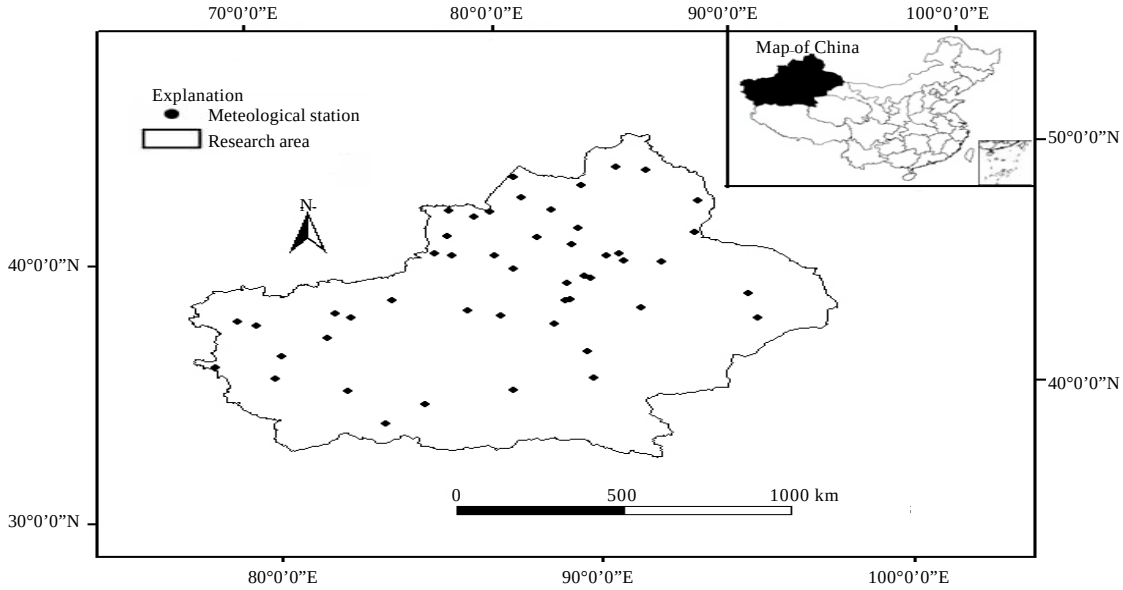

Fig. 1: Study area, elevation and locations of meteorological stations

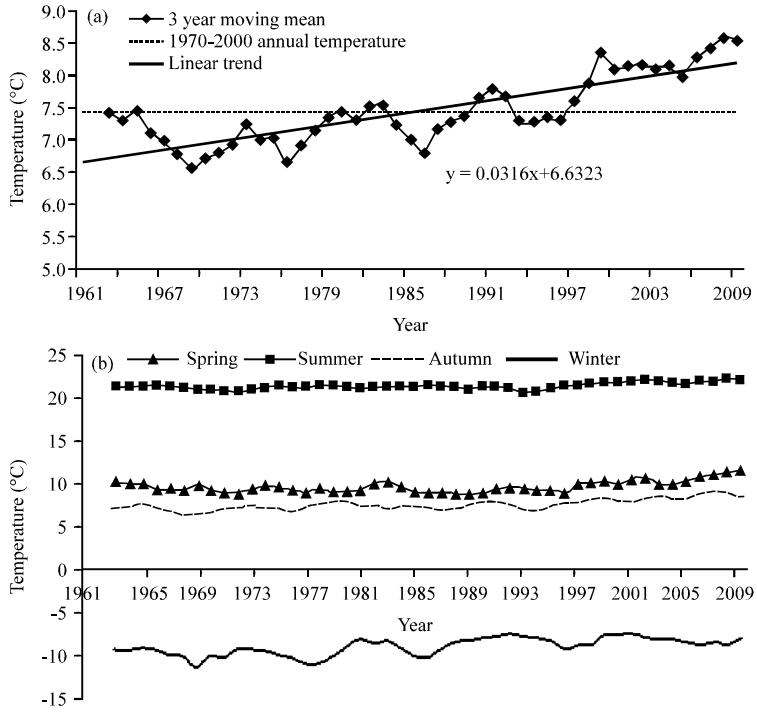

Fig. 2(a-b): Variation of the (a) Annual and (b) Seasonal temperature in Xinjiang China

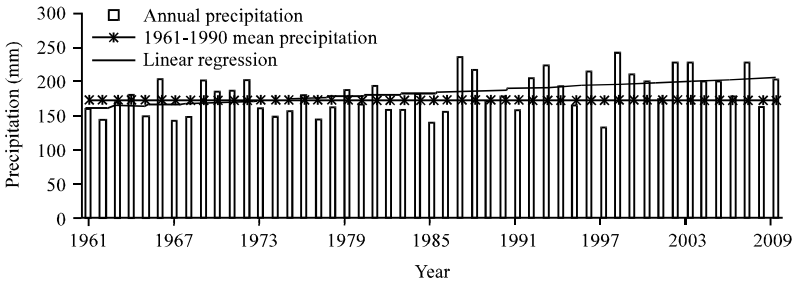

Fig. 3: Variation of the annual precipitation in Xinjiang

0.47°C/10a, second is the autumn which is 0.36°C/10a, spring is about 0.26°C/10a and the smallest range is in summer which is around 0.19°C/10a. Making significance test for rise in temperature range, annual and in winter reach to reliability of 0.01, summer and spring reach to reliability of 0.01, indicates that average temperature rise mainly in winter in past 50 years. In whole country, temperature increasing speed in four seasons, respectively, is winter having 0.36°C/10a, spring 0.23°C/10a, autumn 0.19°C/10a and summer 0.12°C/10a (Ren *et al*., 2005). It is clear that the average air temperature trend change for annual and four seasons in Xinjiang is same with the whole country but average air temperature increasing warm rate in Xinjiang area is obvious higher than the China.

Inter-annual variation for precipitation in past 50 years: Annual precipitation change in Xinjiang area is between 140.9-241.4 mm during 1961-2010. Annual precipitation shows a rising trend in variations with the climatic tendency rate 9.23 mm/10a, which reach to the reliability of 0.05. Annual average precipitation amount is 171.9 mm during 1961-1990 and increased to 195.8 mm during 1991-2010 (Fig. 3) which have slight difference with decrease trend on annual average precipitation fluctuate in China (Shaowu *et al*., 2004). Season precipitation amount show the same increase trend and different variation strength (Fig. 4). Among the maximum precipitation amount, increasing range is in summer which is 4.24 mm/10a and reach to reliability of 0.05 and the minimum increasing range is in autumn with 0.94 mm/10a

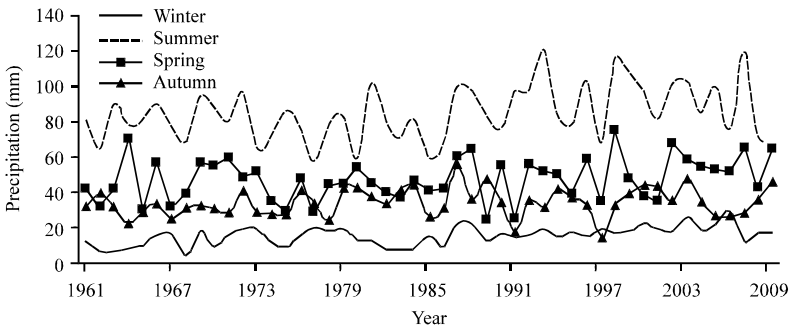

Fig. 4: Variation of the seasonal precipitation in Xinjiang

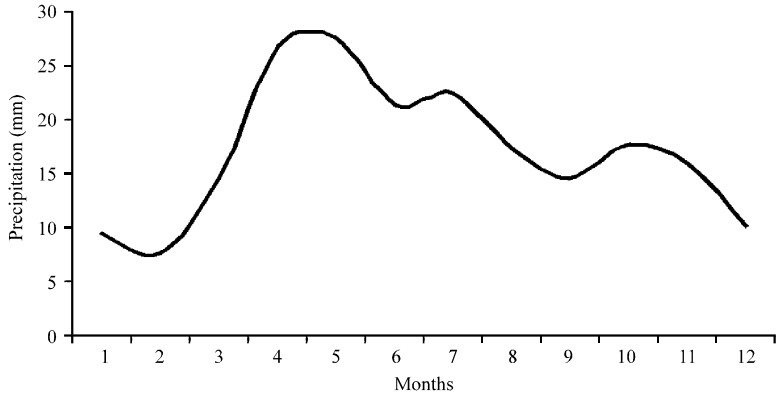

Fig. 5: Precipitation variation in the annual of Xinjiang

which fail to reach the significance test of 0.05 which illustrate that precipitation increases mainly in summer. Further calculation and analysis of annual variance of precipitation in Xinjiang is shown in Fig. 5. Statistics demonstrate the precipitation amount in spring, summer, autumn and winter which account for 26, 46.5, 19 and 8.5% of annual precipitation, respectively. As mentioned above, average air temperature rising is mainly in winter but precipitation increasing amount is in summer that indicate, in past 50 years the variations in heat and humidity were different in different seasons in Xinjiang area.

Inter-decadal variation of air temperature and precipitation in past 50 years: Inter-decadal variation of air temperature display obvious increasing trend in Xinjiang area. Temperature tend to cold during 1961-1970 and 1971-1980 but the air temperature already had showed increasing trend within period. The temperature began to warm from 1981-1990, thereafter the air temperature rose year by year and its rising range is increasing year after year. The inter-decadal variation of precipitation situation in Xinjiang is also same with its air temperature, among which the precipitation incline to less in the year of 1961-1980 and more in the year of 1991-2010.

Spatial change of annual mean air temperature and precipitation in Xinjiang in past 50 years: An insert for annual climatic tendency rate of air temperature and precipitation on 49 weather stations by using IDW was made. The spatial distribution maps for air temperature and precipitation change in Xinjiang area were made (Fig. 6).

Average temperature in Xinjiang area, generally, shows rising trend among 49 stations, the increasing trend is significant ($p<0.05$) in most positions and average increasing scope is 0.32°C/10a. Tianshan mountains area in Xinjiang is one of largest area for temperature rising scope in which climatic tendency rate got to 0.34°C/10a, the second is northern area (0.32°C/10a) and the lowest is southern with 0.3°C/10a) (Fig. 6a).

Annual precipitation of 49 stations (stations of 95%) in Xinjiang area generally shows rising trend with average increasing scope of 9.23 mm/10a. The climatic tendency rate for annual precipitation at each geographical unit as Tianshan mountains area, southern and northern areas in

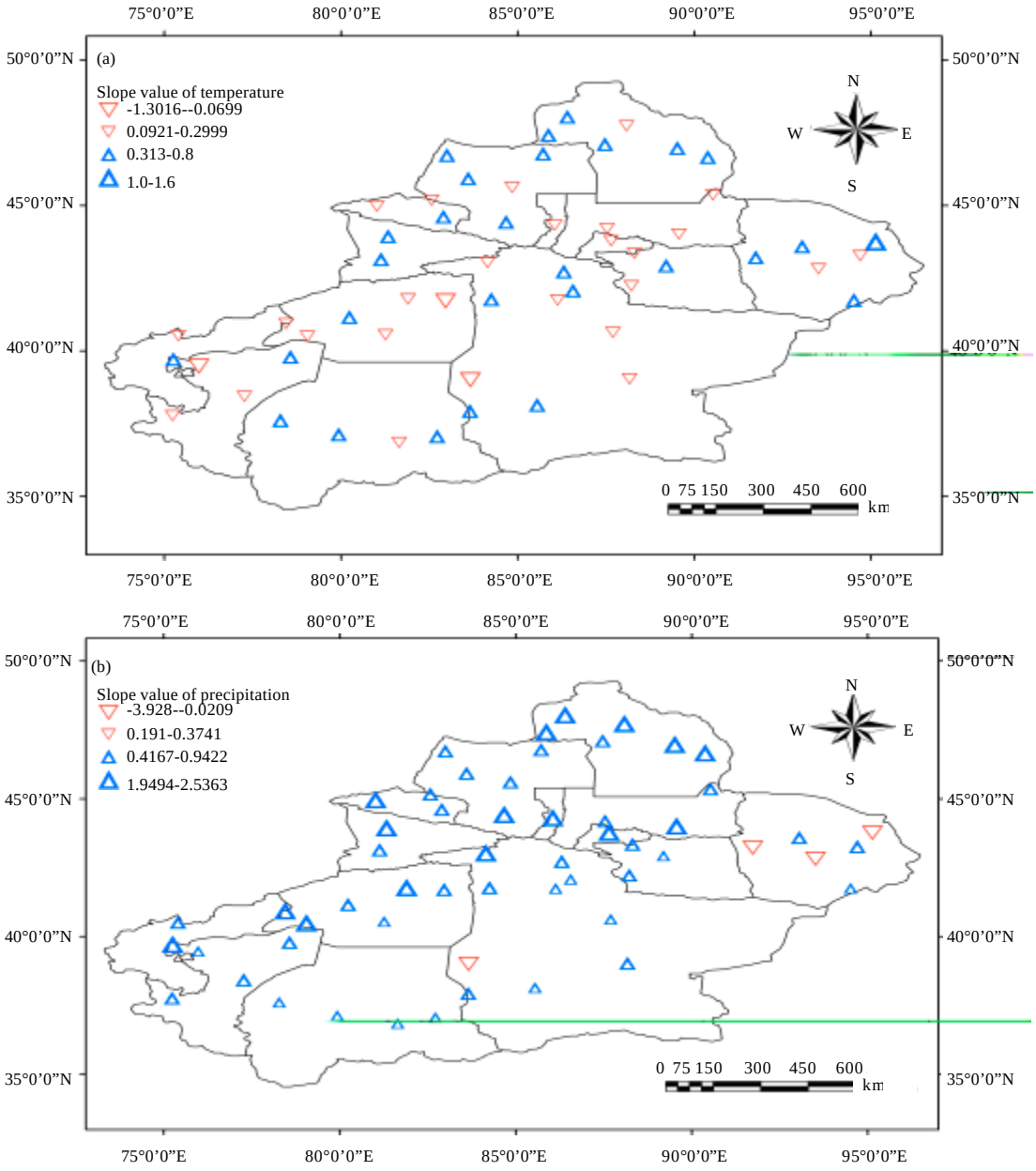

Fig. 6(a-b): Distribution of climate trend coefficient of, (a) Temperature and (b) Precipitation in Xinjiang

Xinjiang are 14.98, 13.46 and 3.4 mm/10a, respectively. This indicates that the maximum increasing range is in Tianshan mountains area, second is in northern and the minimum is in southern (Fig. 6b).

Annual mean temperature and precipitation amount abrupt test in past 50 years in Xinjiang: Making abrupt change test and analysis to annual average temperature and precipitation in Xinjiang area by using Mann-Kendall method (Fig. 7) from Fig. 7a, we can see that UF curve shows fluctuate decreasing trend before 1975 and increasing trend after 1975. This rising trend exceeds reliability level of 0.05 in 1994. The UF curve within reliability area has cross point with UB curve between 1992 and 1994. The accumulate anomaly analysis result display annual average temperature that show first rising after falling trend as "V" pattern and decreasing trend during 1961-989, then show fluctuate increasing trend

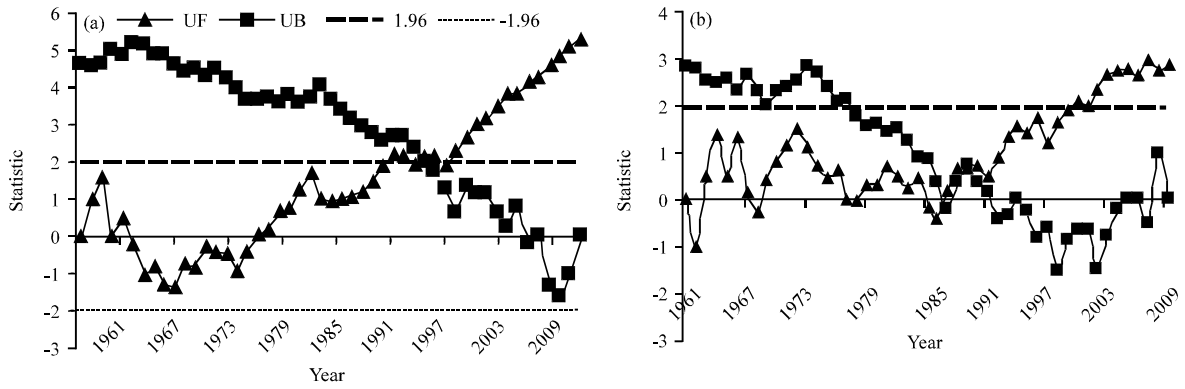

Fig. 7(a-b): Mann-Kendall test of annual mean temperature and annual precipitation in Xinjiang, (a) Temperature and (b) Precipitation

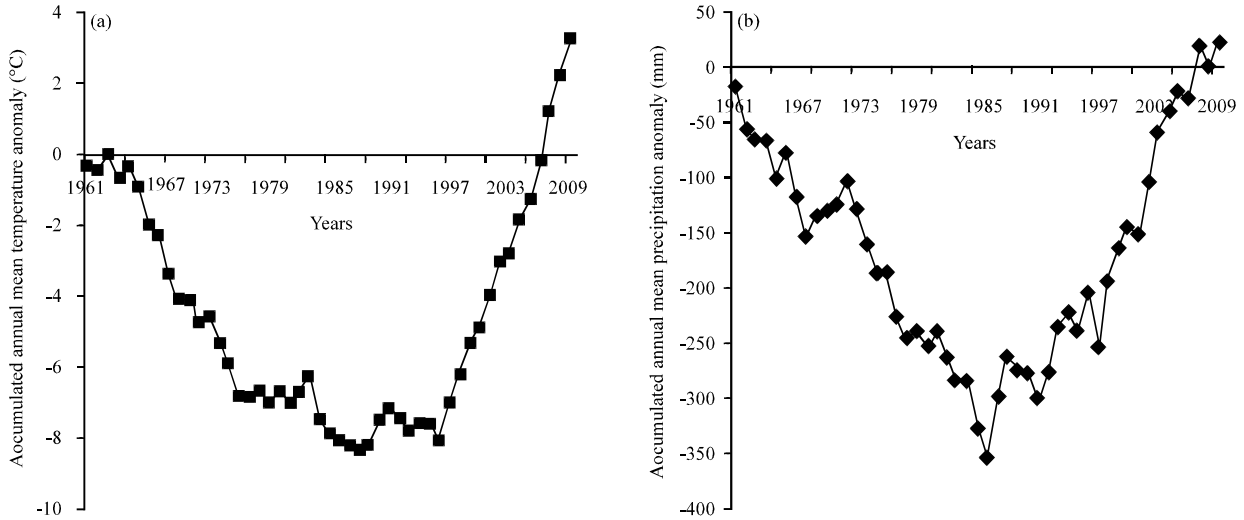

Fig. 8(a-b): Accumulated annual mean, (a) Temperature anomaly and (b) Annual precipitation in Xinjiang

during 1991-2010. It illustrate that the temperature in Xinjiang area had experienced process of rising-down. Temperature abrupt change probably occurred around 1990, as Fig. 7a. We concluded that annual average temperature in Xinjiang area had an abrupt change from low to high during 1990-1994 by combined two methods for analyzing results.

Annual precipitation on Mann-Kendall test result is shown in Fig. 7b and this rising trend exceeds reliability level. UF curve within reliability area has two cross points with UB curve in 1987 and 1991. Accumulated anomaly analysis illustrate that the mean temperature shows decreasing trend from 1961-1998 after that the abrupt change was observed in temperature from 1998-2010 (Fig. 8a). Precipitation in Xinjiang area had experienced process of rising-down as Fig. 8b. Precipitation shows decreasing trend during 1961-1986, then fluctuate increasing trend during 1986-2010, so we can infer that precipitation abrupt change probably occurred around 1987 as Fig. 8b. Concluding that annual average precipitation in Xinjiang area had an abrupt change from less to more during 1987-1991 by combined two methods for analyzing results.

Aridity grade change analysis in Xinjiang: This study quote and re-define precipitation temperature normalization index which can reflect aridity condition in area and upon this basis, combine other index making analysis to arid condition in Xinjiang area in past 50 years (Shen *et al*., 2009). The index of arid applied is as follow.

Precipitation temperature normalization index (for short is) actually is difference of standardized variable between precipitation and temperature, i.e.,

$$I_s = \frac{R - \overline{R}}{\sigma_R} - \frac{T - \overline{T}}{\sigma_T}$$

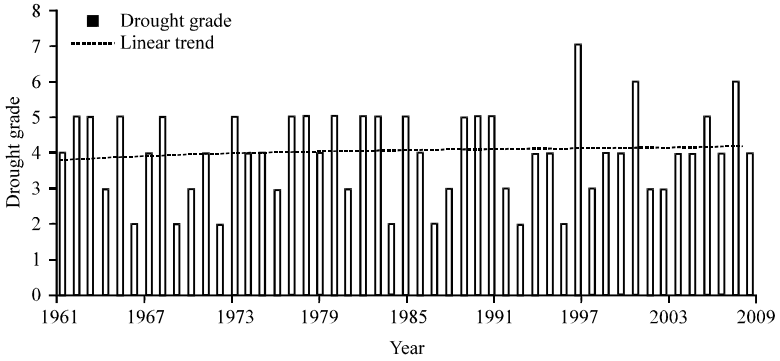

Fig. 9: Index of normalization precipitation and temperature histogram

Table 1: Aridity grade divide norm

I_S	Grade	Type	Frequency (%)
≥3.25	1	Severe wetting	5
1.6~3.25	2	Moderate moist	10
0.85~1.6	3	Mild moist	15
-0.85~0.85	4	Normal	40
-1.6~0.85	5	Light drought	15
-2.25~1.6	6	In the dry	10
≤-2.25	7	Dry weight	5

where, R is precipitation amount in some period, $\bar{R}$ is average annual precipitation, σ_R is precipitation mean square error, T is average temperature in some period, $\bar{T}$ is average annual temperature and σ_T is temperature average variance.

It carried out calculation for aridity conditions in Xinjiang area by using above index (Table 1), the result as following Fig. 9. From this histogram, we can see that after entered into the middle and later period of 1990, compare to 1980, the year of moderate humid and arid were increasing which responsd to fluctuate the strength due to regional climate change since 1980. Making linear trend for matching, it is clear that dry and wet climatic changes have a slight rising trend and show incline to dry situation.

CONCLUSION

- Annual mean temperature was decreasing with range of 0.32°C/10a ($p<0.01$) during 1961-2011 which is higher than average increasing speed temperature (0.22°C/10a) in China. The maximum rising range on spatial is in Tianshan mountains with 0.34°C/10a ($p<0.05$), second is in northern area with 0.32°C/10a ($p<0.05$), minimum is in southern area with 0.30°C/10a ($p<0.05$). For seasonal change, the maximum range for temperature increasing is in winter which reach to 0.47°C/10a ($p<0.01$), second is in autumn with 0.36°C/10a ($p>0.05$), spring is about 0.26°C/10a ($p<0.05$), the minimum is in summer with 0.19°C/10a ($p<0.05$). It is illustrated that temperature rising is mainly in winter in Xinjiang in the past 50 years
- In recent 50 years, annual mean precipitation shows increasing trend with range of 9.23 mm/10a ($p<0.05$) in Xinjiang area, among which the precipitation incline to less during 1961-1980 and more during 1991-2010. The maximum annual rainfall, for each geographical unit, is Tianshan mountains area, second is northern and minimum is southern. Precipitation, for season, in spring, summer, autumn and winter account for 26, 46.5, 19 and 8.5% of annual precipitation, respectively. It is clear that precipitation is mainly concentrated on summer
- The obvious abrupt change from lower to higher was happened on both air temperature and precipitation in past 50 years. Annual average temperature during 1990-1994 had an abrupt change from colder to warmer and annual precipitation during 1987-1991 had an abrupt change from more to less. While, the strength of air temperature rising is different with precipitation increasing that result in arid grade in Xinjiang tend to dry

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