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Full Length Research Paper

Analyzing the two-dimensional plot of the interannual climate variability for detection of the climate change in the Large Karoun River Basin, Iran

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In most studies on climate change, the first problem often faced by the researcher is detecting the climate change of the study area during the past periods and attributing it to the greenhouse gases. In this study, an attempt has been made to introduce a method for detecting the climate change during the past periods in regional scale and attributing it to greenhouse gases with regard to climate processes in a region. For this purpose, at first it is necessary to calculate the interannual variability range of the region climatic variables, resulting from the interaction between the climate systems of the 'earth' (atmosphere, biosphere, etc.). Hence, long-term statistics (1000 years) of the temperature and precipitation, resulting from control run (fix greenhouse gases) of AOGCM models (HadCM3 and CGCM3), were used for Large Karoun River Basin. Then, based on the two-variant normal distribution, the interannual climate variability range of the study area was plotted as two-dimensional temperature-precipitation graphs. Next, the annual temperature and precipitation anomaly values of the observation stations in different regions of Large Karoun River Basin were compared with the region interannual variability range for detecting the climate change of the study area during the past and attributing it to greenhouse gases. The results show increase in temperature and decrease in precipitation trends, denoting the fact that the temperature variable has been influenced by the climate change. So, in all regions of the Large Karoun River Basin, the final years of the period (1971 to 2009) have almost been located outside the interannual climate variability range, indicating the effect of climate change on the climatic variables of the said years.

Key words: Interannual climate variability, detecting the climate change, AOGCM models, Large Karoun River Basin.

INTRODUCTION

Different factors can unbalance the stationary time series of a region's climatic variables, and a recognition of this fact can greatly contribute to the climate assessment of that specific region in future periods. Part of these factors relate to the interactions between the components of the Earth's climate system (atmosphere, hydrosphere, cryosphere, land surface and biosphere), such as Atlantic Multidecadal Oscillation (AMO), Pacific Decadal Oscillation (PDO), El Niño/Southern Oscillation (ENSO) and El Nino which can cause internal variability in time series of climatic variables (Wang and Schimel, 2003; Hegerl et al., 2007). Various studies have been accomplished so far in order to detect such variability. Kazadi and Kaoru (1996) in their research on interannual variability, during long term periods of the climate (30 years from 1960 to 1992) in Zaire river basin (Africa), more attentively dealt with understanding the ENSO phenomenon, its relationship with it and its effect on internal climate variability and showed that solar annual cycles determine the seasonal changes of climatic

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variables over a region. Timilsena et al. (2009) invest-tigated the influence of interannual/interdecadal climate variability on the Colorado river basin. In this research, the relationship between individual impact of ENSO, PDO and AMO and its combined effect on stream-flow was determined using the non parametric 'rank sum' test. The results indicated an increase in stream-flow during ElNiNo and a decrease during LaNiNo phenomena, respectively in the Colorado river basin. Peel and McMahon (2006) investigated the recent changes in internal variability of temperature and precipitation on a global scale. For this purpose, they used empirical mode decomposition (EMD) (Huang et al. 1998) for quantifying the proportion of variation in the annual temperature-precipitation variability. They reported that the annual variability of temperature and precipitation have marginally decreased in the USA, Canada, Europe, Central Asia, China, Japan and Australia since 1970.

Another part of the factors causing non-stationary status in climatic variables in a region may be external factors related to the changes in solar radiation and changes in the earth orbital and volcanic activity. Although changes in solar radiation or in the earth orbital may occur in a several thousand years scale, the temperature of the region tends to get cold for a few months by volcanic eruption. Overall changes due to natural external factors and internal climatic variability within the system are called natural climate variability. Another important factor affecting the stationary status of the climatic variables in a region and thereby resulting in different trends in such variables is increasing the greenhouse gases volume in the atmosphere due to anthropogenic activity (Wang and Schimel, 2003; Hegerl et al., 2007; Baede et al., 2001). Many scientists believe that the primary cause for higher earth's surface temperature in recent decades has been the increased concentration of the greenhouse gases (Pagano and Garen, 2005; Garfin et al., 2008; Milly et al., 2008). To investigate the effect of the said factors on climatic variables of a region, the trend tests are usually used for examining the observation records. Khliq et al. (2009) documented guidelines of different statistical trend tests in time series for detecting the hydrological trends on local scales. Moreover, studies by Chen and Grasby (2009) demonstrated the impacts of the natural fluctuations of the quasi-cyclic components on the Mann-Kendall and Thiel-Sen tests, which are the most common methods used in data analysis and detection of trend in time series. Although, from the results of this study and other similar previous researches, this study provides a better insight for appropriate temporal trend analyses of the hydroclimate and associate climate data time series, inference can be drawn that the main method used in researches for detecting the climate change during the past, has been analyzing the trends in climatic variables using non-parametric tests and one-dimensional test in most cases. The reason for the fame of such tests, probably lie in the fact that for the application of non-parametric methods, no assumptions on parent distribution of the time series are necessary (Khliq et al., 2009). It should be noted that although an increase in greenhouse gases in the atmosphere can create a trend (especially in temperature), the opposite case is not true, that is, the existence of a trend in the climate data of a region can not necessarily be attributed to the increase in greenhouse gases. In other words, after proving the existence of a trend in the past climate data of a region, the relationship between the trend and the increase in greenhouse gases should be proved. In this case, it can be said that the climatic variables of the region in the past have been affected by the climate change. Therefore, in the climate impact assessment studies, the system behavior which is a result of alteration by natural fluctuations or human-induced climate change needs to be separately investigated (Sridhar and Nayak, 2010).

Braganza et al. (2004) showed the influence of the external natural forces (solar radiation and volcanic activities) and the forces resulting from anthropogenic activities on the climate change observed throughout the twentieth century, in the course of considering 5 simple indices of the surface temperature including: the global-mean temperature (GM), mean land-ocean temperature contrast (LO), mean magnitude of the annual cycle in temperature over land (AC), the meridional temperature gradient in the northern hemisphere mid-latitudes (MTG) and the northern/southern hemisphere temperature contrast (NS). For attributing the changes that occurred in the temperature indices, they used simple and multiple linear regression between observation records of the temperature indices and the simulated data derived from the control run (under the influence of natural forces and fix greenhouse gases) of 5 models coupled in the atmosphere-ocean. The linear trends observed in all the indices except for the hemispheric temperature contrast (NS) are significantly larger than the values that resulted from the simulation of such models.

In this research, the detection and attribution of internal variability to the greenhouse gases and surveying the uncertainty of different models has been perfectly performed, but only in one dimension of "temperature", while nothing has been done about the "precipitation" variable. More detailed researches in the field of detection and attribution of variability which occurred in greenhouse gases can be found in the paper presented by the "International ad hoc detection and attribution group" (Barnett et al. 2005). The mentioned paper, while reviewing the best part of the studies regarding the detection of internal variability and attributing them to the greenhouse gases, shows that the main goal of detection and attribution studies during the past several years has been a comparison of the observed changes in climate, primarily during the past century, with the data simulations by the Coupled General Circulation Model (CGCM) that have been forced by estimates of historical

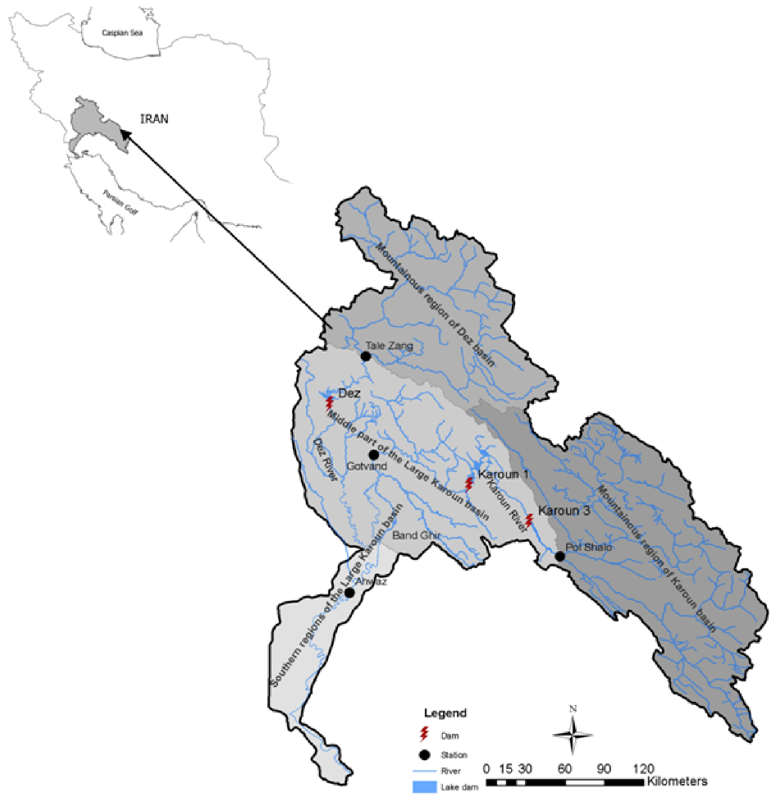

Figure 1. Location of the Large Karoun River Basin in Iran and some of its important installations.

changes in anthropogenic and (natural external forces) most frequently in “temperature” on a global-scale. Also, it is indicated that according to the results of the studies carried out in different parts of the globe, the temperature variable has been influenced by the climate change.

Accordingly, although in a study conducted in the UK by Hulme and Brown (1998), the internal climate variability range and its attribution to greenhouse gases is well recognized, but the uncertainty of the simulation models in internal climate variability calculations has been ignored. This is why in climate change studies there are various uncertainty resources in different stages required by simulation of the climatic variables by Atmosphere-Ocean General Circulation Mode (AOGCM) model on regional scales (Jones and Page, 2001)

It can be seen therefore in most previous researches that first, the natural and internal climate variability have been investigated often in one-dimensional state using trend tests in order to detect the climate change that is not attributed to the greenhouse gases. Secondly, the uncertainty of the simulation models of the internal climate variability has not been considered. Thus, the present study intends to propose a new method for two-dimensional detection of the climate change during the past periods, considering the uncertainty and the way it is attributed to greenhouse gases. Meanwhile, considering the fact that this is contrary to numerous studies in Iran, concerning the trend detection in climate variables time series, no works have been carried out regarding the occurred variability’s attribution to the greenhouse gases and uncertainty analysis.

Description of the study area

The Large Karoun River Basin is located in the south-western part of Iran, and due to the fact that it encompasses the country's largest water potential, this basin houses the most and the greatest water projects in Iran. The basin area of 67,257 km^2 encompasses about 5% of the total area of Iran. 67% of the basin area is mountainous and the remaining 33% is made of high plains. Its two main tributaries, including Karoun and Dez rivers, flow over Khouzestan Plain after journeying separately through anfractuous routes in mountains and join together at Band Ghir located 50 km off north of Ahwaz city. As such, the Karoun River eventually terminates at the Persian Golf (Figure 1).

A brief description of the study area is thus presented and details can be found in Jamab (1999). Climatic

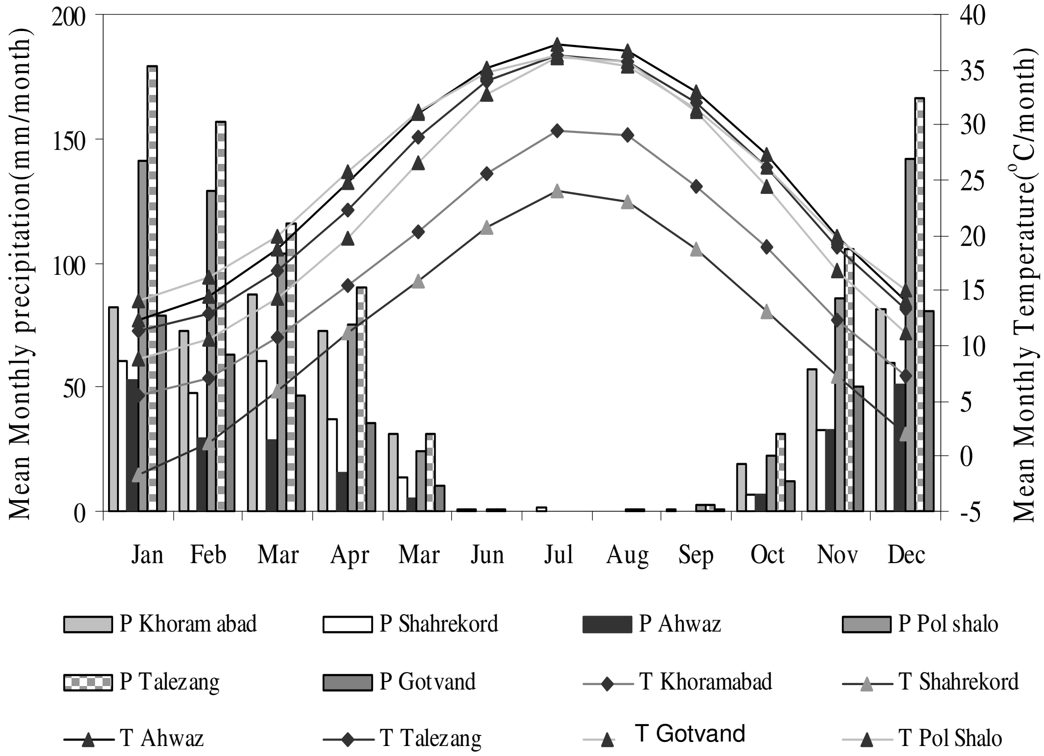

Figure 2. Mean monthly precipitation (P) and mean monthly temperature in different regions of the Large Karoun basin.

variation in Large Karoun River Basin is numerous and the types of dry desert, semi dry, semi wet, wet, very wet Mediterranean and cold humid climates are found in it. Precipitation regime in the basin is Mediterranean, that is, the dry season exactly matches the summer and the rainfall season coincides with winter. About 96% of rainfall occurs between October and May which varies from 1800 mm /year in the heights of 150 mm/year in plain areas (Jamab, 1999).

Fundamentally, Figures 2 and 3 show the precipitation and temperature conditions in different regions of the Large Karoun River Basin. As it is clear from the figures, a wide range of precipitation data have been recorded in basin stations, indicating various climates dominating the Large Karoun River Basin. This is due to the large extent and considerable heights of the basin which makes the investigation of the precipitation variable and climate conditions analysis dependant on the division of the basin into its constituting micro-climates. The classification of the micro-climates has been performed based on the precipitation pattern in relation with the region temperature, vegetation and height of different regions and lesser attention has been paid to the precipitation volume. This means that in classification of micro-climates, some parameters like altitude, temperature and vegetation of land are more influential than precipitation volume. For example, as it can be seen from Figure 3, despite the identical volume of the rainfall in pluviometery stations of Ahwaz and Shahrkurd, these two regions have different climates due to their different height and temperature. Also, Sepid-dasht and Yasouj despite their identical volume of precipitation are located in two regions with different climates. So, the Large Karoun River Basin has been divided into four distinct climatic regions (Figure 1 and Table 1).

Each region will be discussed as a separate uniform sub-basin (Table 1) as follows:

(1) Mountainous region of Karoun River Basin.
(2) Mountainous region of Dez River Basin.
(3) Middle part of the Large Karoun River Basin (from installed stations at an input of Karoun1 and Dez dams reservoirs to Ahwaz).
(4) Southern regions of the Large Karoun River Basin (from Ahwaz to the Large Karoun estuary (Arab, 2009).

MATERIALS AND METHODS

Data

Considering the climatic classification, data verification and suitability of the statistical period, precipitation data of more than 50 years (1956 to 2009) and temperature data of more than 30 years (1971 to 2009), four main stations were selected in this basin

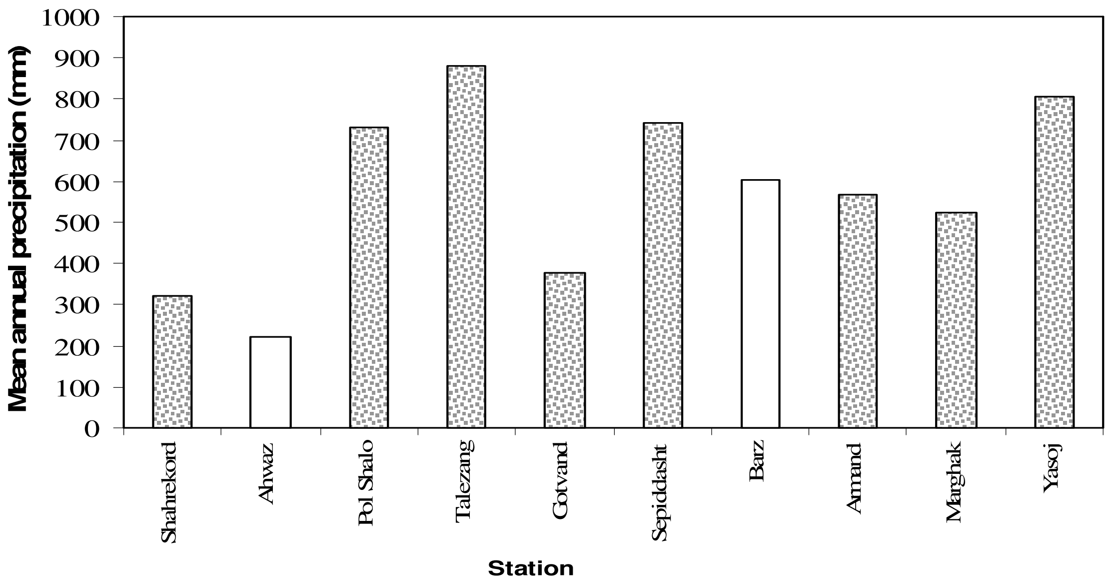

Figure 3. Mean annual precipitation (P) during 1956 to 2009 in different regions of the Large Karoun basin.

Table 1. Geographical characteristics of the selected river stations.

Row	Different regions of Large Karoun River Basin	Station name	Long	Lat	Elevation masl	Drainage area (km^2)	Time period	
							P	T
1	Mountainous region of Karoun River Basin	Pol Shalo	50.08	31.45	700	23400	1956- 2008	1971-2009
2	Mountainous region of Dez River Basin	Tale Zang	48.46	32.49	480	16213	1956- 2008	1971-2009
3	Middle basin of Large Karoun River Basin	Gotvand	48.49	32.15	75	32425	1956- 2008	1958-2009
4	Southern region of Large Karoun River Basin	Ahwaz	48.41	31.2	20	60737	1957- 2008	1957-2009

(Table 1). The aforementioned data were acquired from “Iran Meteorological Organization” and “Ministry of Energy” [Iran Water Resource Management Company and Khouzestan Water and Power Authority (KWPA)].

According to this classification, Pol-e Shaloo (located at Karoun3 dam), Tale Zang (located upstream of Dez dam), Gotvand and Ahwaz stations are considered as the representative of the mountainous region of Karoun river basin, the mountainous region of Dez river basin, the middle part of the Large Karoun River Basin and the southern region of the Large Karoun River Basin, respectively (Figure 1 and Table 1).

Simulation of climatic variables during the past periods using HadCm3 and CGCM3 models

One of the methods for simulating internal climate variability within a region is to explore climatic variables time series in long-term records (that is, more than several hundred years). Due to the lack of long-term observation records around the world, the alternative method will be the use of a three-dimensional coupled ‘atmosphere-ocean general circulation model’ or AOGCM (Wilby and Harris, 2006; Mitchell, 2003). These models are based on the laws of physics represented by mathematical relationships which are resolved in a three-dimensional network on the earth surface. In order to simulate the earth’s climate, the main climatic processes including atmosphere, cryosphere, biosphere and hydrosphere, were simulated in independent sub-models. So far, different general circulation models have been developed by different research institutes including UKMO-HadCM3, CCCma-CGCM3, GFDL_CM2, CM2.1, NCAR_PCM, CCSM3 and CSIRO-MK3 (cited in IPCC-AR4, 2007). In this research, to consider the uncertainty of the model, the outputs of two CGCM3 and HadCM3 models with spatial resolution of roughly 3.75 degrees lat/lon and 2.5/3.75 lat/lon, respectively, were used. In a specific type of simulation by this model, the amount of greenhouse gases over simulation time is kept at an observed level in the year 1850. In this type of simulation, known as the control run, the climatic variables are often simulated over a 1000-year period. Obviously, due to the fixed amount of greenhouse gases in such simulations, the time series of the variable under study is only affected by internal forces of the climate system and thus determines the internal variability of the climate system. If it is assumed that no changes will occur in the external factors including solar radiations and volcanic activities over future periods (that is, the next one hundred years), one can conclude that such simulation reflects natural climate variability (Oldenborgh et al., 2005; Lambert et al., 2005).

Calculation of interannual climate variability

In this study, in order to separate climate changes caused by greenhouse gases from interannual variability, the variability range of the temperature and precipitation are first examined. On the other hand, the recorded statistical periods’ length available at gauging stations is not adequate for calculating the interannual climate variability of the study area. Also, the observation records of the recent decades have been probably affected by radiation force resulting from increasing greenhouse gases, thereby making separation of interannual variability from climate changes quite difficult. Thus, in order to show the interannual variability across a region, long-term records of 1000 years generated by the control run of AOGCM models are used (Ruosteenoja et al., 2002). To analyze the interannual variability range of two “temperature” and “precipitation” variables of the study area, first, their annual anomaly time series with respect to the average base period is calculated. [By definition, temperature anomaly is the temperature difference from a base temperature, while precipitation anomaly is the precipitation ratio difference from a base precipitation]. The world meteorological organization (WMO) has suggested that in order to harmonize the selection of the 30 years base period in different climate change studies and the possibility of comparing them, the 1961 to 1990 base period should be considered. On the other hand, as the organization recommends, where data recorded on the station of the study area for this period is not available, the period of 1971 to 2000 will be replaced (IPCC-TGCIA, 1999).

So, because the statistics of the temperature variable of the Large Karoun River Basin upstream do not cover the 1961 to 1990 period, the period of 1971 to 2000 is considered as the base period. Then, it is assumed that the time series of these two variables follow two-variant normal distribution. With this assumption, the relationship governing the two-variant normal distribution of the temperature and precipitation anomaly will be realized as follows (Von Storch and Zwiers, 2002):

$$\frac{1}{1-\rho^2}\left\{\frac{T'^2}{{\sigma_T}^2}-2\rho\frac{T'}{\sigma_T}\frac{R'}{\sigma_R}+\frac{R'^2}{{\sigma_R}^2}\right\}=\chi^2 \quad (1)$$

Where, T' and R' are temperature and precipitation anomalies, σ_T and σ_R are standard deviation of temperature and precipitation and ρ represents the correlation between the temperature and precipitation anomalies. The amount of χ^2 is determined by square distribution of χ^2 with 2 degrees of freedom which is extracted from the respective tables at 95% confidence level (df = 2, 95% → χ^2 = 5.99). By plotting Equation (1) for 95% confidence level, elliptic circuits whose internal area indicates the interannual climate variability range for temperature and precipitation are obtained and its external area represents the variability related to other factors (like greenhouse gases).

RESULTS

Approximation of interannual climate variability in the study area

Figure 4 shows the interannual climate variability range with regard to the calculated 95% confidence level in the study area. In this figure, the horizontal axis represents temperature anomaly, while the vertical axis shows precipitation anomaly with respect to the base period average of 1971 to 2000. As it can be seen from this figure, most of the points showing annual anomalies are depicted inside the ellipse or too close to its perimeter. It means that the interannual climate variability range of the region has been plotted quite well by the ellipses. Overall, due to low skewness, the depicted figure indicates the assumed two-variant normal distribution of temperature and precipitation as acceptable for plotting the interannual climate variability range of the region under study. On the other hand, the excellent overlap obtained from each of the two models shows low uncertainty of the model selection. Therefore, it can be concluded with 95% probability that the combined interannual temperature-precipitation variability anomaly values of the Large Karoun River Basin are less than 1.5℃ and 75%, respectively.

After the determination of the interannual climate variability range within the study area, for evaluating the significance of climate change in the past half century (its attribution to greenhouse gases), the values of these variability were compared with the observed annual anomalies of temperature and precipitation for each region of the Large Karoun River Basin. Figure 5 shows the two-variant trend of temperature-precipitation anomalies during the past half century with respect to average (1971 to 2000) and the interannual climate variability range in different regions of the Large Karoun River Basin.

Since the inside area of each ellipse represents the combined interannual temperature-precipitation variability range within the study area, a point outside this range is indicative of the temperature and precipitation changes being dependant on factors other than interannual climate variability. Frequency time evolution of annual climate in the Large Karoun River Basin over the last years (1971 to 2009) can be traced from A to Z. As the points, A and Z, are considered as the start and ending years of the recent century, respectively, the results of the two-dimensional trend of temperature-precipitation anomalies for the past half-century with respect to the average (1971 to 2000 period) of four regions specified in Figure 5 shows an increase in temperature and a decrease in precipitation. Approximately, in all regions of the Large Karoun River Basin, especially the most southern part of it, the “temperature” found throughout the ending years of this period lies outside the interannual climate variability range, indicating the significance of climate change (that is, its relationship with the increase of greenhouse gases) in these years. The droughts that occurred in the ending years of the period confirm these results. Meanwhile, water years of 1999 to 2000 and 2000 to 2001 and also 2007 to 2008 and 2008 to 2009 have been defined as ‘dry years’. A review of annual precipitation changes in the representative northern stations of Karoun and Dez river basins, namely Pol-e Shallo and Taleh Zang stations shows more than 50% decrease in precipitation than under normal conditions. As such, higher precipitation in these regions of the basin compared with that of downstream regions, considerably reduces the basin yield, especially on upstream Dez and Karoun 3 dams at Pol-e Shallo and Taleh Zang stations (Arab, 2009). The recent trend towards

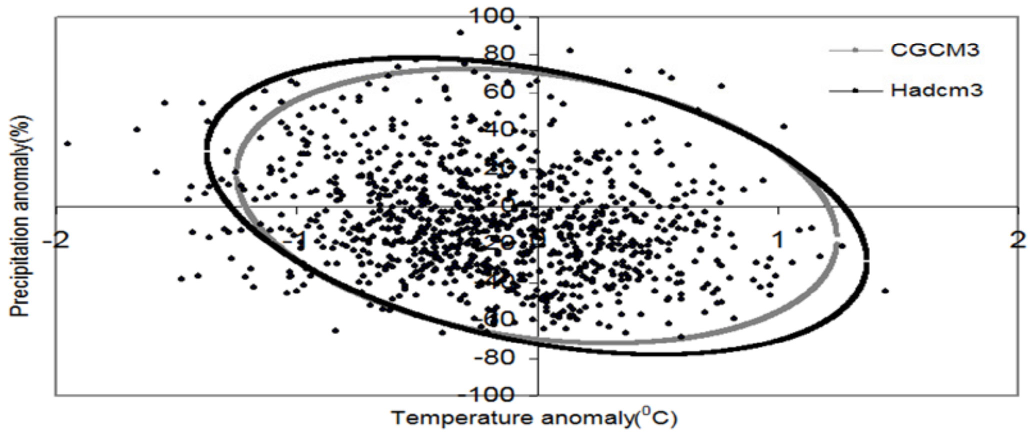

Figure 4. Interannual temperature-precipitation variability, with respect to the average period of 1971 to 2000 for Large Karoun River Basin.

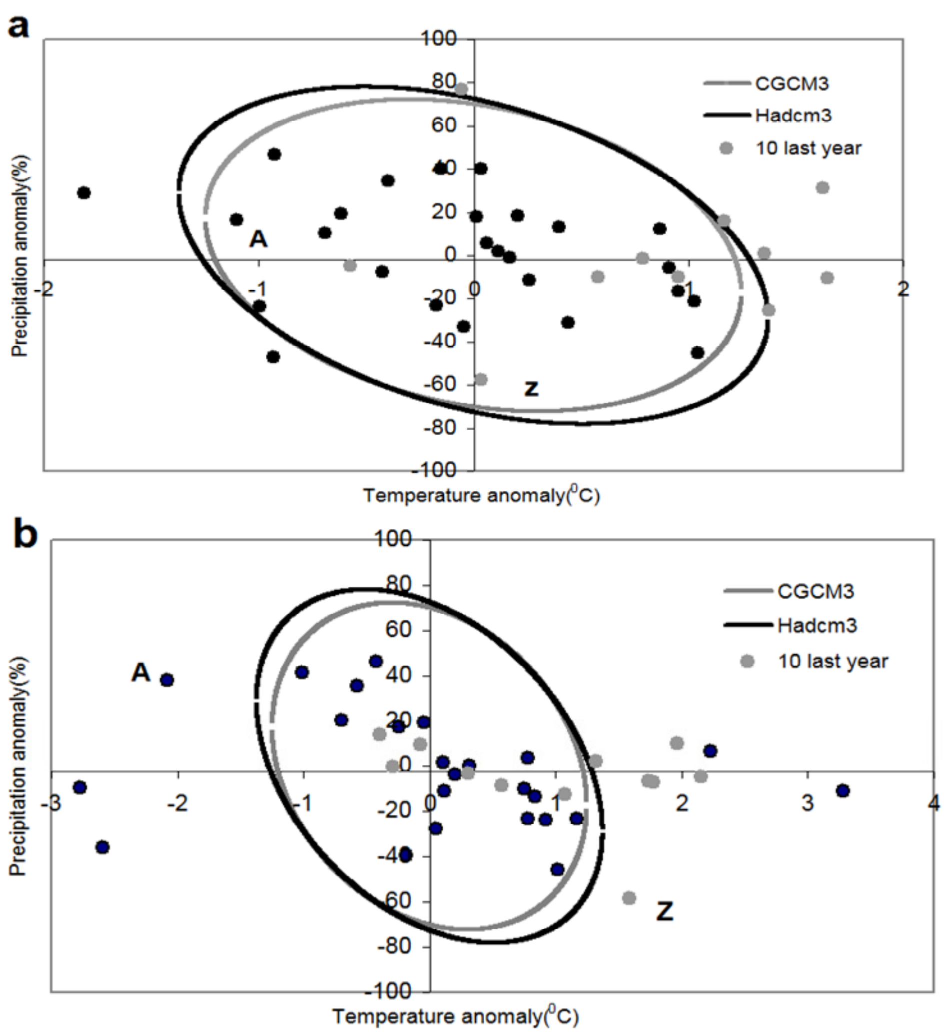

Figure 5. Two-dimensional trend of annual temperature–precipitation anomalies for the past half century with respect to the average period of 1971 to 2000 for the Large Karoun River Basin, together with interannual climate variability range. a: Mountainous region of Karoun river (Pole Shalo station); b: Mountainous region of Dez river (Talezang station); c: Middle basin of Large Karoun River Basin (Gotvand station); d: Southern region of the Large Karoun River Basin (Ahwaz station). Black points: observed data Grey points: Ten last years.

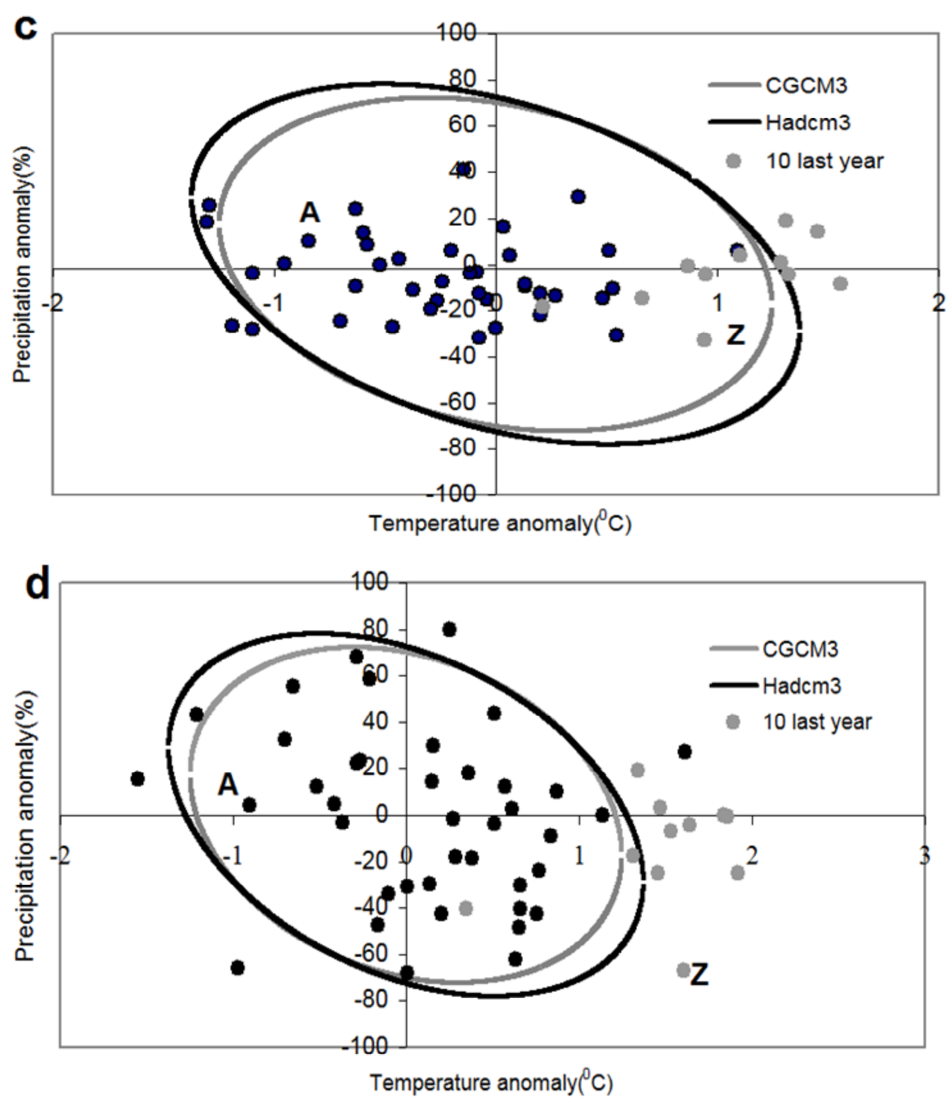

Figure 5. Continued

warming and drying, evidenced in Figure 5 is reinforced and, in the context of the past half century of Large Karoun River Basin climate variability, it becomes more significant. Therefore, detecting the range of inter-annual climatic variability of a region helps in identifying the years when extreme events such as drought and flood occur.

DISCUSSION

In this study, an attempt has been made to present a method of detecting past climate change in a regional scale and attributing it to greenhouse gases with regard to the climate process in a region. For this purpose, initially the variability range of climate variables related to the regional interannual variability was determined using control run data of two AOGCM models. The two models data were used to study the uncertainty of two AOGCM models in interannual variability of the study area. As such, it was assumed that the probability function of the temperature and precipitation was a two-variant normal distribution. With this assumption, the interannual climate variability range of the region was determined. The results of this study showed that: Firstly, the assumption of normality of temperature-precipitation probability function was acceptable due to low skewness of the plotted range. Secondly, the uncertainty between AOGCM models in estimating the natural climate variability range is low.

The comparison between the two-dimensional observed temperature-precipitation trend of the region and the interannual variability range showed that the climatic variable trend in the past half century in Large Karoun river basin had led to increased temperature and decreased precipitation, denoting the fact that the temperature variable has been influenced by the climate change. Khordadi et al. (2008) studies also show that regional climate in Iran is becoming dryer and warmer, and probably this will continue in the future (Montazeri and Fahmi, 2003). Also, the occurrence of low-flow and drought crisis in the second half of the century has been more frequent, incurring considerable damages because of decreased quality water resources on regional and national scales. Meanwhile, the impacts of greenhouse gases are clearly noticeable in the ending years of the observation period. In general, the proposed method in this paper can be used as an alternative to conventional stochastic methods in which only the data trend tests (such as Mann-Kendall test) for detecting and attributing climate change in the past periods are used.

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