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Simulation of climate change in Iran during 2071-2100 using PRECIS regional climate modelling system

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Abstract

Parameters such as future precipitation, temperature, snowfall, and runoff were modeled using PRECIS regional climate modeling system in Iran with the horizontal resolutions of 0.44×0.44°C in latitude and longitude under SRES A2 and B2 scenarios. The dataset was based on HadAM3p during the periods of 1961-1990 and 2071-2100. The overall precipitation error of the model in the period of 1961-1990 was 5.3%. Minimum errors were found to be over Azari, north-central, and Kordi regions. Maximum and minimum monthly precipitation errors were found in September and May, respectively; but, minimum and maximum seasonal biases were found in spring and winter with -0.1 and -17.2% errors, respectively. Results revealed a decrease in mean annual precipitation toward the end of the 21st century by 7.8 mm in B2 scenario and 10.1 mm in A2 Scenario with maximum regional decrease of 100 mm in the southeast of the Caspian Sea. The decrease in precipitation was higher for A2 scenario, whereas it was minimum for B1 scenario. Mean annual temperature of Iran during 2071-2100 would be projected to increase by 4.5-5.5°C in A2 scenario and 3-4°C in B2 scenarios compared to 1961-1990. It was shown that mean annual changes in runoff over the country were negligible both in A2 and B2 scenarios. Maximum annual amount of runoff increase was found over western part of the Caspian Sea, Zagros and Alborz mountain chains by 6.4-15. 8mm. Results also indicated that annual snowfall would decrease by the maximum amount of 22.9-23.7 cm over Zagros and Alborz mountain chains.

Keywords: **C**limate change; Iran; PRECIS, Regional climate modeling; 2071-2100

1. Introduction

Intergovernmental panel on climate change (IPCC) has confirmed the existence of strong evidence for attributing most of the warming observed over the last 50 years to human activities (IPCC, 2007). There is also no doubt that global climate change is an ongoing process. Between the period of 1906-2005, the globally averaged surface temperature changed by +0.74°C ± 0.18°C, with an almost doubled rate of warming over the last 50 years of the same period (Brankovic *et al*., 2010). Many studies have confirmed that global mean temperature is projected to increase by 1.4 to 5.8°C during the 21st century (Kwon *et al*., 2005; Sheperd and Jin, 2004). Lioubimtseva and Henebry (2009) showed that aridity would increase across the entire central Asian regions.

Iran has a variable climate and its mean annual precipitation is 250mm. The major exceptions include higher mountainous area of Zagros and Alborz and the Caspian coastal plain, where mean precipitation is more than 500 mm. In the western part of the Caspian Sea, rainfall exceeds 1500 mm annually and is distributed relatively evenly throughout the year, which is in contrast with some basins in the Central Plateau that receive less than 100 mm of precipitation annually (Alijani, 2001). The climate of Iran has experienced gradual warming of approximately 0.5°C during 1961-2000 (Rahimzadeh and Asgari, 2004; Rahimzadeh *et al*., 2005; Azizi and Roshani, 2008). The frequency of extreme precipitation events is also projected into increase over most parts of Iran due to the emission of greenhouse gases (Asgari *et al*., 2007; Rahimzadeh and

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Asgari, 2006). In recent years, Iran has experienced many extreme weather and climate events such as heavy flooded weather systems and tropical cyclones. Southeastern and southern coasts of Iran have experienced two unusual and major tropical cyclones of Gonu and Phet in June 2007 and 2010 respectively, in which dozens of people were killed or injured. Approximately 300 people were killed in the southeast of Caspian Sea in 2002 flash-flooded summer rainfall. Also, the west and central parts of Iran have experienced dust and sand storms in recent years due to extreme drought conditions in the Middle East. Many studies on Iran have emphasized that mean surface air temperature of the country will increase by 1.5 - 6°C by the end of the 21st century (Babaeian *et al*., 2009; Zarghami *et al*., 2011; Sadat Ashoftehand Massah, 2009).

In order to derive a meaningful interpretation of climate change, climate models are used as the main tools for developing future climate change projection (Houghton *et al*., 1995, 2001). To date, future climate has been widely simulated using global climate models (GCMs) based on IPCC SRES emission scenarios (Min *et al*., 2006). GCMs properly represent broad features of the current climate and can reproduce the observed large-scale changes in climate over recent past. As their horizontal resolution is too coarse, GCMs will fail to capture the local details needed for impact assessments at a regional level where coasts and mountains have significant effects on weather (Im *et al*., 2007). Regional climate models (RCM) have much higher resolution than global climate models and provide climate information with useful local details (Nazirulislam, 2005). Although the ability of coupled models in simulating large-scale climate variability in space and time has substantially improved in recent years, they cannot capture the details required for regional impact assessments due to their coarse resolution (Alvez *et al*., 2009). In this regard, regional climate model is the best tool for dynamical downscaling of climate features in the case of obtaining detailed information for a particular region (Jones *et al*., 1995).

PRECIS (providing regional climate for impact studies) model could be used to obtain fine resolution climate change responses for the south Asian region in 2080s under A2 scenario. The simulated spatial patterns for the region showed an increase in precipitation over the monsoon belt and over some central parts of India. The rise of temperature in Pakistan varied from 6°C in summer to 4 to 5°C in winter (Khan and Chaudhry, 2007). Climate change projection for the 21st century based on A1B scenario suggested the warming of about 3.5-7°C in the period of 2070-2099 in Eastern Mediterranean and Middle East (Lelieveld *et al*., 2012). Some other related studies have also been done using PRECIS in different countries, including Bangladesh (Nazirulislam *et al*., 2007), India (Kolli *et al*., 2006), Nigeria (Beraki, 2005) and China (Yinlong *et al*., 2006).

There is a significant relationship between global warming and increasing rate of extreme weather and climatic events in Iran (Rahimzadeh *et al*., 2009).Therefore, future projection of meteorological variables and hydrological parameters such as precipitation, temperature, snowfall, and runoff are important for climate change adaptation in water resources and agricultural sectors. Considering the existence of complicated natural features of Iran such as mountains, forests, seas, lakes, and deserts, extreme hydro-meteorological events are either not captured by GCMs or their intensity is unrealistically low. One way to overcome this difficulty and resolve detailed climatic and geographical characteristics is to use a regional climate model (example Im *et al*., 2007; Babaeian *et al*., 2009). In this regard, PRECIS regional climate modeling system is used to simulate detailed climate change projection over Iran. In this study, the skill of PRECIS in simulating precipitation and temperature during 1961-1990 period was evaluated. Then, future hydro-meteorological parameters of Iran during 2071-2100 under SRES A2 and B2 scenarios (without sulfur cycle) were modeled and discussed.

2. Study area

The region studied in this paper was bounded between 43 to 68° in the east and 23 to 45° in the north, covering 4900 grid points with approximately 50km horizontal resolution (Fig. 1).

Three water bodies, namely the Caspian Sea, Persian Gulf, and Oman Sea are in the north and south of this region. In general, this region has an arid climate, in which most of the annual precipitation falls are from October through April. There are two regions of maximum precipitation over the country: the first is the southern beach of the Caspian Sea, which has maximum precipitation in fall when northerly humid systems flow up over Mount Alborz and the second is Mount Zagros. Two periods of 1961-1990 and 2071-2100 are selected to simulate the future climate of Iran.

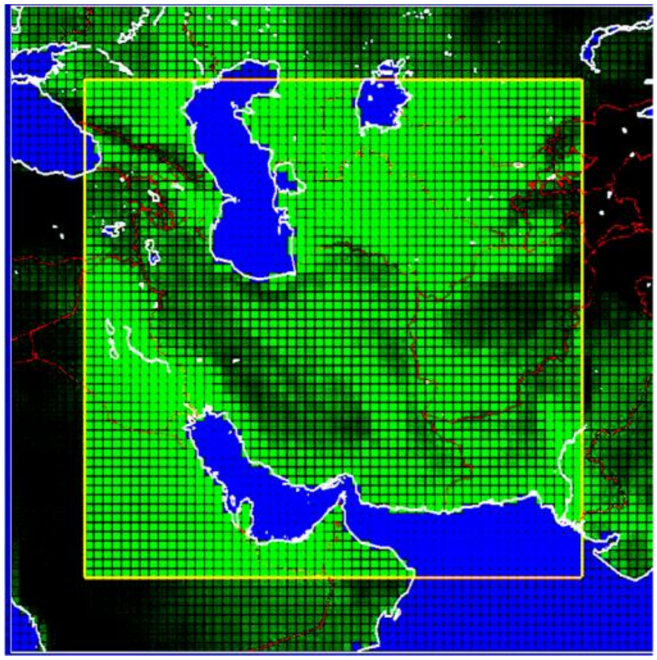

Fig. 1. Geographic area for modeling hydro-meteorological parameters of Iran in two periods of 1961-1990 and 2071-2100 using PRECIS regional model with 0.44º×0.44º resolution

3. Methodology

In this research, PRECIS model, developed by Hadley Center of UK Met office, was used to simulate hydro-meteorological parameters in Iran. PRECIS is easy to set up and run over any area of the earth on a PC. It needs to be driven at its boundaries by data from a GCM model (Wilson *et al*., 2005). Two types of such data were used in this study. The first one was HadAM3P boundary condition data under SRES A2 and B2 scenarios without sulfur cycle. The second type of data was observations from synoptic weather stations in Iran. Skill of PRECIS was analyzed by comparing the model output of 0.44×0.44°C horizontal resolution with the area averaged observed data during the base period of 1961-1990. Masoudian's precipitation zoning (Masoudian, 2008) of Iran was used to assess PRECIS outputs in modeling precipitation over Iran. Table 1 shows the contribution of each precipitation region in seasonal precipitation in Iran.

Table 1. Contribution (weight) of each precipitation region in seasonal precipitation over Iran (Masoudian, 2008)

Region/ Season	Caspian (Khazari)	Baluchi	Azari	Hormozi	Khuzi	Centrl-North	East-Khorasan	West Khorasan	Sistani	Kordi	Farsi	Central South
Spring	0.16	0.07	0.13	0.05	0.06	0.05	0.07	0.09	0.04	0.16	0.06	0.05
Summer	0.54	0,07	0.08	0.01	0	0.01	0.01	0.23	0	0.03	0.01	0.01
Autumn	0.47	0.03	0.07	0.01	0.04	0.02	0.02	0.21	0.01	0.09	0.03	0.01

Geographical precipitation regimes of Iran are shown in Figure 2. According to the figure, Iran was categorized into 12 precipitation regimes of central south, Farsi, Kordi, Sistani, West Khorasan, East Khorasan, central north, Khuzi, Hormozi, Azari, Baluchi, and Khazari (Caspian).The greatest area was Kordi region in the west and the smallest area was Baluchi in the south east of Iran which usually receives summer rainfalls due to Indian Monsoon system (Masoudian, 2008). Absolute and relative errors of the modeled precipitation were computed over all precipitation zones of Iran. To compute relative error, regional contribution of each precipitation regime was calculated in the precipitation of the country.

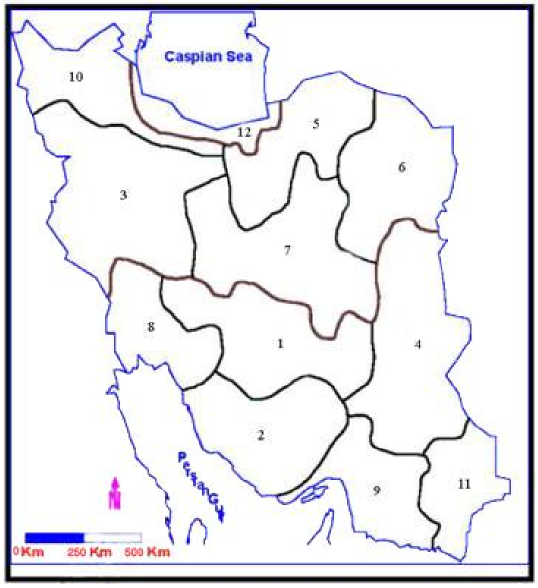

Fig. 2. Precipitation regimes of Iran. 1: Central south, 2: Farsi, 3: Kordi, 4: Sistani, 5: West Khorasan, 6: East Khorasan, 7: Central north, 8: Khuzi, 9: Hormozi, 10: Azari, 11: Baluchi, and 12: Khazari (Masoudian, 2008)

Regarding this method, actual error of each precipitation regime was calculated according to the contributions (weight) to the total precipitation of Iran. The regional precipitation contribution (as shown in Table 1) was computed using Equation (1).

Regional contribution=Regional precipitation/ Total precipitation (1)

4. Results and Discussion

4.1. Validation

Precipitation: Bias and relative percentage errors of the modeled precipitation using PRECIS during the base period of 1961-1990 were computed. Table 2 shows relative percentage errors of the modeled precipitation over different precipitation regions of Iran. Among the two applied scenarios, Farsi, Khuzi and Hormozi regions had the maximum amount of relative percentage errors as 34.7%, 20.4%, and 18.8%, respectively. All of the mentioned regions had significant components of convective precipitation due to warm and humid airflow from the Persian Gulf and Caspian Sea to Alborz, Zagros, and Makran mountain chains. Equation 2 was used for computing the percentage error of the modeled precipitation:

$$RPE = \left(\frac{P_{mod}}{P_{obs}} - 1\right) \times 100 \qquad (2)$$

where, *RPE* is the relative percentage error of modeling, P_{mod} is the amount of modeled precipitation, and P_{obs} is the observed precipitation (Wang *et al*., 2010).
The bias of the meteorological variables was computed as follows:

$$Bias = \sum_{i=1}^{n} \frac{P_{mod} - P_{obs}}{n} \qquad (3)$$

Table 2. Mean relative percentage error of precipitation during1961-1990 over 12 precipitation regimes of Iran

No.	*Regions*	*Relative error (%)*	
		SRES A2	*SRES B2*
1	Central south	13.1	7.1
2	Farsi	34.7	15
3	Kordi	-0.2	-2
4	Sistani	3.5	2.7
5	West Khorasan	-4.5	3.1
6	East Khorasan	-1.8	-2
7	Central north	-1.2	-0.8
8	Khuzi	20.4	3.7
9	Hormozi	14.8	18.8
10	Azari	1	0.7
11	Baluchi	5.3	5.8
12	Khazari (Caspian)	12.1	-8.3
	Country-Average	*8.1*	*3.7*

Almost all of the regions with high percentage errors of precipitation including Farsi (34.7%), Khuzi (20.4%), Hormozi (18.8%), central south (13.1%) and Caspian (12.1%) regimes had high amounts of convective precipitations. For example, due to special regional circulation pattern, Khazari (Caspian) region experienced heavy convective rainfalls in summer, fall, and spring. The minimum precipitation errors were detected in Kordi, Azari, and central north regions as -0.2, 0.7, and –0.8 relative percentage error, respectively. Average precipitation errors over Iran during 1961-1990 were 8.1 and 3.7 in A2 and B2 scenarios, respectively.

The skill of PRECIS in modeling the monthly mean precipitation is shown in Figure 3. In this figure, all regional errors were simply averaged over Iran without considering their contributions/weights to the total precipitation of Iran.

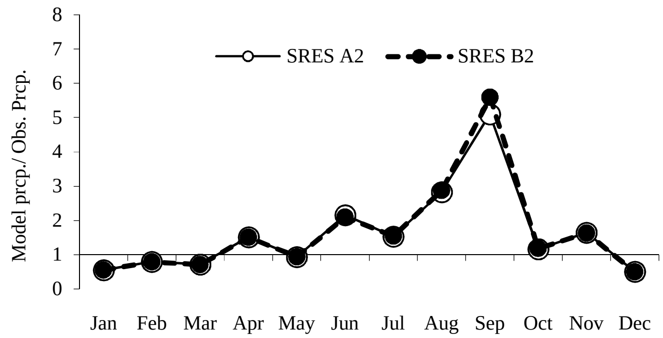

Fig. 3. Skill of PRECIS in modeling regional precipitation of Iran during 1961-1990. Values on the y-axis are relative errors (Model/Obs)

The monthly precipitation simulation was characterized by strong precipitation error in September, which was the transition month from summer to fall. Other higher relative errors were found in August and June. Maximum errors were seen during warm months when there were convective and local rainfalls because of surface instability due to local instabilities and temperature contrast along with land surface and sea surface temperature. Two important regions of convective and local rainfalls were located in the northern (Caspian Sea or Khazari region) and south-eastern (Baluchi and Hormozi regions) parts of Iran. According to Figure 3, it is clear that minimum errors occurred during the rainy season of October to May.

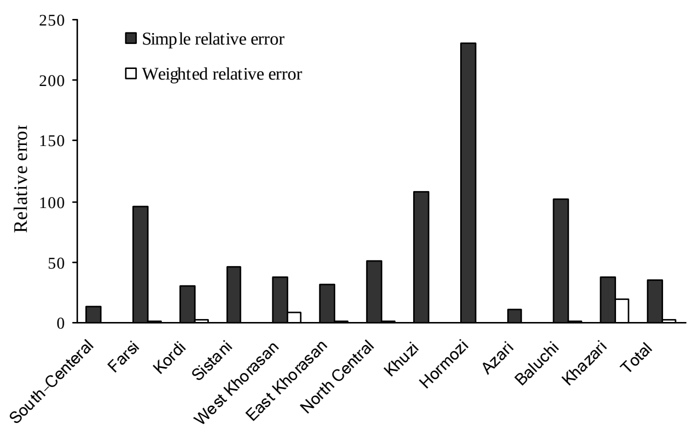

Fig. 4. Simple and weighted regional absolute errors in different precipitation regimes of Iran during the base period of 1961-1990

As mentioned before, regional precipitation contribution varies from region to region. From Table 1, it can be concluded that Khazari, West Khorasan, and Kordi regimes had maximum relative contribution in annual precipitation of Iran. Sistani, Hormozi, central north, and central south had minimum contribution to the annual precipitation of Iran. Figure 4 shows the simple and weighted relative errors of the modeled precipitation over different regions of Iran. Overall skill of PRECIS in modeling the mean seasonal precipitation of Iran was acceptable at the 0.05 confidence level. However, this skill in modeling the seasonal standard deviations, which is shown in Table 3, was not acceptable at the 0.05 confidence level.

Table 3. Skill of PRECIS in modeling seasonal precipitation standard deviation during 1961-1990

Season	*Observed STDEV(mm)*	*Modeled STDEV(mm)*	
		SRES A2	SRES B2
Spring	15.2	60.6	21.8
Summer	16.2	12.2	4.5
Autumn	42.3	48.7	18.5
Winter	20.6	72.5	25.8
Annual	*23.6*	*48.5*	*17.7*

Temperature: Masoudian's temperature zoning of Iran (Masoudian, 2008) was used to investigate the capability of PRECIS in modeling the mean temperature of Iran during 1961-1990. In this approach, temperature regions over Iran were categorized into 6 regimes of cold, cool, mild, semi- warm, warm, and hot. Monthly to annual bias and standard deviation of the model outputs were calculated. The validation of the temperature simulation is shown in Table 4.

Table 4. Mean temperature bias (°C) over 6 temperature regimes of Iran during 1961-1990

Regions	*Temperature bias (°C)*	
	SRES A2	SRES B2
Cold	-0.3	-0.3
Cool	-1.9	-1.7
mild	-2.2	-2.2
Semi- warm	-0.4	-0.4
Warm	1.1	0.8
Hot	1.3	1.2
Country-Average	-0.4	-0.3

PRECIS annual mean temperature patterns in the 1961-1990 period illustrated cold biases of -0.4 to -2.2°C over semi-warm to cold regions, and 0.8 to 1.3°C warm bias over warm to hot temperature regimes of Iran. According to t and F statistical tests, there was no significant difference between modeled and observed temperatures. The comparison between the simulations and observations indicated that January had maximum cold bias up to -3.2°C. In contrast, April and September had minimum warm bias of 0.1°C.

The linear regressions in Figure 5 confirm the capability of PRECIS in modeling monthly temperatures of Iran. Bold line is 1 to 1 line and thick dashed line is the regression line. R-squared is 0.98 which is a highly reliable result. The statistical significance was estimated using student's t-test. There were no significant differences between the modeled and observed temperatures at the 0.05 confidence level.

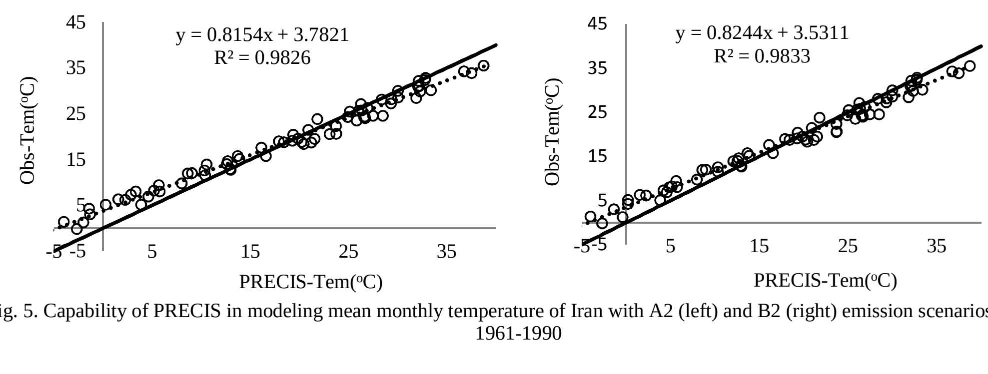

Fig. 5. Capability of PRECIS in modeling mean monthly temperature of Iran with A2 (left) and B2 (right) emission scenarios during 1961-1990

The results confirmed that the skill of PRECIS in modeling mean temperature both at regional and country scales was statistically acceptable.

4.2. `Future climate of Iran during 2071-2100

Precipitation: Relative changes of the mean annual precipitation under A2 and B2 scenarios during2071-2100 relative to 1961-1990 are shown in Figure 6 using ArcGIS software under the geo-statistical methods. The figure shows that mean annual precipitation decreased by more than 15 mm over almost all the regions of Iran during 2071-2100 under A2 scenario. Coastal areas of the Caspian Sea in the central part and leeward side of Zagros mountain chain were the exception. They would experience more than 5mm increase in annual precipitation, with maximum increase of 25mm per year. The amount of reduced precipitation and the area in B2 scenario were much less than those in A2 scenario. Areas of increasing precipitation in B2 scenario on the leeward side of Zagros and west of the Caspian Sea were greater than the areas predicted using A2 scenario. Overall pattern of the precipitation change was almost the same in both scenarios; but, maximum annual precipitation increase in A2 (B2) was 25 mm (11 mm) and maximum annual decreasing rate in A2 (B2) was greater than 75 mm (15 mm). It means that annual precipitation variability in A2 scenario was greater than B2 scenario,

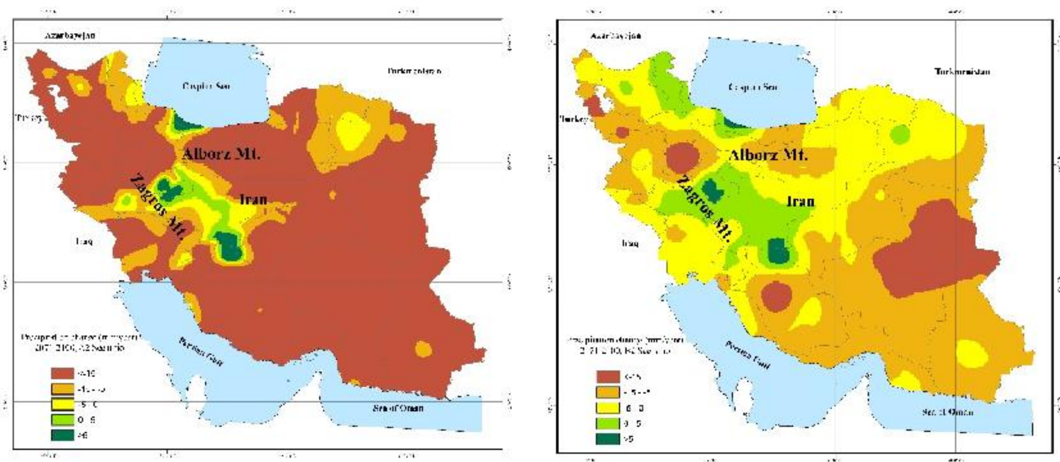

Fig. 6. Annual patterns of precipitation change (mm/year) in 2071-2100 compared to the base period of 1961-1990 in A2 (left) and B2 (right) scenarios

Table 5. Mean decadal changes of precipitation (mm) in 2071-2100 relative to the base period of 1961-1990

Region	*1961-1990*	*2070-2100*	
	Base	*SRES B2*	*SRES A2*
Central south	156.5	419.6	364.7
Farsi	200.1	141.3	136.0
Kordi	353.5	299.3	277.3
Sistani	138.4	107.9	95.1
West Khorasan	404.0	232.1	199.1
East Khorasan	181.1	170.9	149.5
Central north	81.9	194.8	172.4
Khuzi	147.5	85.9	76.9
Hormozi	198.8	154.7	134.6
Azari	378.0	285.5	256.4
Baluchi	109.5	89.7	68.3
Khazari (Caspian)	1160.5	578.9	567.0
Country-Average	292.5	230.1	208.1

As illustrated in Table 5, the annual precipitation in central north and central south regimes located on the leeward side of Zagros mountain chain is expected to increase during 2071-2100. These regions were facing water stress in recent years. Zayandeh-Rud, which is the biggest river of the region, is currently facing drought. The regions with noticeable precipitation decrease were Khazari (Caspian), Azeri, Khuzi, West Khorasan, and Farsi. All of the mentioned regions are located in the west of Iran; with the exception of West Khorasan. However, as the major agricultural products and all water power plants of Iran are located in this region, therefore, reduction of the future precipitation over the mountainous western part of the country should be strongly considered by relevant policy makers to increase energy and food security due to the impact of global warming.

Temperature: Figure 7 shows the mean annual changes of temperature during 2071-2100 relative to 1961-1990. In A2 scenario, maximum annual temperature increase occurred in the eastern and central parts of Iran with more than 9°C over Sistan and Baluchestan province. In the west, central-north, and south-east, minimum temperature increase was projected to be less than 5°C. Temperature rise in other remaining regions was about 5-7°C, which was noticeably decreased by one-third in B2 scenario compared to A2 scenario, especially over south-east of Iran. B2 simulation showed cold biased of more than 2°C compared to the A2 scenario. Mean annual temperature change pattern in B2 scenario was almost similar to A2 scenario. Maximum temperature rise pattern was different in the two scenarios. In A2 scenario, maximum temperature increase was in the east of Iran; but, in B2 scenario, it was distributed more or less uniformly over Iran.

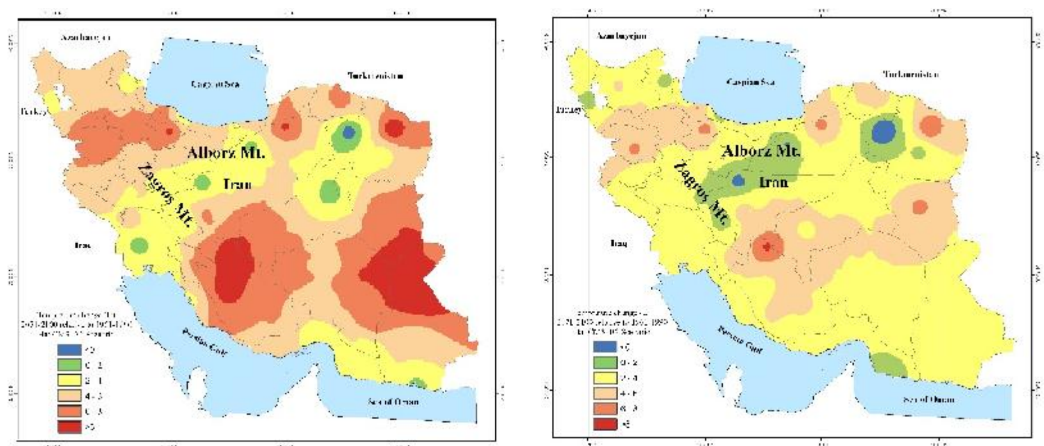

Fig. 7. Annual temperature rise during 2071-2100 compared to the base period of 1961-1990 in A2 (left) and B2 (right) scenarios

Table 6 indicates the mean annual temperature and its increase during 2071-2100 relative to those for the 1961-1990 base period over the six temperature regimes of Iran. The mean temperature rise in A2 and B2 scenarios was 4.95°C and 3.35°C, respectively. Maximum temperature rise was projectedover semi-warm regime with 7.01°C in A2 scenario and 4.14°C in B2 scenario. As indicated in the table, minimum temperature increase was computed over the hot temperature regime with 2.8°C in A2 scenario and 2.03°C in B2 scenario.

Table 6. Mean annual temperature rising in six temperature regimes of Iran in the period of 2071-2100 compared to 1961-1990

Region	*Observation (ºC)*	*A2 Scenario*		*B2 Scenario*	
		T-mean (ºC)	Mean rising (ºC)	T-mean (ºC)	Mean rising (ºC)
Cold	11.5	16.4	4.9	14.8	3.3
Cool	12.9	18.1	5.2	16.5	3.5
Mild	14.5	19.4	4.9	17.9	3.4
Semi-warm	18.0	25.1	7.0	22.2	4.1
Warm	24.5	29.5	5.0	28.2	3.7
Hot	27.9	30.7	2.8	29.9	2.0
Average	18.2	23.2	5.0	21.6	3.3

Mean temperature and precipitation changes can be concluded during 2071-2100 over 12 precipitation regimes of Iran using a paired temperature-precipitation diagram. The combined pairs of temperature (ΔT) and precipitation (ΔP) changes are shown in Figure 8 for A2 and B2 scenarios.

Snowfall: Figure 9 shows the projected snowfall changes of Iran during 2071-2100. The snowfall change was entirely negative in A2 scenario; but, there was a negligible snowfall increase over the limited areas of Iran located in the north-west under B2 scenario. Maximum increase in the snowfall was projected to be over northern north-west of Iran with 16mm in B2 scenario. Maximum decrease in snowfall was found over Mount Zagros with 22.9 mm and 23.6mm under A2 and B2 scenarios, respectively, which can severely limit the production of the country's hydroelectric power plants located mainly in the Zagros area. It can also reduce the available water resources for agricultural demands.

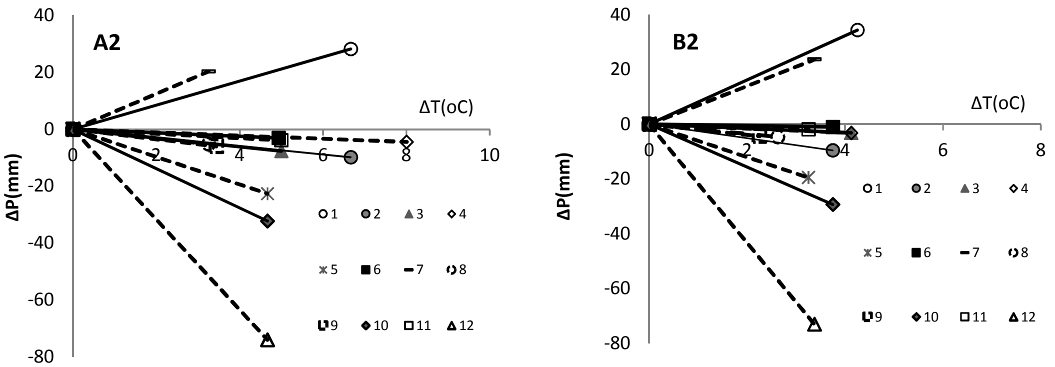

Fig. 8. Combined pairs of temperature and precipitation changes during 2071-2100 in A2 (left) and B2 (right) scenarios compared to 1961-1990 over 12 precipitation regimes of Iran 1: Central south, 2: Farsi, 3: Kordi, 4: Sistani, 5: West Khorasan, 6: East Khorasan, 7: Central north, 8: Khuzi, 9: Hormozi, 10: Azari, 11: Baluchi and 12: Khazari

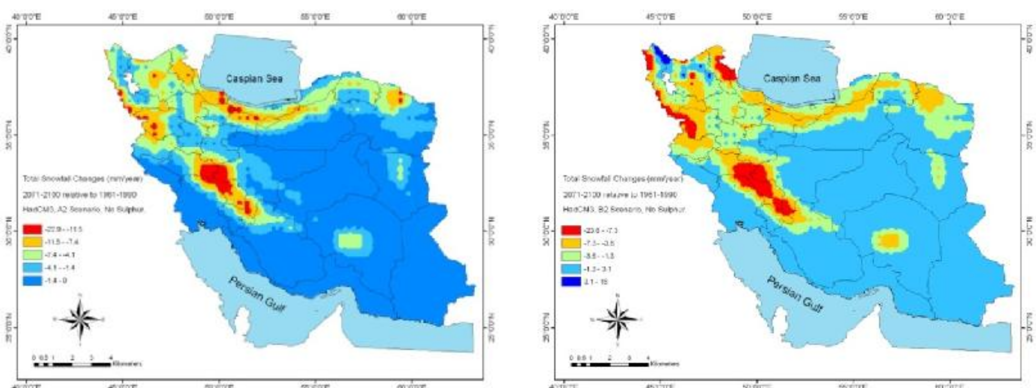

Fig. 9. Annual snowfall change (mm) for the period of 2071-2100 compared to the period of 1961-1990 in A2 (left) and B2 (right) scenarios

Runoff: Based on the PRECIS simulations, the mean annual runoff was projected to decrease over almost the entire areas of Iran both in A2 and B2 scenarios (Fig. 10). With the exception of elevated locations of Mount Alborz, the runoff fell in most regions of Mount Zagros. Eastern Zagros and Hezar-Masjed areas would experience more runoff in B2 scenario. As demonstrated in the figure, maximum increase in the annual runoff was projected over mountainous area of Alborz in south-east neighborhood of the Caspian Sea up to 15.8 mm in A2 and 14.3 mm in B2 scenarios. In the other parts of Iran, there was no significant change in runoff compared to the base period of 1961-1990.

In recent years, there has been major flooding in Caspian basin and East Alborz Mountainous areas. Heavy flood of 2002is an example, in which more than 300 people were killed in Golestan province located in the east of the Caspian Sea. Regarding the results of this research, because of increasing runoff over Caspian basin and Mount Alborz, the risk of heavy flooding would increase at the end of the 21st century.

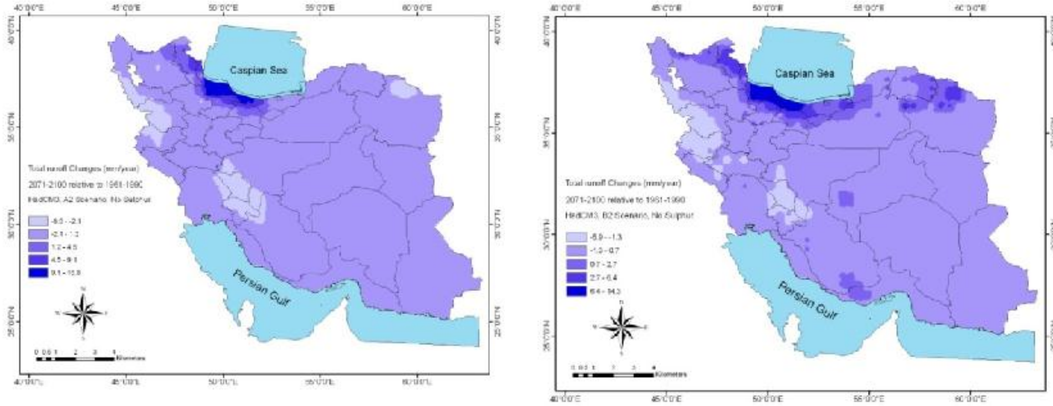

Fig. 10. Annual runoff change during 2071-2100 compared to the base period of 1961-1990 in A2 (left) and B2 (right) scenarios

5. Conclusion

PRECIS regional climate model, driven by HadAM3P boundary condition data under A2 and B2 emission scenarios without sulfur cycle, was used to simulate precipitation, temperature, snowfall, and runoff of Iran during 2071-2100. The capability of PRECIS in simulating precipitation and temperature was investigated. Results showed that PRECIS was capable of capturing the mean monthly temperature of different temperature zones of Iran. The simulated precipitation during 1961-1990 was tested using statistical tests of *student's-t* and F test. Results illustrated that capability of PRECIS in modeling the mean precipitation and temperature over almost all regions of Iran was acceptable at 0.05 confidence level.

It was found that total annual precipitation of Iran would decrease by17.1% in A2 and 15.2% in B2 scenarios. Only central western part of Iran over the leeward side of Mount Zagros and southern boundaries of the Caspian Sea would experience increased precipitation up to 25mm relative to 1961-1990. The area with the increased precipitation in B2 scenario was greater than A2 scenario. The overall pattern of the precipitation change was almost the same in both scenarios. Mean temperature rise in A2 and B2 scenarios was 4.95°C and 3.35°C, respectively.

Maximum temperature rise was modeled to be over semi-warm regime with 7.01°C in A2 and 4.14°C in B2 scenarios. Minimum temperature increase was projected to be over hot temperature regime with 2.8°C in A2 and 2.03°C in B2 scenarios. Moreover, maximum annual temperature rise was computed in north-western and west-central parts of Iran with 5-6°C in A2 scenario. Beaches of the Caspian Sea, Persian Gulf, and Oman Sea would experience minimum annual rising temperature of 3.5-4.5°C. The temperature rise over central parts of Iran was about 4.5-5°C. In B2 scenario, the mean temperature was projected to rise by about 1.5-2°C less than A2 scenario. The temperature pattern was almost the same in both scenarios.

Mean annual runoff decreased over most parts of Iran in both A2 and B2 scenarios. In B2 scenario, more areas, particularly east Zagros and Hezar-Masjed Mountains, would experience more runoff. The present findings confirmed that the greatest increase in annual runoff occurred up to 15.8mm in A2 and 14.3mm in B2 scenarios over the mountainous area of Alborz. There was no significant change in runoff in the other remaining parts of Iran compared to the 1961-1990 base period. Unlike the B2 scenario, snowfall was not predicted to increase in any regions of Iran in A2 scenario. The maximum amount of increased snowfall over the northern north-west of Iran was 16mm in B2 scenario. Maximum decrease in snowfall was projected over Mount Zagros with 22.9 mm and 23.6mm in two applied emission scenarios.

Together with increase in temperature, results showed that the mean annual precipitation in Iran would decrease, and this would lead to an increase in agricultural potential water demands and water stress in all sectors. While runoff and snowfall were predicted to decrease in central Zagros, they would increase in the Caspian Sea area, leading to increased risk of flooding in the Caspian Sea region. Reducing snowfall and runoff over Zagroscan severely limit the production of country's hydropower plants, which are mainly located in this area. Consequently, the results of this study show that, to have a sustainable future, effective adaptation measures are necessary.

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