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Temperature projections over Iran during the twenty-first century using CMIP5 models

David Francisco Bustos Usta[2] · Maryam Teymouri[3] · Uday Chatterjee[1] · Bappaditya Koley[4]

Abstract

A 13-member ensemble from CMIP5 is used to analyze the Iran future climate in terms of surface air temperature (TAS), identifying when anomalies of 1.5 ℃, 2.0 ℃ and 2.5 ℃ would be achieved respect to the preindustrial period (1861–1900) using the time sampling method. The global warming targets ($D_{1.5}, D_{2.0}, D_{2.5}$) are attained by the 2024, 2040 and 2056 under the RCP4.5 scenario, on the other hand, the respectively, attained years for Iran are 2023, 2036 and 2051, an evidence of a higher mean increase in surface air temperature respect to the global behavior. We identified important aspects regarding to temperature anomalies in the Iran region: (1) A mean warming of 1.0 ℃ for the 2001–2010 decade respect to the preindustrial baseline. (2) A mean warming of 0.5 ℃ for the 1960–2005 period respect to the preindustrial period. (3). For the 2006–2100 period under RCP4.5 scenario, was possible to identify a warming trend ($0.028°Cyear^{-1}$), which is above double the trend observed in the period 1960–2005 ($0.012°Cyear^{-1}$). 4) Largest trends over Iran occur for the 2006–2050 period (2.75 ± 0.74 to 4.72 ± 0.82 °C/century) respect to the 2006–2100 period (2.28 ± 0.36 to 3.39 ± 0.37 °C/century) with the most possible reason associated with the fact that under the RCP4.5 scenario, the emission rate increases toward 2040 and then stabilizes to the end of the century. All of these indicators evidence an intensification of the warming over the Iran region respect to the global trends. From the spatial analysis of surface air temperature trends over 5 regions of Iran for the 1850–2005, 1960–2005, 2006–2050 and 2006–2100 periods was possible to identify a significant increase in all the trends over Iran, but specially in the Southwestern of the country with a warming rate higher in warm regions than the cold climate regions. The present study reveled that further research should be development to explore renewable energy and create mitigation plans to minimize greenhouse gas emissions to overcome the increased risk of climate change effects.

Keywords CMIP5 · Surface temperature · Climate change · Iran

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Introduction

For over a century, the Earth's climate has been changing, as consequence of greenhouse gases increase in the atmosphere. Climate change impact includes global warming, sea level rise, changes in atmosphere and ocean dynamics, among others and is considered the greatest threat to the life and livelihood on Earth (Almazroui et al. 2017). Besides, climate change and its related impacts have large regional differences and uncertainties (Qian et al. 2016). As greenhouse gases in the atmosphere are expected to increase in the future, also climate change impacts are expected to grow, enhancing the threats to the planet and society (IPCC 2014a).

Global climate models are irreplaceable tools for evolving climate change projections and improved predictions (Knutti et al. 2013), these models have been created to

assess future climate behavior. Global general circulation models (AOGCM's) simulate dynamic conditions of physical processes of the ocean, atmosphere, cryosphere and land, and the way they interact (IPCC 2014e). These models are considered to be the best current tool to assess the response of the Earth's climate system to different radiative scenarios related to the greenhouse gases concentrations in the atmosphere (RCPs) and are extensively promoted by the World Climate Research Programs (WCRP) (IPCC 2014d). Results of AOGCMs performed by different research groups are evaluated in the Coupled Model Intercomparison Project (CMIP). In this paper, results from the 13 CMIP5 models are presented respect to the surface air temperature. A complete description of the CMIP5 design is explained by (Taylor et al. 2012).

Iran is located in the arid and semi-arid belt of the northern hemisphere from 44°–64° E longitude and 25°–40° N latitude bordering the Caspian Sea (in the north), the Persian Gulf, and Gulf of Oman (in the south), and covering an area of about 1,648,000 km^2 (Rahimi et al. 2020). This country is under is characterized as a subtropical region of West Asia (Fig. 1), with complex topography with a range of elevations from 20 to 5000 m above mean sea level. The precipitation in the region is affected by two important mountains, Alborz located from the West to the East parallel to the Caspian Sea (Stocklin 1974) and Zagros from the Northwestern to the Southeastern region (Paul et al. 2006). This range of elevations allows the presence of a variety of climates. The central

and southeastern regions are covered by two deserts with a very low rainfall regime (Katiraie-Boroujerdy et al. 2019).

The climate over Iran is influenced by various synoptic systems from west, northwest, north, southeast and south. In the west, there is presence of systems rich in humidity from the Mediterranean and North Atlantic cyclones that enhance the precipitation in this region (Sabziparvar 2008). The active months of the Mediterranean systems started from October to March and usually the maximum precipitation occurs around February. The intensity of these systems is weaker when the subtropical high pressure system penetrates into the atmosphere of the country. Since the annual frequency of these systems varies from year to year, the precipitation can be deviated from the normal behavior (Sabziparvar et al. 2015). The southwestern region presents particular climatic conditions with high risk of drought during the year (Sobhani and Zengir 2020).

In Iran, usually the hottest month is July with a range of temperatures between 20 and 30 ℃ and the coldest month is January with values between 0 and 10 ℃ (Alijani et al. 2008). Several studies indicate that latitude is positively correlated with annual temperature (Balyani et al. 2017). The coastal Caspian sea is typically humid and wet with a range of temperatures slightly below 0 ℃ to above 29 ℃. In the mountains is possible to see severe winters with high amount of snowfall and for the remaining areas evidencing an arid pattern with variations of temperature based on the proximity to major water bodies and topography (Soltani
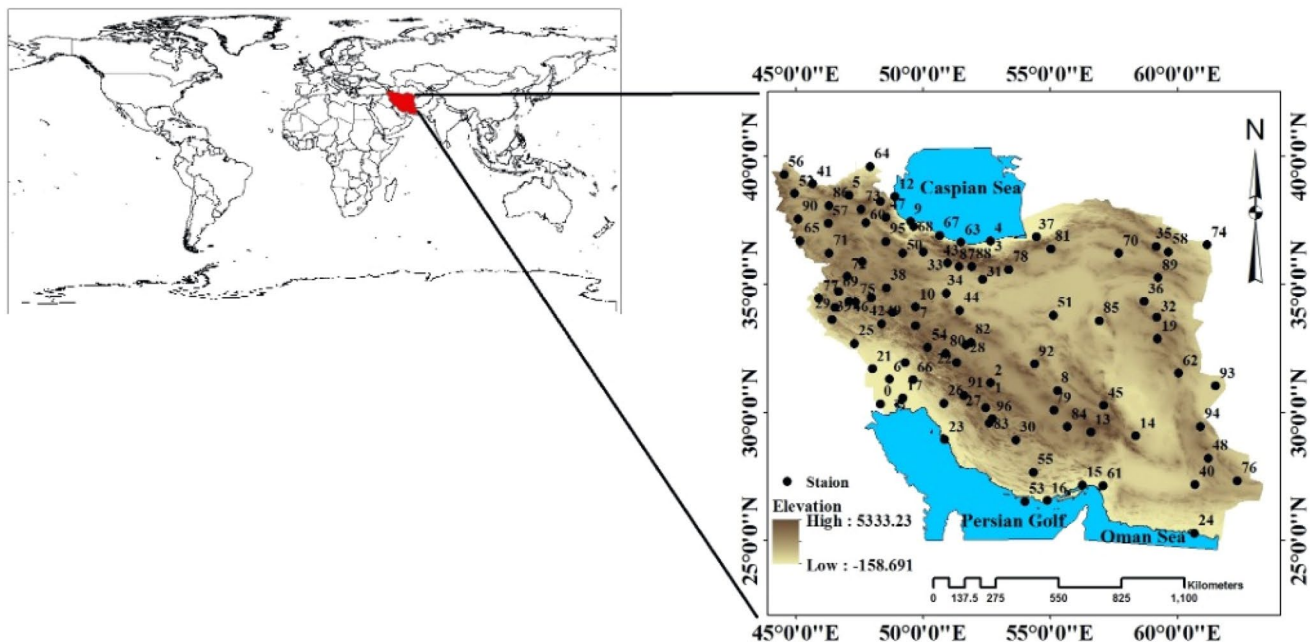
Fig. 1 Spatial distribution for the study area of Iran, including 97 stations from IRIMO

et al. 2016) with the majority of the deserts to the southern and southeastern coasts (Doulabian et al. 2020).

There are several studies around climate change over Iran using results from General Circulation Models, such as changes on temperature and precipitation (Samadi et al. 2012), groundwater (Hashemi et al. 2015), runoff (Shadkam et al. 2016), flood (Khazaei et al. 2012; Maghsood et al. 2019) assessment of climate change (Rahimi et al. 2020) performance in temperature and precipitation (Abbasian et al. 2019), projections of precipitation (Zarenistanak 2019) and drought (Sayari et al. 2013). However, in Iran, there is no complete evaluation of the limits established by the Paris Agreement from 195 countries around the globe to maintain "the increase in the global average temperature below 2.0 ℃ above pre-industrial levels and efforts to limit the temperature increase to 1.5 ℃" (United Nations 2020). This agreement mentions that increase of 2.0 ℃ with respect to the pre-industrial period as a default global target tolerable, but requires global commitments to reduce the greenhouse gas concentration and the use of mitigation technologies (IPCC 2014c).

Beg et al. (2002) proposed that "successfully limiting global climate change to 'safe' levels in the long-term is likely to require connecting climate change policies to sustainable development strategies in both developing and industrialised countries". Change of climatic conditions does not yet feature conspicuously among the economic or environmental policy of developing countries. However, evidence provides that a number of the most adverse effects of global climate change are going to be in developing countries, where people are mainly vulnerable and least likely to easily adapt to climate change, and that climate change will affect the potential for development in these countries (Beg et al. 2002). The sustainability social dimension raises a number of important 'fairness' problems within the context of climate change. These are often categories with respect to outcomes and to process (Rayner and Malone 2001; Beg et al. 2002).

Temperature or climate change is highly impeding the achievement of Sustainable Development Goals (SDGs) through out the world, especially in developing countries (Mousavi et al. 2020). Mousavi et al. (2020) reported that "as the second-largest country of the Eastern Mediterranean Region of World Health Organization, Iran is highly vulnerable to the effects of climate change". For this reason, it is imperative to understand the behavior of surface ambient temperature, to quantify possible impacts of climate change in this country.

In this paper, future climate change profiles for Iran are analyzed using global warming targets of 1.5 ℃, 2.0 ℃ and 2.5 ℃. The aim of the study is determine if there are differences in surface air temperature over Iran for the warming targets respect to the preindustrial levels. This study can be used for planning future crop patterns and farmer resilience when adapting to climate variability. This study also provides a pathway to prevent and minimize such destructive effects in Iran. Additionally, this research can provide insights into transformation and contribute to the sustainability of such adaptation.

The behavior of 13 CMIP5 models for the 1960–2005 period and the future projections under the RCP4.5 scenario (van Vuuren et al. 2011a), which is considered as the "mitigation" pattern are analyzed. RCP4.5 indicates that radiative emission rate increases from 1.5–2 Wm^{-2} with respect to 2006 to ~ 4.5 Wm^{-2} and peak around 2040 (van Vuuren et al. 2011a). To achieve this objective, the paper is organized as follows: Sect. 2 describes the datasets and methods used. Section 3 presents the results, with a description of the behavior of air surface temperature under RCP4.5 scenario, including a discussion to contextualize the results. In Sect. 4 a summary and conclusions are presented.

Data and methods

Data collection

We analyzed air temperature (TAS) for the 1850–2005, 1960–2005, 1990–2005, 2006–2015, 2006–2050 and 2006–2100 periods. We used CMIP5 "HISTORICAL" run before 2005. RCP4.5 (intermediate) emission scenarios were used for the forecast periods. RCP4.5 indicates that radiative emission rate increases 1.5–2 Wm^{-2} respect to 2006 to ~ 4.5 Wm^{-2} (equivalent to 650 ppm of CO_2) and peaks around 2040, then declines for the rest of the century (van Vuuren et al. 2011a). Data and model description was accessed from the Program for Climate Model Diagnosis and Intercomparison (PCMDI) (http://cmip-pcmdi.llnl.gov/mips/cmip5 /). The information was downloaded from the Earth System Grid Federation (https://esgf-node.llnl.gov/projects/cmip5/). Data used come from the realization 1, initialization 1, and physics version 1 (r1i1p1) run of the GCMs analyzed. The reason why the set of models analyzed was narrowed to 13 is explained in (Sect. 2.2).

Observed temperature data from the Republic of Iran Metereological Organization (IRIMO) with 97 metereological stations around Iran are used for comparison with the model data in the 1990–2005 and 2006–2015 periods (Rousta et al. 2020).

Methods

For the analysis, the time sampling method is used. This method consists of identifying the approximate future dates in which D increases are achieved respect to a reference date or period. In this case, the reference period is defined as

the pre-industrial period (1861–1900) defined by the (IPCC 2014a, b). The limits of interest for the study are 1.5, 2.0 and 2.5 ℃ with respect to the reference period denoted by ($D_{1.5}$, $D_{2.0}$, $D_{2.5}$). The data come from simulations of GCM's models defined in Table 1. There are several studies that present the benefits regarding the use of this method, James et al. (2017) identified that this methodology allows to have a greater comprehension of climatic signals and impacts associated with temperature increases. This methodology also has been used to compare climatic responses in various regions of the world (Schleussner et al. 2016) and using different number of models at regional scale (Guo et al. 2016; Taylor et al. 2018).

In CMIP5, there are a total of 42 models. In this study, we only refer to the RCP4.5 scenario because the following reasons. (1) There are more data available since it is part of the "Core" experiments and all the models have information associated (Taylor et al. 2012) compared to the other scenarios like RCP6.0 and RCP2.6. (2) $D_{2.0}$ is never achieved under RCP2.6 by 2100 (IPCC 2013b). (3) RCP4.5 is defined as a mitigaton scenario (reducing the green house emissions) contrary to RCP8.5 which represents the "bussiness as usual" scenario (van Vuuren et al. 2011a).

Spatial assessment of air surface temperature is the main interest; therefore, we decided to use the models from CMIP5 with best performance over the Iran region. We examine three criteria to select the models for the analysis, which have been used to evaluate the model´s global performance. First, a comparison of the space–time mean square error (RMSE) for the 1980–2005 climatological cycle, using 22 variables distributed in 5 categories (Atmosphere, Ozone and Aerosols, Carbon Cycle, Ocean, MISC and extremes)

performed by the (IPCC 2013b) following a methodology adopted from the CMIP3 (Gleckler et al. 2008). Second, comparing observed global temperature anomalies with the models performance for the 1961–1990 period (IPCC 2013a). Third, comparison of Mean Absolute Error (MAE) (Eq. 1), Root Mean Square Error (RMSE) (Eq. 2) and Mean Absolute Percentage Error (MAPE) (Eq. 3) with respect to observed temperature data from 97 meterelogical stations over Iran for the 1990–2005 and 2006–2015 periods.

$$\text{MAE} = \frac{1}{n} \sum_{i=1}^{n} |y_i - \hat{y_i}| \tag{1}$$

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y_i})} \tag{2}$$

$$\text{MAPE} = \left(\frac{1}{n} \sum_{i=1}^{n} \left| \frac{y_i - \hat{y_i}}{y_i} \right| \right) \tag{3}$$

Following these criteria, we selected 13 models (Table 1) which showed the best global and regional performance (Table 2). For comparison purposes, all GCM outputs were re-gridded using bilinear interpolation to a 1° x 1° grid (Libanda and Nkolola 2019).

Surface temperature annual anomalies were obtained for the 1861–2100 period with respect the pre-industrial period (IPCC 2014b), averaged for the globe and for the Iran region using the 13 CMIP5 models selected under RCP4.5 (Table 1). The average under the Iran region was done over 25°–40° N and 44°–64° E (Fig. 1), similar to

Table 1 CMIP5 models evaluated for the study (IPCC 2014a)

Model name	Modeling center	Resolution (latitude x longitude)
ACCESS1.0	Commonwealth Scientific and Industrial Research Organization and Bureau of Metereology, Australia	1.25°×1.875°
ACCESS1.3		1.25°×1.875°
CMCC-CM	Euro-Mediterranean Center on climate Change, Italy	0.7484°×0.75 °
CMCC-CMS		3.711°×3.75°
CMCC-CM5	National Center for Metereological Research/European Center for Research and Advanced Training in Scientific Computing, France	1.4008°×1.40625°
CSIROMk3.6	Commonwealth Scientific and Industrial Research Organization in collaboration with the Queensland Climate Change Centre of Excellence, Australia	1.875°×1.875°
CanESM2	National Center for Atmospheric Research, Canada	2.7906°×2.8125°
GISS-E2-H	NASA Goddard Institute for Space Studies, USA	2°×2.5°
GISS-E2-R		2°×2.5°
HadGEM2-ES	National Institute of Metereological Research/Korea Metereological Administration, Korea	1.25°×1.25°
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo) and National Institute for Environmental Studies, Japan	2.7906°×2.8125°
MIROC-ESM-CHEM		2.7906°×2.8125°
MIROC5	Atmosphere and Ocean Research Institue (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	1.4008°×1.40625°

Table 2 Evaluation of surface air temperature from CMIP5 models analyzed for Hindcast (1990–2005) and Forecast (2006–2015) periods

Model	1990–2005			2006–2015		
	MAE	RMSE	MAPE	MAE	RMSE	MAPE
ACCESS1.0	1,27	1,63	11,86	1,11	1,60	14,06
ACCESS1.3	1,71	2,18	15,13	1,45	1,95	18,63
CMCC-CM	1,45	1,84	13,85	1,00	1,34	13,98
CMCC-CMS	2,31	2,72	21,50	2,03	2,42	25,27
CMCC-CM5	1,45	1,85	13,20	1,43	1,90	14,74
CSIROMk3.6	1,90	2,31	16,62	1,70	2,09	22,72
CanESM2	2,79	3,37	18,30	2,71	3,28	24,84
GISS-E2-H	2,42	3,06	28,27	3,22	4,01	39,35
GISS-E2-R	4,20	4,59	42,25	2,92	3,73	42,20
HadGEM2-ES	3,52	4,08	29,16	4,16	4,76	30,41
MIROC-ESM	3,58	4,04	29,67	3,56	4,07	32,92
MIROC-ESM-CHEM	3,55	4,01	30,01	3,55	4,09	31,65
MIROC5	4,32	4,61	34,33	4,01	4,34	30,50

previous studies (Abbasian et al. 2019; Rahimi et al. 2020). A 10-year running mean time series were used to identify years on which for each model and the multimodel mean (MMM) the $(D_{1.5}, D_{2.0}, D_{2.5})$ limits are achieved with the criteria of all the subsequent years higher than the thresholds. The reason to use a running mean instead of the annual mean is to minimize the impact of seasonality and climate variability. A similar procedure was followed for the Iran region. Results are presented in Sect. 3.

We also analyze the spatial behavior of the surface air temperature trends in the 5 administrative regions of Iran: Region 1 (Alborz, Golestan, Mazandaran, Qazvin, Qom, Semman and Tehran provinces). Region 2 (Bushehr, Chaharmahal, Fars, Hormozgan, Isfahan and Kohgiluyeh-Boyer-Ahmad provinces). Region 3 (Ardabil, East Azerbaijan, gilan, Kordestan, West Aserbaijan and Zanjan provinces). Region 4 (Hamadan, Ilam, Kermanshah, Khuzestan, Lorestan and Markazi provinces). Region 5 (Kerman, North Khorasan, Razavi Khorasan, Sistan-Baluchestan, South Khorasan and Yazd provinces) in the 1850–2005, 1960–2005, 2006–2050 and 2006–2100 periods.

Results

Figure 2a shows the 10-year rolling mean for anomalies of surface air temperature respect to the pre-industrial period for each of the 13 CMIP5 models selected and the ensemble mean (red line). Figure 2b is identical, but for the Iran region (Fig. 1). It is possible to identify that all the 13 models are above the $D_{1.5}, D_{2.0}$ limits by the end of the 21st centuty and for the $D_{2.5}$ limit, the GISS-E2-R model is the only one that did not achieve the target (Fig. 2a). The attainment dates for each of the global thresholds defined previously are 2024 for $D_{1.5}$ (range from 2012 to 2036), 2040 for $D_{2.0}$ (range

from 2030 to 2058), and 2056 for $D_{2.5}$ (range from 2040 to 2085) (Fig. 3a).

On the other hand, the attainment dates for Iran are 2023 for $D_{1.5}$ (range from 2018 to 2038), 2036 for $D_{2.0}$ (range from 2030 to 2055), and 2051 for $D_{2.5}$ (range from 2037 to 2073) (Fig. 3b). Notice that all the ranges for this case are lower compared to the global result, thus indicating that a higher regional warming compared to the rest of the world similar to results obtained in several studies (Heydari Tasheh Kabood et al. 2020; Hassan and Nile 2020).

There are important aspects regarding to the temperature anomalies in the Iran region. (1) A mean warming of 1.0 °C for the 2001–2010 decade respect to the pre-industrial baseline. (2) A mean warming of 0.5 °C for the 1960–2005 period respect to the pre-industrial period. (3). For the forecast 2006–2100 period was possible to see a warming trend (0.028°C year^{-1}), which is above double the trend observed in the period 1960–2005 (0.012°C year^{-1}).

For each station analyzed, the multi-model mean (MMM) indicates positive and statistically significant trends for TAS in all the periods analyzed (Table 3, Fig. 4). The lowest trends in all models (0.06 ± 0.02 to 0.31 ± 0.11 °C/century) are shown for the 1850–2005 period with a mean(median) of 0.19 (0.18) °C/century, maximum (minimum) values for Ahvaz, Ravansar and Hamadan Airport (Ahar, Urmia and Sanandaj). For the 1960–2005 period, which indicates a more industrialized planet, the trends are between 1.06 ± 0.51 and 2.72 ± 0.84 °C/century with a mean(median) of 2.31 (2.39) °C/century, maximum(minimum) values for Ahvaz, Hamadan Airport and Khalkhal (Zabol, Mashhad and Khash). However, largest trends occur in the forecast periods, with values from 2.75 ± 0.74 to 4.72 ± 0.82 °C/century (RCP4.5) for the 2006–2050 period with a mean(median) of 3.57 (3.44) °C/century (Fig. 5) with maximum(minimum) values for Ravansar, Eslam Abad and Ilam (Zabol, Mashhad
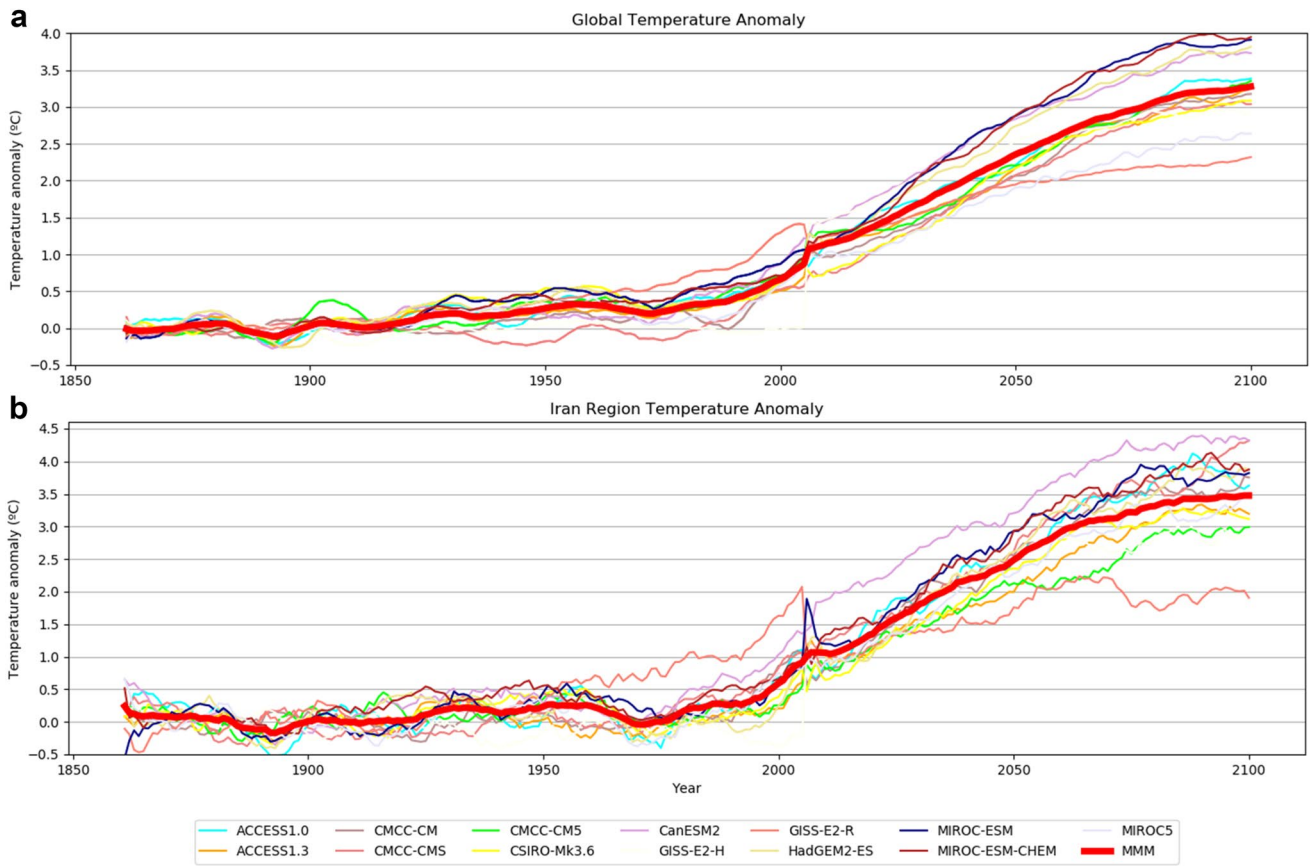
Fig. 2 Historical and future projections of annual surface air temperature anomalies with respect to the pre-industrial period (1861–1900). **a** World and **b** Iran region for each of the 13 models under RCP4.5. The ensemble mean for the 13 models (bold red) is also shown
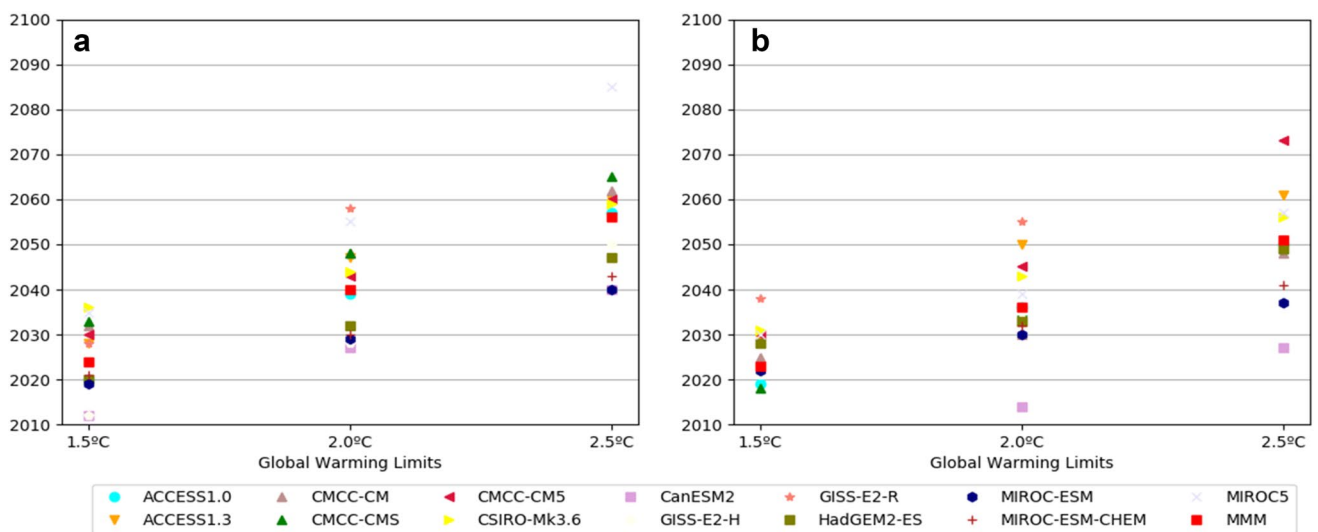
Fig. 3 Years projected by the 13 models under the 3 **a** global **b** Iran warming targets (1.5 ℃, 2.0 ℃ and 2.5 ℃) with respect to the pre-industrial baseline (1861–1900). Values for the ensemble mean for the 13 models (red squares) are also shown.

Table 3 Adjusted trends for 97 stations over Iran under Historical (1850–2005, 1960–2005) and RCP4.5 (2006–2050, 2006–2100) experiments (˚C/century)

Station	1850–2005	1960–2005	2006–2050	2006–2100
Abadan	0.218	2.541	3.934	3.208
Abade	0.143	2.391	3.425	2.826
Abade	0.163	2.422	3.497	2.866
Ahar	0.074	2.245	3.205	2.909
Ahvaz	0.305	2.719	4.372	3.388
Aligudarz	0.245	2.549	3.932	3.182
Anar	0.260	2.376	3.421	2.990
Anzali	0.185	2.334	3.491	2.940
Arak	0.230	2.495	3.822	3.122
Ardabil	0.233	2.571	4.007	3.238
Astara	0.126	2.120	3.051	2.699
Babolsar	0.143	2.391	3.425	2.826
Babolsar	0.163	2.422	3.497	2.866
Baft	0.191	2.312	3.417	2.867
Bam	0.169	2.387	3.379	2.851
Bandar Abass	0.174	2.430	3.440	2.890
Bandar Lengeh	0.178	2.387	3.394	2.894
Bandar Mah-shahr	0.140	2.173	3.161	2.759
Bijar	0.146	2.393	3.570	3.058
Birjand	0.181	1.571	2.976	2.489
Boroojen	0.165	2.350	3.518	2.818
Bostan	0.204	2.512	3.862	3.178
Brojerd	0.111	2.066	2.941	2.638
Bushehr Air-port	0.124	2.218	3.148	2.663
Chabahar	0.183	2.171	3.313	2.753
Dehloran	0.103	2.304	3.351	2.968
Dogonbadan	0.113	2.185	3.056	2.624
Drudzan	0.259	2.646	4.350	3.166
Esfahan	0.217	2.515	3.980	3.011
Eslam Abad	0.268	2.618	4.571	3.231
Fassa	0.224	2.515	3.712	2.988
Garmsar	0.248	2.614	4.257	3.127
Ghaen	0.178	1.775	3.077	2.580
Ghazvin	0.260	2.602	4.042	3.242
Ghom	0.144	2.284	3.333	2.740
Golmakan	0.175	1.979	3.177	2.670
Gonabad	0.172	2.183	3.278	2.761
Gorgan	0.158	2.389	3.387	2.871
Hamadan	0.290	2.689	4.299	3.358
Ilam	0.243	2.591	4.419	3.211
Iranshahr	0.183	1.949	3.199	2.657
Jolfa	0.116	2.455	3.660	3.108
Kangavar	0.189	2.482	3.789	3.148
Karaj	0.155	2.317	3.425	2.779
Kashan	0.186	2.416	3.703	2.895
Kerman	0.243	1.960	3.348	2.797

Table 3 (continued)

Station	1850–2005	1960–2005	2006–2050	2006–2100
Kermanshah	0.089	2.275	3.278	2.939
Khalkhal	0.276	2.660	4.226	3.328
Khash	0.181	1.282	2.859	2.372
Khor	0.219	2.382	3.407	2.942
KhoramAbad	0.247	2.600	4.080	3.268
KhoramDareh	0.155	2.227	3.271	2.820
Khoy	0.243	2.495	4.274	3.140
Kish	0.245	2.545	3.784	3.028
Kohrang	0.275	2.656	4.152	3.303
Lar	0.265	2.576	3.856	3.069
Mako	0.131	2.460	3.744	3.068
Maragheh	0.167	2.509	3.964	3.149
Mashhad	0.187	1.163	2.774	2.309
MasjedSoley-man	0.170	2.281	3.381	2.880
Mianeh	0.161	2.423	3.643	3.088
Minab	0.225	2.077	3.371	2.820
Nehbandan	0.184	2.393	3.426	2.848
Noshahr	0.196	2.449	3.795	2.934
Pars Abad	0.175	2.452	3.716	3.118
Piranshahr	0.091	2.428	3.508	3.087
Ramhormoz	0.200	2.388	3.602	3.001
Ramsar	0.103	2.153	2.963	2.585
Rasht	0.215	2.442	3.712	3.061
Ravansar	0.293	2.645	4.723	3.252
Sabzevar	0.260	1.842	3.325	2.773
Sagez	0.217	2.564	4.267	3.190
Sanandaj	0.060	2.215	3.132	2.879
Sarab	0.132	2.363	3.497	3.028
Sarakhs	0.181	1.505	2.972	2.467
Sararud	0.118	2.334	3.424	2.998
Saravan	0.181	1.768	3.149	2.568
Sarpol Zahab	0.142	2.482	3.812	3.128
Semnan	0.204	2.484	3.641	2.947
Shahr Babak	0.239	2.379	3.414	2.947
Shahr Kord	0.134	2.251	3.240	2.701
Shahrood	0.199	2.384	3.400	2.918
Shargh esfahan	0.227	2.548	4.072	3.050
Shiraz	0.122	2.361	3.353	2.785
Sirjan	0.280	2.374	3.427	3.014
Tabas	0.208	2.195	3.394	2.844
Tabriz	0.192	2.536	4.115	3.169
Tehran	0.176	2.383	3.610	2.856
Tehran Airport	0.238	2.581	4.165	3.089
TorbateHey-darieh	0.184	1.367	2.875	2.399
Urmia	0.066	2.400	3.356	3.067
Yasuj	0.207	2.482	3.888	2.972
Yazd	0.137	2.392	3.380	2.847
Zabol	0.180	1.060	2.746	2.277

Table 3 (continued)

Station	1850–2005	1960–2005	2006–2050	2006–2100
Zahedan	0.182	1.727	3.086	2.562
Zanjan	0.261	2.630	4.153	3.298
Zarghan	0.183	2.453	3.569	2.907

and Khash). For the period 2006–2100, the trends are between 2.28 ± 0.36 and 3.39 ± 0.37 °C/century (RCP4.5) with a mean(median) of 2.93(2.94) °C/century (Fig. 5) with maximum(minimum) values for Ahvaz, Hamadan Airport and Khalkhal (Zabol, Mashhad and Khash).

Discussion

Under RCP4.5, smaller trends and lower variability can be observed for the 2005–2100 period when compared to the 2005–2050 period (Fig. 4), and the reason is that under RCP4.5 scenario, the radiative emissions decline and stabilize after 2040 (van Vuuren et al. 2011b). However, as trends are always positive, TAS is expected to continue to increase in the Iran region during all the twenty-first century.

TAS (Surface air temperature) warming trends in the Iran region shown for the HISTORICAL experiment coincide with regional trends assessed by (Babar et al. 2016), where using 17 CMIP5 models in the Southwest of Asia, including Iran, they identified surface air temperature trends of 0.84 °C/century for the 1901–2000 period, 0.90 °C/century for the 1951–2000 period and 2.7 °C/century under RCP4.5 for the 2000–2100 period. Rahimi et al. (2020) found trends of 3 °C/century in the 1970–2020 period that shows an intensification of the global warming on this zone in the last decades of the twentieth century, a result consistent with what was obtained in this study. Miao et al. (2014) using Bayesian model with averaging methods for 23 CMIP5 models found a trend of 3.11 °C/century under RCP4.5 for the 2006–2099 period over the Northern Eurasia region which is similar to the mean trend obtained under RCP4.5 of 2.93 °C/century (Fig. 5).

When we analyze the spatial behavior surface air temperatures trends over the 5 regions described at Sect. 2.2 (Fig. 4), results from the Historical run are summarized in the following: (a) For the 1850–2005 period, the multimodel mean (MMM) shows the lower variation in all the regions with trends beween 0.06 ± 0.05 and 0.30 ± 0.07 °C/century with maximum at Region 4 and minimum at Region 3. (b) For the 1960–2005 period, there is a significant increase in the trends over all the regions with values between 1.06 ± 0.44 and 2.72 ± 0.18 °C/century with maximum at Region 4 and minimum at Region 5. A considerable different

pattern in terms of variation is observed for the Region 5 probably associated to the large meridional variation of this region with the highest area at Iran. From the results obtained for the 1850–2005 and 1960–2005 periods is possible to observe that there is an intensification of the regional warming in all the regions but specially over the Region 4 and Region 3 in the Northwestern of Iran, this result is consistent with the spatial analysis of trends (Fig. 6a, b) which is possible to identify a consistent increase of temperature trends in the Western zone of Iran.

From the RCP4.5 experiment results obtained for the 2006–2050 and 2006–2100 periods, the most important results are summarized in the following: (1) For the 2006–2050 period, the multimodel mean (MMM) shows an increase of surface air temperature trends in all the regions with almost the double than the trends observed for the 1960–2005 period, with values between 2.75 ± 0.31 and 4.72 ± 0.50 °C/century with maximum at Region 4 and minimum at Region 5. Similar to the 1960–2005 period, Region 5 shows the lowest variation. (b) For the 2006–2100 period, the reduction in the magnitude of the surface air temperature trends with respect to what was observed for the period 2006–2050 is considerable, with trends between 2.28 ± 0.24 and 3.39 ± 0.20 °C/century with maximum at Region 4 and minimum at Region 5, similar to the 2006–2050 period. It is important to remark that there is a reduction in the variability of the trends in this period compared to what was observed in 2005–2050, which shows a stabilization of the rate of radiative emission after the middle of the twenty-first century. For the forecast period, the intensification of the trends similar to the 1960–2005 period occurs in the Western zone of Iran (Fig. 6c, d). These results show that the warm climate regions in Iran are warming at a higher rate than the cold climate regions and this agree with the result obtained by Ghasemi (2015).

From the results obtained, it is reveled that Iran is more severe for climatic change than the Middle East (Mansouri Daneshvar et al. 2019). The present study indicates that for Iran, a drought regime would be expected for the future, accompanied by higher temperatures with a continuous increase in the average temperature until the end of the century, which is more evident in the warm season, according to these results, it would be expected that the precipitation frequency will be decreased in Iran. Under these conditions, Iran will face food and water shortages and and elevated risk of droughts. This present research indicates that a suitable sustainable management strategies are required for future in Iran. It is possible to improve the sustainability of agricultural activities, water consumption and the state of the environment, but mechanisms and strategies are required to face this type of situations. The optimistic future of agriculture depends on whether this sector is able to mitigate negative
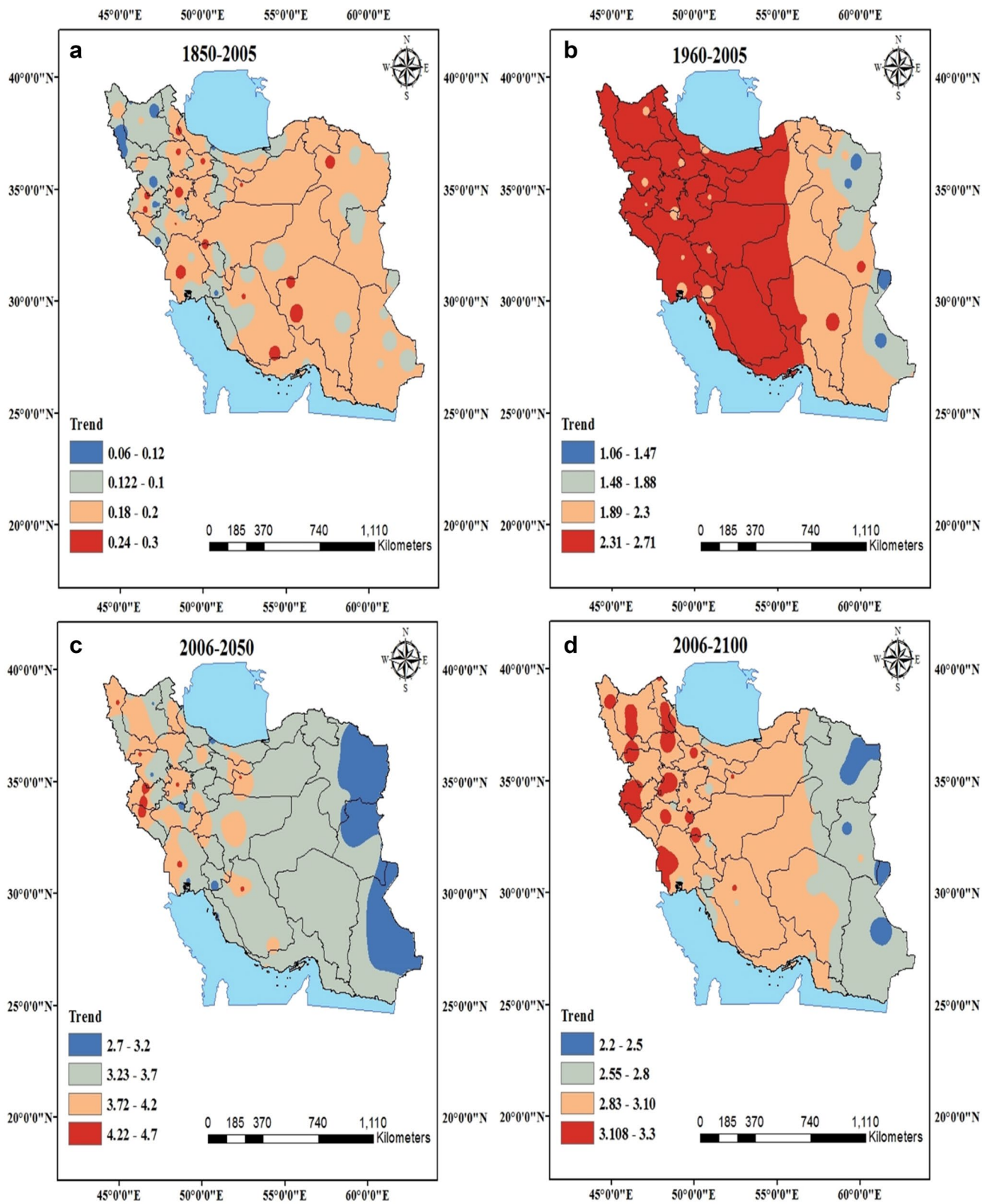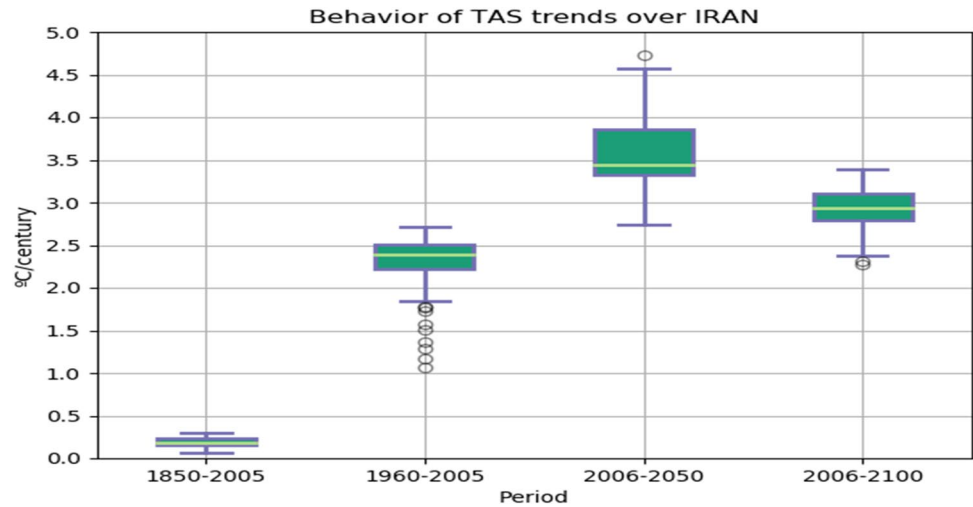
Fig. 4 Surface temperature trends in (℃/century) for the Iran region from multimodel mean (ACCESS1.0, CMCC-CM, CMCC-CM5, ACCESS1.3 and CSIROMk3.6). Period 1850–2005 (**a**) and 1960– 2005 (**b**) from the Historical run. Period 2005–2050 (**c**) and 2005– 2100 (**d**) under RCP4.5

Fig. 5 Boxplot for the surface temperature trends for 97 stations over Iran (℃/century)

Fig. 6 Boxplot for the surface temperature trends for 97 stations over 5 regions of Iran (℃/century)
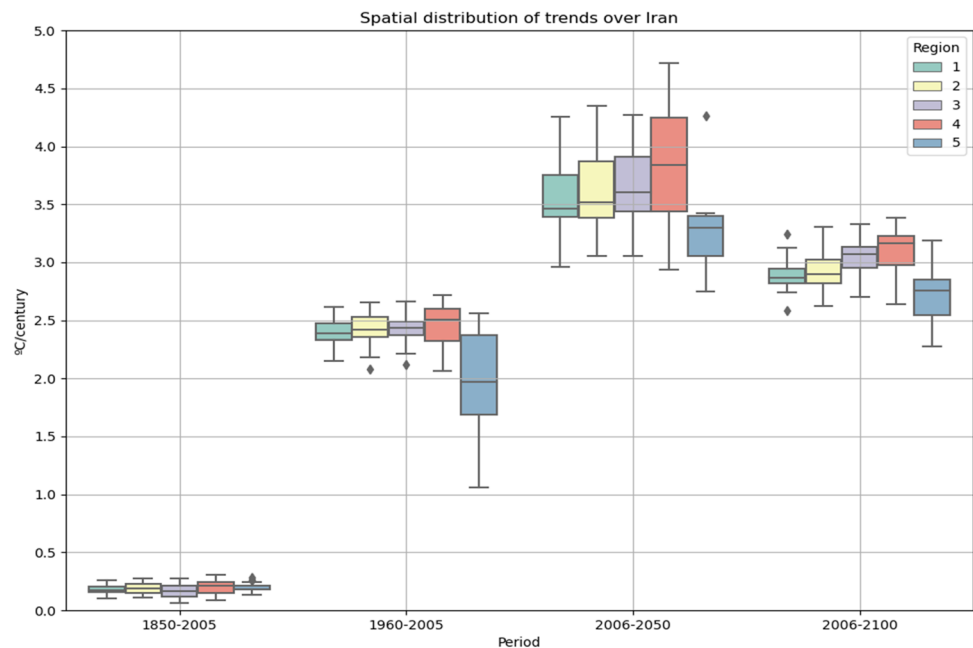
impacts of climate change and manage irrigation water in a sustainable manner.

Summary and conclusion

The climatic conditions in the domain of the Iran region were analyzed taking into account the limits of global mean surface air temperature (1.5 ℃, 2.0 ℃ and 2.5 ℃) with respect to the pre-industrial period.. To achieve this, an ensemble of 13 models with the best performance in Temperature and Precipitation for the region was used, taking into account three different metrics MAE (Mean Absolute Error), RMSE (Mean Square Error) and MAPE (Mean Absolute Percentage

Error). Dates of attainment for 1.5 ℃, 2.0 ℃ and 2.5 ℃ found were 2023, 2036 and 2051, respectively.

According to the regional analysis of surface air temperature trends in Iran, for the Hindcast periods (1850–2005 and 1960–2005), the greatest trends (1.06 ± 0.44 to 2.72 ± 0.18 ℃/century) were for the 1960–2005 period with increases of at least twice that observed for the 1850–2005 period. On the other hand, for the forecast periods (2006–2050 and 2006–2100) significantly, higher trends were observed (2.75 ± 0.31 to 4.72 ± 0.50 ℃/century) for the 2006–2050 period compared to 2006–2100.

It has been found that the regions with the highest warming trends in surface ambient temperature during the twenty-first century are Region 4 (Kermanshah) and Region 3 (Tabriz) to the Northwest of Iran, while the lowest trends

will occur over Region 5 (Mashhad), possibly to the higher meridional variation of this region respect to the others in Iran.

Based on the findings of the present study, it is possible to conclude that climate change in the twenty-first century would change the frequency and behavior of surface air temperature over Iran which can lead to problems and economic losses in future. This study can be used to develop new adaptation methods, explore renewable energy applications in the future to minimize the emission of greenhouse gases and in this way reduce the risks associated with climate change to achieve sustainable adaptation in the future.

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