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Impacts of global warming on extreme temperatures in west of Iran

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Abstract

Studying global warming and assessing its impacts is very important due to economic and social consequences and financial losses. Changes in extreme temperatures can cause enhancement of demands for energy, increase mortality, reduce biodiversity and damage to crops, which makes it essential to be studied. The aim of this study is predicting the changes of extreme temperatures in west of Iran during 2015-2045 period under climate change conditions according to the RCP emission scenarios. To this purpose, the SDSM model under the RCP 8.5 scenario is used for statistical downscaling and data generation of future period, using the GCM models of the CanESM2 and Mann-Kendall nonparametric test is used to analyze trends. From 27 extreme indices of climate change which are defined by ETCCDI, 6 indices of extreme temperatures were selected including diurnal temperature range (DTR), warm and cold days, warm and cold nights, and number of summer days. The results showed that in the predicting period (2015-2045), except Shahr-e-Kord station, the DTR index has a decreasing trend. There was an increasing trend in number of summer days index in all stations, except Hamedan station. In cold night index a decreasing trend is observed in all stations except Shahr-e-Kord station. A significant decreasing trend is observed in number of cold days index in all stations except Sahr-e-Kord. In warm days index, a significant increasing trend is observed in all station. Generally it was found that the significant trend of cold extreme and warm extreme temperatures were decreasing and increasing respectively. Also in most of the studied indices the rate of changes were associated with latitude of the weather station.

Introduction

One of the most important crises of 21st century is climate change which has affected all aspects of human life. Climate change causes changes in climatic averages and extremes. Changes in the frequency and intensity of extreme events have more severe effects on human activities. In most climate change studies, changes of means of long term climatic parameters are analyzed and they have focused on detecting potential trends. Studying variability and changes in trends of climatic extreme events is really essential due to its hazardous impacts. Some climate models showed that climate change can increase the frequency of extreme events and this issue has attracted more attention during the last decades (Mohammadi and Taghavi 2004). One of the most important factors of climate is temperature. Climate studies showed that during the previous decades temperature is increasing in most regions of the world and the average temperature of the world during last century has increased about 0.74° Celsius (IPCC 2014). The predictions for 21st century showed increasing temperature of the world due to increasing greenhouse gases and aerosols. World increasing temperature up to 2.5°C by the end of this century can make fundamental changes in water cycle and consequently in climatic parameters (Azizi and Roshani 2008).

Temperature as an index of heat of the atmosphere, is one of the basic parameters of

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atmospheric studies that can cause further major changes in other climatic parameters such as precipitation, evapotranspiration etc.(Lashkari and Keykhosravi 2010). Temperature is one of the few parameters that is incessant and in all places and spaces can be measured continuously. Also temperature has strong correlation with other climatic parameters such as solar radiation, atmospheric humidity, wind and precipitation and can control climatic processes (Rasouli 2000). That is why that studying temperature changes at different spatial and temporal scales is allocated with large part of the reviewed literature (Asadi and Masoudian 2014). In last decade, studies of long-term climate change, mostly focused on variability in average amounts temperatures while extreme temperature analysis was less considered (Jones and Moberg 2003). Theoretically climate change influences most aspects of weather and climate, particularly extreme events (Revadekar and Kulkarni 2008; Lehner et al. 2006). Extreme temperatures mean lower and higher percentiles (95 and 5), (90 and 10) or can be defined as a quantity of higher/lower than a threshold and or as a continuation of a special hot/cold period. Simple and clear extreme indices based on homogeneous long-term data state the status of extreme events. These indices must represent aspects of climate change and its impacts (Rahimzadeh et al. 2010).

Extreme Temperatures are the result of interaction between general circulation and local features such as topography and AMSL[1] (Asadi and Masoudian 2014).

This phenomenon can occur in each season of the year. Occurrence of this phenomenon in summer may lead to a greater demand for energy and greater demand for beverage, industrial and agricultural water demand. While, during winter, unusual increasing temperature can lead to early melting of snow reserves in the mountains that cause serial impacts including the increased risk of flash floods, shortage of water resources, migration and destroy of species diversity in the environment etc.

Changes in the frequency and intensity of extreme events in short times have more severe effects on human activities and the environment rather than changes in average climate in long terms. For example, 20 percent of all death records in Canada in the days that mortality is higher than normal is due to extreme temperatures (Shouquan et al. 2008). Too hot temperatures in summer can cause severe damage to crops and very low temperatures in winter can also lead to the loss trees (Brown and Katz 1995).

Considerable social and economic effects of extreme temperatures ((Ryoo et al. 2004; Alijani et al. 2012) show the necessity of the present research. There are different ways to study climate change and its impacts on climate elements that most of them use of general circulation model (GCM) and climate change scenarios (SERS[2] and RCPs[3]). Atmospheric circulation models are three-dimensional and able to simulate climate systems considering most processes in global or continental scales (Wilby and Wigley 1997). During last decades many researchers studied temperature trends and focused on the different effects on different sectors such as agriculture and economy and they found that indices of minimum and maximum temperatures with different slopes, will increase significantly in the future (Furió and Meneu 2011; Chamchati and Bahir 2011; Kharin et al. 2013; Muhire and Ahmed 2016). By the beginning of 2010s, CMIP5 proposed new RCPs scenarios. Suggested scenarios are in 4 states: 2.6, 4.5, 6, 8.5. Scenarios while 4.5,6 and 8.5 approximately match to previous B1, A1B, A2 scenarios (Taylor et al. 2012; IPCC 2007; Marengo et al. 2014; Dashtebozorgi et al. 2015; Muhire and Ahmed 2016). Climate predictions and assessments of climate change are faced with some problems such as estimating the level of greenhouse gas emissions and other pollutants in the coming decades and down-scaling of the spatial and temporal resolution of GCMs (Abassi et al. 2012). Despite significant increase in accuracy of numerical general and regional circulation models, so far, none of them are able to predict on a small scale, therefore global models in climatology studies, need to be downscaled (Shahabfar et al. 2001). Various methods for generating climatic scenarios at the regional scale is created which is called downscaling. For this purpose, statistical and dynamic models have been developed to simulate and downscale the outputs of GCM and RCM models (Abbasi et al. 2012). Due to fine resolution of dynamic models and need for high-speed computers, statistical downscaling model are produced and they have fine resolution even in station point scale (Benestad 2004). One of the most frequently used statistical models is SDSM which is used in this study.

Many researches are implemented about the changes of temperature and precipitation extremes in different parts of the world that often focused on the evaluation the indices in the observed periods while a few of them focused on modeling and prediction of changes of extreme indices for future. Mearns et al.

1. Above Mean Sea Level

2. Special Report on Emissions Scenarios

3. Representative Concentration Pathways

1984 demonstrated that the correlation between changes in average temperatures and extreme temperature events is completely non-linear. Horton et al. 2001 studied changes of extreme temperatures in central England at the end of twentieth century. Based on their study in the ocean (sea) surface level temperatures, warm extremes are increased and cold extremes are decreased. Kunkel, 2003 studied trend of extreme precipitation indices in United States. His analysis indicated that there was a significant increase in frequency of precipitation extreme events in 1920s and 1930s. Tzanakou and Deligiorgi, 2006, studied daily maximum temperatures associated with climate change and urbanization in Athens. They found an increase in number of days with high temperatures compared to average temperatures which was due to fast urban development in this region.

Trends of daily mean temperature in Bahrain was studied by Elagib et al. in 2009. During the period of 1947 to 2005, at Manama International Airport Station temperature, a significant increasing trend was observed that was about 1.6º Celsius per decade.

In Iran, Omidvar and Khosravi (2011) investigated trends in the northern shores of Persian Gulf and found that the mean temperature changes are similar to the of minimum temperatures. Alijani et al. (2011) showed that changes in average minimum temperatures are two times bigger than maximum average temperatures. Trends and mutation of extreme indices of temperature and precipitation were investigated by Rahimzadeh et al. (2011) in Hormozgan province and results of this study showed increase of temperature and decrease of precipitation in this province. Alijani et al. (2012) studied trend of extreme temperatures in Iran and showed that growing season of the year and warm days are increasing in most regions of Iran and cold nights are decreasing. Temperature and precipitation trends in the West and North West of Iran using parametric and nonparametric methods have been studied by Omidvar and Salari, 2013, and their results show that annual series of temperature and precipitation data in some stations of the studied area have been decreased or increased in other stations and their behavior is different in different stations.

As above mentioned researches and most reviewed climate change studies such as Revadekar and Kulkarni, 2008: Chung et al, 2000: Zhang et al, 2005: Shirmohammadi et al. 2012: Askari et al. 2012, have not focused on extreme indices of climate, therefore in this study the SDSM model under the RCP 4.5 scenario is used for downscaling and data generation of future to show an estimation in temporal series of extreme data (DTR), warm days, cold days, warm nights, cold nights and summer days) for a period of 2015–2045. Finally using Mann-Kendal graphical test, trend of time series of each of these extreme temperature indices is evaluated in the prediction period.

Data and Methodology

This study is performed on 7 synoptic stations which are located in west of Iran, during a 35-year period of 1980-2015 using extreme data of minimum and maximum temperatures (Figure 1).

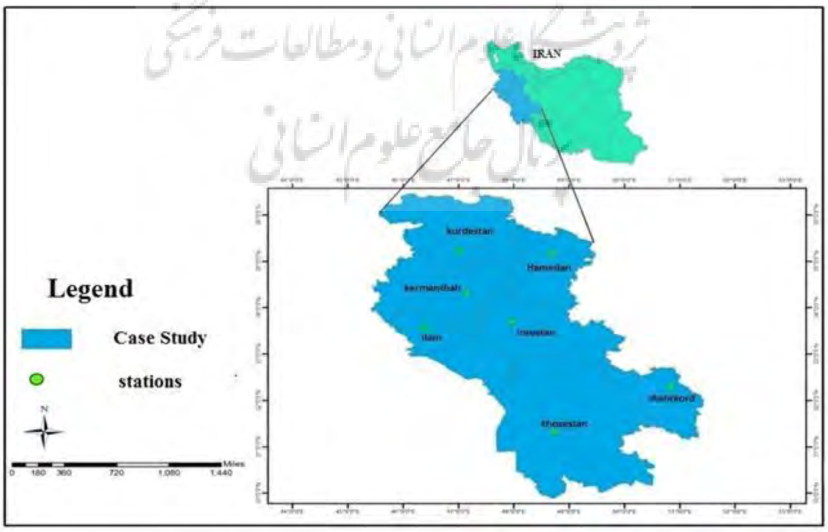

Figure 1. The under Studied area in west of Iran

Table 1. List of indices used

UNITS	Definitions	Indicator name	ID
Days	Percentage of days when TX<10th percentile	(Cold days)	TX10P
Days	Percentage of days when TX>90th percentile	(Warm days)	TX90P
Days	Percentage of days when TN<10th percentile	(Cold nights)	TN10P
Days	Percentage of days when TN>90th percentile	(Warm nights)	TN90P
ºC	Monthly mean difference between TX and TN	(Diurnal temperature range)	DTR
Days	Annual count when TX(daily maximum)>25ºC	(Summer days)	SU25

To calibrate and predict the future temperatures, Statistical Down Scaling Model (SDSM) is used to simulate the minimum and maximum temperatures as a conditional re-sampling and two stage method (Wilby et al. 2007) under the scenario RCP4.5. This scenario is designed by MiniCAM modeling group and in it radiative forcing remains constant due to emission of greenhouse gases before 2100, in 4.5 Watts per square meter. RCP scenarios represents radiation stimulus and among them the RCP2.6 and RCP8.5 scenarios show low and high emission scenarios respectively. Also, RCP4.5 and RCP6 scenarios are in medium range of emission rate (Marengo et al. 2014). The purpose of selecting RCP4.5 scenario is to estimate mediocrity future changes not exaggerated or very optimistic due to different results of previous studies in the studied region. NCEP[4] variables include 27 atmospheric variables of ETCCDI[5] that among them 6 appropriate variables are selected via the correlation coefficient. NCEP published data along with predictors of CanESM2 models that obtained from Canadian Centre for Climate Modelling and Analysis (CCCma) website. CanESM2 model is Fourth generation of climate models (CGCM4). In this model entire Earth is gridded in 64 ×128 cells that each cell covers about 2.8125 º degree (Charron 2014). To downscaling data of general circulation model CanESM2, SDSM statistical model is used that first downscale the prediction variable (such as temperature and precipitation) using hybrid regression methods and a random weather generator method (Tatsumi et al. 2013). Then reproduce precipitation in station scale.

After preparation of two temporal series of minimum and maximum temperatures, one for observation period and the other one for coming period; using the Rclimdex Model, indexing of temperature extremes in observational and future periods is proceeded. These indices are obtained from daily temperature and precipitation data that calculation and analysis of them were focus on threshold (extreme) values. Using proper equation differs from each index and analyzing them in different countries and regions varies in accordance with regional and local conditions and the main purpose of the research. From sixteen indices related to temperature which are introduced by the ETCCDMI Centre, 6 extreme indices were selected that include: DTR, warm days, cold days, warm nights, cold nights and summer days (Table 1). Then selected indices variability and trend were analyzed in two periods using Mann-Kendal graphical test at a 0.95 percent confidence level.

Discussion and Results

Model validation

Generally in atmospheric modeling, the capacity of the model should be tested. First of all, screening is performed among the large-scale atmospheric predictor of NCEP and the strong predictors that have strong relation with minimum and maximum temperature is selected (Table 2).

To ensure the basic period model was simulated using predictors, to determine the capability of the model. As Figs 2a and b show, the model was very exact and efficient in reconstruction of observational data and has capability to predict the future.

4. National Centers for Environmental Prediction (NCEP)
5. Expert Team on Climate Change Detection, Monitoring and Indices

Table 2. Selected predictors

Maximum Temperature		Minimum Temperature	
Mean sea level pressure	-0.70	Mean sea level pressure	-0.75
500 hPa geopotential height	0.913	500 hPa geopotential height	0.78
Mean temperature at 2m	0.92	Mean temperature at 2m	0.85

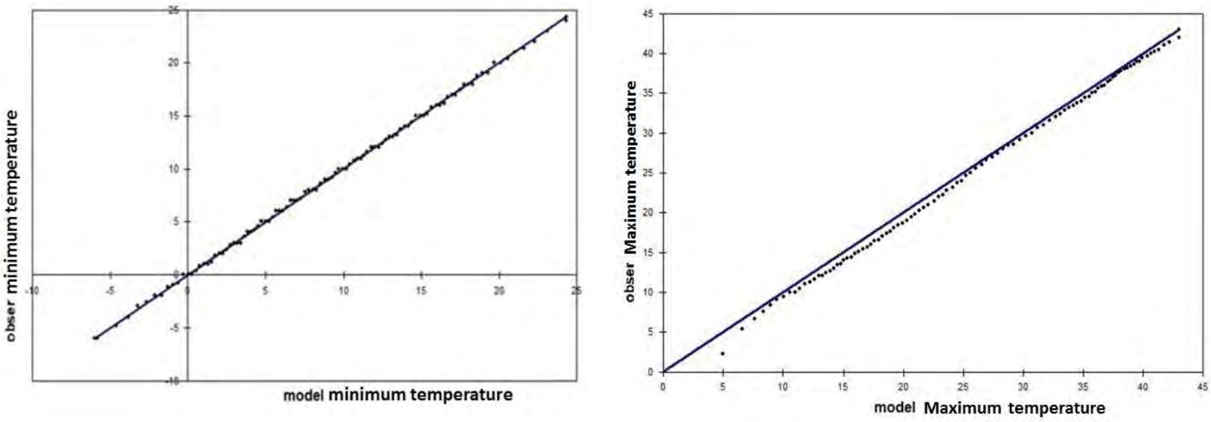

Figure 2a. Annual minimum temperature (Observed and simulated) **2b** annual Maximum temperature (Observed and simulated)

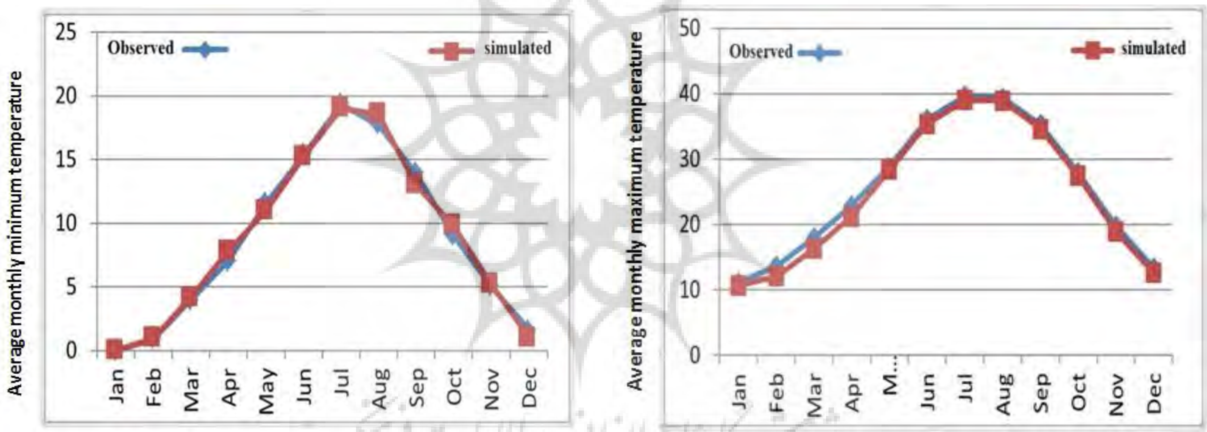

Figure 3a. Average monthly minimum temperature (Observed and simulated). **3b** Average monthly maximum temperature (Observed and simulated)

Changes of Extreme temperatures

Diurnal temperature range (DTR)

According to (Table 3) simulation of DTR index in 2015–2045 shows that in 2015–2045 in all studied stations except Shahr-e-Kord, there will be a significant decreasing trend. The maximum and minimum amounts of decreasing DTR belong to Kermanshah and Ilam stations with 4º C and 0.5º C.

Table 3. Change the index Diurnal temperature range (DTR)

Station / index	Ahvaz	Hamedan	Ilam	Kermanshah	Kordestan	Shahrkord	Khoramabad
DTR (observed)	14.5	16.8	11.2	16.4	16.2	17	16.5
DTR(Predicted)	16.5	13.8	11.7	12.4	14.8	18	15.4
The amount of change	2	3	0.5	4	1.4	1	1.1
Significant	*	*	*	*	*	-	*

*Significant changes in the confidence level of 0.95

Summer Days

The index of number of summer days in the predicted period in all stations except Hamedan showed a significant increasing trend. The highest increase in number of summer days was found in Ahwaz station about 17 days which is the most southern region of studied area and the lowest increase is observed in Sanandaj station about 3 days which is located in most northern region of studied area (Table 4). Therefore, changes in these indicators associated with latitude and in southern latitudes the rate of changes is greater than northern latitudes.

Table 4. Change the index summer days

index \ Station	Ahvaz	Hamedan	Ilam	Kermanshah	Kordestan	Shahrkord	Khoramabad
Summer days (observed)	250	139	164	165	156	139	179
Summer days (Predicted)	267	144	170	174	159	153	186
The amount of change	17	5	6	9	3	14	7
Significant	*	-	*	*	*	*	*

*Significant changes in the confidence level of 0.95

Cold Nights

Prediction of this index for 2015–2045 showed that there is a significant decreasing trend in Ahwaz, Ilam, Sanandaj, Kermanshah, Hamedan and Khorram-Abad stations, but in Shahr-e-Kord station a significant trend was not observed. Most decreasing rate of this index was simulated in Hamedan Station which is about 2.4 nights and in comparison with observed period, number of cold nights decreased 7 nights. The lowest decreasing belongs to Ahwaz station (Table 5). This index also have been correlated with latitude and Ahwaz and Shahr-e-Kord stations that are located in lower latitudes didn't show significant trends. Since decreasing changes is more correlated with higher latitudes, so by increasing latitude, cold nights reduce more in the predicted period.

Table 5. Change the index Cold nights

index \ Station	Ahvaz	Hamedan	Ilam	Kermanshah	Kordestan	Shahrkord	Khoramabad
Cold nights (observed)	9.7	9.4	8.3	9.7	9.5	9.8	9.2
Cold nights (Predicted)	9.2	2.4	7	9	8.1	10.1	8.3
The amount of change	0.5	7	1.3	0.7	1.4	0.3	0.9
Significant	*	*	*	*	*	-	*

* Significant changes in the confidence level of 0.95

Warm nights

Warm nights index in predicted period showed that there is a significant increasing trend in all stations except in Sanandaj, Ilam and Hamedan stations which is still increasing but not significant (Table 6). Most significant increasing rate of warm nights index belongs to Shahr-e-Kord and the lowest one belongs to Kermanshah station.

Table 6. Change the index Warm nights

index \ Station	Ahvaz	Hamedan	Ilam	Kermanshah	Kordestan	Shahrkord	Khoramabad
Warm nights (observed)	9.9	9	7.5	9.7	9.5	9.4	10.1
Warm nights (Predicted)	10.5	9.4	8	10	10.3	10.8	10.9
The amount of change	0.6	0.4	0.5	0.3	0.2	1.4	0.8
Significant	*	-	-	*	-	*	*

*Significant changes in the confidence level of 0.95

Cold days

Prediction of cold days index showed that there is a significant decreasing trend in all of stations except Shahr-e-kord station. In Shahr-e-Kord station didn't observe a significant trend. Highest decreasing trend of this index was observed in Hamedan station while the lowest was in Ahwaz station which were respectively 6 and 0.3 percent (Table 7). In this index also the relationship between latitude and changes was meaningful. The maximum decreasing trend was observed in higher latitudes and vice versa.

Table 7. Change the index Cold days

Station / index	Ahvaz	Hamedan	Ilam	Kermanshah	Kordestan	Shahrkord	Khoramabad
Cold days (observed)	9.6	9	7.5	9.7	9.5	9.4	9.4
Cold days (Predicted)	9.9	3	6.2	9.1	8.7	9.8	8.5
The amount of change	0.3	6	1.3	0.6	0.7	0.4	0.9
Significant	*	*	*	*	*	-	*

*Significant changes in the confidence level of 0.95

Warm days

There is a significant increasing trend in warm days index in all studied stations. The most increasing trend was observed in Ahwaz station (Table 8).

Table 8 Change the index Warm days

Station / index	Ahvaz	Hamedan	Ilam	Kermanshah	Kordestan	Shahrkord	Khoramabad
Warm days (observed)	9.3	9	7.8	9.6	9.9	10	10.1
Warm days (Predicted)	10.5	9.2	8.4	10	10.4	10.2	10.6
The amount of change	1.2	0.2	0.7	0.6	0.5	0.2	0.7
Significant	*	*	*	*	*	*	*

*Significant changes in the confidence level of 0.95

Conclusion and Discussion

Climate change is one of the most dangers that threaten human life on earth. During last couple of decades in academic societies and even between ordinary people, many efforts have been made to raise public awareness and stop the increasing process of greenhouse gases emissions.

In most studies that are implemented in Iran about climate change, the trends of temperature and detection of climate change are focused but in the present research, the extreme temperatures are evaluated in the present and future periods.

To this purpose, the SDSM model under the RCP 8.5 scenario is applied. In downscaling process and weather generation for future, regarding general circulation models, the CanESM2 is applied. Mann-Kendall test was used to analyze the trends. From 27 extreme indices of climate change, 6 thermal indices were selected including DTR, warm days, cold days, warm nights, cold nights and summer days.

The results showed that in DTR index, a significant decreasing trend was observed in all stations except Shahr-e-Kord station which is due to its exceptional and highest altitude. Maximum decrease of DTR belongs to Kermanshah station about 4º C.

In summer days index in all stations except Hamedan, a significant increasing trend was observed. Maximum increase was observed in Shahr-e-Kord station, while in cold night's index a decreasing trend was observed in all stations except Shahr-e-kord station. Maximum decreasing amount of this index was simulated in Hamedan station and the minimum decreasing amount belongs to Ahwaz station.

In warm nights index there was no significant trend in Sanandaj, Ilam and Hamedan stations but an increasing trend was observed in the other stations. Most significant increasing rate of warm night's index belongs to Shahr-e-Kord.

In cold days there was a significant decreasing trend in all stations except Shahr-e-kord station. Also there was a significant increasing trend in warm day's index in all studied stations. Most increasing trend was observed in Ahwaz station.

Based on our results, it is clear that in most indices, the amounts of changes was associated with latitude. It was found that in most studied stations cold extremes showed significant decreasing trends however in warm extremes increasing trends was significant.

Changes in the frequency and intensity of extreme events is going to have more severe effects on human activities and the environment rather than changes in average climate in the short term. Changes in temperature extremes could lead to increasing demand for energy, increase of mortality, destruction of habitat, increasing of species migration rates and reduction in species diversity in the environment, and increase damage to agricultural crops.

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