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RESEARCH ARTICLE

EVALUATION OF TEMPERATURE, PRECIPITATION AND DUST AEROSOL SIMULATIONS FOR TURKEY

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ABSTRACT

Turkey, which is located in the Mediterranean basin, is one of the countries that are the most sensitive to climate change. Due to its geographical location, it is also under the influence of dusts transported from Africa and the Middle East. The Intergovernmental Panel on Climate Change (IPCC) considers dust as a very significant component of atmospheric aerosols which are major climate variables. Therefore, it is important to consider the effects of mineral dusts in climate change studies in Turkey since it is located in the Mediterranean basin. In this study, we focused on projecting temperature, precipitation and dust aerosol data for the period of 1972-2099. We used outputs of the GFDL-ESM2M global climate model and the CAM aerosol model as initial and boundary conditions with the RCP4.5 concentration pathway. According to the projections, the temperatures will increase by 1.5-2°C, and precipitation will decrease by about 10%in Turkey in general. According to the dust aerosol optical depth (dust AOD) projections, dust AOD, which especially increased in fall months, will be extended towards the summer season after 2040 in the study area. The long-term dust concentration projections revealed an insignificant increasing trend in Antalya and a decreasing trend in İzmir. These are the provinces mostly affected by dusts that originate from Africa. Besides, we found an increasing trend in Hakkari, Kilis and Mardin, that are the provinces that are mostly affected by dusts that originate from the Middle East.

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INTRODUCTION

Climate is the average weather conditions experienced in a particular place over a long period. The climate of a place is determined primarily by its latitude, distance from the ocean, and elevation above sea level (Demircan *et al.,* 2016). Particularly the existence of mountains in Turkey results in significant differences in climatic conditions from one region to the other. Coastal areas exhibit milder climates, and the Central Anatolian Region experiences extremes of hot summers and cold winters with limited rainfall. The western (Aegean) and southern (Mediterranean) coasts have cool, rainy winters and hot, moderately dry summers. The northern (Black Sea) coast receives the greatest amount of rainfall. The north-western regions (around the Sea of Marmara) show moderate climatic conditions (4°C in winter and 27°C in summer). The central regions (Anatolian Plateau) has a steppe climate.

The average temperature is 23°C in summer and -2°C in winter. The climate in the Black Sea Region is wet and humid (summer 23°C, winter 7°C). The coastal and central regions have large precipitation differences. The Black Sea coasts receive the greatest amount of rainfall while the central regions receive it the least. The Aegean and Mediterranean coasts have rainy conditions in winters, but they are dry in summers (Sensoy *et al.,* 2012). Climate change is one of the most significant and far-reaching challenges that societies have faced in this century. The evidence of human-induced climate change has been getting stronger on different spatial and temporal scales. Climate change has been damaging ecological, social and economic systems. According to the fifth scientific assessment report of the Intergovernmental Panel on Climate Change (IPCC) (Stocker *et al.,* 2013), the last three decades has been successively warmer on the Earth's surface than any preceding decade since 1850 (Ozturk *et al.,* 2015). The most important factor that is influential on global warming is the carbon dioxide and other greenhouse gasses released into the atmosphere as a result of human activities. 'Greenhouse gasses' were defined in the Article 1 of the United Nations Framework Convention on Climate Change as natural or man-

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made gas bodies that absorb the infrared radiation in the atmosphere and release it back. These gases trap the heat transferred from the Sun to the Earth and lead to increases in temperatures. For this reason, they cause formation of different climate situations. Additionally, desert dust aerosols, which act as one of the four territorial sources of atmospheric aerosols (desert dust, biomass combustion and biogenic and anthropogenic air pollution), are also responsible for significant climatic forcings due to their direct effects on sunlight and thermal radiation (Sokolik and Toon 1996; Li, 2004; Shi *et al.,* 2005) and indirect effects on clouds and precipitation processes (Sassen, 2002; Huang *et al.,* 2010). Moreover, mineral dust aerosols also have acrucial effect on regional climates due to their high amounts transported from arid and semi-arid regions (Huang *et al.,* 2014; Norouzi *et al.,* 2017). On the other hand, IPCC considers dust as a very significant component of atmospheric aerosols, which are among the main variables of climate change (Forster *et al.,* 2007).

The global climate is controlled by interactions of several processes that take place in the atmosphere, oceans, territorial areas and cryosphere (snow, ice and permafrost). As these interactions are very complicated and comprehensive, numerical predictions of the effects of the increase in greenhouse gasses on climate cannot be conducted purely by simple intuitive reasoning. This is why researchers have developed computer models that try to mathematically predict climates, including the interactions among component systems (Wrattand Mullan, 2017). Global climate models are among these models. While running global climate models requires multi-core supercomputers, calculating climate projections may take months. These models create 3 dimensional points on earth and run a detailed simulation of the processes that take place in the atmosphere, oceans and cryosphere (circulation, temperature, precipitation, etc.). These simulations are used to make past and future climate projections for earth. However, as they have low resolution, global climate models cannot account for local effects (IPCC 2016). In other words, global climate models do not have sufficient spatial resolution to represent local atmospheric and territorial process in detail. Therefore, regional climate models are essential.

Regional climate models simulate the physical processes that take place in the climate system as in the procedures followed in global climate models. Regional climate models cover a limited region of the world, and they can work with much higher resolutions. While global models produce data in resolutions of 100-300 km, regional models can provide data in resolutions of 1-50 km. Therefore, these models can account for the interactions between large-scale atmospheric processes and the local terrain (Salathé *et al.,* 2010). Besides, they determine the large-scale effects of changing greenhouse gas concentrations on the global climate. Data calculated by global climate models are used as input (initial and boundary conditions) for regional climate models. Thus, regional climate models produce higher-resolution data that represent a local region better by considering the initial conditions produced by global climate models, meteorological conditions and the boundary conditions of the surface. Several studies have been conducted for Turkey and the surrounding regions regarding regional climate simulations by considering various concentration scenarios (Gao and Giorgi, 2008; Önol and Semazzi, 2009; Önol *et al.,* 2013; Ozturk *et al.,* 2015; Ozturk *et al.,* 2017; Demircan *et al.,* 2017). In summary, all these studies projected that precipitation in the region will decrease, while temperatures will increase. Önol and Semazzi (2009) studied the potential role of global warming while simulating the future climate in the Eastern Mediterranean Region. In their study, they downscaled NASA's GCM (fVGCM) global outputs with the ICTP-RegCM3 model to demonstrate future climate scenario simulations. They found a significant increase (10-50%) in winter precipitation along the Carpathian Mountains, the eastern coast of the Black Sea, the Kaçar Mountains and the Caucasus Mountains. Moreover, they also found that the rainfall in the basin of the Euphrates and Tigris, which are located in the South-Eastern Anatolia Region in Turkey, would reveal the largest decline. The study also demonstrated that the increase in temperature in the summer months would be 7°C in Balkan countries and 3°-4°C for the rest of the region, and that summer temperatures would be much higher than those in winter months. According to the results of a similar study conducted by Gürkan *et al.* (2016), the degree of warming in the period of 2016-2040 will be generally in the range of 0.5°C-1.5°C, there will be a higher than 1.5°C increase in summer in the Aegean and Mediterranean Regions, there will be increases in precipitation by around 10% in entire Turkey in spring except the South-Eastern Anatolia Region, the Lakes Region and the Marmara Region, and there will be decreases in precipitation by around 20% in almost entire Turkey in fall. While increases are predicted in the precipitation levels in the Eastern and South-Eastern Anatolia Regions in summer, decreases in precipitation were projected for almost the entirety of the country in winter, where precipitation is highly important for the country. For the 2041-2070 period, it was projected that the degree of warming will be around 1.5°C-2.5°C in general, and an increase of over 2.5°C was projected for the South-Eastern Anatolia Region in fall. According to the precipitation projections, it was estimated that almost all parts of the country will experience a highly arid period in summer and fall, and some increases will be seen in the northern parts of the country in winter, whereas there will be decreases in most parts of the country, especially in the Mediterranean Region, by up to higher than 30%. It was also projected that there will be decreases in precipitation in fall in the inner parts of the country, especially in the Eastern and South-Eastern Anatolia Regions. For the period of 2071-2099, it was projected that the degree of warming in summer will be higher than 3°C in most parts of Turkey. Accordingly, precipitation will increase by around 10% in spring in most parts, but it will decrease by up to higher than 30% especially in the Mediterranean Region. This study also includes mineral dust data in the model as the initial and boundary condition. Temperature, precipitation and aerosol projections covering the Eastern Mediterranean basin were produced for the period of 1972-2099 with a resolution of 20 km in the light of the Representative Concentration Pathways 4.5 (RCP4.5) scenario by using a regional climate model.

MATERIALS AND METHODS

We used the Reg CM4.3 regional climate model in this study. The outputs of the GFDL-ESM2M global model were used for the atmospheric initial and boundary conditions, and the outputs of the CAM model were used for the initial and boundary conditions of dust. The median stabilization pathway of RCP4.5 was chosen as the representative concentration pathway. The simulations were validated by the Climatic Research Unit (CRU) for temperature and precipitation and by MODIS/Aqua for dust. In comparison to the previous versions, RegCM4 includes new land surface, planetary boundary layer and air−sea flux schemes, a mixed convection and tropical band configuration, modifications to the pre-existing radiative transfer and boundary layer schemes, and a full upgrade of the model code towards improved flexibility, portability and user friendliness. The model canbe interactively coupled to a 1D lake model, a simplified aerosol scheme (including organic carbon, black carbon, SO_4, dust and sea spray) and a gas phase chemistry module (CBM-Z).Overall, RegCM4 shows an improved performance in several respects in comparison to the previous versions, although further testing by the user community is needed to fully explore its sensitivities and range of applications (Elguindi *et al.,* 2011). The model can be used for any selected region of the world for climate simulations at a maximum resolution of 10 km, which is the hydrostatic resolution limit. Regional climate models, which are used in various simulation studies, require initial and boundary conditions. These conditions are obtained from global circulation models. This study used the outputs of the GFDL-ESM2M global climate model which developed by the Geophysical Fluid Dynamics Laboratory (GFDL) associated with the National Oceanic and Atmospheric Administration (NOAA) in the United States. GFDL-ESM2M was developed for examining the circulations of substances such as carbon and water and the interactions of human activities on climate systems together. In addition to integrated atmosphere and ocean circulation, the model also contains the chemistry of the atmosphere. Additionally, model plant biology and plant surface usage, surface physics and hydrology, ocean ecology and biochemistry, ocean circulation and sea glacier components are developed with their configurations. The land component of the model contains a territorial ecology component to create dynamic simulations of carbon and other elements in addition to precipitation and evaporation, flows of water courses, lakes, rivers and surface water. The atmospheric component of theGFDL-ESM2M model is represented at a resolution of 2°x2.5°, and it contains a total of 40 different vertical levels (Dunne, 2013).

The study also used the Community Atmosphere Model (CAM) (Lamarque *et al.* 2012) which can be used as the initial and boundary conditions for the parameter of dust in climate simulations. Dust sources in the model are attributed toZender *et al.* (2003) and Mahowald and Luo(2003). The model uses four different size categories between 0.01 and 10 µm. Moreover, the dust circulation in the CAM model was simulated using different parametrization sets for size distribution and optical characteristics(Collins WD *et al.* 2004). Besides, CAM4 has a Bulk Aerosol Model (BAM) parameterization of dust size distribution (Neale *et al.* 2010b). Additionally, differences in soils' susceptibility to erosion (i.e. in relation to soil grain sizes and textures) are summarized in a multiplicative parameter for dust flux - geomorphic soil erodibility (Zender *et al.,* 2003) - based on the concept of preferential sources (Ginoux *et al.,* 2001). Dust transport is controlled by the CAM4 tracer advection scheme (Neale *et al.,* 2010; Albani *et al.,* 2014). Emission and concentration scenarios are some of the most important components of regional climate studies. A scenario is a story that depicts some events in the future (Gregory and Duran, 2001). In this context, emission scenarios involve description of the potential of substances that disrupt the radiation balance of the Earth such as greenhouse gasses and aerosols to be released into the atmosphere in the future. By this definition, it may be argued that emission scenarios are not a prediction for the future. However, an emission scenario for climate change studies also reflects expert opinions and analyses on future emissions based on scientific studies regarding socioeconomic, environmental and technological trends that are presented in integrated analysis models (Moss *et al.,* 2010). Representative concentration pathways (RCP) are data sets that are produced for total emissions, concentration of greenhouse gasses, land usage, land cover, chemically active gasses and aerosols (Moss *et al.,* 2008). Four different concentration pathways that consider the forcing these data sets create in terms of radiation were developed. The RCP 6.0, RCP 4.5 and RCP 2.6 scenarios represent low and medium-level radiation forcings, while RCP 8.5represents high-level radiation forcings (van Vuuren *et al.,* 2011). This study used the RCP4.5 scenario, which is a median stabilization pathway. This scenario assumes that radiative forcing will be fixed at 4.5 W/m^2 in 2100 and not exceed this value. The advantages of this scenario are that good signal can be obtained due to the difference from the high pathway, and there are several publications on this pathway in the literature (Fig. 1).

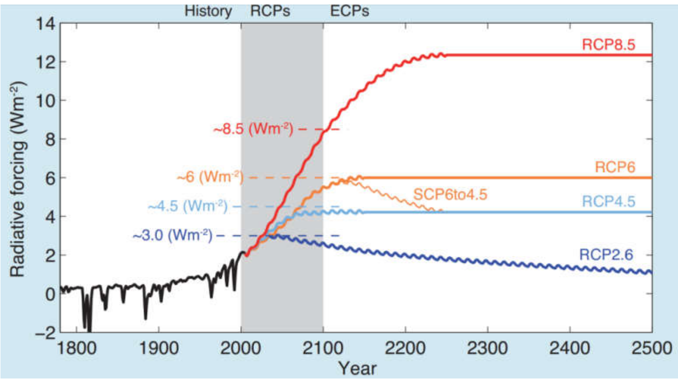

Fig. 1. Anthropogenic and natural radiative forcing of the Representative Concentration Pathways (extracted from Meinshausen *et al.* 2011).

CRU data were used in the study to analyze the consistency of the 1972-2000 period which was selected as the reference period. The CRU data include information on the monthly precipitation and daily temperature values for the period of 1901-2012. The data set has a resolution of 0.5x0.5 degrees, and it is dependent on the records of 4000 independent meteorology stations (Mitchell and Jones, 2005; Harris *et al.,* 2013). Additionally, in order to verify the dust aerosol data, the MODIS/Aqua satellites were used for the observational data they provide. The aerosol optical depth (AOD) data that was provided by the satellites were in a resolution of 1x1 degree, and they provided regional and global dust observation information.

RESULTS

Validation results: Validation of model simulations by using observation data is an important part of regional climate studies. This part shows the error rates in model estimates. Before we ran the model for the entire period, we simulated the model reference period (1972-2000) at least 10 times to investigate the parameterization process. For example, cloud cover, humidity and convective rainfall patterns were tested to obtain better results for the area that was studies. As a result of parameterization, we preferred the Holtslag boundary layer scheme, the Grell cumulus convection scheme for land and ocean, and the SUBEX moisture scheme in the model.

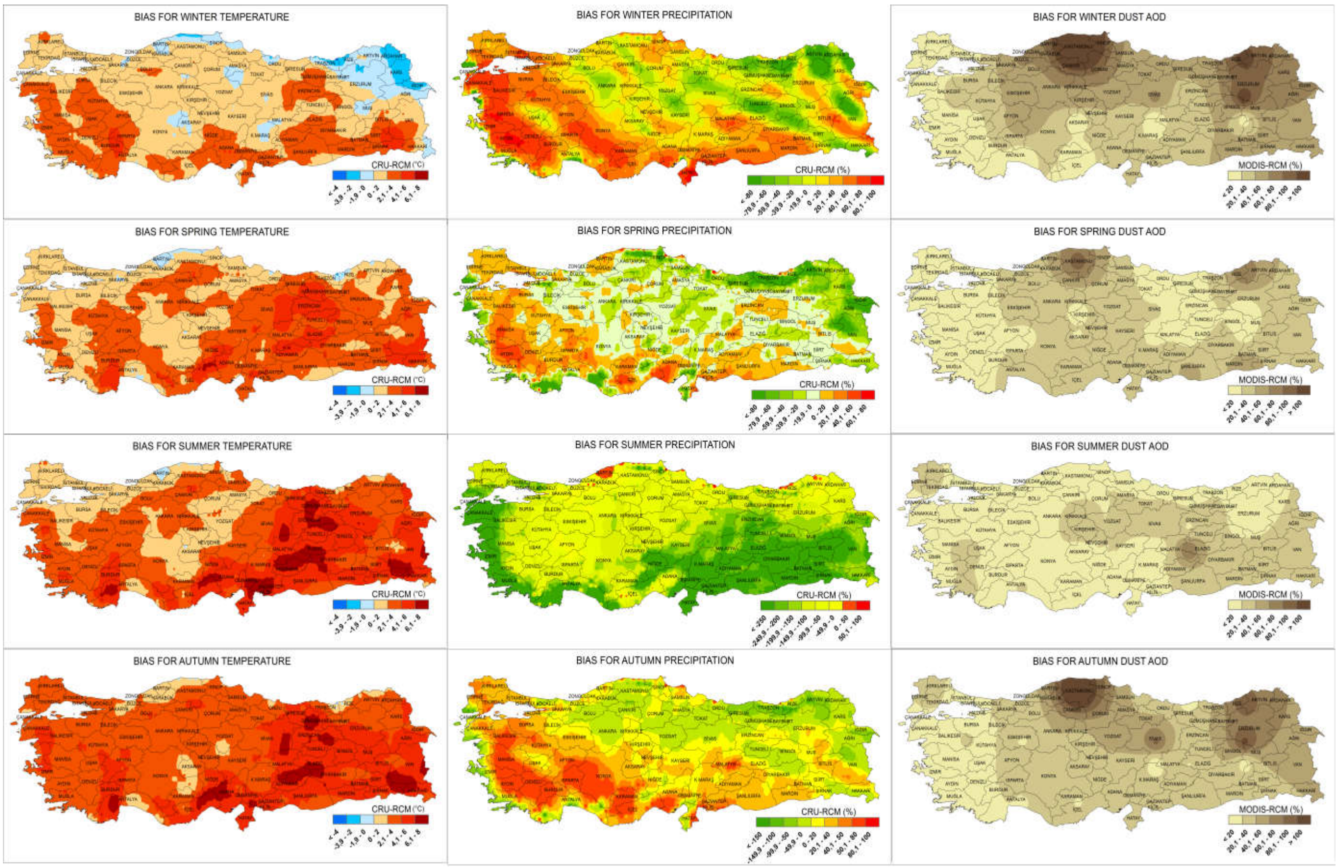

Fig. 2. Spatial seasonal variation of bias for temperature (left column), precipitation (middle column) and dust AOD (right column)

In this context, the simulations of the 1972-2000 reference period were compared to the CRU dataset, which is accepted as an observational dataset around the world. The spatial variation of seasonal bias is shown in Fig. 2. The temperature projections often produced lower values than the observations in general. Observation and projection difference (bias) in temperatures was negative only in the north-eastern part in winter (0- -4 ° C). The western and southern regions had a bias value around 2-4°C, while the others had values of 0-2 °C. In spring and summer, the bias values in the central and north-western regions were 0-2°C. This was around 2-6 ° C in the other regions. The bias values were usually found between 2 and 4°Cover most regions in fall. According to the precipitation projections, the highest bias values (~ 80%) were seen in the western and north-eastern regions in winter. In the other regions, the bias values were mostly in the range of -40% to +40%. Besides, these values were high in the eastern and north-eastern regions in spring. The higher values were almost always located in the western and north-eastern regions. The high bias values seen in these two seasons were in regions where precipitation is generally very high. It was seen that the highest bias values (<-250%) were in summer. These values were concentrated in the negative direction, especially in the south-eastern and western regions. This suggests that the model cannot correctly simulate the seasonal convective activities in summer, which is the season in which the temperature increases are the most visible. For fall, the western parts (~ 80%) and the north-eastern parts (~ 100%) provided high bias values. The bias values in winter were high around the central parts of the Black Sea Region and the north-eastern parts for dust AOD. The lowest bias values were seen in the western and south-western regions. It was seen that the bias values were around 20-40% in the Central Anatolia, Eastern Anatolia and South-Eastern Anatolia Regions in spring and in the South-Eastern Region in summer. The bias values Were lower for the other regions. The bias values were mostly 20-60% except for the western regions in fall. In summary, the region's most affected by dust events in Turkey had bias values of around 0-40%. Table 1 shows the seasonal average temperature and daily precipitation values of RCM and CRU for Turkey. Model simulations were very close to observation data in terms of the temperature values. The difference between observation and simulation was found as 1.206°C in winter, 2.752°C in spring, 3.312°Cin summer and 3.735°Cinfall. The average temperature difference for Turkey was found as 2.710°C. In general, the differences in temperature were found to be in the range of 1-4°C for all seasons.

Table 1. Comparison of the Simulation (RCM) Data and Observation Data (CRU) for the Seasonal Temperature and Daily Precipitation Values of the 1972-2000 Reference Period for Turkey

	Temperature (°C)			Precipitation (mm/day)		
	RCM	*CRU*	*Difference in °C*	*RCM*	*CRU*	*Difference in %*
Winter	-0.716	0.490	1.206	1.769	2.133	17.065
Spring	7.210	9.962	2.752	2.267	1.964	-15.428
Summer	17.516	20.828	3.312	1.756	0.685	-156.350
Fall	8.732	12.467	3.735	1.210	1.340	9.701
Mean	8.182	10.892	2.710	1.751	1.532	-14.295

Table 2. Comparison of the Simulation (RCM) Data and Observation Data (MODIS) for the Dust Aerosol Optical Depth Values of the 2012-2016 Period over Turkey

	Dust Aerosol Optical Depth		
	RCM	*MODIS*	*Difference in %*
Winter	0.129	0.102	26.467
Spring	0.159	0.132	21.024
Summer	0.139	0.102	35.727
Fall	0.118	0.098	20.434
Mean	0.136	0.109	25.636

The model simulation provided lower values in comparison to the observation data in all cases. The precipitation simulation data corresponded to the observation data for all seasons except summer by a difference of 9-17%. The simulation value was found higher than the observation value for spring, while it was found lower in winter and fall. The average difference in Turkey was found as-14.295%.Table 2 shows the verification of the model AOD data with the Aqua satellite for Turkey. The model outputs provided higher values than the observation data. The lowest difference was 20.434% in fall, while the highest difference was 35.727% in summer.

Future simulations: Fig. 3 shows the seasonal temperature simulations based on the periods of 2016-2040 (Period 1), 2041-2070 (Period 2)and 2071-2099 (Period 3). The maps in the figure show the changes in each period in comparison to the reference period (1972-2000).

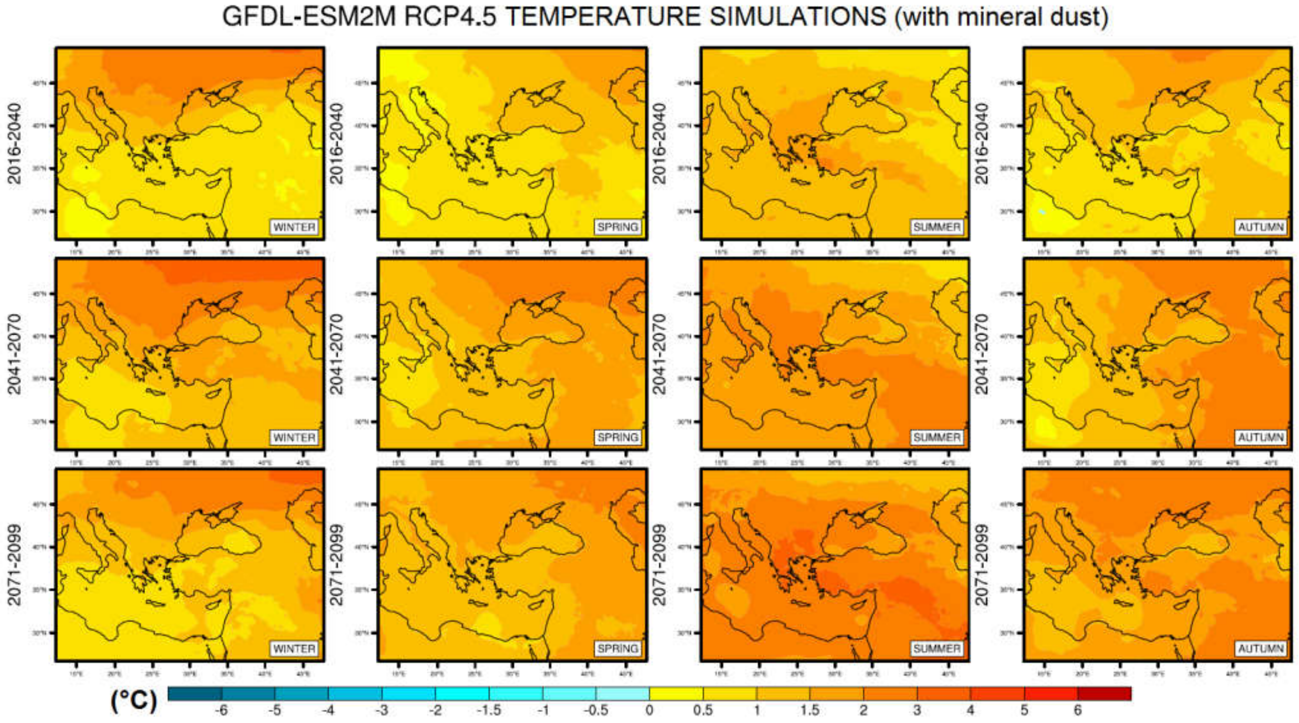

Fig. 3. Seasonal Temperature Simulations for 3 periods (changes in °C)

According to the simulations, the temperatures rise by up to 1°Cin period 1and 2°Cin period 2. It is around 1-1.5°Cin period 3 in winter. These increases appeared even higher in other seasons, especially summer. In spring, these increases reach 1.5°C over the eastern regions of Turkey in period 1, while they are around 1°C for the other regions. The increases are around 1.5-2°Cin periods 2 and 3 in spring. The temperature increases arearound3°C in the southern, western and central regions of Turkey in summer in period 1, while they are around1.5-2°C in other regions. The northern regions of Turkey show a temperature increase of 1.5-2°C and the other regions show a temperature increase of around 2-3°C in period 2.The south-western regions of Turkey show a temperature increase of around 3-4°C, while the other regions show a temperature increase of around 2-3°C in summer in period 3, which shows the highest temperature increase in comparison to the other seasons. Most regions of Turkey except the central and northern regions show a temperature increase of 1-1.5°C in fall in period 1. This increase is around 2-3°C in the eastern regions of Turkey and 1.5-2°C in the western regions of Turkey in fall in period 2. Moreover, it is around 2-3°C in the south-eastern, southern and eastern regions of Turkey in period 3. These increases are around 1.5-2°C for the other regions of the country. Seasonal precipitation simulations are seen in Fig. 4.Most regions of Turkey except the western parts of the Central Anatolia Region and the eastern parts of the Black Sea Region show a precipitation decrease by around 10% in winter in periods 1 and 2. Some regions that previously experienced decreases in precipitation turned towards an increasing regimein period 3.In this period, the northern half of Turkey experiences an increase of 10% in precipitation in winter, while the southern half experiences an increase of 10% in fall. In spring, the Central Anatolia Region shows precipitation decreases of around 10%, whereas the other regions of Turkey show increases of around 20%in period 1. Most regions that showed an increasing trend in period 1 turned towards a decreasing trend. Precipitation decreases of around 20% is seen in Turkey except in certain parts of the Black Sea, Marmara and Aegean Regions in spring in period 2. A new increasing trend is seen in all regions of Turkey except the south-western parts in period 3. In summer, the eastern and south-eastern regions of Turkey experience precipitation increases of 10-20% in period 1. The south-western regions experience a 30% precipitation decrease, and the other regions experience a 20% decrease. The south-eastern parts of the Black Sea Region and the borders of the Black Sea with Turkey show precipitation increases by around 50% in periods 2 and 3. All the other regions in Turkey show a precipitation decrease of around 30%. In fall, the precipitation decreases are around 20% in most regions of Turkey in periods 1 and 2. This decreasing trend in precipitation will be reversed in the eastern parts of the Black Sea, Central Anatolia and Southeast Anatolia Regions in period 3. The precipitation increase is around 10-20% in these regions. Fig.5 shows the dust AOD simulations. The dust AOD increase in fall will be higher in comparison to the other seasons. Dayan (1986) and Kubilayet al. (2000) also found that dust transport to the Mediterranean from sources in the Middle East happens more typically in fall.

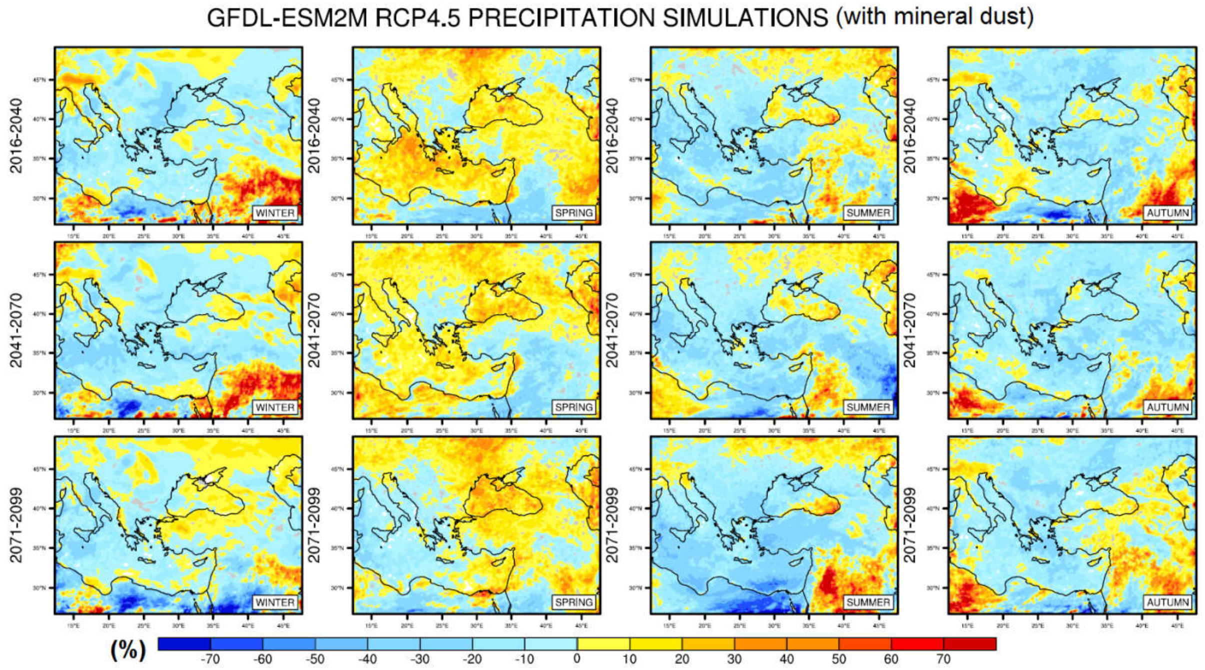

Fig. 4. Seasonal Precipitation Simulations for 3 periods (changes in %)

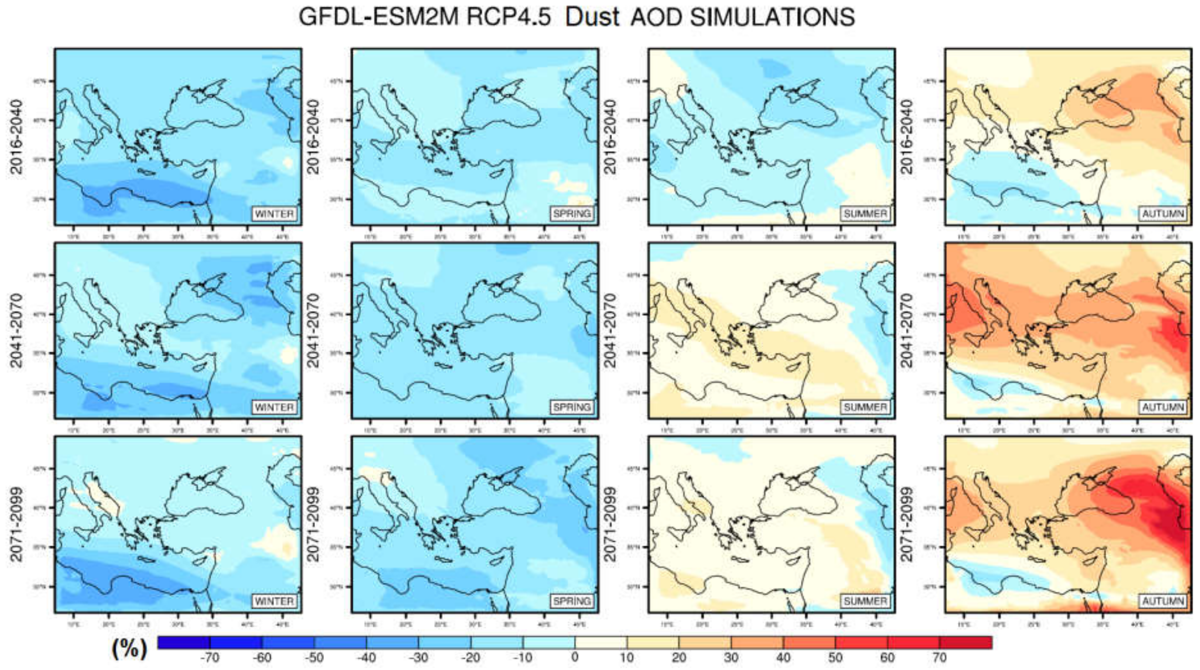

Fig. 5. Seasonal Dust AOD Simulations for 3 periods (changes in %)

Increase in dust AOD is higher than 50% in fall in period 1, and it continues to increase in the following years. According to the projections, dust activity that shows significant increases in fall is extended into summer after 2040in the studied region. The reason for this is linked to the dusts that come off arid areas and areas that have turned into deserts (Winslow and Thomas, 2007; Bucchignani *et al.,* 2018) in the Arabian Peninsula and the Middle East. No significant increase is seen for winter and spring based on the dust AOD simulations. In order to see the regions of dust changes, we selected some points in some provinces in Turkey, North Africa and the Middle East and investigated surface dust concentration trends for the period of 1981-2099. While desert dusts from North Africa generally cross the Central and Eastern Mediterranean Regions and enter the Aegean and Mediterranean regions of Turkey, dust transport from the Middle East is influential by entering through the South-Eastern Anatolia Region of Turkey (Dündar *et al.,* 2015). Therefore, the provinces of Hakkari, Kilis and Mardin were examined to see the desert dust that comes from the Middle East through Turkey, and the provinces of Antalya and İzmir were examined to see the dust that comes from North Africa (Fig. 6). Additionally, in order to see the change in the possible sources of the dust, we examined the provinces of Damascus, Baghdad and Basra in the Middle East and the provinces of Benghazi and Tripoli in North Africa (Fig. 7). Among the provinces whose surface dust concentration changes we examined, the provinces of Hakkari, Kilis and Mardin are close to the borders of Syria and Iraq, while the provinces of Antalya and İzmir are located respectively in the south and the west of Turkey.In the Figs. 5 and 6, the horizontal axes show years, while the vertical axes show projected dust surface concentrations.

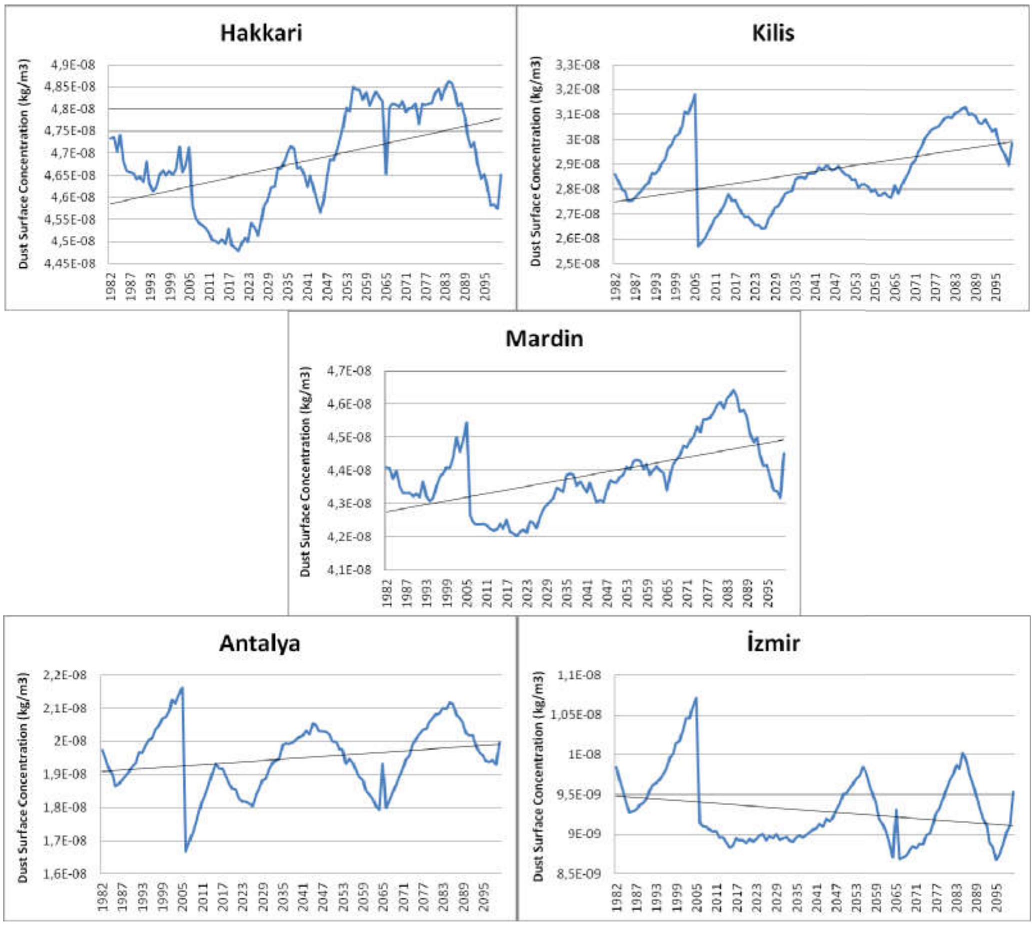

Fig. 6. Dust Surface Concentration Trends in Some Cities in Turkey

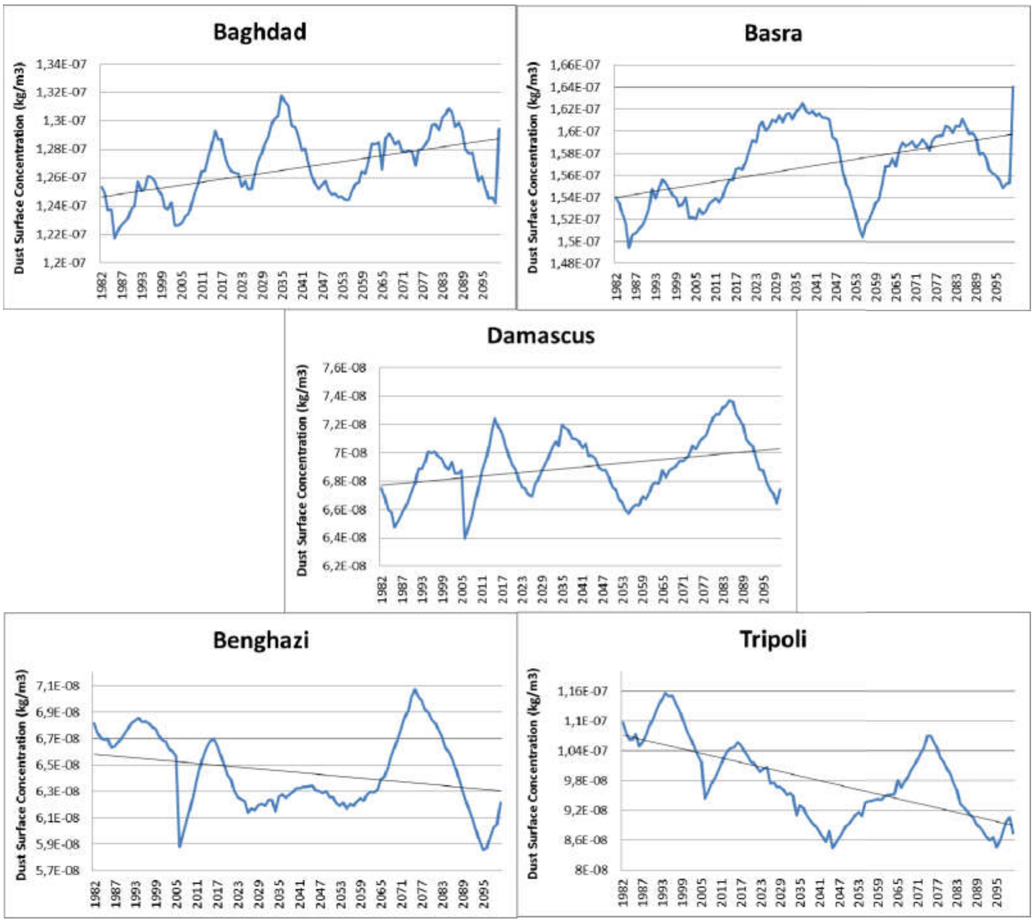

Fig. 7. Dust Surface Concentration Trends in Some Cities in the Middle East and North Africa

The dust concentrations which show a decreasing trend up to 2017 in Hakkari and Mardin started to increase after this date. Again, Kilis showed an increase up to the year 2000 and a decrease up to the year 2005. The values increased again after 2005. All these cities reach their maximum values around the year 2085. The tendency of dust surface concentration for the provinces of Hakkari, Kilis and Mardinhas an upward direction for the period of 1982-2099. Additionally, a slightly increasing trend was seen for Antalya, while a decreasing trend was seen for İzmir. The provinces that show significant increasing trends are settlements that are close to Turkey's borders with Syria and Iraq. The dust surface concentration in Baghdad showed an increasing trend, even including some fluctuations. For Basra, an increase was also seen in dust concentration for the period up to the year 2035, whereas a decrease was projected for the period between 2035 and 2055. The concentration shows increases again after this year. It shows an increasing trend in Damascus, even including some fluctuations, like in Baghdad. All these cities showed the highest values around the year 2085like in the cases of Hakkari, Kilis and Mardin in Turkey. The dust surface concentration decreases for the provinces of Benghazi and Tripoli, which are located in North Africa. All these results show that, dust concentrations increase in cities in the Middle East and decrease in cities in North Africa.

DISCUSSION AND CONCLUSION

This study aimed to conduct climate change simulations in a region that covers the Eastern Mediterranean basin at a resolution of 20 km using the RegCM model based on the theRCP4.5 scenario. The outputs of the GFDL-ESM2M global model were used as the initial and boundary conditions. Additionally, the data sets of the CAM4 model were used to include the effects of mineral dusts. The period of 1972-2000 was used as the reference period, whereas simulations of temperature, precipitation and dust aerosol were obtained for the period of 2016-2099. The high bias values for precipitation in winter and spring were concentrated over the regions that receive the greatest amounts of rainfall. Besides, a huge bias was found for summer precipitations all over Turkey. The possible reason for this is that convective activities might not be well-represented in the model. The temperature biases were not higher than 6°C for all seasons, while winter had the lowest values. The regions that are highly affected by dust events in Turkey had bias values of around 0-40%. According to the results, increased amounts of greenhouse gasses lead to temperature increases in Turkey, as it is the case all over the world. It is clear that temperatures have an increasing trend in all periods for the study area. While the highest temperature increase in Turkey (~4°C) was found for summer in the period of 2071-2099, the lowest temperature increase (~1°C) was found for winter in the period of 2016-2040.From the second half of the century onwards, the potential reason for this increase which is particularly noticeable in the southern regions in summer may be the possible increase in the Basra low pressure center (hot and dry characteristics). The differences in the temperatures between the northern and southern regions of Turkey may be attributed to latitudinal reasons. The highest precipitation increase was projected for spring in the period of 2071-2099. There are significant precipitation decreases in summer in the same period. Besides, the dust aerosol simulations show significant AOD increases in fall season in Turkey and surrounding countries due to dusts from the Middle East and the Arabian Peninsula. The possible increase in desertification and drought that may take place in the Eastern Mediterranean basin can be the reason for these increases in the fall and summer seasons. This increase is also seen in summer s after the year 2041, even though it is lower than that in fall. Furthermore, an increasing trend in dust surface concentration was seen in the South-Eastern Anatolia Region of Turkey that is under the effect of dust transport from the Middle East, while a decreasing trend was seen in the Mediterranean and Aegean provinces that are under the effect of dusts from Africa. Baghdad, Basra and Damascus, which are located in the Middle East, showed the highest values around the year 2085 like the cases of Hakkari, Kilis and Mardin in Turkey. Both international scientific research institutions and national science centers are still working on slowing down global warming, reducing (mitigation) emissions of greenhouse gasses and mineral dusts and taking precautions against the negative effects of climate change (adaptation). The most important stage of such work involves simulation studies for the future. The results that were obtained in this study are intended to act as a foundation for the adaptation and reduction practices mentioned above for Turkey and its neighbors.

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